Water Research Institute

Annual Technical Report

FY 2000

Introduction

WRI Fiscal Year 2000 Annual Program Report March 1, 2000 - Feb 28, 2001

Introduction - Research Program

Maine is endowed with a rich array of water resources that include many clear and clean lakes, rivers, and streams. These appearances are deceiving because although our waters look good, our fish are unsafe to eat because of mercury and persistent organic compounds, and our groundwater is unsafe to drink because of arsenic and radon. The Maine Water Research Institute has supported research to address these and other issues in Maine.

The USGS-WRRI regional and state programs supported six research projects. Project summaries are contained in the Research Program section. These research projects are all collaborative projects with Maine Water Research Institute associates and faculty in Biology, Civil Engineering, Geology, Resource Economics, and Spatial Engineering. We are proud to continue collaboration with social scientists in the University of Maine’s Margaret Chase Smith Center for Public Policy in hosting a workshop on Climate Change and Water Use.

The Water Resources graduate student program has grown during this period with six students enrolled in this option. Four Master’s theses will be completed under this program in 2001.

In October 2000, the Maine Water Research Institute was placed within the newly dedicated Senator George J. Mitchell Center for Environmental and Watershed Research.

Other Institute research conducted in 2000 includes:

Collaborative Research on Maine Surface Water Toxics (Maine DEP 1996-00; $400,000 to Kahl). The Maine Surface Water Ambient Toxics (SWAT: LD 1042) Program, initiated in 1994, is designed to determine the extent and magnitude of toxic contamination in Maine surface waters. The overall program involves fish and sediment monitoring for toxic substances, and other special studies as suggested by data collected This cooperative agreement between the Maine DEP and the Institute provides analytical support for SWAT and the related Dioxin monitoring program in Maine, and provides new input from University of Maine researchers who have substantial expertise in Maine with the environmental chemistry of these compounds. This project utilizes the Institute’s state-of-the-art organic and inorganic environmental research facility.

Long Term Monitoring of Maine Lakes and Streams (EPA, 1991-00, $680,000 to J.S. Kahl and S.A. Norton). The University of Maine was a founding participant in the EPA LTM program begun in 1983. The program has expanded in recent years to include spring sampling of outlets on selected lakes, and now includes lakes sampled in the 1980s by the High Elevation Lake Monitoring project conducted by Kahl and Matt Scott of Maine DEP.

Inferring Regional Patterns and Responses in N and Hg Biogeochemistry Using Two Sets of Gauged Paired-watersheds (EPA, $475,000 to Kahl et al.). This project is part of long-term ecological research using two gauged-watersheds at Acadia National Park through collaborative funding by USGS and EPA. The focus is atmospheric deposition of N and Hg, and their ecological consequences. Both elements are of major concern, both regionally and to the Park Service at Acadia. This location offers the advantages of a) co-funding for cost-effectiveness; b) a natural experimental design for the two watersheds because of a major forest fire in part of the Park in 1947; c) parallel design with the acidic deposition experiment for the two paired- watersheds at the nearby Bear Brook Watershed, Maine (BBWM); and d) prior research at Acadia and BBWM that supply background data, and provide the basis for ecosystem indicators to be applied at Acadia. Our objectives are addressing N cycling and saturation, and Hg input and bioavailability, in paired watersheds with different forest types. We are using the natural landscape contrasts provided by fire to compare patterns and processes in N and Hg sequestration and mobility. N loading to estuaries is being addressed by periodic sampling of estuary tributaries as ’satellite’ locations, whose N-loading will be extrapolated from occasional sampling by using the more intensively monitored main watersheds as index sites.

The results will provide new information for Acadia and for the New England region on the ecological consequences of high N deposition at Acadia, and the loading of N to estuaries in the region. We lack an explanation of the high accumulation rates of Hg in sediment and peat cores compared to wet-only deposition, and have not explained why Acadia has some of the highest Hg concentrations in biota in the world. The general representativeness of Acadia forests for the New England region, combined with the fire history to be included in our experimental design (fire also being ’typical’ of the historical New England landscape), offers the opportunity to understand some key issues for Acadia, thus providing insight into these issues at the regional scale.

New Partnerships A new partnership between the UMaine Mitchell Center and the Maine Lakes Conservancy Institute is providing new resources and opportunities for Maine Project WET.

Research Program

Basic Information

Title:	Using Semipermeable Membrane Devices for Detecting and Assessing Risks of Exposure to Dixoins in Natural Waters
Project Number:	HQ-96-GR-02674
Start Date:	9/1/1998
End Date:	9/31/2000
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Toxic Substances, Hydrogeochemistry
Descriptors:	Pollution Control, Pollutants, Contaminant Transport, Membranes, Organic Compounds, Model Studies
Lead Institute:	University of Maine
Principal Investigators:	Howard Patterson, Rebecca Van Beneden, Jeffrey S Kahl, Therese Anderson, Touradj Solouki

Publication

1. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2001. Semipermeable Membrane Devices: Are they a helpful addition to Maine’s Dioxin Monitoring Program? Platform Speaker at the Maine Water Conference, May 2001, Augusta, Maine.
2. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2001. What’s up? What’s down? Maine’s search for an upstream-downstream dioxoin monitoring method continues. Research Poster at the 3rd Annual Association of Graduate Students Graduate Research Exposition, April 2001, University of Maine, Orono, Maine.
3. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2001. What’s up? What’s down? Maine’s search for an upstream-downstream dioxin monitoring method continues. Research Poster at the Maine Water Conference, May 2001, Augusta, Maine.
4. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2000. Monitoring Dioxin Levels: Determining compliance with Maine’s upstream-downstream law. Platform speaker at the Northeast Regional meeting for the National Council for Air and Stream Improvement, October 2000, Portsmouth, New Hampshire.
5. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2000. Monitoring dioxin levels in Maine rivers with semipermeable membrane devices. Research poster at the 6th International SPMD Workshop and Symposium, July 2000, Columbia, MO.
6. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2000. Monitoring dioxin levels in Maine rivers with semipermeable membrane devices. Research poster presented at the Gordon Research Conference on Environmental Sciences, June 2000, Plymouth, NH.
7. Shoven, H., H. Patterson, T. Anderson, J. Kahl, and T. Solouki. 2000. Monitoring dioxin levels in Maine rivers with semipermeable membrane devices. Research poster presented at the Maine Water Conference, April 2000, Augusta, ME.

Abstract

The Maine Department of Environmental Protection (DEP) currently monitors river dioxin levels through focusing on dioxin's bioaccumulation in fish. Recent state legislation mandates that by 2003, the levels of dioxin in a river downstream from an industrial facility are not to exceed the levels upstream from that facility.

This thesis project seeks to evaluate an alternate method for determining industrial facility compliance to this upstream-downstream law. This new method, semipermeable membrane devices (SPMDs), circumvents many of the problems present in the current fish method.

Over the course of two field seasons, we assessed the feasibility of using SPMDs to monitor dioxin levels in Maine rivers. The 1999 field season focused on developing viable field and laboratory SPMD methods while the 2000 field season looked to applying these methods to upstream-downstream sites on the Androscoggin River.

The 2000 field season data are presented in this report. Increasing the number of replicate SPMDs illustrated the reproducibility of the developed extraction and cleanup processes. Not only was a pair of upstream-downstream sites tested but also two deployment time studies were executed in order to see how the SPMDs sample over the 28-day period. The 2000 field season data set will be used to assess the effects of flow, biofouling, temperature, dissolved organic carbon, and total organic carbon on SPMD dioxin sampling. The promising results from this field season warrant more investigation into this alternate method.

Problem

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), collectively termed as dioxin, are two classes of chemically similar and toxic compounds. Dioxin, specifically 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, has been positively identified as both a carcinogen and an endocrine disrupter (EPA 2000). A wide variety of both anthropogenic and natural processes lead to the inadvertent production of dioxin as a byproduct. These processes include incinerating of waste, chlorine bleaching of pulp, and burning of forest fires. In Maine, the various bleached Kraft pulp and paper mills are currently working with the Department of Environmental Protection (DEP) to comply with the upstream-downstream law by 2003. This law states that the dioxin levels below a bleached Kraft pulp and paper mill are not to exceed the levels above the mill (38 M.R.S.A. §420-A). Therefore, a method is needed which can measure the compliance of mills with this mandate. The search for a cost-effective, convenient, and accurate method of routinely monitoring dioxin levels in natural waters has begun in order to replace the sole reliance on the destructive sampling of fish.

Research Objectives

1. To develop both an accurate and cost-effective method of measuring dioxin exposure in aquatic systems. This objective entails the following determinations for SPMDs:
    - ✓ How do SPMDs respond to a range of environmental conditions?
    - ✓ What method of extraction and cleanup of the SPMDs is feasible for analysis of the extracts by High Resolution Gas Chromatography / High Resolution

Mass Spectrometry (HRGC/HRMS)?

2. To provide the State of Maine with the new tool of SPMDs for monitoring the dioxin concentrations above and below selected paper mills in order to measure compliance with government regulations. For an endorsement of the SPMD monitoring method to be made:
    - ✓ SPMD results must be compared for differences with the DMP fish results for the same field season and relative locations. Identical results between methods are not expected since SPMDs mimic bioconcentration of dioxin while the fish are indicators of bioaccumulation levels. However, the relationship between the two results can reveal potential level ratios of bioconcentration to bioaccumulation.
    - ✓ Environmental conditions among sites for a given deployment must be deemed comparable through examination of water quality data collected at both deployment and retrieval of the SPMDs. Need to investigate the effects of temperature, water velocity, and dissolved organic carbon on SPMD sampling of dioxin.

Purpose and Methods

Over the course of the 1999 and 2000 field seasons, SPMDs were deployed in two different Maine rivers for 28-30 day deployment periods in order to determine the feasibility of using these devices for monitoring the dioxin levels in surface waters. Since SPMDs are subject to biofouling, a process that may interfere with the monitoring process, water quality parameters were monitored at each site both in the field and in the laboratory to ensure comparability in site environmental conditions. The 2000 field season examined the biofouling process through a pair of time deployment studies on the Androscoggin River. The deployment of the devices at a pair of upstream-downstream sites on the Androscoggin was conducted to investigate the performance of the SPMDs in the upstream-downstream test.

In the laboratory, dioxins were extracted from the SPMDs through dialysis into hexane; an acidified silica gel slurry cleaned the resulting dialysates. This was followed by gel permeation chromatography and analysis by high-resolution gas chromatography / high-resolution mass spectronomy (HRGC/HRMS).

2000 FIELD SEASON SUMMARY

TABLE 1. Objectives of the 2000 Field Season Deployments

Objective	# of Deployments	Sites	# of SPMDs
➢ Deployment Time Study: To determine SPMD uptake rates and biofouling over the 28-day deployment period. *Location: Androscoggin River at Dixfield*	2	10-A and 10-B	20 SPMDs per deployment with 5 retrieved each week for 4 weeks
➢ Androscoggin River Upstream/Downstream Study: To test the applicability of using SPMDs to monitor dioxin for the upstream/ downstream law. *Locations: Rumford (13) and Dixfield (10)*	1	10 and 13	20 SPMDs per site with all retrieved after 28 days

TABLE 2. Descriptions of the 2000 Field Season Deployments

Deployment Date	Retrieval Date	Deployment Time (days)	Sites	SPMDs per site	#SPMDs/ sample	# Reps
6/2/00	6/9/00	7	10-A	5	5	1
	6/16/00	14	10-B	5	5	1
	6/23/00	21	10-A	5	5	1
	6/30/00	28	10-B	5	1	5
7/7/00	7/14/00	7	10-A	5	5	1
6/30/00	7/14/00	14	10-B	5	5	1
7/7/00	7/28/00	21	10-A	5	5	1
6/30/00	7/28/00	28	10-B	5	1	5
9/19/00	10/17/00	28	10	20	2	10
			13	20	2	10

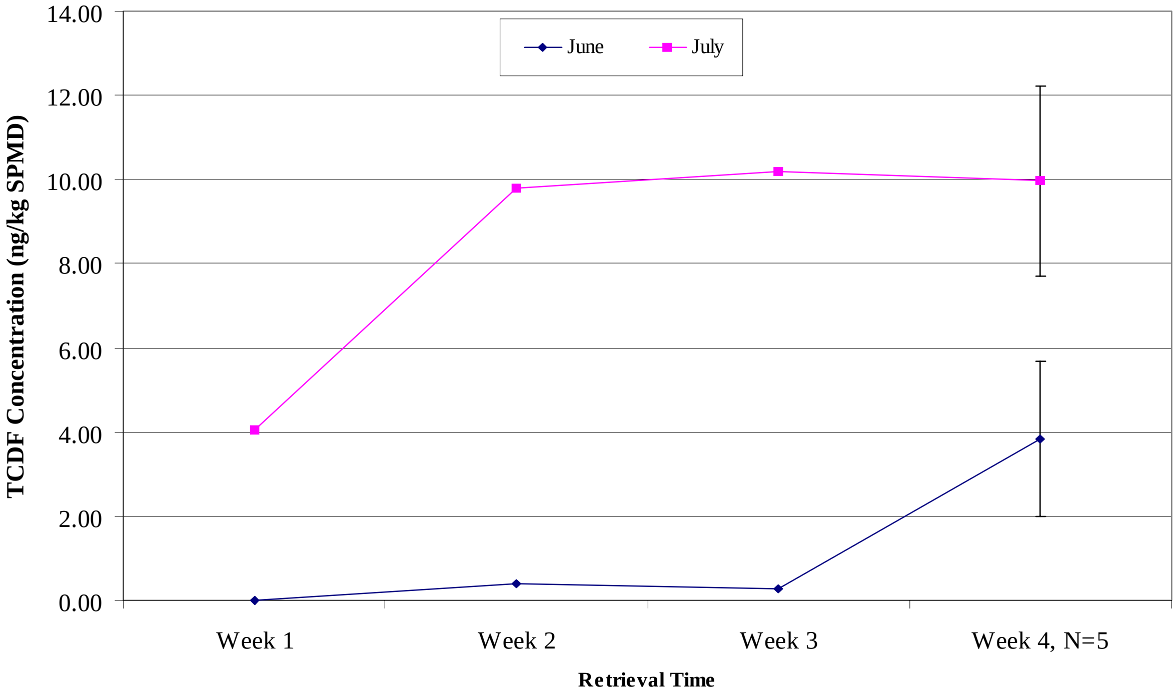
Principle Findings

The 2000 field season consisted of two components. The first included two deployment time studies that were performed on the Androscoggin River over 28-day deployment periods. The goal of these studies was to investigate how the SPMDs sample over our standard deployment period and how biofouling increases over time. Does the biofouling significantly decrease the linear uptake of dioxin by the SPMDs?

For each deployment period, twenty SPMDs were placed three feet below the river surface at site 10 in Dixfield. Each week, for a total of four weeks, five of the SPMDs were retrieved and brought back to the laboratory for analysis.

Qualitatively, the biofouling on the membrane increased in coverage and changed characteristics over the four-week period—progressing from tiny tan specs to larger army green, rod-like shapes. Each week the deployment canisters had more growth collected on the surfaces. Quantitatively, a look at the dioxin level increases each week illustrates that biofouling may have slowed SPMD dioxin sampling during the July deployment period. Figure 1 illustrates the general trend of how SPMD dioxin levels increased over time, using 2,3,7,8-TCDF as an example. The lines generated by the four points do not show a plateau of dioxin levels for the June deployment. However the July deployment does seem to plateau. This plateau may be nonexistent and just reflect the need for more replicates for weeks one through three. After all, the first three weeks only have one sample while the last weeks' data points are generated from an average of five replicates. Moreover, the 95% confidence intervals for week four retrievals illustrated by the error bars indicate that an increase was possible.

FIGURE 1. Comparison of TCDF Concentrations over Two Deployment Time Studies



Comparing the two deployment time studies, July dioxin levels were primarily higher than June levels for the seventeen toxic congeners. This trend could lie in the relationship of SPMD sampling rate with flow, temperature, dissolved organic carbon, and total organic carbon, which varied between the two months. These relationships will be investigated as part of a forthcoming master's thesis by Shoven to be completed in June of 2001. Figures 2 and 3 illustrate the dioxin concentrations throughout both deployment time studies.

FIGURE 2. June Deployment Time Study on the Androscoggin River

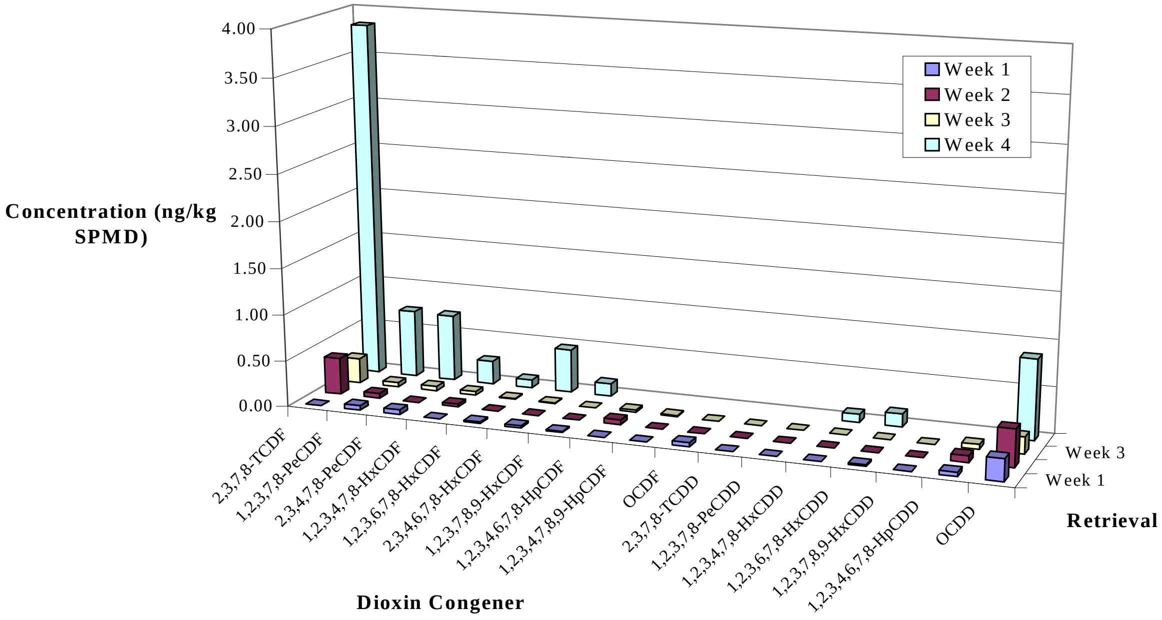
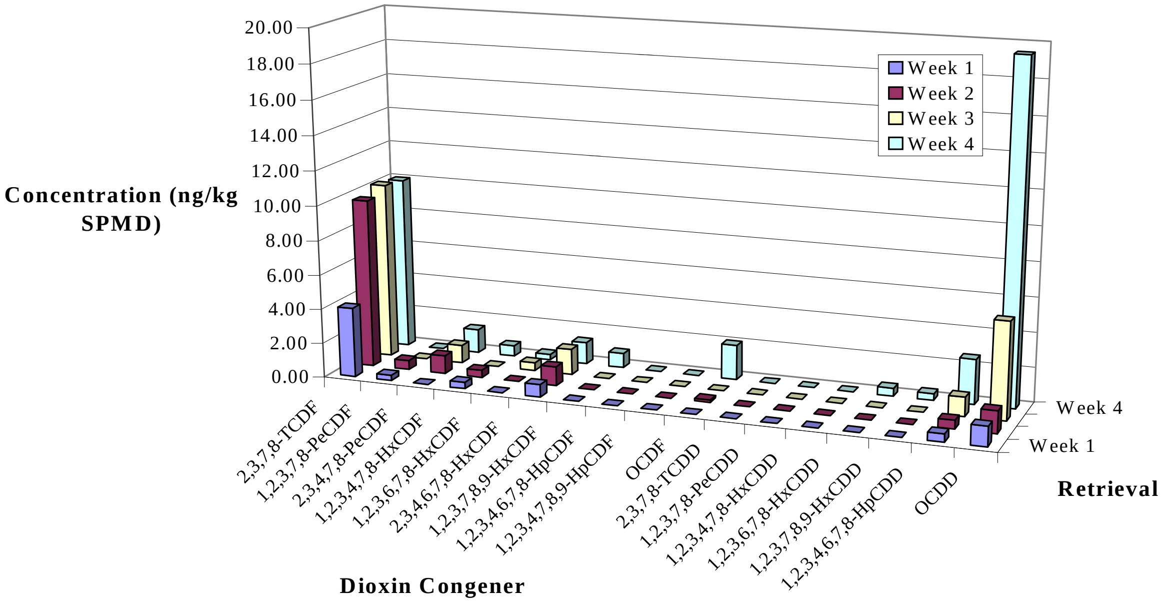
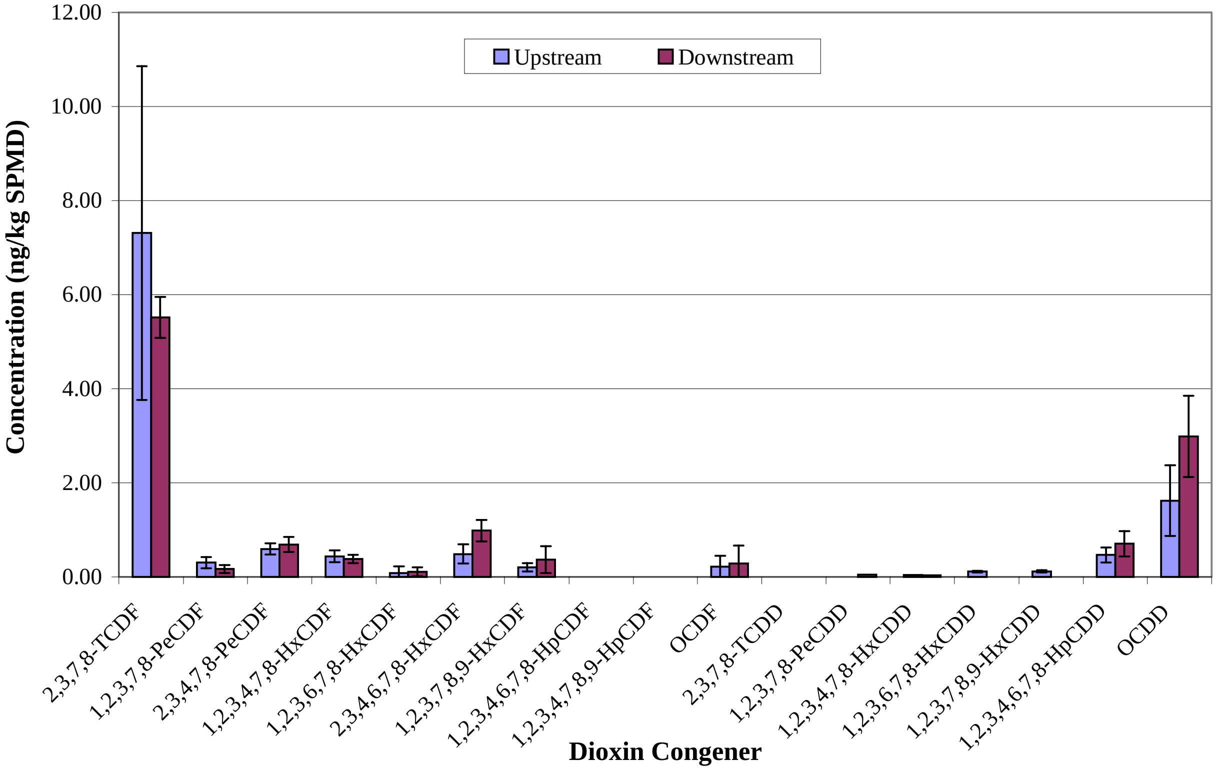


FIGURE 3. July Deloyment Time Study on the Androscoggin River



The second component of the 2000 field season was the testing of SPMD dioxin monitoring at upstream-downstream sites. A pair of sites was chosen on the Androscoggin River in western Maine. The downstream site, Site 10, was located in Dixfield. The upstream deployment, site 13, was in Rumford. At each of these two sites, twenty SPMDs were deployed for a 28-day deployment period. These twenty SPMDs became ten composite replicate samples. The comparison data are offered in Figure 4, which consists of the mean congener concentrations on the y-axis with error bars representing the 95% confidence interval calculated with the student t-value and the standard deviation. The absence of a bar for a congener indicates that there were no detectable levels of the congener at that site.

FIGURE 4. Upstream-Downstream Deployment on the Androscoggin River: 28-days, N=10



It is difficult to compare these two sites looking at all seventeen toxic congeners. One way to assess the total amount of dioxin is through the toxic equivalence (TEQ), which is a sum of the product of each dioxin congener concentration and its toxic equivalence factor (TEF). The TEF value relates the toxicity of a congener with the toxicity of 2,3,7,8-TCDD, which is the most toxic of the congeners and has a TEF of 1. When looking at the TEQ values, one finds no difference between the sites. The upstream site mean TEQ is 1.20 with a 66% relative statistical difference among replicates, while the downstream TEQ is 1.21 with a 37% relative statistical difference among replicates. These TEQs were calculated by assigning all congeners that were non-detects a zero concentration value. Another TEQ can be calculated that assigns all non-detects a concentration at the detection limit. These TEQ calculations yield an upstream value of 7.38 with an 8% relative statistical difference and a downstream value of 6.43 with a 10% relative statistical difference among replicates. It is difficult to assess what value to assign to non-detects among replicate samples. For this report, values of zero, one-half the detection limit, and the detection limit were assigned to determine TEQ values. The method of comparing upstream and downstream data will need to be constructed for future studies.

Future Work

There is still a great deal of data interpretation left to do with the 2000 field season results. The following components will be presented in Shoven's master's thesis to be completed in early summer of 2001.

- Water quality data were collected at each of the sites at deployment and retrieval in order to assess how different variables influence SPMD sampling rate. Variables to be examined at each site include:
    - ✓ Water velocity
    - ✓ Dissolved organic carbon and total organic carbon levels concentrations
    - ✓ Water temperature at the depth of the SPMDs
- How do the SPMDs sample over the 28-day period?
- Does biofouling significantly impede SPMD sampling?
- How do SPMDs sample over the entire field season? Comparison of three 28-day deployment periods at the same site: June through October.
- Qualitative comparison of SPMD dioxin levels with fish and mussel dioxin levels at the same sites.

