Volunteer Water Quality Monitoring by Bangor High School S.E.E.D.s of Bangor Area Streams

Report for 2013 Field Season

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Summary:

In the spring of 2013 Maine Department of Environmental Protection (DEP) was approached by students from Bangor High School with a proposal to help DEP and the City of Bangor to do water quality monitoring on local streams. The students are members of S.E.E.D. (Students Ending Environmental Destruction), an after-school environmental club promoting school awareness of environmental issues, doing community service, and raising money to preserve the rain forest. This study was to develop an up-to-date evaluation of the status of these streams and to provide real hands-on experience in the environmental sciences for student volunteers. DEP equipped and trained the students and this report is a summary of our findings.

This study documents some on-going problems, including contamination by road salt, elevated water temperatures, low summertime dissolved oxygen and occasional high turbidity. One regression model was developed from available lab chemistry to relate field conductivity measurements to chloride. This model is similar to other models developed for Bangor area streams (i.e., the Penjajawoc and Meadow Brook). Another regression used field turbidity tube measurements (i.e., visibility of a black and white Secchi target measured in mm) and lab turbidity (in NTU) to develop another conversion model. These models will be used by state agencies and other volunteer groups to help interpret their findings.

I. Introduction

In the winter of 2013, Maine Department of Environmental Protection (DEP) trained and equipped students from Bangor High School to do water quality monitoring of Bangor area streams. This report is a summary of our findings.

The Bangor area streams are the subject of considerable interest as some are strongly impacted by urban development. The City of Bangor is in the process of upgrading stormwater conveyances in some of these watersheds and is making master plans for other watersheds. Eventually there will be improvements in water quality, fish habitat, and scenic and other human uses of these watersheds. The purpose of this monitoring was two-fold: (1.) to give students real-life experience in environmental science and (2.) to establish existing conditions so that future improvements in the watersheds can be documented.

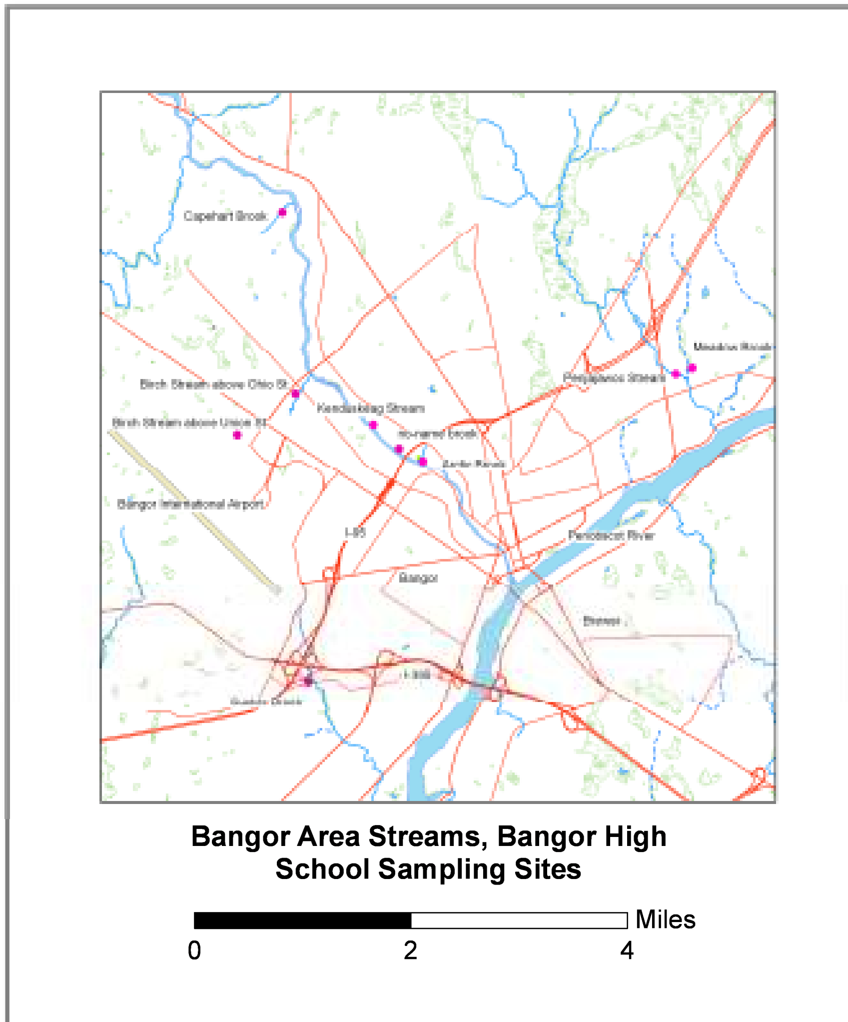
Previous reports are available on the DEP website for Penjajawoc Stream and Meadow Brook (DEP Atlantic Salmon and VRMP web pages (Volunteer River Monitoring Program) see References Section below for web addresses) Sucker, Arctic, Shaw and Capehart Brooks (DEP TMDL – Impervious Cover), and for Birch Stream (DEP TMDL - Streams). Since the City of Bangor has on-going restoration projects, the stream conditions are always changing (and should be gradually improving). There is a continual need for monitoring so that we have a measure of our progress.

II. Methods

Study Sites

This study was primarily conducted on four streams within the Bangor city limits, namely: Arctic Brook, Birch Stream, Kenduskeag Stream and Sucker Brook (Figure 1). A limited number of samples were also taken from Capehart Brook, a no-name stream near Arctic (sampled by mistake), Penjajawoc Stream and Meadow Brook.

