

# **Senator George J. Mitchell Center for Environmental & Watershed Research**

## **Annual Technical Report**

### **FY 2004**

## **Introduction**

The year marked a significant transition for the Maine Institute, part of the Senator George J. Mitchell Center for Environmental and Watershed Research. In August 2004, Steve Kahl, Institute Director and founder of the Mitchell Center departed the University of Maine for Plymouth State University in New Hampshire. Steve was a visionary Director and through his efforts the Maine Institute improved its performance markedly. Following Steve's departure, Assistant Director John Peckenham assumed the Institute Director position, while Professor of Biological Sciences, Chris Cronan, was named as Interim Director of the Mitchell Center. A search for a new Director is now underway.

The Water Resources Research Institute continues as the primary vehicle for research, graduate student support, and outreach within the Center. During the past year the Maine Institute has supported three research projects: Identifying Surface Water Trends (Eastern Lake Survey follow-up); Loss of Metals from Biosolids; and Nutrient Chemistry of the Meduxnekeag River. In addition three specific Information Transfer projects were supported: Virtual Herbarium (online); PEARL (online, map-based water quality database); and a Field Guide to Aquatic Phenomena (online and print). These projects alone provided support to five graduate students and four undergraduate students. Funding from a variety of sources provided support to a total of 14 graduate students that were directly associated with the Mitchell Center.

This year marked the 10th anniversary of our highly successful Maine Water Conference. To commemorate the occasion, Senator George Mitchell agreed to be our keynote speaker. Maine Governor John E. Baldacci also spoke. We take great pride in being able to address many of the important water issues in Maine and bring together diverse interest groups.

The Water Resources Research Institute program is a key component of the Mitchell Center. The Institute gives us the ability to support small projects that address important local needs. It also provides us leverage to develop and attract funding from other agencies. This program is strongly supported by our Vice-President for Research who has contributed \$50,000 to the 104b research projects. In 2004, the Maine Institute had projects funded by state agencies (Atlantic Salmon Commission, Department of Inland Fish and Wildlife, Department of Transportation, Drinking Water Program), federal agencies (Department of Agriculture, Environmental Protection Agency, NOAA-Fisheries, National Park Service), and foundations. Total external funding, including USGS support, exceeded \$1.5 million in 2004.

## **Research Program**

# Evaluating scope and trends for decreasing base cations (and increasing diluteness)

## Basic Information

<b>Title:</b>	Evaluating scope and trends for decreasing base cations (and increasing diluteness)
<b>Project Number:</b>	2004ME27B
<b>Start Date:</b>	4/1/2004
<b>End Date:</b>	3/31/2006
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	2
<b>Research Category:</b>	None
<b>Focus Category:</b>	Acid Deposition, Climatological Processes, Surface Water
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Steve Kahl, Kathy Webster, Ivan Fernandez

## Publication

1. Rosfjord, C., J.S. Kahl, K. Webster, C. Loftin, S. Nelson, 2004. Poster: A 20-Year Re-evaluation of Trends in a Statistical Population of Lakes in the Northeastern U.S. Maine Water Conference, Augusta, ME, April 2004.
2. Rosfjord, C., J.S. Kahl, K. Webster, C. Loftin, S. Nelson, 2004. Poster: A 20-Year Re-evaluation of Trends in a Statistical Population of Lakes in the Northeastern U.S. Graduate Student Expo, University of Maine, Orono, ME, April 2004.

## ***Abstract***

In 1984, the Environmental Protection Agency conducted the Eastern Lake Survey (ELS-I) to assess the overall status of lakes in the east, with particular attention to the relationship between acid deposition and pH. In 1986, a statistical subset of the ELSI lakes, consisting of 145 lakes in the northeast, was re-sampled for ELS-II. Since the 1986 sampling, the Clean Air Act Amendment (CAAA) of 1990 resulted in reductions in sulfate emissions. The goal was to improve the biologically relevant chemistry of surface waters. In 2004, we re-sampled the 145 Northeastern lakes on the 20th anniversary of their original sampling. The data produced by the 2004 re-sampling allow for assessments of biologically relevant chemical trends in a wide range of lakes. Of particular interest are trends in base cation concentrations, the by-products of weathering reactions that produce acid neutralizing capacity (ANC) of surface waters and buffer against acid inputs. The lack of response of surface water pH to increase despite declines in acid deposition has been attributed to a concurrent decline in surface water base cation. Our objectives are to address long-term chemical trends in a wider chemical range of lakes while enhancing the statistical coverage of the northeastern region by using the ELSII sub-population. Trends in base cations have largely been studied in the most sensitive low ANC (<25  $\mu\text{eq/L}$ ) waters with few anthropogenic influences outside of atmospheric deposition. Chemical trends in high ANC lakes (>100  $\mu\text{eq/L}$ ) with greater anthropogenic influences are poorly understood. This research found base cation concentrations declined in a wide range of ANC waters in remote lakes in the northeast. However, lakes affected by road salt have generally experienced increases in base cation concentrations over the past 20 years. This information will allow for assessment of the CAAA and its effectiveness in increasing pH in surface waters through reductions in sulfate emissions. Additionally, this research has important implications for designing future assessments of changes in water chemistry resulting from changes in emissions.

## **Summary**

In response to the Clean Air Act Amendments of 1990, decreases in emission of sulfur dioxide have lead to decreases in deposition of sulfate and subsequent decreases in surface water concentrations of sulfate. In the ELS-II population, sulfate decreased in over 90% of the population with an average decrease from 110.8  $\mu\text{eq/L}$  in 1984 to 85.9  $\mu\text{eq/L}$  in 2004. Regionally there were some differences in declines in sulfate, with the greatest decreases in the Adirondacks and the smallest decreases in Maine. Nitrate also decreased in approximately 75% of the population with average decreases from 1.94  $\mu\text{eq/L}$  in 1984 to 1.13  $\mu\text{eq/L}$  in 2004.

Base cations Ca and Mg showed considerable variation between lakes affected by road salt and lakes unaffected by road salt. In the high Cl population, over 85% of the lakes increased in Ca and Mg with an average increase of +62.30  $\mu\text{eq/L/20yr}$ . In the low Cl group, over 70% of the lakes experienced decreases in Ca and Mg with an average decrease of -6.89  $\mu\text{eq/L/20yr Ca+Mg}$ . For the purposes of this paper, it is assumed that high Cl lakes do not represent changes in lake chemistry resulting from changes in atmospheric deposition. Ca and Mg also showed variation between ANC classes. Within the low Cl group, lakes in the lower ANC classes showed greater decreases in Ca+Mg than did lakes in the higher ANC class.

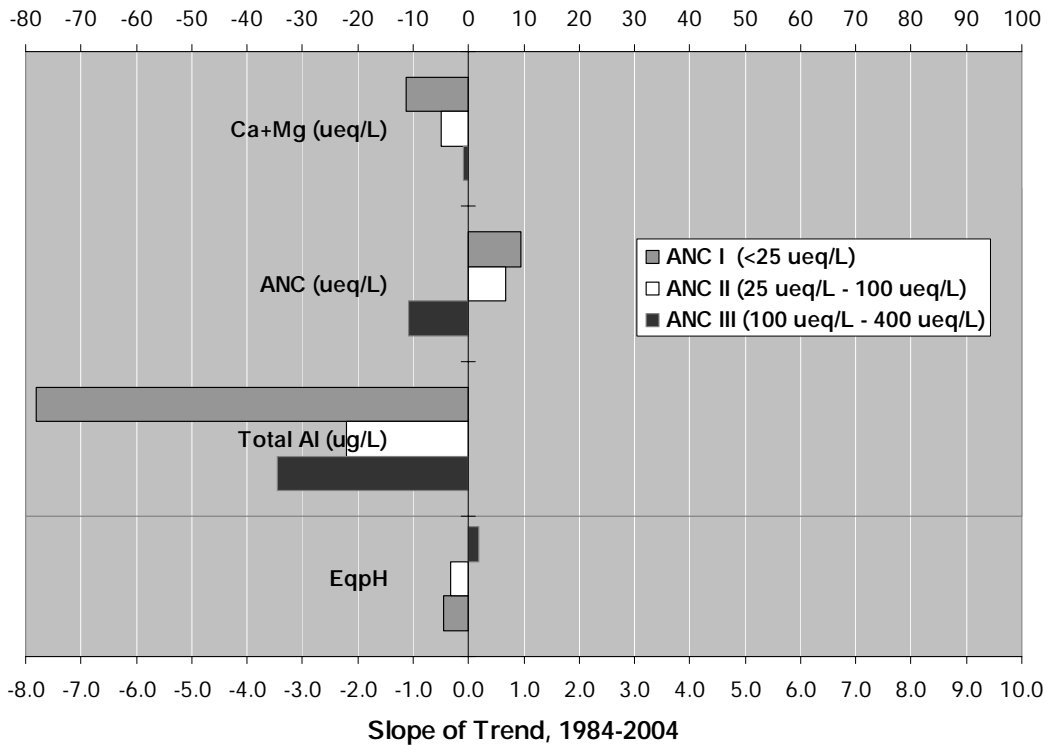
Despite average decreases in Ca+Mg in low Cl lakes, there were average increases in ANC in low Cl lakes, indicating the importance of declines in sulfate to ANC. Nearly 90% of the ANC class I/low Cl lakes experienced increases in ANC over the 20 years with an average increase from -1.66  $\mu\text{eq/L ANC}$  in 1984 to 7.82  $\mu\text{eq/L ANC}$  in 2004. Approximately 80% of the ANC class II/low Cl experienced increases in ANC with an average increase from 61.99  $\mu\text{eq/L}$  in 1984 to 68.70  $\mu\text{eq/L}$  in 2004.

Nearly 80% of the ANC class I in the low Cl group experienced increases in EqpH with an average change of +0.25 pH units/20yr. This brought the average EqpH for ANC class I/low Cl from 5.56 in 1984 to 5.81 in 2004. There were, however, average decreases in EqpH for ANC class II and class III.

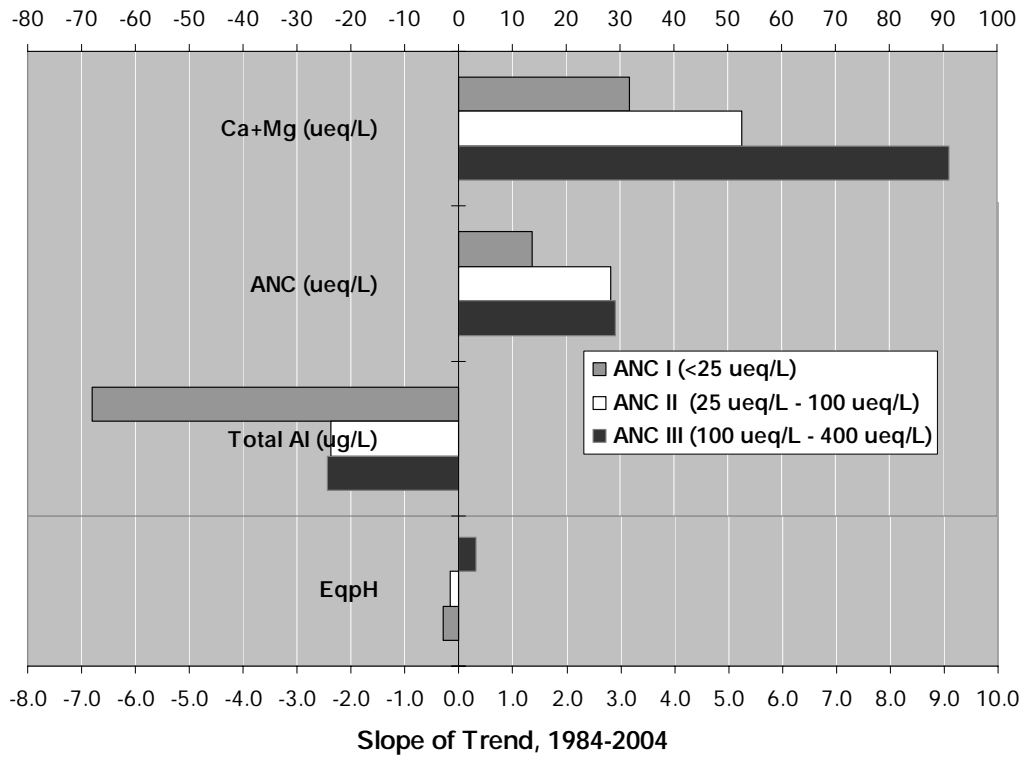
Concentrations of total aluminum decreased in approximately 90% of the population. Changes in total Al differ by ANC class, with ANC class I experiencing the greatest average decrease in total Al of -73.64  $\mu\text{g/L}/20\text{yr}$ .

Approximately 86% of the population experienced increases in DOC with an average increase of +1.51 mg/L from 4.05 mg/L in 1984 to 5.56 mg/L in 2004. There are regional differences in changes in DOC. Maine experienced the greatest increase in DOC out of the 5 regions with an average increase from 4.46 mg/L in 1984 to 6.94 mg/L in 2004.

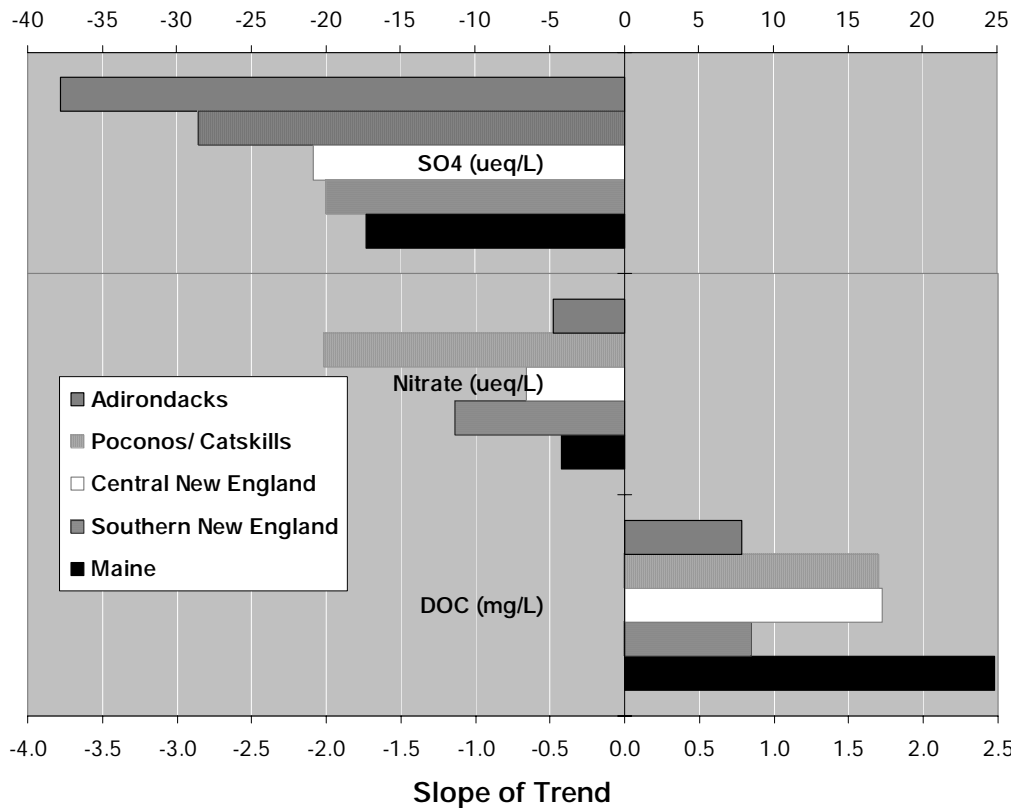
These 20 year trends are summarized in Fig. 5.22, 5.23, and 5.24.



**Figure 22.** Average trends in the low chloride group, 1984-2004.



**Figure 23.** Average trends in the high chloride group, 1984-2004.



**Figure 24.** Regional trends in sulfate ( $\mu\text{eq/L}$ ), nitrate ( $\mu\text{eq/L}$ ) and DOC ( $\text{mg/L}$ ), 1984-2004

### Conclusions

Many of these trends indicate recovery from acid deposition and the success of the Clean Air Act Amendments. Decreases in emissions of sulfur dioxide due to the passage of the CAAA have clearly resulted in decreases in sulfate concentrations in surface waters. Decreases in the acid anion sulfate have resulted in an increase in ANC and an increase in pH, particularly in low ANC systems. Both ANC and pH are indicators of biological conditions and increases in these parameters indicate potential biological recovery in the most sensitive surface waters. Additionally, total Al had considerable decreases,

especially in low ANC lakes. Due to the toxic effects of Al on gilled organisms, decreases in total Al is an important indicator of recovery from acid deposition.

However, there are some trends which indicate that recovery from acid deposition may take longer than expected. Decreases in the base cations Ca+Mg, particularly in low ANC lakes, result in a diminished ability of surface waters to neutralize acid inputs. It is likely that increases in ANC over the 20 years would be more considerable had base cations not decreased during this time. Furthermore, due to increases in DOC, there are additional sources of acidity in many northeastern lakes.

Regionally, the Adirondacks appear to be making the greatest headway in recovery. The Adirondack region has the greatest average decrease in sulfate, the greatest average increase in EqpH, and the greatest average decrease in total Al. Conversely, Maine has the smallest average decrease in sulfate, the smallest average increase in ANC, the greatest average decrease in EqpH, and the smallest average decrease in total Al.

Interestingly, the Adirondack region has the greatest average decrease in Ca+Mg while Maine has the greatest average increase in Ca+Mg. This indicates that while base cation may contribute to the acid neutralizing capacity of surface waters, changes in base cation concentrations are not driving recovery in northeastern surface waters.

The prevalence of road salt in northeastern surface waters proved to be a confounding factor when analyzing the effects of the CAAA on surface waters. The majority of the lakes in this study (56%), were affected by elevated concentrations of Cl, presumably



from road salt. While Ca+Mg had average decreases in low Cl lakes, 85% of the high Cl lakes experienced average increases in Ca+Mg.

# Metal mobilization from municipal biosolids stockpiles: The role of dissolved organic matter.

## Basic Information

<b>Title:</b>	Metal mobilization from municipal biosolids stockpiles: The role of dissolved organic matter.
<b>Project Number:</b>	2004ME29B
<b>Start Date:</b>	4/1/2004
<b>End Date:</b>	8/31/2005
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	2
<b>Research Category:</b>	None
<b>Focus Category:</b>	Solute Transport, Toxic Substances, Water Quality
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Aria Amirbahman, John M. Peckenham

## Publication

1. Peckenham, J., J. Nadeau, A. Amirbahman, W. Brutsaert, and J. Wilson, 2004, Leachate From Biosolid Stockpiles: Nutrients and Metal Mobility , Amer. Geophys. Union Ann. Mtg., Montreal, May 2004.
2. Peckenham, J., J. Nadeau, and A. Amirbahman, 2004 Nitrogen loss from biosolids stockpiles, Maine Water Conference, April 2004.
3. Nadeau J., J. Peckenham, and A. Amirbahman, 2004 Trace Metal Movement from Field Stacked Biosolids, Maine Water Conference, April 2004.

**Interim Project Report to the USGS-WRRI:**

**Metal and Phosphorus Mobilization from Municipal Biosolids Stockpiles:  
Field Experiments**

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## Abstract

Trace metal and phosphorus (P) release, fractionation, and loading from Class B lime-stabilized biosolids that were field stacked for 100 days were evaluated. The biosolids were stacked on a lined cell plot ( $3.6 \times 22.5 \times 0.6$  m) and a zero-tension pan lysimeter plot ( $6 \times 15 \times 0.6$  m) to evaluate the movement of trace metals and P through the biosolids stockpile, and the underlying soil, respectively. Metals and P were analyzed for their total concentration, as well their size fractionation. Cumulative loadings of six regulated metals in Maine, over 90 days were as follows: As, 5.35 kg/ha; Cd, 0.031 kg/ha; Cu, 0.97 kg/ha; Ni, 1.27 kg/ha; Se, 0.52 kg/ha; Zn, 0.37 kg/ha. Stated as a percent of the Maine Revised Statutes Annotated (MRSA) Chapter 419 annual loading limits these were, As, 1070%; Cd, 1.6%; Cu, 1.3%; Ni, 6.4%; Se, 10.4%; Zn, 0.3%. Ultrafiltration of the leachate from the lined biosolids stockpile showed Al, As, Cd, Cr, and Cu to be mostly dissolved (MW cutoff < 1000 Da), and Fe, Mn and P to be predominantly colloidal (MW > 1,000 Da). Zero-tension pan lysimeters were placed at depths of 30, 60 and 90 cm below the biosolids stockpile. Peak average concentrations at 90 cm during a one year period were As, 654  $\mu\text{g/L}$ ; Cd, 19.5  $\mu\text{g/L}$ ; Cu 4820  $\mu\text{g/L}$ ; Ni, 49  $\mu\text{g/L}$ ; Se, 249  $\mu\text{g/L}$ ; Zn, 304  $\mu\text{g/L}$ . Ultrafiltration of lysimeter filtrates showed metals to be predominantly dissolved (MW cutoff < 1000 Daltons), suggesting that most colloidal trace metals are removed by the aquifer material.

## 1.1 Introduction

Biosolids are derived from sewage after the addition of coagulants and flocculants to wastewater. Biosolids stockpiling is necessary for the efficient utilization of the sewage sludge residuals in agricultural practice. Field stacking is common, where biosolids are stored on an open field for up to 8 months [1,2]. Stockpiling options include stacking on concrete pads that may be covered or open to precipitation [1]. Stacking of biosolids on a concrete pad typically includes containment and leachate handling systems to prevent contamination of the surrounding environment.

Possible metal contamination of groundwater, due to stockpiling of biosolids, presents a special case for humans living in rural environments on or near farms with effective biosolids land spreading programs. The Maine Department of Environmental Protection (MDEP) in MRSA Chapter 419, utilizing the EPA's Part 503 rule, has regulated annual metal loadings and lifetime site metal loadings from land applied biosolids for several trace metals, which are shown in Table 1.1 [1]. This table is based on the EPA's risk assessment for metal concentrations and loadings in soil which have been determined as safe for human health. Some of the basic assumptions used in these risk assessments include organic content of biosolids, speciation of the metals and the relative availability of the metals for leaching [2].

The EPA in the part 503 rules states that the risk assessment undertaken for biosolids utilized a scientific approach "to determine acceptable environmental change when biosolids are used or disposed." Acceptable change means that even though environmental changes have occurred public health and safety is still protected. The EPA

**Table 1.1 – Annual metal loading and lifetime site loading limits from land applied biosolids in Maine (MRSA Chapter 419)**

	As	Cd	Cu	Pb	Ni	Se	Zn
<b>Maximum Annual Loading (kg/ha)</b>	0.5	1.9	75	15	20	5	140
<b>Maximum Lifetime Site Loading (kg/ha)</b>	10	39	1500	300	420	100	2800

in part 503 identified 14 exposure pathways associated with biosolids [2]. It was noted in the revision of the exposure pathways for groundwater, surface water and air that better fate and transport models and assumptions as to how much of a pollutant was released from the biosolids was needed [2].

Trace metal release from biosolids has been linked to microbiological activity [3], water solubility [4] and breakdown of organic compounds that bind metals in the soil [5]. McBride et al. showed that shallow groundwater collected via tension lysimeters from an experimental plot that had a one time treatment (high dosage) of biosolids 15 years prior had elevated levels of several trace metals when compared to a nearby control plot that had received no biosolids application [6]. Richards et al. found elevated trace metal levels such as Cd, Ni, Zn and B in soil pore water of a site treated with biosolids 20 years earlier [7,8].

Material balance, as a method of accounting for all the metals in land applied biosolids, has yielded varying results. A basic assumption by the EPA in establishing the part 503 trace metal loading limits was that due to the high organic content of biosolids and the inherent binding properties of organic matter, metal leaching from biosolids was

not of concern [3]. Baveye et al reported losses of 36% to 60% for trace metals in biosolids-amended soils tested to depths of 75 cm [9]. Similar results documenting large fractions of unaccounted for trace metals are reported by Richards et al [7], Dowdy et al [10], Chang et al [11], and Bell et al [12]. Reasons cited for these discrepancies include deficiencies in the analytical extraction methods [10] and lateral dispersion coupled with soil erosion [13]. In a long term study conducted by Bergkvist et al, it was found that 99% of the cadmium applied via bi-annual biosolids applications spanning 41 years was accounted for in the top 17 cm of the soil profile [14]. By contrast, Yingming and Corey found only 15% of the applied cadmium from biosolids remained in the topsoil after 11 years [15].

Data concerning release of trace metals and P from stockpiled biosolids are lacking. This work focuses on measuring the concentrations, loading rates, cumulative loadings, and evaluating the size fractionation of trace metals and P in the stockpiled biosolids leachate and filtrate in the underlying soil column sampled by pan lysimeters. Zero tension pan lysimeter results are analyzed and set the stage for further experimental studies, which measure the mobility of trace metals and P through a laboratory soil column. It must be stressed that the data presented here are for stockpiled biosolids, and not for well-managed land application of biosolids and soil amendments.

Metals presented and discussed in this work include As, Cd, Cu, Ni, Se and Zn. These metals were chosen because MRSA Chapter 419 has set annual and lifetime loading limits on these metals from land applied biosolids. Loadings of the above metals can be directly compared to statutory limits. Additionally, Al, Fe, Mn and P data are presented. While these metals are not considered toxic, they have been associated with

mobility and immobility of other elements such as As. Aluminum, Fe, and Mn form (oxy-)hydroxides that coat soil particles and remove metals and P from solution through sorption. Mineral (oxy-)hydroxides are themselves subject to acid and reductive dissolution, thus becoming mobile and also releasing other elements that were in the matrix [16,17].

## **1.2 Materials and Methods**

The experimental set-up, sample collection, handling and compositing procedures are described in the forthcoming MS thesis by J.A. Nadeau. The experimental set-up included 1) a lined cell ( $3.6 \times 22.5 \times 0.6$  m) with an impermeable geo-membrane designed to collect leachate through the stockpile, and 2) a zero tension pan lysimeter plot ( $6 \times 15 \times 0.6$  m) that collected filtrate passing through a soil column at 30, 60 and 90 cm depths under an unlined stack of biosolids. Trace metal and cumulative loadings were based on trace metal concentrations determined by ICP-AES analysis of acidified archived samples and flow measurements of the leachate from the lined cell plot. Lysimeter trace metal concentration data were obtained from acidified archived samples. Ultrafiltration results reported are for unacidified samples that had been separately archived or freshly obtained in the laboratory.

Archived samples were diluted 10:1 with Nanopure<sup>®</sup> DI water and filtered through  $0.45 \mu\text{m}$  membranes. Metal concentrations were measured on a Perkin-Elmer Optima 3300XL ICP-AES. Calibration curves of stock metal solutions were determined prior to each run on the ICP-AES. Standard additions of a stock solution with known metal concentrations were made to a subset of leachate samples to test the matrix effect



on the ICP-AES measurements. Previous studies by Ure [18] have found that large positive matrix or spectral interferences in water or soil extracts, and especially in soil digests, occur with ICP-AES because of the common occurrence of high concentrations of Al, Ca and Mg in these types of samples. Matrix interferences were found to be insignificant in this work for calculating the loading rates and cumulative loadings for As, Cd, Cu, Ni and Se. Significant effects were found for Zn, however the level of Zn in this study is insignificant compared to allowable limits.

Ultrafiltration experiments were performed on unacidified samples diluted in the same manner as described above. A Millipore / Amicon Model 8200 Stirred Ultrafiltration Cell utilizing cellulose membranes with pore sizes of 10,000 NMWL (10 KDa) and 1,000 NMWL (1 KDa) were used. Each filtered sample utilized the following operational procedure: 200 ml of diluted, 0.45  $\mu\text{m}$  filtrate was placed in the ultrafiltration cell under an  $\text{N}_2$  atmosphere at 50 psi. The first 100 ml of filtrate, passing the 10 KDa membrane were collected and 30 ml were taken for analysis. The remaining 70 ml was placed in the cleaned ultrafiltration cell with a 1 KDa membrane, and the procedure was repeated, where 35 ml of filtrate passing the 1 KDa membrane were collected for analysis. All ultrafiltration membranes were flushed with 100 ml of DI water prior to sample addition to remove any residual impurities on the membranes. The ultrafiltration cell was triple rinsed with DI water after each run. Sample collection glassware was acid washed and rinsed with DI water after each sample.

## 1.3 Results and Discussion

### 1.3.1 Lined Stockpile

Cumulative leachate volumes from the lined cell were measured as described in the forthcoming MS thesis by J.A. Nadeau. Concentration trends, loading rates and cumulative loadings for the leachate collected during the 100 day experiment are presented in Figures 1.1 – 1.3. The metals presented showed four distinct release patterns. Release of Al, As, P and Zn showed a steady concentration for the first 20 days followed by increase in concentration for the remaining 80 days. Release of Fe and Mn showed high concentrations up to day 30 followed by a steady low concentration for the remaining 70 days. Release of Cu and Ni showed high concentrations at day 6, then lower and consistently sustained concentrations over the remaining 94 days of the experiment. Cadmium showed an increasing concentration trend for the first 25 days followed by a decrease in concentration until day 50, and a constant increasing concentration trend until day 100. Selenium showed an increase in concentration until day 25 followed by a consistently declining concentration trend for the remaining 75 days.

Loading rates (mass/day/initial volume of biosolids) were calculated from the leachate concentration and cumulative volume data and normalized to initial biosolids volume as follows:

$$L_i = (F_i - F_{i-1}) * ((C_{j,i} + C_{j,i-1}) / 2) / 1000 * (t_i - t_{i-1}) * V_b \quad (1)$$

Where:

$$\begin{aligned} L_i &= \text{Loading rate at time step } i \text{ (mg/day/m}^3\text{)} \\ F_i &= \text{Cumulative volume at time step } i \text{ (L)} \\ F_{i-1} &= \text{Cumulative volume at time step } i-1 \text{ (L)} \\ C_{j,i} &= \text{Concentration of species } j \text{ at time step } i \text{ (}\mu\text{g/L)} \end{aligned}$$

$C_{j,i-1}$  = Concentration of species j at time step i -1 ( $\mu\text{g/L}$ )  
 $t_i$  = Time at time step i (d)  
 $t_{i-1}$  = Time at time step i-1 (d)  
 $V_b$  = Initial volume of biosolids on lined cell ( $\text{m}^3$ )

Cumulative loadings were calculated as follows:

$$CL_i = CL_{i-1} + ((F_i - F_{i-1}) * ((C_{j,i} + C_{j,i-1}) / 2)) / 1000 \quad (2)$$

Where:

$CL_i$  = Cumulative loading at time step i (mg)  
 $CL_{i-1}$  = Cumulative loading at time step i-1 (mg)

Results of these calculations are presented in Figure 1.2 (loading rates) and Figure 1.3 (cumulative loadings).

Examining the graphs in Figures 1.2 and 1.3 one can observe that the loading rate and cumulative loadings for Al, As, Cd, Cu, Ni, P, Se and Zn all appear to have similar behavior suggesting that the leachate flow is driving the loading rate and cumulative loadings. The Fe and Mn data, however, show a behavior different from the other metals. Loading rates (Fig 1.2) all appear to peak around day 30 and decline for the remaining 70 days of the experiment.

Figure 1.1 – Lined cell leachate temporal trace metal concentration

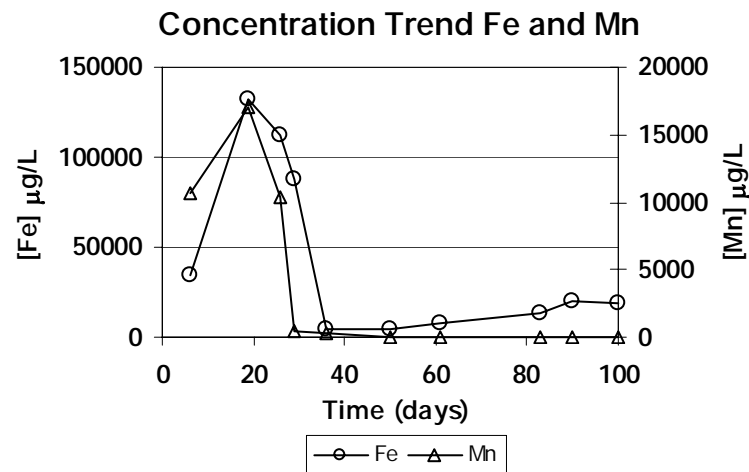
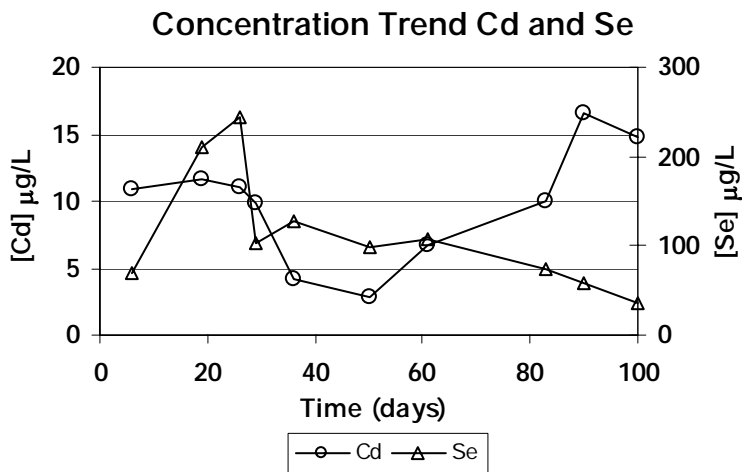
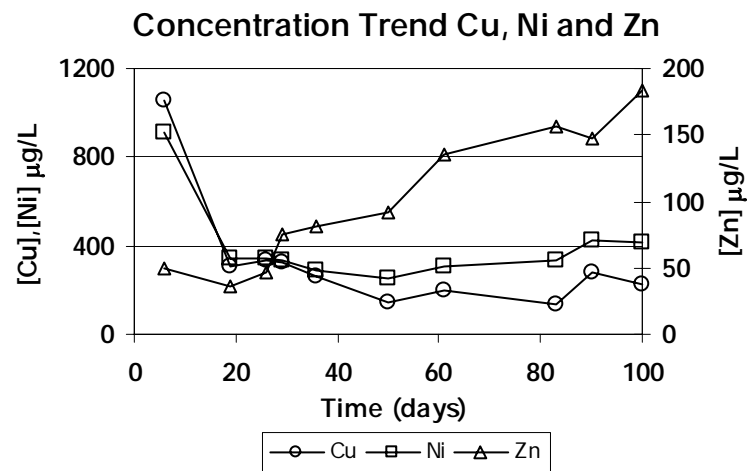
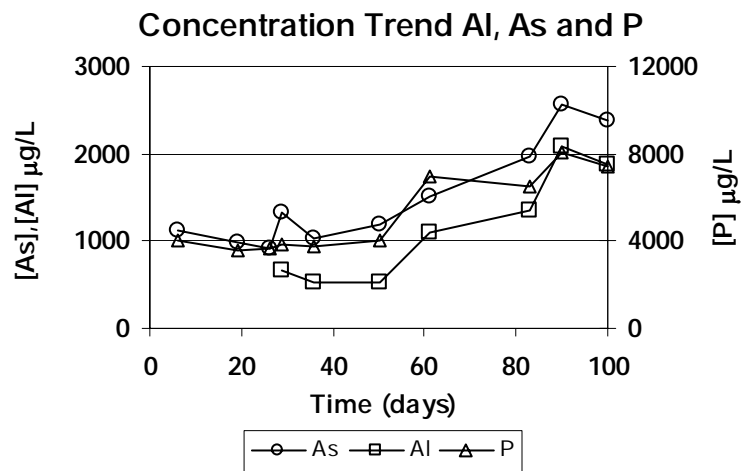