Basic Information

Title:	Ecosystem-wide Effects of Roadway Runoff on Headwater Streams in Maine
Project Number:	
Start Date:	9/1/1999
End Date:	8/31/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Non Point Pollution, Surface Water, Toxic Substances
Descriptors:	Benthos, Bioindicators, Biomonitoring, Ecosystems, Heavy metals, Insects, Land use, Pollutants, Runoff, Streams, Water quality, Water Quality Monitoring
Lead Institute:	University of Maine
Principal Investigators:	Alex D. Huryn

Publication

1. Davies, S.P., L. Tsomides, J. DiFranco and D. Courtemanch. 1999. Biomonitoring Retrospective: Fifteen year summary for Maine rivers and streams. Maine Department of Environmental Protection, Augusta, ME. DEPLW1999-26. pp. 114-117
2. Maine Department of Environmental Protection. 2000. Surface Water Ambient Toxic Monitoring Report, 1998 Final Data Report. Section 3.3 Urban Non-point Source Investigation. Maine Department of Environmental Protection, Augusta, ME. DEPLW2000-6. pp. 1-19
3. Tsomides, L, T. Woodcock, and S. Davies. 2000. Use of Biological Monitoring to Track Nonpoint Sources in Goosefare Brook, York County, Maine. Maine Dept. of Environmental Protection and University of Maine, Orono, ME. Presentation given at: New England Interstate Water Pollution Control Commission (NEIWPCC) Annual Nonpoint Source Meeting. May 23-25, 2000 at URI Narragansett Bay Campus, Narragansett, Rhode Island.

Problem and Research Objectives:

Routine monitoring of water quality by the Maine Department of Environmental Protection (MDEP) indicated the presence of a serious water quality problem in Goosefare Brook in the vicinity of the Maine turnpike. MDEP funded a study, beginning in 1997, of the stream to discover the source of the problem. Possibilities included the turnpike and two industrial establishments located immediately downstream of it, one of which discharges effluent to the stream. The study revealed that while the majority of the pollution stress appeared to be coming from the industrial effluent, the turnpike was also causing a decline in the health of the stream. The nature and magnitude of the ecological impact of the turnpike is the focus of this study.

It is acknowledged by the MDEP that the present level of understanding is not sufficient to provide substantive guidance to public and private groups that may be required to monitor and maintain the quality of surface waters affected by roadway activities (e.g. Maine Department of Transportation, Maine Turnpike Authority). Preliminary evidence based upon research funded by the MDEP indicates that changes in stream invertebrate communities (taxonomic richness, biomass) and ecological processes (detritus decomposition) do occur in some streams as they pass beneath the turnpike. On the basis of this preliminary information, it is clear that the potential for water quality problems because of chronic disturbances from the turnpike (e.g. heavy metals, sediments, other contaminants) should be of public concern. The goal of this research is to narrow the information gap concerning the effect of roadway runoff and non-point heavy metal pollution on streams in southern Maine by quantifying longitudinal gradients of a comprehensive suite of physical, chemical and biological variables for five streams that flow beneath the Maine Turnpike in southern Maine. These data will be used to document the potential ecosystem-wide effect of the Maine Turnpike on stream health, to assess the performance of metrics that measure ecosystem process and function in addition to structure, and to establish an information base required to document the effects of the turnpike construction that began last year.

Methodology:

The specific objectives of this study are to determine and evaluate differences in the following physical and biological variables in reaches above and below the turnpike in each of the five study streams, as well as 3 industrially impacted reaches in Goosefare Brook (53 sampling stations – Figure 1). The variables are categorized into physical, chemical, and biological attributes. Biological attributes are further subdivided in those that more closely reflect ecosystem structure, and those that reflect ecosystem function. For detailed methods for each parameter, consult the original proposal, pp10-12.

Physical and chemical attributes of study reaches

- water chemistry – 9 water samples planned; all have been taken as of 9/16/00. Variables measured from water samples collected upstream and downstream of the turnpike at each sampling period include nitrate-N, ammonium-N, phosphate, alkalinity, and dissolved organic carbon. Variables measured in the field at each station include pH, dissolved oxygen, and specific conductance.
- sediment chemistry – 4 sediment samples planned; only three have been taken during the course of the study, due to financial constraints. The spring sediment sample was chosen for elimination due to weather-related delays in the winter period of sediment sampling, and continuous high flows during the rainy spring that scoured surface sediments. At each sampling period, one composite of 12 core samples was taken at each station from the same locations as the benthic samples. Percent carbon and total and exchangeable concentrations of eight heavy metals were measured.
- suspended sediments (inorganic) – 9 seston samples planned; all have been taken as of 9/16/00.

- reach channel form – habitat within the channel has been documented, and an assessment of riparian habitat has been carried out in all streams. Discharge was measured above and below the turnpike during most field visits.
- catchment land-use – large-scale land use within each catchment has been assessed using a GIS (Maine GAP land use data). A summary is presented in table 1.
- temperature – hourly measurements taken upstream and downstream of the turnpike in each stream (Figure 2).

Ecosystem structure

- community structure (abundance, biomass) for fish and invertebrates in each study reach – benthic samples have been taken 9 times (454 samples). Identification and measuring of several hundred thousand invertebrates has been completed, including mounted chironomids. Data entry and analysis is pending. Fish sampling was carried out in July 2000.
- maximum size of macroinvertebrates (biomass, selected taxa) – Data entry and analysis is pending.
- spatial and temporal patterns of primary producers (chlorophyll *a*) – four sets of samples planned, all had been completed as of August 2000.
- spatial and temporal patterns of benthic organic matter accumulation and storage - benthic samples have been taken 9 times; all have been completed as of September 2000.

Ecosystem function

- macroinvertebrate growth rate (selected taxa) – Data entry and analysis is pending.
- annual macroinvertebrate production – Data entry and analysis is pending.
- transported and stored particulate organic material -9 seston samples planned; all have been taken as of 9/16/00.
- rate of leaf detritus processing – this experiment has been completed as of November 2000.
- leaf pack invertebrate community structure and biomass – Identification and measurement of specimens is ongoing.

Taxonomic work is ongoing in the laboratory. Data entry and analysis, and manuscript writing, will be ongoing through spring 2002. The data presented in this report represents the physical and chemical template on which the invertebrate secondary production data will be superimposed in order to examine ecological processes within the study streams.

Principal Findings and Significance:

Preliminary examination of water and sediment quality data, including suspended solids, nutrients, pH, specific conductance, dissolved oxygen, alkalinity, dissolved organic carbon, and heavy metal concentrations, suggests that the Maine turnpike is indeed affecting the streams, but that examination of physical and biological variables, together with chemical parameters, is necessary to elucidate the nature of these effects on stream health. Data on chemical variables alone are not conclusive.

Suspended solids – No clear pattern relating to the turnpike is visible in annual means of either organic or inorganic suspended solids (Figure 3). An exception is Stevens Brook, where the increase in downstream material is likely due to some widening construction activities that entailed clearing vegetation from the riparian zone and construction of some earthworks around the culvert. Increases in transported material, particularly the inorganic fraction, downstream of industrial runoff and effluent inputs in Goosefare Brook (stations 6, 7, and 8) are evident. This material is probably precipitates of iron, based on its red color and the nature of the industrial discharge.

Water chemistry – Parameters include dissolved oxygen, specific conductance, pH, nutrients (N and P), alkalinity, and DOC. At no time in any stream were measurements of dissolved oxygen lower than 7mg/L; typical measurements were between 8 and 11 mg/L. Trends in pH and specific conductance (Figure 4) were evident in all streams, with the exception of relatively constant pH in Branch Brook. pH values of Cascade, Goosefare, and Stevens Brooks were variable throughout the year; each of these streams drain upland bogs, and decreasing pH values in the autumn were coincident with large influxes of organic acids (see table 2, "DOC"). It is suspected that the increasing longitudinal trend in pH recorded in these streams is due to interactions with carbonate materials in cement culverts as the water passes beneath the turnpike, and natural losses of organic acids through such processes as precipitation and microbial uptake. The decreasing pH trend in Ward Brook is not easily explicable.

Specific conductance showed a clear and significant increase in all streams, beginning immediately upstream of the roadway (aerial deposition of material), and increasing further downstream (aerial deposition plus discharge of runoff). The magnitude of the increase varies with the size of the stream, and is likely related to the degree to which the chemistry of the stream is dominated by drainage from the highway. There is also a large increase in specific conductance downstream of industrial inputs in Goosefare Brook.

The turnpike does not appear to be a source of nitrogen to the streams, and phosphorus was usually below detectable levels (Table 2). Alkalinity also shows little variation due to the turnpike. DOC varies seasonally in the bog-draining streams, and is fairly constant in Ward and Branch Brooks; no stream shows consistent differences related to the turnpike.

Heavy metals – With the exception of the industrial inputs in Goosefare Brook, no clear gradients in either exchangeable or total metal concentrations are observed (Figures 5-9). It is clear, however, that metal concentrations have a tendency to vary together, suggesting that certain stations have characteristics that facilitate metal retention in those sediments. Possible explanations include particle size (recorded in physical habitat data), co-precipitates (iron and manganese), and organic matter content (% carbon). Examination of physical and biological variables that relate to or are affected by the metal concentrations are a major goal of this research, and will be considered in the final analyses when all data are available.

Basic Information

Title:	Association of Methymercury with Dissolved Organic Carbon: Implications for Bioaccumulation in Maine Freshwater Fish
Project Number:	HQ-96-GR-02674
Start Date:	9/1/1998
End Date:	8/31/2000
Research Category:	Biological Sciences
Focus Category:	Hydrogeochemistry, Toxic Substances, Water Quantity
Descriptors:	Dissolved organic carbon, Organometallic compounds, Contaminant transport, Fish ecology, Lakes
Lead Institute:	University of Maine
Principal Investigators:	Aria Amirbahman, Terry Haines

Publication

1. Amirbahman, A., A. Reid, T. Haines and C. Arnold, 2000. Association of Methylmercury with dissolved humic substances. Manuscript in preparation. To be submitted for publication to Environmental Science and Technology.
2. Reid, A. 2000. Association of methylmercury with dissolved organic carbon. M.S. Thesis, University of Maine, Orono, Maine.
3. Reid, A., A. Amirbahman and T. Haines. 1999. Complexation of methylmercury by peat humic acid. Poster presentation: Association of Environmental Engineering and Science Professors, Research Frontiers Conference. University Park, PA.
4. Reid, A., A. Amirbahman, and T. Haines. 1999. Association of methylmercury with dissolved humic acids. Poster presentation: Maine Water Conference. Augusta, Maine.

Annual Progress Report:

Association of Methylmercury with Dissolved Organic Carbon: Implications for Bioaccumulation in Maine Freshwater Fish

Complexation Studies

The purpose of the proposed complexation studies is to develop the energetics of interaction between several species of dissolved organic carbon (DOC) and methylmercury (CH_3Hg). In the last fiscal year we were able to successfully design our experimental setup, optimize the processes involved and analyze CH_3Hg.

Interaction between CH_3Hg and DOC was studied using membrane dialysis. We designed a set of glass reaction vessels for the dialysis experiments, in which a 500 Da membrane separates the two reaction vessels, one containing CH_3Hg and the other the DOC solution. The free CH_3Hg diffuses across the membrane only. Methylmercury recovery in our system was usually above 90%. Mass balance was established by determining the diffusion kinetics across the membrane, adsorption of CH_3Hg to the membrane, efficient mixing scheme and minimizing loss due to evaporation.

Experimental Results:

Dialysis experiments were conducted to study the association of CH_3Hg with 5 well-characterized humic and fulvic acids. The humic substances consisted of peat humic (PHA), peat fulvic (PFA) and Suwannee River humic (SRHA) acids all supplied by the International Humic Substances Society. We also isolated humic and fulvic acid fractions of Baker Brook (BBHA and BBFA), which is a local stream in central Maine draining a wetland.

Adsorption isotherms involving CH_3Hg and each of these humic substances were obtained at different pH values with a DOC concentration of 1 ppm. The data obtained from these isotherms were used to estimate equilibrium binding constants of CH_3Hg to various humic substances. A few experiments were also conducted at a fixed pH but at varying concentrations of DOC.

Typical adsorption isotherms developed using SRHA are shown in Fig. 1 at different pH values. The behavior of all these systems is characterized by a very high affinity between CH_3Hg and SRHA. The equilibrium binding constants were obtained by fitting the following sets of reactions to the experimental data using the computer program Fiteql:

Binding constants and total number of reactive sites for the association of methylmercury with IHSS Suwannee River humic acid.

$RS_1H = RS_1^- + H^+$	$\log K_{a1} = -8$	$RS_{1T} = 7.68\times10^{-11}$ M
$RS_2H = RS_2^- + H^+$	$\log K_{a2} = -10$	$RS_{2T} = 1.84\times10^{-9}$ M
$CH_3HgOH + RS_1H = RS_1CH_3Hg + H_2O$	$\log K_{s1} = 12.58$	
$CH_3HgOH + RS_2H = RS_2CH_3Hg + H_2O$	$\log K_{s2} = 9.49$	
$CH_3HgOH + RSSR = RCH_3HgS^+SR + OH^-$	$\log K_{s3} = 14.81$	$RS_{3T} = 2.68\times10^{-10}$ M

In modeling our data, we have used a discrete log K spectrum without explicit representation of electrostatic energy. According to this scheme, humic substances are represented as an assembly of monoprotic acids, with assumed acidity constants (K_{ai}), the anions of which bind metals in 1:1 complexes. Both Hg and CH_3Hg are known to bind favorably to the reduced sulfur containing functional groups. Previous direct spectroscopic evidence has shown that in the association between Hg and humic substances, these groups are thiol (RSH) and disulfide (RSSR)/disulfane (RSSH) groups.

The first two reactions in the table characterize the dissociation of protons from the thiol/disulfane acidic sites on SRHA. Acidity constants of 10^{-8} and 10^{-10} are chosen to represent these groups on humics. These values are within the range of acidities of most thiol groups. Our data was best simulated using a "three-site model"; two acidic thiol/disulfane groups (RS_1 and RS_2) and a disulfide group. Due to the relatively weak acid character of the thiol groups, binding of CH_3Hg to these groups is most effective at basic pH values. Conversely, binding of CH_3Hg to the disulfide group is most effective at acidic pH values. Therefore, the adsorption isotherm data at pH 9.2 and 7.1 were used to estimate the binding constants of CH_3Hg to the thiol functional groups (K_{s1} and K_{s2}) and the total number of these functional groups (RS_{1T} and RS_{2T}), since at this pH binding to the disulfide group is negligible. It was found that binding to two reactive thiol/disulfan groups modeled the data at pH 9.2 and 7.1 very well (Fig. 1). Likewise, the experimental data at pH 3.5 was used to estimate the equilibrium binding constant and the total concentration of binding sites for the disulfide group. These values were then used to simulate association of CH_3Hg with SRHA at pH values of 4.6 and 5.2 as shown in Fig. 1. In all cases the agreement between the model and the experimental data are good indicating the validity of the proposed model. Similar modeling of binding parameters for other humic substances have been performed. The results along with a more detailed discussion of our findings are reported in Amirbahman et al. (in preperation).

The parameters obtained in this study may be used to simulate speciation of CH_3Hg in natural waters. These parameters may also be used in transport models to predict fate of CH_3Hg. Concentration of total CH_3Hg in natural waters is usually in sub-nanomolar range. Our observations demonstrate that the dissolved organic carbon can indeed control the speciation of CH_3Hg in the aquatic environments.

Algal Studies

A culture of the planktonic green alga *Selenastrum capricornutum* was obtained from the University of Texas and grown in standard media in the laboratory.

Preliminary experiments were conducted in the absence and presence of humic substances. The results from these experiments are shown in Fig. 2. As expected, uptake of CH_3Hg increases with an increase in the total available CH_3Hg concentration. Addition of up to 1 ppm of IHSS peat fulvic acid (PFA) does not affect the uptake of CH_3Hg. A decrease in algal uptake is observed, however, at DOC concentration of 5 ppm. Given the strong binding affinity of CH_3Hg to humic substances even at low concentrations of the latter (Fig. 1), this behavior suggests a strong competition between the algal cell surface and PFA.

Fig. 1a: Association of MeHg with Suwannee River Humic Acid

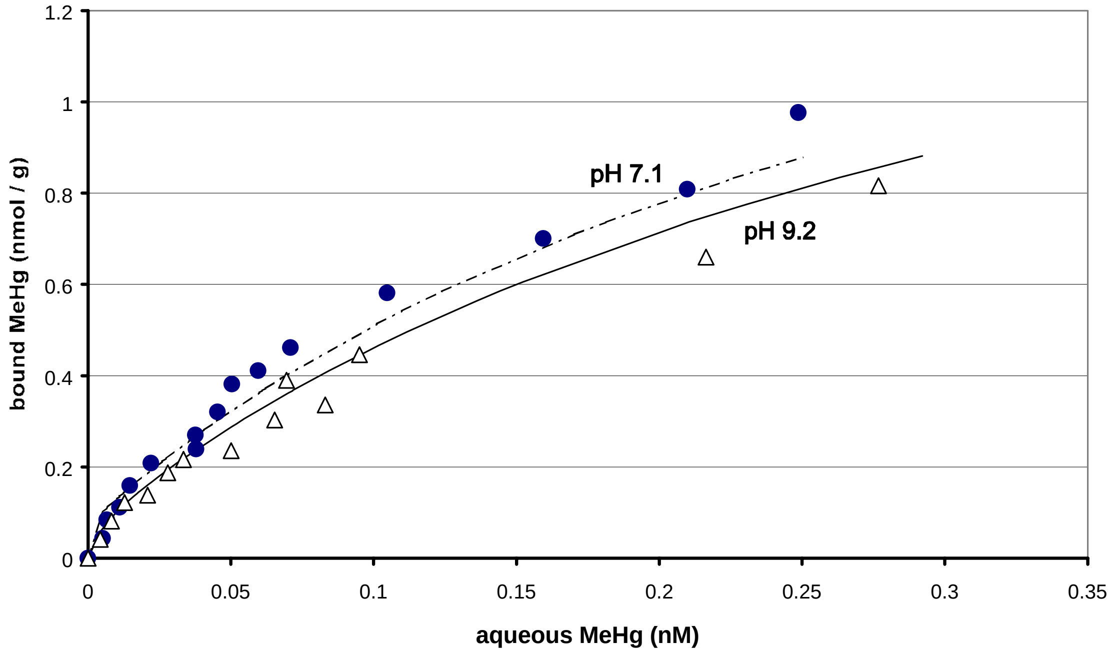


Fig. 1 b: Association of MeHg with Suwannee River Humic Acid

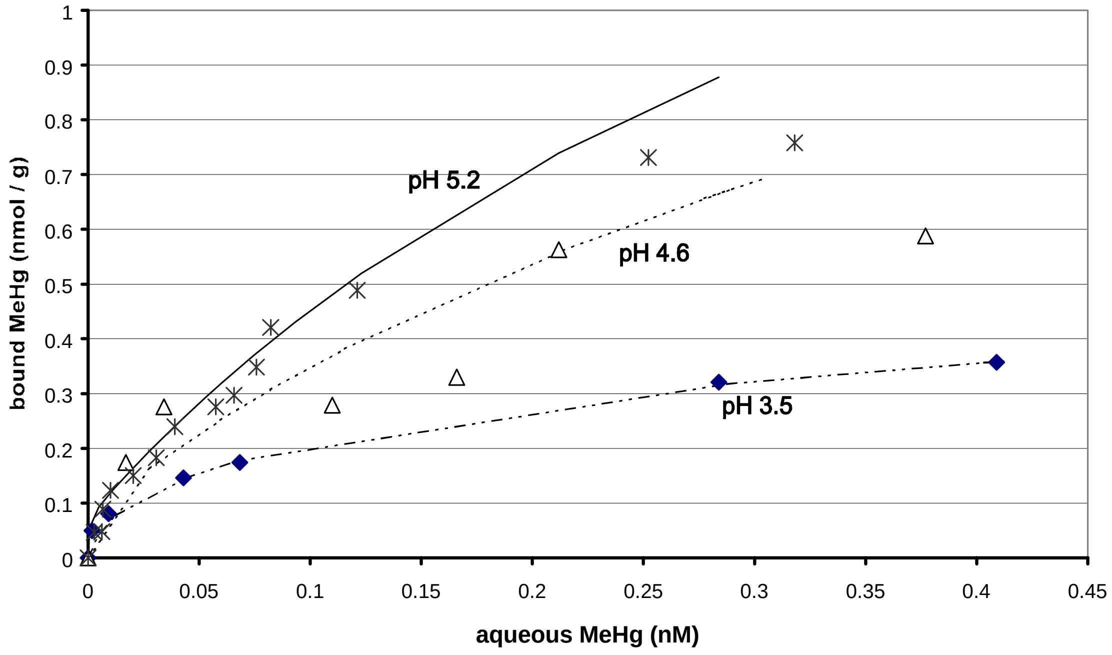


Fig. 2 a: Uptake of MeHg by Algae with no DOC

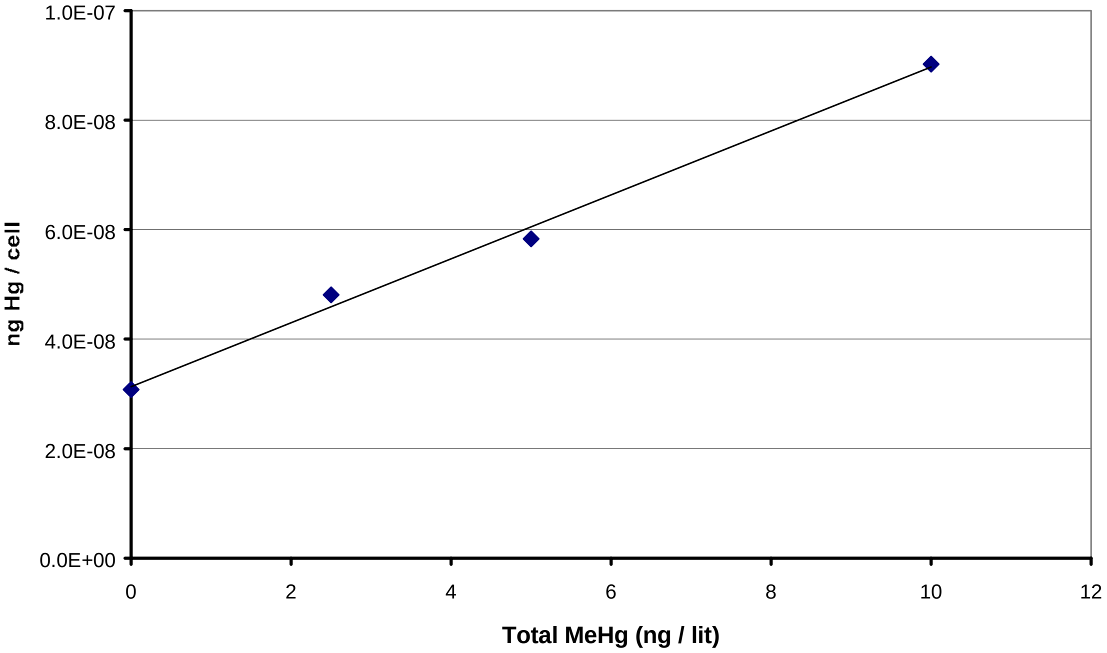
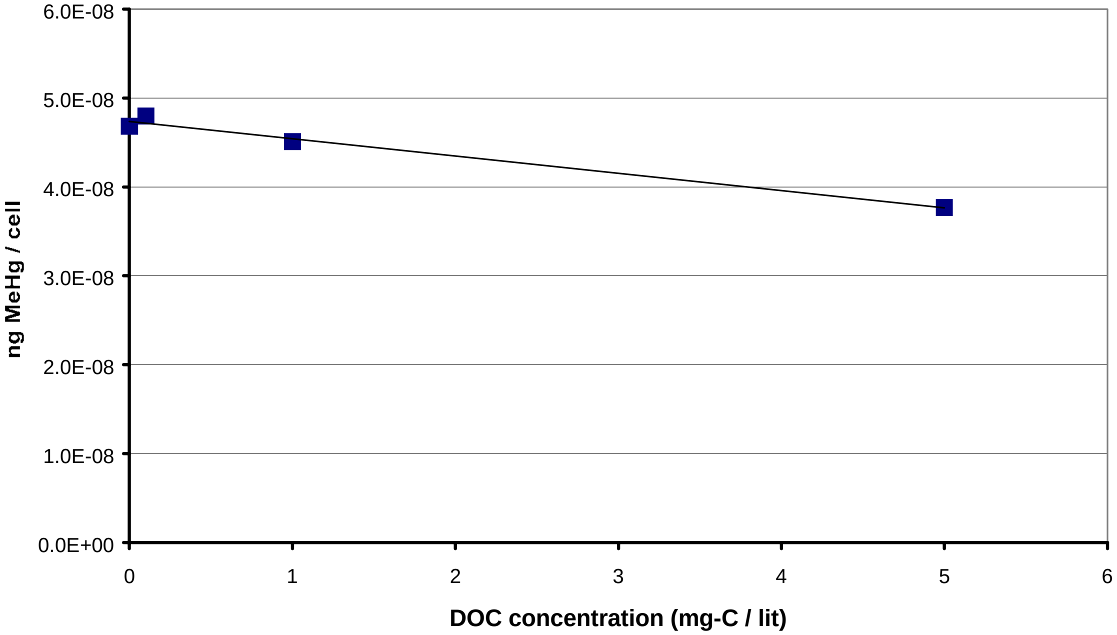


Fig. 2b: Uptake of MeHg by Algae vs. the DOC concentration
Total MeHg = 5 ng / lit



Basic Information

Title:	Differentiating Local Hg Sourcc Contributions from Regional Inputs
Project Number:	HQ-96-GR-02674
Start Date:	9/1/1998
End Date:	8/31/2000
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Toxic Substances, Water Quality
Descriptors:	Mercury, Incinerators, Chlor-alkali, Paleolimnology, Atmospheric Emissions, Atmospheric Deposition, Bog Sediment
Lead Institute:	University of Maine
Principal Investigators:	Stephen A. Norton, David Courtemanch, Jeffrey S Kahl

Publication

1. Benoit, Amy. 1999. A history of atmospheric mercury deposition derived from an ombrotrophic peat bog in Maine: Evidence for a local industrial source? Honors Thesis, University of Maine, 28 p., plus Appendices.
2. Norton, S.A., C. Hess, J. Cangelosi, M. Norris, E. Perry, J. Kahl and D. Courtemanch. 2000. Discrimination between regional and point source atmospheric Hg pollution using sediment records from drainage lakes, Maine, USA. Proc., Internat. Conf. on Heavy Metals in the Environment., Ann Arbor, MI., 4 p. (published electronically).
3. Perry, E.R. and S. Norton. 2000. Human influences on biogeochemical cycles (oral presentation). 6th Annual Earth Sciences Teachers Workshop, University of Maine.
4. Johnson, K., T. Haines, S. Norton, S. Kahl. 2000. Collection of wet-depostion Hg using peat columns. Gordon Conference, New Hampshire.
5. Norton, S.A., E. Perry, M. Norris, C. Hess, J. Cangelosi, J. Kahl and D. Courtemanch. 2001. How has the atmospheric deposition of Hg changed through time in Maine? Maine Water Conference, Augusta, ME
6. Perry, E., S. Norton, J. Cangelosi, C. Hess, and M. Norris. 2001. Mercury storage, release, and transport in the watersheds of seven Maine lakes. Geol. Soc. Am. Northeast Sectional Ann. Mtg., Burlington, VT.

