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# A Systematic Survey of Water Chemistry for Downeast Area Rivers

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# **A Systematic Survey of Water Chemistry for Downeast Area Rivers**

## **FINAL REPORT**

August, 2005

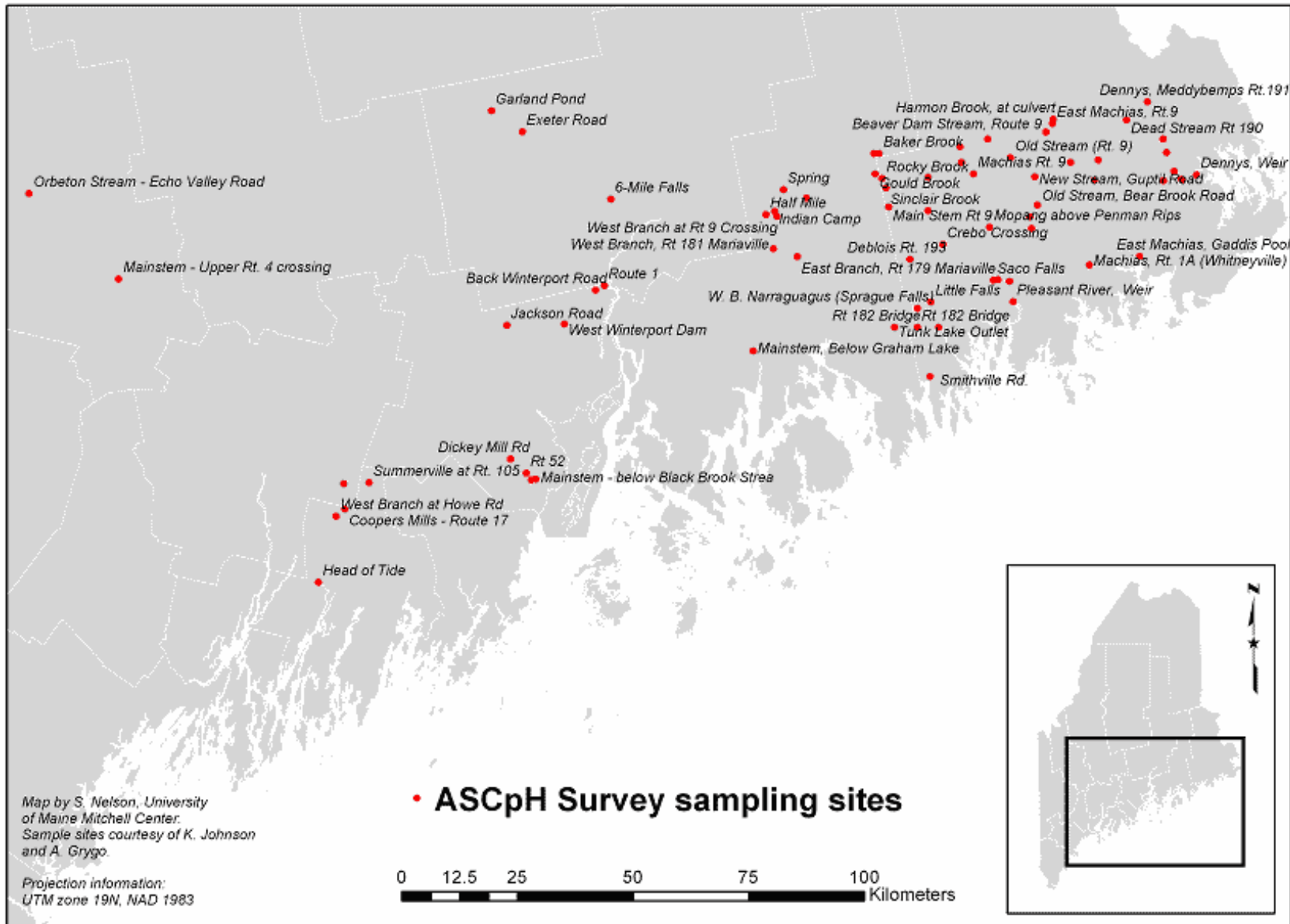
Ken Johnson<sup>1</sup> and Steve Kahl<sup>2</sup>

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for Environmental and Watershed Research  
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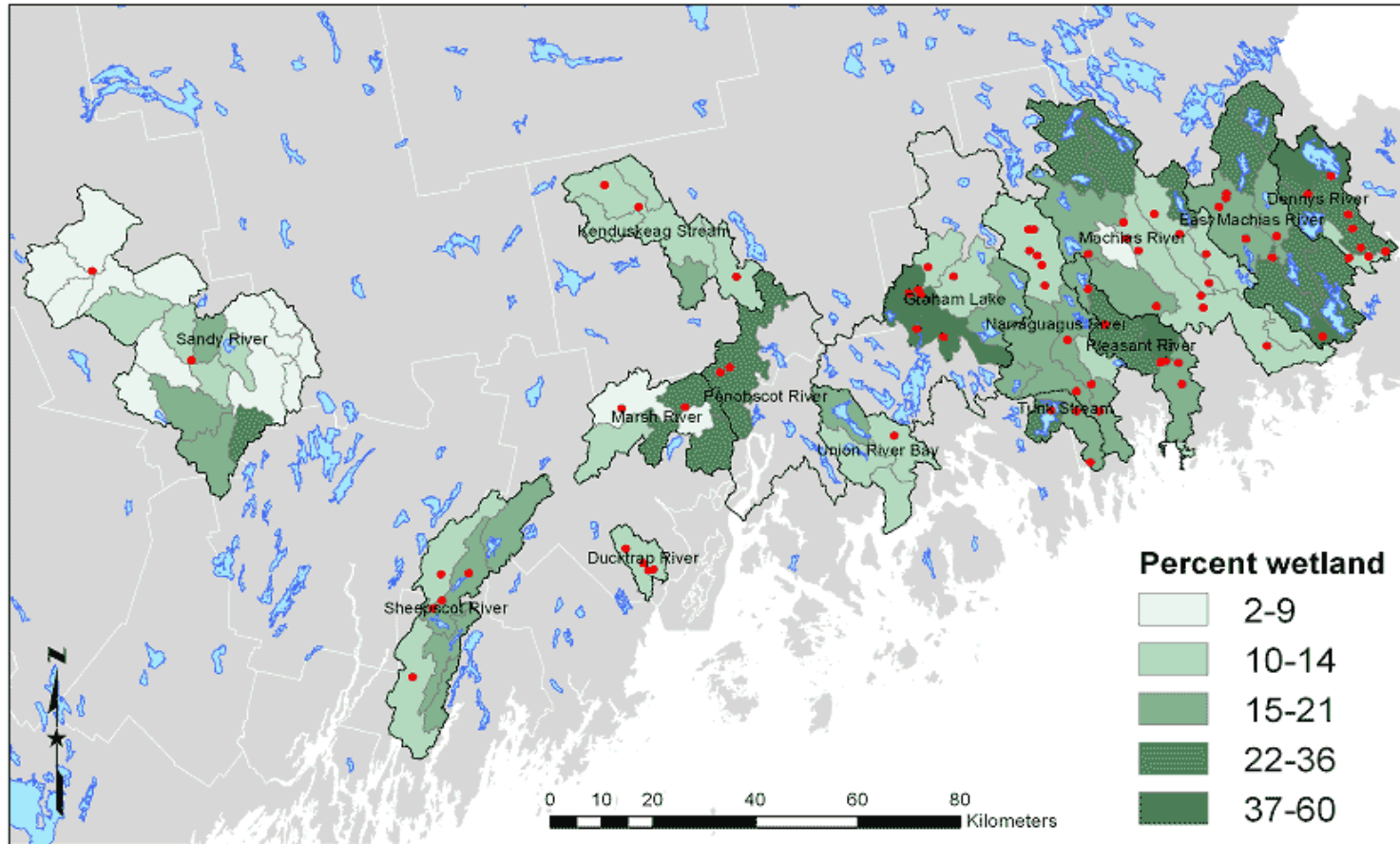
**Figure 1. Map of ASCpH Survey sample sites (2003-04).**

Figure showing all ASCpH survey sites for 2003 and 2004. Sites range from the Sandy River watershed to the Dennys River watershed.



**Figure 2.**  
**Map of the percent of the watershed that is wetland from the ASCpH Survey sites.**

Figure showing the percent of the watershed that is considered wetland (i.e. the Machias River watershed is between 22 and 60 percent wetland depending on the sample site). The percentage of wetland in a watershed in this figure increases from west to east across the map.