Figure 1. Bangor area streams sampled by Bangor High School S.E.E.D.s volunteers in 2013. Those streams and sites are: Arctic Brook (and no-name brook) and Kenduskeag Stream at Valley Drive. No-name brook was mistaken for Arctic and a few samples were taken here before the problem was recognized. Birch Stream above Union Street or above Ohio Street. Birch Stream is a tributary to Kenduskeag Stream. Capehart Brook at the end of the Pushaw Road. Capehart Brook is a tributary to Kenduskeag Stream. Penjajawoc Stream and Meadow Brook at Evergreen Woods off Mount Hope Avenue. The Penjajawoc and Meadow Brook are tributaries to the Penobscot River. Sucker Brook at the Coles Transportation Museum on the Perry Road. Sucker Brook is a tributary to the Penobscot River.



Field Methods

The objective was to sample weekly in the late winter and spring. Later, some students continued monitoring into the summer. Different students adopted different streams. Arctic Brook ended up with the most complete record from the end of January through September 8, 2013. Kenduskeag Stream was sampled from April 1 through August 30, 2013 and is the second most complete record.

Field measurements were made for dissolved oxygen (DO) and conductivity using a YSI 550A DO meter and an Oakton EC11+ pen. Arctic Brook, Birch Stream and Penjajawoc Stream were examined with automated recorders, including a YSI 600 XLM data sonde (Arctic) and an Onset conductivity loggers (Birch) or Onset DO logger (Penjajawoc Stream). A turbidity tube was used to measure water clarity in the field and grab samples of stream water were taken for later lab analysis using a Hach 2000P turbidity meter. Some additional water samples were taken for Lab analysis (paired conductivity and chloride measurements) at the University of Maine Sawyer Environmental Chemistry and Research Lab (SECRL).

Analysis

State water quality classification rules were used to judge conformity with state standards (Title 38, Chapter 3, subsection 465). Regression models were developed to allow the conversion of field measurements (i.e., conductivity and water clarity) into numbers that can be compared to state standards (chloride and turbidity/TSS). There is no actual legal standard for turbidity but since streams are supposed to maintain indigenous fishes, the potential impact to fisheries can be evaluated with comparisons with published literature (Newcombe & Jensen 1996).

The Bangor area streams are mostly classified as Class B (Table 1) although the lower part of Kenduskeag Stream is Class C. Class A is the best water quality, B is intermediate, and C is the poorest water quality. The water quality thresholds are provided in Table 2.

Stream	Class
Arctic & no-name	B
Birch	B
Capehart	B
Kenduskeag above Griffin Rd	B
Kenduskeag below Griffin Rd	C
Penjajwoc & Meadow	B
Sucker	B

Table 1. Statutory class of Bangor area streams. The Griffin Road bridge over Kenduskeag Stream is the road crossing above Birch Stream on the map. Capehart Brook enters Kenduskeag Stream in the Class B part of the stream.

Table 2. Statutory water quality criteria for each water classification category. None of these Class B streams are currently attaining their statutory class and are listed as "Impaired." Kenduskeag Stream is Class C within Bangor and it attains class C standards for aquatic life. Dissolved oxygen is given in ppm (mg/L) and in percent saturation. There is no water quality threshold for conductance, but since there is a relationship between conductance and chloride, a regression model is used to flag samples that might exceed chloride standards based on easily measured specific conductance. Lab samples were used to confirm the relationship between conductivity and chloride (see Results section below).

Classification	Designated uses	Oxygen	Chloride	Conductance
B	fishing	≥ 7 ppm or	230 mg/L	854 uS
	recreation in an on the water	75% saturation	chronic exposure	(as possible
	navigation	(with special		chloride)
	habitat for fish and other	provisions for fish	860 mg/L	3292 uS
	indigineous aquatic life	spawning grounds)	acute exposure	(as possible
	industrial process water and			chloride)
	cooling			
C	fishing	≥ 5 ppm or	230 mg/L	854 uS
	recreation in an on the water	60% saturation	chronic exposure	(as possible
	navigation			chloride)
	industrial process water and		860 mg/L	3292 uS
	cooling		acute exposure	(as possible
	support for all indiginous fish			chloride)
	and maintain structure and			
	function of other aquatic life			

III. Results

Water temperature was taken along with other variables of interest in late winter, spring and summer samples. Water temperature is generally most limiting for cold water fish (such as brook trout and the minnows blacknose dace and creek chub) and other cold water adapted organisms, so only summer temperatures are reported here (Table 3). For the most part, water temperatures were below 24° C, a critical upper limit for salmonids. However, the lower Kenduskeag did have high temperatures (to 30.8° C) in the late afternoon in mid-July. This is warm enough that sensitive species would have to seek refuge in deep shaded pools, undercut banks, cool tributaries and springs.

Table 3. Water Temperatures in degrees C for Bangor area streams, sampled by Bangor High School SEEDS for the 2013 field season.

Site	Sample Interval	# of Samples	Minimum Value	Maximum Value	Average
Arctic	6/8 to 9/8	16	14.8°	22.6°	18.2°
Birch	6/22 to 8/30	12	15.2°	23.3°	19.3°
Kenduskeag	6/22 to 8/30	11	19.3°	30.8°	23.8°

Dissolved oxygen is also generally most limiting during the heat of summer, because gasses are less soluble in warm water (Table 4). Low DO is a problem for all of these streams except for Kenduskeag Stream, but not necessarily for each site. Note that Arctic and Kenduskeag had good oxygen levels for all sample dates at these sites. These sites benefit from elevation drops that provide nice riffle habitat (and aeration). In contrast, the summer DO samples from Birch Stream were too low during July and August (this site is located in a flat area near the airport which offers few riffles).