Figure 1.2 – Lined cell leachate metal temporal loading rates

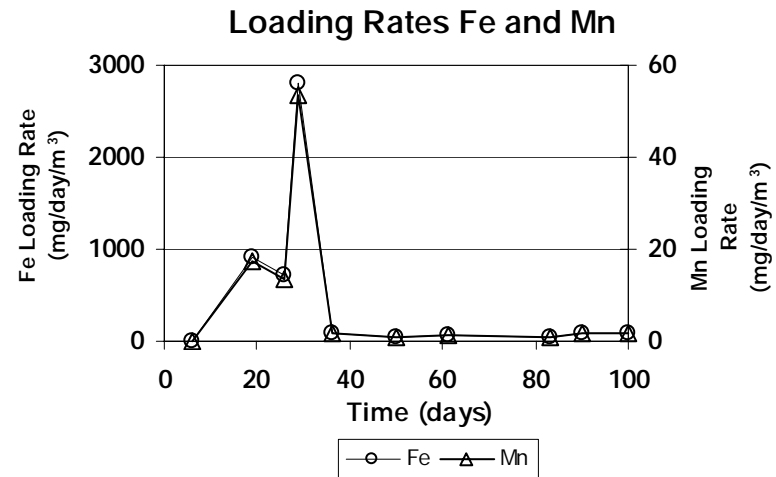
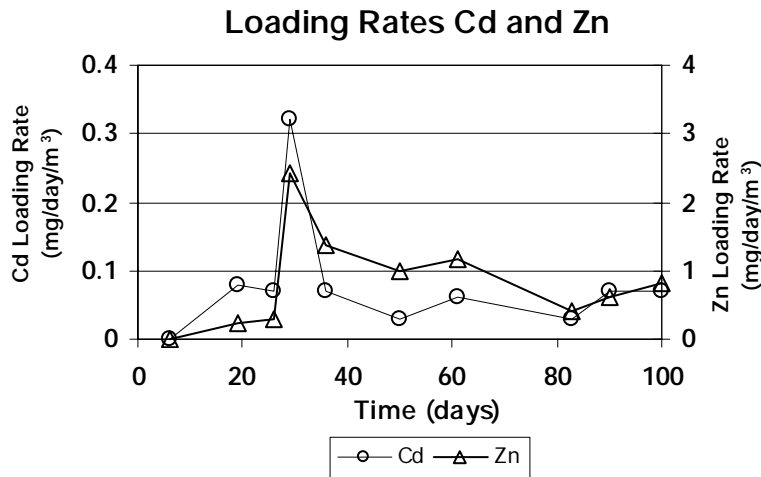
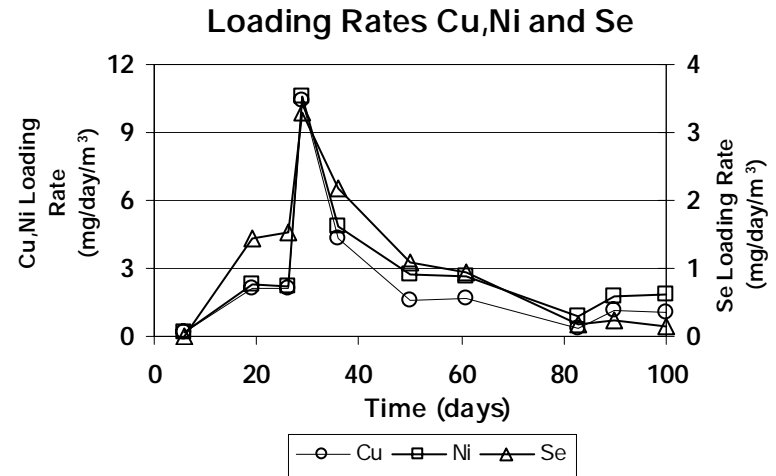
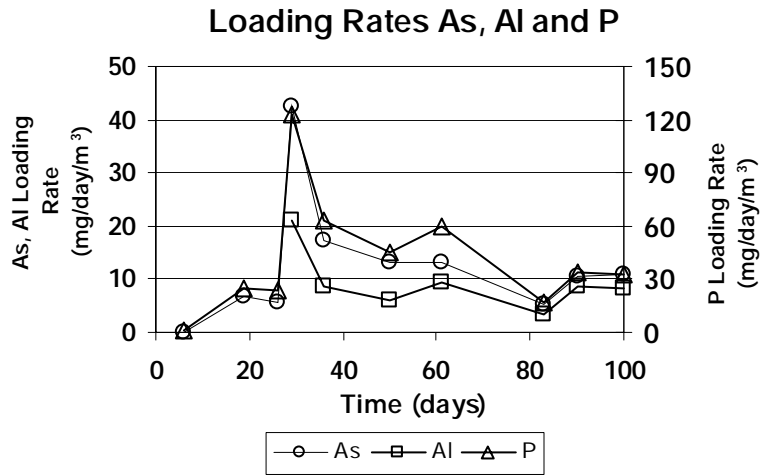
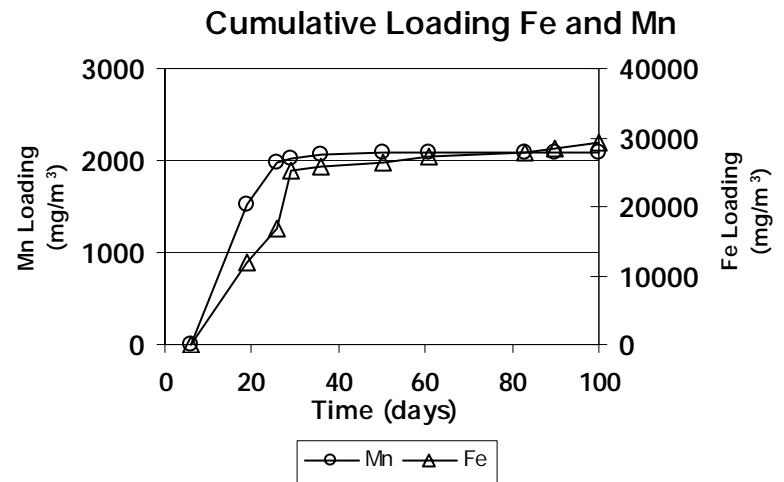
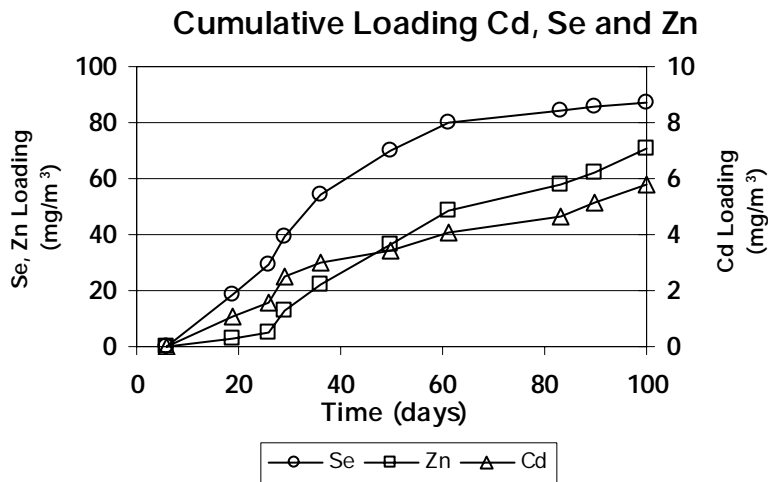
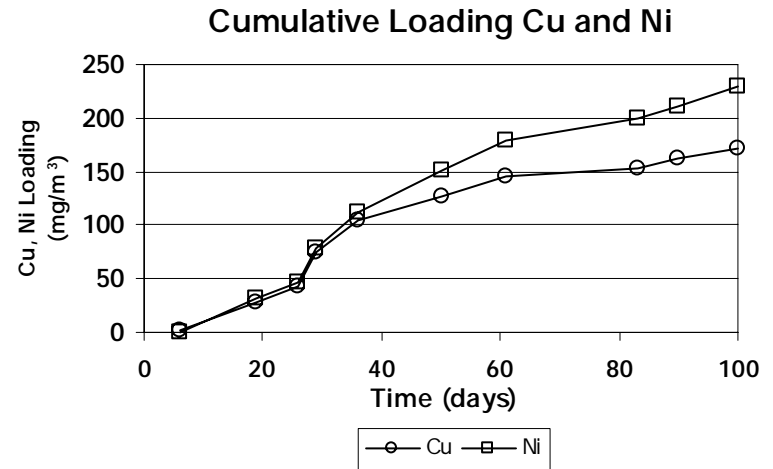
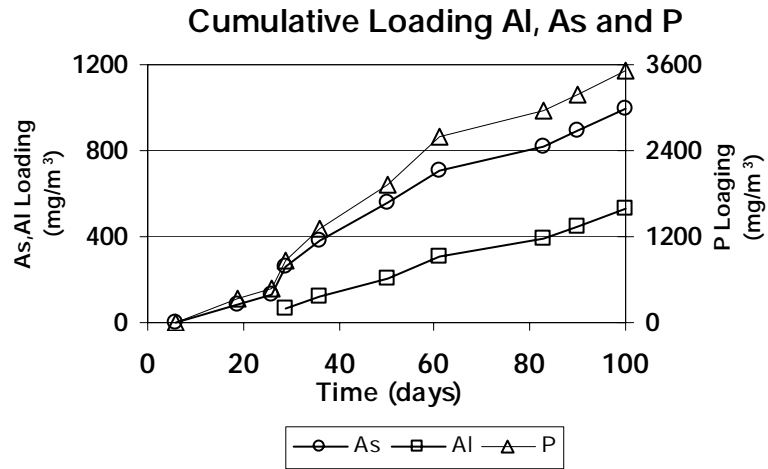


Figure 1.3 – Lined cell leachate metal cumulative loading rates



Comparison of the cumulative loadings of As, Cd, Cu, Ni, Se and Zn at day 90, scaled from a kg/m<sup>3</sup> to kg/ha (1 ha of biosolids with a depth of 0.6 m) for direct comparison to the MRSA Chapter 419 statutory limits in Table 1.1 are presented in Table 1.2. Included in Table 1.2 is the ratio in percentage of the 90 day loadings to the total annual loading limit. Based on the results shown in Table 1.2 all of the regulated metals released from the stockpiled biosolids are below the Chapter 419 annual loading limits except for As at 90 days. If one were to extrapolate from day 90 to day 240 (8 months, maximum allowable field stacking duration) in a linear fashion, all of the regulated metals in Table 1.2, with the exception of As, would still be below the annual loading limits.

**Table 1.2 – Comparison of 90 day metal loadings and annual metal loading limits**

	<b>Calculated 90 Day Loading (kg/ha)</b>	<b>Maximum Annual Loading (kg/ha)</b>	<b>% of Allowable Annual Loading</b>
<b>Arsenic</b>	5.35	0.5	1070
<b>Cadmium</b>	0.031	1.9	1.6
<b>Copper</b>	0.97	75	1.3
<b>Nickel</b>	1.27	20	6.4
<b>Selenium</b>	0.52	5	10.4
<b>Zinc</b>	0.37	140	0.3

### 1.3.2 Lysimeter Stockpile

Lysimeter data are presented in two parts, 1) average concentrations (composite samples) at a given depth over time, and 2) one sampling round showing results of each of the 15 individual lysimeter pans sampled. The four dates shown in the average lysimeter concentration data span over one year and do not include the standard deviation error bars. The reason for this is that on two of the sampling dates (Sep-03 and May-04) only a composite sample for each depth was analyzed, while the Jun-03 and Jul-04 samples had each individual lysimeter analyzed. When standard deviations at a given

depth are calculated using the Jun-03 or Jul-04 data, they are often larger than the average, indicating a wide spread in the concentrations at the same depth. Loading rates for the lysimeters cannot be calculated because flow to the lysimeter pans was not measured. Therefore, we report concentration data at three depths over time in an effort to assess movement of trace metals from the biosolids.

Concentrations of As, Cd, Cu, Ni, Se and Zn collected in the pan lysimeters are presented in Figure 1.4. The original stockpile was emplaced in December 2002 and removed on the day the June 2003 samples were taken. The stockpile was replaced with fresh biosolids in July 9, 2003 and removed June 15, 2004. A notable increase in Cu and Zn between Jun-03 and Sep-03 is observed. This may be attributed to higher levels of Cu and Zn in the biosolids stacked July 9 in comparison to the December 2002 biosolids.

Arsenic concentrations show a steady increase over time but with higher concentrations with depth. Copper concentrations show a steady decreasing trend from Sep-03 until Jul-04 with higher concentrations with depth. In contrast, P and Se concentrations increase over time and decrease with depth. If the only source of a contaminant were from the leachate, one would expect the response shown by P and Se. The response of As and Cu leads one to suspect that additional mechanisms, such as the dissolution of Al, Fe and Mn (oxy-hydr)oxides, may be occurring. The dissolution of these minerals may release the adsorbed metals such as As and Cu. Alternatively, the adsorbed As and P may be desorbed via ligand exchange with the organic matter. Analysis of soil samples at Highmoor Farm showed As and Cu concentrations of 6.1  $\mu\text{g/g}$  and 14.3  $\mu\text{g/g}$  respectively. No Se was detected in the soil, and thus, the only source of this element is the biosolids that further supporting the decreasing concentration of Se



with depth. Dissolution of Fe and subsequent release of As from a landfill contaminated aquifer has been reported by Welch and Stollenwerk [19]. Concentrations of Cd and Ni remain relatively constant over time. The increasing concentration trends of As, P and Se, suggest possible transport implications which will be explored and discussed in the final report.

Individual pan lysimeter results are presented for the June-03 samples in Table

1.3. Large differences in concentrations at the same depth exist. The existence of preferential flow paths is suspected.

Figure 1.4 – Zero tension pan lysimeter temporal average concentrations of As, Cd, Cu, Ni, Se and Zn at depth

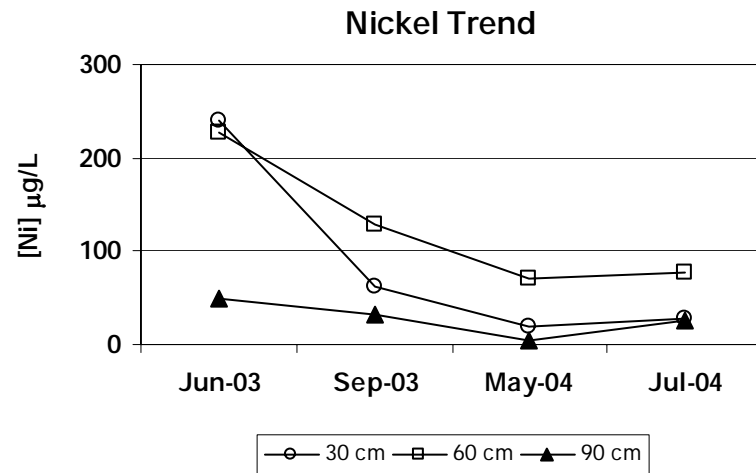
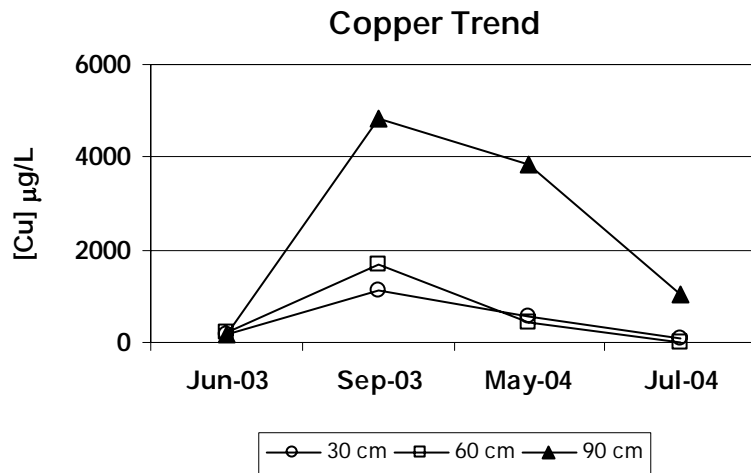
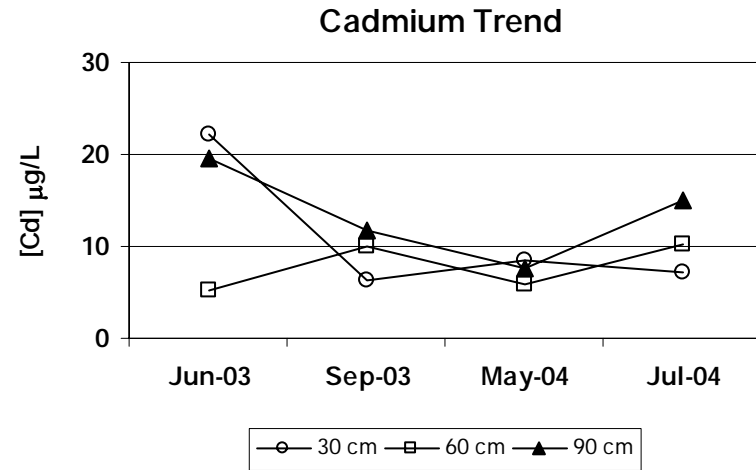
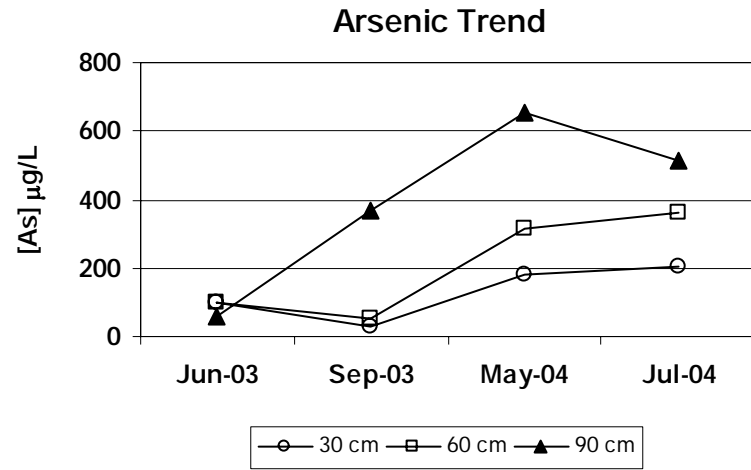


Figure 1.4 (continued) – Zero tension pan lysimeter average concentrations of As, Cd, Cu, Ni, Se and Zn at depth over time

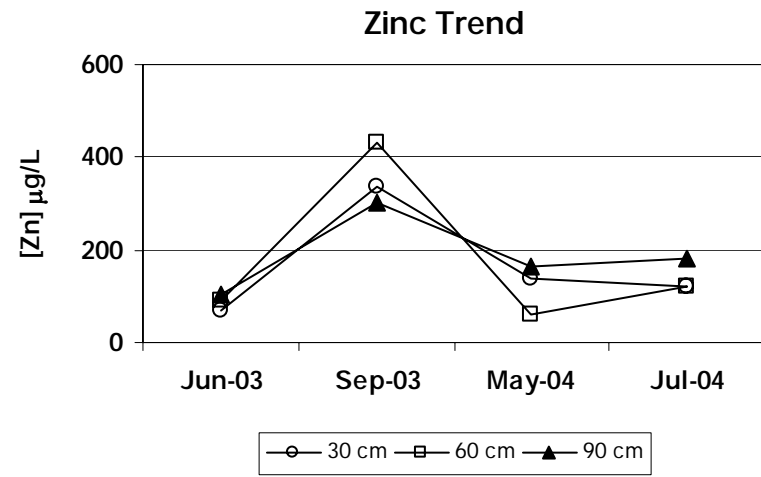
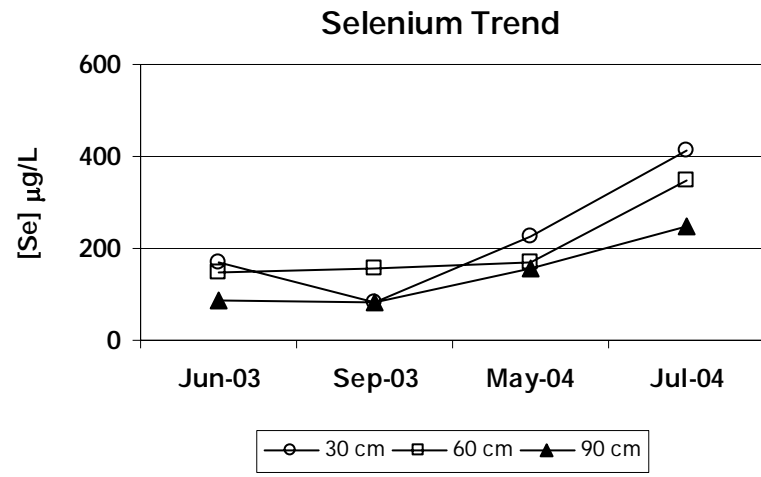
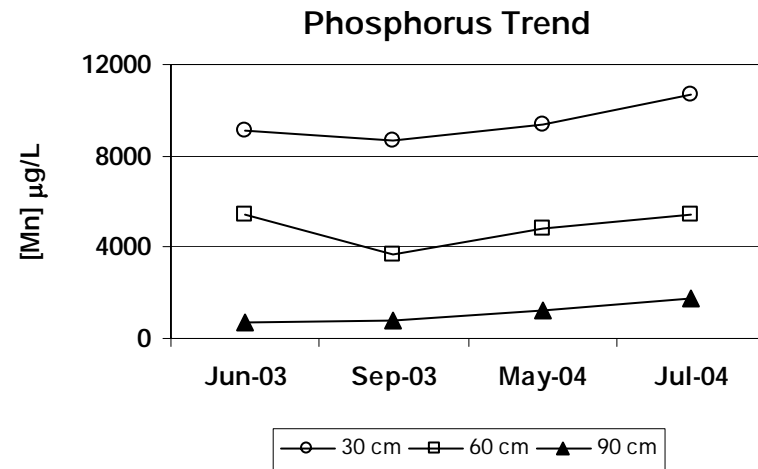
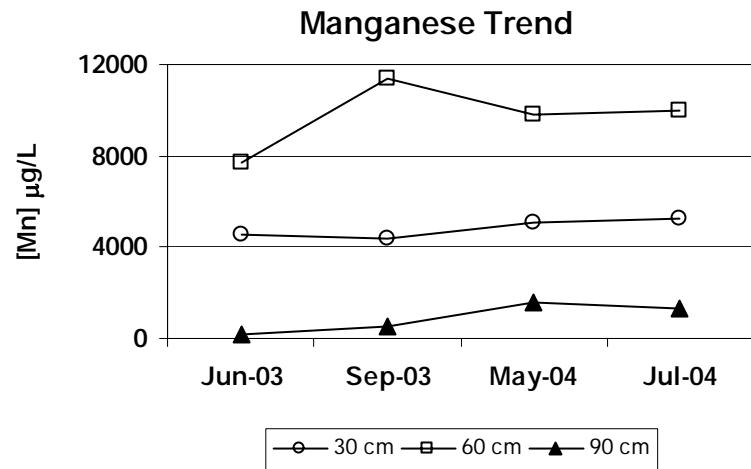
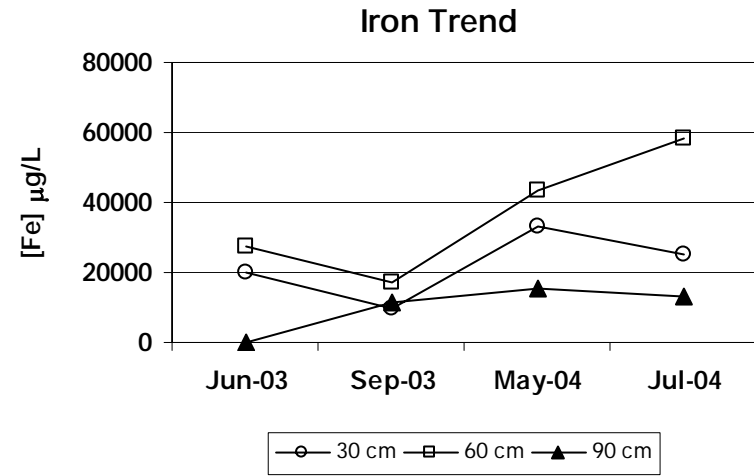
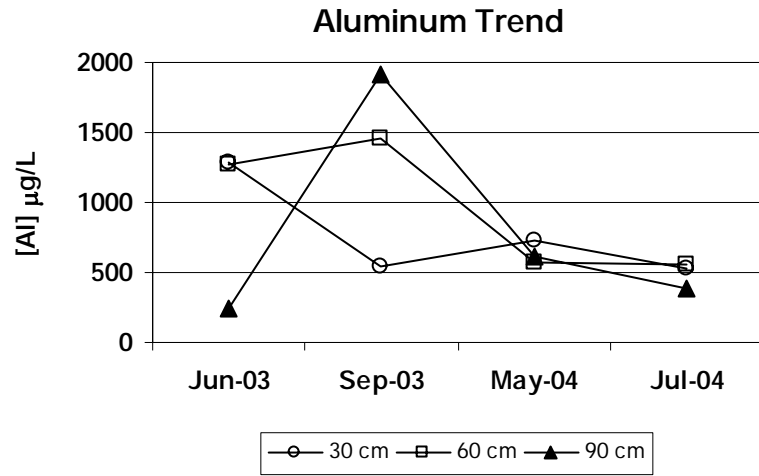


Figure 1.5 - Zero tension pan lysimeter temporal average concentrations of Al, Fe, Mn and P at depth



**Table 1.3 – Zero tension pan lysimeter metal concentrations June 2003**

	<b>Al (mg/L)</b>	<b>As (mg/L)</b>	<b>Cd (mg/L)</b>	<b>Cu (mg/L)</b>	<b>Fe (mg/L)</b>	<b>Mn (mg/L)</b>	<b>Ni (mg/L)</b>	<b>P (mg/L)</b>	<b>Se (mg/L)</b>	<b>Zn (mg/L)</b>
<b>1C1</b>	471	23.7	40.1	236.4	537	195	35.6	2761	79.9	28.2
<b>1C2</b>	930	43.8	0.5	70.1	41370	9415	145.8	2956	118.1	42.9
<b>1C3</b>	1613	128.0	8.1	291.8	10558	3564	307.6	10919	263.0	84.4
<b>1E1</b>	140	1.8	58.7	18.7	55	0	0	144	3.3	11.7
<b>1E2</b>	3248	302.2	3.4	167.5	47905	5049	474.1	28686	391.0	175.0
<b>2C1</b>	2518	267.7	8.5	246.6	53898	44032	500.4	21265	286.6	171.6
<b>2C2</b>	488	38.5	12.9	167.3	428	1184	82.3	1255	99.6	20.8
<b>2C3</b>	156	33.8	4.4	89.2	133	53	0.5	464	36.4	20.2
<b>2E1</b>	2802	134.5	0.4	507.8	82732	32654	514.4	3273	244.5	214.9
<b>2E2</b>	385	31.1	0	99.2	328	230	36.4	881	78.3	21.1
<b>3C1</b>	116	58.9	38.6	0.9	12	0	0	286	55.4	232.8
<b>3C2</b>	631	123.9	6.6	513.3	551	447	136.6	2165	194.2	115.0
<b>3C3</b>	135	33.7	36.7	17.5	31	0	0	112	59.4	78.1
<b>3E1</b>	179	60.0	9.6	14.8	76	5	0.5	670	64.0	43.6
<b>3E2</b>	156	26.9	5.8	23.9	84	14	10.0	121	57.1	45.0

Note: 1=30 cm depth, 2= 60 cm depth and 3=90 cm depth. Letters C=center and E= edge Numbers 1,2 and 3 were assigned to each lysimeter at a given depth for consistent lysimeter filtrate tracking over time.

### 1.3.3 Ultrafiltration

A comparison of ultrafiltration results between the aged leachate (sampled August 2003 and ultrafiltered March 2004) and fresh leachate (sampled May 2004 and ultrafiltered within 10 days) is presented in Table 1.4. Increases in the colloidal fraction (MW cutoff > 1,000) are noted for Fe, Ni, Se, Zn and DOC with aging. The majority of the Al, As, Cd, and Cu pass the MW 1 KDa filter and could be operationally defined as truly dissolved [20], while Fe, Mn and P may be operationally defined as colloidal (size fraction less than 0.45  $\mu\text{m}$  and larger than 1 KDa).

**Table 1.4 – Lined cell leachate Ultrafiltration comparisons**

Metal	Aged Leachate		Fresh Leachate	
	% Passing	% Passing	% Passing	% Passing
	10 Kilodaltons	1 Kilodalton	10 Kilodaltons	1 Kilodalton
Aluminum	92	92	87	62
Arsenic	92	70	81	66
Cadmium	99	84	93	82
Copper	92	90	-	-
Iron	7	2	33	3
Manganese	0	0	0	0
Nickel	45	8	86	20
Selenium	65	51	80	67
Zinc	64	30	96	48
Phosphorus	12	5	-	-
DOC	58	40	94	92

Jensen and Christensen studied the physical size and colloidal nature of metals found in leachate from landfills [20]. Species passing the 1 KDa (MW < 1,000) membrane were defined as truly dissolved and anything larger as colloidal. The findings of this study were that 78-95% of the metals (Cd, Cu, K, Mg, Na, Ni, Pb and Zn) were truly dissolved, while Ca and Mn were evenly split between colloidal and dissolved fractions, and Fe was 85% colloidal. Upon aging, DOC becomes more colloidal when

compared to fresh leachate. Possible reasons for this include polymerization of the DOC into larger molecules [16], an increase in the percentage of larger sized DOC through the degradation of the smaller, simpler molecules by biological activity, and differences in the character of DOC released from the stockpile as a function of biosolids age. In contrast, the species in the filtrate from the lysimeters (Table 1.5) appear to be mainly dissolved, with the exception of P, which may be attributed primarily to the filtration of the colloidal sized materials by the soil column.

**Table 1.5 – Zero tension pan lysimeter filtrate Ultrafiltration comparisons**

Metal	Lysimeter 1-C 6/2003		Lysimeter 2-A 6/2003	
	% Passing	% Passing	% Passing	% Passing
	10 Kilodaltons	1 Kilodalton	10 Kilodaltons	1 Kilodalton
Aluminum	77	45	97	66
Arsenic	92	89	93	78
Cadmium	72	70	98	84
Copper	82	79	89	71
Iron	84	75	94	75
Manganese	87	74	95	76
Selenium	90	87	99	80
Zinc	97	82	98	86
Phosphorus	16	9	80	62
DOC	72	-	82	74

## 1.4 Conclusions

The results of this study indicate that As released from a lime-stabilized Class B biosolids stockpile during the first 90 days exceeded the annual loading limits for land-applied biosolids by an order of magnitude and equaled the lifetime loading limit.

Arsenic release data from the lined stockpile also showed a consistently increasing trend in concentration over time suggesting that the biosolids are an important source of As.

The other controlled metals studied (Cd, Cu, Ni, Se and Zn) were released during the first

90 days of stockpiling at rates ranging from 0.3% to 10.6% of the MRSA Chapter 419 annual limits.

Lysimeter data showed the oxyanions As, P and Se to be mobile through the soil column. Phosphorus and Se concentrations increased with time and decreased with increasing depth as one might expect if their source was the leachate leaving the stockpile and traveling through the soil column. Arsenic concentration in the lysimeters increased with time and with depth. To explain this behavior, another transport and release mechanism such as ligand exchange involving the leachate DOC, or the reductive dissolution of the minerals must be considered. Ultrafiltration of the lined cell leachate showed significant colloidal fractions (MW>1,000 Da) of Fe, Ni, Se, Zn and DOC. Ultrafiltration of the lysimeter leachate, however, showed all metals and DOC with the exception of P to be predominantly dissolved (MW< 1,000 Da). Based on the amount of metals released from stockpiled biosolids and their mobility as determined by sampling a lysimeter plot at various depths and over time, a controlled laboratory study that will determine the mobility of trace metals in biosolids leachate were conducted. The results of this study will be presented in the final report. The high As release rate from biosolids stockpiles should be of concern and justify further laboratory and field experimentation.

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# Nutrient cycling within the Meduxnekeag River and the use of periphytic algae as an indicator of nutrient loading

## Basic Information

<b>Title:</b>	Nutrient cycling within the Meduxnekeag River and the use of periphytic algae as an indicator of nutrient loading
<b>Project Number:</b>	2004ME31B
<b>Start Date:</b>	4/1/2004
<b>End Date:</b>	3/31/2006
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	2
<b>Research Category:</b>	None
<b>Focus Category:</b>	Agriculture, Management and Planning, Non Point Pollution
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Bryan Dail, Steve Kahl, Kathy Webster

## Publication

1. Fretwell, L., D.B. Dail, K.E. Webster, and S.H. Brawley. The relationship between phosphorus and nitrogen concentrations, algal growth, and land use in the Meduxnekeag River watershed. Poster presented at the 2005 Graduate Student Research Exposition, April 11-12, 2005. Orono, Maine.
2. Fretwell, L., D.B. Dail, K.E. Webster, and S.H. Brawley. The relationship between phosphorus and nitrogen concentrations, algal growth, and land use in the Meduxnekeag River watershed. Poster presented at the 2005 Maine Water Conference, March 22, 2005. Augusta, Maine.
3. Fretwell, L., D.B. Dail, K.E. Webster, J.S. Kahl, S.H. Brawley, and L. Wilson. Periphytic algae as an indicator of nutrient loading to the Meduxnekeag River. Poster presented at the 2004 Maine Water Conference, April 21, 2004. Augusta, Maine.
4. Fretwell, L., D.B. Dail, K.E. Webster, J.S. Kahl, S.H. Brawley, and L. Wilson. Periphytic algae as an indicator of nutrient loading to the Meduxnekeag River. Poster presented at the 2004 Graduate Student Research Exposition, April 12-13, 2004. Orono, Maine.

## **Progress Report 2004**

### **Nutrient cycling within the Meduxnekeag River and the use of periphytic algae as an indicator of nutrient loading**

**Bryan Dail**            **Department of Plant, Soil, and Environmental Sciences**  
**Katherine Webster**   **Department of Biology**  
**Lisa Fretwell**        **Masters Candidate, Ecology and Environmental Sciences Program**

**Period covered by this report: April 2004-April 2005**

#### **ABSTRACT**

A 20-mile segment of the Meduxnekeag River in Aroostook County, Maine, that traverses Houlton Band of Maliseet Indian (HBMI) tribal lands is experiencing substantial filamentous algal blooms in summer months. The algal blooms have lowered dissolved oxygen (DO) levels in the river to the extent that a 6-mile stretch within the segment has been deemed “impaired” by the Department of Environment Protection (DEP).

Water chemistry data collected by the HBMI are available from 1995 to the present for this stretch of the river and indicate that the blooms may be phosphorus (P) limited, but that the algae are moderating stream chemistry and responding to flow dynamics to an extent that controls over algal production are unclear. A Watershed Protection Plan/Environmental Assessment for the Main Branch of the Meduxnekeag River was published in 1993, a Total Maximum Daily Load (TMDL) Report was published by the Department of Environmental Protection (DEP) in 2000, and the U.S. Geological Survey (USGS) is finalizing a sediment study it conducted this summer (2003).

Currently, no research has linked the existing water quality data to nutrient dynamics in the river, or pinpointed the relative input contributions from point and non-point sources, of which there are many. These including unbuffered agricultural stream inputs, wetland, and lake recharge as well as industrial and wastewater effluent and proximity to impermeable surface inputs; all of these inputs are upstream of the Maliseet tribal lands. We proposed to evaluate the underlying cause of the eutrophication by compiling and analyzing the existing data, investigating nutrient cycling in the river (including sediment and the water column), identifying nutrient loading areas and relative contributions of point and non-point sources, and determining temporal and spatial changes in the algae. Our overarching goal is to identify the causes of the problem, or to prioritize the likely causes, and thus provide supportive data that may lead to recommendations for remedy.

## **State Water Quality Problem and Research Objectives**

Although environmental regulations have drastically reduced point source pollution, non-point source pollution remains a leading cause of water quality problems nationwide. State inventories indicate that agriculture impacts 48 percent of impaired rivers and streams (EPA, 2002). One of the major constituents of non-point source pollution is sediment, which is transported from agricultural and urban areas and carries heavy metals, pesticides, oils, and nutrients. High nutrient concentrations are a leading cause of impairment and eutrophication, a symptom of which is oxygen-depleting algal blooms.

The algal blooms in the Meduxnekeag River depress dissolved oxygen (DO) levels and alter the habitat of fish and other biota. Throughout the state, rivers are being altered to such an extent that they are losing native fish populations. Tribal members have observed non-native fish (bass, sucker, pickerel) becoming dominant while native trout numbers are declining (Ellis, pers. comm. 2003). The Maine State Planning Office's River Study lists the Meduxnekeag River as having natural and recreational values of statewide significance. However, the algal blooms and resulting low DO levels are threatening this status. A 6-mile segment of the river downstream of Houlton is listed on the state's 303d and 305b list for non-attainment of water quality standards because of high nutrient loads and low DO levels.

Although its presence on the impaired list legally requires corrective measures to be taken, so little is known about nutrient sources and cycling in the Meduxnekeag River that any solution would be speculative at this point in time. Moreover, an evaluation of the Meduxnekeag River eutrophication, which is rare for Maine, will be useful for our understanding of processes statewide, because of increasing pressures on many Maine waters. Also, since the project will quantify the relative inputs from point and non-point sources, our research will be applicable to other areas with non-quantified point and non-point sources of nutrient enrichment.

Several states are battling eutrophication problems that became widespread before they were well understood, forcing a reactive approach; Maine, on the other hand, has an opportunity to be proactive and address the issue while it is still relatively small scale. We can gain an understanding of nutrient cycling in the river and use that knowledge to drive a restoration plan that will be a model for other areas of the state and beyond.

### **Research Goal:**

**To determine the spatial and temporal relationships between nutrients, algal growth, and land use in the Meduxnekeag River corridor?**

This goal is being addressed by three general research objectives:

- 1) What are the spatial and temporal phosphorus and nitrogen trends in the Meduxnekeag River, and how do they correlate to nutrient sources in the watershed?
- 2) Are spatial and temporal patterns in the algal growth an indicator of nutrient concentrations?
- 3) Do the water column and algae have unique  $\delta^{15}\text{N}$  stable isotope signatures that we can relate to specific point source and non-point source nutrient sources within the watershed?

## METHODS

The watershed will be divided into three zones as shown in the conceptual model below (Fig. 1). Zone 1 will extend from the headwaters at Meduxnekeag Lake to just upstream of AE Staley's (a starch plant) and contains predominantly agricultural land. Zone 2 contains AE Staley's, the confluence with the South Branch of the Meduxnekeag River, and downtown Houlton. Zone 3 contains the WWTP and HBMI tribal lands.

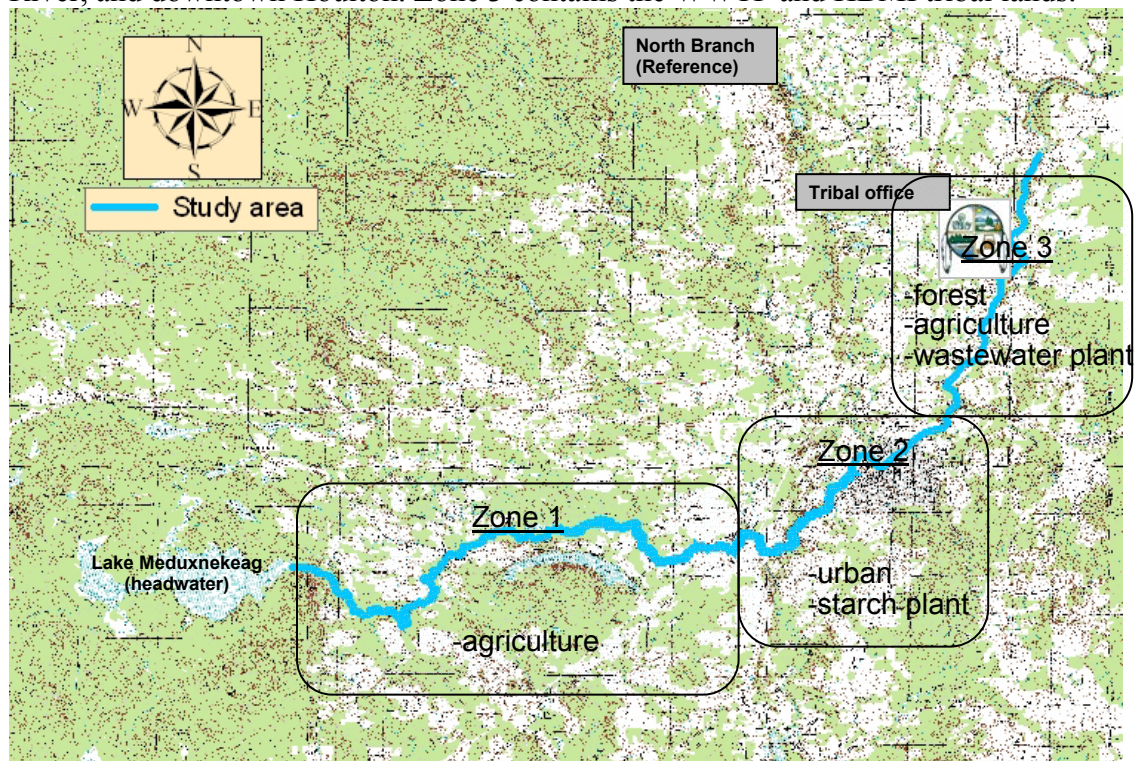


Fig. 1 Conceptual diagram of the Meduxnekeag Study Reach.

We compiled and analyzed existing data, and determine gaps in sampling regimes as they fit within the general framework of the conceptual river chemistry influences in Fig 1. We then devised a detailed sampling plan for the Spring of 2004 which added a substantial number of sampling areas to those already analyzed on a regular basis by the Maliseet Tribe's water quality specialists.

### *Assessing water chemistry and Algal cover patterns*

At each sampling area along the 20 mile reach, we established permanent bank markers to delineate a water sampling plan and an algal assessment plan. The basic features of the water chemistry and algal assessment plan are shown in Fig. 2. Nutrient sampling and algal assessments were performed biweekly from May through September and algal grab samples for identification and natural abundance isotope forensics were obtained twice.

