Penjajawoc Stream, the Second Year of the Baseline Study, with a summary of the 2008 and 2009 Field Seasons.

Including a Discussion of Chloride Impacts and an Investigation of the Kittridge Landfill.

A Progress Report for the Maine Salmon Rivers and the Maine Stream Team Programs

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I. Introduction

Penjajawoc Stream is an urban impaired stream located in Bangor Maine. A description of the pollution problems, the water quality improvement targets, and potential solutions are outlined in a Total Maximum Daily Load (TMDL) study by Maine Department of Environmental Protection (DEP 2007). The City of Bangor, DEP, some local landowners, with some concerned residents have developed a watershed management plan that includes a restoration program (BSA 2008). In addition to many other recommendations, the watershed plan recommended that a volunteer-based stream monitoring program be established to monitor progress as the restoration plan is implemented. In the fall of 2007, the City of Bangor and DEP formed and trained a “stream team” of local residents to do the water quality monitoring. In the spring of 2009, DEP published the results of the first year (2008) “baseline study” of Penjajawoc Stream (DEP 2009). The first restoration projects are planned for the 2010 and 2011 construction seasons. One of the functions of this paper is to review our second baseline year and our cumulative data.

Also included in this report are the results of some studies by the DEP on the Kittridge Road Landfill. The Kittridge landfill is located in the northeastern headwaters of Penjajawoc Stream (Figure 1). The landfill was discontinued and covered under the supervision of the DEP’s Bureau of Remediation and Solid Waste in the late 1980’s. The Bangor Land Trust owns a parcel near the end of the Kittridge Road, just downstream of the landfill. The site is forested with hiking trails. Penjajawoc Stream in this area is a scenic rocky riffle that flows over moss covered rocks. A foot trail provides access to the stream and spans it with a wooden bridge. In spite of the deep forest shade and relatively cool water, initial monitoring at this site found occasional low oxygen. Follow-up monitoring by DEP confirmed the low oxygen, and found elevated alkalinity and chloride. The Bangor Land Trust then asked the DEP if the observed effects were due to the landfill. The available volunteer monitoring data was not adequate to completely answer that question. So in the summer of 2009, DEP staff investigated seepage areas at the base of the landfill.

In the TMDL study, salinity was identified as one of the Penjajawoc Stream impairments. The volunteer Stream Team typically measures conductivity and/or total dissolved solids (TDS) with hand held meters. However, the DEP interprets water quality in terms of statutory criteria. While there are no state conductivity or TDS standards *per se*, there are salinity and chloride thresholds (see DEP Chapter 584, Surface Water Quality Criteria for Toxic Pollutants). So we needed to be able to convert conductivity and TDS into salinity or chloride. For simplicity, since salinity and chloride are so closely related, we chose to concentrate on chloride. In the spring of 2009, DEP and the City of Bangor collaborated to take a number of Penjajawoc Stream water samples for lab analysis at the University of Maine Sawyer Environmental Chemistry and Research Lab (SECRL). These samples were used to create a mathematical model (a regression equation) that could convert our field conductivity and TDS measurements into chloride. We also found a Maine Department of Transportation (DOT) study from the early 1980's that evaluated road salt in the Penjajawoc watershed just as the Bangor Mall was being completed. The third purpose of this study is to review what we currently know about road salt contamination, evaluate trends, and discuss the environmental consequences for the watershed.

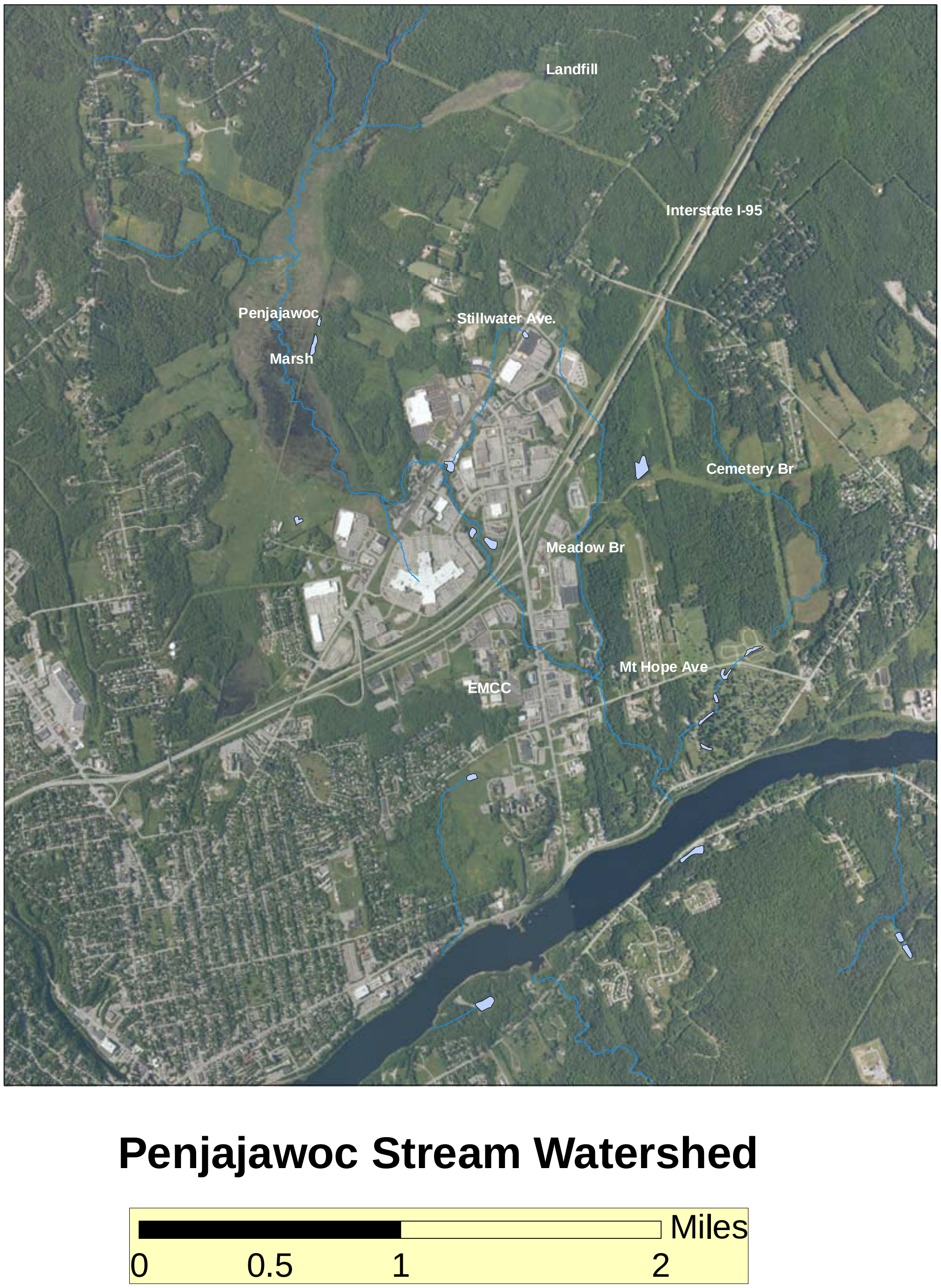


Figure 1. Watershed map of Penjajawoc Stream. The Bangor Mall is the Y-shaped building above interstate highway I-95. This areal view provides a perspective on the amount of development in

different parts of the watershed. The Kittridge Road landfill is in the northeastern headwaters.