Water Research Institute – Annual Technical Report

Reporting Period: March 1, 2000 to February 28, 2001

Principal Investigators: Professor Stephen A. Norton, University of Maine; Dr. David L. Courtemanch, Director of Lakes Division, Department of Environmental Protection, State of Maine; Dr. Jeffrey S. Kahl, Director, George J. Mitchell Center for Environmental and Watershed Research, University of Maine

Problem and Research Objectives: The only operating chlor-alkali plant in the northeastern United States began operation in Maine in 1967. Atmospheric emission data for Hg from the plant are generally unknown prior to 1990. In 1990, self-reported emissions were approximately 460 kg/year and presumably declined during the 1990s. The plant closed in 2000. These emissions represent less than 1% of the annual consumption of Hg by the plant. Regionally, the atmospheric deposition of Hg in Maine started increasing significantly about 1900 and peaked in the 1970s, based on ^{210}Pb dated cores from 15 lakes and two ombrotrophic bogs. Atmospheric deposition has declined in the 1980s and 1990s, based on those same paleolimnological studies as well as a repeated organic soil survey across New England. The principal objective of our investigation was to determine whether or not this point source, and several other smaller nearby sources of atmospheric Hg, exerted a substantial and definable impact on the accumulation rates of Hg in sediment of nearby lakes and bogs.

Methodology: We collected single sediment cores from the deep area of each of eight lakes near Orrington, Maine (Figure 1). For several of these lakes, we had data on concentration of Hg in fish and surface sediments that showed that Hg concentrations were higher than average for Maine lakes near and downwind of the local Hg sources (DEP, 1996). Lakes were distributed from east to southeast of the emission sources, and all were within 20 km of the sources. Cores were collected from two peat bogs where the influence of a canopy on dry deposition of Hg is low relative to a forest canopy. The peat bogs were approximately 20 km north-northeast of the chlor-alkali plant. The lake sediment and peat cores were dated by ^{210}Pb (Norton et al., 1997; Binford et al., 1994) so that the chronology of Hg stratigraphy can be correlated with the emission history of the industrial sources. We separated vascular material (twigs) from the bulk peat (henceforth termed *Sphagnum*) for all the peat samples and used only the *Sphagnum* for ^{210}Pb dating. (The uppermost sample for Caribou Bog Core 2 had an unusually high Hg concentration, and thus high accumulation rate, and is being reanalyzed in July 2001). We report only on Caribou Bog Core 3 and Eddington Bog Core 1.

The twigs typically represent 20-30% of samples in recent peat, decreasing downward due to decomposition to 5-10%. The Hg concentration in twigs is typically 20-30% of that of *Sphagnum*. Thus twigs contain 2-10% of the total Hg in a particular sample. Caribou Bog Core 2 and 3 samples collectively indicate that about 5% of the total Hg is in identifiable twigs. The rationale for calculating accumulation rates based on only the *Sphagnum* is that living woody plant material may occur in *Sphagnum* that is much older than the plant, and dead standing material may persist while *Sphagnum* accumulates around it. This procedure yields Hg accumulation rates that are a slight underestimate of "true" values, about 5%, but the temporal trends are probably more accurate than would be achieved by using whole samples. Total Hg concentrations were determined from intervals of lake sediment. Fluxes of Hg to the lake coring site (ng Hg/cm^2/yr) were calculated based on the sediment chronology, mass accumulation rates, and concentrations of Hg. We have developed algorithms to calculate only the anthropogenic component of the total Hg flux in both bogs and lakes (see attached figures). These fluxes are then compared to the emission history and deposition history for the local area, region, and continent, as determined by other lake and bog studies.

Field work was conducted by Professor Stephen Norton (PI), Amy Benoit (Undergraduate Student in charge of Caribou Bog Core 2 and Eddington Bog core), John Cangelosi (Technician), Ewan Whitaker (Graduate Student), and Ethan Perry, Kate Mahaffey, James Herger, and Amy Winkle (Undergraduate Students). ^{210}Pb laboratory work was supervised by Professor C. Tom Hess and performed primarily by Amy Benoit and Mary-Jo Norris (Graduate Student), with assistance from Perry. Chemical laboratory work was supervised by Norton and Michael Handley (Laboratory Manager), and conducted by Cangelosi, Perry, and Amy Winkle. Corinn Keblinsky separated the Caribou Bog Core 3 into vascular and twig material.

Table 1a: Characteristics of study lakes and bogs

Name	Township	County	Drainage/Lake	Drainage Area (mi^2)	Lake Area (mi^2)	Depth of coring (ft)
Brewer Lake	Orrington	Penobscot	8.7	12.0	1.376	44
Goose Pond	Dedham	Hancock	10.4	3.29	0.316	32
Jacob Buck Pond	Bucksport	Hancock	8.6	2.56	0.297	40
Long Pond	Bucksport	Hancock	65	22.5	0.347	27
Swetts Pond	Orrington	Penobscot	17.5	3.41	0.195	25
Thurston Pond	Bucksport	Hancock	11.2	2.46	0.220	23
Trout Pond	Orrington	Penobscot	14.2	0.27	0.019	24
Williams Pond	Bucksport	Hancock	10	1.75	0.175	49
Caribou Bog, Core 2, Core 3	Orono, Alton	Penobscot, Penobscot				
Eddington Bog	Eddington	Penobscot				

Lake	Wetlands Area (km^2)	Total Watershed Area (km^2)	Wetland Percentage	Watershed Relief (m)	Wetland Area Contiguous to Lake (km^2)	% Wetlands Contiguous to Lake
Brewer	1.67	31.0	5.38	142	0.000	0.00
Goose	0.00	8.52	0.00	292	0.000	0.00
Jacob Buck's	0.00	6.63	0.00	153	0.000	0.00
Long	2.54	58.3	4.35	309	0.164	0.28
Swetts	0.0470	8.83	0.53	187	0.0235	0.27
Thurston	0.00	6.37	0.00	173	0.000	0.00
Trout	0.00	0.700	0.00	91	0.000	0.00
Williams	0.517	4.53	11.41	102	0.517	11.41

Table 1b: Catchment characteristics of eight lakes near Orrington, Maine

Principal Findings and Significance:

- ^{210}Pb-dated lake sediment cores from eight lakes and two ombrotrophic bogs near several significant point sources of atmospheric Hg emission document a 100-year history of increased atmospheric deposition of Hg similar to the regional picture in Maine. Typical pre-industrial accumulation rates of Hg range from <1 to 5 ng Hg/cm^2/yr as a consequence of differences among catchment characteristics (watershed:lake area, relative depth of the lake, presence of upstream lakes, percentage of wetlands, etc.). See accompanying Tables 1-3.
- Maximum accumulation rates for lake sediment range from 8 to 20 ng/cm^2/yr. Several lakes have maximum accumulation rates reached by 1960, several in the 1970s, and several in the 1980s. The bog cores indicate peak accumulation in the 1970s to 1980s, with a decline of perhaps 50% by 1999 or 2000.
- The accumulation rate for total Hg in lake sediment has been deconstructed into (Figure 2):
  - A background (pre-1880 A.D. or “normal”) component (Hg_B) (1-5 ng/cm^2/yr). This value is estimated from sediment intervals older than about 1880.
  - A component determined by fluctuations in the gross sedimentation rate (Hg_V). This rate varies by more than 100% in most lakes. The variation is probably related to changes in land use. The proportion of anthropogenic Hg in this variable flux is unknown. The variable sedimentation rate is estimated using the ^{210}Pb dating and mass accumulation rates of post-1880 sediment compared to pre-industrial rates.
  - An anthropogenic component (Hg_A) that is calculated by difference:
    Total Hg (ng Hg/cm^2/yr) = $Hg_B + Hg_V + Hg_A$

- Profiles of concentration of total Hg (ng/g) versus age of sediment may yield spurrious conclusions relative to Hg_A accumulation rates ($ng/cm^2/yr$).
- Anthropogenic accumulation rates in lakes increase starting late in the 19th century (Figure 3), peaking with one exception, between 1970 and 1999. Modeling of Hg_A deposition to catchments and subsequent leaching to the lake indicates that steady state flux of Hg_A to the lake is only achieved in a short period of time if there is a low retention percentage for the catchment. A step function increase in atmospheric deposition of Hg_A to a catchment with high retention of Hg may take decades to produce steady state deposition in lake sediment. Similarly, a reduction of Hg_A atmospheric deposition may not produce a significant reduction in deposition in lake sediment for decades.
- The pattern of increase is similar for seven of eight lakes (Figure 3). The exception, Williams Pond, has a substantial portion of wetlands in the drainage. The average anthropogenic Hg accumulation rate for the seven similar lakes is a relatively smooth curve that may have reached peak value about 1995 (Figure 4).
- The bog cores (Figure 5) suggest a similar chronology for the start of atmospheric pollution (ca. 1900) with a relatively sharp increase in anthropogenic accumulation rates in the mid-1960s to a peak in the 1975-1985 period, followed by a decline to the present. This history is more reflective of changes in atmospheric chemistry because of the general absence of any lag in chemical changes recorded in the accumulating peat. The sharp increase in the 1960s is coincident with the beginning of Hg production in Orrington. The increase and decline also occur at Acadia National Park at essentially the same time (Norton et al., 1997).
- Accumulation rates for Hg differ dramatically from lake to lake and are weakly related to those of unsupported ^{210}Pb, suggesting that focusing of fine-grained organic matter partly controls these rates. The average anthropogenic accumulation rate for 7 of 8 lakes (Williams Pond not included) is depicted on Figure 4. Although the average accumulation rate increases through the period when the chlor-alkali plant was active (1964-2000), such a pattern is common for remote lakes in Maine, well removed from this point source of pollution. Apparently, even with reduced Hg deposition from the atmosphere (Figure 4), many watersheds continue to have a net accumulation of Hg, and thus a net increase in the rate of leakage of Hg to the lake ecosystem and sediment (Perry et al., 2001).
- Background concentrations, maximum concentrations, background accumulation rates, and anthropogenic accumulation rates, and $^{210}Pb_u$ are all generally proportional in lake sediment cores. This indicates that the lakes process Hg and Pb in a parallel way but that each lake/watershed system is unique, even in a common depositional field for Hg.
- The influence of the point sources of atmospheric Hg within 15 km of the lakes can not be easily detected in the overall accumulation of Hg in either lake sediment or accumulating peat. In particular, the peat profiles show a general decline during the period when the point sources were presumably emitting the greatest amount of Hg to the atmosphere (1990 and slightly earlier?). The measured or calculated variation in all Hg parameters can be reasonably explained by differences among lakes and their catchments. It has become possible, with the use of stable isotopes of Hg, to differentiate more clearly the input of multiple sources of Hg to a site. However, the magnitude of changes at these sites may not appear to warrant the investment.

References Cited:

Appleby, P. G. and Oldfield, F., 1978, The calculation of lead-210 dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment: Catena, 5, 1-8.

Binford, M. W., Kahl, J. S., and Norton, S. A., 1993, Interpretation of ^{210}Pb profiles and inventories in PIRLA Project cores: J. Paleolim.,9, 275-296.

Davis, R. B. and Doyle, R. W., 1967, A piston corer for upper sediment in lakes: Limnol Oceanogr., 14, 643-648.

Department of Environmental Protection, (Mower et al.),1997, Fish tissue contamination in Maine lakes: Maine Dept. Environ. Prot.

Norton, S. A., Bienert, R. W., Binford, M. W., and Kahl, J. S., 1992, Stratigraphy of total metals in PIRLA sediment cores: J. Paleolim., 7, 191-214.

Norton, S. A., Evans, G. C., and Kahl, J. S., 1997, Comparison of Hg and Pb fluxes to hummocks and hollows of ombrotrophic Big Heath Bog and to nearby Sargent Mt. Pond, Maine, USA: Water, Air, and Soil Poll., 100, 271-286.

Perry, E. R., Norton, S. A., Cangelosi, J. A., Hess, C. T., and Norris, M. J., 2001, Mercury storage, release, and transport in the watersheds of seven Maine lakes: Geol. Soc. Am. Northeast Sectional Ann. Mtg., Burlington, VT.

Descriptors: Mercury, sediments, lakes, bogs, paleolimnology, chlor-alkali plants, atmospheric emissions of Hg, atmospheric deposition of Hg

Articles in Refereed Scientific Journals

None

Book Chapters

None

Dissertations

Benoit, Amy, 1999, A history of atmospheric mercury deposition derived from an ombrotrophic peat bog in Maine: Evidence for a local industrial source?: Honors Thesis, University of Maine, 28 p. plus Appendices.

Water Resources Research Institute Reports

None

Conference Proceedings (students in bold)

Norton, S. A., Hess, C. T., Cangelosi, **J. A., Norris, M. J., Perry, E. R**., Kahl, J. S., and Courtemanch, D. L., 2000, Discrimination between regional and point source atmospheric Hg pollution using sediment records from drainage lakes, Maine, USA: Proc., Internat. Conf. On Heavy Metals in the Environ., Ann Arbor, MI., 4 p. (published electronically)

Other Publications/presentations (students in bold)

Perry, E. R. and Norton, S. A., 2000, Human influences on biogeochemical cycles (oral presentation): 6th Annual Earth Sciences Teachers Workshop, University of Maine.

Johnson, K., Haines, T. A., Norton, S. A., Kahl, J.S., 2000, Collection of wet-deposited Hg using peat columns: Gordon Conference, New Hampshire.

Norton, S. A., **Perry, E. R., Norris, M. J.**, Hess, C. T., Cangelosi, J., Kahl, J. S., and Courtemanch, D., 2001, How has the atmospheric deposition of Hg changed through time in Maine? Maine Water Conference 2001, Augusta, ME.

Perry, E. R., Norton, S. A., Cangelosi, J. A., Hess, C. T., and **Norris, M. J**., 2001, Mercury storage, release, and transport in the watersheds of seven Maine lakes: Geol. Soc. Am. Northeast Sectional Ann. Mtg., Burlington, VT.

Table 2: Chemical characteristics of sediment cores from eight lakes near Orrington, Maine

Brewer Lake

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng $Hg/cm^2/yr$)	Hg_A (ng $Hg/cm^2/yr$)
0.0-0.5	11.79	88.55	0.25	1999.00	0.437	179.00	9.40	4.29
0.5-1.0	11.69	91.25	0.75	1998.66	0.376	178.58	15.48	7.04
1.0-1.5	11.57	89.96	1.25	1997.94	0.316	165.31	12.24	5.03
1.5-2.0	11.43	87.88	1.75	1997.22	0.297	159.67	13.49	5.27
2.0-2.5	11.36	86.47	2.25	1996.39	0.278	167.40	14.25	5.96
2.5-3.0	11.54	85.47	2.75	1995.50	0.280	184.89	15.47	7.33
3.0-3.5	11.36	84.40	3.25	1994.50	0.281	194.96	15.69	7.86
3.5-4.0	11.23	83.52	3.75	1993.37	0.283	163.84	12.53	5.09
4.0-4.5	11.10	82.86	4.25	1992.11	0.285	182.03	13.18	6.13
4.5-5.0	11.05	82.54	4.75	1990.74	0.277	170.11	11.83	5.06
5.0-5.5	9.67	81.97	5.25	1989.32	0.269	160.74	11.13	4.39
5.5-6.0	9.66	81.61	5.75	1987.83	0.261	165.66	11.24	4.64
6.0-6.5	9.55	80.72	6.25	1986.28	0.253	169.75	11.54	4.92
6.5-7.0	9.76	80.28	6.75	1984.63	0.244	186.28	12.32	5.88
7.0-7.5	9.74	79.90	7.25	1982.91	0.236	161.68	10.53	4.19
7.5-8.0	9.50	79.64	7.75	1981.13	0.227	180.10	11.53	5.30
8.0-8.5	9.55	79.01	8.25	1979.30	0.219	158.94	10.14	3.93
8.5-9.0	9.52	78.49	8.75	1977.38	0.212	168.21	10.48	4.41
9.0-9.5	9.57	78.14	9.25	1975.35	0.205	170.16	10.26	4.39
9.5-10.0	9.67	77.36	9.75	1973.22	0.199	157.59	9.32	3.57
10.0-11	9.42	76.31	10.5	1970.94	0.189	170.23	12.71	5.45
11.0-12	9.23	74.74	11.50	1965.85	0.179	150.74	8.00	2.83
12.0-13	9.17	74.54	12.50	1959.76	0.168	160.42	7.34	2.89
13.0-14	9.26	73.76	13.50	1952.76	0.147	150.37	6.33	2.23
14.0-15	9.37	73.48	14.50	1945.03	0.126	138.80	5.46	1.63
15.0-16	9.63	74.36	15.50	1936.80	0.104	130.24	4.86	1.23
16.0-17	10.05	76.57	16.50	1928.85	0.083	111.02	4.18	0.52
17.0-18	10.67	77.74	17.50	1922.39	0.070	102.90	4.37	0.24
18.0-19	11.45	78.55	18.50	1916.80	0.057	105.93	5.24	0.43
19.0-20	11.74	79.02	19.50	1912.49	0.044	111.58	7.76	0.99
20.0-21	11.84	80.27	20.50	1909.92	0.032	106.89	15.87	1.42
21.0-22	12.40	80.35	21.50	1909.48	0.040	**106.22**	21.36	1.79
22.0-23	12.51	80.99	22.50	1907.71	0.048	105.54	9.06	0.71
23.0-24	12.57	81.37	23.50	1904.51	0.056	107.36	5.40	0.50
24.0-25	12.69	81.21	24.50	1899.42	0.064	94.79	3.01	-0.08
25.0-26	12.47	81.34	25.50	1891.22	0.058	104.03	2.53	0.16
26.0-27	12.51	81.52	26.50	1882.23	0.053	91.04	2.01	-0.14
27.0-28	12.46	81.95	27.50	1872.48	0.048	80.31	1.64	-0.35
28.0-29	12.46	81.45	28.50	1862.41	0.042	89.37	1.84	-0.16
29.0-30	12.34	81.35	29.50	1852.23	0.040	90.87	1.69	-0.12
30-32	12.48	81.60	31.50	1839.95	0.037	97.32	1.69	
						Background	**1.69**	

Goose Pond

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0.0-1.0	33.76	94.70	0.5	1999.00	1.833	214.72	6.54	3.83
1.0-1.5	34.67	95.51	1.25	1997.21	1.748	251.81	3.51	2.27
1.5-2.0	35.19	94.14	1.75	1995.70	1.695	262.39	4.47	2.95
2.0-2.5	35.26	93.86	2.25	1993.66	1.642	294.60	4.40	3.07
2.5-3.0	36.13	93.57	2.75	1991.45	1.483	279.99	4.20	2.86
3-3.5	35.40	93.41	3.25	1989.21	1.323	289.39	4.48	3.10
3.5-4	35.99	93.22	3.75	1987.03	1.307	281.93	4.35	2.98
4-4.5	35.91	93.05	4.25	1984.65	1.290	282.55	4.09	2.80
4.5-5	35.94	92.70	4.75	1982.04	1.274	282.30	3.86	2.65
5-5.5	35.23	92.62	5.25	1979.09	1.257	279.32	3.47	2.36
5.5-6	36.16	92.47	5.75	1975.85	1.194	272.80	3.19	2.15
6-6.5	36.20	92.32	6.25	1972.38	1.131	264.62	2.93	1.95
6.5-7	36.57	92.38	6.75	1968.63	1.067	251.51	2.60	1.68
7-7.5	35.54	92.32	7.25	1964.68	1.004	256.63	2.51	1.64
7.5-8	36.82	92.22	7.75	1960.44	0.907	247.29	2.32	1.49
8-8.5	37.16	92.22	8.25	1956.04	0.809	244.43	2.23	1.42
8.5-9	37.12	92.21	8.75	1951.56	0.712	219.05	1.98	1.18
9-9.5	36.12	92.42	9.25	1947.07	0.615	236.76	2.14	1.33
9.5-10	37.22	92.36	9.75	1942.81	0.507	219.54	2.14	1.27
10-11	35.17	92.05	10.5	1938.87	0.346	184.71	3.04	1.58
11-12	35.09	92.30	11.5	1932.72	0.283	167.29	2.25	1.05
12-13	34.40	92.11	12.5	1926.93	0.221	156.35	2.40	1.03
13-14	35.16	91.98	13.5	1921.98	0.192	133.58	2.29	0.76
14-15	35.76	91.79	14.5	1917.15	0.163	120.39	2.22	0.58
15-16	35.24	91.87	15.5	1912.67	0.134	117.56	2.45	0.59
16-17	35.02	91.85	16.5	1908.99	0.105	121.61	3.35	0.90
17-18	35.32	91.84	17.5	1906.47	0.103	108.84	3.64	0.66
18-19	35.78	91.83	18.5	1903.88	0.100	99.35	3.23	0.33
19-20	35.39	91.83	19.5	1901.21	0.098	118.88	7.62	
						Background	**2.45**	

Jacob Buck Pond

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0.0-1.0	22.19	93.34	0.5	1999.00	0.592	231.61	17.23	9.43
1.0-1.5	21.89	92.42	1.25	1997.56	0.582	257.39	10.96	6.50
1.5-2.0	21.95	91.29	1.75	1996.72	0.540	240.31	12.74	7.19
2.0-2.5	21.90	90.91	2.25	1995.83	0.462	249.84	13.88	8.06
2.5-3.0	21.90	90.76	2.75	1995.00	0.525	255.76	14.27	8.43
3.0-3.5	21.82	90.11	3.25	1994.09	0.521	247.89	13.24	7.64
3.5-4.0	21.78	89.94	3.75	1993.03	0.518	235.95	11.44	6.36
4.0-4.5	21.75	89.90	4.25	1991.88	0.534	247.47	11.08	6.39
4.5-5.0	21.88	89.79	4.75	1990.64	0.515	234.18	9.88	5.46
5.0-5.5	22.03	89.50	5.25	1989.31	0.514	246.40	9.92	5.70
5.5-6.0	20.88	89.69	5.75	1987.87	0.513	235.46	8.75	4.85
6.0-6.5	20.98	89.72	6.25	1986.37	0.560	227.86	8.04	4.34
6.5-7.0	20.99	89.09	6.75	1984.78	0.510	226.72	7.96	4.28
7.0-7.5	21.31	89.17	7.25	1983.06	0.507	223.63	7.47	3.97
7.5-8.0	21.27	88.86	7.75	1981.32	0.503	240.69	8.07	4.56
8.0-8.5	21.13	88.67	8.25	1979.51	0.483	240.09	7.88	4.44
8.5-9.0	21.24	88.67	8.75	1977.64	0.493	228.50	7.28	3.94
9.0-9.5	21.10	88.64	9.25	1975.71	0.486	232.38	7.21	3.96
9.5-10.0	21.33	88.71	9.75	1973.72	0.477	224.27	6.73	3.58
10.0-11	21.27	88.28	10.5	1971.69	0.420	223.76	8.69	4.62
11.0-12	21.21	87.93	11.5	1967.25	0.438	218.30	5.87	3.05
12.0-13	21.23	87.91	12.5	1962.05	0.408	216.69	4.99	2.58
13.0-14	21.36	87.64	13.5	1955.97	0.374	223.30	4.37	2.32
14.0-15	21.36	88.24	14.5	1948.46	0.387	209.37	3.20	1.60
15.0-16	22.97	88.54	15.5	1939.46	0.296	164.94	2.18	0.80
16.0-17	24.09	89.11	16.5	1929.93	0.255	151.02	1.85	0.57
17.0-18	24.87	89.26	17.5	1920.52	0.214	134.60	1.69	0.38
18.0-19	24.74	89.87	18.5	1911.78	0.128	139.25	2.01	0.50
19.0-20	25.21	90.08	19.5	1905.61	0.136	122.01	2.06	0.29
20.0-21	25.44	89.95	20.5	1899.31	0.102	119.15	1.98	0.24
21.0-22	24.89	89.85	21.5	1892.77	0.073	108.29	1.78	0.06
22.0-23	23.77	89.80	22.5	1886.23	0.075	110.73	1.90	0.10
23.0-24	23.62	89.45	23.5	1880.16	0.068	107.99	1.95	0.06
24.0-25	23.38	89.21	24.5	1873.78	0.061	116.97	2.11	0.22
25.0-26	23.52	89.11	25.5	1867.41	0.054	94.02	1.79	-0.20
26.0-27	23.22	88.97	26.5	1861.57	0.047	101.56	2.28	-0.07
						Background	**2.03**	