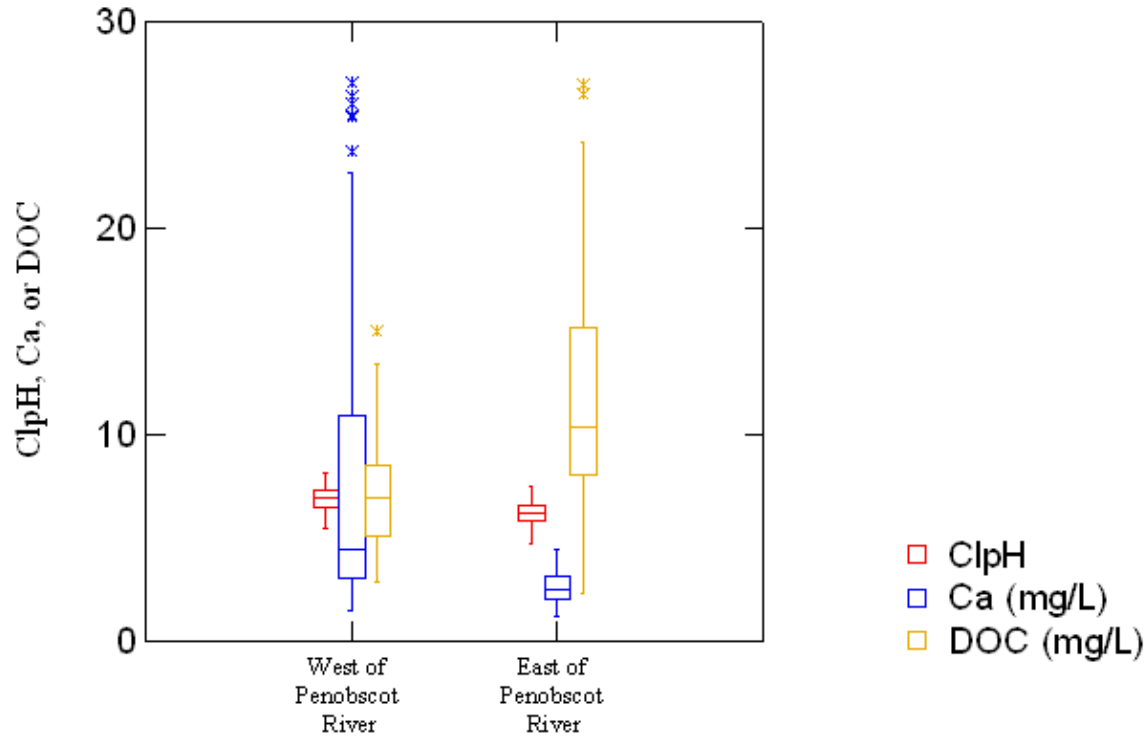
**Wetland coverage  
in major drainages  
sampled by the ASC  
in 2003-2004**

- Survey sampling sites
- Major drainages (HUC 10)
- Large lakes (>400 ac)

*Map and analyses by S. Nelson,  
University of Maine Mitchell Center.  
Sample sites courtesy of A. Grygo  
and K. Johnson. Watersheds, lakes  
and wetlands courtesy of the Maine  
Office of GIS and Maine DEP.*

*Projection information:  
UTM zone 19N, NAD 1983*

**Figure 3.**  
**Graph showing ClpH, Ca, and DOC for ASCpH sites separated by location.**

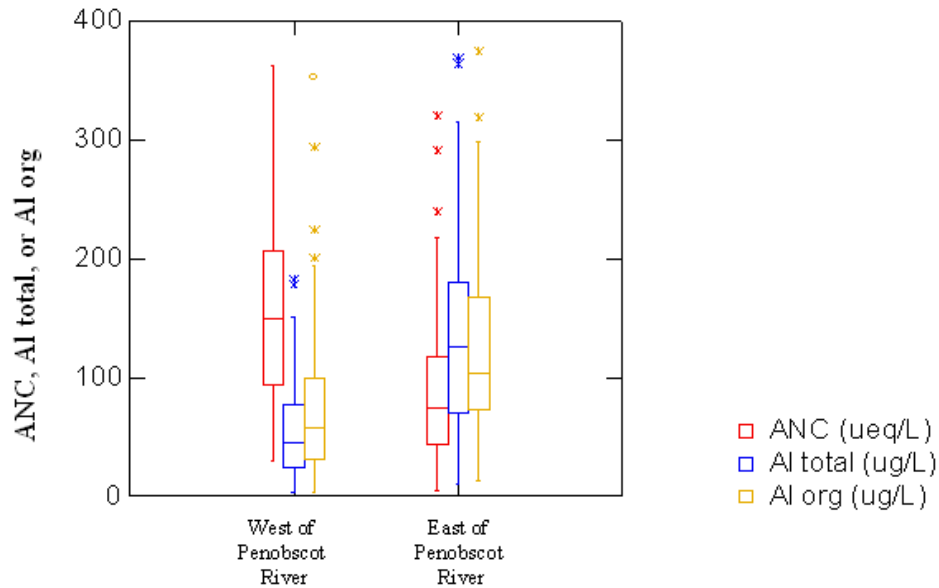


Graph showing ClpH, Ca, and DOC for ASCpH sites separated by location.			
	ClpH (standard units)	Ca (miligrams per liter)	DOC (miligrams per liter)
Number of cases	394	199	199
Minimum	4.680	1.160	2.311
Maximum	8.160	27.043	26.941
Median	6.345	2.782	8.961
Mean	6.339	4.259	10.361
95% Confidence Interval Upper	6.402	4.958	11.106
95% Confidence Interval Lower	6.275	3.559	9.616
Standard Deviation	0.644	5.002	5.330

**Figure 4.**

**Graph showing ANC, AI total, AI org for ASCpH sites separated by location.**

17 data points are not shown because of truncated y-axis. AI-org results can be higher than AI-total results because AI-total is a filtered sample and AI-org is not filtered.



**Graph showing ANC, AI total, AI org for ASCpH sites separated by location.**

	ANC (microequivilants per liter)	Total AI (micrograms per liter)	AI-org (micrograms per liter)
Number of cases	395	198	199
Minimum	5.460	3.254	2.887
Maximum	1934.260	368.500	373.700
Median	93.550	97.140	94.100
Mean	179.043	109.733	109.354
95% Confidence Interval Upper	207.326	120.515	120.080
95% Confidence Interval Lower	150.760	98.952	98.628
Standard Deviation	285.916	76.926	76.729

## Abstract

Atlantic salmon have been returning to Maine rivers in very small numbers for many years. A number of potential explanations have been offered. The National Academy of Sciences (2003) report on Atlantic salmon highlighted water chemistry as a concern for the recovery of Atlantic salmon in Maine, and this factor is currently being evaluated by several studies, including ours. We report here on the first systematic water chemistry survey of Maine salmon rivers. The acid-base chemistry of approximately 70 stations on 13 rivers ranges from well buffered and high pH (mostly those west of the Penobscot River), to low ANC and episodically acidic due largely to natural organic acidity (east of the Penobscot River).

The rivers east of the Penobscot have low base cation concentrations, a typical condition for waters in landscapes dominated by acidic bogs and wetlands. Lakes in the region have become slightly more dilute, with decreased concentrations of base cations, in the past 10 to 20 years, due to reductions in acidic deposition. We do not have adequate data to know if this trend is occurring in salmon river chemistry, although the information available suggests that chemistry has been relatively stable despite the recent ongoing reductions in acidic deposition. The wetlands and bogs are mitigators of acidic deposition, and indeed have yielded waters more acidic than acidic deposition for thousands of years. Therefore, we suggest *that water chemistry is unlikely to have directly caused the demise of salmon populations, but it is possible that the dilute, episodically acidic water chemistry in some rivers may be inhibiting their ability to recover in those rivers.* However, salmon populations have not recovered in the well buffered rivers either, suggesting that water chemistry is not the only factor affecting recovery. Other factors include climate, ecosystem status, and anthropogenic influences, all of which are beyond the scope of the research, which was to characterize the water chemistry in central and Downeast salmon rivers.

## Introduction

The 2003 National Academy of Sciences report (NAS, 2003) highlighted water chemistry as a potential factor in the survival of juvenile Atlantic salmon, especially their ability to make a successful transition from freshwater to saltwater during normal smolt migration. Chemical composition, aquatic habitat, and even water availability are linked, and often difficult to differentiate. Natural factors such as calcium (Ca) and aluminum (Al) concentration, and pH (acidity) will affect salmon. Natural dissolved organic carbon is important because it contributes to natural

organic acidity, and forms chemical complexes with metals such as Al to reduce toxicity.