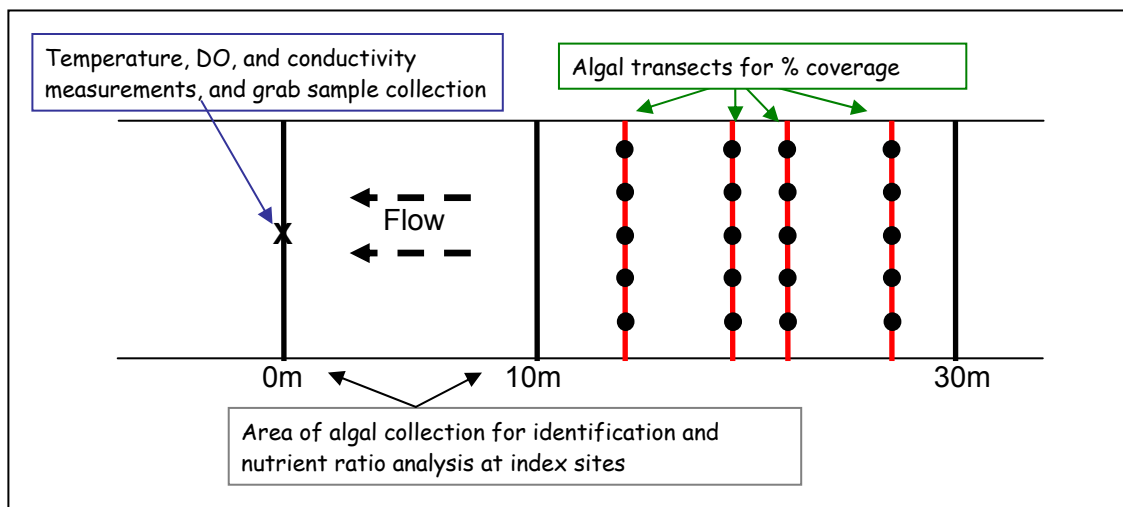


Fig 2. Conceptual diagram of the water chemistry sampling plan and the algal assessment transects.

## PRINCIPLE FINDINGS TO DATE

### *Water chemistry*

Soluble reactive phosphorus, that P which is most available for plant and microbial uptake, was often not differentiable from the detection limits of our method, therefore we report the season average of Total P which includes soluble and particulate P in unfiltered samples (Fig. 3). Season averages for the individual sites necessarily have a considerable amount of error associated with them and this is owing to processes in the watershed that mobilize P as well as the water flow regime. However, we do see a trend in increasing P loading as one goes from headwaters to the furthest point downstream in our study (Fig. 3). Total P levels appear to have a high value just downstream of the waste water treatment plant and the large error is consistent with a discreet treated water release pattern.

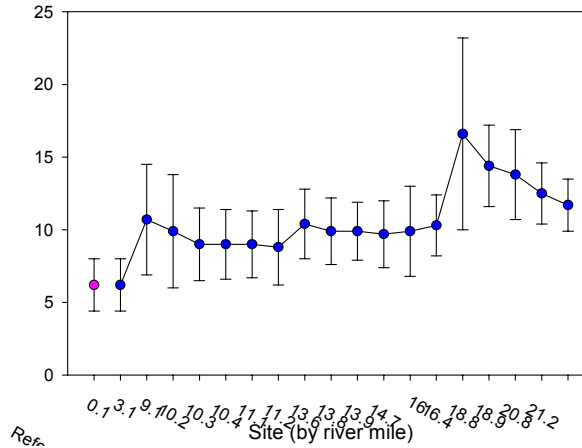


Fig. 3. Total P concentrations averaged from May to September; reported by River Mile.

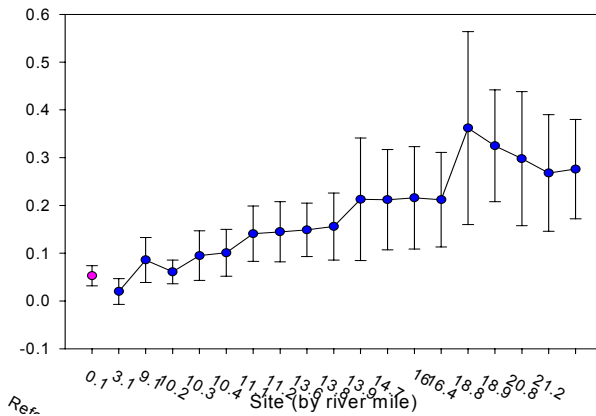


Fig. 4. NO<sub>3</sub><sup>-</sup> N concentrations averaged from May to September; reported by River Mile.

We measured dissolved inorganic N as NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>, however since NH<sub>4</sub><sup>+</sup> concentrations were almost always at the detection limit, we report NO<sub>3</sub><sup>-</sup> only, below (Fig 4). Trends in the concentrations were similar to those for total P; there was a general increase in the concentration of NO<sub>3</sub><sup>-</sup> N despite concomitant increases in water

volume in the river as one heads downstream. NO<sub>3</sub><sup>-</sup> concentrations peaked below the waste water treatment facility and then declined somewhat, probably owing to dilution by other stream confluences and biological N consumption. Samples for 2004 were frozen and the DIN data are currently being utilized to prepare stream waters for natural abundance isotope analysis. This analysis will take place spring 2005 and will be

compared to the isotopic signature of algae collected from the stream over the same period. We will use a simple mixing model to assess the source of N supporting algal growth in the watershed, but this methodology alone does not allow one to assess nutrient limitations on the algal growth and thus “causation” rather, it will give us a sense of where nutrient inputs occur and if they might be associated with point source and non-point source inputs to this river.

### ***Algal Assessments***

In 2004, a cool spring with higher than average precipitation delayed onset of algal growth until late August and early September. Algal cover was less than 5% of the substrate in greater than 60% of the sampling sites. Community analyses revealed three dominant filamentous genera: *Spirogyra*, *Mougeotia*, and *Zygnema*. They are all unbranched green algae belonging to the Class Charophyceae and are not indicative of a particular trophic environment.

### **Implications and Expected Outcomes:**

The HBMI and USGS are investing much into the Meduxnekeag River watershed, and this project will add to the effort by defining the nutrient status of the river and studying the dynamics of the algal bloom. It will help the HBMI to determine the necessity for a nutrient monitoring program in the future and to find areas of the watershed to focus nutrient reductions efforts. The Maine DEP is currently developing nutrient and biological criteria (including algae) for the state’s rivers. The results from this project will be made available to the DEP to add to their database. The historical algal growth in the Meduxnekeag River is rare for the state, and therefore, nutrient and algal growth data for the river will be valuable in helping to define the range of conditions found in Maine.

### **Deliverables:**

**To date, no publications have arisen from this investigation:**

### **Other Activities**

Fretwell, L., D.B. Dail, K.E. Webster, and S.H. Brawley. *The relationship between phosphorus and nitrogen concentrations, algal growth, and land use in the Meduxnekeag River watershed*. Poster presented at the 2005 Graduate Student Research Exposition, April 11-12, 2005. Orono, Maine.

Fretwell, L., D.B. Dail, K.E. Webster, and S.H. Brawley. *The relationship between phosphorus and nitrogen concentrations, algal growth, and land use in the Meduxnekeag River watershed*. Poster presented at the 2005 Maine Water Conference, March 22, 2005. Augusta, Maine.



Fretwell, L., D.B. Dail, K.E. Webster, J.S. Kahl, S.H. Brawley, and L. Wilson. *Periphytic algae as an indicator of nutrient loading to the Meduxnekeag River*. Poster presented at the 2004 Maine Water Conference, April 21, 2004. Augusta, Maine.

Fretwell, L., D.B. Dail, K.E. Webster, J.S. Kahl, S.H. Brawley, and L. Wilson. *Periphytic algae as an indicator of nutrient loading to the Meduxnekeag River*. Poster presented at the 2004 Graduate Student Research Exposition, April 12-13, 2004. Orono, Maine.



# Defining 'natural' reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine

## Basic Information

<b>Title:</b>	Defining 'natural' reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine
<b>Project Number:</b>	2003ME19B
<b>Start Date:</b>	4/1/2003
<b>End Date:</b>	3/31/2005
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	2
<b>Research Category:</b>	None
<b>Focus Category:</b>	Ecology, Non Point Pollution, Recreation
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Kathy Webster, Roy James Bouchard

## Publication

1. Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the Maine Water Conference, March 2005, Augusta.
2. Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the 7th Annual Association of Graduate Students Research Exposition, April 2005, Augusta.

## Basic Information:

<b>Title:</b>	Defining 'natural' reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine
<b>Project Number:</b>	2003ME19B
<b>Start Date:</b>	01 April 2003
<b>End Date:</b>	31 March 2005
<b>Research Category:</b>	Biological Sciences, Water Quality
<b>Focus Category:</b>	Ecology, nonpoint pollution, recreation, surface water, management and planning, water quality
<b>Descriptors:</b>	Biomonitoring, bioindicators, aquatic plants, lakes, shore protection
<b>Lead Institute:</b>	University of Maine
<b>Principal Investigators:</b>	Katherine E. Webster, Roy Bouchard

## Problem and Research Objectives:

Lake ecosystems are currently at risk from increases in shoreline development. Lakes attract residential development (Walsh et al. 2003), placing lakefront property in increasingly high demand for residential construction of vacation and/or permanent homes around lakes. Although Maine is largely rural, many of the state's more than 5,000 larger lakes are at risk from shoreline development. In 1971, the State of Maine Department of Environmental Protection instituted protective shoreline regulations for lake riparian zones. The regulations under this Act control development actions within 250 feet of the high-water mark for ponds greater than 10 acres in size. Development restrictions include: 100 ft setbacks for structures, driveways, and roads, maximum amounts of vegetation that can be removed from a shoreline property, and rules for new septic system installations (Kent 1998). The goals of the Shoreland Zoning Act include prevention and improvements in water pollution, conservation of aesthetically pleasing areas, protection of wetlands, conservation of shoreline habitats, protection of wildlife habitats, and control of recreational activities.

Shoreline development can influence lake ecosystems through two general pathways. Through removal of riparian vegetation and tidying of nearshore areas, people decrease the amount of coarse woody debris (CWD) like trees and branches that provide important structural habitat for fishes and other organisms in the littoral zone. Construction and use of docks and other structures, as well as boating, and other recreation activities associated with them, mechanically disrupt littoral biota such as aquatic plants that provide critical habitat for other organisms. As a result, a simplification of littoral habitats is common in highly-developed lakes (Christensen et al. 1996; Engel and Pederson 1998; Radomski and Goeman 2000; Schindler et al. 2000; Jennings and Emmons 2001). In addition, construction of impervious structures or roads, fertilizer applications to lawns, destruction of riparian buffers, and leaky septic systems in

riparian areas have potential to increase nutrient loading to lakes (Jennings et al. 1996; Engel and Pederson 1998; Dillon et al. 1994). If the capacity of the littoral zone to assimilate these nutrients is exceeded, lake trophic status is likely to degrade. In addition to these more ‘indirect’ pathways, shoreline development can directly affect littoral communities through mechanical disruption and possibly through increasing the probability of invasion by competitive exotic species. The overall impact of these pathways on the integrity of the lake ecosystem and on the resilience of lakes to other stressors like invasive species, eutrophication or climate change is unknown, but is key to effective management and protection.

Our overarching objective is to determine the effects of shoreline development on the habitat complexity of littoral zones in small headwater lakes in Maine. We define habitat complexity in terms of the physical structure provided by macrophytes and coarse woody debris. Macrophytes stabilize littoral sediments, act as a nutrient source upon decay, and provide habitat and food resources for littoral macroinvertebrate and fish species (Voights 1976; Crowder and Cooper 1982). Similarly, coarse woody debris serves as a habitat for macroinvertebrates and a place of colonization for algae which littoral fauna can use for nutrition (Harmon et al. 1986, Nilsen and Larimore 1973; McLachlan 1970; Anderson et al. 1978; Beckett et al. 1992).

Our specific research objectives are to:

1. *Define a ‘natural’ template that predicts structural complexity based on physical attributes in the absence of human activities.* Littoral zones are naturally quite heterogeneous in a range of physical factors such as slope, fetch, and substrate composition. Often the effects of shoreline development on littoral habitat have been determined without considering the range of possible physical conditions. By defining the natural template we can establish expectations for habitat structural complexity needed to quantify the effects of human activities.
2. *Determine how shoreline development influences habitat complexity.* Using expectations from objective 1, we have a more sensitive method for detecting the influence of shoreline development on habitat structure. We will then test whether indicators of response to structural complexity, namely macrophyte species composition and macroinvertebrate community structure, are sensitive to any observed changes in structural complexity. As part of this objective we will also determine whether structures constructed in accordance with Maine Shoreland Zoning Regulations provide better protection to littoral habitats.

## **Methodology:**

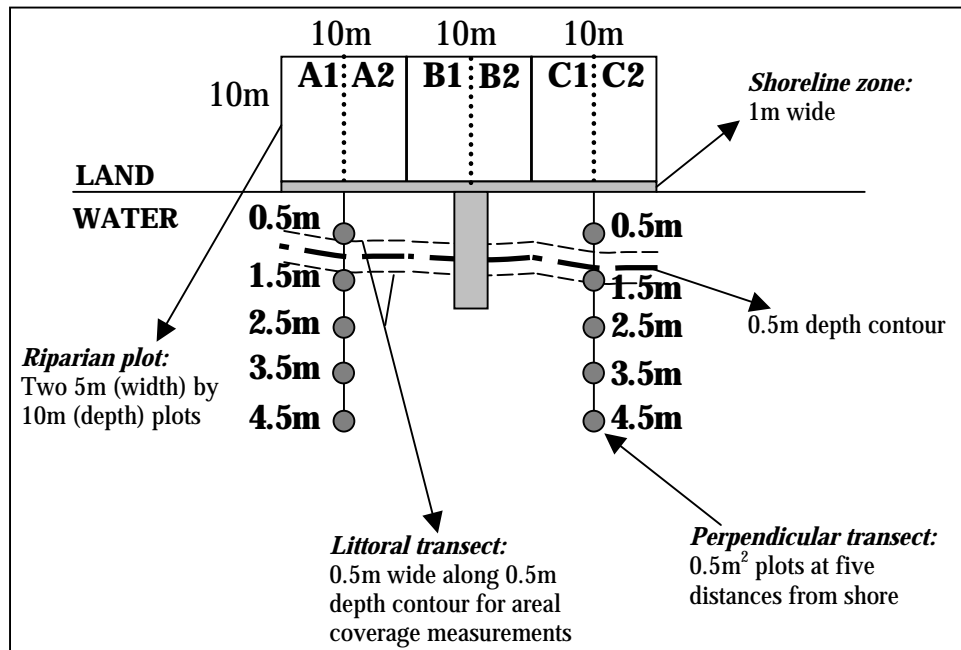
### *Study Lakes*

We selected 11 study lakes located within a similar geologic setting in Hancock and Penobscot counties in eastern Maine. To reduce inherent variability, the lakes have similar hydrology (headwater) and surface area (20-200 hectares). In addition, the lakes were chosen to reflect differences in the extent of residential shoreline development around the perimeter. Six of the 11 lakes had little or no shoreline development along the shoreline (1 to 3 cottages) and were characterized as “undeveloped” lakes. “Developed” lakes had moderate to heavy amounts of development along half or more of the shoreline. Lakes were sampled during July and August of 2003 and 2004, with three sampled only in 2003, three only in 2004, and five sampled both summers (Table 1).

**Table 1:** Characteristics of lakes sampled during summer 2003 and 2004 sampling seasons. The MIDAS (Maine Information Display Analysis System) number is a unique identifier for each lake in the state of Maine.

<i>Lake name</i>	<i>Year(s) sampled</i>	<i>MIDAS</i>	<i>County location</i>	<i>Surface area (ha)</i>	<i>Max. depth (m)</i>	<i>Mean depth (m)</i>
<b>Undeveloped</b>						
Burnt Pond	2003, 2004	4354	Hancock	28.3	7.6	3.4
Fitts Pond	2003	4268	Penobscot	42.9	18.0	10.4
Green Lake #2	2003, 2004	4790	Hancock	25.9	3.7	2.7
Halfmile Pond	2003, 2004	4496	Hancock	44.1	18.6	7.6
Horseshoe Lake	2003, 2004	4788	Hancock	81.7	6.1	3.7
Upper Sabao Lake	2004	4522	Hancock	196.7	12.5	4.6
<b>Developed</b>						
Georges Pond	2004	4406	Hancock	153.8	13.7	4.9
Giles Pond	2003	4548	Hancock	25.9	2.7	1.8
Heart Pond	2004	4338	Hancock	29.5	21.0	9.8
Jacob Buck Pond	2003, 2004	4322	Hancock	76.9	15.8	6.7
Williams Pond	2003, 2004	5538	Hancock	45.3	15.2	7.3

**Figure 1:** Site design used during the 2003 and 2004 sampling seasons. Measurements were taken in subsite B at deliberately chosen developed sites only. Macrophytes were not assessed at 1.5 or 3.5 m along the perpendicular transect in 2003.



### Study Design

In order to assess both the natural template and the effects of shoreline development, we employed two strategies to select sampling sites. On undeveloped lakes all 18 sites (or 8 sites for lakes sampled only in 2003) were randomly chosen to avoid bias inherent when deliberately choosing sites. These randomly selected sites were selected within equi-angular 'slices' to allow us to characterize the entire perimeter of the lake. On developed lakes we sampled 8 random sites, selected as described above, and 10 deliberately chosen sites. The deliberately chosen sites target development that conformed (5 per lake) and did not conform (5 per lake) to Maine Shoreland Zoning Regulations based on the amount of shoreline and riparian vegetation and the setback distance of the structure from the lakeshore. The 'random' sites allow assessment of lake-level effects of shoreline development while the 'developed' sites reflect more site-specific effects.

At randomly chosen sites in both undeveloped and developed lakes, we collected data at two subsites (A and C) to capture heterogeneity at the site level (Fig. 1). At deliberately chosen developed sites, data were also collected at subsite B, that was centered on the residence or the lake access for the property (i.e. docks or paths). For purposes of this report data from A and C are averaged for all analyses. Littoral variables were assessed along the 10 m transect at the 0.5 m depth contour parallel to shore and within 0.5m<sup>2</sup> circular plots located every 1m from the shore to 4.5m. Shoreline variables were measured within the 1m shoreline zone which extended from the water's edge or the normal high water mark (if the lake level was low) to 1m inland. Riparian variables were measured within a 10m by 10m plot behind the shoreline transect.

**Table 2:** Habitat and biological variables measured during 2003 and 2004. Rows indicate the set of variables while columns show the location of data collection (see Fig. 1).

<i>Variables</i>	<i>Littoral Transect (0.5m depth)</i>	<i>Perpendicular Transect</i>	<i>Riparian Plot</i>	<i>Shoreline Zone</i>
<b>Physical template</b>	Substrate type <sup>a</sup> Fetch Aspect	Substrate type <sup>a</sup> Littoral slope	Slope Aspect	Substrate type <sup>a</sup>
<b>Habitat complexity</b>	Macrophyte structural type <sup>b</sup> ; Coarse woody debris	Macrophyte structural type <sup>b</sup> ; Coarse woody debris	Vegetation structure <sup>c</sup> and type <sup>d</sup>	Vegetation structure <sup>c</sup> and type <sup>d</sup> ; Overhanging vegetation
<b>Response Variables</b>	Macroinvertebrate community; Substrate embeddedness <sup>e</sup>	Macrophyte species; Substrate embeddedness <sup>e</sup>		
<b>Human activity</b>	Evidence of human use (boats, docks, etc)		Impervious surface; Type and footprint of structure; Pre- or post- legislation	

<sup>a</sup>Substrate type = sand, cobble, boulder and bedrock; <sup>b</sup>Macrophyte structure = submerged, emergent, floating leaf;

<sup>c</sup>Vegetation structure = tree height category, shrub, etc.; <sup>d</sup>Vegetation type = deciduous, coniferous, or mixed;

<sup>e</sup>Embeddedness = the relative degree to which the sediments are covered with fine silt

### *Data Collection:*

Data collection in the littoral and riparian zone focused on four sets of variables defining: (1) the physical template; (2) structural complexity; (3) biological and physical response variables; and (4) the extent of human activities (Table 2).

Littoral and riparian physical variables. Percent substrate composition was based on size in the following categories: bedrock (larger than a car), boulder (basketball to car size), cobble/gravel (ladybug to basketball size), sand (smaller than a ladybug and gritty in texture), and fine sediments (smaller than a ladybug but not gritty in texture). Slope of the riparian plot was measured using a clinometer. Littoral slope was calculated using depth measurements taken at meter intervals along the perpendicular transect. Aspect was obtained either onsite with a compass or derived from a Digital Elevation Model in ArcGIS. Fetch was calculated using a fetch calculation script in ArcGIS.

Littoral and riparian habitat complexity variables. We estimated littoral and riparian habitat complexity based on macrophyte structural type, coarse woody debris, and riparian vegetation structure. Macrophyte structural type included: emergent, submergent, floating leaf, ground cover, and freely floating. The percent coverage of emergent, submergent and floating leaf plants was combined into a variable reflecting macrophyte structure. All coarse woody debris that was greater than 5cm but less than 10cm in diameter was tallied along the 10 m littoral transect. Coarse woody debris 10cm and larger in diameter was counted and assessed for the degree of decay, amount of branching, elevation above the substrate, orientation to the transect, and length. The percent coverage of coarse woody debris greater than 1cm in diameter was assessed along the perpendicular transect. Within the shoreline and riparian zones, we determined the percent coverage of different strata of vegetation based on the following classification: tree stratum >5m high; high shrub stratum 1.5-5m; low shrub stratum 0.1-1.5 m; and ground stratum <0.1m. The dominant type of vegetation (deciduous, coniferous, or mixed) was determined for the tree and high shrub strata. In the shoreline zone we also measured the percent of the shoreline covered by overhanging trees and shrubs.

Response variables. The response variables included macroinvertebrate community composition, macrophyte species assemblage, and substrate embeddedness. Macroinvertebrates were sampled at 8 sites on undeveloped lakes and 11 sites on developed lakes using activity traps constructed from two 1-L soda bottles (modified from Muscha et al. 2001 and Hyvönen and Nummi 2000). Two traps were supported horizontally approximately 20cm from the substrate in the water column by a PVC support column. Duplicate sets of traps were set at subsites A and B at each site along the 0.5 m depth contour. A yellow-green glow stick placed in each soda bottle served as an attractant to invertebrates. This trapping method is selective but was most efficient for our study because of the short time required for colonization (Muscha et al. 2001; Hyvönen and Nummi 2000). Macroinvertebrates were sorted, counted, and identified to order in the laboratory. In addition to using macrophyte form as part of a measure of habitat structure (see above), we also used measures of species assemblages as a response variable. Macrophyte species were identified in 0.5m<sup>2</sup> plots at meter intervals along the perpendicular transect at each site. Following Jennings et al. (2003), we included measures of substrate embeddedness, which was classified depending on coverage of boulder and cobble/gravel substrates by sand or fine sediments. The percent coverage categories included: <5%, 5-25%, 25-50%, 50-75%, and 75-100% (Platts et al. 1983).

Human activity. In order to assess the effects of shoreline development on riparian and littoral habitats, we measured the human activity at developed sites. Measures included the set



back distance of the structure from the shoreline, the size and type of structure, whether it conformed to regulations or not, and the presence of boats and docks. At the whole lake scale, the number of residences was recorded for each lake.

### *Data Analysis*

We are using a multivariate technique, nonmetric multidimensional scaling (NMS), to define the 'natural' template using data on physical variables collected at sites in undeveloped lakes. NMS is an appropriate technique for our data set because the model does not require normality and variables measured at different scales can be included in the same analysis. The physical variables included in the NMS were the percentages of bedrock, boulder, cobble/gravel, sand and fine sediments along the littoral transects and littoral slope, riparian slope, and fetch. We ran the NMS model using PC-ORD 4.36 (McCune and Mefford 1999) in autopilot mode using the Sorensen (Bray-Curtis) distance measure, random starting coordinates, and 40 runs with the real data to find the number of dimensions to describe the data set. After determining the appropriate number of dimensions, the model was rerun using starting coordinates from the initial model and one run with the real data for the final model. The percent coverage of littoral macrophyte types was then overlain to explore relationships with the physical variables. While the results are not included in this report, the output from the NMS will be used to determine combinations of physical variables that best explain distributions of coarse woody debris and macrophyte form, variables that we are using to define structural complexity.

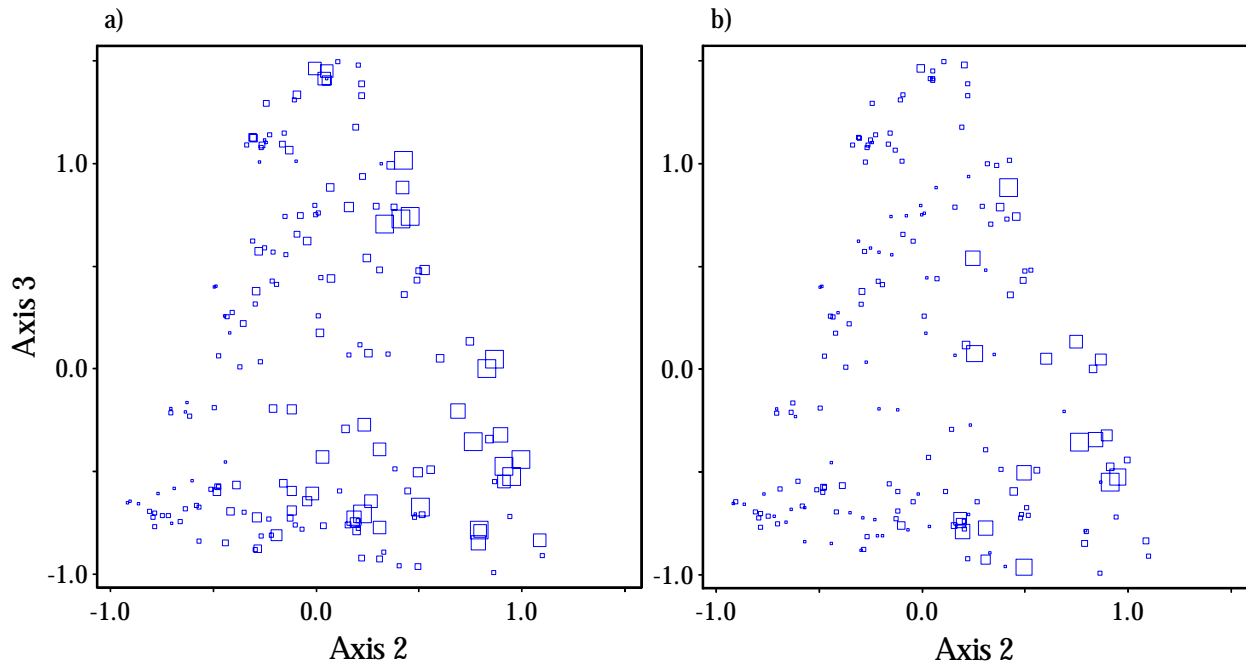
We then examined differences in riparian and littoral structural features among undeveloped sites on undeveloped lakes, random sites on developed lakes, and developed sites on developed lakes. Because the data were not normally distributed, randomization tests were performed to determine differences among site types, lakes, and sites. The data were shuffled and Monte Carlo analyses were performed using PopTools in Microsoft Excel (Hood 2005). The Monte Carlo analysis involved 1000 iterations for each variable and used an F statistic to determine the p value. We focus here on two comparisons: undeveloped vs. random sites and random vs. developed sites.

## **Principal Findings:**

### *Natural Template*

The NMS model described patterns in the physical variables that comprise the natural template for the littoral zone. For the final model, the second and third axes accounted for 14% and 61% of the variance, respectively, among undeveloped sites. Undeveloped sites were grouped primarily by substrate type and lake fetch, while riparian and littoral slope seemed less important. The overlay of macrophytes on the NMS axes suggests that percent coverage of macrophytes (emergent + submergent + freely floating) was related to percent coverage values of fine sediments (Fig. 2). Additionally, this group of macrophytes was generally not found in areas with high values for lake fetch. Floating leaf and ground cover macrophytes were more evenly distributed across substrate types and did not show strong relationships with any particular substrate type. The results support our hypothesis that physical features influence habitat complexity and need to be accounted for when evaluating littoral zone structure.

**Figure 2:** Results of the NMS analysis of physical variables measured at undeveloped sites on undeveloped lakes. Higher values off (a) % fine sediment and (b) % emergent + submergent + freely-floating macrophytes are shown by the size of the symbol on the graphs below. Macrophyte data are shown as an overlay on the NMS plots.



### Effects of Shoreline Development on Habitat Structure

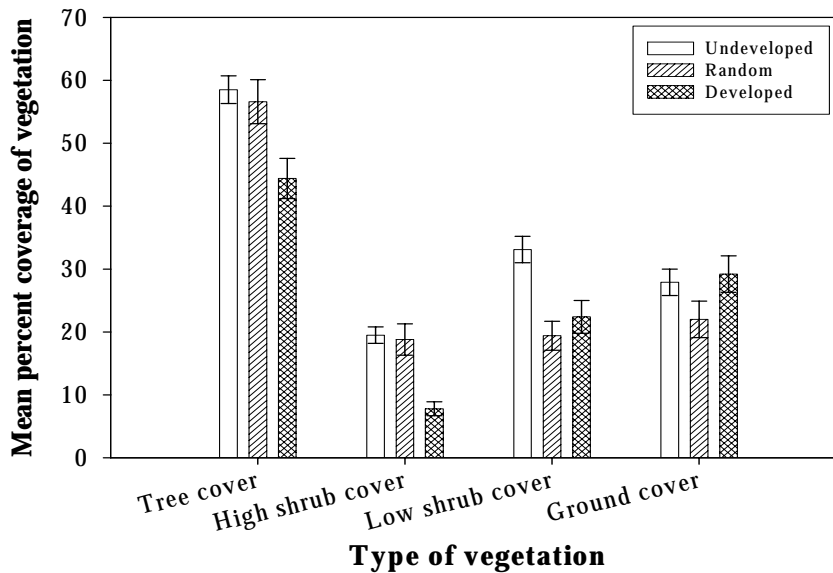
For this analysis we compared percent coverage of our key riparian and littoral structural variables among *undeveloped* sites (on undeveloped lakes), *random* sites (on developed lakes), and *developed* sites (on developed sites). Results are shown in Table 3 and Fig. 3-6 below. Note that statistical analyses were not done for the coarse woody debris data.

**Table 3:** Results of randomization tests comparing undeveloped vs. random sites and random sites vs. developed sites. Significant difference noted by the *p*-values; ns=not significant.

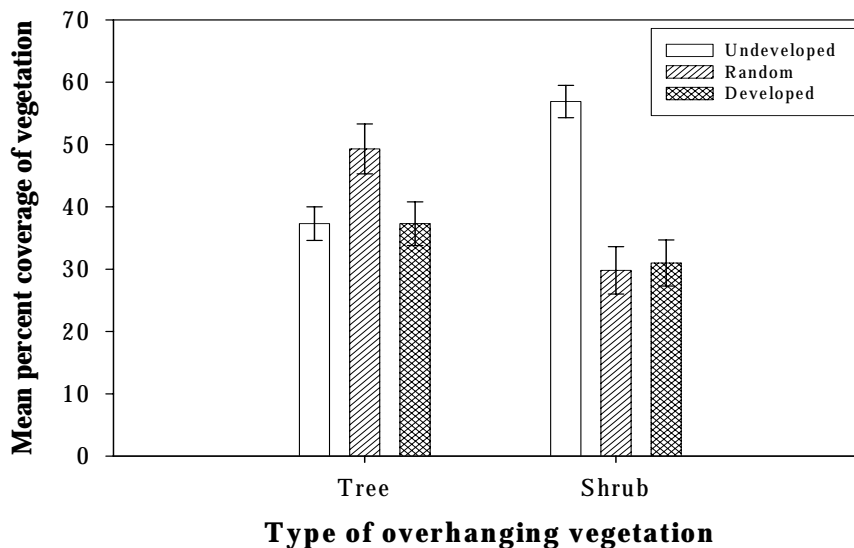
<b>Variable</b>		<b><i>Undeveloped vs. Random</i></b>	<b><i>Random vs. Developed</i></b>
<b>Riparian Vegetation</b>	Tree cover	ns	$p < 0.01$
	High shrub cover	ns	$p < 0.001$
	Low shrub cover	$p < 0.05$	ns
	Ground cover	ns	ns
<b>Shoreline Vegetation</b>	Overhanging trees	ns	$p < 0.05$
	Overhanging shrubs	$p < 0.01$	ns
<b>Littoral Macrophytes</b>	Emerg+subm+floating	ns	ns
	Floating leaf	ns	ns
	Ground cover	ns	ns

**Riparian and shoreline vegetation:** In the riparian zone, both tree and high-shrub cover were lower in developed compared to random sites in developed lakes, but were not different when random sites were compared to undeveloped lake sites (Table 3; Fig. 3). In contrast, low-shrub cover was lower in random sites in developed lakes compared to undeveloped lake sites but there was no difference between random and developed sites. Ground cover showed no pattern. Overhanging vegetation was significantly higher in random sites compared to developed sites for trees. In contrast, overhanging shrubs were more abundant in undeveloped compared to random sites but there was no difference between sites in developed lakes (Fig. 4).

**Figure 3:** Mean ( $\pm$ std error) of percent coverage of different strata of riparian vegetation in undeveloped sites in undeveloped lakes and in random and developed sites in developed lakes.

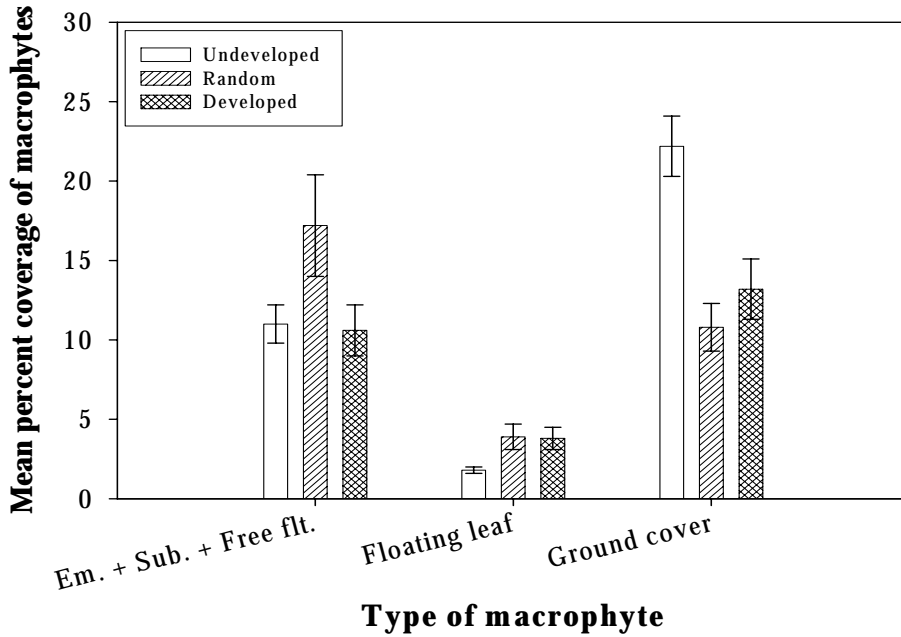


**Figure 4:** Mean ( $\pm$ std error) of % coverage of overhanging shoreline trees and shrubs in undeveloped sites, and random and developed sites from developed lakes.



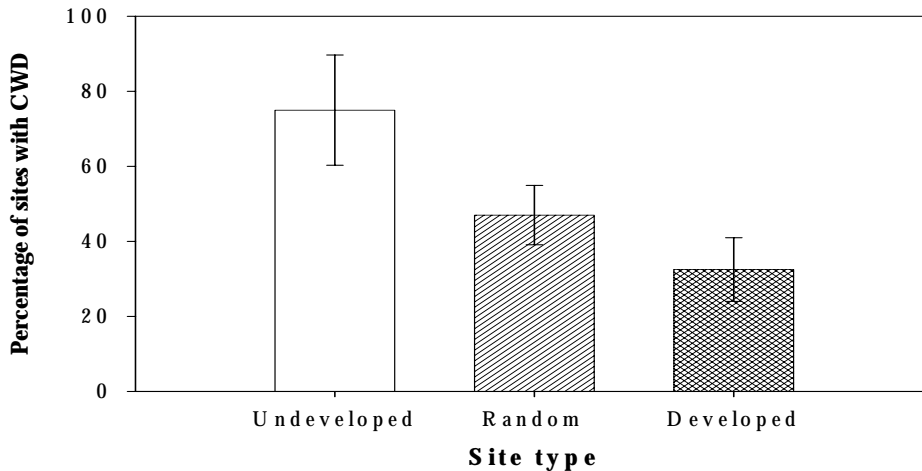
Littoral aquatic vegetation: We did not find any significant patterns in the coverage of littoral macrophytes for any of the functional groups (Table 3; Fig. 5).

**Figure 5:** Mean ( $\pm$ std error) of macrophyte percent coverage in undeveloped lakes and in randomly chosen and developed sites in developed lakes. The percent coverage by emergent, submergent, and freely floating vegetation were added together for this analysis.



Coarse woody debris. Coarse woody debris (CWD), summarized as the percentage of sites on a lake with coarse woody debris, was more common on undeveloped lakes compared to developed lakes (Fig. 6). Within developed lakes, CWD was more commonly encountered on random sites compared to developed sites. Note that statistical analyses are not yet available for these data.

**Figure 6:** The percentage of sites with coarse woody debris in undeveloped lakes, random sites on developed lakes, and developed sites on developed lakes. Means ( $\pm$ std error) are based on lake means.



## **Significance:**

Results from the NMS analysis support our hypothesis that variation in habitat complexity is in part defined by physical factors such as fetch and sediment composition. The group of macrophytes (emergent + submergent + freely floating) that provide structure to the littoral zone was found in the highest percent coverage at sites with fine sediments. Fetch and wave action in shallow littoral areas generally remove fine grained sediments (Håkanson 1982; Petticrew and Kalff 1991). The removal of fine grained sediments in areas with high wave action can have an effect on the macrophyte community structure because macrophytes can be physically damaged by waves and conditions may not be as favorable for plant growth (Keddy 1982). Defining these patterns in physical variables is an important step for creating expectations regarding the presence of macrophytes and coarse woody debris in our Maine study lakes.

Based on comparisons of developed and randomly chosen sites in developed lakes, the site-specific effects of shoreline development included fewer trees and high shrubs along the riparian zone and the shore. Surprisingly, low shrubs and overhanging shrubs were lower in randomly chosen sites in developed lakes compared to undeveloped lakes suggesting that the effects of shoreline development were manifest at the whole lake scale, in addition to the direct and mechanical effects of development. An effect of shoreline development on littoral habitat complexity was suggested by the patterns shown by coarse woody debris occurrence, with highest occurrence in undeveloped lakes, followed by random sites then developed sites in developed lakes. We did not find strong evidence for an effect of shoreline development on macrophyte structure. If anything, the data in Fig. 5 suggest that the random sites in developed lakes have the most structure based on the sum of percent coverage by emergent, submerged and freely floating forms. The logistic regressions needed to statistically test patterns of occurrence for both coarse woody debris and macrophytes are in progress.

Our finding that the incidence of coarse woody debris is lower in developed lakes corresponds to conclusions from other studies (Christensen et al. 1996). Our lack of clear-cut results for macrophytes, however, differs from studies that have reported a reduction in macrophytes with shoreline development from recreational use of the littoral zone and physical removal of plants by residents (Radomski and Goeman 2001; Jennings et al. 2003). One possible reason for these differences is the low intensity of development in our downeast Maine lakes. We will further refine our analysis through including a variable from the NMS to account for intra-lake variation related to the natural template.