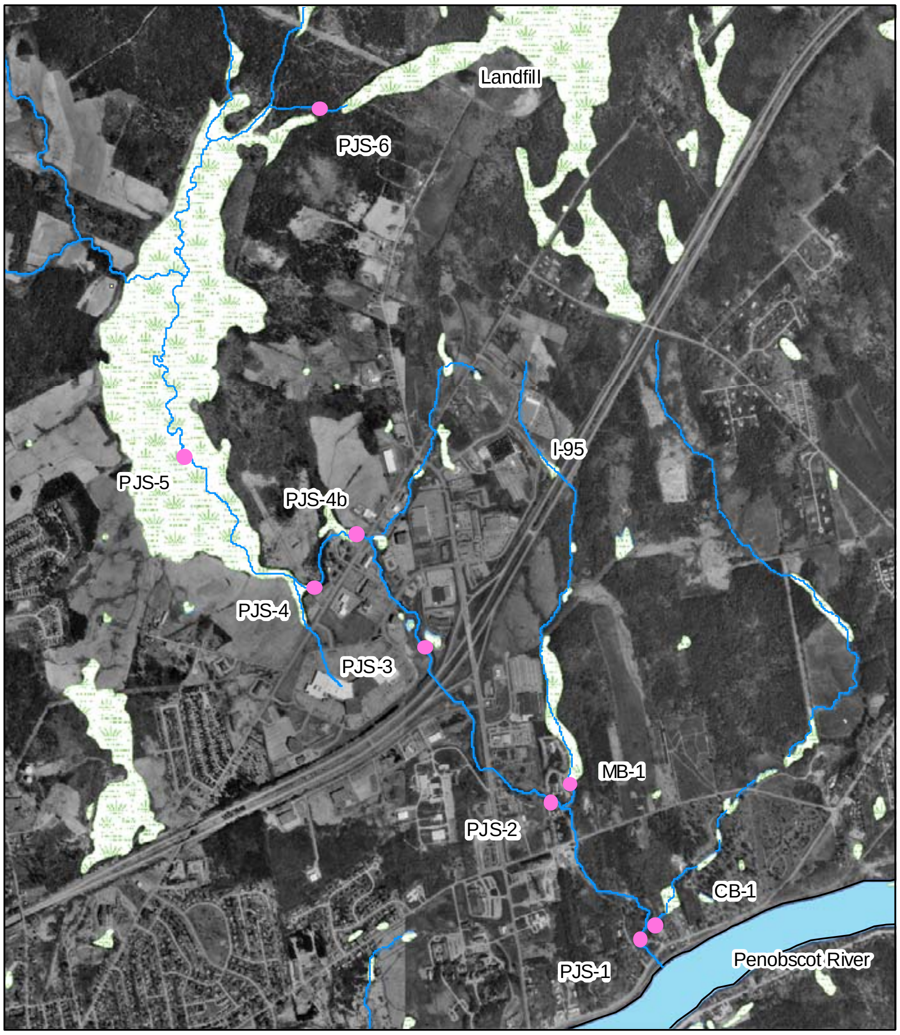
II. Methods:

A. The Sample Sites:

The headwaters of Penjajawoc Stream begin in vast wetlands in the northern part of the watershed (Figure 1) which then flow south to Penjajawoc Marsh. Below the marsh, the stream reforms and flows through a large commercial development along Stillwater Avenue, past the Bangor Mall complex, and then under interstate highway I-95. Below the interstate, the stream continues south past Eastern Maine Community College (EMCC) and a number of commercial developments on the Hogan Road. Still flowing south, the stream enters the largely wooded Evergreen Woods professional park and combines with Meadow Brook. After flowing under Mt Hope Avenue, the stream flows through a residential area where it combines with an unnamed stream that drains Mount Hope Cemetery. We called the unnamed stream "Cemetery Brook." The Penjajawoc then passes under US Route 2 where it joins the Penobscot River. The total watershed area is 8.57 square miles (22.20 square kilometers).

The Penjajawoc watershed can be divided into three subwatersheds based on the predominant land uses. In the northern part of the watershed, there are large wetlands and forests, some pasture and cultivated fields, and some low density residential development. In the central part of the watershed, there is concentrated urban commercial and institutional development, including the Bangor Mall, EMCC, and smaller malls and automobile dealerships. In the lower and eastern parts of the watershed, there is some low density residential development, a Maine DOT maintenance yard, some wetlands and forests, and a large cemetery.

Our sample sites (Figure 2) were chosen to represent this diversity in land use. Not shown on this figure are the sample sites at the base of the Landfill on the north side (the wetland side) and an open stream channel to the east of the landfill that flows toward the landfill (the upstream site). The downstream site for the landfill study was PJS-6 on the Bangor Land Trust parcel.



**Penjajawoc Stream, Bangor
Stream Team Sites**

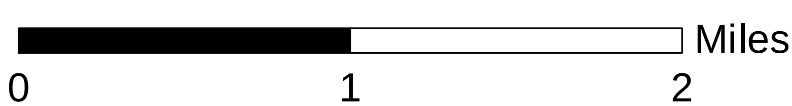


Figure 2. Map of Penjajawoc watershed showing sample sites. Sites PJS-1 through PJS-6 are on the mainstem of Penjajawoc Stream, while MB-1 is on Meadow Brook and CB-1 is on Cemetery Brook. Access at PJS-4 turned out to be problematic and the site was moved downstream to PJS-4b. Wetlands are shown in white with green cross hatching.

B. The Field Methods:

Our field methods were covered in last year’s report (DEP 2009). For the reader’s convenience, those methods are reproduced here. We used two different strategies for field sampling, namely (1.) volunteers who are distributed throughout the watershed (8 sites) and who sampled at approximately the same time and (2.) automated environmental recorders called “data sondes” that provided a lot of detail from a single site. The sondes were programmed to sample at hourly intervals. Depending on the probes installed on the sonde, they may record water depth, water temperature, specific conductance, pH, dissolved oxygen, and turbidity.

Stream team members measured water temperature, dissolved oxygen (DO), and specific conductance or total dissolved solids (TDS). In addition, water samples were taken in the summer and fall for *Escherichia coli* (*E. coli*) bacteria. Samples were taken for turbidity analysis any time the water looked muddy. The bacteria and turbidity samples were analyzed in the DEP lab in Bangor.

Sample timing was organized primarily by season. In the fall of 2007, and in the spring of 2008 samples were collected after storm events whenever there was at least an inch of rain recorded at the Bangor International Airport. In the summer of 2008, volunteers collected weekly samples. Finally, in the fall of 2008, sampling was scaled back to once per month. This seasonal sampling pattern was repeated in 2009.