In Maine salmon rivers, non-point source pollution is a potential factor from commercial logging operations or agriculture. Climate warming is another potential factor, because salmon are near their southern limit already. Regionally, acidic deposition has been implicated for both chronic acidification and for episodic acidification, although the historical influence of acidic deposition on Downeast rivers is still in question because of the large watersheds with complex geology and abundant wetlands which yield organic acidity. Either climate change or reductions in acidic deposition may affect organic acidity, which has been demonstrated to be a major control of pH in Downeast rivers.

In response to the need to understand the spatial and seasonal patterns in water chemistry in Maine salmon rivers, this project conducted the first systematic and comprehensive survey of water chemistry in these rivers. The analyses evaluated the natural chemistry variables in Downeast rivers that that may be pertinent to salmon. The results of this project are also directly related to the plans for mitigation actions such as liming (NAS, 2003) because of the need to document and understand spatial and temporal patterns in salmon river chemistry before chemical manipulation of the water chemistry is undertaken.

The main goal of this set of surveys was to characterize the water quality of salmon rivers by sampling water at multiple sites along the rivers on the same day. The surveys were repeated seasonally to determine the range of chemistry found in each river. All the samples were analyzed at the Watershed Research Laboratory of the Senator George J. Mitchell Center to eliminate differences in analytical techniques that arise among different workers and laboratories. This report compares the water chemistry of spatially different sites and establishes general chemical comparisons between them.

Additional goals of this report are to explain the importance of the chemical factors reported here. Each analysis is described both in terms of how the specific measurement is conducted as well as the way in which the analyte contributes to the overall chemical status of the system. Summary data are presented in tables in each section, grouped by major drainage, in ascending order by means.



## Methods

Staff from the Maine Atlantic Salmon Commission (ASC), Maine Department of Environmental Protection (MDEP), and the Mitchell Center conducted the fieldwork during 2003-04. We simultaneously sampled approximately 70 stations on 13 major drainages, 3 times per year for 2 years (Table 1).

**Table 1. ASCpH survey dates and site numbers. Pleasant River discharge provided as a general reference.**

Survey	Collection Date	Number of sites	USGS daily average discharge for Pleasant River at Epping Maine in cubic feet per second
Spring 2003	5/7/2003	63	206
Summer 2003	7/29/2003	66	28
Fall 2003	10/28/2003	66	208
Spring 2004	4/6/2004	69	279
Summer 2004	7/27/2004	69	35
Fall 2004	10/26/2004	69	51

Each survey was conducted on the same day for all stations, to provide a consistent and comparable snap-shot of regional chemistry under similar hydrologic conditions ([Figure 1](#)). Sites were chosen to achieve spatial coverage of the study area with relative ease of accessibility. Samples were collected in 500 mL HDPE bottles for major ion chemistry, and a 60 mL syringe for closed-system pH and delivered to the Mitchell Center lab for analysis within 12 hours of collection. The preparation, sampling, and analytical methods are well-established protocols based on approved EPA methods employed by the research group of PI Kahl and co-workers for nearly 20 years.

The initial focus of this survey was on pH and alkalinity, hence the first year of the project analyzed samples for closed-system pH, air-equilibrated pH, acid-neutralizing capacity, color, and conductivity (Table 2). The second year of the project was funded by NFWF to add full water chemistry: dissolved organic carbon, base-cations, acid-anions, Al-total-dissolved, and Al-organic (Table 2). Color was not analyzed during the second year because dissolved organic carbon was being measured directly.

We analyzed samples for two types of pH in this study. Closed-system pH (ClpH) is analogous to field pH but measured in the laboratory under

controlled conditions for reproducibility. ClpH is strongly influenced by the natural supersaturation of carbon dioxide, and therefore is variable seasonally and even diurnally due to biological activity. This natural variability makes it difficult to characterize the typical field pH of a river, or to evaluate trends based on 'field pH'.

The mechanism for the influence of carbon dioxide is as follows: Carbon dioxide (CO<sub>2</sub>) dissolves into natural waters producing carbonic acid (H<sub>2</sub>CO<sub>3</sub>). Pure water, with no impurities or dissolved gasses, should theoretically have a pH of 7.00. The same water should have a pH of 5.62 when in equilibrium with atmospheric CO<sub>2</sub> (~380 ppm) because of H<sub>2</sub>CO<sub>3</sub> formation. Biological respiration contributes CO<sub>2</sub> to natural waters faster than the CO<sub>2</sub> can off-gas to the atmosphere, causing an over-saturation of CO<sub>2</sub>, which can depress the pH. Groundwater contributions to surface waters are also supersaturated with CO<sub>2</sub> due to biological activity.

Air-equilibrated pH (EqpH), the second method we employ to measure pH, represents the pH of a sample purged of excess CO<sub>2</sub>. The sample is equilibrated with air of standardized CO<sub>2</sub> concentration. EqpH represents the "geochemical" pH of the sample controlled by geology and perhaps influenced by acid rain. EqpH data are well suited to trend analysis and represent a reproducible measure of the typical pH of a given location.

We speciated Al into three fractions: total, organic, and exchangeable (ionic). A small portion of the sample is poured over a cation exchange resin to remove exchangeable Al (Al<sup>+3</sup>, a.k.a. Al-x, exchangeable Al, labile Al) and the rinsate is collected and analyzed. The fraction of the sample that passes through the column contains uncharged, organically bound Al (Al-org). Then a small amount of the original sample is filtered through a 0.45 μm filter and analyzed; this fraction is known as total dissolved Al (Al-total). The difference between total and organic is the fraction bound to the exchange resin: exchangeable (ionic) Al.

**Table 2. Analytical Methods for the Mitchell Center Laboratory.**

Analyte	Method	Reference
pH, closed cell	Electrode	Hillman et al. <sup>4</sup> , EPA 19.0 <sup>3</sup>
pH, aerated	Electrode	Hillman et al. <sup>4</sup> , EPA 5.0 <sup>3</sup>
Specific conductance	Wheatstone bridge	EPA 120.1 <sup>2</sup> , EPA 23.0 <sup>3</sup>
Apparent color	Spectrophotometer, 457.5	EPA 110.2 <sup>2</sup>

	nanometers	
ANC	Gran titration	Hillman et al. <sup>4</sup> , EPA 5.0 <sup>3</sup>
Anions (Chloride, Nitrate, Sulfate)	Ion chromatography	EPA 300.0 <sup>1</sup>
Cations (Calcium, Magnesium, Sodium, Potassium)	Ion chromatography	ASTM D 6919-03 <sup>5</sup>
Aluminum (total)	Atomic absorption spectroscopy with graphite furnace	EPA 200.9 <sup>1</sup>
Dissolved Organic Carbon	Infrared carbon analyzer, persulfate oxidation	EPA 415.1 <sup>2</sup>

AAS=atomic absorption spectrophotometry  
 IR=Infrared Spectrophotometry

***Method references:***

- <sup>1</sup> Methods for the Determination of Inorganic Substances in Environmental Samples, EPA 600/R-93-100, 1993.
- <sup>2</sup> Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, 1979, Revised 1983.
- <sup>3</sup> Handbook of Methods for Acid Deposition Studies: Laboratory Analysis for Surface Water Chemistry, EPA 600/4-87-026, 1987.
- <sup>4</sup> Hillman,D.C., J. Potter, and S. Simon, 1986. Analytical methods for the National Surface Water Survey, Eastern Lake Survey. EPA/600/4-86/009, EPA Las Vegas.
- <sup>5</sup> ASTM D 6919-03 Standard Test Method for Determination of Dissolved Alkali and Alkaline Earth Cations and Ammonium in Water and Wastewater by Ion Chromatography. Annual Book of ASTM Standards, Vol 11.01, 2003.

***Geology***

The bedrock geology of eastern Maine can be simplified into two types of terrane separated by a line running from the Penobscot River near Winterport northeast towards Topsfield (Norumbega Fault). North and west of this line the rocks are mostly derived from former marine sediments with some rocks containing a fraction of carbonate minerals. South and east of this line the rocks are derived from volcanic rocks and more recent intrusive igneous rocks. These rock types differ in their chemistries (especially

calcium, magnesium, aluminum, and iron) and resistance to erosion or dissolution (Surficial Geologic Map of Maine, 1985).