However, low dissolved oxygen can also be a problem under winter ice and snow. This is not generally a problem for flowing water, but can be a problem for dead-water regions such as Penjajawoc marsh in the headwaters of Penjajawoc Stream (Figure 2). Due to a lack of water movement and lack of sunlight under the ice and snow, microbial decomposition of organic bottom sediments can locally deplete oxygen. In the late winter and early spring, during thaw events and especially during rain-on-snow events, rising flood waters can break up the winter ice and flush low oxygen water downstream. This was actually observed in the spring of 2013. Often this water has a sewer-like odor that generates complaints from the public (in this case, from businesses and residences in the Stillwater Avenue area).

Table 4. Dissolved oxygen as a percent of saturation for Bangor area streams for the 2013 field season. All samples are taken during daylight hours after school (generally 2:30 to 6:00 pm).

Site	Sample Interval	# of Samples	Minimum Value	Maximum Value	Average
Arctic	3/31 to 9/8	21	92	110	99
Birch	6/22 to 8/30	12	42	99	73
Kenduskeag	6/22 to 8/30	11	80	120	103

High DO values (above 100%) are super-saturated due to photosynthesis during the day. Some super-saturation is normal especially in the summer sun. Values much higher than this are sometimes indicators of nutrient enrichment and algal blooms. Neither abnormally high DO values nor algal blooms were observed by the students.

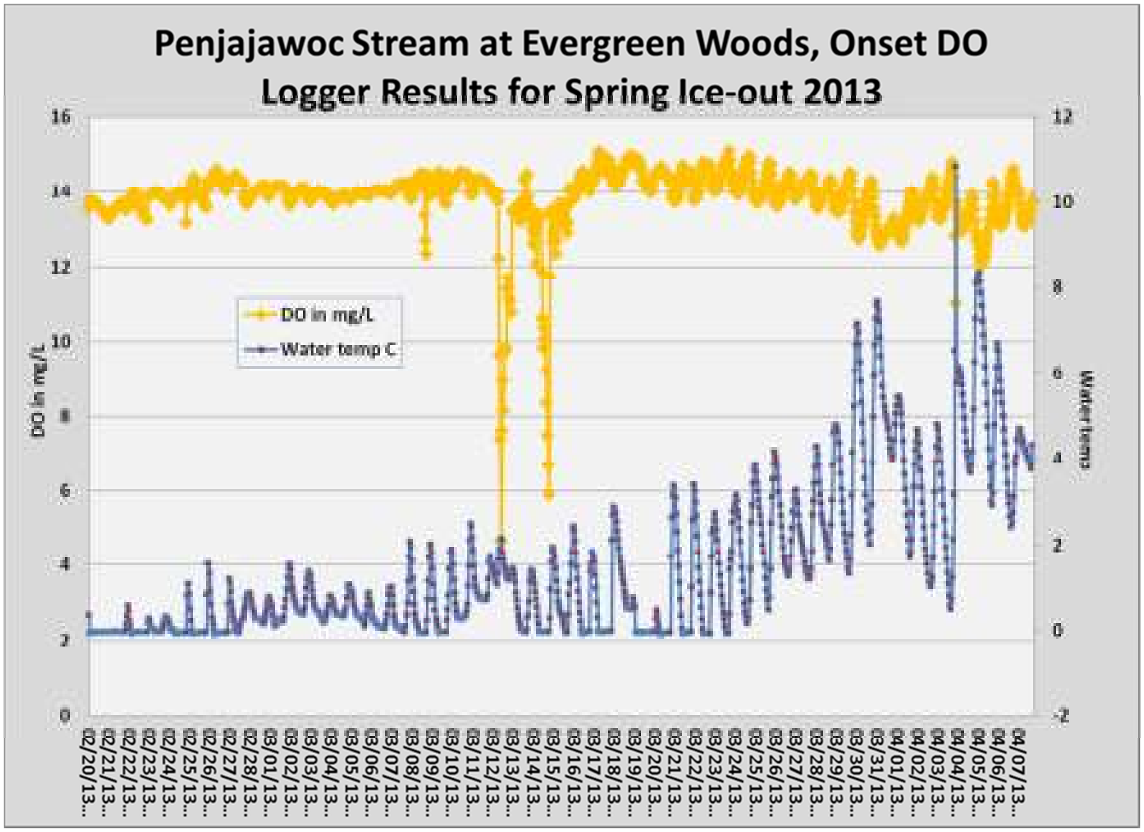


Figure 2. Water temperature and dissolved oxygen (DO) for Penjajawoc Stream during ice out in March of 2013. DO values are in mg/L (same as ppm). Temperature shows a warming trend with rain on snow event (not shown) beginning on March 11. Ice cover on Penjajawoc marsh went out the next day during high flows and flushed oxygen poor water downstream to the sonde site. There was more rain on March 15. DO soon stabilized as did stream flow. Continued warming led to greater daily fluctuations in temperature and in DO (higher daytime and lower nighttime DO). Later rainstorms (e.g. March 20 and April 1) did not have the same effect (the marsh was now open to the atmosphere and to sunlight).