Long Pond

Interval	**Loss on Ignition (%)**	**% H_2O**	**Midpoint (cm)**	**Age of Midpoint (years)**	**^{210}Pb Activity (bq/g)**	**Hg Concentration (ng Hg/g sediment)**	**Hg_T (ng Hg/cm^2/yr)**	**Hg_A (ng Hg/cm^2/yr)**
0-0.5		86.78	0.25	1999.00	0.239	199.10		
0.5-1	15.26	87.48	0.75	1998.32	0.229	183.31	17.67	6.33
1-1.5	15.27	86.11	1.25	1997.60	0.218	193.01	19.35	7.56
1.5-2	15.31	84.33	1.75	1996.82	0.208	196.09	20.51	8.21
2-2.5	15.19	83.12	2.25	1995.95	0.197	187.61	19.82	7.39
2.5-3	15.12	82.15	2.75	1995.05	0.187	200.27	21.73	8.97
3-3.5	15.08	81.71	3.25	1994.12	0.177	176.81	19.63	6.57
3.5-4	14.90	80.99	3.75	1993.20	0.191	175.51	18.74	6.18
4-4.5	15.26	80.69	4.25	1992.12	0.206	192.88	17.92	6.99
4.5-5	15.07	80.16	4.75	1990.87	0.220	194.12	16.01	6.31
5-5.5	13.21	79.91	5.25	1989.40	0.235	197.38	14.27	5.77
5.5-6	13.06	79.67	5.75	1987.72	0.219	186.90	12.93	4.79
6-6.5	13.19	79.25	6.25	1986.07	0.202	212.79	15.35	6.87
6.5-7	13.13	79.28	6.75	1984.45	0.186	169.80	12.68	3.90
7-7.5	13.10	78.92	7.25	1982.92	0.170	186.79	14.97	5.55
7.5-8	12.81	78.71	7.75	1981.45	0.166	188.27	15.42	5.79
8-8.5	12.78	78.35	8.25	1979.95	0.162	191.51	15.47	5.97
8.5-9	12.90	78.45	8.75	1978.39	0.158	197.83	15.51	6.29
9-9.5	12.85	78.08	9.25	1976.81	0.154	181.65	14.17	5.00
9.5-10	12.71	77.87	9.75	1975.17	0.164	201.48	14.48	6.03
10-11	12.91	77.07	10.5	1973.28	0.178	172.34	13.50	4.29
11-12	12.68	76.34	11.5	1968.41	0.148	183.21	10.62	3.80
12-13	12.59	75.24	12.5	1963.81	0.118	177.88	11.88	4.03
13-14	12.66	75.30	13.5	1959.76	0.107	164.88	11.79	3.38
14-15	12.41	75.36	14.5	1955.75	0.097	167.68	12.25	3.66
15-16	12.42	75.25	15.5	1951.88	0.086	159.54	12.30	3.23
16-17	12.43	74.63	16.5	1948.25	0.076	146.78	12.57	2.50
17-18	12.34	73.38	17.5	1944.93	0.071	132.02	12.38	1.35
18-19	12.40	72.68	18.5	1941.53	0.066	125.16	12.12	0.73
19-20	13.85	74.94	19.5	1938.22	0.060	127.62	12.43	0.98
20-21	16.73	79.28	20.5	1935.51	0.055	130.08	13.45	1.29
21-22	18.96	81.61	21.5	1933.67	0.054	131.49	15.68	1.66
22-23	19.01	82.13	22.5	1932.07	0.053	133.56	16.89	2.02
23-24	18.99	82.56	23.5	1930.53	0.052	125.63	16.12	1.03
24-25	19.38	82.90	24.5	1929.05	0.051	130.96	17.14	1.75
25-26	18.84	83.47	25.5	1927.63	0.055	113.03	12.83	-0.52
26-27	19.15	84.17	26.5	1925.83	0.059	111.94	9.75	-0.49
27-28	18.66	84.76	27.5	1923.63	0.063	120.77	8.30	0.22
28-29	19.49	84.73	28.5	1920.97	0.067	118.04	6.58	0.02
29-30	19.25	84.37	29.5	1917.63	0.064	127.36	6.35	0.49
30-32	19.11	84.56	31	1914.09	0.061	126.64	7.95	0.57
32-34	19.35	84.41	33	1906.84	0.056	120.15	5.56	0.12
34-36	19.54	83.95	35	1899.30	0.052	111.70	5.19	-0.27
36-38	19.03	83.80	37	1891.63	0.047	120.89	5.75	0.16
38-40	19.80	83.62	39	1884.30	0.043	112.20	6.03	-0.29
40-42	20.56	84.27	41	1878.19	0.039	113.93	12.89	-0.42
						Background	**5.50**	

Swetts Pond

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0.0-0.5		97.53	0.25	1999.00	0.791	257.32		
0.5-1.0	25.15	93.53	0.75	1996.84	0.625	257.90	4.23	2.47
1.0-1.5	24.90	92.13	1.25	1994.91	0.460	263.92	5.79	3.43
1.5-2.0	24.21	91.83	1.75	1993.09	0.456	273.48	6.13	3.72
2.0-2.5	24.15	91.56	2.25	1991.09	0.451	278.12	5.90	3.62
2.5-3.0	23.81	90.63	2.75	1988.91	0.447	267.67	5.54	3.31
3.0-3.5	23.63	90.32	3.25	1986.31	0.443	270.92	5.04	3.04
3.5-4.0	23.55	89.67	3.75	1983.41	0.399	276.00	5.08	3.10
4.0-4.5	23.87	89.50	4.25	1980.36	0.354	281.67	5.18	3.20
4.5-5.0	23.75	89.24	4.75	1977.34	0.286	276.65	5.55	3.39
5.0-5.5	21.77	88.87	5.25	1974.64	0.217	239.92	5.77	3.18
5.5-6.0	20.61	87.92	5.75	1972.40	0.228	228.23	5.88	3.11
6.0-6.5	20.56	88.03	6.25	1969.60	0.238	216.75	4.66	2.34
6.5-7.0	20.10	87.46	6.75	1966.42	0.208	201.06	4.26	1.98
7.0-7.5	19.79	86.61	7.25	1963.23	0.178	198.30	4.51	2.06
7.5-8.0	23.91	87.49	7.75	1960.05	0.151	199.06	4.57	2.10
8.0-8.5	19.62	86.83	8.25	1957.37	0.123	187.39	5.21	2.22
8.5-9.0	19.54	86.40	8.75	1954.93	0.119	171.94	5.00	1.87
9.0-9.5	19.48	86.10	9.25	1952.30	0.115	174.79	4.85	1.87
9.5-10.0	19.58	86.06	9.75	1949.49	0.111	157.48	4.14	1.31
10.0-11	19.68	84.69	10.5	1946.54	0.105	150.23	5.01	1.42
11.0-12	19.25	84.10	11.5	1939.42	0.090	142.98	3.36	0.83
12.0-13	19.45	83.79	12.5	1931.65	0.076	126.90	2.85	0.43
13.0-14	19.26	83.75	13.5	1923.54	0.061	136.88	3.09	0.66
14.0-15	19.71	84.03	14.5	1915.77	0.046	112.74	2.83	0.13
15.0-16	20.11	83.89	15.5	1909.52	0.047	107.54	2.66	0.00
16.0-17	20.31	83.89	16.5	1901.45	0.048	108.88	2.01	0.02
17.0-18	20.23	83.85	17.5	1890.35	0.042	116.17	1.71	0.13
18.0-19	20.64	83.71	18.5	1877.22	0.037	91.93	1.14	-0.19
19.0-20	21.46	84.02	19.5	1861.32	0.031	104.93	1.08	-0.03
20.0-21	21.69	84.63	20.5	1842.95	0.025	117.82	1.12	0.10
21.0-22	22.17	85.33	21.5	1825.75	0.024	118.20	0.95	0.09
22.0-23	21.92	85.50	22.5	1803.19	0.022	114.98	0.62	0.04
23.0-24	22.29	85.73	23.5	1767.53	0.020	122.13		
						Background	**0.98**	

Thurston Pond

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0.0-0.5		94.90	0.25	1999.00	0.571	220.53		
0.5-1.0	27.57	92.72	0.75	1998.22	0.547	214.98	8.67	4.69
1.0-1.5	27.28	91.96	1.25	1997.12	0.523	220.32	8.01	4.42
1.5-2.0	27.11	91.59	1.75	1995.91	0.511	219.00	7.72	4.24
2.0-2.5	27.04	91.18	2.25	1994.62	0.500	219.60	7.63	4.20
2.5-3.0	27.02	90.96	2.75	1993.24	0.488	232.71	7.84	4.51
3.0-3.5	27.06	90.84	3.25	1991.79	0.477	230.42	7.56	4.32
3.5-4.0	26.93	90.73	3.75	1990.29	0.492	226.72	7.05	3.98
4.0-4.5	26.84	90.66	4.25	1988.65	0.508	218.60	6.24	3.42
4.5-5.0	26.67	90.54	4.75	1986.84	0.523	221.36	5.80	3.22
5.0-5.5	26.92	92.67	5.25	1984.84	0.538	219.79	5.22	2.87
5.5-6.0	26.44	91.31	5.75	1982.63	0.529	207.18	4.37	2.29
6.0-6.5	26.52	91.06	6.25	1980.51	0.520	209.04	4.45	2.35
6.5-7.0	26.28	91.06	6.75	1978.21	0.511	208.64	4.15	2.19
7.0-7.5	26.47	91.57	7.25	1975.78	0.502	208.81	3.81	2.01
7.5-8.0	26.23	91.23	7.75	1973.37	0.440	203.83	3.93	2.03
8.0-8.5	26.08	91.28	8.25	1971.00	0.377	195.00	3.97	1.96
8.5-9.0	25.92	91.39	8.75	1968.86	0.313	205.78	4.67	2.43
9.0-9.5	25.85	91.44	9.25	1967.02	0.249	192.08	5.16	2.51
9.5-10.0	26.11	91.07	9.75	1965.52	0.234	184.18	5.69	2.64
10.0-11	24.82	90.87	10.5	1963.98	0.212	175.63	7.39	3.24
11.0-12	25.06	90.64	11.5	1960.95	0.198	171.98	5.48	2.34
12.0-13	25.18	90.47	12.5	1957.78	0.184	167.76	5.24	2.16
13.0-14	26.07	90.08	13.5	1954.50	0.170	162.86	5.07	2.00
14.0-15	25.98	90.13	14.5	1951.03	0.156	157.81	4.75	1.78
15.0-16	25.89	90.00	15.5	1947.55	0.142	161.41	4.88	1.90
16.0-17	26.02	90.17	16.5	1944.02	0.129	140.49	4.20	1.25
17.0-18	25.87	90.09	17.5	1940.59	0.115	137.97	4.27	1.22
18.0-19	25.92	89.89	18.5	1937.23	0.102	129.69	4.21	1.01
19.0-20	25.95	89.83	19.5	1933.99	0.097	125.32	4.05	0.86
20.0-21	26.11	89.73	20.5	1930.56	0.093	120.84	3.73	0.68
21.0-22	25.99	89.49	21.5	1926.92	0.089	113.01	3.33	0.42
22.0-23	26.05	89.48	22.5	1922.98	0.084	110.88	3.05	0.34
23.0-24	26.18	89.43	23.5	1918.80	0.080	110.64	2.88	0.31
24.0-25	26.30	89.25	24.5	1914.36	0.075	102.93	2.55	0.11
25.0-26	26.27	89.06	25.5	1909.56	0.070	97.43	2.27	-0.03
26.0-27	26.06	89.25	26.5	1904.36	0.066	100.17	2.16	0.03
27.0-28	24.53	89.26	27.5	1898.93	0.060	92.98	1.92	-0.12
28.0-29	24.59	89.11	28.5	1893.31	0.055	98.69	2.01	0.00
29.0-30	24.91	89.14	29.5	1887.51	0.049	100.30	4.00	0.06
						Background	**2.01**	

Trout Pond

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0-1	43.67	98.21	0.5	1999.00	0.673	523.77	3.24	2.15
1-1.5	44.14	96.68	1.25	1998.08	0.648	526.13	6.74	4.48
1.5-2	43.90	96.23	1.75	1996.36	0.632	527.24	5.40	3.60
2-2.5	43.24	95.55	2.25	1994.33	0.617	549.82	5.52	3.75
2.5-3	42.78	95.35	2.75	1991.82	0.601	550.54	4.96	3.37
3-3.5	42.46	94.77	3.25	1989.04	0.585	519.91	4.56	3.01
3.5-4	42.58	94.69	3.75	1985.68	0.510	496.91	4.09	2.64
4-4.5	42.28	94.22	4.25	1982.40	0.434	470.12	4.22	2.64
4.5-5	41.89	94.07	4.75	1979.04	0.358	478.01	4.51	2.84
5-5.5	41.73	93.54	5.25	1975.91	0.283	436.01	4.81	2.86
5.5-6	41.67	93.46	5.75	1972.98	0.268	454.06	5.12	3.13
6-6.5	41.41	93.47	6.25	1969.90	0.253	402.92	4.36	2.45
6.5-7	41.30	93.17	6.75	1966.72	0.237	414.27	4.42	2.54
7-7.5	40.75	93.22	7.25	1963.25	0.222	392.70	3.93	2.16
7.5-8	40.35	93.05	7.75	1959.68	0.199	379.79	3.79	2.03
8-8.5	39.97	93.01	8.25	1956.03	0.176	353.35	3.54	1.77
8.5-9	39.60	93.09	8.75	1952.44	0.153	331.37	3.41	1.59
9-9.5	39.34	93.03	9.25	1949.05	0.130	318.34	3.53	1.57
9.5-10	39.29	92.95	9.75	1945.90	0.117	306.52	3.58	1.52
10-11	38.63	92.28	10.5	1942.78	0.097	271.47	4.58	1.61
11-12	38.53	92.02	11.5	1936.36	0.071	270.26	3.78	1.31
12-13	37.79	91.81	12.5	1930.87	0.046	256.09	4.87	1.52
13-14	37.63	92.05	13.5	1927.35	0.040	243.25	6.06	1.67
14-15	36.74	91.90	14.5	1924.21	0.035	234.26	6.66	1.65
15-16	37.15	91.36	15.5	1921.40	0.030	231.45	7.99	1.90
16-17	37.32	91.40	16.5	1918.96	0.025	221.71	9.63	1.97
17-18	37.18	91.15	17.5	1917.24	0.026	222.11	11.19	2.30
18-19	36.62	90.57	18.5	1915.27	0.026	**213.83**	9.76	1.71
19-20	35.66	90.42	19.5	1912.89	0.027	205.55	8.10	1.15
20-21	35.06	90.26	20.5	1910.14	0.027	201.48	6.94	0.87
21-22	34.45	90.15	21.5	1906.92	0.027	202.53	6.24	0.81
22-23	33.95	90.07	22.5	1903.38	0.027	213.97	6.03	1.06
23-24	33.72	90.29	23.5	1899.46	0.026	**210.82**	5.30	0.87
24-25	33.68	90.03	24.5	1895.22	0.026	207.68	4.78	0.72
25-26	32.72	90.08	25.5	1890.30	0.026	194.07	3.78	0.35
26-27	32.84	90.37	26.5	1884.46	0.026	177.33	2.81	0.02
27-28	32.24	90.18	27.5	1877.48	0.026	**179.12**	2.29	0.04
28-29	32.83	90.34	28.5	1868.22	0.027	180.91	1.66	0.04
29-30	33.03	90.41	29.5	1855.27	0.023	167.21	1.27	-0.07
30-32	33.08	90.55	31	1841.60	0.018	172.58	2.35	-0.05
32-34	33.04	90.55	33	1826.00	0.017	190.19	2.11	0.15
34-36	32.04	89.89	35	1805.67	0.016	173.76	1.42	-0.02
36-38	31.32	88.37	37	1773.50	0.016	170.67	2.64	-0.09
						Background	**1.96**	

Williams Pond

Interval	Loss on Ignition (%)	% H_2O	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g sediment)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0.0-0.5	32.50	97.18	0.25	1999.00	0.914	345.72	31.68	11.26
0.5-1.0	33.02	93.30	0.75	1998.69	0.916	315.50	20.14	5.91
1.0-1.5	33.53	91.82	1.25	1997.91	0.919	318.61	15.48	4.65
1.5-2.0	34.00	91.07	1.75	1996.93	0.879	335.02	15.35	5.14
2.0-2.5	34.70	90.78	2.25	1995.86	0.840	354.22	16.00	5.93
2.5-3.0	34.74	90.54	2.75	1994.78	0.801	368.40	16.86	6.66
3.0-3.5	34.65	90.15	3.25	1993.68	0.761	384.71	18.08	7.61
3.5-4.0	34.51	89.90	3.75	1992.56	0.722	372.04	17.71	7.10
4.0-4.5	34.52	89.78	4.25	1991.44	0.682	375.05	18.16	7.37
4.5-5.0	34.15	89.61	4.75	1990.33	0.701	371.98	17.68	7.09
5.0-5.5	32.44	90.45	5.25	1989.12	0.720	406.21	17.16	7.74
5.5-6.0	32.45	90.44	5.75	1987.94	0.739	384.46	15.89	6.68
6.0-6.5	32.19	90.21	6.25	1986.68	0.759	380.08	14.85	6.14
6.5-7.0	32.64	90.05	6.75	1985.29	0.704	412.26	15.81	7.26
7.0-7.5	33.15	90.10	7.25	1983.94	0.649	401.16	15.88	7.06
7.5-8.0	32.53	90.08	7.75	1982.65	0.699	400.91	15.30	6.80
8.0-8.5	33.19	89.76	8.25	1981.19	0.749	414.93	14.21	6.58
8.5-9.0	33.14	89.99	8.75	1979.48	0.763	437.61	13.21	6.48
9.0-9.5	34.02	89.96	9.25	1977.68	0.778	441.39	12.50	6.19
9.5-10.0	34.14	89.78	9.75	1975.73	0.785	470.31	9.41	4.95
10.0-11	34.58	90.05	10.50	1971.30	0.796	478.17	9.60	5.13
11.0-12	34.51	90.01	11.50	1966.23	0.752	495.83	9.77	5.38
12.0-13	33.96	90.02	12.50	1960.58	0.707	525.26	9.21	5.30
13.0-14	34.66	89.97	13.50	1954.21	0.535	562.80	9.89	5.97
14.0-15	35.59	89.94	14.50	1948.50	0.363	579.80	12.32	7.59
15.0-16	35.36	89.73	15.50	1944.20	0.392	577.78	12.66	7.78
16.0-17	35.34	89.66	16.50	1938.58	0.421	555.70	9.25	5.54
17.0-18	34.89	89.86	17.50	1931.04	0.382	581.86	7.81	4.82
18.0-19	35.82	90.05	18.50	1922.58	0.343	578.24	6.70	4.12
19.0-20	36.39	90.22	19.50	1912.90	0.303	403.66	3.95	1.77
20.0-21	36.62	90.12	20.50	1901.49	0.264	357.83	2.88	1.09
21.0-22	36.18	90.02	21.50	1886.96	0.190	285.47	2.03	0.44
22.0-23	36.39	90.21	22.50	1871.75	0.116	231.00	1.86	0.07
23.0-24	36.94	90.04	23.50	1861.35	0.104	241.18	2.25	0.17
24.0-25	37.10	90.18	24.50	1849.15	0.092	217.93	1.74	-0.04
25.0-26	37.39	90.04	25.50	1835.38	0.079	212.06	1.53	-0.08
26.0-27	37.02	89.84	26.50	1820.09	0.067	200.84	1.48	-0.16
27.0-28	36.51	89.47	27.50	1806.18	0.063	195.22	1.35	-0.19
28.0-29	36.85	89.51	28.50	1787.93	0.060	182.58	0.95	-0.21
29.0-30	37.07	89.23	29.50	1763.37	0.059	184.03		
						Background	**1.65**	

Table 3: Chemical characteristics of peat cores from two ombrotrophic bogs, Maine

Caribou Bog Core 3

Interval	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g peat)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
living	0	1999.00	0.670	62.16		
0-5.0	2.50	1994.33	0.598	89.02	0.37	0.18
5-7.5	6.25	1990.12	0.489	88.99	0.52	0.33
7.5-10	8.75	1987.90	0.427	85.59	1.04	0.84
10-12.5	11.25	1982.88	0.365	95.74	0.70	0.50
12.5-15	13.75	1979.43	0.323	126.03	1.04	0.85
15-17.5	16.25	1976.58	0.282	156.69	1.57	1.38
17.5-20	18.75	1973.44	0.264	162.81	1.48	1.28
20-22.5	21.25	1970.45	0.246	178.40	1.19	0.99
22.5-25	23.75	1968.78	0.233	158.19	1.77	1.58
25-27.5	26.25	1966.13	0.221	126.62	1.14	0.94
27.5-30	28.75	1963.40	0.215	111.90	1.10	0.90
30-32.5	31.25	1959.40	0.208	91.59	0.65	0.45
32.5-35	33.75	1955.90	0.201	87.60	0.72	0.52
35-37.5	36.25	1950.67	0.195	85.35	0.65	0.45
37.5-42.5	40.00	1944.84	0.151	121.95	0.68	0.48
42.5-45	43.75	1936.01	0.107	98.13	0.70	0.51
45-47.5	46.25	1929.42	0.078	82.36	0.65	0.45
47.5-50	48.75	1922.38	0.049	74.68	0.58	0.38
50-52.5	51.25	1918.08	0.047	68.33	0.68	0.48
52.5-55	53.75	1912.93	0.046	64.47	0.54	0.34
55-57.5	56.25	1907.19	0.045	68.72	0.48	0.28
57.5-60	58.75	1901.20	0.043	131.75	0.95	0.76
60-62.5	61.25	1886.97	0.033	86.95	0.42	0.22
62.5-65	63.75	1865.58	0.022	69.27	0.22	0.02
65-67.5	66.25		0.011	73.48		
67.5-70	68.75		0.001	89.25		
70-72.5	71.25		0.002	84.00		
72.5-75	73.75		0.003	79.46		
75-77.5	76.25		0.003	54.14		
				Background	**0.20**	

Eddington Bog Core 1

Interval	Midpoint (cm)	Age of Midpoint (years)	^{210}Pb Activity (bq/g)	Hg Concentration (ng Hg/g peat)	Hg_T (ng Hg/cm^2/yr)	Hg_A (ng Hg/cm^2/yr)
0-5	2.50	1998.00	0.206			
5-10	7.50	1993.69	0.181		2.71	2.17
				101.33		
10-15	12.50	1989.62	0.191		2.18	1.63
				96.45		
15-20	17.50	1985.64	0.159		2.34	1.80
				106.94		
20-25	22.50	1982.59	0.142		3.03	2.49
				111.11		
25-30	27.50	1979.20	0.137		2.60	2.05
				118.03		
30-35	32.50	1976.45	0.143		2.71	2.17
				107.07		
35-40	37.50	1972.36	0.101		2.18	1.63
				89.25		
40-45	42.50	1969.35	0.185		1.37	0.83
				77.95		
45-50	47.50	1959.88	0.134		1.09	0.54
				79.27		
50-55	52.50	1947.12	0.118		1.09	0.54
				105.46		
55-60	57.50	1927.07	0.088		1.08	0.54
				156.38		
60-65	62.50	1897.59	0.042		0.90	0.35
				121.30		
65-70	67.50	1866.91	0.025		0.54	0.00
				46.65		
70-75	72.50					
				26.20		
75-80	77.50					
				18.84		
80-85	82.50					
				19.68		
				Background	**0.54**	

Figure 1: Location of study lakes and bogs near Orrington, Maine

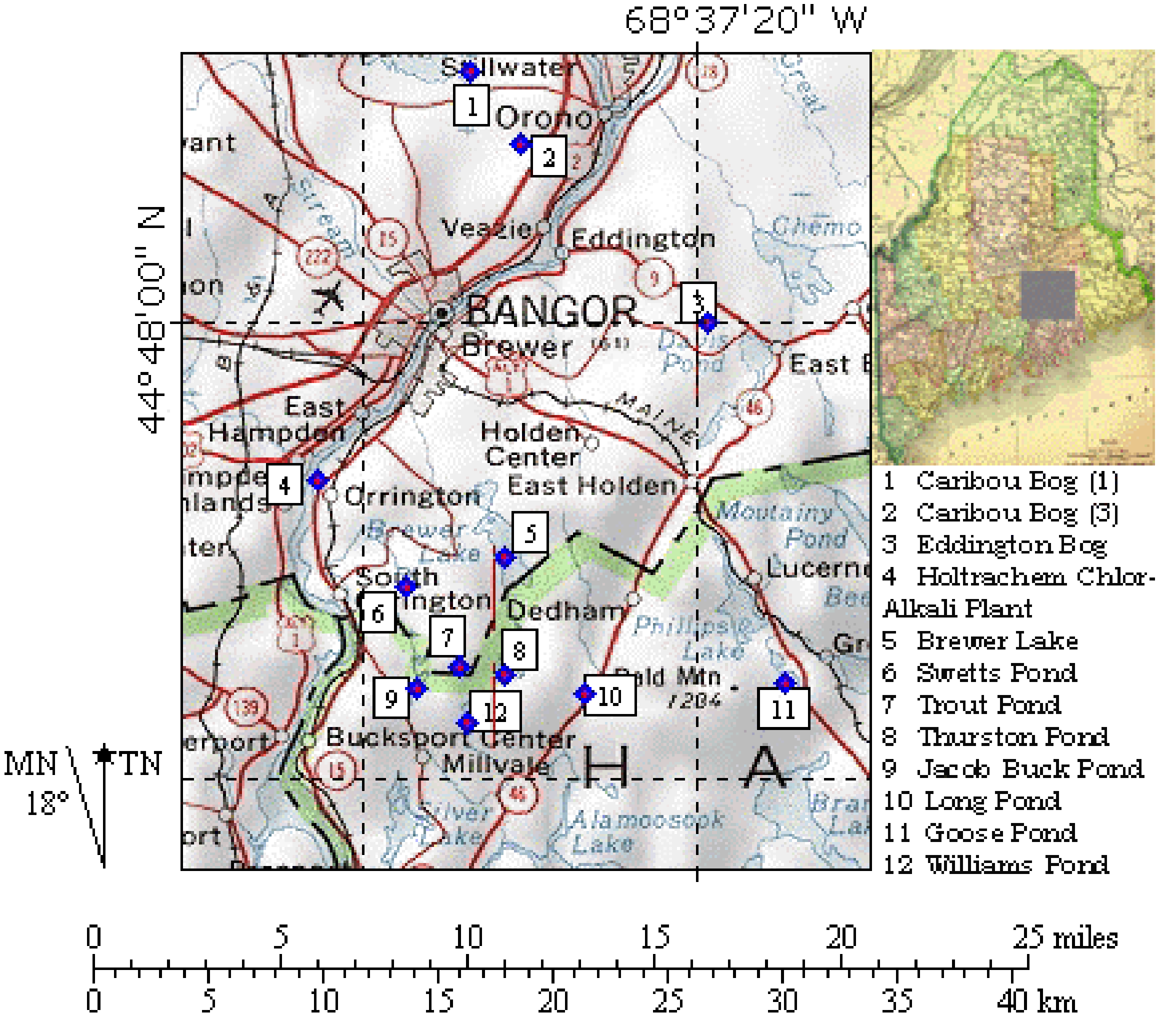


Figure 2: Total Hg concentration and deposition rate of total and anthropogenic Hg, and sediment for Williams Pond, Bucksport, Maine USA