The surficial geology of eastern Maine is largely dominated by the effects of continental glaciation that ended approximately 12,000 years ago. Nearly all the region has a layer of till- a heterogeneous mixture of sand, silt, clay, and rocks. Downeast Maine has extensive glacio-marine deltas composed predominantly of sand. These features are generally surrounded by extensive forested wetlands, open wetlands, and bogs. These wetlands are generally underlain by marine silts and clays deposited at the end of the glacial period, during the period of marine submergence. This Presumpscot Formation occurs discontinuously over nearly a quarter of Maine's land area from an elevation of about 70 m (250 feet) near the coast, to as much as 120 m (400 ft) well inland (Surficial Geologic Map of Maine, 1985). The result of this glaciation is a mosaic of smaller well-drained glacial features interspersed in a landscape with poor drainage and abundant wetlands. The percentage of wetland in a given watershed increases from west to east in this part of Maine ([Figure 2](#)), a value added spatial analysis. These wetlands produce large quantities of soluble organic matter that gives surface waters the color of tea.

The chemistry of surface waters is affected by the geology in several ways. Rocks that weather slowly produce fewer ions per unit time (i.e., less calcium, magnesium) under similar conditions of hydrology. In addition, the mantle of marine clay or wetland may hydrologically isolate bedrock or till from weathering. Therefore, surface waters in these areas have naturally low concentrations of major cations derived from chemical weathering, and relatively high influence of vegetation on ion and nutrient chemistry. In waters with low ionic strength and abundant watershed wetlands, dissolved organic carbon in the form of organic acids is most likely to be the major control on acid-base chemistry. Kahl et al. (1989) documented wetland ponds in salmon river watersheds with pH values as low as 3.5, compared to the pH of precipitation of 4.6. The mean pH of these wetland ponds was less than 4.0. Clearly, 'acid rain' is not controlling the pH of these acidic waters. Because of the landscape, it is likely that the pH in the Downeast salmon rivers has historically been strongly influenced by naturally occurring organic acids.

## **Results and Discussion**

### ***Spatial Patterns***

A broad range of chemical conditions exist in the Maine salmon rivers and streams (Table 3). The rivers sort into a high pH group (west of the

Penobscot River) and a low pH group (east of the Penobscot). [Appendix A](#) includes a complete list of the sample sites, drainages, location relative to the Penobscot River, UTMs, and the surveys that include the site. Statistical tables for each region and individual drainage are included below. A general description of the water chemistry variables is provided to complement the comparison of the differences between rivers or sites on the same river.

**Table 3. Summary of all samples from both years of the survey.**

<b>Analysis</b>	<b># of cases</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Median</b>	<b>Mean</b>	<b>Standard Deviation</b>
ClpH (standard units)	394	4.68	8.16	6.34	6.34	0.64
EqpH (standard units)	395	4.73	8.36	6.90	6.81	0.67
ANC (microequivalents per liter)	395	5.5	1934.3	93.6	179.0	285.9
Conductance (microsiemens per centimeter)	395	17.9	239.5	31.7	42.4	32.9
Color (platinum cobalt units)	196	3	200	63	70	41
Ca (microequivalents per liter)	199	58.0	1352.1	139.1	212.9	250.1
Ca (milligrams per liter)	199	1.2	27.0	2.8	4.3	5.0
Mg (microequivalents per liter)	199	27.7	326.1	56.6	72.9	57.7
Na (microequivalents per liter)	199	49.7	399.1	122.9	132.7	52.6
K (microequivalents per liter)	199	4.8	56.1	11.3	12.9	6.9
Cl (microequivalents per liter)	199	14.9	391.8	92.9	108.4	64.2
NO3 (microequivalents per liter)	178	0.1	29.7	1.4	2.9	4.7
SO4 (microequivalents per liter)	199	14.2	131.0	45.4	50.0	22.9
DOC (milligrams per liter)	199	2.3	26.9	9.0	10.4	5.3
Total Al (micrograms per liter)	198	3.3	368.5	97.1	109.7	76.9
Al-org (micrograms per liter)	199	2.3	373.7	94.1	109.3	76.9

Sample sites located to the west Penobscot River tend to have higher pH, ANC, Ca and lower DOC and Al than sites to the east of the Penobscot River ([Figure 3](#) and [Figure 4](#)). The lower ANC and higher DOC make the eastern sites more susceptible to event-driven pH depressions than sites to the west of the Penobscot River (Tables 4 and 5).

Spatial patterns that relate to surficial geology are recognizable within individual drainages. Tributaries may have different chemical makeup than the main stem of the receiving body. Tributaries that drain bogs tend to have lower pH and higher DOC concentrations than tributaries that drain hillsides or sandy areas. An example of this pattern is the Dennys River. During the 2003 summer survey, the ClpH and ANC values for the Meddybemps outlet location were 7.26 and 124 µeq/L respectively. During the same day the sample taken just above head tide at the weir on the Dennys had a ClpH of 6.44 and ANC of 104 µeq/L, due to the contributions of naturally acidic tributaries draining wetlands upstream.

**Table 4. Summary of water chemistry for drainages west of the Penobscot River.**

Analysis	# of cases	Minimum	Maximum	Median	Mean	Standard Deviation
ClpH (standard units)	86	5.65	8.16	6.99	7.00	0.52
EqpH (standard units)	86	6.40	8.36	7.44	7.52	0.44
ANC (microequivalents per liter)	86	52.0	1934.3	296.6	508.6	476.2
Conductance (microsiemens per centimeter)	86	22.2	239.5	73.0	85.0	49.4
Color (platinum cobalt units)	38	10	125	36	50	31
DOC (milligrams per liter)	48	2.9	11.9	6.9	6.7	2.2
Ca (microequivalents per liter)	48	117.7	1352.1	286.9	481.6	401.5
Ca (milligrams per liter)	48	2.4	27.0	5.7	9.6	8.0
Mg (microequivalents per liter)	48	45.3	326.1	98.9	137.7	87.3
Na (microequivalents per liter)	48	49.7	399.1	173.3	185.8	68.7
K (microequivalents per liter)	48	7.7	56.1	18.6	21.0	8.6
Cl (microequivalents per liter)	48	14.9	391.8	167.8	179.2	79.4
NO <sub>3</sub> (microequivalents per liter)	47	0.5	29.7	3.1	7.0	7.5

liter)						
SO <sub>4</sub> (microequivalents per liter)	48	35.8	131.0	73.2	77.1	25.6
Total Al (micrograms per liter)	48	3.3	113.9	34.6	40.2	26.0
Al-org (micrograms per liter)	48	2.9	351.9	43.2	68.1	70.7

**Table 5. Summary of water chemistry for drainages east of the Penobscot River.**

<b>Analysis</b>	<b>#of cases</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Median</b>	<b>Mean</b>	<b>Standard Deviation</b>
ClpH (standard units)	308	4.68	7.44	6.18	6.15	0.55
EqpH (standard units)	309	4.73	7.84	6.76	6.61	0.59
ANC (microequivalents per liter)	309	5.5	403.1	75.6	87.3	57.0
Conductance (microsiemens per centimeter)	309	17.9	93.4	29.9	30.6	7.8
Color (platinum cobalt units)	158	3	200	75	75	42
DOC (milligrams per liter)	151	2.3	26.9	10.2	11.5	5.5
Ca (microequivalents per liter)	151	58.0	232.2	124.5	127.5	40.0
Ca (milligrams per liter)	151	1.2	4.6	2.5	2.6	0.8
Mg (microequivalents per liter)	151	27.7	142.4	52.7	52.3	15.5
Na (microequivalents per liter)	151	57.9	273.7	110.9	115.8	31.3
K (microequivalents per liter)	151	4.8	29.0	10.1	10.3	3.5
Cl (microequivalents per liter)	151	36.7	272.1	83.9	85.9	36.8
NO <sub>3</sub> (microequivalents per liter)	131	0.1	7.9	1.1	1.4	1.3
SO <sub>4</sub> (microequivalents per liter)	151	14.2	72.6	41.8	41.4	13.3
Total Al (micrograms per liter)	150	10.7	368.5	124.7	132.0	74.5
Al-org (micrograms per liter)	151	13.3	373.7	102.6	122.5	74.1

**pH**

pH is a measure of the activity (concentration) of hydrogen ( $H^+$ ) in solution. A change of 1 pH unit represents a 10 fold change in  $H^+$  concentration because pH is logarithmic. pH affects metal speciation, weathering of soils and bedrock, nutrient cycling, and cation and anion exchange reactions in soil and overburden, and is in turn largely controlled by weathering reactions of rocks and soils. pH is difficult to analyze accurately in the field, due to supersaturation of carbon dioxide that is a major control on pH, and due to the dilute nature of hydrogen ion in natural waters (1 part per million at pH 7).