Conductivity was measured throughout the field season and is summarized in Table 5. In all cases there was a large amount of seasonal variation with the highest values in late winter and early spring (associated with the flushing of road salt off the roads by thaw and/or rain events). Baseflow samples from the summer (i.e., samples taken during dry weather) show that there is some contamination of groundwater with road salt. The lowest conductivity values occurred with rain events in the summer when contaminated groundwater is diluted with relatively clean rain water.

Table 5. Conductivity in uS for Bangor area streams for the 2013 field season. Samples were taken in the spring and then some sites were continued into the summer. No-name brook was sampled by mistake, this is the next stream west of Arctic Brook on Valley Drive.

Site	Sample Interval	# of Samples	Minimum Value	Maximum Value	Average
Arctic	3/7 to 9/8	25	308	1800	939
No name	5/18 to 6/22	3	159	986	628
Birch	2/20 to 8/30	14	110	1315	530
Capehart	2/20 to 4/11	3	240	1693	743
Kenduskeag	6/22 to 8/30	11	173	270	229
Penjajwoc	2/20 to 4/8	2	440	1040	740
Meadow	2/20 to 4/9	3	760	1233	1051
Sucker	3/7 to6/22	7	654	1962	1456

Note that most of the maximum values and even many of the averages were above 854 uS, a level where it was likely that chloride values exceeded the 230 mg/L chronic exposure threshold. Notice that even the minimum value at Meadow Brook was near the chronic limit. This indicates that groundwater that feeds Meadow Brook has too much chloride to sustain natural macroinvertebrate communities and that this was the case for most of the year. The seasonal variation in conductivity (and chloride) was also detailed by sonde records (Figure 3). There was a large flush of road salt with the first spring thaw events. This cleaned road salt from the roads and roadside ditches. Subsequent rains had less effect, and soon actually diluted the salt content. During storms, the changes took place quickly (the sonde recorded conductivity every hour, so each peak only lasted for a few hours). This made it unlikely that volunteer monitors could be there at the right time to find the very highest values. The sonde record was in mS, so the highest values were around 8500 uS and greatly exceeded the acute threshold of 3292 uS (where the chloride values likely exceeded 860 mg/L). Thus the highest values (acute exposure) and the day-to-day exposures (chronic) exceeded values designed to protect aquatic communities. In fact, DEP biomonitoring shows that macroinvertebrate communities are impaired and do not meet state standards for all of these streams except for Kenduskeag Stream (which had the least salt contamination and is Class C) (see individual DEP Biomonitoring reports online).

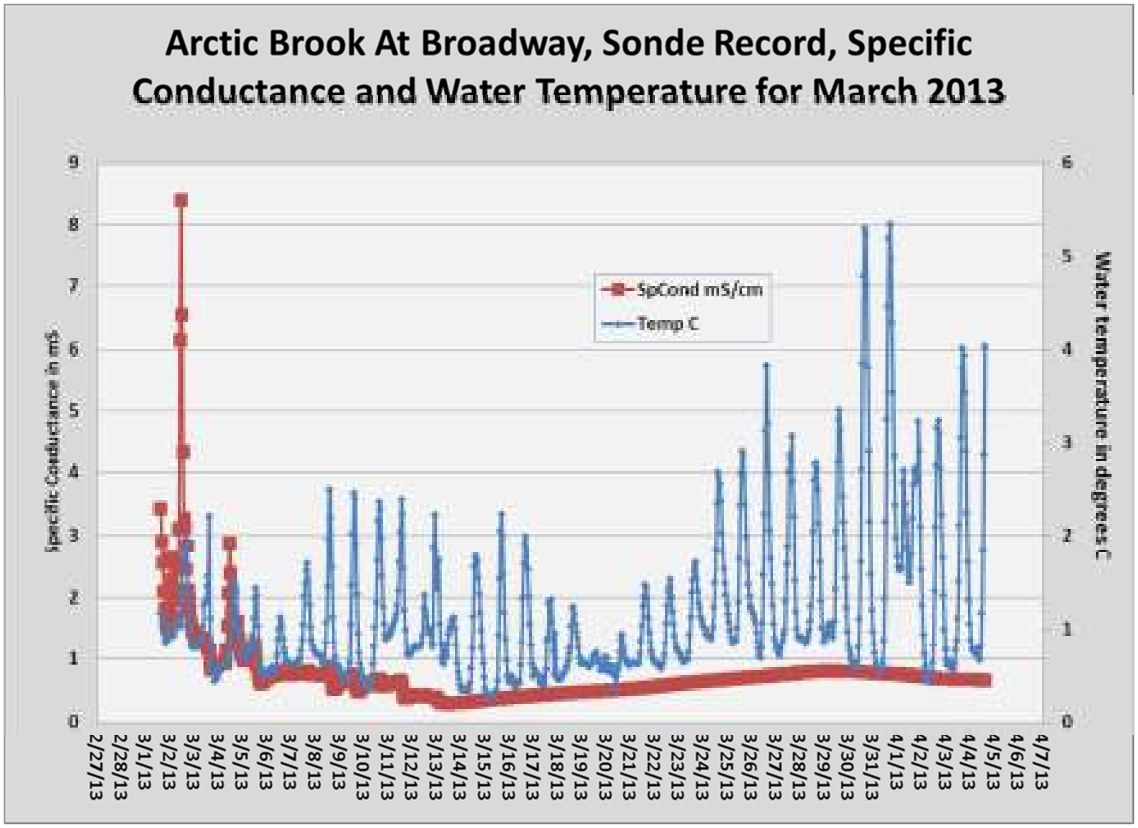


Figure 3. Water temperature and specific conductance in mS(there are 1000 uS in one mS, so these were very high values) for a YSI data sonde in Arctic Brook. The spike in conductivity represents short lived flushes of road salt in a March 2 rainstorm. Note that much of the road salt came off in the first flush during the first rains of the season. Rain on March 4 flushed only a little more salt.