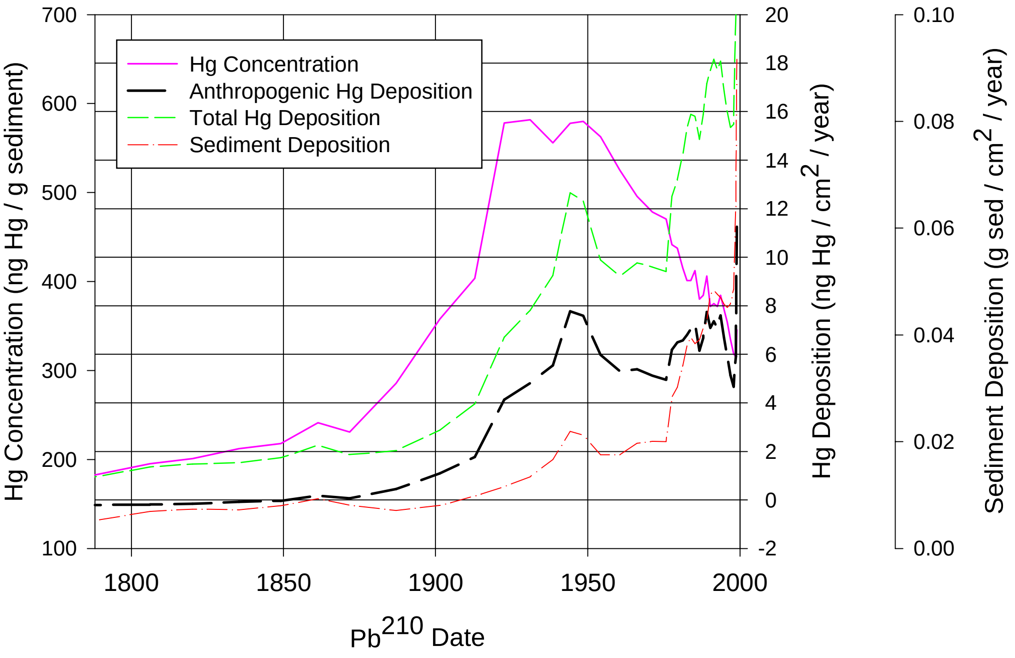


Figure 3: Anthropogenic Hg deposition rates for eight study lakes near Orrington, Maine

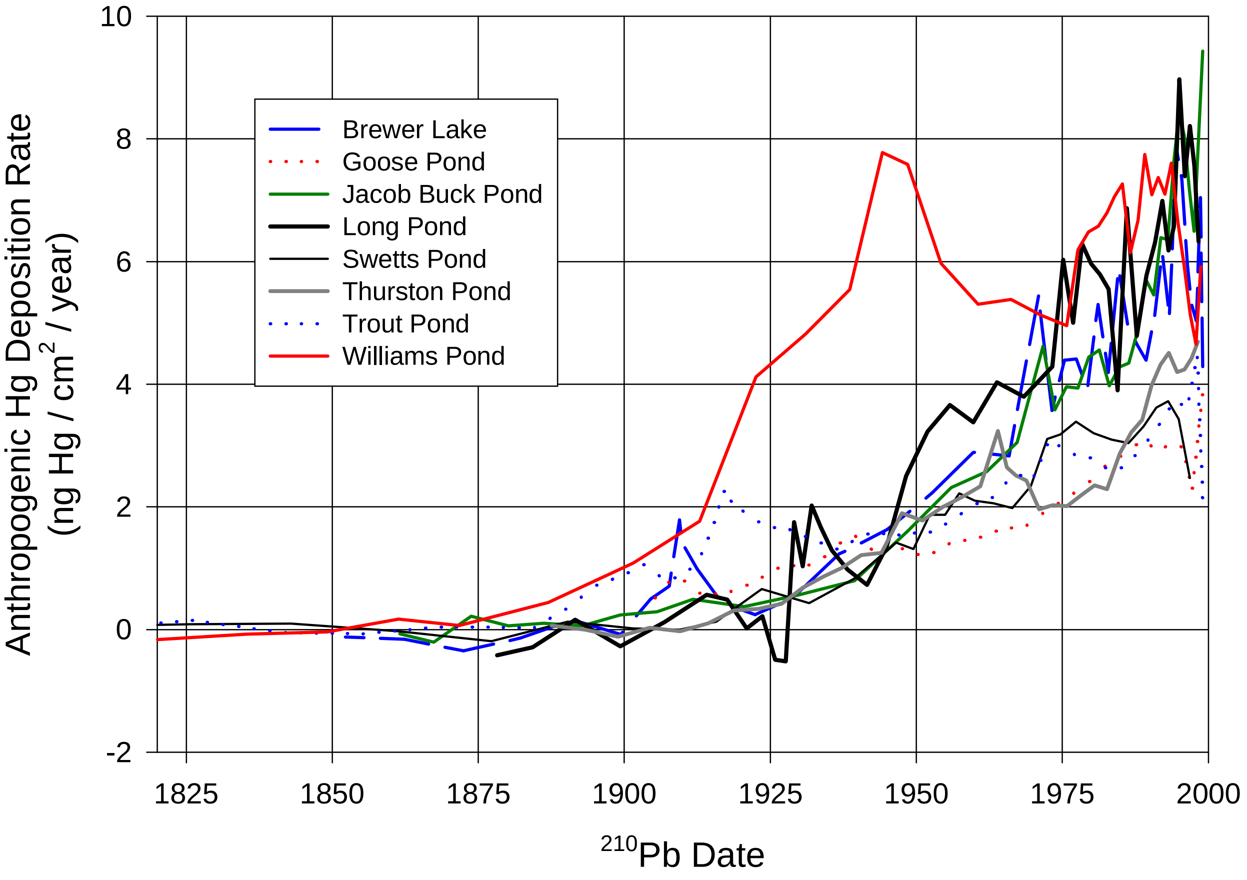


Figure 4: Anthropogenic Hg deposition rates and average for seven study lakes near Orrington, Maine

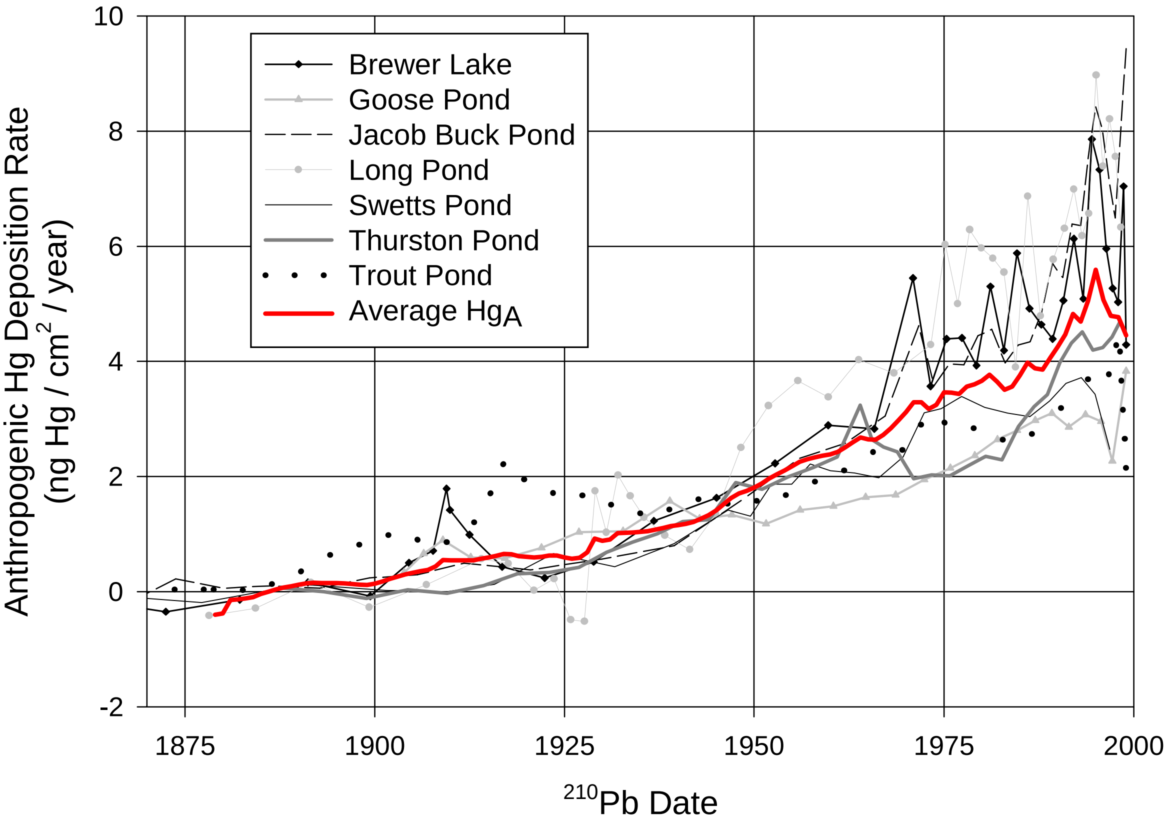
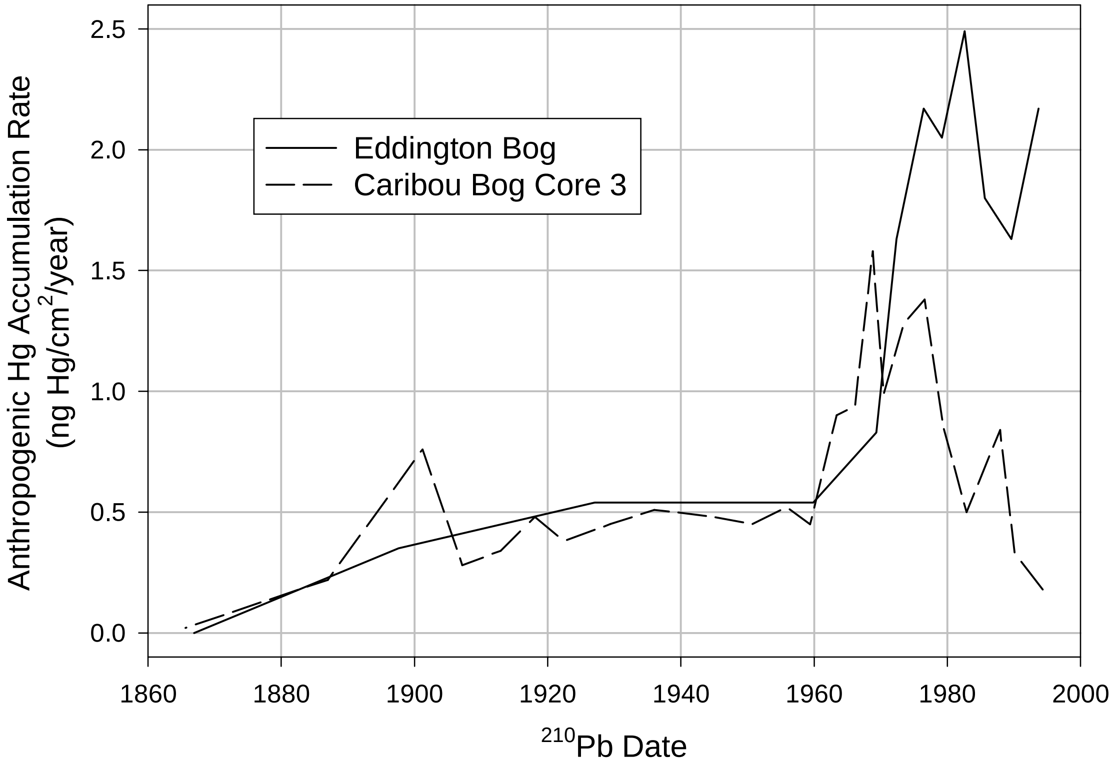


Figure 5: Anthropogenic Hg deposition rates for cores from Caribou and Eddington Bogs, Maine



Basic Information

Title:	Maine Climate Change and Water Use
Project Number:	
Start Date:	9/1/1999
End Date:	8/31/2001
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Drought, Economics
Descriptors:	Climate, Conflict management, Drought, Hydropower, Information Dissemination, Irrigation, Water Resources
Lead Institute:	University of Maine
Principal Investigators:	John M. Peckenham, Robert Lent

Publication

1. Peckenham, J., S. Kahl and S. Vidito, 2001. Proceedings of the Maine Climate Change and Water Use/Availability Workshop, July 26, 2000. 32 p.
2. Peckenham, J., S. Kahl and S. Vidito, 2001. Planning for Future Water Use and Availability, Our Future Water Supply - Is There Cause for Concern. International Conference on the St. Lawrence River Ecosystem, Cornwall, Ont., May, 2001.

Problem and Research Objectives:

Identifying the Problems.

There is a link between climate change and water resources, but over a period of months to years the cause and effect relationships are unclear. Projections of water use and availability are limited by our current inability to predict the direction and magnitude of climate change combined with the natural variations in weather. We do know that water resources are affected by weather and that historical weather patterns are difficult to interpret. The purpose of this workshop is to review the state of our knowledge and identify the data gaps. Specific workshop goals include:

1. What are the predicted regional effects of climate change?
2. How will these changes affect Maine's water resources and supplies?
3. What will be our water requirements in the next two decades?
4. Do we have conflicts with current water resources and what new types of conflicts can be expected?
5. How do we evaluate the need for alternative water supplies?

Methodology:

The changes in weather patterns and yearly variations of climate in Maine have a direct and measurable relationship with water resources. This includes the mass balance of the hydrologic cycle, the timing of demand and recharge, the maintenance of flowing rivers, the ability to support fisheries, hydropower production, and water-related tourism. When totaled, Maine's water resources account for billions of dollars of the state's economy. The stakeholders are not prepared to react to all the potential changes in water resources and it is expected that demands on these resources will only increase over the next decade.

The Climate Change and Water Use Workshop is the first organized attempt in Maine to look beyond problem identification and apply research to generate management objectives. This project brought together the research community, regulatory agencies, and resource managers to coordinate current information and water resource objectives in a common action plan. The potential scale of water resource change could have a tremendous negative effect on all stakeholders. The workshop participants identified how these critical resources can be shared for mutual benefit, or at least to minimize mutual loss.

Our objectives are:

1) To identify the key researchers on regional climate change and weather patterns.

It is essential to get as clear a prediction of decadal-scale trends as possible. The USGS is the primary provider of water resource measurements and the NWS/NOAA is the primary provider of weather and climatic data. There are researchers in Maine and the northeast who have particular expertise on climate changes and this workshop will be the opportunity to get the most current interpretations to the stakeholders.

2) To enhance communication among stakeholders.

Changes to the quantity or quality of water resources will affect everyone in the state. If trends in water resources stress natural systems, then there will be secondary sociological stress. Since water resources are common to a population with often conflicting priorities and needs, this workshop will be the first step in forging new management strategies. This workshop will give key stakeholders an opportunity to work together to develop a strategic plan to respond to the stresses.

3) To develop a draft strategic action plan.

The University of Maine-GMC is taking the lead in water resource educational efforts in the state. The workshop will result in a draft action plan for the Drought Task Force that can be used to manage our collective response to changes in the water resources. As a management tool, it is more effective to have a response action plan with some uncertainties than no plan and a certainty of unclear action.

4) To develop a framework for future action.

Once this workshop is complete, a summary of proceedings and a draft action plan will be prepared. The workshop organization will be a template for future workshops if deemed necessary by the stakeholders.

Principal Findings and Significance:

The following is a summary of the key conclusions of the workshop.

Information Analysis-

- Maine’s weather patterns are naturally variable, but the data do not indicate a consistent trend in any parameter.
- Weather patterns appear to be cyclical with periods of 2 to 30 years.
- The recent patterns reflect a slightly warmer and wetter climate near the coast and a cooler and drier climate in extreme northern Maine.
- Precipitation ranges have become more extreme along the coast due to strong coastal storms.
- Climate models suggest that Maine could become slightly warmer (+3° F) and wetter (+1 inch) over the next several decades.
- Water supply overall is adequate to meet current needs with some notable exceptions in downeast salmon rivers.
- Demand on surface water supply is expected due to agricultural demands.

Planning Guidance-

- Short cycles of 1 to 2 years duration of wet and dry years are probable.
- High intensity precipitation events are more likely.
- Earlier ice-out and peak-spring flow is likely resulting in earlier flood potential.
- Competing quantity demands in certain rivers will increase regardless of climate.
- Predicting flood or drought years is not feasible.
- Demographic changes will have an effect on water quality and quantity, especially in southern and coastal regions.

- Water conservation needs to be part of the management process.

Needs Analysis-

- Water data information collection needs to be coordinated between agencies.
- A centralized hosting of information and data is needed.
- Support is needed to maintain existing monitoring activities.
- Research is needed to understand trends in data.
- Better quality consumptive-use information is needed.
- Climate forecasting is needed but accuracy depends upon a new generation of high-resolution climate models.
- Work needs to begin on developing a comprehensive water-management policy.

Basic Information

Title:	Impact of Manure on Stream Water Quality
Project Number:	
Start Date:	4/1/1999
End Date:	3/20/2000
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Surface Water, Waste Water
Descriptors:	Agriculture, Nutrients, Non Point Pollution
Lead Institute:	University of Maine
Principal Investigators:	John Jemison, John Jemison

Publication

Abstract

Wesserunsett Stream and Cold Brook in Somerset County, Maine offered a unique opportunity to assess the effects of manure runoff from dairy farms on benthic macroinvertebrate (BMI) communities and water quality. Both farms have inadequate manure storage facilities, limit stream access by cattle, and choose not to use chemical pesticides and fertilizers. Nutrient loads (N,P) and bacterial counts were measured to determine the presence of manure runoff in the streams. Macroinvertebrate communities were sampled with artificial substrates placed above and below the pollution inputs for a 28-day colonization period. Statistical analyses of total BMI abundance, EPT abundance, genus richness, functional group abundances, and separate genus abundances were conducted to determine significant differences in community structure between the upstream and downstream sites. The Maine Department of Environmental Protection linear discriminant model was used to ascertain each site's water quality class. No significant difference between the two sites at Cold Brook were found for any community parameters during either the 1999 or 2000 sampling events. Both sites in Cold Brook were assigned Class B rating, indicating that manure impacts are unlikely in this stream. In 1999, Wesserunsett Stream had no significant differences in abundance or richness, except for a significant downstream decrease of Trichoptera and filter feeders. In 2000, the abundance of Trichoptera and scrapers were significantly decreased at the Wesserunsett downstream site; no other significant differences in abundance or genus richness were detected. Although both sites in Wesserunsett Stream were listed as Class A in 1999, the downstream site changed to Class B during the following year, despite a relatively dry year with little runoff from the site. The re-classification of Wesserunsett's

downstream site suggests that the manure runoff produced moderate pollution in this stream.

Introduction

Organic enrichment of surface waters persists as a major problem in the United States, despite reductions in point sources such as municipal and industrial wastewater discharges (U.S. EPA 1990, 1996). Currently, non-point sources generate most of the excessive organic carbon and nutrient inputs found in freshwater systems (Carpenter et al., 1998). Although urban runoff, paper-mill effluent, and food-processing wastes produce substantial amounts of organic pollution, agricultural operations release the greatest quantity of nutrients into adjacent water bodies (Konrad et al., 1986; U.S. EPA, 1996). Animal manure, either as fertilizer applied to cropland or wastes generated by livestock operations, is the predominant source of agricultural inputs (Carpenter et al., 1998; Eghball and Gilley, 1999). Generally, the amount of organic carbon, nitrogen, and phosphorus exported depends on the season, quantity and timing of rainfall, chemical form of the nutrients, local topography, soil type, and riparian vegetation (Young et al., 1980; Nelson et al., 1996; Eghball and Gilley, 1999).

In aquatic systems, the effects of agricultural runoff extend beyond eutrophication due to excessive nutrient inputs (Carpenter et al., 1998). Other impacts include changes in carbon fluxes regulated by biological processes (Fontvieille and Cazelles, 1990), blooms of filamentous bacteria and algae (Curtis, 1969; Couillard and Li, 1993; Lemly, 1998), high fecal coliform concentrations (Stephenson and Street, 1978), and decreases in dissolved oxygen (DO) levels (McCahon et al., 1991; Ackerman and Taylor, 1995).

Organic matter from manure entering streams causes aquatic microbial populations to increase because the carbon provides a new food source; this population explosion depletes DO concentrations since the microbes use oxygen in metabolic activities (Overcash et al., 1983). The excess carbon and nutrients provide ideal growing condition for algae, aquatic macrophytes, and a complex matrix of filamentous bacteria and fungi called "sewage fungus" (Gray, 1982; Couillard and Li, 1993; Carpenter et al., 1998). The resulting oxygen shortages due to the senescence and decomposition of these organisms may adversely affect fish and aquatic macroinvertebrates (McCahon et al., 1991; Ackerman and Taylor, 1995).

Aquatic plants and "sewage fungus" may also modify stream habitats, leading to changes in the diversity of plants and animals. Rooted macrophytes can alter local current, which promotes the succession of plant species by enhancing deposition and erosion (Madsen and Adams 1989). The modification of benthic habitats through the loss or accumulation of sediments may favor the colonization or propagation of some macroinvertebrate species but exclude others (Lemly, 1982). The filamentous bacteria and fungi comprising "sewage fungus" can form macroscopic slimes capable of completely covering any available substrates, including aquatic fauna (Curtis, 1969). By coating the streambed, these slimes alter the habitat of the local invertebrate fauna, leading to changes in species abundance and diversity (Gray, 1982; Wellnitz et al., 1994). Additionally, the slimes reduce fish populations by smothering eggs and invertebrate prey (Gaufin and Tarzwell, 1955). The aquatic insects suffocate because their gills become coated with the filamentous matrix; insect abundance and diversity may change according to the relative tolerances of the species present in a given community (Lemly, 1982; Lemly, 1998).

Although many methods of assessing pollution impacts in streams exist, biological approaches based on benthic macroinvertebrates (BMIs) are particularly appropriate because they can detect both acute (Seager and Abrahams, 1990; Willemsen et al., 1990; McCahon et al., 1991) and chronic (Whitehurst and Lindsey, 1990; Bazzanti, 1991; Cao et al., 1997) effects of organic enrichment. Most of the biotic indices in use today classify the pollution status of a stream or reach based on the pollution-tolerance values assigned to sampled macroinvertebrates (Rosenberg and Resh, 1996). Whitehurst and Lindsey (1990) stated that the Chandler Score Index and the *Gammarus:Asellus* Ratio indicated severe organic pollution immediately below discharge sites, and moderate pollution levels further downstream, because fewer taxa were present at the heavily polluted sites. They suggest that this loss of diversity was due to the decrease in pollution-intolerant species (Whitehurst and Lindsey, 1990). Using a modified Chandler-ASPT Index, Cao et al. (1997) reported substantial losses of intolerant species at heavily polluted sites with concurrent increases in the number of tolerant species.

Other observers indicated similar findings in their studies concerning the effects of organic pollution on stream macroinvertebrate communities (Dance and Hynes, 1980; Marsh and Waters, 1980; Pinder and Farr, 1987; Bazzanti, 1991). According to Dance and Hynes (1980), aquatic insect diversity can be similar in organically enriched and non-polluted streams; the loss of intolerant species may be compensated by a gain in the number of taxa that can withstand the low oxygen levels frequently found in nutrient-enriched waters. Pinder and Farr (1987) reported that the apparently similar abundances between clean and moderately polluted sites may be due to an increase in taxa considered true indicators of organic inputs, especially certain species of Oligochaeta. A greater number of tolerant species may reflect a shift in feeding-group dominance because these organisms are commonly filter-feeders or collector-gatherers that utilize the abundant fine or coarse particulate matter generated by organic pollution (Bazzanti, 1991). These persisting taxa may be rare or absent at unpolluted sites but their abundance gradually increases in response to the amount of organic pollution present in the stream (Coa et al., 1997).

Many studies examining the influences of organic pollution on stream macroinvertebrates used sewage effluent (Seager and Abrahams, 1990; Whitehurst and Lindsey, 1990; Bazzanti, 1991) or a combination of sewage and agricultural discharges (Pinder and Farr, 1987; Willemsen et al., 1990) as the source of enrichment. Most work evaluating the effects of agricultural operations fail to isolate the impacts of nutrient enrichment due to animal-waste discharges from other pollutants such as pesticides, sedimentation, or cropland drainage (Dance and Hynes, 1980; March and Waters, 1980; Lemly, 1982). Few studies have examined the effects of a single pollutant source such as concentrated manure runoff (Rutt et al., 1993; Lemly, 1998). Although Rutt et al. (1993) reported runoff from livestock operations as the only source of organic pollution, they include a variety of pollutant types such as milk-parlor washings, lagoon overflows from sheep-manure, and silage effluent from beef-cattle waste. The various wastes are difficult to characterize because manure composition differs depending on the type of animal and its diet (Elrashidi et al., 1999). Lemly (1998) isolated runoff from beef-cattle pastures as the sole nutrient input but this source is diffuse since it is derived from extensive areas of land.