All of our volunteer data was a mixture of early or late in the day samples. The volunteers usually collected samples on their way to work in the morning or on their way home in the late afternoon. Thus, samples were taken within 8 hours of each other. It was not possible to fine-tune the storm event sampling with any relationship to stages of the storm or runoff (i.e., we did not try to sample the “first flush” of pollutants from the early part of a storm). Also, in terms of analysis, early morning water temperatures are often the lowest of the day while late afternoon temperatures are often the highest. Oxygen also follows a daily cycle in aquatic environments, with early morning generally representing the low point of the day (due to a lack of photosynthesis over night) and late afternoon is often the high point.

Field measurements by volunteers were made with hand-held mercury-free thermometers, Oakton TDS or Hanna conductivity pens. Dissolved oxygen was measured with LaMotte syringe-style Winkler titration kits. The TDS/conductivity pens were calibrated in the fall of 2007 using a single point calibration. Volunteers practiced using the Winkler kits at Bangor High School using an oxygen-saturated solution. Field samples were collected in 100 ml polycarbonate bottles from the stream bank or from the middle of the stream for bacteria and turbidity analysis. *E. coli* were analyzed using the IDEXX Colilert method and turbidity was analyzed using a Hach 2100 turbidity meter. The turbidity meter was calibrated initially at the beginning of the season using a three point calibration. Prior to the analysis of any samples, the Hach 2100 meter was tested against 3 turbidity standards.

Data sondes provided the intensive sampling over short intervals that volunteers simply cannot provide. Data sondes are automated programmable environmental recorders. The units we used were YSI model 600-XLM, 6920 or 6600 EDS. The sondes were calibrated and serviced according to USGS protocols for stream deployments (USGS 2000). All of the sondes had conductivity/temperature probes. Since turbidity is known to be a problem in the lower Penjajawoc, turbidity probes were deployed at Evergreen Woods in Meadow Brook (site MB-1) and in Penjajawoc Stream (PJS-2) in late winter and spring. All of our sonde data in this report is from the 2008 field season.

C. The DEP Landfill Study:

In the summer of 2009, DEP staff identified five iron-stained seeps at the foot of the Kittridge Road Landfill on the north (wetland) side. An open stream channel was found upstream on the east side of the landfill. This served as the upstream control site. The Bangor Land Trust site on Penjajawoc Stream (PJS-6) served as the downstream site. Pore water was collected from the seepage sites and was analyzed for ***volatile organic compounds***: (1,1,2-trichloro-1,2,2-trifluorethane meth-t-butyl ether (MTBE), 1,1,1-trichloroethane, and total organic carbon), ***inorganics***: (ammonia as nitrogen, arsenic, calcium, chloride, iron, manganese, magnesium, nitrate as N, potassium, sodium, sulfate, total alkalinity, and total dissolved solids), and ***field parameters***: dissolved oxygen, pH, specific conductance, and turbidity.

The downstream Penjajawoc site was analyzed at the University of Maine SECRL for the ***major cations***: calcium, sodium, potassium, and magnesium, then the ***major anions***: chloride, nitrate, and sulfate, then ***alkalinity*** and ***pH***, and then the ***trace metals***: aluminum, manganese, iron, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and zinc.

D. The Calibration of Conductivity and Chloride Measurements

Conductivity in this context is the ability of water to carry an electrical current. Naturally, this has a lot to do with the mineral and organic salts found in the water. As long as the dominant salts remain the same throughout the year, conductivity can be used an easy-to-measure surrogate for salinity or chloride. Eleven samples from the Penjajwoc and its tributaries from three different dates were sent to the University of Maine SECRL lab for analysis. A linear regression was used to describe the relationship.

E. Data Analysis:

Our previous report also discussed data analysis. This too is reproduced here for the reader's convenience. Our data was represented graphically and some summary statistics were used for comparative purposes. Median values were used instead of means, because of the nature of the conductivity and turbidity results (brief spikes of extreme values). A median is a value that represents the middle of a population of values, so that one-half of all values are below this value and one-half lie above. A mean is the same thing as an average, and is more sensitive to a few large values that pull the mean away from the central tendency. We decided to use medians.

In order to help explain causal relationships, we relied on weather data from the Bangor International Airport (BIA). This is available on-line at http://www.wunderground.com/history/. The depth sensors from the sondes, when available, were used to show changes in stream stage.

The Maine DEP has a Water Classification Program which assigned Penjajawoc Stream and its tributaries Class B status (a middle of the road water quality). However, urban development has caused the mainstem and Meadow Brook to not meet this classification. These streams are currently listed as "impaired" (DEP 2008). The problems are seasonal high temperatures, seasonal low oxygen, high nutrients, high conductivity, toxics (mostly metals and organics (especially petroleum products) from roads), sediment, altered hydrology and impaired biological communities (DEP 2007).

Our water quality results were interpreted in terms of the state classification system for natural waters MRSA Title 38, Article 4A (see References for Maine statutes on-line). Penjajawoc Stream and its tributaries are expected to meet Class B water quality criteria (Table 1). Because aquatic communities are not supposed to be impaired, DEP Chapter 584 Rules apply for toxic pollutants.

Table 1. A summary of Maine's water quality criteria for Class B waters.

Aquatic uses	**Suitable for drinking water supply after treatment, fishing, recreation in and on the water and as habitat for fish and other aquatic life**
Habitat	**Shall be characterized as unimpaired**
DO	**Shall not be less than 7.0 ppm or 75% saturation whichever is higher, except that for the period from October 1st through May 14th, in order to ensure spawning and egg incubation of indigenous fish species the 7-day mean DO shall not be less than 8.0 ppm in identified fish spawning areas. However, were natural conditions, including marshes bogs, and abnormal concentrations of wildlife cause DO to fall below the minimum standards, those waters will not be considered to be failing.**
Bacteria	**Between May 15th and September 30th, the number of Escherichia coli bacteria of human origin in these waters may not exceed a geometric mean of 64 colonies per 100 ml or an instantaneous level of 427 colonies per 100 ml**

Maine Department of Transportation (DOT) did a study of road salt in Penjajawoc Stream just after the Bangor Mall opened in the late 1970's (DOT 1982). Data was collected for four years, 1979-1982. We will compare our results with this historic snapshot from 30 years ago.

III. Results and Discussion:

A. Water Temperature:

Penjajawoc Stream and its principal tributaries are seasonally warm. Most of the watershed is too warm to support year-around populations of salmonids (Table 2). For instance, Atlantic salmon thrive in waters that range from 15-19º C (59-66º F) (Danie et al 1984) and are excluded from stream reaches where summer temperatures exceed 24º C (75º F) for several days. Brook trout prefer stream reaches where temperatures do not exceed 18ºC (64º F) (EBTJV 2005) but can tolerate exposures up to 24ºC (75ºF) for 24 hours or less (Brungs & Jones 1977).