The data tables include two types of pH values. Closed-system pH (ClpH) is analogous to field pH but measured in the laboratory under controlled conditions. ClpH includes the natural influence of supersaturation of carbon dioxide and is the pH that fish experience. Air-equilibrated pH (EqpH), the second method we employ to measure pH, represents the pH of a sample purged of excess  $CO_2$ . The sample is equilibrated with air of standardized  $CO_2$  concentration. EqpH represents the “geochemical” pH of the sample; the pH of the sample resulting from the influence of geology and ‘acid rain’.

The controls on pH in the salmon rivers include atmospheric inputs of  $NO_x$  and  $SO_x$ , soil contributions of aluminum and base-cations,  $CO_2$  from the atmosphere, and dissolved organic carbon from soil and bogs. The major control on pH is clearly natural organic acidity from DOC, and this control maybe increasing as the influence of acid rain declines (Kahl et al., 2004). Rivers dominated by DOC (east of the Penobscot) have a wider annual range of pH (2 to 3 pH units) for two reasons: one, DOC-dominated rivers have lower ANC and two, DOC-derived acids can acidify surface waters to a much lower pH (pH < 4) than acid rain (pH generally > 4.5), as demonstrated by Kahl et al. (1989).

Summary data for pH are included in Tables 6 and 7. “# of cases” represents the number of samples used to create the statistic. Number of samples is different between drainages because each drainage has a different number of sites within that drainage. All subsequent summary-tables will follow this format.

**Table 6. ClpH results, separated by drainage, in ascending order by means. Data are from 2003 and 2004 surveys.**

Drainage	Analysis	# of cases	Minimum	Maximum	Median	Mean	Standard Deviation
Tunk	ClpH	18	5.28	6.27	5.95	5.93	0.28
Pleasant	ClpH	34	4.70	7.25	6.05	6.05	0.63



Dennys	ClpH	45	4.84	7.26	6.12	6.09	0.56
Machias	ClpH	69	4.68	7.05	6.17	6.11	0.6
East Machias	ClpH	42	5.17	7.17	6.11	6.13	0.48
Narraguagus	ClpH	53	5.09	7.44	6.28	6.26	0.55
Union	ClpH	47	5.45	7.10	6.36	6.34	0.45
Ducktrap	ClpH	15	5.65	6.77	6.39	6.35	0.32
Sandy River	ClpH	6	6.38	7.03	7.00	6.84	0.27
Sheepscot	ClpH	23	6.32	7.67	6.83	6.87	0.37
Marsh Stream	ClpH	12	6.68	7.45	6.96	7.02	0.24
Cove Brook	ClpH	12	6.49	8.16	7.50	7.40	0.55
Kenduskeag	ClpH	18	7.04	7.88	7.50	7.49	0.25

**Table 7. EqpH results, separated by drainage, in ascending order by means. Data are from 2003 and 2004 surveys.**

Drainage	Analysis	# of cases	Minimum	Maximum	Median	Mean	Standard Deviation
Tunk	EqpH	18	5.66	6.81	6.44	6.44	0.33
Pleasant	EqpH	34	4.73	7.55	6.66	6.49	0.73
Machias	EqpH	70	4.73	7.84	6.74	6.53	0.67
Dennys	EqpH	45	4.92	7.42	6.77	6.56	0.59
East Machias	EqpH	42	5.24	7.44	6.72	6.61	0.52
Narraguagus	EqpH	53	5.13	7.54	6.83	6.70	0.57
Union	EqpH	47	5.73	7.56	6.98	6.85	0.39
Ducktrap	EqpH	15	6.40	7.37	7.13	7.06	0.29
Sandy River	EqpH	6	7.06	7.47	7.33	7.28	0.18
Sheepscot	EqpH	23	6.95	7.87	7.31	7.30	0.26
Marsh Stream	EqpH	12	7.07	7.94	7.62	7.57	0.29
Cove Brook	EqpH	12	7.47	8.35	7.88	7.89	0.36
Kenduskeag	EqpH	18	7.51	8.36	7.93	7.97	0.26

### **Acid Neutralizing Capacity**

Acid neutralizing capacity (ANC) reflects the ability of natural waters to neutralize inputs of acids (i.e. buffering capacity). The source of ANC is from carbonate minerals in soils or rock or from DOC (organic acidity), which can also serve as a pH buffer by lowering the pH then holding it there. As ANC increases, the range of EqpH decreases, as expected from the relationship

between pH and ANC. The Pleasant River had the greatest pH range of almost 3 pH units with a mean ANC of 88  $\mu\text{eq/L}$ , while the EqpH of the Kenduskeag had a pH range of less than one unit and a mean ANC of 1019  $\mu\text{eq/L}$  (Table 8).

**Table 8. ANC results, separated by drainage, in ascending order by means. Data are from 2003 and 2004 surveys.**

Drainage	Analysis ( $\mu\text{eq/L}$ )	# of cases	Min.	Max.	Median	Mean	Standard Deviation
Tunk	ANC	18	14.9	54.4	27.0	29.0	12.0
Dennys	ANC	45	15.5	211.2	75.6	76.9	39.9
East Machias	ANC	42	28.2	209.0	70.7	81.5	44.0
Machias	ANC	70	5.7	191.7	75.4	82.9	48.1
Pleasant	ANC	34	5.5	403.1	56.6	88.8	84.3
Union	ANC	47	30.4	216.1	96.9	104.3	50.3
Narraguagus	ANC	53	18.6	320.1	84.2	110.6	65.8
Ducktrap	ANC	15	52.0	217.9	129.0	131.5	51.0
Sandy River	ANC	6	85.8	210.2	140.8	142.1	46.9
Sheepscot	ANC	23	92.1	736.7	164.9	248.5	174.1
Marsh Stream	ANC	12	192.2	708.1	408.4	438.0	187.1
Cove Brook	ANC	12	300.2	1934.3	855.8	966.4	649.0
Kenduskeag	ANC	18	481.9	1504.0	1000.3	1019.0	323.8

### **Conductivity**

Conductivity is a measure of the total ion concentration in a sample (ionic strength), measured by the amount of electrical resistance in a sample. The lower the total concentration of ions in the water, the greater is the resistance to electrical conductance, and therefore the lower the conductivity of the water. Specific Conductance is the conductivity of a water sample measured over a 1 cm distance between electrodes, at 25 degrees C, labeled here as conductivity. Surface waters with low conductivities ( $< 20 \mu\text{S/cm}$ ) are typically considered to be 'dilute'. Conductivity measures only ions and organic anions (deprotonated organic carbon); suspended solids, biological components, and particulates are not measured. Conductivity is positively correlated with ANC because base cations and ANC contribute to ionic strength.

**Table 9. Specific conductance (conductivity) results, separated by drainage, in ascending order by means. Data are from 2003 and 2004 surveys.**

Drainage	Analysis ( $\mu\text{S}/\text{cm}$ )	# of cases	Min.	Max.	Median	Mean	Standard Deviation
Machias	Conductance	70	17.9	57.1	27.2	28.9	7.7
Narraguagus	Conductance	53	19.5	45.7	29.5	29.4	6.2
Tunk	Conductance	18	23.7	34.9	30.0	29.5	3.4
Union	Conductance	47	19.5	47.1	29.2	29.7	6.5
Pleasant	Conductance	34	21.7	64.6	29.9	32.3	9.2
East Machias	Conductance	42	20.0	93.4	31.1	32.4	11.5
Dennys	Conductance	45	21.4	42.7	33.2	32.8	5.6
Sandy River	Conductance	6	22.2	45.3	31.0	33.0	8.9
Ducktrap	Conductance	15	37.2	51.8	43.3	43.3	4.5
Sheepscot	Conductance	23	42.9	123.7	53.5	62.4	23.6
Marsh Stream	Conductance	12	51.3	111.3	79.1	78.8	16.5
Kenduskeag	Conductance	18	85.4	179.5	131.0	132.8	29.7
Cove Brook	Conductance	12	72.7	239.5	137.6	141.3	62.7

Downeast rivers are more dilute in part to igneous dominated bedrock geology, and in part to hydrologic control by wetlands, which isolates bedrock and till from runoff and reduces chemical contributions to surface waters. Agricultural activities in watersheds west of the Penobscot increase the conductivity of the receiving streams.