Wesserunsett Stream located in Somerset County, Maine offers a unique opportunity to examine the impacts of a concentrated source of dairy manure on benthic macroinvertebrate communities. The Maine Department of Environmental Protection (MDEP) classifies the Wesserunsett Stream as a “priority water” for bacterial and nutrient remediation. Since farming is a major land use in the Wesserunsett watershed, runoff from agricultural operations is the probable source of contamination. Two dairy farms likely contribute to the organic pollution in the Wesserunsett Stream and one of its tributaries, Cold Brook. Both farms have inadequate storage facilities, limit stream access by cattle to minimize erosion, and do not use chemical pesticides or fertilizers that might obscure effects due to organic pollution. Between the 1999 and 2000 growing seasons, changes in manure management were made at the Cold Brook stream farm. A manure storage and spreading plan was developed to meet the requirements of the law. The farm on the Wesserunsett Stream met the legal requirements of the law, so no changes were made at that farm between the 1999 and 2000 sampling year. Because these factors are controlled, manure runoff should be the only pollutant entering these stream reaches during the course of this study (Jemison et al., 1999).

Although the study sites on Cold Brook and Wesserunsett Stream are located within sight of each other, the flow and substrate properties in each stream vary considerably. The Wesserunsett exhibits the typical cobble substrate found in fast flowing waters; Cold Brook possesses the sand or silt substrates associated with very slow currents (Allen, 1995; personal observation). Most researchers examining the effects of organic pollution on benthic macroinvertebrates conduct their investigations in fast flowing streams, similar to the Wesserunsett (Dance and Hynes, 1980; Marsh and Waters, 1980; Lemly, 1982). Relatively little is known about the impacts of organic pollution in slow-flowing streams because few scientists work with these systems (Cook, 1976; Bazzanti, 1991). Therefore, the conditions in Cold Brook provided a good opportunity to investigate the effect of nutrient enrichment in a stream with low current velocities.

The main objective of this study is to assess the impacts of manure runoff on benthic macroinvertebrate community structure and water quality of Wesserunsett Stream and Cold Brook during two successive years. This will be assessed by measuring benthic macroinvertebrate communities below and above each farm and assessing changes to the macroinvertebrate communities. When possible, water nutrient and bacteria samples were taken to support what we found in the stream invertebrate data.

Methods

Habitat Analysis

A macro-habitat analysis was conducted to provide an overview of the general area or watershed in which the study sites are located. This ensured that the sites are as similar as possible in order to minimize the effects of confounding influences (i.e., geographic location and physical-chemical traits of streams) that influence the distribution and abundance of benthic macroinvertebrates (Vannote et al., 1980; Davies and Tsomides, 1997). The description included the site's latitude and longitude, distance from the nearest municipality, and local land use determined from topographic maps. A description of the area's topography was also included because the habitat's spatial organization influences critical physical components such as light intensity, temperature, soil properties, and drainage (Brower et al., 1990). Therefore, the site's elevation above sea level, the slope and form of the encompassing terrain, and stream channel characteristics were all assessed and included in this report.. The channel delineation describes the dominant features, such as average stream width and depth (Davies and Tsomides, 1997).

The microhabitat portion of the analysis is a recored of the characteristics of the specific sampling sites, to ensure the selected habitats are comparable (Kendall et al., 1996). Data such as canopy coverage, substrate composition and embeddedness, temperature, and water velocity were all obtained as described by the Maine Department of Environmental Protection (MDEP) methods for analyzing Maine's fresh waters (Davies and Tsomides, 1997).

Chemical Analysis

In conjunction with the University of Maine Cooperative Extension, a chemical survey was conducted that includes general descriptive measures and parameters specific to the suspected pollutant. For the general habitat description, dissolved oxygen, pH, and specific conductivity were measured with appropriate field meters, since these parameters are among the dominant ones that can affect aquatic environments. Because manure runoff suspected of entering the study streams may lead to nutrient enrichment, the levels of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and phosphorous (P) were sampled within four hours of a storm event sufficient in size to cause overland flow. Nutrient levels were determined according to standard methods. Water samples for bacteria (E. coli) were collected in duplicate at the four sampling sites by the personnel at the University of Maine Cooperative Extension and processed by the Kenebec Sanitary Treatment Facility. The water samples were filtered through 0.45 m membranes. The NO_3-N and NH_4-N analyses were run colorimetrically by autoanalyzer; phosphorous was determined by plasma emission.

Microinvertebrate Samples

Using the MDEP methods, macroinvertebrate sampling events were conducted during the fall of 1999 and 2000. Rock baskets were placed in Wesserunsett Stream and Cold Brook above and below the manure runoff; each sampling site will have three replicate rock baskets, which were left for a colonization period of 28 days. Following this period, each rock basket was removed with a sampling net to prevent the loss of BMIs during the collection process. After preserving each sample in 70% ethyl alcohol (EtOH), the BMIs were sorted by hand in the laboratory and identified to genus using appropriate keys in Merritt & Cummins (1996).

Bacterial growth on aquatic insects may also indicate elevated nutrient conditions in streams (Lemly, 1998). The addition of nutrients to streams, especially organic carbon, produces bacterial blooms of filamentous genera, such as *Sphaerotilus* and *Leptothix* (Curtis, 1972, Lemly, 1982). Lemly (1998) suggests that the percent of bacterial growth on benthic macroinvertebrates is a reliable indicator of nutrient enrichment in streams. Significantly lower densities of insects were found in nutrient enriched reaches due to the accumulation of bacterial growth on the insect's respiratory structures (Lemly, 1998). Visual assessments of the level of bacterial growth on aquatic insects was used as an additional method of detecting detrimental impacts of manure runoff into streams. If the insects exhibited high levels of bacterial growth, water samples were collected and plated on agar mediums to determine whether the “sewage fungus” organisms are present in the study streams.

Data analysis

For the field study, t-tests were used to determine significant differences between the upstream and downstream sites per stream. The difference for total abundance, genus richness, EPT abundance (Ephemeroptera, Plecoptera, Trichoptera), abundance per genera and abundance of each functional-group were all calculated. In addition, the Maine DEP statistical model (linear discriminanth analysis) was used to assess the impact of manure runoff in each stream (Davies & Tsomides, 1997). The Maine DEP system uses 25 quantitative variables to determine the probability that an unknown sample meets the criteria for one of the four water quality classes listed in Maine’s Water Classification law. The biological standards for each class are described in Table 1 (Davies et al. 1995, 1999).

Results

Habitat Analysis

The study sites at Wesserunsett Stream were located approximately 4.25 km northeast of Skowhegan, Maine (latitude 44° 47´N; longitude 69° 40´W). The sites had an elevation of about 490 m and the stream gradient was 25 m/km. The surrounding terrain was consisted of rolling pastures and upland mixed forests; canopy cover was less than 25 percent. The substrate composition was primarily gravel and rubble-sized rocks that were about 25-50% embedded; algae and macrophyte growth was sparse and no foreign materials were found.

The sites at Cold Brook were roughly 4 km from Skowhegan, Maine just above the confluence with Wesserunsett Stream (latitude 44° 47´N; longitude 69° 41´W). The sites were located approximately 490 m above sea level and had a stream gradient of 20 m/km. The stream had an open canopy (< 25% shaded) and was surrounded by pastures, except for a narrow strip of trees and shrubs along each bank. Macrophyte and algae growth were sparse at both sites, although a greater amount of aquatic vegetation occurred upstream. Both sites contained foreign debris. The substrate at the upstream site consisted of approximately equal amount of sand and gravel that were over 75% embedded. The downstream substrate was composed of mostly gravel with lesser amounts of rubble-sized rocks that were about 75% embedded. Stream depth, width, flow rates, and temperature for both streams are listed in Table 2.

Chemical Analysis

Although a lack of proper equipment prevented the collection of field data during the 1999 sampling season, measurements of dissolved oxygen, conductivity, and pH were conducted during the 2000 season and appear similar for all sites (Table 2). Although nutrient standards are generally lacking for streams, water quality problems are likely to occur if phosphorous and NO_3-N levels exceed 0.13 and 10 mg/L, respectively (Younos et al., 1998). The maximum level of NH_4-N that is considered safe for freshwater fish is 2.47 mg/L (USEPA, 1985). Nitrogen and phosphorous were below detection limits in the water samples collected during 1999. According to the results of the 2000 nutrient analyses, the downstream NH_4-N and P values exceeded the acceptable limits in

Wesserunsett Stream but NO_3-N was lower than the level considered potentially detrimental. None of the nutrient levels were above the acceptable limits in Cold Brook that year (Table 3).

Microinvertebrate Samples

The results for Cold Brook indicated a greater abundance of benthic macroinvertebrates below the pollution source than above but this increase was not significant for either 1999 or 2000 (Figure 1). Genus richness was not significantly different between the upstream and downstream sites for either year (Figure 2). The total EPT abundance did not differ significantly between sites during 1999 or 2000 (Figure 3) and there were no significant differences when each family was compared separately (Figure 4). None of the functional groups exhibited significant differences in abundance between the above and below pollution sites (Figure 5). In the individual genera comparisons, only the abundance of *Stenonema* (Ephemeroptera; Heptageniidae) showed a significant decrease at the downstream site in 1999. During 2000, *Cricotopus*, *Dicrotendipes* (Diptera; Chironomidae) and *Hydropsyche* (Trichoptera; Hydropsychidae) significantly increased in abundance downstream; *Helicopsyche* (Trichoptera; Helicopsychidae), *Paraleptophebia* (Ephemeroptera; Leptophlebiidae), and *Planorbella* (Gastropoda; Planorbidae) significantly decreased in abundance downstream. The separate genera t-test results are listed in Appendix 1. According to the Maine DEP classification model, there were no significant differences between the upstream and downstream sites in Cold Brook because both are listed as Class B for 1999 and 2000 (Table 4).

The results for Wesserunsett Stream suggest that a greater abundance of benthic macroinvertebrates may be present above the pollution source than below it, although the difference in total abundance was not significant for either 1999 or 2000 (Figure 1). For both years, genus richness between the upstream and downstream sites did not differ significantly (Figure 2). During 1999 and 2000, the total EPT abundance between both sites was not significantly different although the abundance of Trichoptera was significant greater at the downstream site (Figures 3 and 4). In 1999, there was a significant decrease in filter feeders but the other functional groups did not exhibit significant differences (Figure 5). In 2000, the number of scrapers significantly decreased although the abundance of the other functional groups did not significantly differ between sites (Figure 5). The results of the 1999 individual genera t-tests showed that *Brachycentrus, Hydropsyche*, and *Psilotreta* (Trichoptera; Brachycentridae, Hydropsychidae, and Odontoceridae, respectively), and *Simulium* (Diptera; Simuliidae) had significantly decreased abundances at the downstream sites. During 2000, *Pteronarcys* (Plecoptera; Pteronarcydae) significantly increased downstream, while *Helicopsyche* (Trichoptera; Helicopsychidae) significantly decreased downstream. The Maine DEP classification model indicated that there were no significant differences between the upstream and downstream sites during 1999 because both sites were listed as a Class A water body. In 2000, the upstream site retained its Class A listing but the downstream site's listing changed to Class B (Table 4).

Additional Analyses

The total coliform analysis for 1999 indicated that total coliform counts were generally greater than the recommended bacteriological standard for surface waters

(10,000 organisms/100 ml of water; USDI, FWPCA, 1968). The E. coli counts at both Cold Brook sites usually met or exceeded the accepted 64 organisms / 100 ml of water for Class B streams (Davies et al., 1995). In Wesserunsett Stream, the E. coli counts exceeded the standard on two out of three dates at the downstream site (Table 5). No coliform samples were collected during 2000 because the runoff-producing storms occurred on the weekends and the Kenebec Sanitary Treatment Facility only processed samples from Monday to Thursday.

No macroscopic bacterial growths were found on any benthic macroinvertebrates during either the 1999 or 2000 field seasons. Therefore, water samples were collected to determine the presence or absence of the "sewage fungus" organisms in Cold Brook and Wesserunsett Stream. The constituents of "sewage fungus" were identified in lab-cultured colonies from the water samples, indicating low levels of these organisms in the study streams.

Discussion

Manure runoff appears to be reaching both Cold Brook and Wesserunsett Stream during storm events. The elevated total coliform and E. coli counts in both study streams signifies the presence of manure because the occurrence of these bacteria is directly related to the occurrence of animal wastes in aquatic environments (Stephenson and Street, 1978). Excess nitrogen and phosphorous in streams are typically indicative of runoff from agricultural activity, such as manure storage or fertilizer applications (Carpenter et al., 1998; Eghball and Gilley, 1999). While N and P were below detection in 1999, both streams showed elevated levels of these nutrients during 2000. The nutrient levels in Cold Brook were below recommended levels so the manure inputs are unlikely to produce detrimental effects in this stream. In Wesserunsett Stream, the NH_4-N and P levels downstream from the manure runoff were greater than the acceptable limits, increasing the potential for detrimental effects at this site (Younos et al., 1998). A more consistent and thorough sampling schedule for monitoring the manure runoff may have improved the documentation of organic enrichment in the study streams (Line et al., 1998). However, timing of precipitation events, and distance to the site made this documentation more difficult than expected.

The influence of manure runoff appears to be short-lived in Cold Brook as indicated by the lack of significant differences in the benthic macroinvertebrate communities occurring above and below the organic input. Cold Brook generally exhibited an increase in BMI abundance, genus richness, EPT abundance, and functional-group abundances at the downstream site in relation to the upstream site, although these differences were non-significant. Similar abundances and genus richness between clean and moderately polluted streams may be due to tolerant species replacing intolerant ones at the polluted site (Dance and Hynes, 1980; Coa et al., 1997). The greater number of tolerant species may reflect a shift in functional-group dominance to filter feeders and collector-gathers because these organisms often benefit from the particulate matter generated by organic pollution (Bazzanti, 1991; Nelson et al., 1996).

The individual genus comparisons from Cold Brook do not substantiate the idea that the loss of intolerant species was compensated by an increase in tolerant species since a greater number of Ephemeroptera and Plecoptera were found at the downstream sites. These groups are notoriously sensitive to the low oxygen levels, indicating the absence of heavy organic pollution (Hynes, 1960; Hawkes, 1979). The downstream increase of filter feeders and collector-gatherers in Cold Brook appears to support the hypothesis that increases in particulate matter from manure runoff results in an increase in the abundance of these functional groups. Because the shift in Cold Brook's functional groups was non-significant, however, this difference could be due to natural variation in microhabitats or colonization rather than the result of moderate organic pollution (Willemsen et al., 1990).

Another possibility for a lack of significant results in Cold Brook may have to do with the type of sampling method used in this stream. Rock baskets were used to collect the BMI samples in Cold Brook because the substrate characteristics of this stream technically met the Maine DEP criteria for the use of these devises, although the stream's substrate particles were typically finer than the rocks used in the baskets (Davies and Tsomides, 1997). However, these samples may not have been representative of the benthic macroinvertebrate communities in Cold Brook because species with a preference for a different substrate or particle size may not have colonized the rock baskets (Williams and Mundie, 1978; Khalaf and Tachet, 1980). By excluding the finer sediments found in Cold Brook, some organisms that typically inhabit sandy substrates, such as many Oligochaeta and Chironomidae, may also have been excluded from the samples. Because many of these organisms are good indicator species for detecting moderate organic pollution in running waters, their exclusion may have prevented the identification of detrimental effects from the manure inputs (Bazzanti, 1991).

The results from the Maine DEP statistical analyses indicate that the impact of organic pollution in Cold Brook was not significant in either year because both sites were identified as Class B water bodies. Although pollution studies typically rely on statistical comparisons of the sites above and below the pollution source, the linear discriminant model used by the Maine DEP determines a site's aquatic life class independently of data from a matched reference site. Each unknown sample is compared to the characteristics of the four groups defined in the model and assigned to a specific class based on the probability that the sampled site fits the traits of its designated class. Because both sites in Cold Brook were assigned to Class B, these sites were comparable to each other and all Class B streams in the state of Maine (Davies et al., 1995; Davies et al., 1999). Lastly the change in manure management at the farm on Cold Brook between 1999 and 2000 did not appear to affect benthic macroinvertebrate populations.

During both years, the results for Wesserunsett Stream indicate a non-significant decrease in BMI and EPT abundances below the pollution source. Although the lower abundances of most functional groups at the downstream site were not significant, two groups exhibited significant decreases during different years. Filter feeders were significantly less abundant in 1999 and scrapers were significantly less abundant in 2000. If manure runoff was impacting the stream, a shift toward increased numbers of filter-feeders and scrapers at the downstream site would be expected due to the increased nutrient and organic carbon loads (Bazzanti, 1991; Nelson et al., 1996). Therefore, these patterns most likely resulted from natural differences in habitats and colonization rates unless the manure was detrimental to some of the benthic organisms (Willemsen et al., 1990).

The Maine DEP classification model assigned Class A listings to the upstream and downstream sites in Wesserunsett Stream during 1999, indicating that the water quality at both sites were comparable. Since Class A streams have high quality water by definition, Wesserunsett Stream would not appear to be affected by the manure runoff. The change in the downstream site's classification to Class B in 2000 suggests that moderate impacts from the manure runoff may have occurred between the two sampling dates. The individual genus comparisons showed a decreased abundance of Class A indicator taxa at the downstream site in 2000; this may have contributed to the decrease in the site's classification because these organisms tend to be pollution sensitive species (Davies, 1995).

The Maine DEP classification model may provide a more accurate assessment of the water quality in Wesserunsett Stream than the separate statistical analyses, such as total BMI abundance and genus richness. Rather than relying on a few independent tests or biotic indices, the DEP's model uses twenty-five different biological community variables to determine the assignment probability of an unknown sample to one of four water quality classes (Davies, 1995). Separate tests or indices may detect differences between pristine and heavily polluted sites, but they often fail to distinguish finer distinctions in water quality (Cao et al., 1997). Changes in community structure are a complex function of species richness, composition, relative abundance and density of individuals. A single community attribute cannot adequately describe and quantify community changes (Boyle et al., 1990). Moreover, some traditionally measured attributes are complex variables. For example, changes in species richness are caused by interactions between species loss and species gain; thus, a consistent value of species richness may obscure a significant alteration in species composition. Similarly, two communities with identical species compositions can have substantial differences in the relative abundances of the constituent species (Boyle et al., 1990; Cao et al., 1997). According to the individual comparisons of richness or abundances, the two sites in Wesserunsett Stream were not significantly different from each other during either year, indicating little or no impacts due to manure runoff. However, the DEP model detected a significant difference between the sites in 2000 because the additional variables incorporated into the model increased its sensitivity enough to detect the moderate change in water quality (Davies, 1995).

Despite manure runoff entering the streams, the water quality in Cold Brook and Wesserunsett Stream remains fairly high since a rating of Class B was the lowest classification that either stream received. This classification indicates that the effects of the organic pollution may be only slight to moderate because the ambient water quality in Class B streams must be sufficiently great to support all indigenous species without detrimental community changes (Davies, 1995; Davies, 1999). One reason for the apparent lack of harmful effects due to manure runoff may be each stream's capacity for self-purification. In large streams, such as Cold Brook and Wesserunsett Stream, the impacts of pollution inputs may be diminished through dilution and mixing with large volumes of better quality water from upstream (Willemsen et al., 1990). The high flows of these third order streams may have flushed the organic pollution out of the stream reach quickly enough to prevent the contaminant from causing community changes in the downstream benthic fauna (Schlosser and Karr, 1981; Willemsen et al., 1990). The excess organic load may also be eliminated or transformed by microbial assimilation or sedimentation (Fontvielle and Cazelles, 1990).

A second explanation for the moderate levels of organic pollution in the study streams involves the buffering capacity of the riparian vegetation. At both study locations, the manure runoff must flow across approximately 100 m of pasture before entering the streams. Bands of indigenous or planted vegetation along streams can significantly decrease the amount of nutrients in manure runoff as the water moves down slope. Because buffer strips between 20-35 meters wide were apparently effective in reducing the nutrient loads in manure runoff, the vegetation along Cold Brook and Wesserunsett Stream may be sufficiently wide enough to lessen the effects of the organic pollution (Young et al., 1980; Schlosser and Karr, 1981; Younos et al., 1998).

Cold Brook and Wesserunsett Stream differed from previous studies because dairy farms, which were the source of the manure runoff, did not use chemical fertilizers or pesticides and prevented cattle from entering the streams. Since previous studies usually did not isolate the impacts of organic enrichment from these other sources of pollution, the actual effects of organic enrichment may have been obscured by the effects of sedimentation or pesticides (Dance and Hynes, 1980; March and Waters, 1980; Lemly, 1982). Although the results of this study suggests that a concentrated source of dairy manure appears to produce only moderate impacts on water quality and BMI communities, additional research is needed to confirm these findings. The moderate level of pollution seen in Cold Brook and Wesserunsett Stream may be due to their self-purifying capacity but streams with a lower initial water quality may exhibit more profound effects (Schlosser and Karr, 1981; Willemsen et al., 1990). If the farm near Wesserunsett Stream corrects the manure storage problems, subsequent monitoring of this stream is recommended to assess the changes in BMI communities and water quality following the removal of the pollution source.

Laboratory and field studies should be conducted to determine if the temporary increase in nutrient concentration following runoff events causes short-term effects on macroinvertebrates in streams (Younos et al., 1998). Stream macroinvertebrates are usually able to avoid many adverse conditions by swimming or drifting downstream from a pollution source. Because these animals have the capacity to migrate, they can often re-colonize the discharge area once the unfavorable conditions improve (Willemsen et al., 1990). Additional research is also needed to examine the effects of repeated ammonia exposures on benthic macroinvertebrates because episodes of manure contamination are rarely isolated incidents; manure runoff usually coincides with intermittent rain events so stream fauna are subjected to pulses of ammonia with every storm (McCahon et al., 1991; Line et. al., 1998). Studies examining the effects of environmental stressors on benthic macroinvertebrates indicate that they exhibit increased sensitivity with longer or repeated exposures (Maki et al., 1975; Spehar, 1978; Weatherly & Ormerod, 1987).

TABLES AND FIGURES

Table 1. Maine's water quality classification system for rivers and streams, with associated aquatic life and habitat standards (adapted from Davies 1995).

Class	Management	Biological Standard
A	High quality water for recreation and ecological interests. No discharges or impoundments permitted.	Habitat natural and free flowing. Aquatic life as naturally occurs.
B	High quality water with limited human interference. Discharges limited to non-contact process water or highly treated waste-water equal to or better than the receiving water. Impoundments allowed.	Habitat natural. Aquatic life as naturally occurs.
C	Good quality water. Discharge of well treated effluent with ample dilution permitted.	Habitat unimpaired. Ambient water quality sufficient to support all life stages of indigenous aquatic species. Only non-detrimental changes in community composition allowed.
Non-Attainment	Poor quality water that does not meet the minimum requirements for Class C.	Habitat impaired. Poor aquatic life characteristics.

Table 2. Habitat analysis results for Cold Brook (CB) and Wesserunsett Stream (WS) in 1999 and 2000. Up = upstream, Down = downstream.

	1999				2000			
Parameter	CB - Up	CB - Down	WS - Up	WS - Down	CB - Up	CB - Down	WS - Up	WS - Down
Width (m)	24	22	25	24	15.5	11.8	11.7	11.2
Depth (cm)	70	150	79	86	32	48	33	25
Flow (cm/s)	10.5	5	19.5	21	14	17	36.5	21
Temp (^{o}C)	-----	-----	-----	-----	18.7	19.1	20.3	21
D.O. (mg/l)	-----	-----	-----	-----	8.6	7.7	8.3	8.9
Conductivity	-----	-----	-----	-----	91.4	82.4	88.4	90.5
pH	-----	-----	-----	-----	8.6	7.7	7.7	7.5
Substrate (%)								
Bedrock	0	0	5	5	0	0	0	0
Boulders (<10")	0	0	20	15	0	0	5	10
Rubble (3-10")	0	0	55	50	5	20	40	25
Gravel (0.125-3")	20	20	10	20	40	60	30	35
Sand (< 0.125")	30	40	0	0	40	10	10	20
Silt-Clay	45	35	0	0	10	10	10	5
Detritus	5	5	10	10	5	0	5	5

Table 3. Nutrient analysis results for Cold Brook (CB) and Wesserunsett Stream (WS) in 2000. UP = upstream, DN = downstream.

Date	Site	NO3-N mg/l	NH4-N mg/l	P mg/l
10/6/2000	CB-UP	0.30	< 0.05	< 0.01
	CB-DN	0.07	< 0.05	< 0.01
	WS-UP	< 0.05	0.38	< 0.01
	WS-DN	< 0.05	< 0.05	< 0.01
11/27/2000	CB-UP	0.34	0.06	0.45
	CB-DN	0.51	0.15	0.10
	WS-UP	0.12	< 0.05	< 0.01
	WS-DN	1.06	4.50	0.80

Table 4. Classification attainment probabilities based on the Maine Department of Environmental Protection linear discriminant model for Cold Brook (CB) and Wesserunsett Steam (WS) in 1999 and 2000. Up = upstream, Down = downstream, N-A = non-attainment.

Year	1999				2000			
Model	CB - Up	CB - Down	WS - Up	WS - Down	CB - Up	CB - Down	WS - Up	WS - Down
First Stage								
Class A	0.168	0.219	0.753	0.773	0.561	0.174	0.456	0.395
Class B	0.669	0.716	0.247	0.226	0.432	0.806	0.534	0.601
Class C	0.163	0.065	0.001	0.001	0.007	0.020	0.009	0.005
Non-Attainment	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C or Better								
Class A,B or C	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Non-Attainment	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B or Better								
Class A or B	0.999	0.998	1.000	1.000	1.000	1.000	1.000	1.000
Class C or N-A	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000
A Model								
Class A	0.188	0.039	0.972	0.984	0.423	0.111	0.633	0.160
B, C or N-A	0.812	0.961	0.028	0.016	0.577	0.889	0.367	0.840

Table 5. Mean bacterial counts for Cold Brook (CB) and Wesserunsett Stream (WS) in 1999. UP = upstream, DN = downstream, TNTC = too numerous to count.