Table 2. Summary of median water temperatures for the 2008 data, and for all data since the last annual report. The sites are listed from the headwaters to the bottom of the watershed, just above the confluence with the Penobscot River. The principal tributaries, Meadow Brook and Cemetery Brook are listed at the bottom of the table.

Sites	2008 data only				all data 2008-2009		
	Water Temp. Centigrade				Water Temp. Centigrade		
	No. values	Median	Range		No. values	Median	Range
PJS-6					34	10.3º	0.5-21.5º
PJS-5	3	24º	24-27º		6	22º	15-27º
PJS-4	5	4º	0-27º		5	4º	0-27º
PJS-4b	21	20º	5-25º		30	18.3	5-25.3º
PJS-3	28	17.5º	0.5-25.5º		29	16.4º	0.5-27.2º
PJS-2	22	17.5º	0-28.5º		32	15º	0-28.5º

PJS-1	**18**	**18º**	**0-27º**		**31**	**15º**	**-0.05-27**
MB-1	**22**	**12º**	**0-16º**		**42**	**15º**	**0-19º**
CB-1	**17**	**17.5º**	**0-23º**		**29**	**12º**	**0-23º**

Median water temperatures have changed very little since the original report (DEP 2009). Meadow Brook and Cemetery Brooks remain cooler than the mainstem. This is especially visible in the maximum values. Meadow Brook in particular is often 3-8º cooler (5-14º F) than the mainstem in the summer. Site PJS-4 was discontinued in the spring of 2008, and so without summer temperatues the median is artificially low. PJS-4b is more representative of this part of the stream. Site PJS-3 was abandoned early in 2009 due to beaver activity that flooded the site. The headwaters (PJS-6) are the coolest part of the mainstem. The apparently warmest site, PJS-5 may be misleading. This is the Penjajawoc Marsh site. The water in the stream channel is deep and probably thermally stratified (and our volunteers can only reach the surface waters). We have not been able to investigate springs and deep pools, which could provide refuge from the heat of summer. The other active sampling sites are rocky riffles and are well mixed.

While most of the Penjajawoc is too warm to support cold water fish in the summer, it is possible that brook trout and other fish use the watershed seasonally. Furthermore, with the deep marsh and cooler headwaters and tributaries, cold water fish have some seasonal refuges from temperature extremes. Black nose dace have been observed in Meadow Brook in the heat of the summer (personal observation).

B. Dissolved Oxygen:

Oxygen is one of the other limiting factors for aquatic organisms in the Penjajawoc. Since no fish spawning areas have been identified in the watershed, the applicable Maine dissolved oxygen thresholds are 7 ppm (mg/L) or 75% saturation. The acute lethal limits for brook trout and many other fish species range from 2-4 ppm for 92 hour exposures (Raleigh 1982). We see many days in the summer where oxygen levels are very low (Table 3).

Table 3. Summary of median dissolved oxygen values for the 2008 data, and for all data since the last annual report. The sites are listed from the headwaters to the bottom of the watershed. The principal tributaries, Meadow Brook and Cemetery Brook are listed at the bottom of the table.

Sites	2008 data only				all data 2008-2009		
	Dissolved Oxygen				Dissolved Oxygen		
	No. values	Median	Range		No. values	Median	Range
PJS-6	2	6.2 ppm	5.2-7.2 ppm		34	7 ppm	4-11 ppm
PJS-5	8	3.2 ppm	1.8-7.8 ppm		15	4 ppm	1.8-9 ppm
PJS-4	5	4.7 ppm	2.1-8.3 ppm		5	4.7 ppm	2.1-8.3 ppm
PJS-4b	21	5 ppm	1.6-8.5 ppm		32	5 ppm	1.6-8.4 ppm
PJS-3	27	5.4 ppm	2-11 ppm		28	5 ppm	2-11 ppm
PJS-2	18	8.4 ppm	6.7-13 ppm		28	8 ppm	6.7-13 ppm
PJS-1	18	7.2 ppm	6.2-8.6 ppm		28	9 ppm	6.25-12.2 ppm
MB-1	18	6.8 ppm	3.0-12.2 ppm		26	7.4 ppm	3-12.2 ppm
CB-1	12	8.5 ppm	6.3-12.5 ppm		25	8.1 ppm	6.5-12.5 ppm

Like the temperature data, the addition of the 2009 data has not changed the oxygen medians by very much. Both 2008 and 2009 were good water years, with strong summer rain totals. The middle part of the stream (sites PJS-5, PJS-4 and PJS-3) experience the poorest oxygen conditions, while the larger and faster lower stream sites have better medians and ranges.

Many parts of the watershed have potentially lethal oxygen conditions during at least part of the year. This is true even for rocky riffles such as PJS-4b. Fortunately, fish are very mobile and will seek out areas that are more comfortable, such as cooler and better oxygenated water. No fish kills have been reported in the Penjajawoc.

C. Bacteria (*E. coli*)

Because bacteria counts are so variable, they are evaluated by geometric means. A geometric mean is the *nth* root of the product of all the values from a given site, where n is the number of values. Also due to the natural variability in bacteria, we need at least 8 values to calculate the geometric mean. In last year's report, we had only one site with more than 8 bacteria values. But with a second years worth of values, we can now report geometric means (Table 4). A geometric mean greater than 64 colonies per 100 ml sample exceeds the state Class B standard.

Table 4. Summary bacteria (*E coli*) geometric means and ranges for all data so far. The sites are listed from the headwaters to the bottom of the watershed. The principal tributaries, Meadow Brook and Cemetery Brook are listed at the bottom of the table.

Sites	all data 2008-2009 Number of E coli colonies		
	No. values	Geo Mean	Range
PJS-6	6		17.3-488.4
PJS-5	8	55.2	9.7- >2419
PJS-4			
PJS-4b	11	40.9	10.9-193.5
PJS-3	6		21.6-517
PJS-2	17	116.8	13- >2419
PJS-1	11	63.3	1-1732.8
MB-1	14	62.8	0-1413.6
CB-1	9	49.8	2- >2419

The lower Penjajawoc Stream sites (PJS-1 and PJS-2) and Meadow Brook appear to violate state bacteria standards. But to be considered "pollutants" the bacteria sources are supposed to be from human or domestic animal waste, and we have no way to determine sources. Very high values in the upper watershed (e.g., values at PJS-5 which exceeded the IDEXX detection limit) suggest that wildlife sources are often important.

D. Conductivity and Chloride:

Our volunteers measured specific conductivity or TDS, which are inter-convertible (we used specific conductance in uS X 0.707 = TDS in mg/L). In order to convert conductivity into one of the statutory criteria (chloride), we used 11 samples to create a regression equation (Figure 3).