Figure 4 provides a similar conductivity record from Birch Stream, which drains the Bangor airport and Union Street commercial development. Like Arctic Brook there was a flush of salt with early thaw events, but this one was almost a month later. There were separate flushes that reflected peak rainfall events and thaws. Each event lasted only a few hours. A large storm on April 25 lifted the logger out of the water and deposited it on the stream bank. The falling water level left it stranded and exposed to air temperatures (which fluctuated more than water temperatures do). Like Arctic Brook, both acute and chronic chloride standards were probably exceeded.

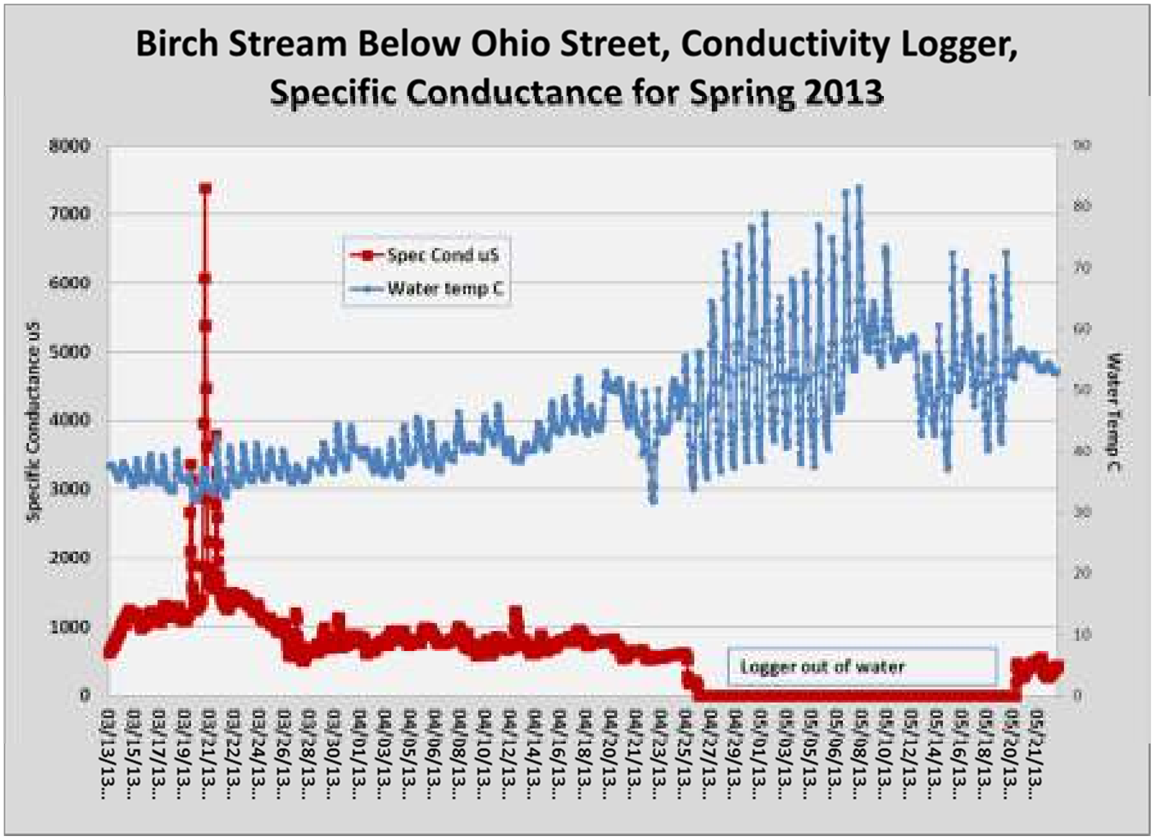


Figure 4. Water temperature and specific conductance in uS from an Onset conductivity logger in a March rainstorm on March 20. A storm on April 25 lifted the logger off the stream bottom and deposited it on the stream bank. Exposure to air increased the magnitude of daily temperature fluctuations.

The lowest value for conductance in Table 3 was 110 uS, found at Birch Stream site 1, located above the canal that drains most of the airport. In a different study, the background conductivity for upper Penjajawoc Stream was estimated at 113 uS, the average value for the minimally developed part of the watershed measured at Penjajawoc Marsh (Whiting 2010). These values, 110-113 uS are probably good approximations of the original pre-development conductivity for Bangor area streams.

The SEEDS volunteers measured turbidity using two different methods. Grab samples of water were delivered to DEP for lab analysis. The readings in NTU were compared to turbidity tube readings (Table 6). Turbidity is a measurement of the scattering of light by suspended particles in water sample. The cloudier the water, the more light is scattered and the higher the reading in NTU units. Turbidity tubes work the other way, where visibility of a black and white target is measured in mm. A high measurement means that the water is clear and a low measurement means the water is cloudy. Volunteer organizations often use turbidity tubes since they are relatively inexpensive and every volunteer can have their own device. The results from 2013 showed mostly low values with some occasional sharp spikes and only after storms. Some of these were spring storms that entrained winter road maintenance sand. Bangor road crews cleaned the roads of any remaining sand after the last winter storms. Other turbidity events occurred in the summer and water cloudiness was more related to stability of the stream channel.

Table 6. Turbidity meter readings in NTU and turbidity tube readings (visibility of a Secchi target in mm) for Bangor area streams for the 2013 field season. The turbidity tube is 120 mm long, so the maximum reading (120 mm) indicates clear water.