Date		5/20/1999		5/20/1999		10/4/1999
Site	E. coli # /100 ml	Total Coliform # /100 ml	E. coli # /100 ml	Total Coliform # /100 ml	E. coli # /100 ml	Total Coliform # /100 ml
CB-UP	64.0	TNTC	617.5	TNTC	61.0	TNTC
CB-DN	50.5	TNTC	1643.0	TNTC	1020.5	TNTC
WS-UP	31.0	TNTC	1483.5	TNTC	43.0	1357.0
WS-DN	196.5	TNTC	1267.0	TNTC	46.0	1356.5

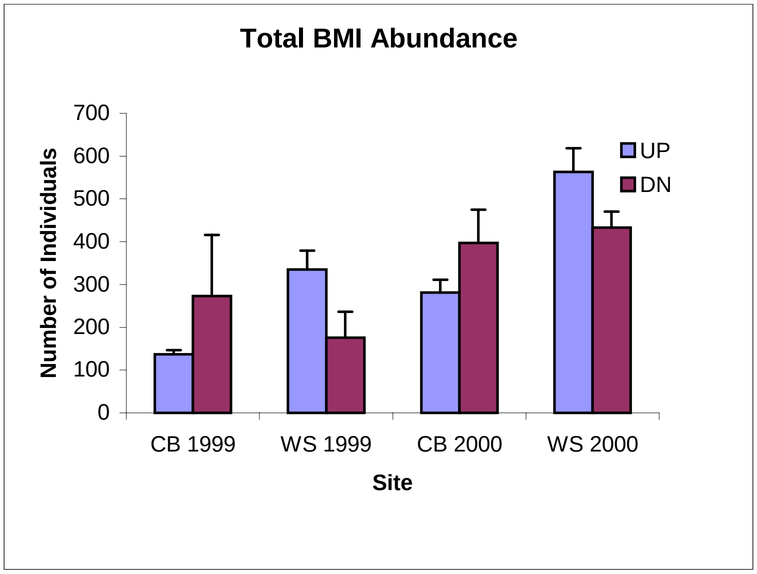


Figure 1. Mean (+/- SE) total benthic macroinvertebrate (BMI) abundance in Cold Brook (CB) and Wesserunsett Stream (WS) for 1999 and 2000. UP = upstream site, DN = downstream site.

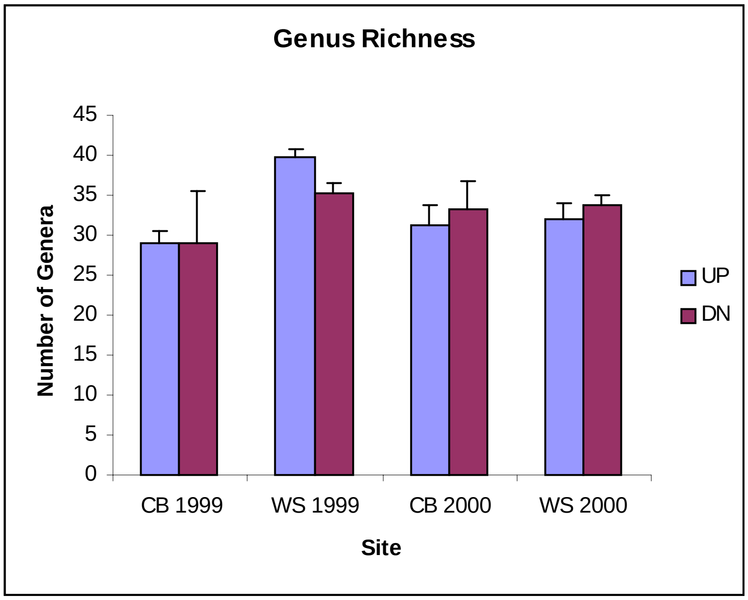


Figure 2. Mean (+/- SE) genus richness in Cold Brook (CB) and Wesserunsett Stream (WS) for 1999 and 2000. UP = upstream site, DN = downstream site.

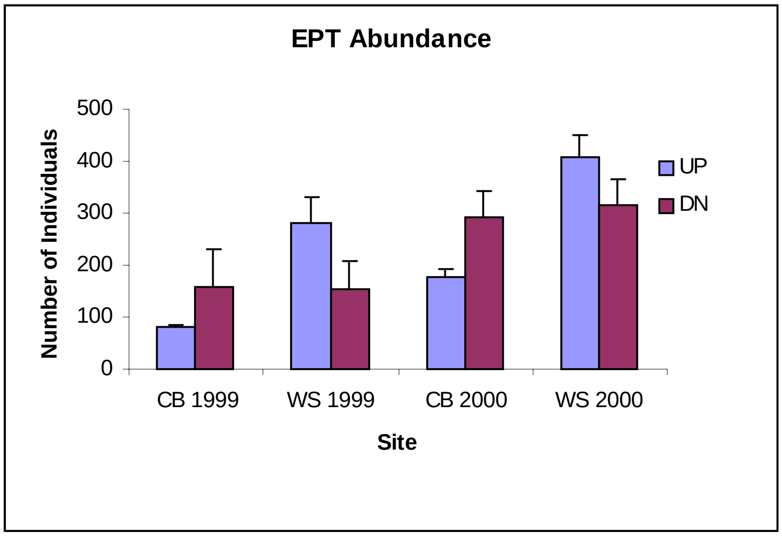


Figure 3. Mean (+/- SE) EPT (Ephemeroptera, Plecoptera, Trichoptera) abundance in Cold Brook (CB) and Wesserunsett Stream (WS) for 1999 and 2000. UP = upstream site, DN = downstream site.

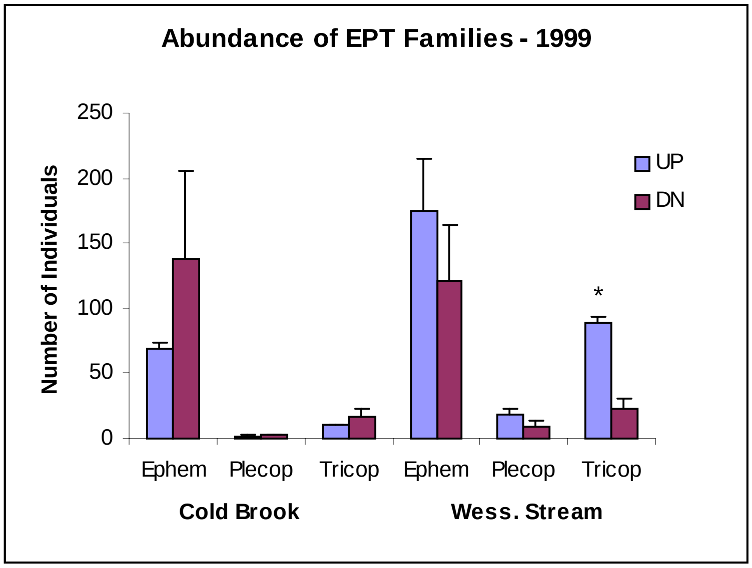


Figure 4a. Mean abundances of Ephemeroptera, Plecoptera and Trichoptera in Cold Brook and Wesserunsett Stream in 1999. UP = upstream, DN = downstream.

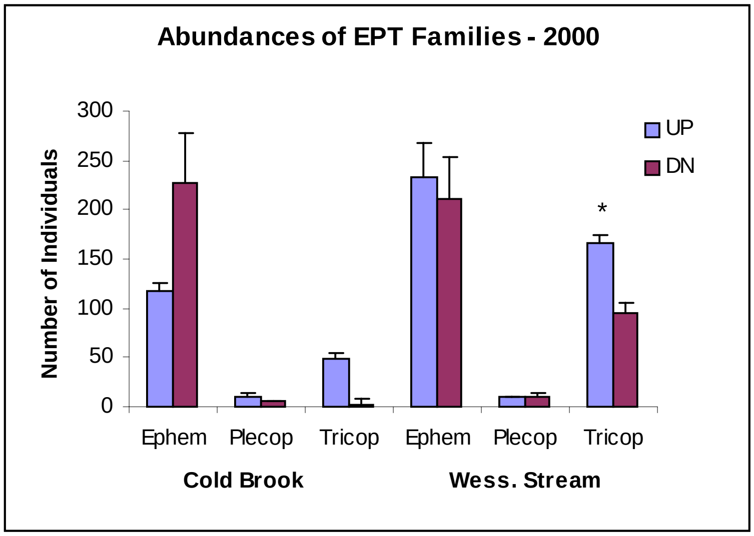


Figure 4b Mean abundances of Ephemeroptera, Plecoptera and Trichoptera in Cold Brook and Wesserunsett Stream in 2000. UP = upstream, DN = downstream.

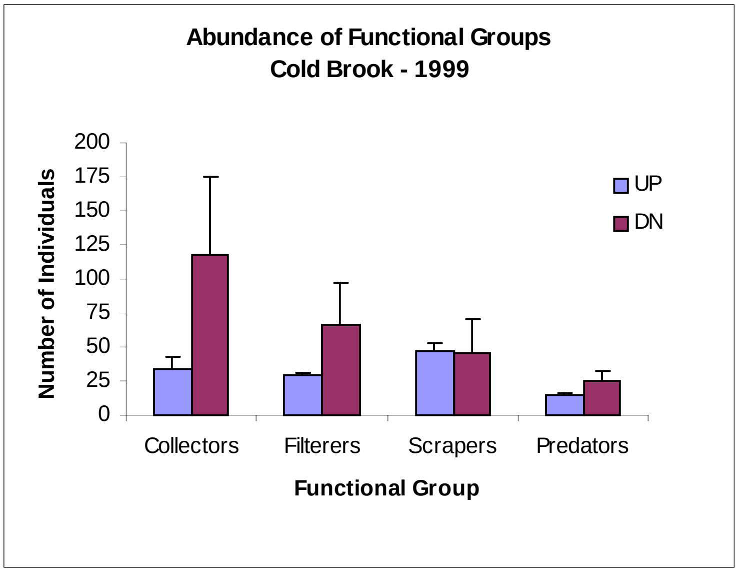


Figure 5a. Mean abundances of macroinvertebrate functional groups in Cold Brook in 1999. UP = upstream, DN = downstream.

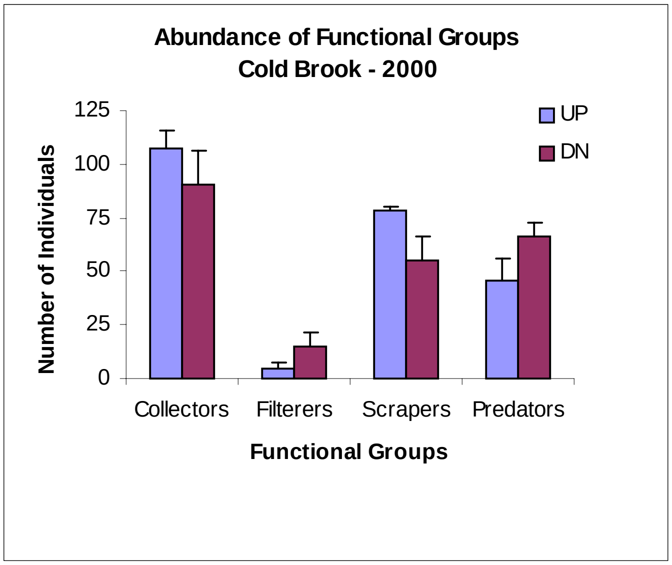


Figure 5b. Mean abundances of macroinvertebrate functional groups in Cold Brook in 2000. UP = upstream, DN = downstream.

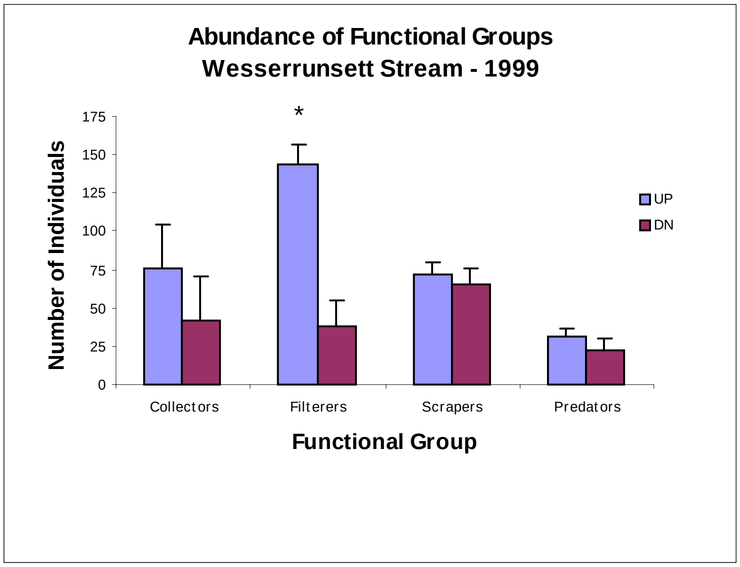


Figure 5c. Mean abundances of macroinvertebrate functional groups in Wesserunsett Stream in 2000. UP = upstream, DN = downstream.

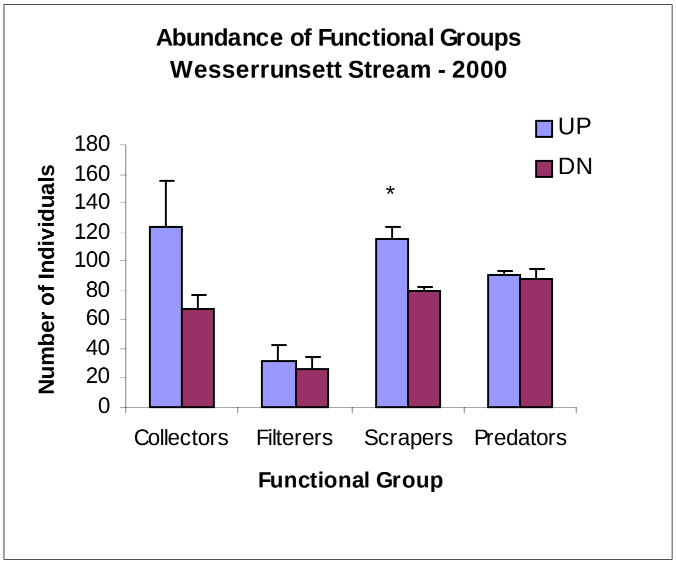


Figure 5d. Mean abundances of macroinvertebrate functional groups in Wesserunsett Stream in 2000. UP = upstream, DN = downstream.

Literature Cited

Ackerman3 EO, and Taylor AG. 1995. Stream impacts due to feedlot runoff. In K. Steele (ed.). Animal waste and the land-water interface. Lewis Publishers, Boca Raton, FL. pp. 119-125.

Allan JD. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, London. pp.388.

Bazzanti M. 1991. Sandy bottom macroinvertebrates in two moderately polluted stations of the River Treia (Central Italy): structual and functional organization. *Annis Limnol*. 27:287-298.

Boyle TP, Smillie GM, Anderson JC, and Beeson DR. 1990. A sensitivity analysis of nine diversity and seven similarity indices. *J. Wat. Pollut. Control Fed.* 62:749-762.

Brower JE, Zar JH, and von Ende CN. 1990. Field and laboratory methods for general ecology. 3rd ed. Wm. C. Brown Publishers. Dubuque, IA. pp. 237.

Cao Y, Bark AW, and Williams WP. 1997. Analysing benthic macroinvertebrate community changes along a pollution gradient: a framework for the development of biotic indices. *Wat. Res.* 31:884-892.

Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, and Smith VH. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecol. Applic.* 8:559-568.

Cook SEH. 1976. Quest for an index of community structure sensitive to water pollution. *Environ. Pollut.* 11:269-288.

Couillard D, and Li JF. 1993. Assessment of manure-application effects upon the runoff water quality by algal assays and chemical analyses. *Environ. Pollut.* 80: 273-279.

Curtis EJC. 1969. Sewage fungus: its nature and effects. *Wat. Res.* 3:289-311.

Curtis EJC. 1972. Sewage fungus in rivers in the United Kingdom. *Wat. Pollut. Control*. 71:673-685.

Dance KW, and Hynes HBN. 1980. Some effects of agricultural land use on stream insect communities. *Environ. Pollut.* 22:19-28.

Davies SP, and Tsomides L. 1997. Methods for biological sampling and analysis of Maine's inland waters. Maine Department of Environmental Protection. Augusta, ME. pp29.

Davies SP, and Tsomides L, Couremanch DL, and Drummond F. 1995. Maine biological monitoring and biocriteria development program. Maine Department of Environmental Protection. Pp. 60.

Davies SP, and Tsomides L, DiFranco JL, and Couremanch DL. 1999. Biomonitoring Retrospective: Fifteen year summary for Maine rivers and streams. Maine Department of Environmental Protection. 2-24.

Eghball B, and Gilley JE. 1999. Phosphorus and nitrogen in runoff following beef cattle manure or compost application. *J. Environ. Qual*. 28: 1201-1210.

Elrashidi MA, Baligar VC, Korcak RF, Persaud N, and Ritchey KD. 1999. Chemical composition of leachate of dairy manure mixed with fluidized bed combustion residue. *J. Environ. Qual.* 28:1243-1251.

Fontvieille D, and Cazelles B. 1990. Changes in biologically controlled carbon fluxes in a small stream following continuous supply of excess organic load. *Hydrobiologia*. 192:123-141.

Gaufin AR, and Tarzwell CM. 1955. Environmental changes in a polluted stream during winter. *Am. Midl. Nat. 54:78-88.*

Gray NF. 1982. A key to the major slime-forming organisms of 'sewage fungus.' *J. Life Sci. R. Dubl. Soc.* 4:97-102.

Hawkes HA. 1979. Invertebrates as indicators of water quality. In: Evison JA. (ed.) Biological indicators of water quality. J. Wiley and Sons, Chinchester. 2/1-2/45.

Hynes HBN. 1960. The biology of polluted waters. Liverpool Univ. Press, Liverpool, England. Pp. 202.

Jemison Jr. JM, Mack R, and Hopkins K. 1999. Impact of manure on stream water quality. Unpublished data.

Kendall RJ, Bens CM, Cobb III GP, Dickerson RL, Dixon KR, Klaine SJ, Lacher Jr. TE, LaPoint TW, McMurry ST, Noblet R, and Smith EE. 1996. Aquatic and terrestrial ecotoxicology. In CD Klaassen, MO Amdur, and J Doull (eds.). Casarett and Doull's toxicology: the science of poisons. 5th ed. McGraw-Hill, New York. pp. 883-906.

Khalaf G, and Tachet H. 1980. Colonization of artificial substrata by macro-invertebrates in a stream and variations according to stone size. *Fresh. Biol.* 10:475-482.

Konrad JG, Baumann JS, and Oh JA. 1986. Non-point source planning and implementation in Wisconson. In JF de LG Solbé (ed.). Effects of land use on fresh waters: agriculture, forestry, mineral exploitation, urbanization. Ellis Horwood Ltd. Chichester, West Sussex, U.K. pp. 283-295.

Lemly AD. 1982. Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. *Hydrobiologia*. 87: 229-245.

Lemly AD. 1998. Bacterial growth on stream insects: potential for use in bioassessment. *J. N. Am. Benthol. Soc.* 17: 228-238.

Line DE, Harman WA, and Jennings GD. 1998. Comparing sampling schemes for monitoring export from a dairy pasture. *J. Amer. Water. Res. Assc*. 34: 1265-1273.

Madsen JD, and Adams MS. 1989. The distribution of submerged aquatic macrophyte biomass in a eutrophic stream, Badfish Creek: the effect of environment. *Hydrobiologia*. 171:111-119.

Maki AW, Geissel L, and Johnson HE. 1975. Comparative toxicity of the larval lampricide TFM (3-triflouromethyl-4-nitrophenol) to selected benthic macroinvertebrates. *J. Fish. Res. Board Can.* 32:1455-1459.

Marsh PC, and WAters TF. 1980. Effects of agricultural drainage development on benthic invertebrates in undisturbed downstream reaches. *Trans. Am. Fish. Soc.* 109:213-223.

McCahon CP, and Poulton MJ. 1991. Lethal and sub-lethal effects of acid, aluminium and lime on *Gammaru pulex* during repeated simulated episodes in a Welsh stream. *Freshwat. Biol.* 25:169-178.

McCahon CP, Poulton MJ, Thomas PG, Xu Q, Pascoe D, and Turner C. 1991. Lethal and sub-lethal toxicity of field simulated farm waste episodes to several freshwater invertebrate species. *Wat. Res.* 25:661-671.

Merritt RW, and Cummins KW (eds.). 1996. An introduction to the aquatic insects of North America. 3rd ed. kendall/Hunt Publishing Company, Dubuque, IA. pp. 862.

Nelson PN, Cotsaris E, and Oades JM. 1996. Nitrogen, phosphorus, and organic carbon in streams draining two grazed catchments. *J. Environ. Qual.* 25:1221-1229.

Overcash MR, Humenik FJ, and Miner JR. 1983. Livestock waste management. Vol. I. CRC Press, Inc., Boca Raton, FL. pp.225.

Pinder LCV, and Farr IS. 1987. Biological surveillance of water quality - 3. The influence of organic enrichment on the macroinvertebrate fauna of small chalk streams. *Arch. Hydrobiol.* 109:619-637.

Rosenberg DM, and Resh VH. 1996. Use of aquatic insects in biomonitoring. In RW Merritt and KW Cummins (eds.). An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co. Dubuque, IA. pp. 87-97.

Rutt GP, Pickering TD, and Reynolds NRM. 1993. The impact of livestock-farming on Welsh streams: the development and testing of a rapid biological method for use in the assessment and control of organic pollution from farms. *Environ. Pollut.* 81:217-228.

Schlosser and Karr . 1981.

Seager J, and Abrahams RG. 1990. The impact of storm sewage discharges on the ecology of a small urban river. *Wat. Sci. Technol.* 22(10/11):163-171.

Spehar RI, Anderson RI, and Fiandt JT. 1978. Toxicity and bioaccumulation of cadmium and lead in aquatic invertebrates. *Environ. Pollut.* 15:195-208.

Stephenson GR, and Street VL. 1978. Bacterial variation in streams from a southwest Idaho rangeland watershed. *J. Environ. Qual*. 7: 150-157.

U.S.D.I. (U.S. Department of Interior), FWPCA. 1968. A report of the Committee on water quality criteria. U.S.D.I., Washington, D.C., U.S.A.

U. S. EPA (U. S. Environmental Protection Agency). 1985. Ambient water quality criteria for ammonia. **EPA 440/5-86-001**. USEPA, Office of Water (4503F), U.S. Government Printing Office, Washington, D.C., USA.

U. S. EPA (U. S. Environmental Protection Agency). 1990. National water quality inventory. 1988 Report to Congress. USEPA, Office of Water (4503F), U.S. Government Printing Office, Washington, D.C., USA.

U. S. EPA (U. S. Environmental Protection Agency). 1996. Environmental indicators of water quality in the United States. EPA **841-R-96-002**. USEPA, Office of Water (4503F), U.S. Government Printing Office, Washington, D.C., USA.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, and Cushing CE. 1980. The river continuum concept. *Can. J. Fish. Aquat. Sci.* 37: 130-137.

Weatherley NS, and Ormerod SJ. 1987. The impact of acidification on macroinvertebrate assemblages in Welsh streams: towards an empirical model. *Environ. Pollut.* 46:223-240.

Wellnitz TA, Grief KA, and Sheldon SP. 1994. Response of macroinvertebrates to blooms of iron-depositing bacteria. *Hydobiologia.* 281:1-17.

Whitehurst IT, and Lindsey BI. 1990. The impact of organic enrichment on the benthic macroinvertebrate communities of a lowland river. *Wat. Res.* 24:625-630.

Willemsen GD, Gast HF, Franken ROG, and Cuppen JGM. 1990. Urban strom water discharges: effects upon communities of sessile diatoms and macroinvertebrates. *Wat. Sci. Technol.* 22(10/11):147-154.

Williams DD, and Mundie JH. 1978. Substrate size selection by stream invertebrates and the influence of sand. *Limnol. Oceanogr.* 23:1030-1033.

Young RA, Huntrod T, and Anderson W. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. *J. Environ. Qual.* 9:483-487.

Younos TM, Mendez A, Collins ER, and Ross BB. 1998. Effects of a dairy loafing lot-buffer strip on stream water quality. *J. Am. Water Res. Assoc.* 34:1061-1069.

Basic Information

Title:	The PEARL CD: Public Educational Access to Resources on Lakes
Project Number:	
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Social Sciences
Focus Category:	Education, Surface Water, Water Quality
Descriptors:	Education, Geographic Information System, Lakes, Ponds, Water Quality
Lead Institute:	University of Maine
Principal Investigators:	Mary Beard-Tisdale, Jeffrey S Kahl

Publication

PEARL: Public Educational Access To Resources on Lakes in Maine

Annual Technical Report
Reporting Period: March 1, 2000 to February 28, 2001

Project Objectives

To develop and integrate new capabilities into the existing PEARL Internet GIS framework to (1) expand its geographic scope; (2) extend the environmental features represented through PEARL; (3) increase the public education utility; and (4) broaden usability for statewide scientists, in part by developing a PEARL application distributed via CD-ROM.

PEARL was developed because Maine is a 'lake state', with nearly 6,000 lakes in the state listing. However, access to information on Maine lakes is complicated by the number of agencies and organizations who independently collect and store these data. Dwindling government budgets for environmental monitoring means increased reliance on citizen participation. Involved citizens need information in a timely manner or else their efforts seem to have no meaning for them. Becoming an informed citizen can be a frustrating endeavor. Moreover, much information on Maine lakes still resides in paper files buried in filling cabinets or personal computer files. This information may be lost as people retire and outdated computer formats can no longer be accessed. A need exists to gather and collate this information before it is lost.

Methods

A prototype application was developed using the ESRI Internet GIS software, ArcIMS (Internet Map Server), to accommodate new spatial and environmental data sets. The existing Microsoft NT Internet Information Server was retained. ArcIMS JavaScript was modified to integrate the prototype with the current PEARL deployment. New cooperating partners were recruited to increase project support and to enhance data offerings (Table 1). Base data were converted to NAD 83 (North American Datum 1983) to improve compatibility for multiple-source spatial data.