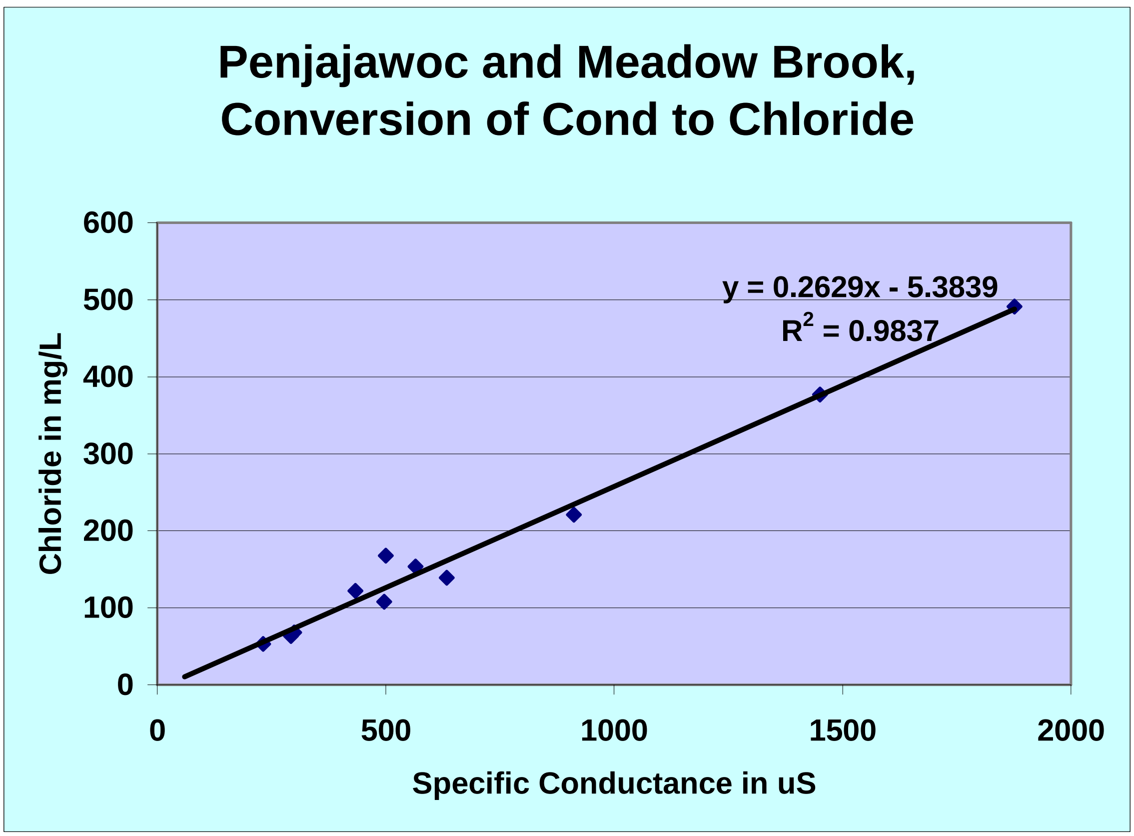


Figure 3. The results of a regression analysis of chloride in mg/l versus specific conductance in uS. The samples came from the lower Penjajawoc and from Meadow Brook. The R-square shows

that more than 98% of the variation in the data is accounted for by the regression model.

The 2008 and cumulative data are given in Table 5. In order to save space, only the cumulative data are converted into chloride medians and ranges. Since our last report, the ranges have expanded a little, but in many cases the medians are identical or almost so.

Aquatic communities are thought to be impaired if chloride exceeds an average of 860 mg/L for acute (one hour) exposures or an average of 230 mg/L for chronic (4-day) exposures (DEP 06-096 Chapter 584). The lower watershed sites PJS-2, PJS-1 and MB-1 exceed the acute exposures, usually during spring runoff conditions. Only Meadow Brook exceeds the chronic exposure limit most of the time. Even summer conditions at MB-1 usually exceed the threshold. This means that the lower Penjajawoc and Meadow Brook are impaired for salinity/chloride, among their many other problems.

Table 5. Summary of median conductivity values for the 2008 data, and conductivity and chloride for all data since the last annual report. The sites are listed from the headwaters to the bottom of the watershed. The principal tributaries, Meadow Brook and Cemetery Brook are listed at the bottom of the table.

Sites	2008 data only				all data 2008-2009				
	Specific Conductance				Specific Conductance			Chloride	
	No. values	Median	Range		No. values	Median	Range	Median	Range
PJS-6					33	265 uS	60-640 uS	64 mg/L Cl	10-163 mg/L Cl
PJS-5	5	113 uS	99-113 uS		11	113 uS	71-141 uS	24 mg/L Cl	17-32 mg/L Cl
PJS-4	5	155 uS	85-268 uS		5	155 uS	85-268 uS	35 mg/L Cl	17-65 mg/L Cl
PJS-4b	20	250 uS	84-510 uS		28	180 uS	84-510 uS	42 mg/l Cl	17-129 mg/L Cl
PJS-3	27	410 uS	146-800 uS		29	403 uS	146-800 uS	100 mg/L Cl	33-205 mg/L Cl
PJS-2	23	523 uS	165-4254		35	503 uS	116-4254	127 mg/L	25-1113 mg/L

			uS				uS	Cl	Cl
PJS-1	**15**	**593 uS**	**189-3200 uS**		**26**	**565 uS**	**85-3200 uS**	**143 mg/L Cl**	**17-836 mg/L Cl**
MB-1	**23**	**1307 uS**	**565-1583 uS**		**35**	**1307 uS**	**297-3200 uS**	**338 mg/L Cl**	**73-836 mg/L Cl**
CB-1	**15**	**311 uS**	**135-382 uS**		**25**	**311 uS**	**85-382 uS**	**76 mg/L Cl**	**17-95 mg/L Cl**

New Hampshire's Department of Environmental Services (DES) also uses a regression equation to convert specific conductance into estimated chloride values (DES 2006). As a rule of thumb, DES considers any conductivity measurement greater than 850 uS to be likely to exceed the state chloride standard for chronic exposure (230 mg/L) (DES 2008). Our regression estimates 230 mg/L chloride to be 854 uS. So the New Hampshire and Maine regressions yield essentially the same results. DES takes an additional step, in that they consider streams with chronic conductivity exceeding 501 uS to be "highly impacted" by chloride (DES 2008).

The severity of the impairment depends not only on the intensity but also the duration. Grab samples represent single points in time and are inadequate for determining duration of a problem. So we will review some of our data sonde data from 2008. Meadow Brook was the worst case scenario for long-term exposures (Figure 4). The data provides specific conductivity in mS (1 mS is equal to 1000 uS) and duration is recorded in one hour intervals.