Turbidity Meter readings in NTU

Site	Sample Interval	# of Samples	Minimum Value	Maximum Value	Average
Arctic	1/31 to 9/8	26	1	228	34
No name	5/18 to 5/29	2	3	19	11
Birch	2/20 to 8/30	11	3	90	22
Kenduskeag	4/1 to 8/30	16	1	22	8
Meadow	3/13	1	172	172	172
Sucker	1/31 to 6/22	2	29	243	136

Turbidity Tube readings in mm

Site	Sample Interval	# of Samples	Minimum Value	Maximum Value	Average
Arctic	1/31 to 9/8	20	14	120	89
No name	5/18 to 5/29				
Birch	2/20 to 8/30	14	13	120	90
Kenduskeag	4/1 to 8/30	10	86	120	114
Meadow	3/13				
Sucker	1/31 to 6/22	7	15	95	53

Turbidity and water clarity are optical measurements of water cloudiness. Cloudiness affects aquatic organisms by preventing them from seeing clearly. However, optical properties of water are most affected by small particles, while many biological effects are more related to larger particles that clog gills or settle into spaces between bottom gravel and cobble substrates. These spaces are essential habitat for small organisms such as invertebrates, fish eggs and fry. Often the impact of suspended sediments on fish and benthic organisms are measured by total suspended solids (TSS) a measurement of the total weight of the particles (Newcomb & Jensen 1996). Unfortunately, TSS and turbidity in NTU are not easily related. The relationship is dependent on the types of particles (such as organic or mineral), their relative sizes, and their dry weights (e.g., large organic particles have strong visual impact, but are light and can have little impact on total weight). However for urban streams, mineral particles generally dominate and turbidity can be converted into TSS by a simple linear function (which is still only an estimate): $\ln(TSS) = 1.32 * \ln(NTU) + 0.15$ (Packman et al 1999).

Some of the high values, especially those over 100 NTU are significant stresses for aquatic life. One problem with interpreting this kind of data is that we do not know what the duration of the turbidity event was. The biological consequences of turbidity and TSS are dependent both on the concentration and by the exposure time (Newcomb & Jensen 1996). In the Penjajawoc, turbidity peaks are typically high (60-140 NTU or more) but the peaks last only for about an hour, while turbidity over 20 NTU may last for days (1-3 days) (Whiting 2010). If the other streams have a similar pattern, then the long-term exposures are more severe than the short term peaks. For instance for non-salmonid adult fish (most of the fish in these streams are minnows), a one hour peak of 145 NTU (about 828 mg/L TSS) is a “moderate physiological stress,” while a 2 day exposure of 20 NTU (about 61 mg/L TSS) is a “major stress” causing poor feeding success and leading to a poor body condition and reduced populations (Newcomb & Jensen 1996)

Likewise, conversions from water clarity to NTU are approximate. A regression equation was developed for this paper using data from Bangor area streams plus some data from the Sheepscot River (Figure 5). The R^2 (the quality of the model) is moderately good.