## **Summary:**

Our research has begun to develop a system for including measures of the natural physical template underlying heterogeneity in the littoral zone into an analysis of the effects of lake shoreline development on habitat complexity. Through this work we can ultimately identify rapid assessment metrics for use by management agencies to assess the impacts of shoreline development. Our results to date suggest both site specific and lake scale effects of shoreline development on riparian vegetation. By refining these and including an analysis of the biotic responses to alterations in habitat complexity we can more fully assess the effects of development initiated prior and after the passage of shoreline regulations.

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## Student Support

This grant supports Kirsten Ness' research for her M.Sc. degree in Ecology and Environmental Science (EES), with a concentration in Water Resources. Matching funds from the University of Maine have provided additional support via a Research Assistantship (2003-2004) from the Maine Agricultural and Forestry Experimental Station (USDA) and a Teaching Assistantship (2004-2005) from the Department of Biological Sciences.

## Notable Awards and Achievements

Kirsten Ness won the best oral presentation in the Ecology and Marine Sciences category at the University of Maine Association of Graduate Students Research Exposition, April 2005.

## Publications and Presentations

- Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the Maine Water Conference, March 2005, Augusta.
- Ness, K., K.E. Webster, R. Bouchard. 2005. What are the effects of shoreline development on lakes in Maine? Oral presentation at the 7<sup>th</sup> Annual Association of Graduate Students Research Exposition, April 2005, Augusta.

# Effects of local and landscape heterogeneity on mercury loadings in palustrine amphibians from Acadia National Park, Maine

## Basic Information

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<b>Principal Investigators:</b>	Aria Amirbahman, Michael Bank, Cynthia Loftin

## Publication

1. Bank, M.S., 2005. Mercury bioaccumulation and habitat dynamics of lotic and lentic amphibians. "Ph.D. Dissertation" University of Maine, Orono, Maine. 177 pp.

# Evaluating the effect of the Clean Air Act on lake and stream chemistry in the northeastern U.S.

## Basic Information

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<b>Descriptors:</b>	
<b>Principal Investigators:</b>	Jeffrey S Kahl, Kathy Webster

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## FINAL REPORT

### *Evaluating the effect of the Clean Air Act on lake and stream chemistry in the northeastern U.S.*

*IAG Award Number 99HQGR0226*  
(to the University of Maine)

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**Project period:** August, 1999 to July, 2004 (including no-cost extension)

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**Web sites that contain project information:**

<http://www.plymouth.edu/cfe/>  
<http://www.umaine.edu/WaterResearch/>

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February, 2005

*Evaluating the effect of the Clean Air Act on lake and stream chemistry  
in the northeastern U.S.*

*IAG Award Number 99HQGR0226*

Steve Kahl  
*Plymouth State University*

Katherine Webster  
*University of Maine*

**Executive Summary**

Objectives. This project is part of the Environmental Protection Agency's program to address scientific uncertainty relating to surface water and watershed acidification. Our goals and methods were hierarchical, ranging from site-specific data to regional statistical surveys. The objectives were to:

- 1) determine the changes and trends in aquatic chemistry for defined sub-populations and sites that are known to be susceptible to acidification or recovery,
- 2) evaluate the relationships between surface water and precipitation chemistry using site-specific deposition data, and regional NADP data, and
- 3) characterize the effectiveness of the Clean Air Act (and amendments) in meeting its goals of reducing acidification of surface waters and improving biologically-relevant chemistry in the northeastern US.

Approach. The schedule of tasks used during 1999-2004 ranged from weekly to annual. We evaluated chemistry on a weekly basis year-round at the small watershed-scale at BBWM, weekly during the spring melt period at RLTM lakes outlets, quarterly in LTM and RLTM lakes, and during an annual index period for the HELM and TIME lakes. The specific tasks:

- a) examined the patterns of acidification and recovery in the experimental watershed project at the Bear Brook Watershed in Maine (BBWM), originally part of the EPA Watershed Manipulation Project,
- b) continued the 17 year chemistry record for selected lakes in Maine which were part of the original EPA Long Term Monitoring Program (LTM),
- c) expanded the scope of LTM using the EPA Regionalized Long Term Monitoring Lakes which have a broader distribution of chemistry to match the regional chemical characteristics (Table 1),
- d) provided an estimate of seasonal chemical extremes that occur in these RLTM lakes,
- e) re-sampled a subset of the high elevation lakes (HELM), surveys of which in 1986-88 revealed the most acidified lakes in Maine, and
- f) provided a statistical regional estimate of chemical changes using lakes in the EPA Temporally Integrated Monitoring of Ecosystems (TIME) program in New England and the Adirondack region (Table 2).

The annual schedule and scope of work were as follows:

	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	# samples
TIME lakes (75x1)	x	x											75
LTM:													
spring outlets (9x5)									x	x			45
drainage lakes (9x3)	x	x		x	x					x	x		27
seepage lakes (3x3)	x			x							x		9
LTM lakes (3x1)					x								3
HELM lakes (20x1)				x									20
BBWM streams (2x50)	weekly sampling ->												100

The project components provided a *statistical framework* for inferring regional chemical patterns using TIME and RLTM. The *long term records* of LTM, RLTM, HELM and BBWM provided seasonal and annual variability data that help put the statistical results in context.

*Impact.* This information is fundamental for federal agencies to meet the Congressional mandate in the Clean Air Act Amendments (CAAA) to ascertain trends in ecological response, and to determine the effectiveness of the CAAA in influencing these trends. The information was summarized in the 2003 EPA assessment report to Congress (Stoddard *et al.*, 2003), written while Kahl was on sabbatical at EPA ORD, Corvallis. The sabbatical was funded by supplemental funding to this IAG. The policy-relevant results were published in the peer-review literature, an article in Environmental Science and Technology (Kahl *et al.*, 2004).

*Publications.* During the project period, the results of this research were used to support 24 peer-review publications and a public outreach document on the potential effects of acid rain on the recovery of endangered Atlantic Salmon. Eight graduate students used data from Bear Brook and regional sites in their theses, and PI Kahl gave 30 professional talks about the CAAA and regional trends during the project period. Full citations are included for these documents and presentations at the end of the literature cited section of the main report. The peer-review papers are included on the accompanying CD in PDF format.

*Quality Assurance overview.* This research has been conducted in laboratories developed and managed by PI Kahl since 1982. During 2001-02, data reporting and quality assurance were complicated by a transition in laboratories. In 2001, the University of Maine administration elected to spin off the LTM-TIME laboratory into an independent university contract laboratory, not managed by active researchers. As a result, the laboratory no longer focused on low ionic strength water analyses, its speciality for two decades. The change in management resulted in substantial delays in data delivery beginning in 2001, and a doubling of laboratory sample costs charged to this project in 2002. In addition, the laboratory management declined to produce quality assurance reports as part of the project deliverables.

As a result of these changes, the University administration asked Kahl to develop a new laboratory within the Mitchell Center, in order to re-focus university expertise on low ionic strength surface waters, including this grant and related research on salmon river water chemistry. This laboratory was quickly established and was responsible for all 2002-2004 sample analyses for this project. Many samples from 2001-02 were re-run in the new Mitchell

Center laboratory, to confirm or replace values from the contract laboratory, because of deteriorating audit results in the contract laboratory.

The new Mitchell Center laboratory received a ‘satisfactory’ rating (the second highest classification) from two rounds of Environment Canada inter-laboratory audits in 2002 and 2003. The laboratory received a perfect score in the USGS dilute precipitation audit program in 2004.

Table 1. *LTM lakes sampled 1 to 3 times per year, plus seasonal spring outlet sampling*

<i>Regular LTM sites:</i>	Class	Schedule (# yr)	Area (ha)	Depth (m)	Elev (m)
Abol Pond	thick till	spr/qtrly (8)	36	10	181
Bean Pond	med. till, high DOC	spr/qtrly (8)	12	9	381
Bracey Pond	GW seepage	quarterly (3)	8	9	117
Crystal Pond	perched/seepage	quarterly (3)	10	9	113
Duck Pond	perched/seepage	quarterly (3)	2	3	82
Jellison Pond	med. till, low DOC	spr/qtrly (8)	18	17	123
Newbert Pond	thin till, high DOC	spr/qtrly (8)	13	4	89
Mud Pond	thin till, low DOC	spr/qtrly (8)	1	15	104
Partridge Pond	thin till, low DOC	spr/qtrly (8)	9	7	175
Salmon Pond	med. till, low DOC	spr/qtrly (8)	4	10	94
Second Pond	thin till, high DOC	spr/qtrly (8)	27	13	126
Wiley Pond	med. till, high DOC	spr/qtrly (8)	11	6	235
<i>LTM Supplemental Lakes (once per year):</i>					
Anderson Pond	thin till, low DOC	fall only (1)	5	6	66
Little Long Pond	thin till, low DOC	fall only (1)	24	25	75
Tilden Pond	thin till, low DOC	fall only (1)	15	9	72

Table 2. *Locations of the Temporally Integrated Monitoring of Ecosystems lakes (TIME), sampled once each summer.*

Lake	State	Latitude	Longitude
Muddy Pond	MA	42.6011	71.8894
Number Six Reservoir	MA	42.1144	71.7428
Knights Pond	MA	42.3519	72.4133
Scokes Pond	MA	41.9222	70.5430
Bickford Pond	MA	42.4865	71.9288
Lake Wyola	MA	42.5014	72.4310
Wickett Pond	MA	42.5511	72.4316
Kingsbury Pond	MA	42.1223	71.3739
Copicut Reservoir	MA	41.7103	71.0365
Mountain Pond	ME	44.8950	70.6442
Round Pond	ME	43.4017	70.7589
Bog Pond	ME	44.8855	69.5748
East Branch Lake	ME	45.5188	68.7340
Ivanhoe Pond	NH	43.6003	70.9922
Highland Lake	NH	43.1081	72.0889
Hodge Pond	NH	42.7975	72.0675
Russell Pond	NH	44.0091	71.6538
Pratt Pond	NH	42.7394	71.9074
Island Pond	NH	42.7395	71.9345
Gregg Lake	NH	43.0347	71.9849
Skatutakee Lake	NH	42.9375	72.0770
Seavers Reservoir	NH	42.9436	72.1281
Childs Bog	NH	42.9572	72.1227
Miller Pond	NH	43.5402	72.1687
North Pond	NH	43.2414	72.0999
May Pond	NH	43.2299	72.1120
Pisgah Reservoir	NH	42.8201	72.4508
Hope Pond	NY	44.5125	74.1272
Second Pond	NY	43.6622	74.0831
Squaw Lake	NY	43.6331	74.7394
Indian Lake	NY	43.6164	74.7533
Big Alderbed	NY	43.3253	74.7056
Long Lake	NY	43.3133	74.7192
Little Lilly Pond	NY	43.9111	74.7758
Upper Sister Lake	NY	43.8836	74.7619
Twin Ponds (E)	NY	44.5197	74.6933
Bennett Lake	NY	43.3153	74.1944
Taylorville Pond	NY	43.9264	75.3028
Effley Falls Pond	NY	43.9203	75.2606
Parmeter Pond	NY	44.3556	74.9917
North Lake	NY	43.5381	74.9269
Razorback Pond	NY	43.8492	74.9206
Snake Pond	NY	43.8350	74.9147
South Lake	NY	43.5114	74.8861
Boottree Pond	NY	44.2428	74.6572
Horseshoe Pond	NY	44.2458	74.6481
Rock Pond	NY	43.9869	74.6419
Antediluvian Pond	NY	44.0017	74.6225
Seven Sisters Pond	NY	44.2811	74.6183
Pear Pond	NY	43.9500	74.6136
Hamilton Pond	NY	43.9467	74.6103
Doctors Pond	NY	44.0053	74.6011
Canada Lake	NY	43.1578	74.5453
Bickford Pond	NY	44.3975	74.3175
Pond NR Spitfire L.	NY	44.4164	74.2883
No Name	NY	43.4689	74.6978
Wolf Pond	NY	44.3040	74.8104
Henderson Lake	NY	44.0921	74.0671
Rocky Lake	NY	44.1694	75.1402
Miner Mill Vly	NY	43.2340	73.9960
Trout Pond	NY	44.0942	74.6427
McCuen Pond	NY	44.3919	74.6739
Witchhopper Lake	NY	43.9652	74.9167
Willys Lake	NY	43.9693	74.9547
Lower Beech Ridge Pond	NY	43.9655	74.9824
Dismal Pond	NY	43.9559	74.9749
No Name	NY	43.9451	74.9250
Payne Lake	NY	43.7951	75.2912
Whitney Lake	NY	43.5889	74.5637
Little Moose Pond	NY	43.5525	74.5421
Clear Lake	NY	41.4294	73.8408
Little Cedar Pond	NY	41.1803	74.2764
Dry Channel Pond	NY	44.3522	74.4364
Quidnick Reservoir	RI	41.6800	71.6820
Somerset Reservoir	VT	43.0139	72.9447

*Summary of Findings* (from Kahl *et al.* 2004). Title IV of the 1990 Clean Air Act Amendments (CAAA) in the United States set target reductions for sulfur and nitrogen emissions, in order to reduce acidity in deposition. These targets continued a trend of decreasing sulfur deposition during the past 30 years. The rate of decline accelerated when Phase I controls of the CAAA were implemented in 1995<sup>1,2</sup>. Changes in nitrogen emissions have been minimal, with only slight reductions since 1996.

Documentation of acidification of surface waters began more than three decades ago in Scandinavia<sup>3</sup>, with a few reports of acidic lakes in North America in the 1950s<sup>4</sup>. Recognition of ‘acid rain’ became common in the U.S. in the early 1970s<sup>5</sup>, with identification of impacts on fish by the mid-1970s<sup>6</sup>. Many assessments have been made on trends in deposition and surface waters<sup>7-10</sup>. Trend assessments have become more robust as data records became longer. In this paper, we use data from both long-term site-specific records and long-term repeat surveys of statistical populations. The results summarize nearly 20 years of data from regional EPA programs specifically designed to meet the Congressional assessment requirements of the Clean Air Act.

One of the intended effects of the CAAA was to decrease the acidity of waters with low acid neutralizing capacity, and thereby improve their biological condition<sup>11</sup>. Therefore, we address the following science and policy questions related to aquatic resources and the CAAA:

- 1) *Have declines in emissions translated into reductions in acidic deposition?*
- 2) *Have changes in deposition translated into changes in surface water chemistry, and are these changes an improvement in biologically-relevant chemistry?*
- 3) *What are the expectations for the rate and timeframe of recovery?*

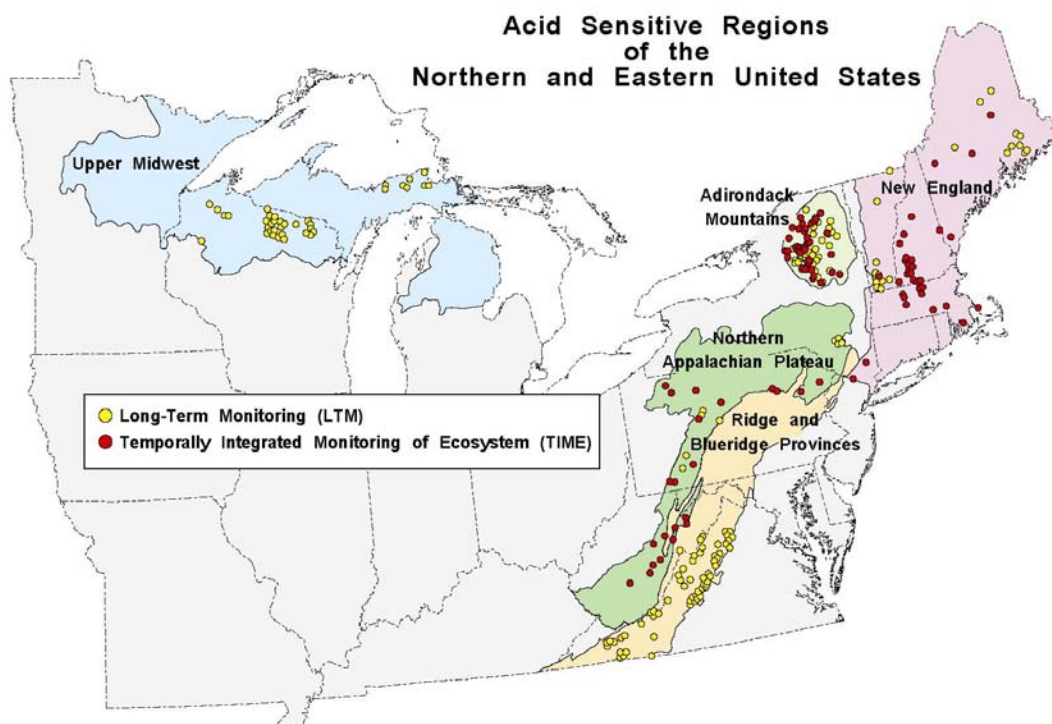
We report changes in chronic acid-base chemistry of surface waters, using data from regions of the northern and eastern U.S. that are considered at risk from acidic deposition, and that are most likely to respond to changes in deposition. Emissions reductions under Title IV were much greater in the eastern US because coal-fired emissions sources are predominant here. The measures of expected ‘recovery’ in sensitive waters include decreased acidity, decreased sulfate, and decreased toxic dissolved aluminum concentrations<sup>8</sup>.

The surface water data are from the EPA Long Term Monitoring (LTM) and Temporally Integrated Monitoring of Ecosystems (TIME) projects, part of EMAP (Environmental Monitoring and Assessment Program<sup>12</sup>). The LTM sampling schedules and analytical methods for these programs are coordinated by EPA-Corvallis, providing for reasonable data comparability across the regions of the program. TIME samples have been analyzed in the same laboratory (Mitchell Center, University of Maine), since program inception in 1991.

The regions (Figure 1) are New England, the Adirondack Mountains of New York, the Northern Appalachian Plateau (New York, Pennsylvania and West Virginia), the Ridge and Blue Ridge provinces of Virginia, and the Upper Midwest (Wisconsin and Michigan). The period covered includes 1982 through 2000. We focus on 1990 to 2000, the period since the last major science review by NAPAP (National Acidic Precipitation Assessment Program<sup>13</sup>), and since the 1995 implementation of the CAAA.



The results are encouraging. All but one region exhibited declines in the primary acidifying anion,  $\text{SO}_4^{2-}$ , during the 1990s. Several regions show decreases in lake and stream water acidity. There were 1/3 fewer acidic lakes in the Adirondacks in 2000 compared to 1990. These are signs of recovery, defined as trends moving in the right direction. True recovery should probably be considered to be a return to conditions of more than 100 years ago, both in terms of chemistry and biology. When only *naturally* acidic lakes and streams remain in these regions, then we may reasonably conclude that true recovery has occurred, particularly if we can document parallel recovery in biological assemblages.



**Figure 1.** Map of TIME and RLTM sites and study regions.

*Question 1: Have changes in emissions translated into changes in deposition in the intended target areas?*

Yes, there is a direct correlation between sulfur emissions and deposition<sup>2</sup>. Correlations between nitrogen emissions and deposition are complicated by multiple sources of emissions, some of which are not related to fossil-fuel combustion (e.g. fertilizers and animal waste). Moreover, changes in nitrogen emissions and deposition were small through 2000, so there has not been an opportunity to develop an empirical relationship between *changes* in emissions and deposition.

*Decline in sulfur emissions and deposition.* Between 1980 and 2000, sulfur emissions from power generation sources regulated under Phase I of the 1990 CAAA declined by 35%. Over the same time period, sulfate declined by more than 45% at National Atmospheric Deposition Program (NADP) sites<sup>2,14,15</sup>. Compared to trends during 1983-94, the decline in wet deposition of sulfate *accelerated* after 1995 at 74% of NADP sites in the eastern U.S., in parallel with the decrease in emissions<sup>2</sup>. Sulfate concentrations in wet deposition declined in each of the acid-

sensitive regions reported here, at a median rate between -0.8 and -1.5  $\mu\text{eq/L/year}$  during 1990 to 2000 (see Table 1 in the ES&T on-line supplement).

*Decline in nitrogen emissions and deposition.* There were only small declines in nitrogen deposition in the northeastern corridor (see Table 1 in the ES&T on-line supplement). Between 1990 and 2000, nitrogen oxide emissions from power generation sources affected by Title IV of the 1990 CAAA declined by 18%<sup>13</sup>. However, NO<sub>x</sub> emissions from electric power generation contribute only approximately 22% of NO<sub>x</sub> emissions from all sources, and therefore the reductions achieved under the CAAA have not resulted in substantial changes in NO<sub>x</sub> emissions or deposition.

*Increase in pH and base cations in deposition.* Lynch et al.<sup>2</sup> reported significant decreases in hydrogen ion (i.e. an increase in pH of wet deposition) at many NADP stations, although rates of decrease were less than the decrease in sulfate. In the TIME/LTM regions, decreases in wet deposition of hydrogen ion occurred in every region, and were significant in every region except the Ridge and Blue Ridge provinces. Base cation deposition increased non-significantly in four regions, and increased significantly in the Upper Midwest, continuing the trend during the past 20 years (see Table 1 in the ES&T on-line supplement).

*Question 2: Have changes in deposition translated into changes in surface water chemistry in the intended target areas, and are these changes an improvement in biologically-relevant chemistry?*

Yes, changes in deposition have changed surface water chemistry, and *the changes are a net positive for biota*. Of the indicators of chemical recovery, the most important to biota are increasing pH and Gran ANC (Acid Neutralizing Capacity), and decreasing Al. Response in ANC and pH has been small in most regions, and no region is showing an average trend toward lower Gran ANC or pH. Changes in aluminum are modest in TIME and RLTM, although other data suggest a stronger response toward lower aluminum<sup>7,16</sup>. However, the quantitative decline in base cations in surface waters is a major uncertainty for recovery, both for future acid-base chemistry and the biological need for Ca<sup>2+</sup>.

We compared rates of sulfate decline in surface waters and deposition (Figure 3), to determine whether the surface water response is rapid or delayed. We conclude that the surface water response for sulfate has been relatively rapid. The chemical changes that *result from* declines in sulfate, such as an increase in Gran ANC, are much less direct, and appear to be mitigated by the interactions of several other factors discussed later in this paper.

*Status of surface waters.* One of the most accurate methods to assess the extent of surface water acidification is through probability surveys<sup>17</sup>. Statistical survey techniques have been used for two decades in acid-sensitive regions to estimate the number and proportion of acidic lakes and streams in each region. The definition of 'acidic' commonly used in this type of assessment is when baseflow Gran ANC is less than zero, although biological impacts are not necessarily limited to Gran ANC  $\leq 0$ .

The National Surface Water Survey (NSWS), conducted between 1984 and 1988, estimated the chemical conditions of 28,300 lakes larger than 4 ha, and 56,000 perennial stream reaches in the

major acid-sensitive regions of the U.S.<sup>18</sup>. Of these regions, the only one not included in our current assessment is Florida, which has a high proportion of *naturally* acidic lakes, and does not have data from the EPA programs discussed in this paper.

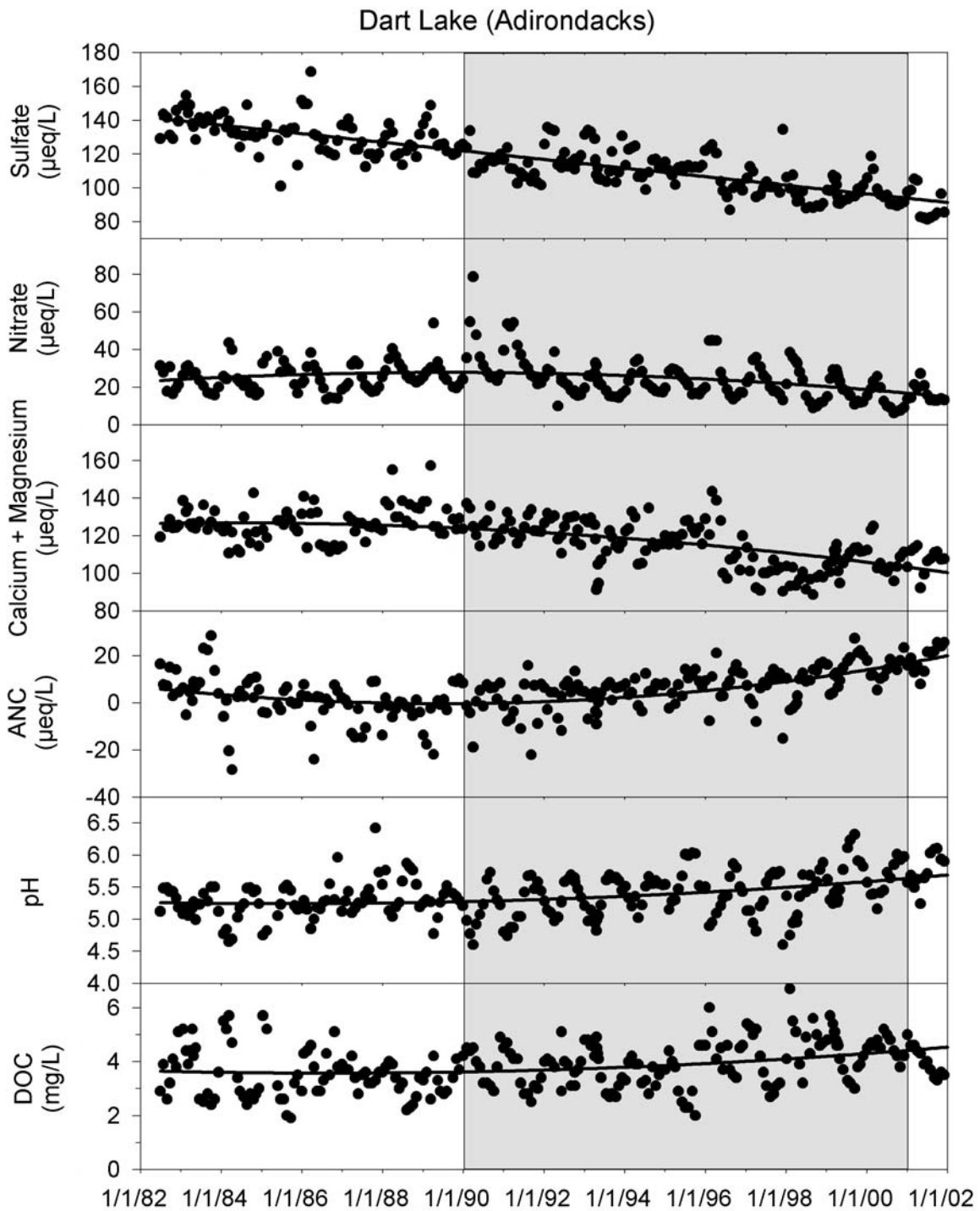
The regions represented here (see Table 1 in the ES&T on-line supplement) are estimated to contain 95% of the lakes and 84% of the streams that have been anthropogenically acidified in the U.S. The Adirondacks had the largest proportion of acidic lakes (14%). The proportions of acidic lakes in New England and the Upper Midwest were 5% and 3%, respectively. Because of the large numbers of lakes in these regions, these small proportions represent several hundred acidic waters in each region. The Valley and Ridge province and Northern Appalachian Plateau had 5% and 6% acidic stream segments, respectively.

*Changes in surface water chemistry.* Our analysis of surface water response to changing deposition focuses on the key variables in acidification and recovery: sulfate and nitrate, divalent base cations, aluminum, pH and Gran ANC, and dissolved organic carbon (an indicator of natural organic acidity). The major ion chemistry of Dart Lake in the NY Adirondack region (Figure 2) is representative of the general patterns observed for lakes and streams in the glaciated terrain of New England, New York, and the Upper Midwest, including substantial declines in sulfate and base cations, and small increases in pH, Gran ANC, and DOC.

*Significant declines in aquatic sulfate concentrations.* Between 1990 and 2000, surface water sulfate declined in the glaciated regions of the North and East by median rates between  $-2$  and  $-4$   $\mu\text{eq/L/year}$  (Figure 3), with the smallest changes in New England and the largest declines in the Upper Midwest. The exception was in the Ridge/Blue Ridge province, where soil chemistry characteristics minimized the response to changes in deposition<sup>19</sup>. All of the regional  $\text{SO}_4^{2-}$  declines are highly significant (see Table 2 in the ES&T on-line supplement), and are consistent with the trends reported previously, including other regions of North America and Europe<sup>10,20</sup>.

The declines in surface water  $\text{SO}_4^{2-}$  concentrations in the glaciated portions of the North and East are inferred to be direct responses to declining emissions and  $\text{SO}_4^{2-}$  deposition in the 1990s (Figure 3). These changes represent success for Title IV of the CAAA and prior emission reductions. The small increase in  $\text{SO}_4^{2-}$  concentrations in the Ridge and Blue Ridge provinces reflects the  $\text{SO}_4^{2-}$  adsorption properties of soils in this unglaciated region. Soil chemistry has lowered stream concentrations of  $\text{SO}_4^{2-}$  below those in deposition and decoupled (in time) trends in deposition and surface waters. See Webb *et al.*<sup>21</sup> for further examination of  $\text{SO}_4^{2-}$  dynamics and surface water response in the Ridge and Blue Ridge provinces.

In New England, the Adirondacks and the Northern Appalachian Plateau, the decline in deposition of sulfate (expressed as  $\% \text{SO}_4^{2-}$ ) exceeds the decline in surface waters (Figure 3), indicating a lagged response in surface waters. There are at least two explanations for a lagged response: soil desorption of accumulated sulfur, and/or net mineralization of accumulated organic sulfur<sup>19</sup>. However, some surface waters had declines in surface water  $\text{SO}_4^{2-}$  that paralleled the decline in deposition, suggesting that the most responsive watersheds are acting essentially as pass-through systems.

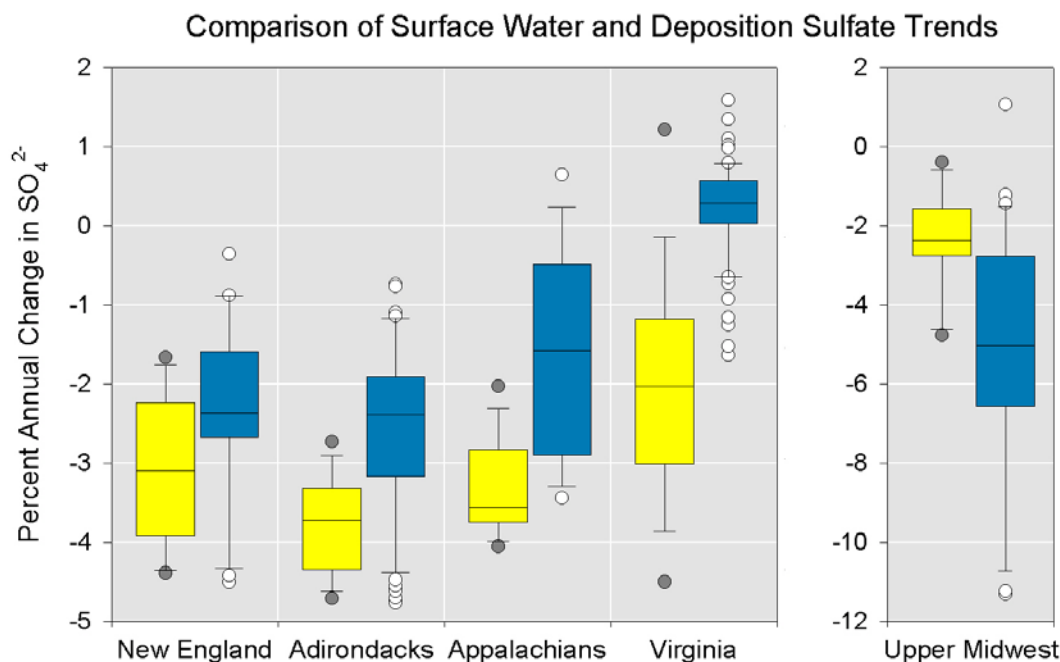


**Figure 2.** Time series data for  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , divalent base cations [ $\text{Ca}^{2+} + \text{Mg}^{2+}$ ], Gran ANC, pH, and DOC in Dart Lake, NY (Adirondack region). Significant trends are indicated by trend lines. Shaded box indicates time period of analyses reported here.

In the Upper Midwest, the rate of decline of %SO<sub>4</sub><sup>2-</sup> in lakes is *greater than* the decline in deposition. These lakes are seepage lakes, with long residence times. The decline in sulfate may reflect the residual effects of the drought of the late 1980s<sup>22,24</sup>.

We conclude that surface waters in glaciated terrain have responded relatively rapidly to the decline in sulfate deposition. Additional reductions in deposition are expected to result in additional declines in surface waters. The rate of decline in sulfate *without* further reductions in sulfate emissions and deposition is unknown.

*Minor changes in nitrate.* Changes in NO<sub>3</sub><sup>-</sup> in surface waters were much smaller than changes in SO<sub>4</sub><sup>2-</sup>. Lakes in the Adirondacks and streams in the Northern Appalachian Plateau exhibited small but significant downward trends in NO<sub>3</sub><sup>-</sup> in the 1990s (Figure 4) that are reversals of trends in the 1980s (Figure 2 illustrates the typical pattern for these regions). Both regions are central to the debate over whether nitrogen saturation is a threat to the health of forests and surface waters<sup>25,26</sup>. While declining NO<sub>3</sub><sup>-</sup> concentrations in these regions are a positive development, the changes are not thought to reflect recent trends in deposition<sup>26</sup>.



**Figure 3.** Comparison of percent change in sulfate, by region, for concentrations in wet deposition (yellow boxes) and surface waters (blue boxes) between 1990 and 2000. Range of boxes shows 25<sup>th</sup> to 75<sup>th</sup> percentiles for each region, with the median indicated by the line. Error bars indicate 5<sup>th</sup> and 95<sup>th</sup> percentile values, and dots indicate extreme values in each region. Deposition SO<sub>4</sub><sup>2-</sup> is declining more steeply than surface water SO<sub>4</sub><sup>2-</sup> in every region except the Upper Midwest.

*Increase in Gran ANC and pH.* Gran ANC is the main target indicator of recovery from acidification. There were modest, significant increases in the Adirondacks, Northern Appalachian Plateau, and Upper Midwest (Figure 4). Median increases of 1 to 2  $\mu\text{eq/L/year}$  represent significant progress toward recovery from acidification. Hydrogen ion (acidity) showed small declines in each region of  $-0.1$  to  $-0.2$   $\mu\text{eq/L/year}$ .

These changes have not been monotonic. Using data through 1995, Stoddard et al.<sup>20</sup> concluded that Gran ANC was *not* increasing in the Adirondacks. Our analysis of data from 1990 through 2000 suggests that the pattern of increasing ANC has occurred only recently in the Adirondacks, as shown by Dart Lake (Figure 2). In contrast for New England, we find no increase in ANC in the 1990s, despite the opposite conclusion of Stoddard et al.<sup>20</sup> based on data through 1995.

*Low ANC waters respond fastest.* We analyzed Gran ANC trends by ANC class and determined that the lowest Gran ANC waters recovered faster in the 1990s, as follows:

ANC < 0 $\mu\text{eq/L}$ in 1990 ( $n=26$ )	increase in ANC during 1990-2000 (13 $\mu\text{eq/L}$ )
(0 < ANC < 25 $\mu\text{eq/L}$ ) in 1990 ( $n=51$ )	increase in ANC during 1990-2000 (8.4 $\mu\text{eq/L}$ )
(ANC > 25 $\mu\text{eq/L}$ ) in 1990 ( $n=43$ )	change in ANC was not significant

The increase in Gran ANC for both classes of lake with ANC less than 25 was significant at  $p < 0.01$ . The response for the most acidic waters suggests that their watershed soils are capable of relatively rapid recovery. The lack of response in the higher Gran ANC class suggests that an ANC of 25 may be an upper limit for recovery of currently acidic lakes and streams (see Question 3, expectations for the future).

*Decreases in the number of chronically acidic waters.* The results from EMAP and NSWS probability surveys were combined with rates of change in TIME and LTM data to estimate the number of chronically acidic waters (Gran ANC < 0 in 1990) that are no longer acidic. In the Adirondacks and Northern Appalachians, approximately one-third of previously acidic sites (in the early 1990s) are no longer chronically acidic (see Table 4 in the ES&T on-line supplement). In the Upper Midwest, the decline in the proportion of acidic lakes was nearly 70%, measured from the 1984 NSWS (the most recent probability survey of lakes in this region). Because neither New England nor the Ridge and Blue Ridge provinces exhibited significant changes in Gran ANC, we conclude that the number of acidic systems in these regions has not declined significantly. However, the current rate of Gran ANC change in all regions is small, and recovering lakes and streams remain sensitive to future changes in deposition. It is clear that response is not monotonic, the interpretation of recovery is subject to the time period analyzed, and (re)acidification is still possible.

*Influence of episodic acidification.* Because our statistical population inferences are based on summer and fall baseflow index period sampling, our estimates are for chronic, not episodic, acidification. It is well documented that many non-acidic surface waters undergo short-term, or episodic, acidification during periods of high discharge<sup>28</sup>. The relationship between mean summer Gran ANC and the spring minimum (See Figure 5 in the ES&T on-line supplement) suggests that lakes and streams with summer values greater than 30 did not experience spring acidification. Therefore, one definable target for 'recovery' is Gran ANC values above 30  $\mu\text{eq/L}$  during baseflow conditions, to minimize occurrence of episodic acidification.

### Regional Trends, 1990-2000 (in lakes and streams)

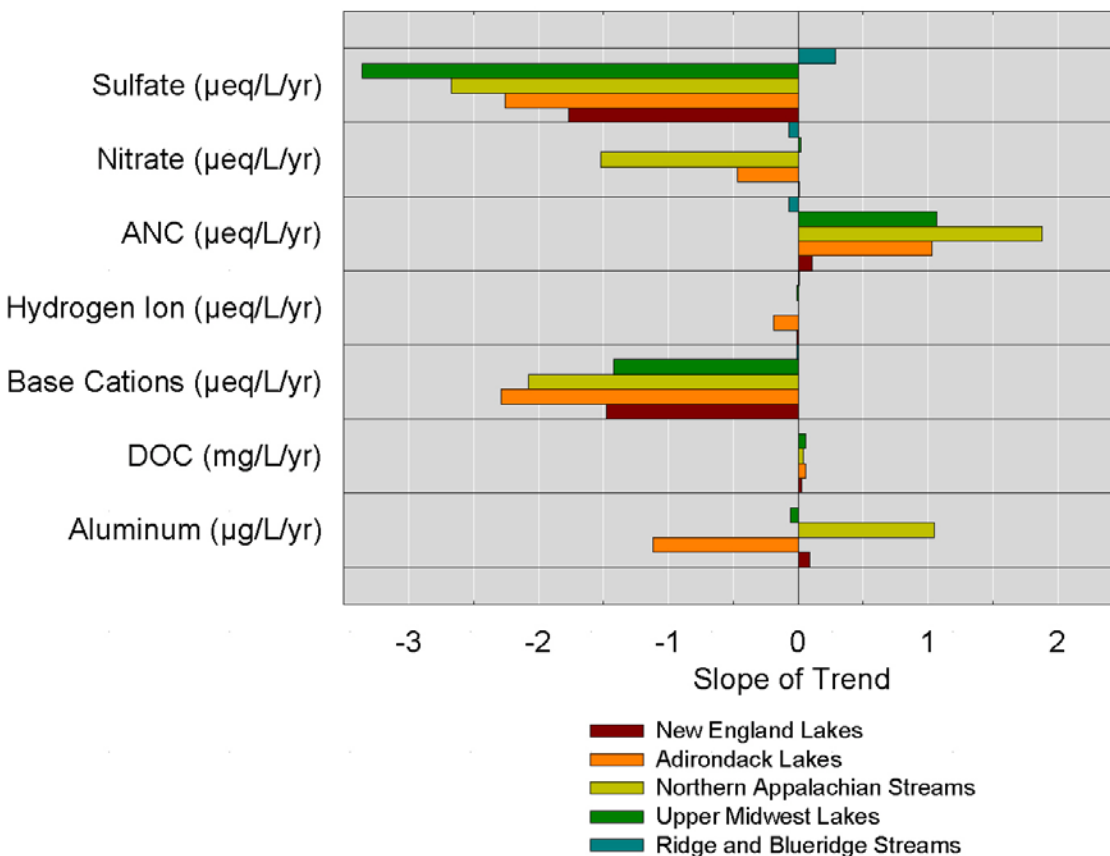


Figure 4. Summary of regional trends in surface water chemistry in study regions.