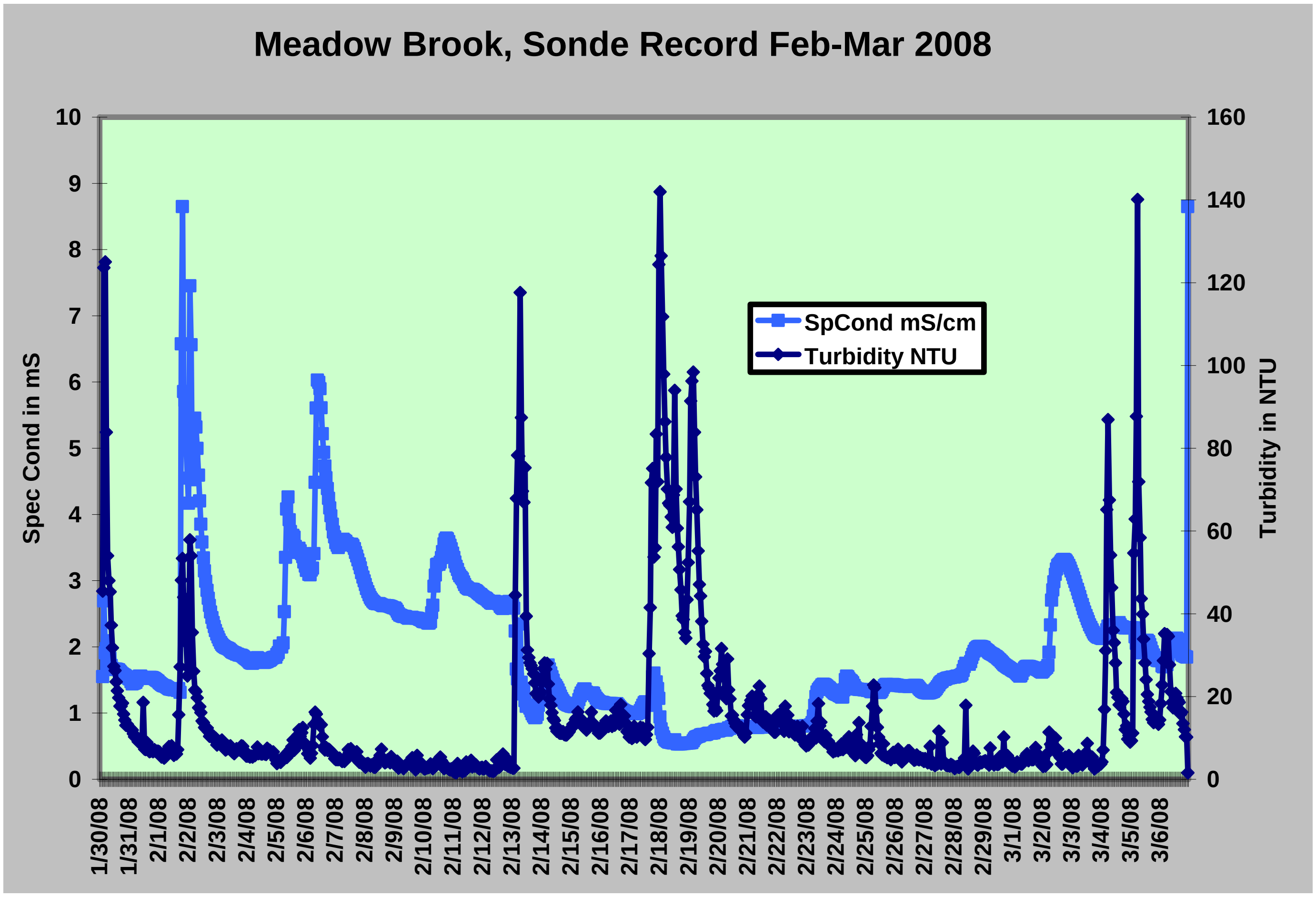


Figure 4. Data sonde record for February 2008 at Meadow Brook MB-1. Sondes are automated samplers that record environmental data at programmed intervals (in our case it was hourly). Both specific conductivity and turbidity are shown in the graph. The acute standard 860 mg/L for Cl translates to a conductivity of 3,292 uS and the chronic standard of 230 mg/L Cl translates to 854 uS. While turbidity problems last for 1-3 days, conductivity with an average greater than 854 uS lasted all month.

The maximum specific conductance for February 2008 was 8.65 mS on February 2 and stayed above 3.293 mS for 19 hours. This translates to a maximum of 2,269 mg/L chloride for about an hour and at least 521 mg/L for 40 hours. This record is above the acute standard of 860 mg/L chloride for 18 hours. The period from

2/6/09 to 2/8/09 has 96 hours above 860 mg/L. So the lower Penjajawoc and Meadow Brook exceed state acute exposure standards sometimes for days at a time. Comparing these exposures to those listed by Environment Canada's literature review of the lethal ranges for various test organisms (Environment Canada 2001) our exposures would not be lethal for any of the fish and would not kill most of the invertebrate species. This means that we would not expect fish kills from chloride alone, but that many aquatic species would not thrive in these streams. This is important, because the recovery of our aquatic communities would not be expected unless the stream restoration also includes reductions in road salt use.

F. Chloride Trends

Winter salt sand is the most important source of chloride in most New England watersheds. For instance, in a study of the Dinsmore Brook watershed in New Hampshire (DES 2007) state roads accounted for 50% of the total chloride budget, municipal and private roads were 22%, parking lots were 26%, atmospheric deposition was 1%, and all other sources (salt storage piles, landfills, & water softeners) were the remaining 1%. The sources change in different watersheds depending on how urban they are and how much exposure they have to ocean aerosols, but the overwhelming importance of winter road and parking lot maintenance is a constant for urban watersheds.

The 1982 Maine DOT study gives us a glimpse of the Penjajawoc watershed 30 years ago. The study had 8 sites, located above and below roads in order to study sodium chloride spatial patterns and sources in the watershed. Background Cl levels ranged from 6-16 mg/L at the Stillwater Avenue upstream site. Extreme values as high as 621 mg/L chloride were reported below the Bangor Mall entrance on January 25, 1978, and again a value of 575 mg/L Cl below the Bangor Mall entrance on March 10, 1980. Nothing above 42 mg/L Cl was found in 1981 and 1982. Many of the 1981 and 1982 values are below our assumed background (20-25 mg/L). The DOT study (Figure 5) shows that the two strongest sources of salt 30 years ago are the Bangor Mall area (below Stillwater Avenue to above I-95) and below Mount Hope Avenue (below Mt Hope and above Route 2) in the lower watershed.