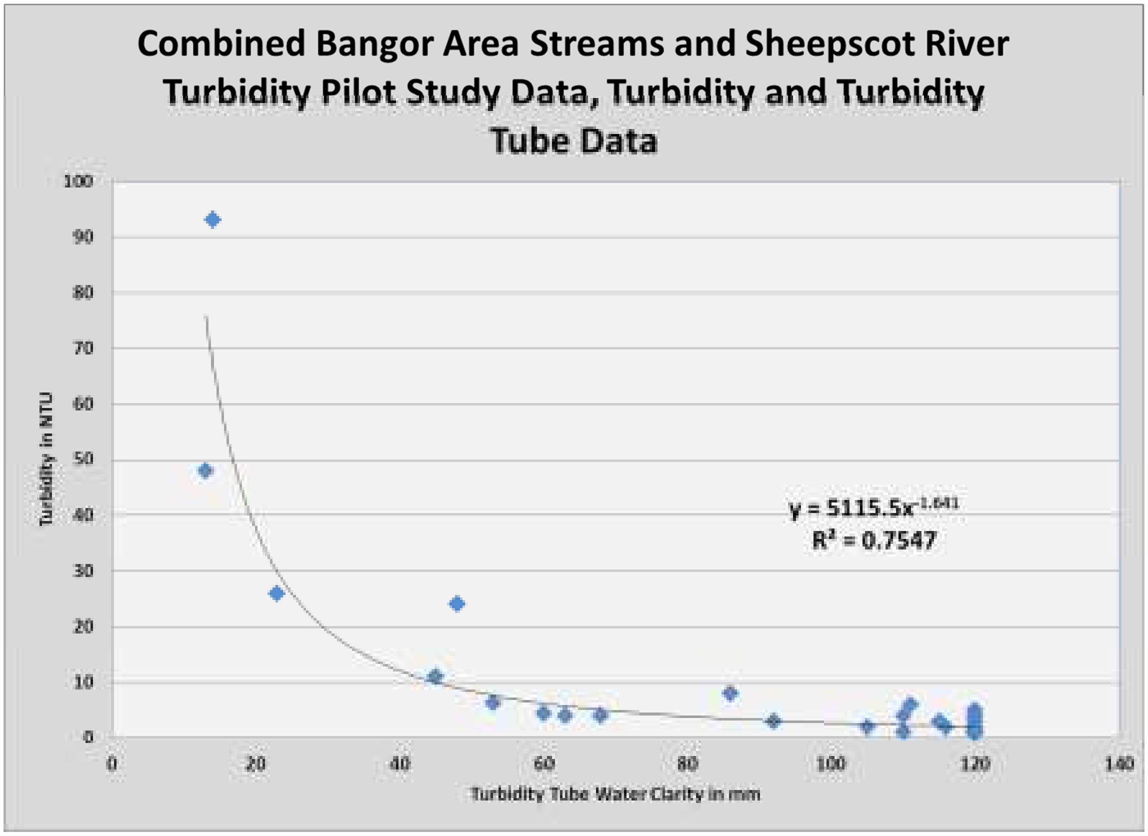


Figure 5. A comparison of turbidity in NTU with water clarity measured by a turbidity tube in mm. In order to improve the quality of the model, Bangor area stream data was pooled with an earlier study from the Sheepscot River. The equation converts water clarity (x) to turbidity as NTU(y).

Our results are similar to a turbidity tube conversion from the Utah State University Cooperative Extension Office (Figure 6) for their volunteer stream monitoring program. The two models yield almost the same results. For a value of y = 60 mm the DEP model gives 6 NTU and the USU model is 8 NTU. For a value of y = 25 mm the DEP model result is 26 NTU and the USU result is 30 NTU. Since the reading of the turbidity tube is somewhat subjective, our conversion model yields satisfactory results.

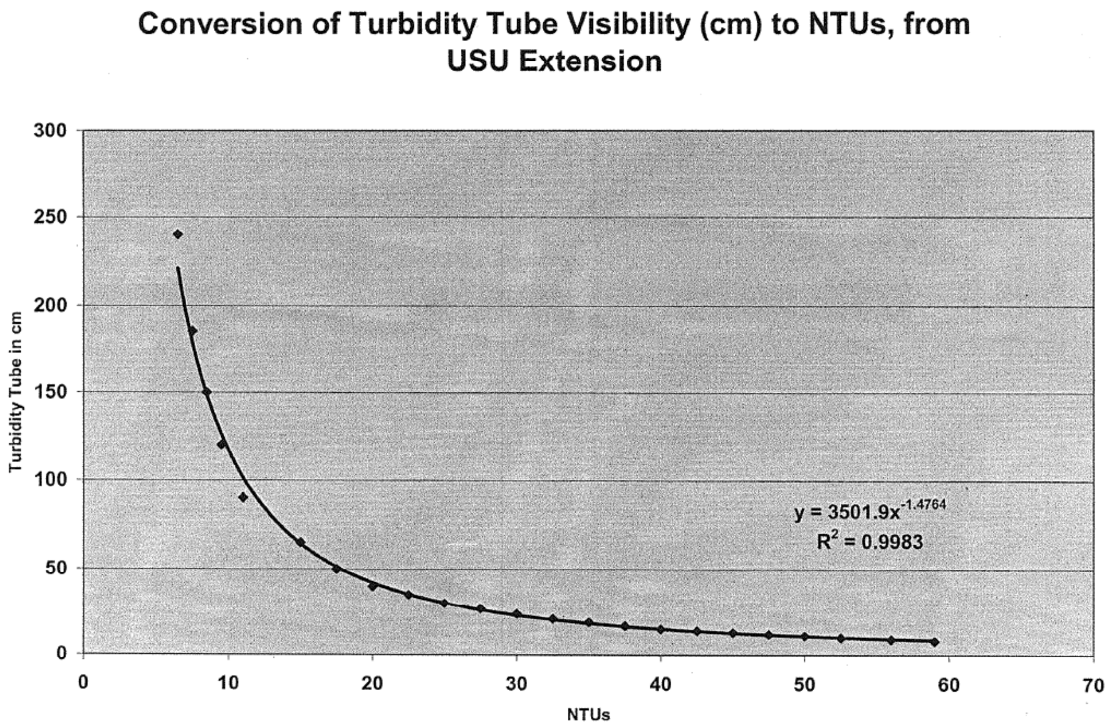


Figure 6. A turbidity tube conversion model from Utah State University's Stream Side Science Program.

IV. Conclusions

The Bangor area streams have some water quality impairments that are common to urban streams. The hydrology was flashy. Storms filled streets and gutters with fast flowing water that were quickly conveyed to streams. The streams also flood quickly, and the strong current carries pollutants and causes scour of the bottom. Due to lots of pavement and high runoff, the recharge of groundwater is inadequate. Urban streams tend to have too much water during storms and too little flow between storms. The intensities of the high flows can result in narrow and entrenched channels in erosional areas or over-sized and shallow channels in depositional areas. The pollutants and bottom instability are important stresses for the organisms that live there. The lack of shade and low groundwater input can lead to over-heated streams in the summer. High summer temperatures and sometimes organic pollutants (such as the glycol deicers found in Birch Stream) can cause low dissolved oxygen. In contrast, winter oxygen levels are often very good; but winter road maintenance can lead to high salt content and spring turbidity. If stream channels are destabilized by high flows, then turbidity can be a problem during any high flow event. High temperatures, low dissolved oxygen and high salt content can often exceed tolerances of some aquatic organisms, leading to a loss of stream biodiversity. Sometimes urban streams can be without fish, amphibians or other obvious wildlife. Our volunteer monitoring efforts found all of these water quality issues. Still, there is evidence that the Bangor area streams are slowly improving. Also, we have identified two regression equations that allow reasonable approximations for turbidity, TSS and chloride conversions. These are good enough to flag these issues for future study and for routine monitoring to track changes.