*Decreasing base cation concentrations in surface waters.* One of the most universal watershed responses to acidic deposition is the mobilization of base cations from soils<sup>29</sup>. As the supply of acid anions from acidic deposition decreases, the rate of cation mobilization to surface waters is also expected to decrease, a change widely observed in the northern hemisphere for more than a decade<sup>9,10,20,21,23</sup>. In surface waters of the glaciated regions on the northern and eastern U.S., base cations [ $\text{Ca}^{2+} + \text{Mg}^{2+}$ ] declined at a rate between  $-1.5$  and  $-2.5$   $\mu\text{eq/L/year}$  (Figure 4). This decline in base cations has offset some of the observed decline in sulfate concentrations, limiting the magnitude of recovery in Gran ANC.

*The interaction of S, N, and cations.* The rate of change in Gran ANC represents the difference between the combined rates of change for acid anions and base cations, i.e.:

$$\Delta\text{ANC} = \Delta[\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+] \text{ minus } \Delta[\text{SO}_4^{2-} + \text{NO}_3^- + \text{Cl}^-] \text{ (equation 1)}$$

In the 1990s, surface water  $\text{SO}_4^{2-}$  decreased at approximately  $-2.5$   $\mu\text{eq/L/year}$  (the mean of regional slopes), and  $\text{NO}_3^-$  at  $-0.5$   $\mu\text{eq/L/year}$ . The sum of these rates of change sets an upper limit to Gran ANC response of  $+3$   $\mu\text{eq/L/year}$ . The actual increase in Gran ANC was about  $+1$   $\mu\text{eq/L/year}$ . The difference between the actual Gran ANC increase and the maximum increase

from rates of acid anion change can be almost entirely explained by regional declines in base cations of about  $-1.8 \mu\text{eq/L/year}$  (Figure 4).

*Question 3: What are the expectations for the rate and timeframe of recovery (chemical and biological)?*

*Chemical recovery targets: pH 6.0 and ANC of 30  $\mu\text{eq/L}$ .* The lowest Gran ANC lakes are recovering (i.e. trend of increasing ANC) faster than lakes with higher ANC, a pattern observed in other regions of the world<sup>32</sup>. This pattern represents the reverse of the acidification process, in which the lowest pH lakes acidified the most. For example, using paleolimnological assessments, Cummings *et al.*<sup>33</sup> demonstrated that Adirondack lakes with pre-industrial pH of 5 to 5.5 acidified to the mid 4s, lakes with pH of 5.5 to 6.3 did not acidify, and lakes with pH greater than 6.3 became more basic. Cummings *et al.*<sup>33</sup> inferred that above Gran ANC of 40  $\mu\text{eq/L}$ , lakes did not acidify. Based on the rate of ANC change in the ANC classes, our analyses suggest that reductions in acidic deposition will cause the chemistry of acidified waters to evolve toward a pH range of 5.0 to 6.0 (ANC 0 to 30  $\mu\text{eq/L}$ ). Studies of pre-industrial lake pH agree that the historical pH of presently acidified lakes was typically less than pH 6.0 before the onset of acidic deposition<sup>33</sup>. Therefore, we infer that pH of about 6 and Gran ANC of about 30 will represent ‘full recovery’ for most acidic waters.

We suggest that the higher rate of response in the most acidic waters indicates that the response is happening faster and more broadly than expected. Moreover, the response of the lowest pH waters suggests that the mechanisms of recovery have not been irreparably damaged; watershed soils are still capable of recovery in a timeframe of years to decades. We believe that the trend toward more dilute waters (i.e. the decline in sulfate, nitrate, and base cations) represents a return toward pre-historical water chemistry. Acidic deposition artificially increased the ionic strength of surface waters as part of the neutralization process, and this process is reversing.

If ANC continued to increase at the rate of the past decade in the lowest Gran ANC waters in the Adirondacks, the target of 25 to 30  $\mu\text{eq/l}$  will be achieved in less than two decades in the ‘median lake’. However, we do not know if this rate of increase in ANC will continue without further reductions in deposition. Moreover, the recent decreases in  $\text{NO}_3^-$  complicate future assessments of recovery. Decreases in  $\text{NO}_3^-$  do not appear to be linked to decreases in atmospheric deposition. If watershed retention of nitrogen decreases in the future, increases in  $\text{NO}_3^-$  could delay recovery of surface waters. Major questions that remain unanswered are: a) to what extent does current ‘recovery’ already fully reflect reductions in deposition, and b) are additional reductions required to maintain the present trends? The only way to answer this question is to maintain the commitment to long-term assessments of regional surface water chemistry. Deposition monitoring alone cannot address the ultimate question of whether ecosystems are recovering in response to changes in emissions and deposition.

*Biological recovery.* We rely entirely in this report on chemical monitoring data to assess recovery, with a focus on biologically-relevant chemistry (e.g., pH, Gran ANC, and aluminum, which may be the most direct biologically relevant indicator of recovery). This is not because we favor chemical over biological data, but because long-term data collection has not historically addressed the question of biological response. For example, there are no equivalent monitoring networks to the TIME and LTM programs on fisheries, for good reason. Systematic assessments



of response are hampered by a lack of historical fishery data, and by confounding factors that can also result in fishery depletion or loss, such as over-fishing and stocking. Moreover, an ongoing monitoring program for fisheries might impact the resource and obscure the results. For now, we infer that improvements in chemistry will eventually lead to biological recovery. This hypothesis will be tested in the summer of 2004 using zooplankton as a biological indicator of recovery in lakes that were surveyed for zooplankton during the Eastern Lake Survey in the 1980s.

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**Graduate student theses supported, in part, by this grant**

1. Chadwick, M.A., 2003. Effects of nitrogen deposition and flow permanence on stream organic matter dynamics. Ph.D. thesis, University of Maine, Orono, ME.
2. Diehl, M.S., 2005 (expected). Sulfur and nitrogen flux in an experimentally acidified watershed. M.S. thesis, University of Maine, Orono, ME.
3. Pellerin, B., 2000. Inferences from Soil Chemical Properties on Linkages Between Soil and Surface Water in Maine Forested Watersheds. M.S. thesis, University of Maine, Orono, ME.
4. Reinhardt, R., 2005 (in progress). Al-Fe-P relationships in Maine surface waters. M.S. thesis, University of Maine, Orono, ME.
5. Rosfjord, C., 2005 (expected). Recovery and biologically relevant lake chemistry following the Clean Air Act Amendments of 1990: A 20-year re-evaluation of trends in a statistical population of lakes. M.S. thesis, University of Maine, Orono, ME.
6. Szillery, J., 2003. Soil Solution Dynamics in Response to Elevated Nitrogen and Sulfur Treatments at the Bear Brook Watershed in Maine. M.S. thesis, University of Maine, Orono, ME.
7. Shah, S., 2002. Decadal Responses in Soil N Dynamics at a Pared Watershed Experiment in Maine. M.S. thesis, University of Maine, Orono, ME.
8. Evans, J., 2000. Forest Soil C and N in Watersheds Influenced by Wildfire, Harvesting, and N Enrichment. M.S. thesis, University of Maine, Orono, ME.

### **Professional presentations using project results, during project period:**

1. Kahl, J.S., R. Haeuber, and J. Stoddard, 2005, Tracking Response and Recovery of Surface Water Chemistry to Changes in Acid Deposition in the Northeastern U.S (*invited*). Ecological Society of America annual meeting, Montreal, August, 2005.
2. Kahl, J.S., 2004. The 2003 evaluation of the Clean Air Act: trends in northeastern surface waters. Research lecture series, Plymouth State University, November, 2004
3. Kahl, J.S., S. Nelson, and A. Grygo, 2004. Surface water chemistry data for the northeastern US for interpreting climate and acid rain trends. Northeast Ecosystems Research Consortium meeting, Durham, NH, October, 2004.
4. Kahl, J.S., K. Webster, M. Diehl, and C. Rosfjord, 2004. Successes of the Clean Air Act Amendments of 1990. Maine Water Conference plenary talk, Augusta, ME, 2004.
5. Kahl, J.S. and K. Johnson, 2004. Acid-Base Chemistry and Historical Trends in Downeast Salmon Rivers. Maine Water Conference, Augusta ME, April 2004.
6. Kahl, J.S., 2004. The Clean Air Act Amendments of 1990; testing a program designed to evaluate environmental policy. Invited lecture, Colby College. April, 2004
7. Kahl, J.S., 2004. The Clean Air Act of 1990: a hemispheric experiment with unintended(?) consequences. VP-R Research Café, University of Maine, Feb. 2004.
8. Kahl, J.S., S. Paulsen, and J. Stoddard, 2003. Evaluating of the effectiveness of the Clean Air Act for changes in surface water acidification. *Invited plenary*, National Atmospheric Deposition Program annual meeting, October, 2003. Washington DC
9. Kahl, J.S., 2003. Is water chemistry the smoking gun for endangered Atlantic Salmon? *Invited lecture*, College of the Atlantic, July, 2003.
10. Kahl, J.S., 2003. Chemistry trends and spatial distribution of Maine lakes. Maine Volunteer Lake Monitoring Program annual meeting. Lewiston ME. June, 2003 (*invited*).
11. Kahl, J.S., 2003. The environmental chemistry of salmon rivers: is there an acid rain link? *Invited lecture*, College of the Atlantic, May, 2003.
12. Kahl, J.S., 2003. Biologically-relevant aquatic chemistry: the intersection of the Clean Air Act and the Endangered Species Act. US EPA Corvallis OR Research Laboratory, April 18, 2003 (*invited*).
13. Kahl, J.S., J. Stoddard, and D. Manski, 2003. Evaluating the effectiveness of the Clean Air Act in recovery of surface waters: The 2002 EPA Assessment of the Clean Air Act. George Wright Society biannual meeting. San Diego, CA, April 15, 2003.
14. Kahl, J.S., and K. Johnson, 2003. Status and trends in water chemistry in downeast Maine relative to Atlantic salmon. Proceedings, Water quality and recovery of Atlantic Salmon; is there a link? March, 2003.
15. Kahl, J.S., 2003. pH: the persistently problematic parameter for public policy planning. Proceedings, Water quality and recovery of Atlantic salmon; is there a link? March, 2003.

16. Kahl, J.S., J. Stoddard, K. Webster, and R. Haeuber, 2002. The 2002 Assessment of the Clean Air Act: surface water trends from the northeast US and upper midwest US. North American Lake Management Society annual meeting, Anchorage Alaska. October 30, 2002.
17. Kahl, J.S., 2002. '*How Maine lakes work*'. Invited talk in special session on lakes, Maine Water Conference, May, 2002.
18. Kahl, J.S., 2001. Indicators of recovery from acidification (or not) in surface waters of the northeastern US. Gordon Research Conference on Biogeochemistry of Forested Watersheds, July, 2001 (*invited plenary talk*).
19. Kahl, J.S., 2001. Northeastern regional aquatic chemistry: implications for the Clean Air Act. Invited talk, Desert Research Institute, Reno NV. May 9, 2001.
20. Kahl, J.S., 2001. A multi-system assessment of status and trends related to acid rain. 25<sup>th</sup> annual meeting of New England Association of Environmental Biologists. Norwich CT, April 4, 2001 (*invited plenary talk*).
21. Kahl, J.S., 2001. Chemical mass balances and trends in PRIMENet watersheds: comparison with long-term regional responses. Third annual Aquatic Research in Acadia symposium, College of the Atlantic, Bar Harbor, ME. March 27, 2001.
22. Kahl, J.S., 2000. A regional assessment of aquatic effects from acidic deposition. Annual meeting of the Northeast Regional Air Quality Committee, November, 2000 (*invited*).
23. Kahl, J.S., 2000. Acid rain and Maine salmon: is there a link? Forum on restoration of salmon, University of Maine, Machias, October, 2000 (*invited*).
24. Kahl, J.S., 2000. Maine and the Clean Air Act re-authorization. Spring meeting, Maine Lakes Conservancy Institute, April 1 (*invited keynote*).
25. Kahl, J.S. S.A. Norton, and S. Vidito, 2000. Comparative major ion chemistry in upland watersheds. Symposium on Aquatic Research in Acadia National Park, March, 2000.
26. Kahl, J.S., and S.A. Norton, 2000. Long term regional response in aquatic chemistry: how Acadia fits in. Symposium on Aquatic Research in Acadia National Park, March, 2000.
27. Kahl, J.S. 1999. Acid-base trends in Maine lakes; the 1990s surprise!. Annual meeting of the New England Chapter of the North American Lake Management Society, Lewiston ME June 1999. (*invited*).
28. Kahl, J.S., S. Norton, P. Lowkes, M. Handley, J. Cangelosi, I. Fernandez, 1999. Relative changes in sulfate and base cations, 1982-1999. AGU annual meeting, May, 1999. Boston (also session co-organizer).
29. Kahl, J.S., I. Fernandez, D. Mageean, S. Ballard, J. Cosby, S. Norton, P. Ludwig, L. Rustad, 1999. Linking watershed scale indicators of changes in atmospheric deposition to regional response patterns. Annual NSF/EPA Water and Watersheds program meeting, Washington DC. April, 1999 (*invited*).
30. Kahl, J.S., S. Norton, and I. Fernandez, 1999. Response of Maine surface waters to changing atmospheric deposition. The 1990s response to acidic deposition, March, 1999, Washington DC. Ecological Society of America special topic workshop on acid rain. (*invited keynote talk*).

**Special Session at American Geophysical Union annual meeting, Boston (1999)**

(S. Norton and J.S. Kahl, organizers)

**1999 Spring Meeting**

**June 1 - 4, 1999**

**Boston, Massachusetts**



American Geophysical Union

**Special session: Cation Supply and Surface Water Acidification**

Sulfate concentrations in surface waters of glaciated terrain have declined significantly during the past decade due to decreases in SO<sub>x</sub> emissions and deposition. Nitrate has also declined despite little change in deposition. However, surface water ANC has not universally increased due to these changes in acid anions. Hypotheses to explain this conundrum include declining atmospheric deposition of base cations, climate-related factors, decreased export of cations from soils, and changes in DOC quantity or character. This session will evaluate such hypotheses through analysis of data and models of water, soil, and precipitation chemistry. Presenters are asked to include statements of untested hypotheses in their presentations for a panel discussion on future research directions at the conclusion of the session.

Conveners: Stephen A. Norton, Department of Geological Sciences, University of Maine  
Jeffrey S. Kahl, Water Research Institute, University of Maine

*Patterns of Stable S Isotopes in a Forested Catchment as Indicators for Biological S Turnover.*

\*C Alewell, M Gehre

*Possible Contribution of Mineral Sulfur Sources to Sulfate in Drainage Waters in NH and VT.*

\*M J Mitchell, B Mayer, S Bailey, J W Hornbeck, C Alewell, P J McHale

*Sub-Soil Depletion of Calcium in Watersheds of Western Adirondack Lakes in New York*

B Momen, \*G B Lawrence, J P Zehr

*Role of Soil-Base Depletion in Episodic Acidification of Catskill Mountain Streams of Southeastern NY*

\*G B Lawrence, P S Murdoch, D A Burns, D M Wolock

*Relative Changes in Base Cations in Maine Surface Waters, 1982-1998*

\*J S Kahl, S A Norton, P Lowkes, M Handley, J Cangelosi, I J Fernandez

*Investigating Long Term Recovery of Streams and Groundwater Based on Short Term Dynamics*

\*G Lischeid

*Constraints on the Recovery of Seepage Lakes in WI and MI from Acidification: Effects of Climate, Deposition, and Sediment Processes.*

\*K E Webster, T R Asplund, P L Brezonik

*The Effect of Variable Soil PCO<sub>2</sub> on Cation Supply and Surface Water Alkalinity*

\*S A Norton, B J Cosby, I J Fernandez, J S Kahl, P J Lowkes, M R Church

*Hydrogeochemical Properties Affecting Acidification in Watersheds - Comparison of Chemical Weathering Rates Between Acidified and Non-acidified Watersheds*

\*H Ikeda, Y Miyanaga



## Quality Assurance Overview

This research has been conducted in laboratories developed and managed by PI Kahl since 1982. During 2001-02, data reporting and quality assurance were complicated by a transition in laboratories. In 2001, the University of Maine administration elected to spin off the laboratory developed by Kahl into an independent university contract laboratory. This laboratory was no longer focused on low ionic strength water analyses. The change in management resulted in substantial delays in data delivery beginning in 2001, and a doubling of laboratory sample costs charged to this project in 2002. In addition, the laboratory no longer produced quality assurance reports as part of the project deliverables.

As a result of these changes, the University administration asked the Mitchell Center to develop a new laboratory, in order to re-focus university expertise on low ionic strength surface waters, including this grant and related research on salmon river water chemistry. This laboratory was quickly established and was responsible for all 2002-2004 sample analyses for this project. Many samples from 2001-02 were re-run in the new Mitchell Center laboratory, to confirm or replace values from the contract laboratory.

The new Mitchell Center laboratory received a ‘satisfactory’ rating (the second highest classification) from two rounds of Environment Canada inter-laboratory audits in 2002 and 2003. The laboratory received a perfect score in the USGS dilute precipitation audit program in 2004 (Table QA-1).

Two changes were made to protocols during the project period. Both changes were unanimously approved by six project PIs, including PIs on separate projects for salmon water chemistry and Bear Brook. The first change was in 2002, when the Mitchell Center laboratory adopted the EPA Corvallis cleaning protocol using distilled water, rather than an acid wash. The advantage was cost-savings in acids, less caustic conditions for staff and equipment, and reduced chance of acid contamination that could change the pH or ANC.

The second change was in 2003, when the laboratory adopted a single injection simultaneous cation and anion analysis on a two channel Dionex ion chromatograph. The advantage was streamlined sample processing, and faster data turn-around, and reduced costs. Figures 1-4 document the comparison between the previous ICP method and the new IC method, as well as the change from flame AAS to ICP in 1999. Table QA-2 summarizes the equations for the cation method comparisons.

Quality Assurance reports for 2001-2003 are included in electronic documents on the report CD. QA reports for 1999 and 2000 were sent with data that were used in the 2003 EPA assessment report (Stoddard *et al.*, 2003).

Table QA-1. Laboratory audit results from 2004

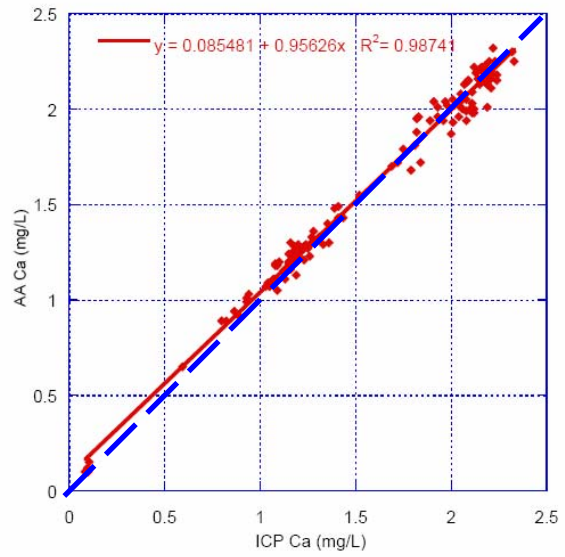
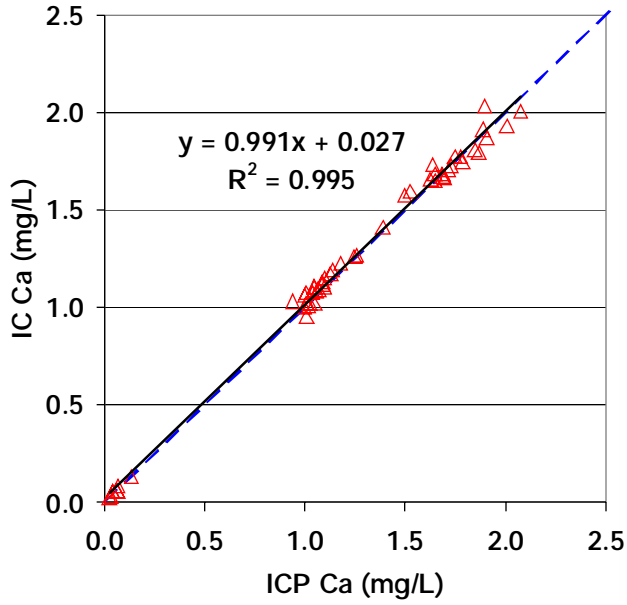
	Environment Canada 1/30/2004	Environment Canada 8/6/2004	USGS 10/22/2004
Alkalinity Gran Titration	Ideal	Ideal	na
Aluminum	na	1 flag	na
Ammonia	na	1 flag, low bias 9.57%	
Calcium	Ideal	4 flags	rating of 4.0
Chloride	4 flags, high bias 11.6%	Ideal	rating of 4.0
Color	2 flags	Ideal	na
Conductivity	Ideal	Ideal	rating of 4.0
DIC	Ideal	Ideal	na
DOC	Ideal	Ideal	na
Fluoride	Ideal	Ideal	rating of 4.0
Magnesium	10 flags, high bias 9.7%	Ideal	rating of 4.0
Nitrate	1 flag	3 flags	na
Potassium	Ideal	Ideal	rating of 4.0
Sodium	Ideal	Ideal	rating of 4.0
Sulfate	Ideal	Ideal	rating of 4.0
pH	Ideal	Ideal	rating of 4.0
<b>Performance rating</b>	<b><i>Satisfactory</i></b>	<b><i>Satisfactory</i></b>	<b><i>rating 4.0 out of 4.0</i></b>
Environment Canada Proficiency Testing for Rain and Soft Waters U.S. Geological Survey Fall 2004 SRS Inter-laboratory comparison study			

Table QA-2. Regression equations for the comparisons among cation analytical methods.  
See graphical representations in Figures 1-4 on the next pages.

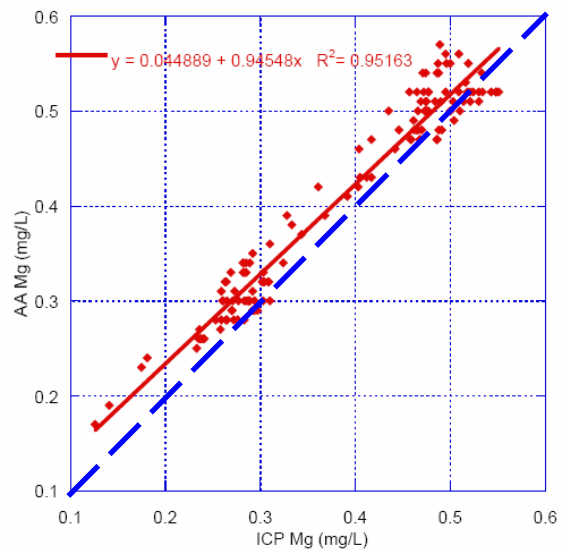
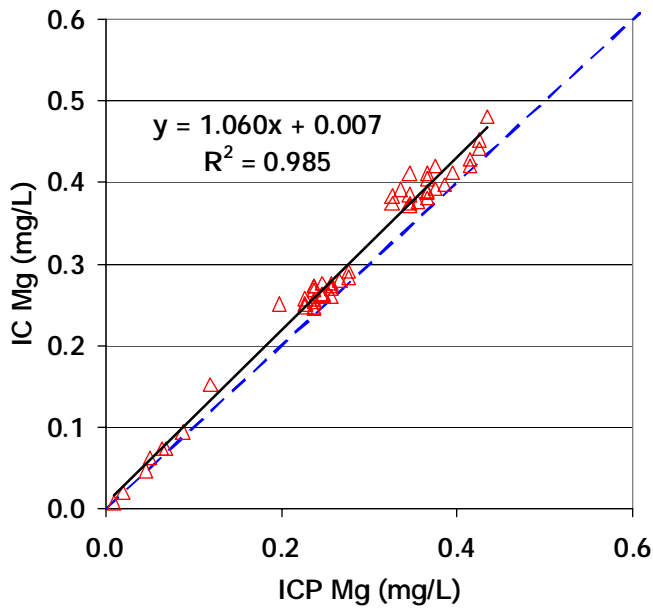
Ca	IC v. ICP	$y=0.99x + 0.027$	$r^2=0.995$
	ICP v AAS	$y=0.95x + 0.085$	$r^2=0.987$
Mg	IC v. ICP	$y=1.06x + 0.01$	$r^2=0.985$
	ICP v AAS	$y=0.94x + 0.04$	$r^2=0.951$
Na	IC v. ICP	$y=0.97x + 0.07$	$r^2=0.979$
	ICP v AAS	$y=1.02x - 0.01$	$r^2=0.986$
K	IC v. ICP	$y=1.02x + 0.00$	$r^2=0.984$
	ICP v AAS	$y=1.04x - 0.01$	$r^2=0.988$

Figures 1-4. Comparison of ICP cation data (pre-2002) to IC cation data (2002 and subsequent).

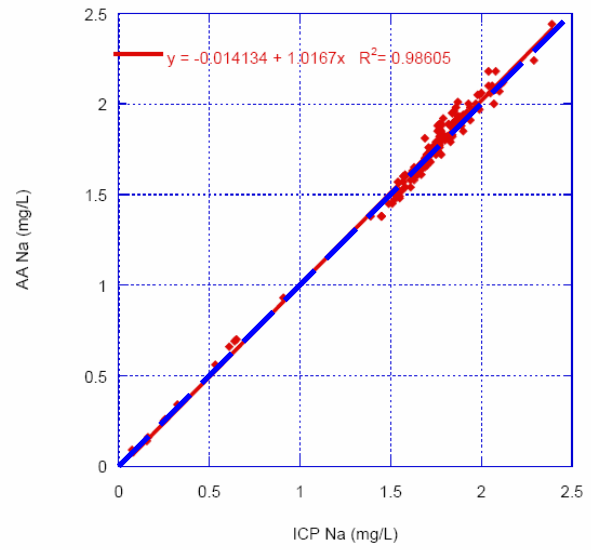
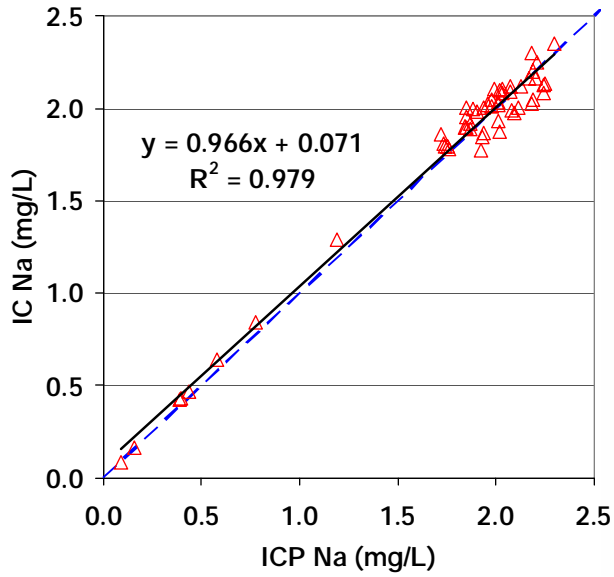
### Calcium



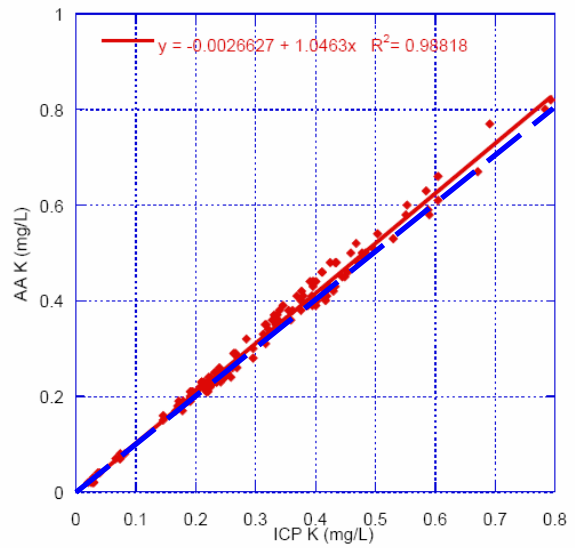
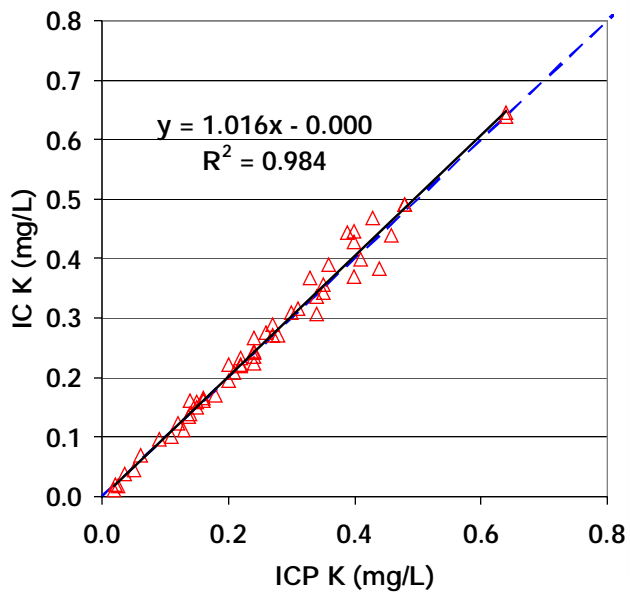
### Magnesium



### Sodium



### Potassium



# **Information Transfer Program**

# Integrating Biological and Streams Data into PEARL

## Basic Information

<b>Title:</b>	Integrating Biological and Streams Data into PEARL
<b>Project Number:</b>	2004ME28B
<b>Start Date:</b>	4/1/2004
<b>End Date:</b>	3/31/2005
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	2
<b>Research Category:</b>	None
<b>Focus Category:</b>	Education, Management and Planning, None
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Peter Vaux, Steve Kahl, Mary Beard-Tisdale

## Publication

1. Vaux, Peter, Jeffrey S. Kahl, 2004, PEARL - The Source for Environmental Information in Maine. Website, Senator George J. Mitchell Center for Environmental and Watershed Research. Live site [www.pearl.maine.edu](http://www.pearl.maine.edu) ; production site [www.pearlmaine.com](http://www.pearlmaine.com).

# Integrating Biological & Streams Data into PEARL

## Progress Report

May 2005

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Prepared by:

Peter D. Vaux

Senator George J. Mitchell Center for Environmental and Watershed Research,  
University of Maine, Orono.

## **Project Overview**

This project builds on an existing website (PEARL) to provide a forum for accessing and integrating a multidisciplinary array of data pertaining to lake and stream systems in Maine. Expansion of PEARL is being implemented in three arenas. First, the site has been re-designed to permit the incorporation of stream-based data – formerly PEARL focused entirely on lakes. Second, a broad range of biological data, already compiled by a separate project, is being uploaded to PEARL. Third, two new information interfaces are being designed for the following targeted user-groups: lake association members and other lake users, educators/students, and anglers. Design of these interfaces, along with overall site design, has benefited from input from surveys and focus group sessions that have solicited site reviews from a range of user groups. In addition to these three primary project objectives, PEARL's data submission feature has been upgraded to permit direct uploading by data providers of their stream-based and biological data sets.

PEARL is designed to serve a diverse audience, including scientists, resource managers and planners, educators and students, and segments of the general public. PEARL is able to address these audience segments by adopting two broad approaches to information access. First, users interested in accessing the PEARL data bank are able to execute targeted data searches that are structured on one or more criteria, including: (a) data category (e.g. water quality, flora and fauna); (b) town; (c) lake or stream name or waterbody code, (d) watershed. These initial search(es) will yield a list of data sets, any of which can then be selected, providing access to both metadata and to the underlying data table(s). The user is offered a choice of which fields are to be presented from the full data table. The data are downloadable for additional data manipulation and analysis by the user. Numerical parameters can be graphed via a new, on-line, plotting feature.

The second approach to accessing information in PEARL entails the development of customized information interfaces for targeted, user-groups: lake users, educators and students and anglers. These interfaces are being designed for a largely non-technical audience. They will focus on guiding users to those parts of the PEARL data bank that are likely to be of most interest to them. The interfaces will also provide series of data syntheses and interactive data queries designed to extract pertinent information summaries from the PEARL data bank.

## **Development Overview**

All work undertaken on PEARL over the past year has been implemented at a parallel development address: [www.pearlmaine.com](http://www.pearlmaine.com). For review purposes, this address has been made available to state and federal agency personnel, and other interested individuals. It is important



to underscore the fact that, as a development site, this version of PEARL is a work in progress. In addition to on-going site enhancements taking place on the development server, some of the 'background' material is being compiled on non-server machines and is being added to the development server as this material is completed. Current plans are to migrate the development version of the site to the primary PEARL address ([www.pearl.maine.edu](http://www.pearl.maine.edu)) in summer 2005.

## **Project Deliverables: Status Update**

### **(1) Enabling PEARL for streams data.**

This capability is now in place. Enabling PEARL for streams data has been the key technical site development during the project. It represents the core feature for ensuring seamless integration of a broad range of biological and chemical data into PEARL. To "tag" stream data, PEARL uses stream segment codes from the National Hydrographic Dataset. Through the use of a master look-up table in PEARL, all on-line stream records automatically display county, town and watershed (HUC-12) attributes, in addition to stream code and NHD-based stream segment name (where available). Supplementing the NHD data, we have generated a series of dummy stream codes to use for stream segments that are not currently present in NHD – generally the smallest streams. There is one dummy stream code for each unique township / HUC-12 combination. Thus, all streams data in PEARL, whether or not they are from an NHD-mapped stream, always display on-line – and can be accessed via town-based and watershed-based searches. A similar system of dummy lake codes has also been implemented so that data from "uncoded" ponds can be served on-line.

### **(2) Site enhancement: providing access to a broad range of information on Maine's lakes and streams, including both chemistry and biology data sets.**

Major site enhancements are now in place and operational. PEARL's home page has been re-designed to provide a simpler, cleaner, entry into the site (Figure 1). From PEARL's "front end" interface, users can browse available datasets (Figure 2A). Users can also execute text-based and map-based searches (Figures 3 and 4). Both text- and map-based searches can return data records by watershed (down to HUC-12), town or river name/code. (Note that the latter is likely to be of limited use at the current time because of the way river segments are coded and named in the National Hydrographic Dataset.) Searches extract and display location-specific records from the pertinent data tables, not the entire data table. The map search feature in PEARL has been completely re-designed over the past 6 months and now runs in ArcIMS. This has provided not only substantial enhancements to functionality, but also the foundation for the future development of a series of truly interactive mapping modules

**(3) An enhanced version of the PEARL data submission feature allowing providers to upload streams data in addition to lakes data.**

Extensive re-development of PEARL's Data Annex system (the "back-end" of the site, not viewable through the main pages) has been implemented in order to enable the site for streams data. Anyone provided with password access can now remotely upload data tables (Figure 5) and then configure them for on-line viewing (Figure 6). There is now also in place a system for specifying the order in which data tables appear when the user browses available information in the PEARL data bank.

**(4) Customized information access and display interfaces.**

A "Lakes Guide" is being developed (currently approximately 70% complete in terms of required time investment) that focuses on non-technical lake users as well as students and educators (Figure 7A). The Water Quality sections of the Lakes Guide contain background information on various water quality parameters, how they are measured and what the data typically can mean (Figure 7B). Users can then access pertinent data for any selected lake. The Lake Overview section will be implemented in the fall of 2005 and will generate lake summary forms "on-the-fly" from the most recent data in the PEARL data bank. The fisheries and biodiversity components of the Lakes Guide (Figures 8A and 8B) are still under development – they will contain direct access to key data tables and information syntheses. Data tables are already in the PEARL data bank. Information syntheses (text and graphics) are largely complete, although they do not yet appear on-line.

**(5) A brochure describing PEARL and how it can be used.**

This will be prepared in fall of 2005, towards the end of the project period to ensure that all site developments are accurately represented in the brochure.

**(6) A procedures manual (on-line and hardcopy versions) explaining data uploading protocols to data providers.**

As with the brochure, the procedures manual will be developed in fall of 2005 so that it can be fully representative of PEARL.

**(7) User-group focus sessions designed to test draft versions of the information interfaces.**

A survey instrument was designed and mailed to a group of PEARL users in 2004 (Appendix 1). Results have been summarized in a report and have been used to inform site developments. A second round of consultations with users is currently (May-June 2005) in progress (Appendix 2).

These consultations take the form of focus group sessions. Groups include students, teachers, lake association members and lake volunteer monitors.

**(8) PEARL presentations at the Maine Water Conference and other venues.**

Three poster presentations were given at the 2005 Maine Water Conference:

Ph.D. student, Dave Kramar: Presentation focused on PEARL architecture.

M.S. student, Sara McCabe: Presentation focused on the “Lakes Guide” section of PEARL.

PEARL Director, Peter Vaux: Presentation focused on the Maine Aquatic Biodiversity Project, whose database is providing the majority of the biological information presented on PEARL.

Vaux has also made presentations about PEARL to Maine Dept. of Environmental Protection, Maine Dept. of Inland Fisheries & Wildlife, and the Atlantic Salmon Commission.

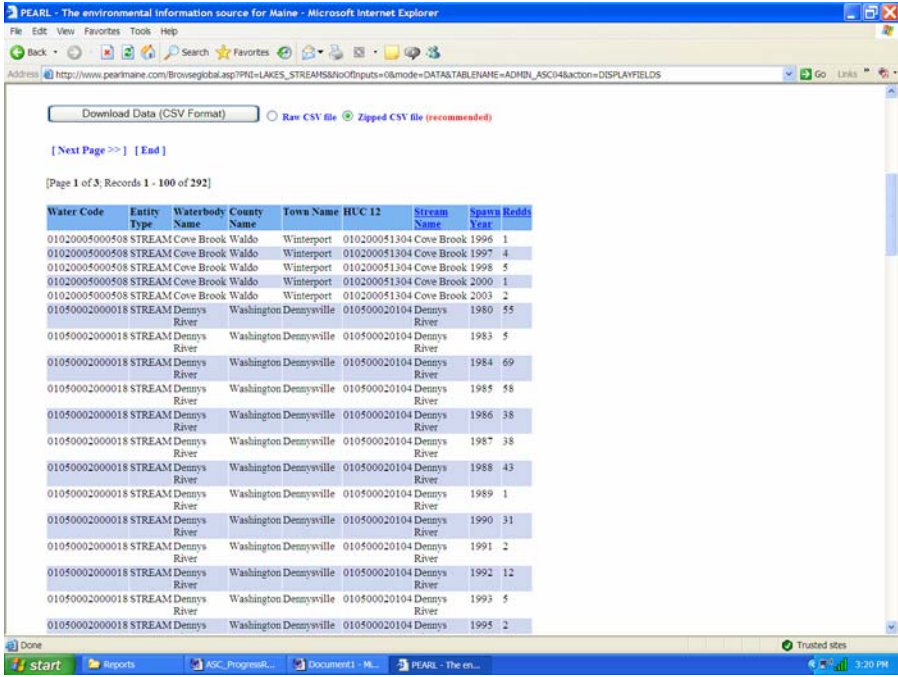
McCabe has also made a presentation at the Maine Stream Team Summit in March 2005, as well as numerous teacher/student groups.