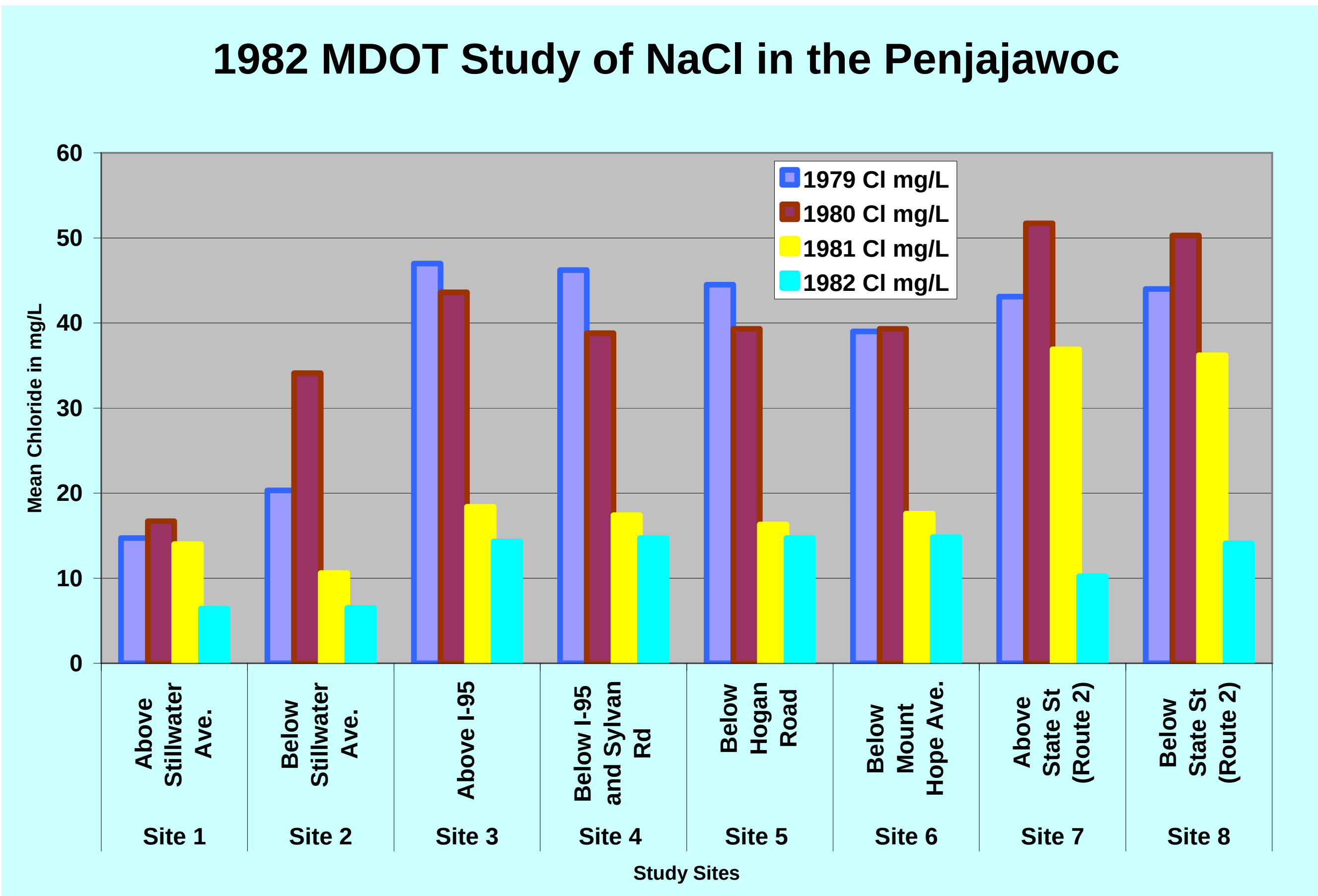


Figure 5. Summary of 1982 Maine DOT study of salt in Penjajawoc Stream. Values are yearly chloride means for each site. The sites are arranged from the upper watershed (left) to the lower watershed (right). The Bangor Mall is located between Sites 2 and 3. The DOT maintenance yard is between sites 6 and 7.

There is no surprise that the Bangor Mall area is a salt source. Note the amount of parking space in Figure 1. Some of this salt would also come from the Stillwater Avenue area on the southern side of the road. New Hampshire DES studies have shown that parking lots are important sources of salt. Because of the linear nature of roads, they tend to deposit salt in one watershed, then the next and the next. But parking lots represent a lot of pavement that often drains to one place or one watershed. In four completed studies of lake watersheds in New Hampshire, parking lots account for 5-50% of the total salt budget (NH DOT 2009). In the 1982 Penjajawoc Stream study, the second salt source, below Mount Hope Avenue, might be the DOT maintenance yard. In the 1970's salt sand would have been stored out doors without covers and salt would have made its way to the Penjajawoc by overland runoff and/or groundwater flow.

Our summary data shows a similar pattern but with much higher values than DOT's study (Figure 6). The DOT values are means, and ours are medians, which are similar but not exactly the same. But the trends are so overwhelming, it does not matter that the summary statistics are not identical. The Bangor Land Trust Parcel (PJS-6) has values well above our assumed background (20-25 mg/L) and probably reflects the inputs from the landfill just upstream. Penjajawoc Marsh (PJS-5) shows the dilution of the landfill influence with the addition of the cleaner headwaters to the north and northwest (Figure 1). The development around Stillwater Avenue, including the road itself, contributes some road salt. With all the development above and below I-95, the contribution of the Bangor Mall no longer stands out as much as it used to. There is now a more gradual increase in chloride in the middle and lower watershed. For some reason, Meadow Brook, has more chloride contamination than the Penjajawoc.