### ***Color and Dissolved Organic Carbon***

Dissolved organic carbon (DOC) is operationally defined as organic carbon (OC) that can pass through a 0.45  $\mu\text{m}$  filter. Particulate organic carbon (POC) does not pass the filter. Together POC and DOC sum to provide total organic carbon (TOC). DOC is considered to be the fraction that contains the reactive chemical sites that bind metals and control acidity. DOC is composed primarily of humic substances, poorly biodegradable, hydrophilic (water-loving), decomposition by-products of natural organic matter produced by plants and animals (Snoeyink and Jenkins, 1980). DOC adds color to the water, provide nutrients to microorganisms, and play a major role in the mobility and availability of metals in natural systems (Drever, 1997). Depending on hydrologic conditions and the source of DOC, these substances may contribute acidity to surface waters.

DOC in rain at Acadia National Park (ANP) can range from 0.5 to 5.0 mg/L, while throughfall (rain that falls through the canopy) can contain as much as 80-100 mg/L of DOC (Nelson, 2002). Rivers in Eastern Maine can range from ~2-23 mg/L (this study) and higher. A subset of samples from the fall 2003 ASCpH survey (samples taken after a massive precipitation event) were analyzed for informational purposes, as a value added part of this project, and are listed in Table 10 (max 45 mg/L at Bowles Brook 58000 Rd.). Drever (1997) estimates groundwater and ocean concentrations to be ~0.5 mg/L. Natural waters with DOC concentrations exceeding 10 mg/L are highly colored with true color values exceeding 50 PCU (Tables 11 and 12).

Apparent color, unfiltered sample, is a surrogate for TOC. Color is analyzed by measuring the amount of light that is absorbed by the sample and represented by platinum cobalt units (PCU). The samples are unfiltered to account for turbidity (suspended particles) in the water column. DOC gives color to water by absorbing light at different wavelengths based on the size and shape of the DOC molecules. Therefore, different waters with the same color value can have different amounts of DOC because of the difference in the composition of the DOC in different areas.

Mean DOC concentrations in Downeast rivers are higher than rivers to the west of the Penobscot River due to the glacial history of eastern Maine and the formation of bogs that supply the Downeast rivers. Sources of DOC include throughfall precipitation, overland runoff, and leaf litter, but bogs are the largest sources of DOC in Downeast river systems.

**Table 10. Dissolved organic carbon (DOC) and EqpH results for selected sites during the fall, 2003 survey only.**

Site	Drainage	DOC (mg/L)	EqpH
Rocky Brook	Narraguagus	27.9	5.13
Sinclair Brook	Narraguagus	22.6	5.25
Baker Brook	Narraguagus	23.4	5.99
Main Stem Rt. 9	Narraguagus	21.0	5.99
Little Falls	Narraguagus	18.9	6.28
31-00-0 Road crossing	Narraguagus	21.9	6.10
Deblois Rt. 193	Narraguagus	17.2	6.76
W. B. Narraguagus (Sprague Falls)	Narraguagus	23.2	5.18
Gould Brook	Narraguagus	27.2	5.65
Bowles Brook, 58000 Rd	Machias	45.2	4.83
Crooked River on 52000 Rd	Machias	35.3	4.94

Holmes Brook on Holmes Falls Rd	Machias	40.6	5.10
Machias Rt. 9	Machias	22.9	5.65
Machias, Rt. 1A (Whitneyville)	Machias	19.6	5.93
Machias, Holms Falls	Machias	24.1	5.52
Mopang 2nd Lake Outlet	Machias	6.0	6.78
Mopang above Penman Rips	Machias	27.1	5.00
New Stream, Guptil Road	Machias	37.5	4.73
Old Stream (Rt. 9)	Machias	26.7	6.10
Old Stream, Bear Brook Road	Machias	26.7	5.82
West Branch on 52000 Rd	Machias	30.5	5.28
Beaver Dam Stream, Route 9	East Machias	25.0	5.32
East Machias, Gaddis Pool	East Machias	13.0	6.56
East Machias, Munson Riffles	East Machias	20.8	6.15
East Machias, Rt.9	East Machias	23.9	5.91
Harmon Brook, at culvert	East Machias	25.5	5.71
Northern Stream on 19000 Rd	East Machias	25.1	5.24
Seavy Stream, 85-00-00 Rd Bridge	East Machias	20.3	5.32
Dennys, Meddybemps Rt.191	Dennys	5.1	6.56
Dennys, Garner Rips (Gardner Landing)	Dennys	23.2	5.60
Dennys, Weir	Dennys	24.1	5.68
Cathance Stream, Route 86 crossing	Dennys	20.9	5.53
Cathance Stream, Flume at Dodge Rd	Dennys	17.4	6.19
Venture Brook, Venture Brook Road	Dennys	29.1	4.92
Curry Brook, Venture Brook Road	Dennys	25.3	4.95
Dead Stream	Dennys	22.0	5.30
Creebo Crossing	Pleasant	13.5	5.87
Little River on Cross Rd	Pleasant	27.7	4.94
Pleasant River, Weir	Pleasant	25.7	5.30
Pleasant River, Pleasant Lake Outlet	Pleasant	8.9	6.36
West Little River	Pleasant	41.0	4.73
Saco Falls	Pleasant	24.5	5.11

**Table 11. Dissolved organic carbon (DOC) results, separated by drainage, in ascending order by means. Data are from 2004 surveys only.**

Drainage	Analysis (mg/L)	# of cases	Min.	Max.	Median	Mean	Standard Deviation
Sandy River	DOC	6	2.9	5.1	3.5	3.7	0.7
Tunk	DOC	9	2.3	6.6	4.2	4.0	1.4
Cove Brook	DOC	6	5.3	7.5	5.8	6.0	0.8
Kenduskeag	DOC	9	3.4	11.9	4.8	6.1	3.1
Marsh Stream	DOC	6	3.7	9.8	7.1	6.9	2.4
Sheepscot	DOC	12	6.8	10.7	7.3	7.9	1.2
Ducktrap	DOC	9	6.1	10.1	7.8	8.0	1.1
Union	DOC	23	3.2	18.7	8.7	9.5	4.6
Dennys	DOC	21	5.1	26.9	8.6	12.0	7.1
East Machias	DOC	21	6.9	19.5	10.9	12.0	3.6
Pleasant	DOC	17	6.9	23.4	11.7	12.3	4.6
Narraguagus	DOC	26	6.3	26.5	10.6	12.8	5.6
Machias	DOC	34	4.0	24.2	11.6	13.0	5.3

**Table 12. Apparent color (unfiltered) results, separated by drainage, in ascending order by means. Data are from 2003 surveys only.**

Drainage	Analysis (PCU)	# of cases	Min.	Max.	Median	Mean	Standard Deviation
Sandy River	Color	0	No samples taken in 03, no color analysis in 04				
Tunk	Color	9	3	75	25	31	28
Kenduskeag	Color	9	10	88	25	36	26
Cove Brook	Color	6	15	100	35	48	36
Marsh Stream	Color	6	20	88	35	48	31
Ducktrap	Color	6	35	88	50	53	21
Union	Color	24	18	125	50	58	28
Sheepscot	Color	11	20	125	50	61	36
East Machias	Color	21	25	175	75	75	32
Dennys	Color	24	15	175	75	78	49
Narraguagus	Color	27	25	175	75	79	36
Pleasant	Color	17	30	150	75	80	40
Machias	Color	36	5	200	88	88	48

## Base Cations

Base cations ( $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ) in surface waters are largely derived from soil with a minor contribution from atmospheric deposition. In the cool-temperate acidic forest soils of eastern Maine, soil cation exchange sites are dominated by aluminum, with the remainder of the sites occupied by base cations and  $\text{H}^+$ , resulting in low base saturation (Norton et al., 1999). Low base saturation results in acidic soils (pH commonly between 3 and 4) that can result in low pH water exiting the soil column.

Surface waters with high base cation concentrations reflect the underlying geology and soil chemistry. High base cation concentrations in surface waters, most notably Ca, can also be a result of agricultural practices, which are more common west of the Penobscot River. Typical agricultural activities east of the Penobscot, most commonly low-bush blueberry cultivation, favor the naturally acid soils and may actually add additional acidity which blueberries prefer. Surface waters with low base cation concentrations may reflect base-poor soils, or reflect local hydrologic conditions which can limit weathering reactions that neutralize acids and yield base cations as by-products of the weathering reactions.