Figure 1: New PEARL homepage.

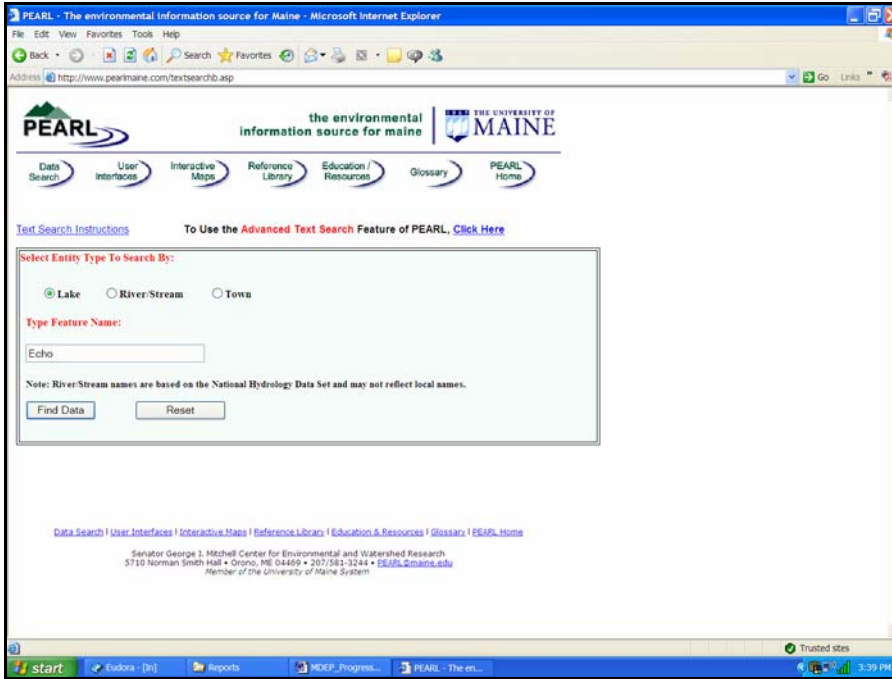


(A)

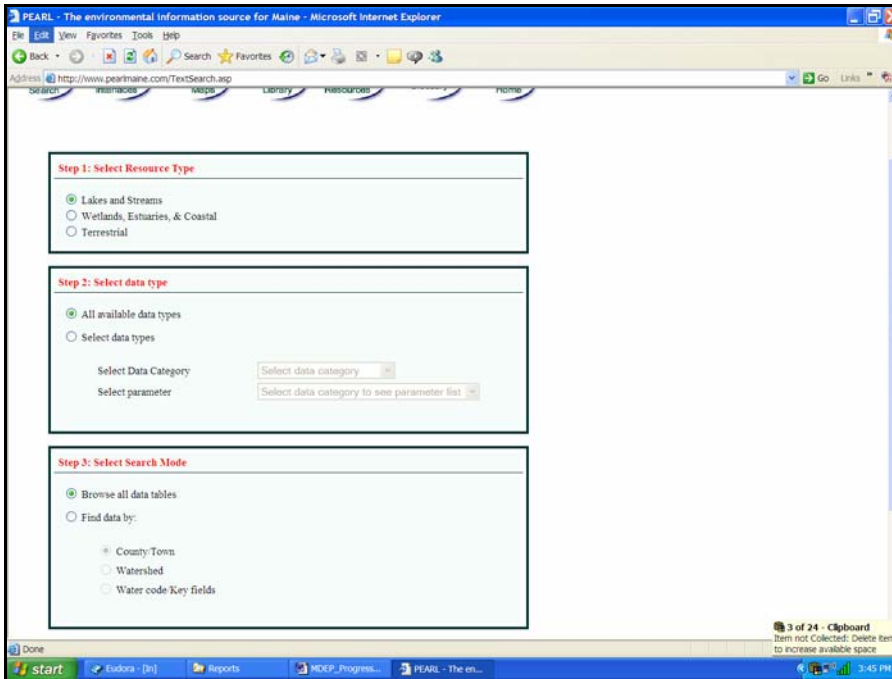


(B)

Figure 2: (A) Section of the Browse Data Sets (Fauna) page on PEARL. (B) Section of one of the PEARL stream data tables.



(A)



(B)

Figure 3: (A) Basic text-search and (B) advanced text-search windows in PEARL.



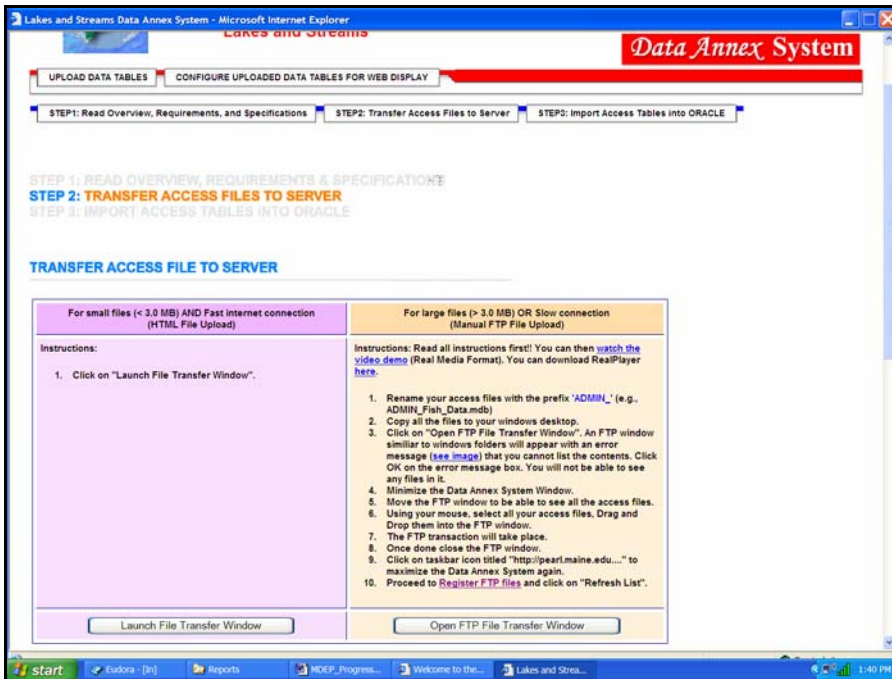
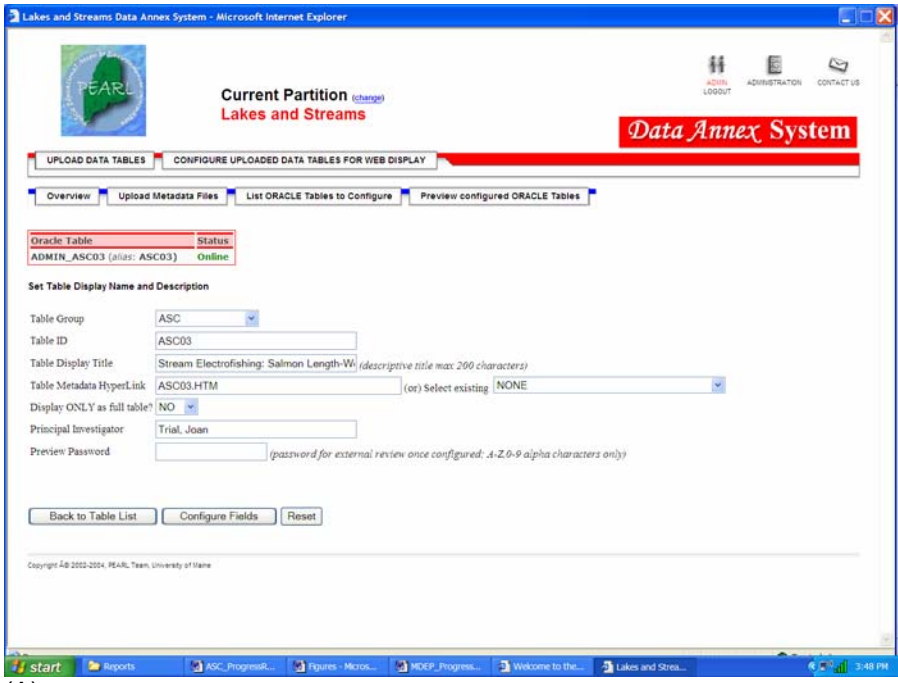
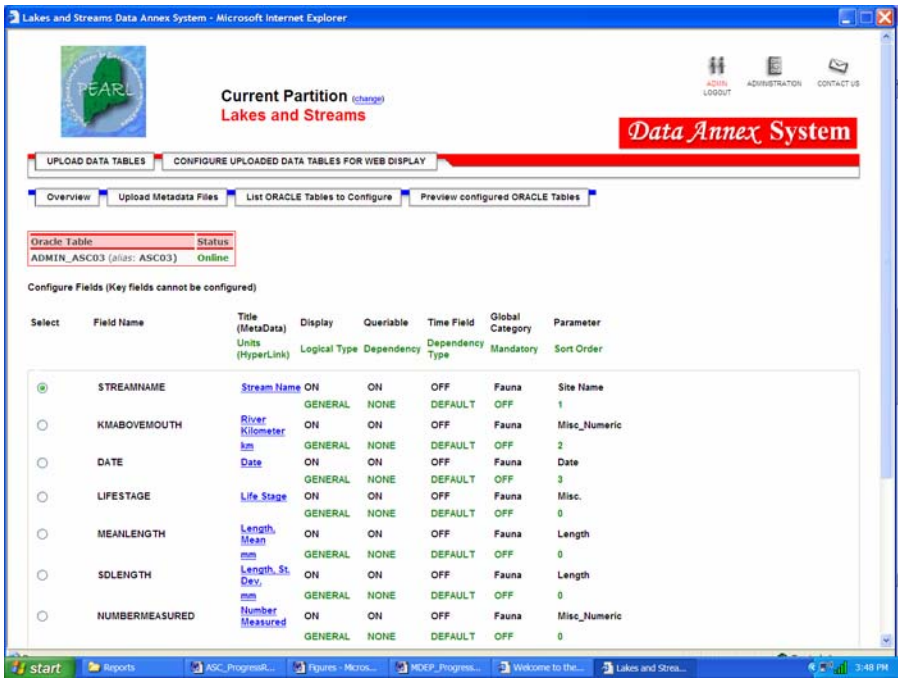


Figure 5: Data upload window in the PEARL Data Annex System.



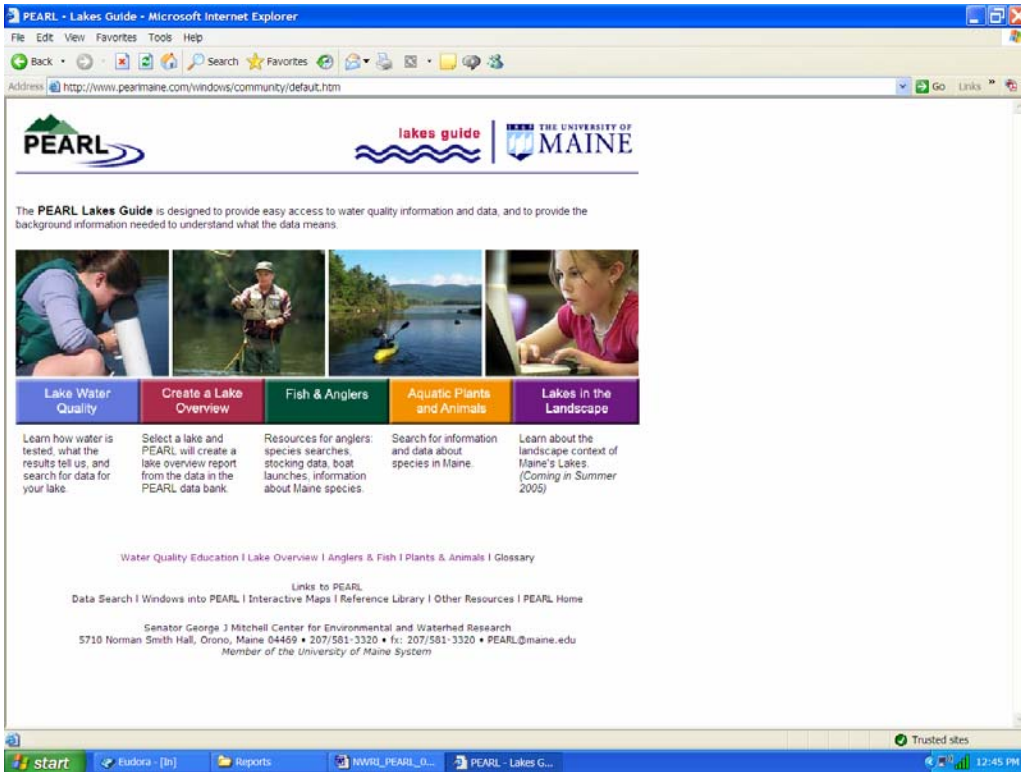


(A)



(B)

Figure 6: Table configuration windows in the PEARL Data Annex System. (A) Table title, P.I., etc. (B) Individual table fields.

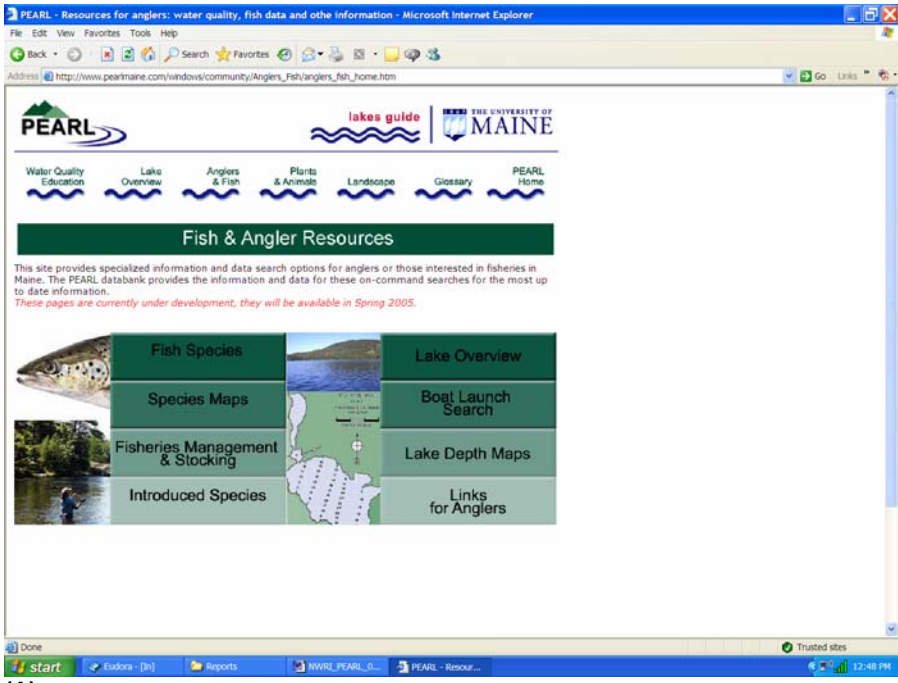


(A)

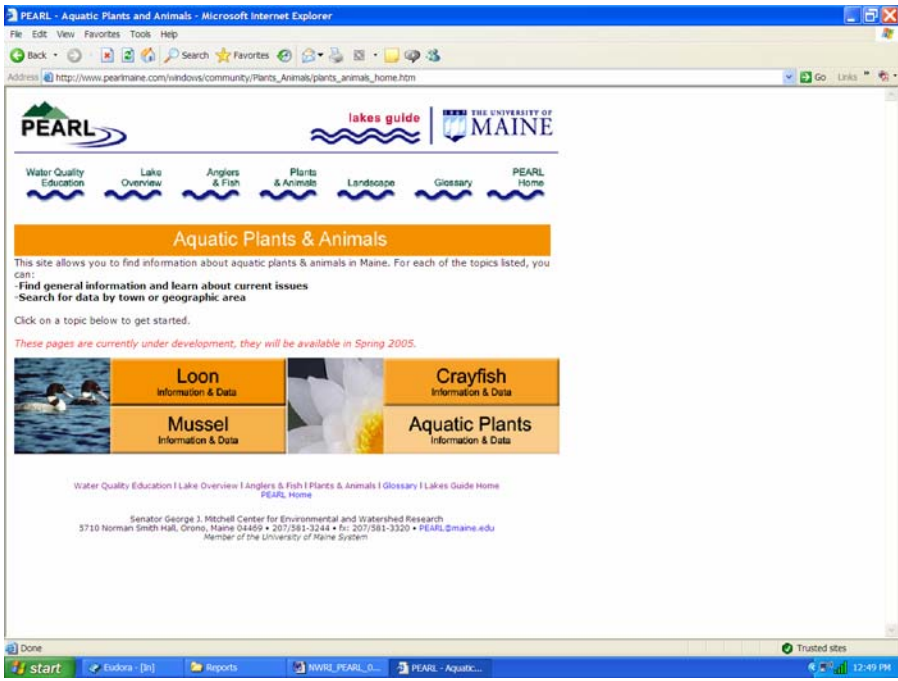


(B)

Figure 7: (A) Front page of new “Lakes Guide” in PEARL. (B) Index page of the Lake Water Quality component of Lakes Guide.



(A)



(B)

Figure 8: (A) Fisheries, and (B) Biodiversity components of PEARL's new Lakes Guide.

## APPENDIX 1

### A User Survey of Lake Information Websites: Lessons for the Improvement of PEARL

Summer 2004

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## **Introduction**

The PEARL website was designed in the mid-90's as a way to compile and communicate lake data collected by state and federal agencies, non-profit groups and community organizations. The PEARL website management and design team is in the process of re-working and revitalizing the site to enhance its flexibility and user-friendliness. As a beginning step, an evaluation of the current website was designed. There are two major purposes of The Lake Information Website User Survey. The first is to evaluate the current PEARL website, and the second is to compare it to other similar functioning websites in order to identify its strengths and areas where it can be improved.

The survey was sent to a wide range of PEARL website users including members of state agencies, volunteer lake water quality monitors, and teachers. Thirteen volunteers completed the survey and provided feedback on the PEARL site. Gained from this survey were ideas and feedback that will be vital to the improvement of the site. Members of this group who have chosen to stay involved in the evaluation and improvement process will form a core evaluation group who will give the needed feedback as the site is revamped.

This report summarizes the comments and ideas expressed by the survey participants. Specifically, it examines the strengths of PEARL as it is today, the areas of PEARL in need of improvement, what other similar sites are doing, ideas for new user interfaces, and ultimately how we can improve the PEARL site for the future.

### **Part I Strengths of the PEARL Website Today**

Before the idea of PEARL existed, environmental data from state, local, and non-profit agencies resided in separate databases throughout the state. One of the successes of the PEARL website that users commented on is the amount of environmental data that is available. Some individuals commented favorably to specific aspects of the website. These comments included: the ease of finding lakes when using a text search, the

usefulness of the datasets, and the fact that multiple searches were not necessary to find meaningful data.

## **Part II Areas in Need of Improvement**

The major task ahead for PEARL seems to be exactly how to organize data, information and searches in the clearest most user-friendly manner. All of the survey participants voiced this concern in at least one area of the survey. This was probably the most common comment on the survey. We can expect user-friendliness to be a top priority on a website improvement survey. As computer programs and web design become more sophisticated, the general public becomes more computer savvy and the bar is raised for user-friendliness and efficiency in web design.

With user-friendliness the focus, survey participants cited many specific areas in need of improvement. We can group these comments into 5 general areas of concern: improving the visual design of the site, redesigning the data search process, improving links to supplementary information like metadata, data explanation and the glossary, changing the vocabulary so that the site is more usable to the average person, and additional information that would be useful on the site.

### **1) Improving the Visual Design of the Site**

Making the site more visually appealing, simplifying the appearance of the site, and the inclusion of more visuals and pictures were priorities to many survey participants. Increasing the consistency of design between different parts of the website was also a concern.

Specific ideas included link buttons at the top of the page, more pictures of lakes and boat launches

### **2) Redesigning the Data Search Process**

The data search process was a major concern with a majority of the participants. Suggestions included: redesigning the data search process so that it

is more intuitive and so that it requires less steps, more efficient ways of displaying categories of datasets available, and fixing errors in data tables. Many survey users thought that other websites such as the Minnesota DNR website had a better data search process (see Part III).

Another concern expressed was that of problems with the data tables. The use of the number “999.9” in the data tables for data that is missing was a particular point of frustration for several users. Frustration was centered around the fact that it was not apparent in the data table that “999.9” meant missing data, and that these “999.9” numbers threw off the plotting of the data. Other users had problems with plotting Secchi depth. A suggestion for improving the “Plotting the Data” option was to permit the plotting options for only meaningful data relationships. All of the users responded favorably to the option to creating their own graphs. This option would allow users to choose the specific data for the x and y axis and the format of the graph.

One other area where users found problems and frustration in the data search process was when they tried to use the “Back” button in their browser, they received a “Page Expired” message. The option to go back to the previous page is not built into how the website currently works, but users agreed that internal links back would be helpful.

### **3) Improving Links to Supplementary Information like Metadata, Data Explanation and the Glossary**

Participants responded that they did not notice the Metadata button, which is at the top of the page when any data table is shown. The metadata can be very



useful to users because it gives supplemental information about how the data was collected, and contact information for those responsible for data collection. Participants voiced the need to make the metadata button more noticeable.

Other participants commented that they would like access from the data search area of the website to the supplementary information that is available in the education section. An option like this would allow users the option to learn more about the data they are looking at in the tables by clicking on a button for supplementary information such as background information on a water quality topic, or links to the glossary.

#### **4) Changing the Vocabulary so that the Site is More Usable to the Average Person**

Comments from several areas of the survey indicated that users thought that the vocabulary on the website either needed to be changed to a more simplified, universal vocabulary, or if scientific vocabulary was used, a short explanation should accompany it so that the non-academic community could easily complete a data search. An example of this is the “List by Dataset or List by Parameter” option in the search process. If a user does not understand the meaning of the word “dataset” or the word “parameter”, which are essentially scientific vocabulary, they are forced to click on either term to continue their data search by trial and error. Users all agreed that a few words to explain the function of these search processes would be helpful. Another specific suggestion was to change the names of datasets so that they are more identifiable to the general public.

## **5) Additional Information that Should be Included on the Site**

Users were also given the opportunity identify additional information that would be useful on the website. These areas of interest included the addition of river, stream and estuary data to the site, fisheries and other biological data, a list of ponds/lakes in recent watershed surveys, TMDL Reports, climate data, more graphs and maps to help interpret data, and more up-to-date data for lakes. A significant amount of the information requested for the website can be grouped into education-focused topics. These topics included: more background information for the layperson, current issues, history, understanding lakes, understanding fish and other biology of water systems, and links to environmental information on other websites. There is a clear desire for more generalized information about water systems in Maine on the PEARL website.

### **Part III**

#### **What Other Sites are Doing Well, and How We Can Learn From Them**

As part of the survey process, three sites with similar purpose and function were identified for comparison with the PEARL site. The first site was the Minnesota Department of Natural Resources “Lake Finder” site [www.dnr.state.mn.us/lakefind/index.html](http://www.dnr.state.mn.us/lakefind/index.html). Of the three sites selected, participants responded with the most enthusiastic comments about this site. The site (which is just a small part of the Minnesota DNR site) has a very efficient and simplified search process for lakes data, and is reason that most users rated it above the PEARL site in preference. The first page has a space to enter a lake name in a text box, or below that there is an option to find the lakes in a certain county, and gives a drop-down box that lists all of the counties in the state.

The part of the site that users seemed to respond most enthusiastically to was the way that the lake name and information/data categories available for that lake are displayed. The screen has a list of the lake names on the left side and the names of the categories of information/data are listed along the top of columns which go across the top of the screen. A checkmark appears in the column if that type of information/data is available. Visually, the way that the screen is set up is very efficient. Users liked the way that you could see the categories of information/data available for all lakes on one page, and suggested adopting this format for the PEARL data search process. The survey participants found many strengths to this site, most of which they thought should be incorporated into the PEARL site. The comments included that the site was “cleaner”, “faster”, “more user-friendly” and “you can jump right in”. Some survey participants still liked PEARL’s organization of information better, but the majority thought that the Minnesota site as stronger than PEARL.

One thing to remember when comparing PEARL to this site is that PEARL contains much more data than the Minnesota DNR site, and the data is more varied on the PEARL site. Simplicity and efficiency is a huge lesson that can be learned, however, by studying the design of the Minnesota DNR site.

Data/information categories included in the Minnesota site that users suggested adding to the PEARL website include: fish consumption advisories, recreational compass maps, satellite images, lake maps and water lake levels.

The next site on the survey was the Wisconsin Department of Natural Resources (DNR) site [www.dnr.state.wi.us/org/water/fhp/lakes](http://www.dnr.state.wi.us/org/water/fhp/lakes) .Users agreed that this site was too busy and not well organized. One trap to stay away from is clutter and too much information on the site.

The last website used in the survey is the Lake Access website [www.lakeaccess.org](http://www.lakeaccess.org) . Users responded positively to several areas of the site: the way that the navigation buttons were located along the top of the page, the current issues, history and angler sections, and the graphing applettes.

## **Part IV**

### **New User Interfaces**

In planning a way to communicate information to the specific user groups, the idea of specialized user interfaces was developed. The target user groups for these interfaces are groups that could potentially use the data on the PEARL website, but do not currently use the information because of a “barrier” in scientific understanding or vocabulary. The target groups are currently teachers/ students, anglers, and the general public concerned with lakes/water issues (lake association members, for example).

Ideas from survey participants for information to include in the new user interface for anglers include: fish stocking reports, Maine fish species information for the general public, depth and transparency information, thermoclines and Secchi depth, individual lake regulations, locations of boat launches, fish surveys, historic stocking records, and warning about illegal introduction of non-native species. For the teachers/student interface, suggestions included information on water quality, aquatic plants, fish, lake stewardship programs, and community service needs. These ideas are currently in consideration as the new user interfaces are developed.

### **Conclusions**

The feedback gained from the survey can be used to construct a framework of priorities for the improvement of the PEARL site. The priorities would be to:

- Improve the accessibility of the data and information on the website for the general public.
- Redesign the data search process so that it is more intuitive and efficient.
- Improve the visual design of the site.
- Improve the connection between data and tools on the site that facilitate understanding and synthesis of the data. (for example, connections from data sets to “Understanding the Data” pages or to the glossary)
- Add more data and background information to the site.

With these priorities in place, we are able to clearly look forward and plan strategies to make these ideas happen. As we move through this process of improvement it will be important to seek and document more feedback from users,

respond to the concerns or suggestions that are voiced, and to modify our actions accordingly. Understanding the relationship that the user has with the PEARL interface will be the key to continuing the success of the site.

## Lake Information Websites: A User Survey

Name \_\_\_\_\_ Organization \_\_\_\_\_

Date of completion of the survey \_\_\_\_\_

### Part One: Evaluation and suggestions for the PEARL site

Please go to the homepage of the PEARL website: [www.pearl.maine.edu](http://www.pearl.maine.edu)

1. On first impression, how visually appealing is the homepage in comparison to other websites?
- |                         |   |                    |   |               |
|-------------------------|---|--------------------|---|---------------|
| Very visually appealing |   | Somewhat appealing |   | Not appealing |
| 1                       | 2 | 3                  | 4 | 5             |

*First, please take some time to navigate around in the site so you have a feel for how the site is organized and the information that it contains. Next, pretend that you are coming to this site to find specific water quality data for a lake that you are interested in. Please try to complete a search for information on your chosen lake by following the directions listed below. Please answer the questions as you conduct the search.*

**Go to the first page of the site. Scroll down to the search buttons at the bottom of the page.**

2. Are the labels on the search buttons "Browse Data Sets" and "Text search" easy to understand? **YES NO**

**Click on the "Text Search" button. Next click on the scrolling menu labeled "County" and choose a county. Look at your results (we will use this in comparison to another site later).**

**Go back to the "Text Search" page and type in your lake name under "Lake Name"**

3. How easy was it to find the lake that you were looking for under "Lake Name" only?
- |           |   |               |   |              |
|-----------|---|---------------|---|--------------|
| Very Easy |   | A little work |   | Hard to find |
| 1         | 2 | 3             | 4 | 5            |

4. Were the options to select multiple search criteria helpful to find the lake that you were looking for?
- |              |   |                  |   |             |
|--------------|---|------------------|---|-------------|
| Very Helpful |   | Somewhat Helpful |   | Not Helpful |
| 1            | 2 | 3                | 4 | 5           |

5. Are there other ways of searching for lakes by text that would be helpful to you? Please give specific ways that you would like to search for data by text.

6. Would you use a multiple-lake search if it was available? **YES NO POSSIBLY**

**Once you have reached the Lake Summary Data page for your lake...**

7. How useful is the information listed on this page?
- |             |   |                 |   |            |
|-------------|---|-----------------|---|------------|
| Very useful |   | Somewhat useful |   | Not useful |
| 1           | 2 | 3               | 4 | 5          |

8. Is there other useful summary data that you would like to see on this page? Please list your ideas:

9. How clear is it that the buttons with pictures (Labeled Water Quality, Fauna, ect.) contain data sets for the lake that you have selected?

|            |   |                    |   |                                             |
|------------|---|--------------------|---|---------------------------------------------|
| Very Clear |   | A little confusing |   | Not clear, I had to click on it to find out |
| 1          | 2 | 3                  | 4 | 5                                           |



|                       |   |                        |   |        |
|-----------------------|---|------------------------|---|--------|
| Not long<br>long time |   | A short amount of time |   | A very |
| 1                     | 2 | 3                      | 4 | 5      |

23. How easy was the map tool to use?

|                          |   |                                |   |               |
|--------------------------|---|--------------------------------|---|---------------|
| Very easy<br>frustrating |   | Somewhat difficult/frustrating |   | Difficult and |
| 1                        | 2 | 3                              | 4 | 5             |

24. Would the amount of time that it took for the maps to load discourage you from using this tool in the future? **YES NO**

25. How useful is the "Map Search" tool in your opinion?

|                       |   |                 |   |     |
|-----------------------|---|-----------------|---|-----|
| Very Useful<br>useful |   | Somewhat useful |   | Not |
| 1                     | 2 | 3               | 4 | 5   |

26. How could the "Map Search" tool be improved?

**Click on the "Education and Outreach" button on the left side of the page.**

27. How well do you think this page is organized for an average user to find educational information?

|                     |   |                    |   |               |
|---------------------|---|--------------------|---|---------------|
| Very well organized |   | Somewhat Organized |   | Not organized |
| 1                   | 2 | 3                  | 4 | 5             |

**The PEARL team is in the process of developing new user interfaces for two specific user groups: anglers, and students/teachers. We would love your feedback and ideas about this future program.**

28. How could you see data from the PEARL database utilized by specific user groups such as fishermen/anglers and teachers/students? What type of data/information would be useful for each these groups?

fishermen/anglers:

teachers/students:

## Part Two: Evaluating Similar Sites

**Please go to the Minnesota Department of Natural Resources "Lake Finder" site [www.dnr.state.mn.us/lakefind/index.html](http://www.dnr.state.mn.us/lakefind/index.html) Please take a few minutes to navigate through this site.**

1. What are your first impressions of the site, as it compares to PEARL?

**Go back to the first page of the site. Under the tab that is labeled "Find a Lake", click on the pull down list under "County". Choose a county from the list and click on the "Get Lake Data" button. The "Search Results" page should come up.**

2. How does the way that available data is organized on this page compare to the way it is organized on PEARL?

|                                              |   |                     |   |           |
|----------------------------------------------|---|---------------------|---|-----------|
| PEARL is more effective<br>is more effective |   | They are comparable |   | Minn. DNR |
| 1                                            | 2 | 3                   | 4 | 5         |

3. Do you like the way that this page shows the available data in each category for each lake? **YES NO**

**Click on one of the information categories for a lake in your selected county by clicking on the checkmarks located under each column category. Please view all 9 categories.**



4. In comparison to the information provided on PEARL, please comment on the communication of data on the Minnesota DNR site. Specifically, please identify methods of data communication that would be helpful on the PEARL website.

Lake Survey:

Lake Maps:

Lake Water Levels:

Fish Consumption Advisory:

Lake Water Quality:

Lake Water Clarity:

Lake Water Quality by Satellite:

Recreation Compass:

Topographic Maps:

**Go back to the first page of the “Lake Finder” site. Use the search for “Stocking Reports” and “Generate a Report”**

5. How useful do you think this tool would be for the PEARL site?

|             |   |   |                 |   |  |            |
|-------------|---|---|-----------------|---|--|------------|
| Very Useful |   |   | Somewhat Useful |   |  | Not Useful |
| 1           | 2 | 3 | 4               | 5 |  |            |

**Please go to the Wisconsin Department of Natural Resources “Wisconsin Lakes” site [www.dnr.state.wi.us/org/water/fhp/lakes](http://www.dnr.state.wi.us/org/water/fhp/lakes)**

**Take a few minutes to navigate through the site. Next, go back to the first page. Click on the “Lake Data” choice on the list on the left side of the page. Then click on the “Download Data” button at the top of the next page.**

1. How does their searching method for lake data compare to those on PEARL and the Minnesota DNR “Lake Finder” site?

2. Look around on this site, are there things that you like that might be applied to the PEARL site? Please be specific.

**Please go to [www.lakeaccess.org](http://www.lakeaccess.org) to answer the questions below. Please keep in mind that the Lake Access site is different from PEARL in that it only manages lake data from a few lakes, and the data managed on the site is real-time data gathered from specialized data collection tools. The site was chosen because of its design elements and the pages designed for specific user groups.**

1. Do you think that the format of the link buttons on the top of their homepage would benefit the PEARL website? **YES NO**  
Why/ why not?

**Click on the “Anglers” button on the left side of the screen on the homepage. Look at the graph that shows where the thermocline is (dissolved oxygen to depth).**

2. How valuable do you think that this graph would be to anglers?

|               |   |   |                   |   |  |                     |
|---------------|---|---|-------------------|---|--|---------------------|
| Very Valuable |   |   | Somewhat Valuable |   |  | Not Valuable At All |
| 1             | 2 | 3 | 4                 | 5 |  |                     |

**Scroll down the page and look at the chart “Fish Water Quality Needs”**

3. How valuable do you think that a graph like this with Maine species would be to anglers using the PEARL website?

|               |   |   |                   |   |                 |
|---------------|---|---|-------------------|---|-----------------|
| Very Valuable |   |   | Somewhat Valuable |   | Not Valuable At |
| All           | 1 | 2 | 3                 | 4 | 5               |

**Click on the “Lake Data” link button at the top of the page, and then click on the “About the Data” on the left hand side of the page.**

4. How useful are the Data Visualization Tools included in this part of the site?

|             |   |   |                 |   |            |
|-------------|---|---|-----------------|---|------------|
| Very Useful |   |   | Somewhat Useful |   | Not useful |
|             | 1 | 2 | 3               | 4 | 5          |

5. Do you think that these tools would be useful on the PEARL website? **YES NO**

**Click on the “Understanding Lakes” button at the top of the page. Check out the pages included in this section.**

6. What do you like about this section of the Lake Access site? What parts could be used on the PEARL website- especially on the education section of the site?

7. What else about this website do you like and think might be useful on the PEARL website?

### Part Three: Conclusions

1. Based on what you have seen on the other sites, and based on what you have noticed while completing the question ere, what do you think should be the top three priorities in improving the PEARL site?

2. What other data or information would you like to see on the PEARL website?

3. Please provide any other suggestions or ideas for improvement:

## APPENDIX 2

**Materials prepared by Sara McCabe (M.S. student) for PEARL-evaluation focus sessions, May-June 2005.**

## PEARL Website Research Project Teacher Participant Survey

Age: \_\_\_\_\_ Gender: M / F Profession,  
Title: \_\_\_\_\_

### Computers:

1. What computers do you normally use? (circle all that apply)
- A school laptop
  - A computer at home
  - Computers at school(in a class or library not laptops)
  - A computer at a friend or relative's house
  - A computer at a local library
  - Other, list \_\_\_\_\_

### Internet Use:

2. How often in a week do you use the internet? (circle one)
- 1 – 2 days
  - 3 – 4 days
  - 5 – 6 days
  - Everyday
3. How much time do you spend using the internet on a daily basis? (circle one)
- do not use daily
  - 1-30 min.
  - 30 min.- 1 hour
  - 1 - 2 hours
  - 2 – 3 hours
  - more than 3 hours
4. Where do you use the internet? (circle all that apply)
- at home
  - at work
  - at a local library
5. What do you use the internet for? Circle all that apply, and give the percentage of total time on the internet that you use for this task (all should add up to 100)
- | <u>Task</u>                       | <u>Percentage of time on Internet</u> |
|-----------------------------------|---------------------------------------|
| ▪ e-mail for work                 | _____                                 |
| ▪ e-mail for fun                  | _____                                 |
| ▪ search for information for work | _____                                 |

- search for information for fun  
(travel, topic of interest) \_\_\_\_\_
- search for info. for personal task  
(Government info ex. tax laws) \_\_\_\_\_
- surfing for fun \_\_\_\_\_
- playing games \_\_\_\_\_
- Other \_\_\_\_\_

6. As a teacher, do you use the internet in you classes? Yes / No

7. How often do you use the internet in your class? (circle one)

- Every couple of months
- Once a month
- Several times a month
- Once a week
- Several times a week
- Everyday

8. What do you use the internet for? (circle all that apply)

- Research
- Word processing
- Online tutorials
- Online learning games
- E-mail
- Other, list \_\_\_\_\_

9. What are the greatest barriers to using the internet in your classroom?

10. What are frustrating aspects of using the internet in the classroom?

11. What are the things that you look for most in an internet source to use in your classroom?

12. Did you use the PEARL website [www.pearl.maine.edu](http://www.pearl.maine.edu) before getting involved in this research? Yes / No

13. Have you had a chance to use the new PEARL website [www.pearlmaine.com](http://www.pearlmaine.com) before attending the meeting?  
Yes / No

14. If yes, how much time did you spend on the site? \_\_\_\_\_

15. Do you have any general comments or questions about the site?

## Teacher Focus Group Script

### Introduction

Hello, my name is Sara Colburn McCabe, I am a graduate student at the University of Maine. I work for the Senator George J. Mitchell Center for Environmental and Watershed Research. The focus of my graduate thesis is about how people interact with environmental data on the internet, and how website design effects this interaction.

In this group interview I will be asking you some questions and I would like everyone to feel like you can talk freely to each topic.