Table1. PEARL funding sources and collaborative partners

Funding Sources:
United States Geological Survey
Maine Department of Environmental Protection
Maine Volunteer Lake Monitoring Program
Maine Outdoor Heritage Fund **(New)**
Maine Department of Human Services -- Drinking Water Program **(New)**
Maine State Planning Office – Coastal Monitoring Program **(New)**
Maine Lakes Conservancy Institute **(New)**

Other Collaborations
Maine Environmental Monitoring and Assessment
http://pearl.spatial.maine.edu/Cema/intro.htm
Maine Audubon Society – Annual Loon Survey

ESRI MapObjects component software and MS Visual Basic were used to develop an application for eventual distribution on CDROM that access the same – or subsets of the same – data that are available via the PEARL Internet application. Data access and map navigation tools and interface design of the 'offline' VB/MO application more closely mimic the options available in the 'online' ArcIMS prototype than the current VB/MO IMS application. This will facilitate a smoother transition for users who access data from both Internet and CD mediums (Figure 1).

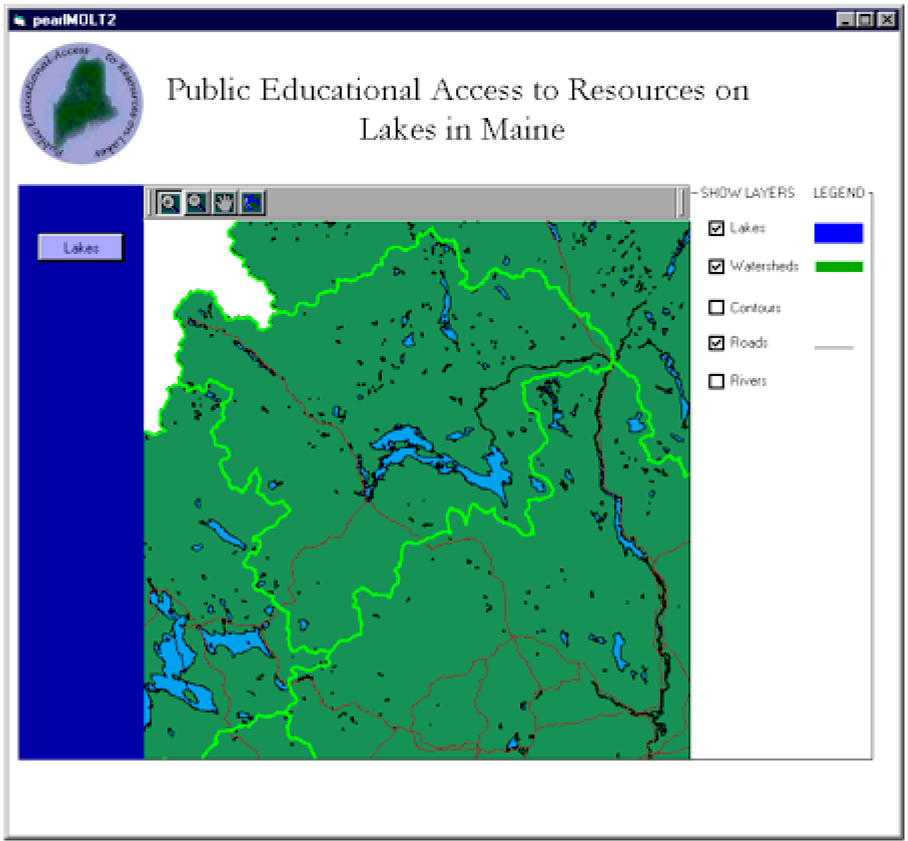


Figure 1. PEARL CD ROM map navigation prototype.

Principle Findings

Distributed data delivery applications – an inherent characteristic of geographically broad GIS projects – require the direct cooperation and coordination of its participants. Participants in project development, especially those who also benefit from the end product, must interact and maintain communication with other partners for the project to achieve optimum success. Centralized data management and technical solutions alone will not be sufficient for project success. Project costs can be reduced through an efficient and coordinated development approach that reduces redundant, collateral agency efforts. Maintaining a cooperative understanding and work environment among disparate groups of collaborators, each with a vested interest, is an essential component for shared success. Much effort has been expended to get disparate information into a uniform database.

Commercially available application development tools such as the ESRI ArcIMS can reduce product delivery time and reduce development costs, but might limit the ability to develop custom applications. Expected advances in commercial software will enable application developers to more affordably create Internet GIS applications to meet researchers specific demands. We have made progress in making PEARL usable as a GIS analytical tool; but web-access for this feature needs more development.

The value derived from applications designed to accommodate multiple end users is likely to be achieved through a balance between versatility and usability. In general, the more tasks an application is designed to accomplish, and the more users it targets, the more complex the project development and use will be. Maintaining project scope and increasing versatility, however, can be achieved by expanding data sets over a geographic scale that builds logical and intuitive connections between features. Rivers and river attributes can be added to a lakes application, especially if the same tool set and interface components can be applied to all features. This, for example, is why expanding the ecological representation to an interrelated watershed level (e.g., the Gulf of Maine watershed) might make more sense then expanding it to a broader political region, unless the political structure is the binding feature (e.g., lake data for cooperating agencies across New England). Both require interagency or even international cooperation, but the shared ecological features provide a consistent context in which the participants can proceed. Watersheds, lakes, and other natural features often span political borders, demonstrating the appeal for applying ecological and geographic concepts to project development rather than implementing projects solely to address political and agency concerns.

Overall, PEARL has been very successful in hosting lakes data. The use of this site has provided a new and valuable educational tool for the Maine Water Resources Research Institute. The implementation of PEARL as a research tool is now taking place with graduate student research in Spatial Engineering and at the Senator George J. Mitchell Center.

PEARL has provided a link for many federal, state, volunteer agencies, and industries that have common interests in water. As can be seen from the list in Table 1, the number or cooperators has exceeded our initial expectations.

Future Work

Continued integration of ecologically or geographically related features and datasets and expansion of educational content will be ongoing through 2002. Additional financial support will be sought to contribute to the completion of this work and to further implement the project expansion to build on the existing prototypes, in addition to ongoing maintenance and project coordination, and to accommodate increasing use. Other current efforts include:

- Maine Drinking Water Program public water supply information
- Maine State Planning Office, Volunteer Coastal Monitoring Program data
- Maine Outdoor Heritage Fund award to begin development of Student/Teacher Education web portal.
- Enhancing fisheries and other biological data, including Maine Audubon Society annual loon survey results.
- Continue development of interactive CD (approximately 60% completed).
- Implement new data access and web application systems (e.g. Oracle spatial data objects or ESRI Spatial Data Engine geodatabases).

Publications / Presentations

SIE Graduate Seminar—Research potential for data models and advanced query methods.
30 March 2000, Orono, Maine

Maine Water Conference – PEARL demonstration and exhibit. April 2000, Augusta, Maine

Department of Spatial Information Science and Engineering — PEARL as a research platform for Internet GIS. 21 April 2000, Orono, Maine

PEARL: Public Educational Access to Environmental Information
http://pearl.spatial.maine.edu
PEARL ArcIMS prototype: Acadia National Park
http://pearl.spatial.maine.edu/website/newpearl

Theses and Student Training

PEARL can be used directly or peripherally by students, either as the focus of research, or as a source of data and information for research:

1. Tom Noonan: Graduated from UMaine Department of Spatial Information Science and Engineering (SIE) with M.Sc. degree; emphasis on Internet distributed GIS, focused on PEARL development.
2. Eric Herbert: Former graduate student, George Mitchell Center (GMC).
3. Charles Merrill: SIE graduate student – scheduled for summer employment, 2001.
4. Erin McCormack / Katherine Schmitt: GMC graduate students, spatial analysis of surface water chemistry.
5. Seung-Ki Woo: SIE graduate student – spatial analysis, development tools for large scale multiple regression and correlation of environmental parameters; lake/watershed interactions.

Tom Noonan is a Research Associate at the University of Maine and continues to coordinate PEARL Project development.

Appendix

Comments

The following e-mail messages are verbatim submissions to the PEARL website. They are included as an example of one form of user feedback, good and bad, used to assess project effectiveness. Inclusion of user comments about the activities of other states or organizations are not intended as criticism, but rather, are intended to emphasize the importance of the PEARL Program and other similar projects. (*NOTE: obtain permission if necessary from users prior to other publication of this report, or delete senders' names and addresses*).

From: "Nicely, Holly"
To: "'Pearl@mail.spatial.maine.edu'" <Pearl@basin.spatial.maine.edu>
Subject: **Not working**
Date sent: Wed, 14 Mar 2001 12:40:40 -0500

Hello.

I believe the lake "search" function isn't working. I have used your site many times to check clarity of Maine lakes in our attempts to pick a vacation spot for this summer. Your information is great! Thanks. Holly

Holly Nicely

From: Roberta Hill
To: "'Pearl@mail.spatial.maine.edu'" <Pearl@basin.spatial.maine.edu>
Subject: **FYI - Error on the WEBSITE**
Date sent: Fri, 16 Feb 2001 15:04:16 -0500

Hi. When you click on Little Sebago Lake (In Windham, near Sebago Lake) to "identify," it lists it as Tarkill Pond. Tarkill Pond is a small pond south of Little Sebago.

Great website! Please keep up the good work!

Thanks!

Date sent: Fri, 29 Dec 2000 04:58:11 -0500
To: pearl@basin.spatial.maine.edu
From: Stan & Lisa < >
Subject: **pond maps**

I just found this site and I do Like it very much, but I don't see any fish list or description of the lakes history

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Date sent: Thu, 21 Dec 2000 13:54:00 -0800 (PST)
From: Don Boyer < >
To: pearl@basin.spatial.maine.edu

Your lake search page is extremely helpful. I use it all the time for recreational purposes. I'm wondering if you or any other agency you might know can provide a list of Maine waters ranked by water quality/clarity.

Thank you

Don Boyer

From: Ann_Dieffenbacher
To: Pearl@basin.spatial.maine.edu
Date sent: Wed, 1 Nov 2000 14:33:26 -0500
Subject: Pearl

Hi.
I greatly appreciate having bathymetric maps and other data about so many Maine lakes at my finger tips. Pearl is great!

I wonder two things:

1. Is there a way to increase the search capabilities so that wild characters can be used? In searching for Mansell Pond in Alton, also known as Hatch Pond, I was not able to find the pond under either name because it is listed in Pearl as "Hatch (mansell) Pond". I found it by searching for all lakes in Alton. (Incidently, I believe Mansell is the more commonly used name for the pond.)

2. The paper copies of the bathymetric maps obtainable from Dept of Inland Fisheries include a narrative on the back telling about fish species, etc. Sometimes it includes useful historical information. Are there plans to add this to Pearl in the future?

Thank you.
- Ann Dieffenbacher-Krall

From: BetGailor
Date sent: Wed, 19 Apr 2000 18:49:54 EDT
Subject: **your website**
To: pearl@basin.spatial.maine.edu
Copies to: Barb.Welch@state.me.us

Hi! My son, Knute, is doing a science fair project in which he is comparing the water quality of a few lakes in Maine with a few lakes in Connecticut, where we live. My family lives in Harrison, Maine, and Knute was interested in why Maine lakes are so much cleaner than those in Connecticut. Barbara Welch, who works for Maine DEP (and with whom I went to college), gave us your website address. We are writing to tell you what a terrific resource your website is! Connecticut's website pales in comparison! You have presented so much helpful information, and we have both learned so much! Knute collected samples and tested for phosphate levels, nitrogens, sulfates, and chlorides in Long Lake in Bridgton, Highland Lake in Bridgton, and Sebago Lake in Raymond. It was so great to be able to compare our results with those reported on your website. Thanks for putting together such a wonderful resource. It is truly outstanding and we are most appreciative. Sincerely, Bet Gailor

References

ESRI, 1996, Building Applications with MapObjects™: Environmental Systems Research Institute, Inc., 1-201.

Florescu, D., Levy, A., and Mendelzon, A., 1998, Database Techniques for the World-Wide Web: A Survey: SIGMOD Record, Vol. 27, No. 3, 59-69.

Harrower, M., MacEachren, A., and Griffin, A.L., 2000, Developing a Geographic Visualization Tool to Support Earth Science Learning: Cartography and Geographic Information Science, Vol. 27, No 4. 279-293.

Longley, P.A., Goodchild, M.F., Maguire, D.J., and Rhind, D.W., 1999, Geographical Information Systems: Principles and Technical Issues: John Wiley & Sons, Inc., 1-16.

Noonan, T.J., 2000, PEARL annual report:
http://pearl.spatial.maine.edu/Reports/pearlAnnualReport2000.pdf

Tractinsky, N., 1997, Aesthetics and Apparent Usability: Empirically Assessing Cultural and Methodological Issues: CHI 97, ACM Inc., 115-122.

Basic Information

Title:	Cycling and Speciation of Mercury and Methylmercury in the Soil of Acadia National Park
Project Number:	
Start Date:	6/1/1999
End Date:	5/31/2001
Research Category:	Water Quality
Focus Category:	Hydrogeochemistry, Toxic Substances, Water Quality
Descriptors:	Geochemistry, Toxic Substances
Lead Institute:	University of Maine
Principal Investigators:	Aria Amirbahman, Jeffrey S Kahl, Terry Haines

Publication

1. Ruck, P., A. Amirbahman, I. Fernandez, J. Kahl, and T. Haines. 2001. Manuscript in preparation for thesis and future publication.
2. Poster presented at the 2000 Maine Water Conference, Augusta, ME. "Cycling and Speciation of Hg in Soils at Acadia National Park.
3. Oral presentation at the 2001 ARIA Conference: "Cycling and Speciation of Hg in Soils at Acadia National Park."

Problem and Research Objectives:

Mercury is a contaminant of major concern in the northeastern United States. Fish and eagles in Acadia National Park (ANP), Maine have some of the highest Hg concentrations in the world for the sites with no point source. This is primarily due to the atmospheric input of Hg. According to the 1999 Mercury Deposition Network Annual Report, the wet-only deposition for ANP was 8.0 $\mu g/m^2$ for 1999. Dry deposition may also be a major source of Hg.

The role of soil in ANP in the accumulation and possible methylation of Hg is not fully understood. The distribution and speciation of Hg will vary depending upon the presence of organic carbon in soil and in groundwater and physical factors, such as soil drainage,. In the forested watersheds, production of CH_3Hg is expected to take place primarily in the subsurface under anaerobic conditions.

The University of Maine and the National Park Service are currently conducting a paired watershed study to gain more insight into the biogeochemistry of Hg at ANP. One watershed recently burned, with thin soils and deciduous vegetation, and one unburned, with thicker soil and coniferous vegetation are being compared. As part of this study, the concentrations of Hg and methylmercury (CH_3Hg), loss on ignition, base cations, carbon:nitrogen ratios, and pH were measured in soils. The data collected from this study and the ongoing PRIMENET study at ANP may be incorporated into watershed models to provide a complete regional mass balance for Hg. The different vegetative covers, organic matter concentrations and groundwater chemistry should influence the distribution of Hg and CH_3Hg in the burned and the unburned watersheds in ANP.

Methodology:

Total Hg was extracted from soil samples by the addition of concentrated HNO_3 and 30% H_2O_2 to the samples followed by microwave treatment. Total Hg in soil was determined using EPA method 1631. This method involves the addition of 0.2 M BrCl to approximately 0.5g of soil sample, and subsequent reduction of Hg with 20% $SnCl_2$.

Methylmercury extraction from soil was performed using pre-established methods. The soil samples were suspended in 25% KOH in methanol and then placed in a 75°C oven. MeHg in soil was measured using ethylation, purge and trap, desorption, and cold-vapor atomic fluorescence detection. For both Hg and CH_3Hg measurements, a Brooks-Rand cold vapor atomic fluorescence spectrometer was used.
Organic carbon was determined by loss-on-ignition in a muffle furnace at 550º C for 5 hours. It was assumed that LOI is attributed to organic material only. Soil pH was measured in deionized water and in 0.01 M $CaCl_2$ with a Corning 340 pH Meter, and a Corning GP combination pH electrode.

Principal Findings and Significance:

The fire of 1947 probably impacted the Cadillac Brook (burned) watershed significantly by raising the soil pH, and altering the vegetation, and carbon pools. Soil pH was significantly higher in all horizons of the Cadillac Brook watershed soils than in the Hadlock Brook (unburned) watershed soils. Total Hg (ng Hg/g soil) concentrations were higher in the O horizon of the Hadlock Brook watershed soils than in the Cadillac Brook watershed soils, most likely as a result of the fire. Methylmercury concentrations, both non-normalized and normalized to LOI, were higher in the Cadillac Brook watershed vs. the Hadlock Brook watershed, also most likely as a result of the fire.

Mercury adsorption isotherms were also developed for each of the soil horizons for both watersheds at different pH ranges (pH 3, 4, and 5) to establish the physical mechanisms by which Hg reacts with the soil. The amount of Total Hg adsorbed to soil was compared to Total Hg in solution at a given pH to examine the binding capacities of soils from each watershed. Results from these isotherms indicate that at low Hg concentrations, Hg speciation is controlled by the type of organic matter in solution (DOM), rather than that bound to soil. Once the available binding capacity of the DOM is exceeded, then Hg adsorbs onto the soil surfaces. At pH 5, more dissolved organic matter is in solution, therefore more Total Hg was found to be bound to DOM. Early results indicate that as a result of the fire, the type of DOM released into solution from burned soils is less efficient at binding Hg than that of the unburned soils.

Based on findings to date, this study hopes to explain the relationships between pH, DOC, and Hg and how they affect Hg cycling and speciation in the two watersheds. Results from this study will be incorporated into the PRIMENET Acadia study to explain Hg export from the burned and unburned watersheds.

Information Transfer Program

We have organized our Information Transfer efforts into three sections: Publications, Conferences, and Public Service.

Publications

Kahl, Steve, 2000. Researching Acadias Waters. Friends of Acadia Journal, 5:1:16 This article describes park-based watershed research being conducted by the UMaine Water Research Institute. The article written by Steve Kahl, WRI director, notes that Acadia lies in the path of polluted air from the south and west. As a result, the park provides a useful test for theories on mercury, acid rain, and water quality.

Anderson, Therese, Richard Dill, Barry Mower and Andrew Smith, 2000. Risk Assessment Methods for Low Resolution PCB Homologue Analysis. The Standard, Cambridge Isotope Laboratories, 5:1:2

Shoven, Heather, 2000. Dioxin Determinations. Maine Perspectives, University of Maine Newsletter. 12:7:9

Peckenham, John and Sherman Hasbrouck, 2000. Safe Drinking Water. Maine Geographical Digest Series. This publication offers information to the public about protecting the quality of drinking water from wells.

Peckenham, John, J. Steve Kahl, and Sarah Vidito, eds., 2001. Climate Change and Water Use/Availability, Workshop Proceedings, University of Maine, Orono, Maine. Available in pdf format at http://www.umaine.edu/WaterResearch

Nielsen, Martha and John Peckenham, 2000. Methyl tert-Butyl Ether (MTBE) in ground water, air, and precipitation in an urbanized area in Maine, USGS Water Res. Invest. Report 00-4048, 28 p.

Norton, Stephen and Steve Kahl. 2000. Road Assault. Audubon, Jan./Feb 2000. This article discusses the environmental effects on the 17 million tons of road salt used to de-ice roads in the United States. Kahl & Norton developed a rapid, simple chemical test to differentiate the source of salt contamination in groundwater wells.

Conferences, Workshops, Annual Meetings

All Research In Acadia Meeting, University of Maine, Orono, Maine. March 13, 2000. Organized by the Water Research Institute and Acadia National Park, this meeting was a platform for all researchers conducting projects at Acadia National Park. The goal of this meeting was to share research information and to foster cooperative studies. Annual meetings are planned.

Maine Water Conference 2000. Augusta Civic Center, Augusta, ME. April 13, 2000. 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. This years conference featured five afternoon sessions including: Arsenic in Maine Groundwater, Maine Water Quality Issues, Water Quality Impacts on Wildlife, Role of Citizen Monitoring in Maine, and Success Stories in Ecologically Friendly Development.

Planning for Water Use and Water Availability in Maine in a Changing Climate. University of Maine, Orono, ME. July 26, 2000.

Water resource specialists from state and federal agencies, tribal governments and the UMaine research community met to discuss planning efforts to deal with increasing water demand, seasonal changes in water availability, and other issues relating to future recreational and economic development. Conference sponsors included: UMaine Water Research Institute and UMaine Margaret Chase Smith Center for Public Policy. Conference proceedings are in the final stages of review.

Protecting Maines Drinking Water, China Conference Center, China, Maine, September 28, 2000. This educational seminar was organized with the US EPA-Region I, New England Interstate Water Pollution Control Commission, Maine Drinking Water Program, and Maine Department of Environmental Protection, and sponsored by the New England Water Works Association. The goal of this seminar was to introduce watershed management practices to surface water supplies.

Northern Maine Childrens Water Festival, 2000. University of Maine, Orono, Maine. October 10, 2000. Organized by the Maine Department of Environmental Protection and the Mitchell Center for Environmental and Watershed Research, this all-day environmental event drew over 800, 5th and 6th grade students and teachers to the University of Maine campus. The goal of the Festival is to educate about water, its uses in meeting human needs, water quality protection for human and ecosystem health, the different forms water takes in the water cycle, and water conservation.

Northeast Regional Air Quality Committee Meeting, November 28, 2000. This committee consists of regional state agency and park service staff and is involved in policy issues that relate to air quality and ecosystem response to atmospheric pollutants.

2001 National Ocean Sciences Bowl, Northern New England Regional, Noreaster Bowl, Feb. 2001. University of New England, Brunswick, ME.

Source Water Protection Workshops, January-March, 2000. Organized by the Mitchell Center and Maine Water Utilities Association with support from the Maine Drinking Water Program, this series of eight workshops were designed to help educate small utilities about source water protection. The goal of these workshops is to bridge the gap between source water assessment and source water protection.

The following are other Information Transfer and Public Service Activities.

Bangor Daily News, October 2000. UMaine Facility Focuses on Water. The University of Maine honored the environmental achievements of Maine Senator George J. Mitchell by dedicating the Water Research Institute in his name on October 6, 2001. Senator Mitchell played a major role in such environmental laws as the Clean Air Act, Clean Water Act and the Safe Drinking Water Act. The Senator George J. Mitchell Center for Environmental and Watershed Research conducts research on topics such as acid rain, lake pollution, mercury in fish, drinking water source protection, MTBE and arsenic in groundwater.

Bangor Daily News, August 2000. Mussels Used to Measure PCB Levels in Kennebec. This article highlights the Mitchell Centers involvement in a caged mussel biomonitoring project underway in the Kennebec River in Maine. This project is part of the research effort to address the requirements of the 1998 Maine law requiring that dioxin concentrations downstream from paper mills must be no higher than concentrations upstream.

Lincoln County News. September 2000. Article focuses on outreach programs in environmental education. Programs featured included Maine Project WET (Water Education for Teachers) and PEARL (an interactive GIS database on the Internet).

USGS Weekly Highlights September 2000. High Mercury Levels in Tree Swallows at Acadia National Park. Jerry Longcore and Terry Haines.

Lewiston Sun-Journal, October 18, 2000. Cleaning Rivers: Its Science, Its the Law. The work of Heather Shoven, UMaine Mitchell Center graduate student was highlighted in a front-page story in the Lewiston Sun Journal. Shoven is involved with monitoring the dioxin levels downstream from paper mills, to measure compliance with Maines strict 1997 law.

Bangor Daily News, October 25, 2000. Comments re: Atlantic Salmon, Acid Rain and Climate Change Conference in Machias.

British Broadcasting System, November, 2000. Kahl interviewed by Jill Rankin of the BBC who is producing a science series for The Learning Channel on weather.

Maine Public Radio, December 2000. Heather Shoven, UMaine Mitchell graduate student featured in a story about pollution monitoring technology and the use of semi-permeable membrane devices for detecting dioxin in Maine rivers.

Maine Public Broadcasting, Maine Watch, June 2000. Broadcast featured interviews with T. Anderson, S. Kahl as they discussed UMaines role in dioxin research conducted at the Mitchell Center. The Center conducts research that the State of Maine uses to set fish consumption advisories and is central in progress toward compliance with the 1997 Maine dioxin reduction law. Expanding Your Horizons, March 2000. The Mitchell Center participated in the EYH program giving laboratory tours to groups of 7th and 8th grade girls from Maine school systems. This program encourages participation in Science and Math disciplines by introducing them to career opportunities in these fields.

Testimonial: Maine Board of Environmental Protection. Kahl, S. Acidic Precipitation and Aquatic Effects in Maine State of the Science. Presented: Maine Board of Environmental Protection, Augusta, ME, January 6, 2000.

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	12	0	1	0	13
Masters	35	0	0	0	35
Ph.D.	10	0	0	0	10
Post-Doc.	2	0	0	0	2
Total	0	0	0	0	0

Notable Awards and Achievements

Awards

Vidito, S., K. Johnson, H. Shoven, June 2000. University of Maine Alumni Association Group Travel Grant. Gordon Research Conference, Plymouth, NH. Poster Presentations.

S. Vidito, May 2000. Best Student Poster, Maine Water Conference.

Peckenham, J. PEAC Professional Travel Award. March, 2000. National Institutes for Water Research Meeting. Washington, D.C.

Shoven, H. May 2001. First Place for Best Student Poster Presentation. Presentation Title: Semipermeable Membrane Devices: Are they a helpful addition to Maine’s Dioxin Monitoring Program? Maine Water Conference, Augusta, ME.

Shoven, H. April 2001. Best Academic Content. Presentation Title: What’s up? What’s down? Maine’s search for an upstream-downstream dioxin monitoring method continues. 3rd Annual Association of Graduate Students Graduate Research Expedition. Presentation Title: What’s up? What’s down? Maine’s search for an upstream-downstream dioxin monitoring method continues. University of Maine.

Shoven, H. April 2000. Honorable Mention. Poster Presentation: Monitoring dioxin levels in Maine rivers with semipermeable membrane devices. Maine Water Conference, April 2000.

Shoven, H. April 2000. UMGAA Nancy Morse Dysart ’60 Travel Grant. Invited Poster: Gordon Research Conference, June 26 - June 30, 2000.

Shoven, H. June 2000. Individual Award. University of Maine Association of Graduate Students, University of Maine, Orono, ME.

Publications from Prior Projects

1. See Information Transfer summary.