**Table 13. Calcium results, separated by drainage, in ascending order by means. Data are from 2004 surveys only.**

Drainage	Analysis (mg/L)	# of cases	Min.	Max.	Median	Mean	Standard Deviation
Tunk	Ca	9	1.2	1.7	1.3	1.4	0.2
Pleasant	Ca	17	1.2	4.3	2.1	2.2	0.9
Machias	Ca	34	1.2	3.6	2.4	2.4	0.6
East Machias	Ca	21	1.5	3.6	2.9	2.7	0.6
Dennys	Ca	21	1.8	3.7	2.7	2.7	0.6
Narraguagus	Ca	26	1.2	4.4	3.0	2.9	0.9
Union	Ca	23	1.5	4.6	2.9	3.0	0.9
Ducktrap	Ca	9	2.7	3.9	2.9	3.1	0.4
Sandy River	Ca	6	2.4	4.8	3.3	3.5	0.9
Sheepscot	Ca	12	3.5	13.3	4.2	6.0	3.4
Marsh Stream	Ca	6	4.7	11.4	9.4	8.6	2.6
Cove Brook	Ca	6	7.1	27.0	22.2	18.8	9.0
Kenduskeag	Ca	9	9.6	26.0	19.1	19.7	5.8

## Anions

The positive charge of base cations (e.g.  $\text{Ca}^{+2}$ ) and hydrogen ion ( $\text{H}^+$ ) is balanced in surface waters by the negative charges of the major inorganic anions ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{-2}$ ) plus the generic soup of organic anions (in DOC). Atmospheric deposition is a main source of  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{-2}$ . Sulfate and  $\text{NO}_3^-$  are products of the combustion of fossil fuels (acid rain), and Cl is from the ocean in the form of marine aerosols and from road salting. Nitrate in surface water is unrelated temporally to deposition from the atmosphere, reflecting the substantial amount of re-cycling of N in forested watersheds (Campbell et al., 2004). Nitrate concentrations are very low in downeast rivers because forests are N-limited and tightly recycle N. A smaller fraction of Cl input can be associated with the application of Cl salts to roads in winter ( $\text{NaCl}$  and  $\text{CaCl}_2$ , MDOT, 2003). Large concentrations of Cl and  $\text{SO}_4$  together with high concentrations of Na and Mg can indicate substantial oceanic influence (i.e. sampled in salt wedge, during high tide, or within the influence of sea spray). Sulfate is an important contributor of acidity to rain, but this study indicates that DOC influences the pH of Downeast rivers more than  $\text{SO}_4$  does. Quantitatively determining the contributions of  $\text{SO}_4$  and DOC to the overall acidity of these systems is beyond the scope of this project.

### **Aluminum**

Aluminum (Al) in surface waters is a natural weathering product from soils. Acidic waters and high DOC waters typically have highest concentrations of dissolved Al. We report here three fractions of Al: 1) total dissolved Al, 2) exchangeable Al (the ionic fraction considered to be the toxic form of Al), and 3) organic Al, the form bound to DOC and considered to be non-toxic.

Total dissolved Al is the standard, most reproducible analysis for Al. A comparison of total value through time is a reasonable estimate of trends in Al concentrations, but it does not necessarily reflect the biologically active concentrations of Al. In the salmon rivers, total Al concentrations are often quite high, but the toxicity is probably low because of the high Al binding capacity of DOC. Therefore, we emphasize the organic fraction of Al in this report.

Drainages to the east of the Penobscot have higher total-dissolved Al concentrations than drainages to the west primarily due to the dual factors of lower pH and higher DOC (Table 14). The pattern is similar for organically bound Al.

**Table 14. Total dissolved aluminum results, separated by drainage, in ascending order by means. Data are from 2004 surveys only.**

Drainage	Analysis	# of	Min.	Max.	Median	Mean	Standard
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	(µg/L)	cases					Deviation
Kenduskeag	Total Al	9	3.3	49.1	14.0	16.1	14.3
Cove Brook	Total Al	6	10.8	32.6	16.5	20.3	9.8
Marsh Stream	Total Al	6	13.5	46.0	27.5	27.5	12.8
Tunk	Total Al	9	18.8	74.4	30.2	39.4	23.6
Sheepscot	Total Al	12	24.5	86.1	39.1	49.1	22.7
Sandy River	Total Al	6	30.1	113.9	51.4	60.0	30.0
Ducktrap	Total Al	9	32.3	94.9	59.3	61.0	19.4
Union	Total Al	23	42.6	207.3	118.4	115.5	44.0
East Machias	Total Al	21	59.6	196.8	124.5	121.1	34.8
Dennys	Total Al	21	18.7	311.2	92.7	125.2	99.9
Pleasant	Total Al	17	49.5	308.2	123.9	137.5	69.0
Narraguagus	Total Al	26	45.1	250.4	144.9	144.7	55.6
Machias	Total Al	33	10.7	368.5	173.9	167.2	92.0

**Table 15. Organically bound aluminum (Al-org) results, separated by drainage, in ascending order by means. \* Data are from 2004 surveys only.**

Drainage	Analysis (µg/L)	# of cases	Min.	Max.	Median	Mean	Standard Deviation
Tunk	Al-org	9	15.4	103.3	30.3	46.1	34.7
Sandy River	Al-org	6	20.6	83.1	36.3	46.9	25.0
Marsh Stream	Al-org	6	19.9	119.0	35.1	47.1	36.0
Kenduskeag	Al-org	9	2.9	199.7	27.1	59.3	68.7
Ducktrap	Al-org	9	30.3	110.4	58.7	67.6	29.6
Sheepscot	Al-org	12	22.7	193.3	53.0	67.9	56.6
East Machias	Al-org	21	51.2	138.9	96.3	92.8	21.1
Dennys	Al-org	21	17.8	279.4	82.0	101.6	79.6
Cove Brook	Al-org	6	14.3	351.9	35.7	124.4	154.9
Union	Al-org	23	27.8	282.9	102.6	128.1	68.9
Narraguagus	Al-org	26	38.5	262.1	109.0	133.1	58.8
Machias	Al-org	34	13.3	373.7	136.2	140	79.8
Pleasant	Al-org	17	39.5	318.8	163.2	166.7	96.6

### **Seasonal Patterns**

Spring flows are typically derived from snowmelt and spring rains. During spring melt the conductivity and base cation concentration of receiving streams and rivers is generally diluted as flow increases (Heath et al., 1993; Kahl et al., 1992), although the early spring flushes may be acidic or quite basic, depending on the hydrology of the location. These snowmelt periods can result in decreased pH from base cation dilution and/or influx of DOC from overland flow and bog drainage (Kahl et al., 1992). Some small streams may experience increased concentrations of nitrate, although the rivers in this study do not.

Summer flows are typically the lowest of the non-winter months, concentrating analytes through evapoconcentration and shift in the proportion of groundwater that supplies the rivers. ANC and pH are highest in summer and early fall, and Al is lowest. DOC concentrations may be high in the summer if wetland influence persists, or DOC concentrations may decrease if photo-oxidation of in-stream DOC is greater than influx.

Fall flows can be as high as spring flows or as low as summer flows (Table 1). During the Fall 2003 survey, samples were taken on the receding arm of a major hydrologic event (e.g. Pleasant River at Epping: 208 cfs). The Western Little River sample had a color value of 150 PCU (DOC concentration of 41.0 mg/L) and a ClpH value of 4.70. During the spring 2003 survey the Western Little River sample had a color value of 100 PCU and a ClpH value of 5.42 with a comparable discharge value (206 cfs). These data indicate that DOC may be more mobile or available during fall hydrologic events, or more active organic material is available in the fall (i.e. fresh leaf litter). Perhaps the DOC is immobilized to some degree in the spring because the ground is partially frozen, runoff patterns are driven by surface flow more than sub-surface flow, or much of the flow is derived from snow and ice melt, both of which have very low concentrations of DOC.

As we have known for many years, water chemistry is driven largely by hydrology (e.g. Kahl et al., 1992). We know that DOC has the capacity to drive the pH to values lower than possible by acidic deposition alone (Kahl et al., 1989) and that seasonal differences exist in the mechanisms of episodic acidification. We postulate that organic acidity is an increasingly important factor as the importance of acidic deposition declines. We also postulate that the fall is now the season prone to the greatest pH depressions in the salmon rivers, but the spring has the longest prolonged periods of lowered pH and ANC.

### ***The influence of acidic deposition***

Precipitation, both wet and dry, can influence surface water chemistry in a number of ways. A high volume of precipitation can dilute base cations, resulting in lower ANC.