### Opening

To get us started, let's do some introductions. Tell us your name, where you teach, and your favorite activity when you are not teaching.

### Question #1

Think back to the past couple of years since the internet has become such a major part of our society. What is the best experience you have had using the internet in your classroom?

### Question # 2

Based on your experience, what types of things do you think make websites successful for student learning?

### Question # 3

Thinking about the units or topics that you have taught, what ways could you see using existing environmental data in your classroom?

Let's go ahead and start looking at the PEARL website.

The first thing I would like you to do is to just look at the homepage- don't go any further than that yet.

I want you to imagine that you are looking for information about chlorophyll on the lake in town.

### Question # 4

Is it clear on this page where you would go for this information?

Do you have any ideas of how this could be improved?

Next, we are going to look at the different ways of searching for data and information on the PEARL site. I am going to point them out to you on the projector screen, and then I would like you to try them out.

- Basic Text Search

- Advanced Text Search

- Browse Datasets

- Map Search

## Lakes Guide

### Question # 5

Which mode of searching would you be most likely to use yourself? With students? Talk about the features that you found most useful.

### Question # 6

Were there specific parts of the search process that were confusing, frustrating, or in need of change?

Now we are going to look more closely at the Lakes Guide. I would like you to look at the different sections within the Lakes Guide. Keep in mind that because the site is still under construction, there may be many dead links. Take a few minutes to try it out and then we will discuss.

### Question # 7

Think about if you were using this site with your class, what aspects of the Lakes Guide would help your students find and understand data?

### Question # 8

Were there any confusing or frustrating parts of the Lakes Guide?

### Question # 9

Can you identify things that are missing on the Lakes Guide that would be helpful to you or your students?

Now let's go back to the home page again. Check out the other tools and resources on the site such as the Education Resources, the Glossary, and the other "Windows" such as the Atlantic Salmon, Freshwater Biodiversity and Penobscot River Synthesis sections that are coming in the future.

### Question # 10

If you could add one thing to the PEARL website to make it more useful for teachers and students, what would it be?



## PEARL Website Research Project Student Survey

Age: \_\_\_\_\_

Gender: M / F

### Computers:

1. What computers do you normally use? (circle all that you use)

- A school laptop
- A computer at home
- Computers at school(in a class or library not laptops)
- A computer at a friend or relative's house
- A computer at a local library
- Other, list \_\_\_\_\_

### Internet Use:

2. How often in a week do you use the internet? (circle one)

- 1 – 2 days
- 3 – 4 days
- 5 – 6 days
- Everyday

3. How much time in a day do you spend using the internet? (circle one)

- do not use daily
- 1-30 min.
- 30 min.- 1 hour
- 1 - 2 hours
- 2 – 3 hours
- more than 3 hours

4. Where do you use the internet? (circle all that apply)

- at home
- at school
- at a local library
- at a friend or relative's house

5. What do you use the internet for? Circle all that apply, and give the percentage of total time on the internet that you use for this task (all should add up to 100) For example, I use email 50% of the time and search for information for school the other 50% of the time I use the internet. Break 100 down how ever you want to.

Task

Percentage of time on Internet

- e-mail for fun \_\_\_\_\_
- search for information for school \_\_\_\_\_

- search for information for fun  
(hobby, something you like) \_\_\_\_\_
- surfing for fun \_\_\_\_\_
- playing games \_\_\_\_\_
- Other \_\_\_\_\_

6. Do you use the internet in your school classes? Yes / No

7. How often do you use the internet in class at school? (circle one)

- Every couple of months
- Once a month
- Several times a month
- Once a week
- Several times a week
- Everyday

8. How many different classes do you have at school? \_\_\_\_\_

How many of those classes use the internet? \_\_\_\_\_

9. What do you use the internet for in class? (circle all that apply)

- Research
- Word processing
- Online tutorials
- Online learning games
- E-mail
- Other, list \_\_\_\_\_

10. Do you like using the internet in the classroom? Why or why not? Give examples if you can.

11. Are there any frustrating parts of using the internet in the classroom? What are they?

12. What are the things that a website can have that makes it better than another site?

13. Did you use the PEARL website [www.pearl.maine.edu](http://www.pearl.maine.edu) before getting involved in this research? Yes / No

14. Have you had a chance to use the new PEARL website [www.pearlmaine.com](http://www.pearlmaine.com) before attending the meeting?  
Yes / No

15. If yes, how much time did you spend on the site?\_\_\_\_\_

## Student Assent Script for Interview

Thank you for agreeing to talk to me today about the PEARL website. I am trying to find out more about the ways that people use the website, and how people use environmental data on the internet. Our discussion will take about 50 min, including time that you will be using the website, and time filling out an anonymous survey. The survey should take no more than 5 min. and includes questions like “How much time do you spend on the internet each day”, and “Do you enjoy using the internet for learning in the classroom”. I have some questions to ask you. You are free to answer however you wish, and also to skip any questions you do not want to answer. Also you can end the interview any time you want. I would like to record the interview on tape. The only people who will hear the tape are the researchers at the University of Maine. I will be combining the information you share with the information that other students, teachers, and lake volunteers share with me to write a report. I will not use your name or identify you in any way in these reports. Do you have any questions for me before we begin? Are you still willing to talk with me?

1min. Read Student Assent Script

5min Student Survey

2min Intro question- What is your first name, and what is your favorite website?

3min #1 Think about how you have used the internet in your classes in the past, do you enjoy using the internet to learn in school?  
Explain why or why not- try to give specific examples

5min #2 What do you think makes one website for learning new information better than another? Lets make a list of requirements for websites that hold your attention and help you learn.

Have students look at the first page only of PEARL

2min #3 Pretend that you are looking for water quality data for a certain lake, is it clear where you could go to find

this? What might help make this page clearer so that you can get to the information you need?

Have students look away from their computers, show them the search methods available- text, map.

3min Have them try the search method out for a lake in their town.

5min #4 How did your search for data go? Was the process clear or confusing? What parts did you get stuck on? What parts did you like?

3min Now look at the Lakes Guide- water quality section. Pretend you are looking for information about chlorophyll.

5min #5 How does this way of finding information compare with the other searches you did on PEARL? Is it easier to use or not? Given three different ways of finding data, which is the easiest for you? Why?

How easy is the information on chlorophyll to read and understand?

Should it be changed in any way to make it easier to understand?

Do the pictures help you learn more about the subject?

What could be added to this to make it easier to understand and more interesting?

3 min Now, look at the other parts of the Lakes guide- lake overview, fish & angler, aquatic plants and animals.

5min #6 How could you see using this data and information in your classroom or at home?

What other types of data or information would be interesting to you?

What could be included that is not on the site now?

3min What is your favorite part of the site? Why?  
If you had the power to change or add one thing to this site to make it better (more interesting, more effective), what would it be?

**PEARL Website Research Project Lake Volunteer Participant Survey**

Age: \_\_\_\_\_ Gender: M / F Profession,  
Title: \_\_\_\_\_

**Computers:**

1. What computers do you normally use? (circle all that apply)
- A computer at home
  - Computers at work
  - A computer at a friend or relative's house
  - A computer at a local library
  - Other, list \_\_\_\_\_

**Internet Use:**

2. How often in a week do you use the internet? (circle one)
- 1 – 2 days
  - 3 – 4 days
  - 5 – 6 days
  - Everyday
3. How much time do you spend using the internet on a daily basis? (circle one)
- do not use daily
  - 1-30 min.
  - 30 min.- 1 hour
  - 1 - 2 hours
  - 2 – 3 hours
  - more than 3 hours
4. Where do you use the internet? (circle all that apply)
- at home
  - at work
  - at a local library

5. What do you use the internet for? Circle all that apply, and give the percentage of total time on the internet that you use for this task (all should add up to 100)

| <u>Task</u>                                                     | <u>Percentage of time on Internet</u> |
|-----------------------------------------------------------------|---------------------------------------|
| ▪ e-mail for work                                               | _____                                 |
| ▪ e-mail for fun                                                | _____                                 |
| ▪ search for information for work                               | _____                                 |
| ▪ search for information for fun<br>(travel, topic of interest) | _____                                 |

- search for info. for personal task  
(Government info ex. tax laws) \_\_\_\_\_
- surfing for fun \_\_\_\_\_
- playing games \_\_\_\_\_
- Other \_\_\_\_\_

6. What aspects of the internet do you enjoy the most?

7. What are frustrating aspects of using the internet?

8. Have you used the internet to look for information about lakes or environmental topics?

Yes / No

-Was the search successful? Yes / No

-Were there frustrating parts of that process? What were they?

9. Has your volunteer group used the internet to guide any understanding about lake ecology or lake issues? Describe your experience.

10. What are the things that you look for most in an internet source for environmental information?

11. Did you use the PEARL website [www.pearl.maine.edu](http://www.pearl.maine.edu) before getting involved in this research? Yes / No

12. Have you had a chance to use the new PEARL website [www.pearlmaine.com](http://www.pearlmaine.com) before attending the meeting?

Yes / No



13. If yes, how much time did you spend on the site?\_\_\_\_\_

# Field Guide to Aquatic Phenomena

## Basic Information

|                                 |                                   |
|---------------------------------|-----------------------------------|
| <b>Title:</b>                   | Field Guide to Aquatic Phenomena  |
| <b>Project Number:</b>          | 2004ME32B                         |
| <b>Start Date:</b>              | 4/1/2004                          |
| <b>End Date:</b>                | 3/31/2005                         |
| <b>Funding Source:</b>          | 104B                              |
| <b>Congressional District:</b>  | 2                                 |
| <b>Research Category:</b>       | None                              |
| <b>Focus Category:</b>          | Ecology, Education, Water Quality |
| <b>Descriptors:</b>             | None                              |
| <b>Principal Investigators:</b> | Kathy Webster                     |

## Publication

1. Schmitt, C., 2004. A Field Guide to Aquatic Phenomena. Information Digest, Senator George J. Mitchell Center, Maine Department of Environmental Protection, 6p.
2. Schmitt, C., 2004. A Field Guide to Aquatic Phenomena. Web Site, Senator George J. Mitchell Center, Maine Department of Environmental Protection, <http://www.umaine.edu/waterresearch/FieldGuide>.



Senator George J. Mitchell  
Center for Environmental  
and Watershed Research

Member of the University of Maine System

# A FIELD GUIDE TO AQUATIC PHENOMENA

This digest is a publication of:  
MITCHELL CENTER  
at the University of Maine,  
the U.S. Geological Survey  
Water Resources Research  
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Prepared by:  
Catherine Schmitt

March 2005

Additional copies are available  
from Maine DEP, the Mitchell  
Center, and on the web at  
[www.umaine.edu/WaterResearch](http://www.umaine.edu/WaterResearch)



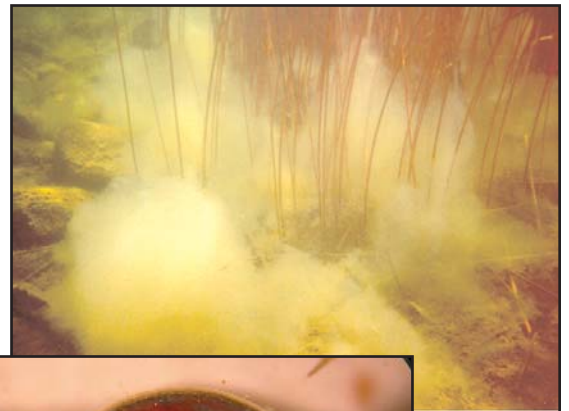
## WHY IS WATER DIFFERENT COLORS?

## WHAT'S THAT FLOATING ON THE WATER SURFACE?



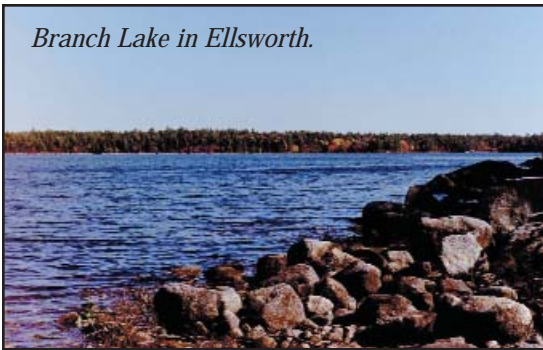
Lakes and streams don't always look  
or behave the way we expect.  
Water can be full of strange colors,  
unidentified blobs, and swimming  
creatures. Something that at first  
glance looks like pollution actually  
might be a natural phenomenon.  
The aquatic world is diverse. There  
are all kinds of cool, weird, and  
interesting things waiting to be dis-  
covered in your nearby lake or  
stream. This field guide will help  
you identify some common phe-  
nomena, and help you  
distinguish pollution  
from something natural.  
To see more, visit {web-  
site}.

## WHAT'S THAT STUFF IN THE WATER?



## SPECKS, BLOBS, AND CLUMPS?

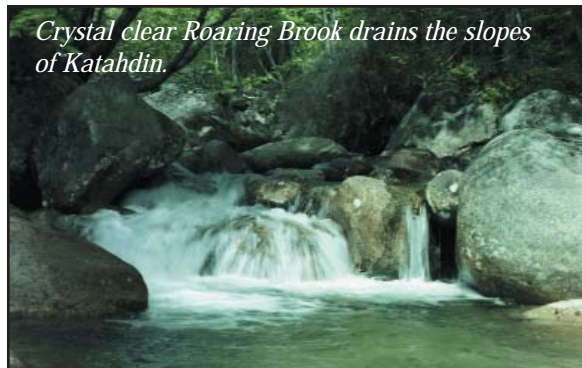
# WHY IS WATER DIFFERENT COLORS?



*Branch Lake in Ellsworth.*

Clear **BLUE WATER** does not contain a lot of particles or dissolved, colored material to intercept and reflect other colors. Blue wavelengths of sunlight are longer, and penetrate into deeper water. The darker the blue, the deeper the water. Shallow areas appear lighter blue or greenish.

Why do some lakes and rivers have no color? **CLEAR WATER** has less dissolved and suspended material. Mountain streams that start as snowmelt or runoff are often clear, because they run over bare rock without sediment or vegetation. Seepage lakes in sand and gravel settings may also look clear, and very shallow water is clear because there is not enough depth for the long, blue wavelengths of light to travel and be reflected back, so instead we see the color of the river or lake bottom.

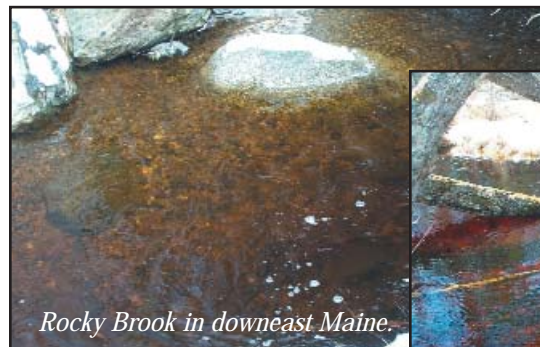


*Crystal clear Roaring Brook drains the slopes of Katahdin.*

When we think of a lake or river, we picture clear, blue water. But the color of rivers and ponds can range from red to brown to green to gray. Color is the result of material in the water that reflects back different wavelengths of the light spectrum. This material can be either dissolved or suspended. Dissolved material may make water look clear and blue or clear and brown.

What about water that is **TRANSPARENT, BUT BROWN** like tea or root beer? This color is the result of dissolved organic material from the breakdown of plants. The material leaches into slow moving streams and lakes from surrounding forests, bogs and wetlands.

Suspended material makes water look **MURKY OR CLOUDY** (this is sometimes referred to as turbidity). Eroding soil can make water muddy brown in color. Strong winds and waves may stir up sediment from a lake bottom, and water near shore may look cloudy as a result. Runoff from urban areas can make water look gray.



*Rocky Brook in downeast Maine.*



*The Dead River which flows through a cedar swamp in Appleton.*



*The gray color of an urban stream.*

Particles of living material can also be suspended in the water. **GREEN WATER** probably has a large population of algae (microscopic plants). Algae and other microscopic organisms have colored pigments. When they grow in large numbers ("bloom"), they can color certain areas or entire lakes and streams. Blooms of an organism called *Euglena* may appear red. A bloom of diatoms, a kind of algae, can look brown. (See inside for more about blooms.)



*Algae have colored this lake green. Photo courtesy SCSWCD.*

An **OILY SHEEN** that reminds you of rainbow puddles in an asphalt parking lot might be from spilled petroleum. But "oil" can also come from natural sources. Some bacteria that live in waterlogged places get their energy from iron and manganese, and as these bacteria grow and decompose, they may appear oily, or slimy



*Oily sheen near a stream.*

black, red or orange as the iron and manganese solidify. • In the spring and summer, a dark cloud in the water accompanied by an oily sheen could also be the outer skeletons of insect cases left behind from a hatch of aquatic insects. A bloom of diatoms, a kind of algae, can leave an oil behind as the algal cells die. • How to tell the difference between petroleum spills and natural oil sheens? Poke the sheen with a stick. If the sheen swirls back together immediately, it's petroleum. If the sheen breaks apart and does not flow back together, it is from bacteria or plant or animal decomposition.



*Clumps of pollen.*

A **YELLOWISH POWDER OR DUST** on the surface of still water in spring and early summer is probably pollen from pine and other trees. After becoming water-logged, the

pollen sinks to the bottom or may collect along the shore. Lines of pollen may be left on rocks as water levels drop in summer. Sometimes pollen clumps together and forms small blobs.



*Pollen collects in a cove. Photo courtesy C. Smith.*

On a windy day, **LINES OF FOAM OR DEBRIS** may form along the length of a lake, reservoir, or river. These lines are called windrows or Langmuir streaks. Wind can cause water to circulate in a pattern that makes material collect in lines on the surface. The lines are roughly parallel to the wind direction, and the windier it is, the further apart the lines.



*Langmuir streaks. Photo courtesy A. Thurnherr.*

## WHAT'S THAT FLOATING ON THE WATER SURFACE?



**ORANGE OR REDDISH BROWN SLIME OR FLUFF** is produced by a group of bacteria that use iron as an energy source. This is the same group of bacteria that create oily sheens. The masses of bacteria excrete slimy or fuzzy-looking material as they grow and reproduce, and the slime becomes coated with rusty iron hydroxide. This is usually a natural phenomenon and is generally associated with acidic soils. However in large amounts (orange fluff that fills a stream bed) iron bacteria might indicate pollution. • In some areas, iron-rich groundwater may seep to the surface, and the iron solidifies and settles to the bottom as it becomes exposed to air. In this case, the iron will appear as an orange crust or stain, and will not be fuzzy-looking.



*Iron precipitate at a groundwater seep.*

*Iron bacteria. Photo courtesy C. Smith.*

Fuzzy, **GREEN FLOATING DOTS** on lakes and in the top few feet of water, or tiny green tapioca-like balls might be an alga (microscopic plant) called *Gleotrichia echinulata*.

*Gleotrichia* usually appear mid-summer for brief periods, but can persist longer in some lakes. The presence of *Gleotrichia* does not necessarily indicate poor water quality since it is commonly present in Maine lakes that have good water clarity. Wind and currents can concentrate them in one part of the lake and high densities can collect in coves.



*Gleotrichia floating in a pond.*  
Photo courtesy R. Hill.

Don't mistake floating plants like **DUCKWEED** and water meal for algae. Duckweed (*Lemna* spp.) look like miniature lily pads, with a flat, round floating leaf and a tiny root. Water meal (*Wolffia* spp.) also floats but does not have a root, it is a round grain-like plant, about the size of a poppy seed.



*Duckweed in a swamp.*



*Strands of algae from a drainage pipe.*

**FLOATING GREEN STRANDS**, "cotton candy", and **GREEN CLUMPS** are formed by filamentous algae. These colonies of microscopic plants live in shallow water on the bottom near shore or on submerged objects.



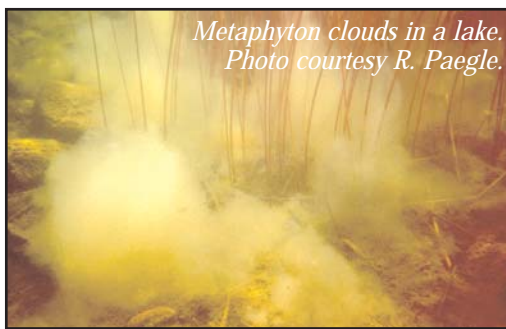
*Clumps of algae in a stream*

## WHAT'S THAT STUFF IN THE WATER?

**GREENISH-YELLOW CLOUDS** that look like cotton candy in shallow water along the shoreline are groups of algae known as metaphyton.

Clouds often form in spring after heavy runoff or following a long hot spell in the summer.

Metaphyton clouds, made up of several different kinds of algae, may be a foot or more in length. This kind of algae does not necessarily indicate that there are excess nutrient levels in the water.



*Metaphyton clouds in a lake.*  
Photo courtesy R. Paegle.



*Algae bloom in a lake.*  
Photo courtesy SCSWCD.

### SHOULD YOU BE CONCERNED ABOUT ALGAE BLOOMS?

Algae are an important source of food and oxygen for other plants and animals in the water, and a diverse community of algae is healthy. Sometimes, certain conditions might favor a species that is normally rare in a lake or stream. With the right temperature, light, and nutrients in the water, the organism might multiply rapidly, forming a "bloom". When an algae bloom is persistent or occurs routinely, too many nutrients may be entering the water. Nutrients (especially phosphorus) fertilize a lake just as they fertilize your lawn or garden, causing microscopic plants in the lake to grow. In Maine, to report an algae bloom call DEP at 1-800-452-1942.

**GREEN OR BLuish-GREEN SCUM** on the surface of a lake, pond, or stream might be a bloom of blue-green algae (cyanobacteria).

Jelly-like masses and clumps floating on the surface of shallow, calm waters or attached to sticks under the water might be the **EGG MASSES** of insects, fish, or amphibians. Frog eggs usually look like a round mass and float on the water surface. Salamander eggs are huge masses with lots of jelly, and may or may not be attached to plants or sticks below the surface of the water. Toad eggs are laid in a string and usually are attached to plants and sticks. While amphibian eggs are found in masses, fish eggs and other eggs



*Dragonfly eggs on a New Hampshire lake.*

may be found individually or in small groups. • Female "basket tail" dragonflies (*Epiptera* spp.) carry a batch of eggs and drag their abdomen across the water surface to deposit their eggs in long gelatinous strings. They are clear to milky white with tiny spots of embryos. Toad eggs look similar but they are larger and more silty in appearance. Also, toad eggs are often right along the shoreline in weedy shallows among plant stems, and dragonfly eggs will be slightly further out in deeper water. • In early spring, long, flat, purplish ribbons wrapped around plant stems or on sand bars are yellow perch eggs.



*Perch eggs. Photo courtesy S. Diamond.*



*A water mite trapped inside of an aquatic, carnivorous plant. Photo by K. Ness.*

Small, red specks swimming in shallow waters are most likely **WATER MITES**. Often found in and around plant beds, water mites can range in size from a pinhead to a pencil eraser. With eight legs, water mites look like tiny spiders but closer inspection will show they only have one body part, unlike spiders which have two.

Greenish spongy-looking clumps attached to submerged sticks and plant stems in clear, well-oxygenated lakes might be **FRESHWATER SPONGES**.

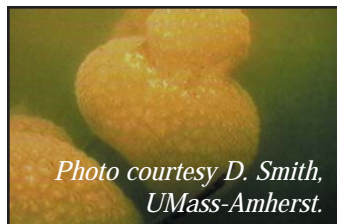
Sponges are members of the animal kingdom but are often mistaken for aquatic plants or algae. Most sponges are green, because they have algae living in their tissues. Freshwater sponges vary in size from a less than an inch to three feet. They are usually finger-shaped, and can look soft or hard. They are most commonly seen in summer or fall. They may appear sporadically and be abundant in a lake one year and absent the following year.



*The freshwater sponge Spongilla lacustris. Photo courtesy Hugh Clifford & Bio-DiTRL.*

They are most commonly seen in summer or fall. They may appear sporadically and be abundant in a lake one year and absent the following year.

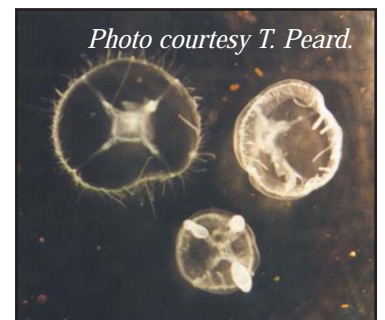
## SPECKS, BLOBS, AND CLUMPS: MINERAL, PLANT, OR...ANIMAL?



*Photo courtesy D. Smith, UMass-Amherst.*

Jelly-like blobs, sometimes seen attached to submerged sticks or docks, might be a colony of **BRYOZOANS**. These can be confused with egg masses. Bryozoans are animals, similar but unrelated to corals. Some bryozoans are wispy and moss-like (giving rise to a common name of "moss animals"), others are large and round, gelatinous, firm, and slimy to the touch. While they may be unsightly on piers and docks, bryozoans are not a water pollution problem and in fact help to filter water.

About the size of a quarter, with hundreds of tentacles, the **FRESHWATER JELLYFISH** can occur sporadically as populations explode and decline. They are translucent but may have a white or green tinge. Freshwater jellyfish have been found in rivers but prefer standing water and are most likely to be seen in lakes and reservoirs in late summer, just below the water surface. They do have stinging cells but are not harmful to humans. Only small fish and insects are harmed by their stings.



*Photo courtesy T. Peard.*

**INSECT EXUVIA:** The larvae of mayflies and some other aquatic insects molt and shed their skins as they leave the water and become flying adults. The skins are called exuvia, and can be seen floating on the water or piled up on wave-swept shores, where they are sometimes mistaken for fish kills. You can find dragonfly skins attached to docks, plants, and objects near shore. As exuvia decompose, an oily film sometimes forms on the water surface.



*The cast-off skin (exuvia) of the damselfly, Calopteryx splendens. Photo courtesy British Dragonfly Society.*

**LINES ON ROCKS** along the shore are a result of fluctuating water levels, and can be created by several different materials. Pollen that settles on a lake or quiet stream in spring may get left behind on rocks when the water drops in summer.

- Algae that live on the surface of the water can likewise adhere to rocks and dry in a line. A white crust on rocks may be leftover diatom shells. Diatoms are a kind of algae with silica in their cells. The hard, white silica may be left behind when the algae die. A wet black zone of algae will form where the water meets the air, similar to bands of seaweed along the coast.
- Bands of bare rock just above the black algae layer are areas where winter ice has scoured the rock.



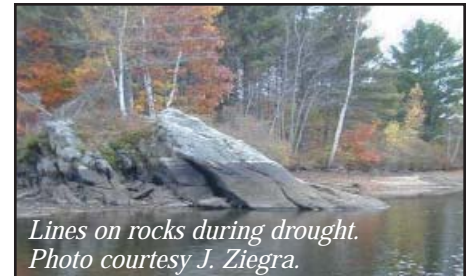
*Lines of pollen on rocks in Davis Pond.*

## WHAT'S THAT ALONG THE SHORELINE?

**FISH KILLS** are rarely the result of toxic pollution. Possible causes include lack of oxygen (especially on hot, windless days where excess nutrients decrease oxygen levels), lack of food, viral or bacterial infections, and fish stranding from low water levels. Some fish die after migration or spawning (like suckers). Smelts die from moderate stress, such as high temperatures or low oxygen. Winter fish kills can occur when oxygen is used up beneath the ice.

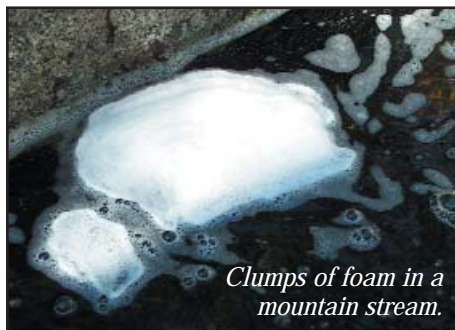


*Fish kill in Maine stream. Photo courtesy Maine-DEP.*



*Lines on rocks during drought. Photo courtesy J. Ziegler.*

Above the bare scour zone is often a band of moss or lichens, where there is enough water and condensation for the lichen to live but above the zone of ice damage. Lichens grow so slowly that they are a good indicator of how high the ice is pushed in winter.



*Clumps of foam in a mountain stream.*

Most **FOAM** on lakes and streams is natural and does not indicate pollution. Foam forms when water is mixed with air, such as by a waterfall or waves breaking against shore. Organic material from decomposing plants and animals lessens the surface tension of water and creates bubbles. Natural foam may smell fishy or earthy, and may be white, off-white, or brownish, and breaks apart easily when disturbed.



*Foam collects in a stream pool.*

### Additional Information

For more photographs and detailed descriptions of aquatic phenomena, visit the Field Guide website at XXXX.

Funding for this project was provided by DEP, and the Maine WRRI grant program through the Mitchell Center.

Thank you to the following people for their invaluable assistance: Katherine Webster, Barb Welch, Christine Smith, Roy Bouchard, Scott Williams and John McPhedran.

### Other Resources:

- [www.state.me.us/dep/blwq/doclake/FAQs.htm](http://www.state.me.us/dep/blwq/doclake/FAQs.htm)
- <http://mainevolunteerlakemonitors.org/index.htm>



# NATIVE AND INVASIVE AQUATIC PLANT VIRTUAL HERBARIUM

## Basic Information

|                                 |                                                     |
|---------------------------------|-----------------------------------------------------|
| <b>Title:</b>                   | NATIVE AND INVASIVE AQUATIC PLANT VIRTUAL HERBARIUM |
| <b>Project Number:</b>          | 2004ME33B                                           |
| <b>Start Date:</b>              | 4/1/2004                                            |
| <b>End Date:</b>                | 3/31/2005                                           |
| <b>Funding Source:</b>          | 104B                                                |
| <b>Congressional District:</b>  | 2                                                   |
| <b>Research Category:</b>       | None                                                |
| <b>Focus Category:</b>          | Conservation, Ecology, Economics                    |
| <b>Descriptors:</b>             | None                                                |
| <b>Principal Investigators:</b> | Dan Buckley, Steve Kahl, Scott Williams             |

## Publication

1. Buckley, Dan, Jeffrey S. Kahl, Scott Williams. 2005. Maine Center for Invasive Aquatic Plants Virtual Herbarium. Website, Volunteer Lakes Monitoring Program, University of Maine Farmington, [www.mciap.org/herbarium](http://www.mciap.org/herbarium)

Maine Water Resources Research Grants Program Final Report

for

Maine Volunteer Lake Monitoring Program's

**MAINE CENTER FOR INVASIVE AQUATIC PLANTS  
VIRTUAL HERBARIUM**

Published on line at: [www.mciap.org/herbarium](http://www.mciap.org/herbarium)

The screenshot shows a Microsoft Internet Explorer browser window with the following content:

- Browser Title Bar:** Curly Leaf Pondweed - Microsoft Internet Explorer
- Address Bar:** <http://www.mciap.org/herbarium/>
- Page Header:** Maine Center for Invasive Aquatic Plants Virtual Herbarium
- Text:** The herbarium is currently under peer review. We welcome your feedback either using the survey at the bottom of each page or send comments to [herbarium@mainevlmp.org](mailto:herbarium@mainevlmp.org)
- Navigation Menu (Left):** Herbarium, Home, Scientific Name, Common Name, Native Plants, Invasive Plants, Look Alike Invasives, Glossary of Terms, Image Gallery, Maine Center
- Species Information:**
  - Scientific Name: *Potamogeton crispus*
  - Common Name: Curly-leaf Pondweed
  - Alternative Name: CURLY-LEAVED PONDWEED
  - Status: **NOT NATIVE TO MAINE - INVASIVE**
- Images:** A photograph of a leaf with a ruler for scale, and a botanical illustration of the plant habit and fruit.
- Text:** Click Images for Larger Version
- Taskbar:** Shows the Start button and several open applications including Sent Items - Microsoft..., Inbox - Microsoft..., Virtual Herbarium..., Curly Leaf Po..., and Adobe Photosho... The system clock shows 3:42 PM.

**Project Timeframe:** April 1, 2004 to April 1, 2005

**Agency Funding Requested:** \$4,000

**Matching Funds Provided:** \$15,000

**PI Names and Affiliations:**

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**Scott Williams** - Executive Director, Maine Volunteer Lake Monitoring Program

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**Congressional District:** Second

**Problem and Research Objectives:** The introduction of non-indigenous invasive plant and animal species to the United States has been escalating with widespread destructive consequences. Until now Maine has been spared the worst introductions, but we would be remiss to assume that this situation will continue indefinitely. Significant habitat disruption, loss of native plant and animal communities, loss of property values, reduced fishing and water recreation opportunities and large public/private expenditures have accompanied invasive plant introductions in all of the lower 48 states except Maine.

Though Maine is a relative latecomer to the national invasive aquatics scene, as awareness of this new threat to Maine waters has emerged across the state, Mainers have taken swift and decisive action. In 2000, the State of Maine passed legislation that outlaws the sale, propagation, or introduction to Maine waters eleven invasive aquatic plants. (Currently, four of these plants are known to be established in Maine waters: variable leaf water-milfoil (and a hybrid form of this plant), Eurasian water-milfoil, curly-leaf pondweed and hydrilla. In 2001 further legislation was enacted, instituting more sweeping authorities, programs and planning requirements relating to invasive plants and other nuisance species. The law put in place some key components for an effective invasive aquatic species program for inland waters including: a boat sticker program to raise funds and public awareness for prevention, detection, and control of

invasive species; an inspection and education program; and an emergency authority to regulate surface use in plant infested waters. The law also established an *Interagency Task Force on Invasive Aquatic Plants and Nuisance Species* comprised of state agency personnel and private citizens representing a wide array of stakeholders. One of the first tasks of the Task Force was the development of the *State of Maine Action Plan for Managing Invasive Aquatic Species*, a document created to provide guidance for the State's management of invasive aquatic species for the subsequent four-year period.

One of the five main objectives of Maine's *Action Plan* includes the development of a practical and effective statewide "early detection" system. And one of the key action steps listed for meeting this objective is the continuance of the VLMP's Invasive Plant Patrol training. "The Volunteer Lake Monitoring Program will continue to train volunteers [and agency personnel] to identify freshwater plants and conduct invasive aquatic plant screening surveys on lakes and ponds." <sup>1</sup>

One of the major players in bringing this issue to the public's attention, the VLMP has continued to provide leadership through the recent establishment of the Maine Center for Invasive Aquatic Plants (MCIAP). Through the Center, the VLMP has developed a comprehensive hands-on workshop series and field guide to aid Plant Patrollers with identification of the eleven target invasive aquatic plants and conducting screening surveys. With support from the MDEP and the boat sticker program, the VLMP/MCIAP has trained more than 1250 volunteers to date, and has implemented what has come to be considered one of New England's most comprehensive and successful citizen-based plant patrol programs. Public feedback on both the training program and the guide has been excellent. *However many patrollers, especially those who are new to plant identification, have expressed the need for additional visual and descriptive resources, to provide further aid in identifying and understanding the target invaders and also in identifying the native plants most frequently encountered during the screening survey process.* Our vision for the development of the on-line "Virtual Herbarium" has taken form in direct response to the specific needs and suggestions of Maine's citizen volunteers, agency collaborators, teachers, students and others.

The Herbarium will consist of photos, line drawings, and scanned images for eleven target invasive species, as defined under Maine law, as well as for native plants that are often mistaken for invaders and others that will likely be encountered during the survey process. The photos will include plants in situ, close-up shots, and micrographs of structures that are key to definitive identification. Factual information will be provided for each of the featured plants, including: species description, similar species, origin and range, habitat and yearly growth cycle, value in aquatic communities (native species) and case studies of infestations and management strategies (invasive species). The site will also include links to survey maps and data collected by State agencies and

volunteers. A dichotomous key will be provided to allow users to rule-out target species. The web site will link to PEARL, the on-line database for Maine lakes, providing additional value-added information for the data and educational activities of PEARL (<http://pearl.maine.edu>). PEARL is a collaborative of the Umaine Mitchell Center, VLMP and Maine DEP.

**Methodology:** The following is the work plan for the project. Asterisks (\*) indicate tasks that involved a high degree of student involvement.

1. A project team was activated, comprised of VLMP/MCIAP staff, principal investigators, agency partners and student investigator. The team met several times and communicated regularly throughout the project period.\*
2. The scope of the initial version of the herbarium was defined by the project team.
3. Resources needed for the project were assembled, and inventoried. \*
4. A list of needs (images, permissions, narrative material, etc.) was developed. \*
5. A layout and functional prototypes of herbarium pages were developed
6. "Needed" items were collected, created, and/or obtained.. \*
7. Individual plant pages and glossary were constructed and hyperlinks were developed and integrated into a "draft version" of the Virtual Herbarium website
8. The draft website was sent out to project team and others for peer and user review and comment
9. The website was revised in accordance with peer feedback.
10. The website was formally launched at the 2005 Maine Water Conference
11. The website was publicized through various media: e-mail list serves, newsletters, television news and radio spots, and articles in regional and national journals.
12. The website continues to invite public feedback. A user-friendly on-line feedback loop provides timely response to recommendations.
13. The Virtual Herbarium website will continue to develop. "Phase two" of the project is now in the planning stage, and will be implemented in stages from 2005 – 2006.

### **Principal Findings and Significance**

The primary and most beneficial expected outcome of this project is the *early detection* of new invasive aquatic plant infestations. Certainly preventing infestations through education, public awareness campaigns and courtesy boat inspection programs is the best and foremost defense against the spread of invasive organisms. But lessons learned from other states also make it clear that no defense can be 100% effective, a fact that is even more certain in a state with close to 6000 lakes and ponds and thousands of miles of stream and river habitat. In time, invaders will most certainly slip through the cracks. Our second line of defense: an active, effective and widespread early detection system is ultimately just as critical to the future of Maine's lakes as prevention efforts.

With the vast amount of potential invasive aquatic plant habitat in the State, and with the limited amount of funds available to screen all waterbodies for the presence of these invaders, volunteers will play an essential role in the statewide early detection program. One excellent example of an effective volunteer-based monitoring effort is very near at hand! Volunteer lake water quality monitors, trained and organized by the VLMP for over thirty years, have provided enormous benefits to the State in the form of high-quality lake data. The contribution made by qualified volunteers to the better understanding and protection of Maine's water resources is beyond measure.

Building upon the water quality monitor model and adapting it to meet the needs of our current challenge, the VLMP's Invasive Plant Patrol Program has already begun to produce promising results. In the four years of the Invasive Patrol Program, over 1250 volunteers and agency personnel have been trained. The number of Maine waterbodies screened for invasive aquatic plants has grown steadily during that four year period from one waterbody screened in 2001, to 51 in 2002, to 146 in 2003, to 249 in 2004. Trained volunteers have conducted a majority of the surveys done in Maine to date.

Creating a web-based, Maine-specific, aquatic plant information resource will go a long way in helping to ensure the future viability of this promising effort. The cost benefits of this project will greatly exceed the total budget if only a single Maine waterbody is protected through the encouragement and support of citizen-based efforts.

The feedback we have received from Plant Patrollers and the general public points to a second, extremely valuable result of this project. Through training and educational outreach, Maine citizens are not only becoming more aware of the threat of invasive plant species, they are gaining a greater appreciation for, and interest in, Maine's native plant communities. The Virtual Herbarium features many common native Maine plants, which will help to enhance and support this growing interest. (In the second phase of this project, more native plants will be added).