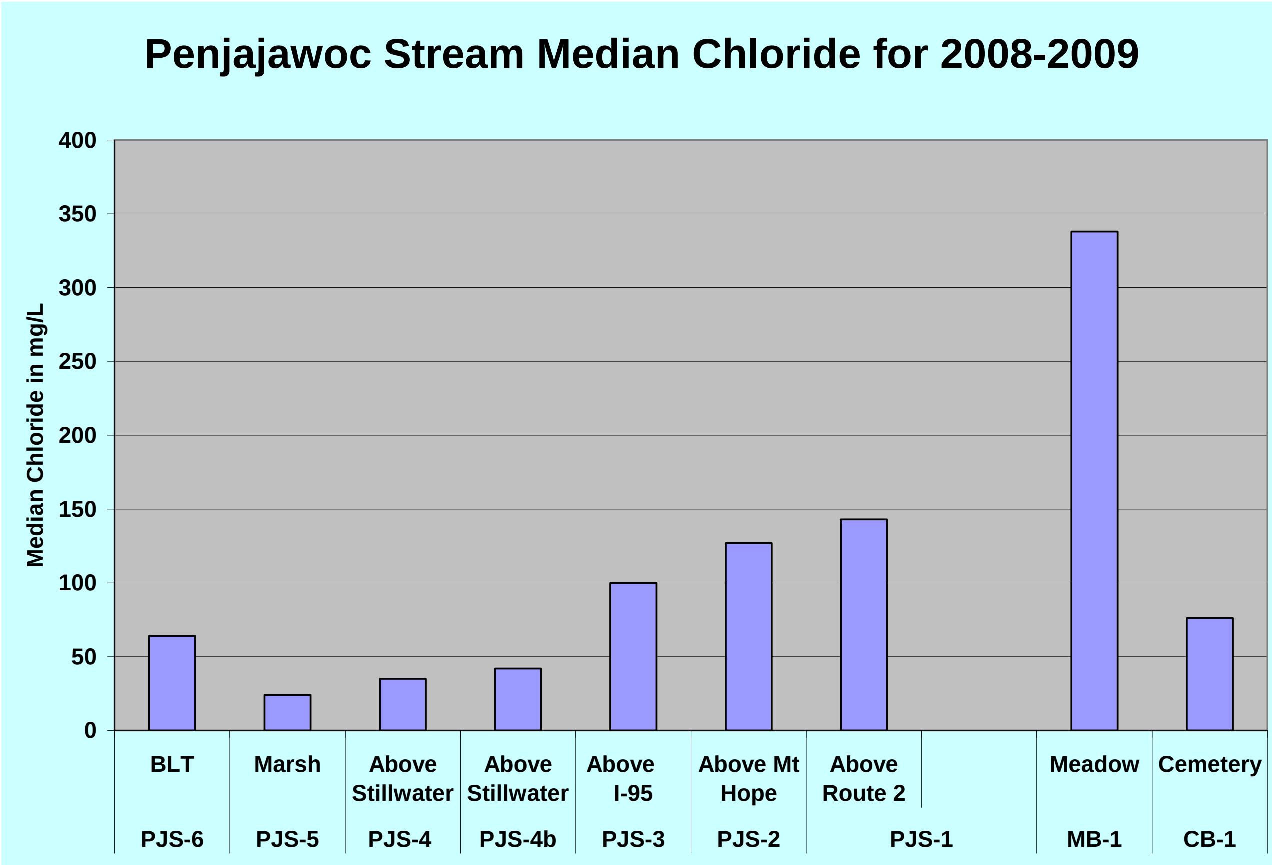


Figure 6. Graphic summary of Penjajawoc Stream estimated median chloride concentrations (based on the above regression). The sites are arranged from the upper watershed to the lowest, with the tributaries set off to the right.

In an investigation of 100 stream watersheds in 15 northern states and 1,329 wells in 19 northern states, the US Geological Survey (USGS) found widespread chloride enrichment in urban watersheds (Mullaney et al 2009). Forested and rural watersheds had less enrichment, and agricultural watersheds were intermediate. The best predictors of chloride enrichment were the road densities, evapotranspiration potential, and percentage of the annual water budget that is from surface runoff. That is, road salt is the chief source, it can be concentrated by evapotranspiration, and runoff is an important means by which the salt contamination is spread from source areas.

G. The Kittridge Landfill

The DEP investigation of the landfill resulted in mostly good news. Heavy metals were not detected downstream (Table 6). Traces of organic compounds were present (Table 7) but only in single parts per billion or less, with many below detection limits. Iron, magnesium and manganese were abundant but were not found in toxic amounts downstream. Calcium, potassium and sodium were abundant, as were chloride and sulfate. These are the salts that we are detecting at the downstream Bangor Land Trust site (PJS-6). But again, the levels are not toxic.

Table 6. Summary of lab chemistry from the U of Maine Sawyer Environmental Chemistry and Research Lab for the Bangor Land Trust parcel (PJS-6) site (the first site below the landfill). The results are listed (in order) the major cations: calcium, sodium, potassium, and magnesium, then the major anions: chloride, nitrate, and sulfate, then alkalinity and pH, and then the trace metals: aluminum, manganese, iron, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and zinc.

Site	Date	Ca mg/L	Na mg/L	K mg/L	Mg mg/L	Cl mg/L	NO3 mg/L	SO4 ueq/L	Alkalinity mg/L	pH	Al ug/L	Mn ug/L	Fe ug/L	As ug/L	Cd ug/L	Cr ug/L	Co ug/L	Cu ug/L	Pb ug/L	Ni ug/L	Zn ug/L
PJS-6	9/15/2008	36.8	20	4.11	7.96	22.8	<1	13.5	116	7.23	36	23.8	120	<4	<0.5	<2	<5	<5	<2	<2	<1

Table 7. Summary of DEP tests on pore water collected from landfill leachate sites, with pore water from one upstream site, and surface water from the downstream Bangor Land Trust site.

Parameter	PW1 upstream 6/1/2009	PW2 upper landfill 6/2/2009	PW3 middle landfill 6/3/2009	PW4 lower landfill 6/4/2009	PJS-6 BLT parcel 9/15/2009
LABORATORY PARAMETERS					
VOLATILE ORGANIC COMPOUNDS:					
1,1,2-TRICHLORO-1,2,2-TRIFLUORETHANE ug/L	NA			0.7	NA
METH-t-BUTYL ETHER (MTBE) ug/L	NA			0.5	NA
1,1,1-TRICHLOROETHANE ug/L	NA	1.3	1.1	1	NA
TOTAL ORGANIC CARBON mg/L	12	13	11	9.2	NA
INORGANIC PARAMETERS:					
AMMONIA AS NITROGEN mg/L	0.5	1.6	1.1	1.2	NA
ARSENIC mg/L					0.004
CALCIUM mg/L	17	150	300	170	36.8
CHLORIDE mg/L	59	70	82	45	22.8
IRON mg/L	2.1	28	9.8	44	0.12
MAGNESIUM mg/L	3	23	54	25	7.96
MANGANESE mg/L	0.72	5.4	2.5	5.6	0.024
NITRATE AS N mg/L	0.3				NA
POTASSIUM mg/L	0.7	7.7	29	16	4.11
SODIUM mg/L	31	54	97	50	20
SULFATE mg/L	0.7	6.4	460	58	13.5
TOTAL ALKALINITY mg/L	28	430	560	480	116
TOTAL DISSOLVED SOLIDS mg/L	180	620	1400	710	
FIELD PARAMETERS:					
PH	6.09	6.4	6.76	6.75	7.3
SPECIFIC CONDUCTANCE uMHOS/cm	274	1041	1918	1188	NA
TURBIDITY NTU	11.9	7.7	3.7	22.3	NA

The landfill is apparently leaching dissolved organic matter which is being consumed by bacteria at the base of the landfill. High bacterial metabolism generates a lot of alkalinity, which in turn probably causes heavy metals (we assume there must be some, since it's a landfill) to be precipitated as hydroxides. The now insoluble metals are trapped near the landfill. The salts and the alkalinity (which are soluble) are detectable downstream at PJS-6, but the effect is harmless.

IV. Summary and Conclusions:

The additional data from the 2009 field season has changed our median values very little. This gives us additional confidence that we have achieved a good baseline by which we can measure progress during the Penjajawoc Stream restoration. Our new information, especially our ability to translate our field measurement into chloride data, highlights the importance of road salt in our watershed. The 30 year old DOT report reminds us that chloride has been increasing in northern states, including Maine, especially where there is continuing development within the watershed. Chloride is an important issue in many urban streams, and it can be a liming factor for aquatic organisms. Finally, the landfill does have an effect on downstream salt and alkalinity. However, this is not a problem for the immediately downstream site PJS-6, but does add to the cumulative salt problems in the watershed.

The current recovery plan for the Penjajawoc watershed does not have any plans to reduce the use of road salt sand. Because road salt sand is related to public safety concerns, it can be a difficult problem to address. We have best management practices (BMTs) for various stormwater related problems, but we cannot treat for chloride. We need to develop state and municipal partnerships to review what more we can do to decrease salt use while maintaining a high standard for public safety. For Penjajawoc Stream, we may not be able to restore aquatic communities without addressing the road salt problem.

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