Many of the improvements in Bangor area streams have been habitat improvements and treatments for polluted runoff. For instance, Birch Stream collects runoff from the airport that is contaminated by de-icing products (propylene glycol). This chemical acts like a sugar, promoting microbial digestion and oxygen depletion. This glycol runoff has been largely addressed by designation of de-icing areas at the airport which collect and drain runoff to the city wastewater treatment facility. In addition, there are holding tanks at the airport so that release of the glycol is slow enough to not overwhelm the capacity of the treatment plant. Because some de-icing takes place on the runway, there is still some contamination of stormwater runoff. Some of this runoff is collected in ditches that are intercepted and treated by a windmill-driven aeration pump and artificial riffles. This combination on off-site and on-site treatment of the glycol has greatly improved the water quality. The bacterial films that fed on the glycol are no longer found in Birch Stream and odor complaints are now rare. While seasonal problems still exist, small fish (blacknose dace, creek chub, and ninespine stickleback) are locally abundant in Birch Stream.

In the Penjajawoc and Meadow Brook drainages, the City of Bangor has day-lighted some runoff. It used to be piped in the Bangor Mall area and now has been replaced by a grassy swale that helps to aerate and filter runoff that flows into Penjajawoc Stream. A box culvert that was part of the old Sylvan Road used to act as a small dam and backed water up under the Interstate I-95. This was removed in 2012. Natural stream channels have been restored in 2012 and 2013. Two new catch basin inserts at a local gas station on Hogan Road now filter petroleum and other contaminants out of runoff that flows into the Penjajawoc. Other stormwater improvements are part of a city-wide master plan (City of Bangor). Blacknose dace are abundant in Penjajawoc Stream and Meadow Brook in the lower half of the watershed. Atlantic salmon use the mouth of the stream at the confluence with the Penobscot River as a cold water refuge on their annual spring migration up Maine's most important salmon river.

For Capehart Brook, the City of Bangor has implemented a Phase I plan that installed stormwater subsurface bioretention cells, one in a residential subdivision and another at the Downeast School. Within the residential area two dozen rain barrels and/or rain gardens have been installed. A Phase II implementation plan is currently seeking funding for stormwater catch basin inserts, tree box subsurface filters, and for the reconstruction of a wet pond with an innovative Deepwater outlet (that takes cold water off the bottom of the pond) and splashes and aerates the outflow which is part of the headwaters of Capehart Brook.

Sucker Brook crosses town lines, and is the object of a Bangor – Hampden collaboration. The monitoring and assessment phase is complete and a planning phase is well under way. Arctic Brook is still in the monitoring and assessment phase, but my soon have a draft watershed plan.

Salt will be one of the hardest problems to address. Public safety has to be balanced with environmental protection. There are no BMPs that can remove salt from runoff. The best BMPs are those that are still effective for traffic safety while minimizing the use of salt, or by substituting some kinds of salts for others. For instance, calcium chloride is sodium-free, but still has chloride. Calcium chloride is effective at lower temperatures, but costs much more than sodium chloride. Some organic salts avoid the chloride issue (but they too cost more). Maine DOT and the City of Bangor already take advantage of salt mixtures for winter road treatments. Bangor and several other Maine municipalities are piloting the development of winter road and parking lot BMPs that they hope to recommend to the state (see Think Blue Maine website under City of Bangor in "References" section for news and updates). The best ideas include ways of using less salt, minimizing areas that are treated, and minimizing the contamination of groundwater by managing how snow storage piles are handled and where runoff is directed. Sand and trash are also issues, and will be addressed by traps and filters in the storm drains.

Overall, while urban streams continue to have problems, Bangor area streams are being improved one by one. The involvement of the City and local citizens, including some of the younger ones, is a positive sign for Bangor's future.

References Cited and Useful Resources

City of Bangor, see index for Watershed Management Plans for five streams and other documents at http://www.bangormaine.gov/index.php?id=2&sub_id=1501

City of Bangor, for winter salt maintenance and stormwater pollution prevention, see Think Blue Maine website at http://www.thinkbluemaine.org/docs/index.htm

Department of Environmental Protection (DEP) the Atlantic Salmon page can be found at **http://www.maine.gov/dep/water/monitoring/rivers_and_streams/salmon/index.htm**

DEP Biomonitoring Program data can be found in the data index at http://www.maine.gov/dep/gis/datamaps/index.html

DEP TMDL (Total Maximum Daily Load) Reports, both "Impervious Cover" and "Streams" have Bangor area reports, and can be found at **http://www.maine.gov/dep/water/monitoring/tmdl/tmdl2.html**

DEP VRMP (Volunteer River Monitoring Program) can be found at **http://www.maine.gov/dep/water/monitoring/rivers_and_streams/vrmp/index.html**

Newcombe, CP & JOT Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16(4): 693-727

Packman, JJ, KJ Comings & DB Booth. 1999. Using turbidity to determine total suspended solids in urbanizing streams in the Puget lowlands. University of Washington, College of Forest Resources available on-line at https://digital.lib.washington.edu/researchworks/bitstream/.../tssturb.pdf?.

Utah State University Cooperative Extension, the old regression figure has been replaced by a conversion table that is available at http://extension.usu.edu/utahwaterwatch/htm/tier-1/turbidity/turbidity-conversion-chart

Whiting, M. 2010. Penjajawoc Stream, second year of the baseline study, with a summary of the 2008 and 2009 field seasons. Maine DEP, report number DEPLW – 1170, available on the DEP website at
www.maine.gov/dep/water/...and_streams/.../penjajawoc-2010.pd