The project also provided an outstanding collaborative opportunity, through which many stakeholders came together to produce a high-quality product, one well positioned to attract additional support to ensure the ongoing maintenance and improvement of the website. The response of the public to this new resource has been overwhelmingly positive. An e-mail sent out to roughly 1000 volunteers, agency partners and interested members of the public, announcing the formal launching of the Virtual Herbarium (and providing a quick link to the website) produced the largest, most positive response ever received by the VLMP in its 35 year history.



# Maine Information Transfer, FY04

## Basic Information

|                                 |                                  |
|---------------------------------|----------------------------------|
| <b>Title:</b>                   | Maine Information Transfer, FY04 |
| <b>Project Number:</b>          | 2004ME34B                        |
| <b>Start Date:</b>              | 4/1/2004                         |
| <b>End Date:</b>                | 3/31/2005                        |
| <b>Funding Source:</b>          | 104B                             |
| <b>Congressional District:</b>  | 2                                |
| <b>Research Category:</b>       | None                             |
| <b>Focus Category:</b>          | None, None, None                 |
| <b>Descriptors:</b>             | None                             |
| <b>Principal Investigators:</b> | Steve Kahl, John M. Peckenham    |

## Publication

1. Bank, M. C. Loftin, A. Amirbahman, J. Peckenham, T. Haines, and R. Jung, 2004. Mercury bioaccumulation in lotic and lentic amphibians: regional conservation implications for aquatic ecosystems in the Northeastern United States. Abstrc. ARMI
2. Campbell, J. L., J.W. Hornbeck, M.J. Mitchell, M.B. Adams, M.S. Castro, C.T. Driscoll, J.S. Kahl, J.N. Kochenderfer, G.E. Likens, J.A. Lynch, P.S. Murdoch, S.J. Nelson, and J.B. Shanley, 2004. A Synthesis of Nitrogen Budgets from Forested Watersheds in the Northeastern United States. *Water, Air, and Soil Pollution* 151: 373-396.
3. Dupont, J., Clair, T.A., Gagnon, C., Jeffries, D.D., Kahl, J.S., Nelson, S.J. and Peckenham, J.M., 2004: Estimation of critical loads of acidity for lakes in northeastern United States and eastern Canada, in press, *Environmental Monitoring and Assessment*.
4. Evans, G.C., S. Norton, I. Fernandez, J.S. Kahl, and D. Hanson, 2004. Changes in concentrations of major and trace metals in northeastern U.S and Canadian sub-alpine forest floor. *Water, Air, and Soil Pollution*, in press.
5. Fernandez, I, L. Rustad, S. Norton, J.S. Kahl, and B.J. Cosby, 2003. Experimental acidification causes soil base cation depletion at the Bear Brook Watershed in Maine. *J. Soil Soc Assoc Am.*, in press.
6. Johnson, K.B., Nelson, S.J., Kahl, J.S., Haines, T.A. and Fernandez, I.J.: 2004b, Mass balances of mercury and nitrogen in burned and unburned forested watersheds at Acadia National Park, Maine, USA, *Environ. Monit. Assess*
7. Kahl, J.S. and S. Nelson (guest editors), 2005. The PRIMENet gauged watersheds at Acadia National Park: a natural-design paired watershed experiment. Special issue of *Environmental Monitoring and Assessment*.



8. Kahl, J.S., S. Nelson, I. Fernandez, T. Haines, G.B. Wiersma, S. Norton, G. Jacobson Jr., A. Amirbahman, K. Johnson, M. Schauffler, J. Peckenham, L. Rustad, K. Tonnessen, M. Neilsen, K. Weathers, R. Lent, M. Bank, J. Elvir, J. Eckhoff, H. Caron, P. Ruck, J. Parker, J. Campbell, D. Manski, R. Breen, C. Roman, K. Sheehan, and A. Grygo, 2005. A conceptual framework for control of stream water geochemistry by landscape factors, Acadia National Park, USA. *Environmental Monitoring and Assessment*, in press.
9. Kahl, J.S., J. Stoddard, R. Haeuber, S. Paulsen, R. Birnbaum, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, K. Roy, W. Sharpe, S. Urquhart, R. Webb, and K. Webster, 2004. Response of surface water chemistry to changes in acidic deposition: implications for future amendments to Clean Air Act. *Environmental Science and Technology*, Feature Article, in press.
10. Kahl, J.S., S.J. Nelson, J.L. Stoddard, S.A. Norton, T.A. Haines, 2004. Lakewater Chemistry at Acadia National Park, Maine, in *Response to Declining Acidic Deposition*, in *Protecting our Diverse Heritage: The Role of Parks, Protected Areas, and Cultural Sites*. Proceedings of the George Wright Society/National Park Service Joint Conference, April 14-18, 2003, San Diego, CA. David Harmon, Bruce M. Kilgore, Gay E. Vietzke, eds. The George Wright Society, Hancock, MI. pp. 314-321.
11. Lawlor, J., J. Rubin, B.J. Cosby, I. Fernandez, J.S. Kahl, S. Norton, 2004. Predicting recovery from acidic deposition: Applying a modified TAF (Tracking Analysis Framework) Model to Maine' High Elevation Lakes, *Water Air Soil Pollut*, in press.
12. Nielsen, M.G., and J.S. Kahl, 2004. Nutrient export from watersheds on Mount Desert Island; differences in export as a function of fire history. *Environmental Monitoring and Assess.*, in press.
13. Peckenham, J., J. Rubin, and C. Clavet (2005) Maine's Experiment With Gasoline Policy to Manage MtBE in Groundwater, *Proc. Of the 20th Conf. on Cont. Soils, Sediments, and Water*, Univ. Mass., October, 2004.
14. Peckenham, J., 2004, in prep. The persistence of MtBE in groundwater in Maine, to be submitted *Groundwater Contamination and Remediation*. (revisions in progress).
15. Peckenham, J., J. Kahl, S. Nelson, K. Johnson, and T. Haines, 2004. Landscape controls on mercury in streamwater at Acadia National Park, USA, *Env. Monit. Asses.*, in press.
16. Peckenham, J.M. and M. G. Nielsen, 2004, in prep. Spatial and temporal patterns of MTBE in ground water in Windham, Maine.
17. Peckenham, J. M., Schmitt, C, Tolman, A. and McNelly, J. (2004) *Source Water Protection*, submitted to *Journal Amer. Water Works Assoc*.
18. Schauffler, M., Nelson, S.J., Kahl, J.S., Jacobson, G.L., Jr, Haines, T.A., Patterson, W.A., III, and Johnson, K.B.: 2004, *Paleoecological assessment of watershed history in PRIMENet watersheds at Acadia National Park, USA*, *Environ. Monit. Assess.*
19. Schmitt, C. and J. Peckenham, 2004. *Source Water Protection*, submitted to *Journal Amer. Water Works Assoc*
20. Hallsworth, R., Schmitt, C., Boothroyd, J., 2005. *Waterlines* Vol. 11 No. 1. Newsletter, Senator George J. Mitchell Center, February 2005.
21. Hallsworth, R., Schmitt, C., Boothroyd, J., 2004. *Waterlines* Vol. 10 No. 3. Newsletter, Senator George J. Mitchell Center, October 2004.
22. Hallsworth, R., Schmitt, C., 2004. *Waterlines* Vol. 10 No. 2. Newsletter, Senator George J. Mitchell Center, July 2004
23. Hallsworth, R., Schmitt, C., 2004. *Waterlines* Vol. 10 No. 1. Newsletter, Senator George J. Mitchell Center, March 2004.
24. Kahl, J.S., S.J. Nelson, I.J. Fernandez, October 2004. *Annual Report to the National Park Service: Correlating predictive contaminant deposition maps with streamwater chemistry at Acadia National Park.*

Project PMIS Number: 75017

25. Peckenham, J.M. (2004) Maine Biosolids Stockpile Study-Summary Report, prepared for Maine Department of Environmental Protection, August, 2004, 44 p.
26. Schmitt, C. 2005. Piecing Together Acadia's Mercury Puzzle. Friends of Acadia Journal, Winter 2004/2005.
27. Schmitt, C. 2005. The Effects of the 2001-2002 Drought on Maine Drinking Water Supplies. Mitchell Center digest.
28. Schmitt, C. 2004. Trashing Tumbledown. For the Sake of Maine Lakes (Maine Congress of Lake Associations, Scarborough, ME): Issue 15.
29. Schmitt, C., J.L. McNelly, and J.B. Storer. 2004. Surface water supplies and the environmental permitting process: Is human consumption being appropriately considered? Maine Water Utilities Association journal, October 2004: 36-46.
30. Schmitt, C., Hallsworth, R., 2004. Safe Drinking Water. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p.
31. Schmitt, C., Hallsworth, R., 2004. Protecting Groundwater Supplies: Maines Source Water Protection Program. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p

## **INFORMATION TRANSFER, FY04**

### *The Senator George J. Mitchell Center for Environmental and Watershed Research*

Dr. Jeffrey S. Kahl, Director (3/04-8/04)  
John Peckenham, WRI Director (9/04+) and  
Assistant Director Mitchell Center  
Dr. Chris Cronan, Interim Director Mitchell Center (9/04-2/05)  
Ruth Hallsworth, Outreach and Development Manager  
Sarah Nelson, Assistant Scientist  
Ken Johnson, Field Coordinator  
Tanya Hyssong, Laboratory Manager  
Jennifer Boothroyd, Scientific Technician  
Dr. Mary Ann McGarry, College of Education (3/04-8/04)  
Dr. Peter Vaux, PEARL Project Director  
Catherine Schmitt, Research Assistant/Science Writer  
Andrea Grygo, Research Assistant  
Kim Raymond, Administrative Assistant

### **Introduction**

One goal of the Mitchell Center is to foster increased cooperation and communication between the academic community, state agencies, environmental organizations, and private companies. The Mitchell Center is a vehicle for the State of Maine to access the substantial technical abilities of the University of Maine on issues of water resources. Information transfer is an important role in this mission. Using part-time staff and non-federal funding, the Center will continue to disseminate research results, organize meetings, participate in statewide forums, serve on committees dealing with water resource issues, work with teachers and conduct special projects.

### **Summary for 3/04-2/05**

#### **Publications**

##### **Peer-reviewed articles.**

- Bank, M. C. Loftin, A. Amirbahman, **J. Peckenham**, T. Haines, and R. Jung, 2004. Mercury bioaccumulation in lotic and lentic amphibians: regional conservation implications for aquatic ecosystems in the Northeastern United States. Abstrc. ARMI
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- Kahl, J.S., S.J. Nelson**, J.L. Stoddard, S.A. Norton, T.A. Haines, 2004. Lakewater Chemistry at Acadia National Park, Maine, in Response to Declining Acidic Deposition, in *Protecting our Diverse Heritage: The Role of Parks, Protected Areas, and Cultural Sites*. Proceedings of the George Wright Society/National Park Service Joint Conference, April 14-18, 2003, San Diego, CA. David Harmon, Bruce M. Kilgore, Gay E. Vietzke, eds. The George Wright Society, Hancock, MI. pp. 314-321.
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Schauffler, M., **Nelson, S.J., Kahl, J.S.,** Jacobson, G.L., Jr, Haines, T.A., Patterson, W.A., III, and Johnson, K.B.: 2004, 'Paleoecological assessment of watershed history in PRIMENet watersheds at Acadia National Park, USA', Environ. Monit. Assess.

**Schmitt, C. and J. Peckenham,** 2004. Source Water Protection, submitted to Journal Amer. Water Works Assoc.

### **Reports and Miscellaneous Publications**

**Hallsworth, R., Schmitt, C., Boothroyd, J.,** 2005. Waterlines Vol. 11 No. 1. Newsletter, Senator George J. Mitchell Center, February 2005.

**Hallsworth, R., Schmitt, C., Boothroyd, J.,** 2004. Waterlines Vol. 10 No. 3. Newsletter, Senator George J. Mitchell Center, October 2004.

**Hallsworth, R., Schmitt, C.,** 2004. Waterlines Vol. 10 No. 2. Newsletter, Senator George J. Mitchell Center, July 2004.

**Hallsworth, R., Schmitt, C.,** 2004. Waterlines Vol. 10 No. 1. Newsletter, Senator George J. Mitchell Center, March 2004.

**Kahl, J.S., S.J. Nelson,** I.J. Fernandez, October 2004. Annual Report to the National Park Service: Correlating predictive contaminant deposition maps with streamwater chemistry at Acadia National Park. Project PMIS Number: 75017

**Peckenham, J.M.** (2004) Maine Biosolids Stockpile Study-Summary Report, prepared for Maine Department of Environmental Protection, August, 2004, 44 p.

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**Schmitt, C.** 2004. Trashing Tumbledown. *For the Sake of Maine Lakes* (Maine Congress of Lake Associations, Scarborough, ME): Issue 15.

**Schmitt, C., J.L. McNelly, and J.B. Storer.** 2004. Surface water supplies and the environmental permitting process: Is human consumption being appropriately considered? Maine Water Utilities Association journal, October 2004: 36-46.

**Schmitt, C., Hallsworth, R.,** 2004. Safe Drinking Water. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p.

**Schmitt, C., Hallsworth, R.,** 2004. Protecting Groundwater Supplies: Maine's Source Water Protection Program. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p.

## **Professional Presentations**

**Boothroyd, J., J.S. Kahl,** 2004. Assessing the Integrity and Effectiveness of Vegetated Buffer Strips on Projects Approved by the Maine Department of Environmental Protection. Maine Water Conference, Augusta, ME, April 2004.

**Cronan, C.,** 2004. Oral: A systems analysis and ecological assessment plan for dam removals and restoration on the Penobscot River. Penobscot River Forum, University of Maine, Orono, ME, October 2004.

**Diehl, M., J. Kahl,** S. Norton, I. Fernandez, L. Rustad, **S. Nelson,** J. Cangelosi, 2004. Poster: Acidification and Recovery at Bear Brook Watershed, Maine. Maine Water Conference, Augusta, ME, April 2004.

**Diehl, M., J. Kahl,** S. Norton, I. Fernandez, L. Rustad, **S. Nelson,** J. Cangelosi, 2004. Poster: Acidification and Recovery at Bear Brook Watershed, Maine. Graduate Student Expo, University of Maine, Orono, ME, April 2004.

**Fretwell, L.,** D.B. Dail, K.E. Webster, **J.S. Kahl,** S.H Brawley, L. Wilson, 2004. Poster: Periphytic Algae as an Indicator of Nutrient Loading to the Meduxnekeag River. Maine Water Conference, Augusta, ME, April 2004.

**Fretwell, L.,** D.B. Dail, K.E. Webster, **J.S. Kahl,** S.H Brawley, L. Wilson, 2004. Poster: Periphytic Algae as an Indicator of Nutrient Loading to the Meduxnekeag River. Graduate Student Expo, University of Maine, Orono, ME, April 2004.

**Grygo, A., J.S. Kahl,** K.E. Webster, C. Loftin, K. Tonnessen, **S.J. Nelson,** 2004. Poster and Abstract: Development of the SPARC Database for National Park Watershed Research: Searchable Park Access to Research Catchments. Maine Water Conference, 2004.

**Johnson, K.,** 2005. Current Water Chemistry Conditions in Downeast Rivers. Atlantic Salmon Commission, January 2005.

**Johnson, K.,** 2004. Water Quality in the Denny's River. Denny's River Watershed Council, November 2004.

**Johnson, K.,** 2004. Oral: Acid Based Chemistry in Downeast Rivers. Project SHARE, June 2004.

**Johnson, K.,** 2004. Oral: Atlantic Salmon Commission pH Surveys and Calcium Enhancement in Downeast Rivers. NOAA and ASC meeting, June 2004.

**Kahl, J.S., S. Nelson,** and **A. Grygo,** 2004. Oral: Surface water chemistry data for the northeastern US for interpreting climate and acid rain trends. Northeast Ecosystems Research Consortium meeting, Durham, NH, October, 2004.

- Kahl, J.S.**, K. Webster, **M. Diehl**, and **C. Rosfjord**, 2004. Successes of the Clean Air Act Amendments of 1990. Maine Water Conference plenary talk, Augusta, ME, April 21, 2004.
- Kahl, J.S.** and **K. Johnson**, 2004. Acid-Base Chemistry and Historical Trends in Downeast Salmon Rivers. Maine Water Conference, Augusta ME, April 2004.
- Kahl, J.S.**, 2004. The Clean Air Act Amendments of 1990; testing a program designed to evaluate environmental policy. Invited lecture, Colby College. April, 2004
- McCabe, S.**, J.S. Kahl, P. Vaux, 2005. Oral: Making Websites Work in New Ways: Initiating Dynamic Relationships Between People and Environmental Data. Mitchell Center, University of Maine, Orono, ME, February 2005.
- McCabe, S.**, C. Smith, 2004. Oral: Using PEARL in an Educational Environment. Maine Environmental Education Association Annual Meeting, Chewonki Education Center, Wiscasset, ME, April 2004.
- McGee, C.**, I. Fernandez, S. Norton, C. Stubbs, **J.S. Kahl**, 2004. Poster: Bioaccumulation of Cadmium (Cd) in Moose: Identifying Cd Variation in Common Moose Browse. Maine Water Conference, Augusta, ME, April 2004.
- McGee, C.**, I. Fernandez, S. Norton, C. Stubbs, **J.S. Kahl**, 2004. Poster: Bioaccumulation of Cadmium (Cd) in Moose: Identifying Cd Variation in Common Moose Browse. Graduate Student Expo, University of Maine, Orono, ME, April 2004.
- Nadeau J.**, **J. Peckenham**, and A. Amirbahman (2004) Trace Metal Movement from Field Stacked Biosolids, Maine Water Conference, April , 2004.
- Nelson, S.J.**, K.C. Weathers, **K.B. Johnson**, **J.S. Kahl**, 2004. Poster and abstract: Seasonal patterns and total deposition of mercury at Acadia National Park, Maine: relationships to MDN monitoring data. National Atmospheric Deposition Program 2004 Scientific Symposium and Annual Technical Committee Meeting, Halifax, Nova Scotia, September 21-24, 2004.
- Ness, K.**, K. Webster, R. Bouchard, 2004. Poster: Defining the Natural Template for Lake Littoral Zones in Maine. Maine Water Conference, Augusta, ME, April 2004.
- Ness, K.**, K. Webster, R. Bouchard, 2004. Poster: Defining the Natural Template for Lake Littoral Zones in Maine. Graduate Student Expo, University of Maine, Orono, ME, April 2004.
- Peckenham, J.** and A. Tolman (2005) Source Water Protection in Maine: Implementing the Results of the Assessment Process, Ammerican Water Works Assoc. Source Water Protection Symposium, Palm Springs Gardens, FL, January 2005.
- Peckenham, J.** (2004) The Biosolids White Paper Project- The Impact of Bioslids Use on Soil and Water Quality, New England Water Environment Association Annual Meeting, Rever, MA, November, 2004.

- Peckenham, J., J. Rubin, and C. Clavet (2004)** Maine's Experiment With Gasoline Policy to Manage MtBE in Groundwater, 20<sup>th</sup> Conf. on Cont. Soils, Sediments, and Water, Univ. Mass., October, 2004.
- Peckenham, J., S. Kahl, S. Nelson, and B. Mower (2004)** Geochemical Associations of Background Mercury Concentrations in Maine Rivers, National Atmos. Dep. Proj. Ann. Mtg., Halifax, September, 2004.
- Peckenham, J. (2004)** Biosolids White Paper Project, NE101 Biosolids Working Group meeting, July, 2004.
- Peckenham, J., J. Nadeau, A. Amirbahman, W. Brutsaert, and J. Wilson (2004)** Leachate From Biosolid Stockpiles: Nutrients and Metal Mobility , Amer. Geophys. Union Ann. Mtg., Montreal, May 2004.
- Peckenham, J., J. Nadeau, and A. Amirbahman (2004)** Nitrogen loss from biosolids stockpiles, Maine Water Conference, April , 2004.
- Rosfjord, C., J.S. Kahl, K. Webster, C. Loftin, S. Nelson, 2004.** Poster: A 20-Year Re-evaluation of Trends in a Statistical Population of Lakes in the Northeastern U.S. Maine Water Conference, Augusta, ME, April 2004.
- Rosfjord, C., J.S. Kahl, K. Webster, C. Loftin, S. Nelson, 2004.** Poster: A 20-Year Re-evaluation of Trends in a Statistical Population of Lakes in the Northeastern U.S. Graduate Student Expo, University of Maine, Orono, ME, April 2004.
- Thornton, T., L. Osher, 2004.** Agricultural Herbicide Movement from Upland to Estuary. Maine Water Conference, Augusta, ME, April 2004.
- Thornton, T., L. Osher, 2004.** Agricultural Herbicide Movement from Upland to Estuary. Graduate Student Expo, University of Maine, Orono, ME, April 2004.

## **Conferences, Workshops, Annual Meetings**

### *Maine Water Conference 2004*

Augusta Civic Center, Augusta, ME. April 21, 2004.

The Maine Water Conference was founded in 1994 by the University of Maine Water Research Institute as an annual forum for water resource professionals, researchers, consultants, citizens, students, regulators, and planners to exchange information and present new findings on water resources issues in Maine. The tenth annual conference key note address was given by Senator George Mitchell. Maine Governor John Baldacci also attended and spoke during the plenary session. Other guest speakers at this year's plenary session included: Mitchell Center Director Steve Kahl; Lincoln Jeffers, Deputy Director of Economic and Community Development for the Town of Lewiston; Laura Rose Day, Scott D. Hall, and Butch Phillips of the Penobscot River Restoration Project; and University of Maine President Peter Hoff. Afternoon sessions included: Lake Management Tools and Strategies; Maine's Salmon Rivers; Riverfronts - A Legacy of Pollution, a Trend Towards Renewal; Groundwater, Sludge and Toxics; and a Water Issues Roundtable. A juried student poster competition and exhibit area were available for viewing throughout the day.



***Penobscot River Science Forum: Exploring Research Opportunities on the Penobscot***  
University of Maine, Orono, ME. October 19-20, 2004. This meeting was cosponsored by Penobscot Partners, a coalition of the Penobscot Indian Nation and conservation groups and the Senator George J. Mitchell Center. Approximately one hundred members of the scientific community met to review scientific research on the Penobscot River watershed and discuss needs and opportunities for new research related to the dam removals proposed as part of the Penobscot River Restoration Project. One constant theme of the forum was the opportunity that the Penobscot River project represents to the research community, both in the timing and diversity of potential topics. The dam removals will not occur for a number of years, and researchers will have the opportunity to jump-start collection of baseline data that will assist them in the long-term assessment of the project. In addition, there was a strong sense that the unique multi-party collaboration that has brought the project thus far must be carried over into the scientific community to maximize project success.

***Northern Maine Children's Water Festival 2004***

University of Maine, Orono, ME. October 12, 2004.

The sixth Northern Children's Water Festival was co-sponsored by the Mitchell Center, Maine Department of Environmental Protection, Maine Department of Human Services, UMaine College of Education and Human Development and UMaine Cooperative Extension. More than 800 5<sup>th</sup> and 6<sup>th</sup> grade students from schools in Indian Township, Skowhegan, Hampden, Trenton, China and other communities in northern and central Maine, participated in hands-on activities, demonstrations and quizzes on their knowledge of water resources during the morning and early afternoon. Penobscot Legends, stories about the Penobscot River and the Penobscot people, were presented in both the Penobscot language and English.

***Project SHARE Symposium***

University of Maine, Orono, ME. February 7, 2005.

Mitchell Center staff members coordinated with Project SHARE on this day-long symposium that focused on bringing stakeholders together to protect Atlantic salmon habitat. The watersheds of the five Downeast salmon rivers cover approximately 840,000 acres, the majority of which are managed by a handful of commercial landowners. Conflicts have arisen between protecting salmon and the continued use of the land for timber harvesting, blueberry crops, and recreation. For the last 10 years, Project SHARE has been promoting and supporting collaborative efforts to improve salmon habitat in Washington County. At this symposium, landowners and state and federal agency representatives gathered at the University of Maine with the purpose of strengthening existing partnerships and creating new ones.

***Maine Stream Summit (MESS)***

University of Maine Hutchinson Center, Belfast, ME. April 7, 2004.

Mitchell Center staff and students participated in the planning and coordination of the second annual Maine Stream Summit (MESS) in collaboration with Maine Department of Environmental Protection. MESS included a wide variety of presentations, including the keynote presentation by Andy Goode of the Atlantic Salmon. Other topics included alewives; native & invasive fish species in Maine; strategies of effective grassroot watershed organizations; watershed studies done by local schools; and watershed education program techniques. Workshops occurring throughout the day covered a number of topics including stream life, water

quality, macroinvertebrates, how to deal with data, and integrating stream studies into the classroom.

### ***Communicating Science on Campus and Beyond***

Fogler Library, University of Maine, Orono, ME. September 30, 2004.

Speakers Catherine Schmitt of the Mitchell Center and Maine Sea Grant, Kathryn Hunt of the Margaret Chase Smith Center, and Nick Houtman of the Dept. of Public Affairs discussed their approaches to publicizing research activities in the news media, UMaine publications and other venues.

### **Exhibits at Conferences and Events**

Maine COLA Annual Conference – Mitchell Center and PEARL Exhibits

Maine Lakes Day, State Hall of Flags – Mitchell Center and PEARL Exhibits

Maine Water Conference – Mitchell Center and PEARL Exhibits

## **Public Service**

### **Media/Press**

10/24/04, Foster Daily Independent, John Peckenham, interview and article on *MtBE in Groundwater*.

11/04/04, Ellsworth American, John Peckenham, interview and article on *Gravel Pits and Water Quality*.

6/30/04, WLBZ-TV, Channel 2, Sarah Nelson, Catherine Schmitt, Tanya Hyssong, interview and story on *How Watershed Processes Affect Mercury Concentrations in Fish and Other Organisms at Acadia National Park*.

4/22/04, Lewiston Sun Journal, interview (various) and article on the *2004 Maine Water Conference*.

4/22/04, Bangor Daily News, interview (various) and article on the *2004 Maine Water Conference*.

4/22/04, WVII-TV, interview (various) and story on the *2004 Maine Water Conference*.

3/29/04, WLBZ-TV, Channel 2, Steve Kahl, interview and story on *Spring Weather and Groundwater*.

## **Workshops and Other Activities**

### ***Fall/Spring 04-05 Seminar Series***

In 2004, the Mitchell Center initiated a seminar series at the University of Maine campus. Seminars are open to all and take place over lunch break to allow for maximum participation. The seminars were well attended and plans are underway to continue the series for the fall 2005 semester. Speakers for fall 04 and spring 05 included: Dave Evers, Director, Biodiversity Research Institute; Arlene Olivero, GIS Manager/Aquatic Ecologist, The Nature Conservancy; Jeff Varrichionne, Maine Department of Environmental Protection; Neil Kamman, Vermont

Department of Environmental Conservation; Dave Courtemanch, Maine Department of Environmental Protection.

***PEARL – The Source for Environmental Information in Maine***

*Live site:* [www.pearl.maine.edu](http://www.pearl.maine.edu)      *Production site:* [www.pearlmaine.com](http://www.pearlmaine.com)

Under the direction of Peter Vaux, major new funding was secured in 2003/2004 which moved PEARL into the next phase of development. The completely revamped site, while still undergoing improvements and additions, is slated to go live in June 2005. Funding from Maine Inland Fisheries and Wildlife and USGS allowed integration of stream and river data into the database. This provided the support for the addition of databases from the Maine Aquatic Biodiversity Project and from IF&W. Salmon fisheries data has been added using funding from the Atlantic Salmon Commission. New interfaces for specific user groups provide educational features along with data specific to that particular group – for example, anglers. Maine Department of Environmental Protection continues to provide long-term support for the project.

***Lake Information Websites: A User Survey***

May 2004: Graduate student Sara McCabe completed a survey of individuals interested in Maine lakes such as volunteer lake monitors, teachers, and water resources professionals. The survey was aimed at users or potential users of the PEARL website. The survey evaluated the current PEARL website, compared it to other similar websites in different parts of the United States, and asked for suggestions to improve the site, especially to make it more user-friendly.

***Maine Project WET***

Project WET Director Mary Ann McGarry continued her work with Maine Lakes Conservancy Institute to integrate aspects of Project WET, PEARL, and Maine's Laptop Initiative into an educational program. Working with middle school students and teachers, the project provides hands-on study of Maine's most important freshwater natural resource utilizing MLCI's floating classroom. Professional development workshops draw on Project WET's interdisciplinary hands-on activities and demonstrate the ease with which these activities can be implemented. Participating teachers are also introduced to the PEARL database system to which students and teachers will have the opportunity to funnel scientific findings and data that they have researched themselves. Teachers have the opportunity to become a dynamic part of the creation of PEARL's "Students Portal," an exciting concept which allows students a view into, and a means to contribute interactively to, comprehensive lake-science findings represented by PEARL.

***Graduate Student Interns with Maine Lakes Conservancy Institute***

May 2004 – February 2005: Graduate student Sara McCabe worked with Project WET coordinator Mary Ann McGarry in co-leading trips with the Maine Lakes Conservancy Institute to teach lake ecology and proper use of water quality monitoring equipment to groups of students and adults. These trips took place aboard the Melinda Ann, the Maine Lakes Conservancy Institute's floating classroom. Sara worked with the communities of Lake Wassokeg, China Lake and Eagle Lake:

***Penobscot River and Bay Institute***

May-June 2004: Penobscot River Keepers Expeditions. These were day-long canoe expeditions on the Penobscot River with students in grades 7 to 12. In 2004 we provided about 450 students with an opportunity to learn about rivers, watersheds, history, and ecology.

### ***NIWR Annual Meeting***

Feb. 28 - Mar. 2004: Director **Steve Kahl**, along with Mitchell Center staff and students organized the 2004 NIWR annual meeting in Washington DC. Planning included scheduling speakers, registering participants, preparing evaluations, and traveling to DC to ensure the event ran smoothly.

### ***Waterlines***

Four issues of our Waterlines newsletter were published in 2004. The newsletter is a hybrid web/hard copy that has decreased paper and mailing costs while simultaneously increasing circulation and content. The main publication of Waterlines is now done online with an accompanying email sent to our subscription list. A printed, one-page “headline” version is still available and is sent to select subscribers including media sources, our congressional delegation, University administration, Board members and others including those without e-mail capabilities. This hard copy version is also used to provide an introduction to organizations and individuals who may not be familiar with the Mitchell Center. Our intent is to reduce costs, increase circulation, and augment the scope of coverage on water issues in Maine. The newsletter continues to contain information on ongoing and upcoming grants, developments at the Center, news releases from the University on water resources related issues, and announcements for our conferences.

### ***Informational Digests***

Informational digests provide an important outlet for the Mitchell Center to publish research and technical information in a format where it is readily available to the public. The addition of a part-time science writer to the Mitchell Center staff has greatly improved both the quality and quantity of digests we are able to produce. New digests are available both in online and hard copy format. Online publications are published as Acrobat and html documents to meet accessibility requirements. Three new digests were published during 2004: *Safe Drinking Water*, *Protecting Groundwater Supplies: Maine’s Source Water Protection Program*, and *The Effects of the 2001-2002 Drought on Maine Drinking Water Supplies*. All three of these digests were published in collaboration with the Maine Drinking Water Program.

### **Committees and Service:**

#### ***Steve Kahl***

- Judge, Graduate Research Exposition, University of Maine (2004)
- Environmental Policy Roundtable, University of Maine (2004)
- Freshwater Ecology Research Group, University of Maine (2003 - 2004)
- University Research Council, University of Maine (VP-Research; 2002 - 2004)
- Testimony to Maine legislature: Surface use of lakes (2004).
- Maine Land Use Regulation Commission (gubernatorial appt, 2004 - )
- Hancock County Aquatic Invasive Plant Working Group (2003 - )
- Union River Watershed Coalition (local agencies, 2001 - )
- Atlantic Salmon Research and Information Management Committee (multi-agency, 2001 - )
- Maine Watershed Management Advisory Committee (2000 - )
- Drought Task Force (multi-agency, 2000 - )
- River Flow Management Commission (gubernatorial appt, 1998 - )

- Co-chair, Council on Environmental Monitoring & Assessment (gubernatorial appt, 1997 - )
- Hopkins Pond Lake Association, Board of Directors (2003 - )
- Friends of Acadia National Park, Board of Directors (2001 - )
- Maine Lakes Conservancy Institute, Board of Directors (1999- )
- ME Lake Volunteer Monitor Program, Board of Directors (1996-2004)
- Nat'l Institutes Water Research, President Elect (2003-2004)
- Co-chair, UCOWR national annual meeting, Portland ME (2004)
- Organizer, National Institutes for Water Resources annual meeting, 2004, Washington DC

### **John Peckenham**

- River Flow Advisory Commission- Drought Task Force
- Maine Water Conference Organizing Committee
- Maine Water Utilities Association- Water Resources Committee
- Sustainable Water Withdrawal- Land and Water Resources Council
- Maine Waste Water Control Association- Residuals Management Committee
- Penobscot River and Bay Institute- Board of Directors
- Northern Maine Children's Water Festival
- DEP-Consulting Engineers of Maine Task Force
- Ad Hoc Committee on Antimony in Drinking Water
- Planning Consortium- Environmental Health Tracking System, Maine DHS

### **Sarah Nelson**

- Maine Water Conference Organizing Committee (2001-present)
- Co-Chair, Maine Water Conference (2004)
- Professional Employees Advisory Council, University of Maine (2002-present)
- Chair, Planning Board, Town of Clifton, Maine (2003-present)
- Member, Planning Board, Town of Clifton, Maine (2001-present)
- Northern Maine Children's Water Festival Volunteer (October 2004)

## **Student Support**

### **Notable Awards and Achievements**

#### *Kahl lead author on feature article in Environmental Science and Technology*

The December 15, 2004 issue of Environmental Science and Technology, published by the American Chemical Society, featured a cover article on lake water quality. Scientists have seen improvements in acid rain-related water quality in lakes, but continued monitoring is important to document trends with nitrate, calcium and other chemicals. Kahl and 15 co-authors note that Clean Air Act regulations have led to a reduction in acidity in lakes in New England, the Adirondacks, the Appalachians and the upper Midwest. The article documents a reduction in sulfate which, along with nitrate, accounts for the bulk of acidity related to air pollution. Ongoing research focuses on the biological response to acid reduction and the progress of

surface waters toward pre-industrial era chemistry. In 2004, Mitchell Center graduate student Catherine Rosfjord resampled a set of lakes that the U.S. Environmental Protection Agency had monitored in 1984 for acid status.

#### ***Mitchell Center Lab Rated by Auditors***

In 2004, the Mitchell Center's Watershed Research Laboratory received an excellent and a satisfactory performance rating from two separate, independent audit programs. The lab received a rating of "excellent" from the U.S. Geological Survey's Standard Reference Sample project — putting the lab in the top 15% of those participating. This audit is by invitation only. A rating of satisfactory was received from Environment Canada's Proficiency Testing Program, which is distributed to several hundred environmental laboratories in Canada and around the world. The audit results allow the participating laboratories to compare their performance with other similar labs and allow independent verification of performance by state and federal agencies working with the Mitchell Center.

#### ***Mitchell Center Graduates***

Heather Caron, completed her Master's thesis defense on January 11, 2005. Caron researched groundwater and nutrient dynamics in the Fresh Meadow wetland on Mount Desert Island. This work is part of a larger study of the effects of residential development on the Northeast Creek estuary. Emily Seger graduated in August 2004 with a Master of Science degree in Ecology and Environmental Sciences. Emily's thesis examined the chemistry of seepage lakes as a possible indicator of climate change.

#### ***Mitchell Center Students receive awards at UMaine Graduate Student Expo***

Melinda Diehl and Catherine Rosfjord received third place awards at the 2004 University of Maine Graduate Student Expo for their poster submissions entitled *Acidification and Recovery at Bear Brook Watershed, Maine* and *A 20-Year Re-evaluation of Trends in a Statistical Population of Lakes in the Northeastern U.S.*

#### ***Mitchell Center Science Writer Noted in National Audubon Magazine***

In a column in the November-December 2004 issue of Audubon magazine, environmental writer Ted Williams credits a visit from Mitchell Center science writer Catherine Schmitt for stimulating his thoughts recently on environmental trends. Williams quotes an article that Schmitt wrote about him for Northern Sky News and says that his optimism regarding environmental improvements stems from the successes of environmental activists. Despite significant hurdles ahead, trends related to world population, pesticide use, dam removal and wildlife reintroduction all point to long-term gains for environmental quality, he adds.

#### ***Mitchell Center Staff Work with Engineering Student to Design Lab Tools***

Students don't often get a chance to design and build laboratory research tools. In an effort to increase laboratory efficiency, Terina Rollins, a senior in Bioresource Engineering, is working with Mitchell Center researcher Ken Johnson to design and build a mechanical system for the Center's Watershed Research. Her device will automatically load and remove samples from a spectrophotometer, saving time and reducing the chance for human error. The machine is used to analyze the phosphorus content in surface water samples. Currently, technicians manually load,

unload and rinse glass cells that hold individual samples.

The USGS base grant provided a basis for the Senator George J. Mitchell center to secure other research funding. In addition to support from the US EPA to continue acid-rain related research, the following projects were funded in 2004:

Title: PEARL

Investigator: Kahl/Vaux

Agency: Maine Department of Environmental Protection.

Title: Fisheries Data Integration Project (on-going)

Investigator: Kahl/Vaux

Agency: Maine Department of Inland Fisheries and Wildlife

Title: Developing PEARL as the Environmental Database for Atlantic Salmon Restoration (on-going)

Investigator: Kahl/Vaux

Agency: Atlantic Salmon Commission

Title: Water Chemistry Trends in Downeast Salmon Tributaries (on-going)

Investigator: Kahl/Johnson

Agency: Atlantic Salmon Commission

Title: Investigating the Effects of Water Chemistry on Juvenile Atlantic Salmon in Downeast Maine (Year II)

Investigator: Kahl/Johnson

Agency: NOAA Fisheries

Title: Calcium Enhancement of Downeast Area Rivers (Year II)

Investigator: Kahl/Johnson

Agency: Project SHARE

Title: Biosolids White Paper (on-going)

Investigator: Peckenham

Agency: State Planning Office

Title: Systematic Chemistry Survey of Salmon Rivers

Investigator: Kahl/Johnson

Agency: National Fish and Wildlife Foundation

Title: Road Salting Impacts on Atlantic Salmon

Investigator: Kahl/Johnson

Agency: National Fish and Wildlife Foundation

## Student Support

| Student Support |                        |                        |                      |                     |       |
|-----------------|------------------------|------------------------|----------------------|---------------------|-------|
| Category        | Section 104 Base Grant | Section 104 RCGP Award | NIWR-USGS Internship | Supplemental Awards | Total |
| Undergraduate   | 2                      | 0                      | 1                    | 3                   | 6     |
| Masters         | 9                      | 0                      | 0                    | 4                   | 13    |
| Ph.D.           | 1                      | 0                      | 0                    | 3                   | 4     |
| Post-Doc.       | 0                      | 0                      | 0                    | 0                   | 0     |
| <b>Total</b>    | 12                     | 0                      | 1                    | 10                  | 23    |

## Notable Awards and Achievements

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## **Publications from Prior Projects**