The same high volume event can also mobilize large amounts of DOC, which can depress pH. The soils in the watershed have a greater influence on the chemistry of surface waters than does the precipitation.

## **Summary**

In general, rivers and streams east of the Penobscot River are susceptible to pH depression because of low buffering capacity and high DOC concentrations. These conditions are a result of the geologic formation of this area of Maine. As you move east through the sample sites, the percentage of the watershed that is considered a wetland increases and the base cation content of the rivers decreases.

Stream flows are typically high in the spring from snow and ice melt, low in the summer from lack of precipitation, and can vary in the fall. These hydrologic conditions help to shape the chemical makeup of the water in these systems. High flows in the spring dilute base cations and reduce the buffering capacity of the water. In systems east of the Penobscot River high flow mobilizes large amounts of DOC, which in turn decreases the pH.

The ASCpH Survey sampled rivers and streams from two distinctly different populations. The group of streams to the west of the Penobscot River are well buffered, clear-water systems, while the streams to the east of the Penobscot River are poorly buffered, colored-water systems. Both sets of systems react similarly to hydrologic events, but to much different degrees because of the geology of their source water areas.

## Appendix A.

### List of sample sites, drainages, location relative to the Penobscot River, UTM's, and the surveys that include the site.

Site Name	Drainage	Penobscot Divide	Easting (Zone 19)	Northing	Spr 03	Sum 03	Fall 03	Spr 04	Sum 04	Fall 04
Back Winterport Road	Cove Brook	West	510131	4947972	X	X	X	X	X	X
Route 1	Cove Brook	West	512010	4948957	X	X	X	X	X	X
Cathance Stream, Flume at Dodge Rd	Dennys	East	632906	4971603	X	X	X	X	X	X
Cathance Stream, Route 86 crossing	Dennys	East	633572	4977753	X	X	X		X	X
Curry Brook, Venture Brook Road	Dennys	East	624872	4984793	X	X	X	X	X	X
Dead Stream Rt 191	Dennys	East	632861	4980646	X	X	X		X	X
Dennys, Garner Rips	Dennys	East	629456	4988661	X	X	X	X	X	X
Dennys, Meddybemps Rt.191	Dennys	East	639993	4972919	X	X	X	X	X	X
Dennys, Weir	Dennys	East	636826	4971880	X	X	X	X	X	X
Venture Brook, Venture Brook Road	Dennys	East	635191	4973714	X	X	X		X	X
Dickey Mill Rd	Ducktrap	West	491742	4911475		X	X	X	X	X
Mainstem - below Black Brook Stream	Ducktrap	West	497202	4907124				X	X	X
Rt 52	Ducktrap	East	495141	4908428		X	X	X	X	X
Upstream at Black Brook confluence	Ducktrap	East	496209	4906980		X	X			
Beaver Dam Stream, Route 9	East Machias	East	607502	4982172	X	X	X	X	X	X
East Machias, Gaddis Pool	East Machias	East	627706	4955306	X	X	X	X	X	X
East Machias, Munson Riffles	East Machias	East	617921	4971697	X	X	X	X	X	X
East Machias, Rt.9	East Machias	East	608917	4983982	X	X	X	X	X	X
Harmon Brook, at culvert	East Machias	East	609065	4984891	X	X	X	X	X	X
Northern Stream on 19000 Rd	East Machias	East	618789	4976084	X	X	X	X	X	X
Seavy Stream, 85-00-00 Rd Bridge	East Machias	East	612833	4975625	X	X	X	X	X	X
6-Mile Falls	Kenduskeag	West	513360	4967685	X	X	X	X	X	X
Exeter Road	Kenduskeag	West	494271	4982233	X	X	X	X	X	X
Garland Pond	Kenduskeag	West	487581	4986752	X	X	X	X	X	X
Bowles Brook, 58000 Rd	Machias	East	594943	4980681	X	X	X		X	X
Crooked River on 52000 Rd	Machias	East	589235	4975574	X	X	X	X	X	X

Holmes Brook on Holmes Falls Rd	Machias	East	604018	4963802	X	X	X	X	X	X
Machias Rt. 9	Machias	East	591835	4973101	X	X	X	X	X	X
Machias, Holmes Falls	Machias	East	604380	4961303	X	X	X	X	X	X
Machias, Rt. 1A (Whitneyville)	Machias	East	616889	4953434	X	X	X		X	X
Mopang 2nd Lake Outlet	Machias	East	582012	4972394	X	X	X	X	X	X
Mopang above Penman Rips	Machias	East	595311	4961619	X	X	X	X	X	X
New Stream, Guptil Road	Machias	East	605061	4972458	X	X	X		X	X
Old Stream (Rt. 9)	Machias	East	599833	4976634	X	X	X	X	X	X
Old Stream, Bear Brook Road	Machias	East	605666	4966377	X	X	X	X	X	X
West Branch on 52000 Rd	Machias	East	588894	4979045	X	X	X	X	X	X
Jackson Road	Marsh Stream	West	490924	4940379	X	X	X	X	X	X
West Winterport Dam	Marsh Stream	West	503376	4940684	X	X	X	X	X	X
31-00-0 Road crossing	Narraguagus	East	570311	4977549	X	X	X			
Baker Brook	Narraguagus	East	571429	4977549	X	X	X	X	X	X
Deblois Rt. 193	Narraguagus	East	578059	4954649	X	X	X	X	X	X
Gould Brook	Narraguagus	East	570578	4973134	X	X	X		X	X
Little Falls	Narraguagus	East	582638	4945447	X	X	X	X	X	X
Main Stem - Stillwater Dam, Cherryfield	Narraguagus	East	584246	4939963				X	X	X
Main Stem Rt 9	Narraguagus	East	573501	4965912	X	X	X	X	X	X
Rocky Brook	Narraguagus	East	572067	4972124	X	X	X	X	X	X
Sinclair Brook	Narraguagus	East	572924	4970096	X	X	X	X	X	X
W. B. Narraguagus (Sprague Falls)	Narraguagus	East	579705	4944049	X	X	X	X	X	X
Crebo Crossing	Pleasant	East	585201	4957842	X	X	X	X	X	X
Little River on Cross Rd	Pleasant	East	599637	4949882	X	X	X	X	X	X
Pleasant River, Weir	Pleasant	East	600371	4945495	X	X	X	X	X	X
Pleasant River, Pleasant Lake Outlet	Pleasant	East	581988	4965176	X	X	X		X	X
Saco Falls	Pleasant	East	596104	4950073		X	X	X	X	X
Western Little River on Cross Rd	Pleasant	East	597139	4950231	X	X	X	X	X	X
Mainstem - Upper Rt. 4 crossing	Sandy River	West	407013	4950412				X	X	X
Orbeton Stream - Echo Valley Road	Sandy River	West	387635	4968876				X	X	X
Coopers Mills - Route 17	Sheepscot	West	455824	4900699				X	X	X
Head of Tide	Sheepscot	West	450188	4884803	X	X	X	X	X	X
Summerville at Rt. 105	Sheepscot	West	461117	4906333		X	X	X	X	X

West Branch at Howe Rd	Sheepscot	West	454030	4899147	X	X	X	X	X	X
West Branch at Rt. 105 in Windsor	Sheepscot	West	455650	4906122	X	X	X			
Rt 182 Bridge	Tunk Stream	East	579697	4939925	X	X	X	X	X	X
Tunk Lake Outlet	Tunk Stream	East	574779	4939981	X	X	X	X	X	X
Tunk Stream, Rt. 1 Bridge	Tunk Stream	East	582425	4929331	X	X	X	X	X	X
East Branch, Rt 179 Mariaville	Union	West	553726	4955205	X	X	X	X	X	X
Half Mile	Union	West	546997	4964334	X	X	X	X	X	X
Indian Camp	Union	West	548813	4965034	X	X	X	X	X	X
Mainstem, Below Graham Lake	Union	West	544194	4934820	X	X	X	X	X	X
Middle Branch at Rt 9 Crossing	Union	West	555700	4967838	X	X	X	X	X	X
Spring	Union	West	550761	4969737	X	X	X		X	X
West Branch at Rt 9 Crossing	Union	West	549339	4963992	X	X	X	X	X	X
West Branch, Rt 181 Mariaville	Union	West	548530	4956939	X	X	X	X	X	X
<b>Total number of samples</b>					<b>62</b>	<b>67</b>	<b>67</b>	<b>60</b>	<b>69</b>	<b>69</b>

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