Penjajawoc Stream Watershed Analysis and Options for Refining Management Recommendations

PREPARED FOR: City of Bangor

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COPIES: Penjajawoc Watershed Stakeholders

DATE: June 26, 2009

Executive Summary

An independent evaluation was performed to assess and evaluate measures for managing the watershed for the Penjajawoc Stream Watershed (PSW) in Bangor, Maine. The stream has been identified as having multiple water quality problems as a result of urban stormwater, nonpoint source runoff, and habitat modification and has been determined to violate Maine's Class B water quality standards for dissolved oxygen (DO), biological criteria, and habitat. Thus, it was included on Maine DEP's impaired waters or 303(d) list (based on Section 303 of the Clean Water Act) in 2006. In response to this impaired status, Maine DEP developed a draft TMDL for the watershed based on the impervious cover (IC) analysis methodology and also required the City of Bangor to develop a Watershed Management Plan (WMP) (BSA Environmental Consulting, 2008). The WMP recommends over 75 tasks in four different pollution-reduction categories, including education and prevention, stream restoration, retrofitting existing stormwater structures, and government administration. The WMP also indicated that further studies will be needed to evaluate the effectiveness of the plan, and that there should be planned reviews and an adaptive management approach for the implementation.

The evaluation described in this Technical Memorandum (TM) represents the beginning of the adaptive management process for watershed protection efforts for PSW. Five major areas were addressed as summarized below.

Available Data Review

Historical data were reviewed and observations were made as it relates to watershed impairment characteristics and potential management opportunities. Some key observations included:

- Biomonitoring results since 1997 showed varying attainment of Class C or Class B depending on location in the watershed and year of monitoring. The most downstream station attained either Class C or Class B in all but one year. Analysis of precipitation data indicate that years with higher annual and summer precipitation, like 2006, showed more widespread attainment than years with low summer precipitation. Class B has not been attained anywhere since 2001 and an examination of data used to assess attainment

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indicates that sensitive organisms such as stoneflies, whose presence is necessary to attain Class B, are largely absent from the watershed, especially at the upstream stations.

- Instream habitat information is largely qualitative and is inadequate to fully characterize stream habitat characteristics in the watershed.
- Water quality data indicate there is some contribution of temperature, DO and nutrients to impaired conditions of the watershed. Specific conductivity information indicates that residual road salt and/or condensate discharges may also contribute to impaired conditions. Insufficient data is available to assess other toxic substances typically known to be present in urban stormwater.

Modeling and Geomorphic Study Review

Prior modeling and geomorphic studies were reviewed as tools for identifying and managing watershed improvement activities. Some key observations include:

- The three modeling studies previously undertaken used different models will different scales of resolution. Each of the modeling studies was limited by a lack of calibration data for watershed hydrology. None of the models could provide a characterization of baseflow and storm flow hydrology which seems to be important for assessing and developing strategies to attain biological criteria.
- The geomorphic study provided a comprehensive characterization of conditions and good indication of potential stream improvement and restoration projects for the watershed. Ability to design specific improvements is limited by lack of specific hydrological data and calibrated hydrological models.

Stressor Comparison

A stressor identification workshop was conducted by Maine DEP and the City of Bangor in 2004; however, these stressors were not prioritized. As part of this independent assessment, each of the stressors was reviewed and the following prioritization of stressors was suggested for focus of additional monitoring, modeling and management activities:

- Altered Hydrology
- Habitat
- Other Water Quality Concerns

Two stakeholder workshops were held to review information and discuss the stressor prioritization (See Attachments B and C). At the second workshop in February 2009, the stakeholders reached consensus that altered hydrology should be the highest priority because the lack of hydrologic data does not allow for a systematic analysis with habitat and water quality data. Habitat was selected as the second highest priority stressor with all other stressors (other water quality concerns) rated in equal priority following habitat. It was also agreed that more data are needed before specific remedies to address these stressors could be implemented. It was noted that while altered hydrology is the highest prioritized stressor, opportunities to easily or inexpensively address other stressors, specifically nutrients and toxics, should not be overlooked while collecting hydrologic data.

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Gap Analysis

The gap analysis identified a lack of a formal stakeholder process as an issue and this was discussed during the first workshop in October 2008 (Attachment B). While stakeholders have been involved in the stressor workshop and the development of the WMP, there has been no formal identification of stakeholders or chartering to define roles and responsibilities. It was suggested that the stakeholder process be chartered to clearly define the stakeholder process going forward. The City is currently completing its designation of stakeholders.

The gap analysis also determined that the lack of identified "indicators of impairment" limited the ability to design focused watershed management activities to improve conditions. The following steps are suggested for developing indicators of altered hydrology:

- Stakeholders should review the pertinent information and select potential hydrological indicators for watershed management. An approach to setting targets for these indicators should also be identified.
- Based on the indicators, the applicability of watershed models should be reviewed, including those previously applied, and a model should be selected for moving forward. [Note: model selection should also consider other stressors of concern, such as habitat indicators, pollutants, etc. so that a multi-purpose model can be selected]
- A hydrological data collection effort should be implemented in the watershed, including precipitation and flow gauging stations.
- A calibrated watershed model should be developed and analyses conducted to support quantification of indicators and development of targets.
- Results should be reviewed with stakeholders, and indicators and targets should be selected for watershed management. [Note: this process may identify other issues so the approach may need to be adaptive, with the establishment of interim targets, to be validated/modified by subsequent analyses.]

To develop indicators of impairment for habitat, a more quantitative approach to habitat assessment was suggested. Monitoring information could be used to identify thresholds for impairment and targets for improvement. While the geomorphic assessments previously completed are more quantitative and concepts have been identified for improving channel stability (Parish Geomorphic, 2006), moving forward with channel improvements should be in conjunction with development of a better understanding of watershed hydrology through gauging and the development of a hydrological model for the watershed.

Conclusions and Recommendations

Recommendations are included for watershed monitoring programs, development of additional modeling tools, a formalized stakeholder process, and a workplan.

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The monitoring program included specific recommendations for hydrological monitoring of the watershed, habitat assessment, and overlap of DEP and stream team evaluation stations. A process is included for evaluating and implementing a watershed modeling process. Several watershed models are discussed but a specific watershed model is not recommended since this needs to be accomplished in conjunction with stakeholders and the selected modeling consultant. A formalized stakeholder process, with a stakeholder charter is recommended. The efforts of the City in formalizing the watershed stakeholder group are described.

Finally, a workplan framework is provided as an initial step in indentifying tasks to be completed. This plan will require input from City staff, stakeholders and DEP and should be updated frequently.

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Attachments

Attachment A – Penjajawoc Stream Watershed Biomonitoring Data
Attachment B – Minutes and Presentation Information from Workshop No. 1 – October 9, 2008
Attachment C - Minutes and Presentation Information for Workshop No. 2 – February 27, 2009

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Purpose of the Review

The purpose of this technical memorandum (TM) is to provide an independent evaluation of efforts to monitor and assess the Penjajawoc Stream Watershed (PSW) and identify further steps necessary to refine the watershed management program for the watershed. To accomplish this review, the following steps were taken:

- Available monitoring and assessment data from the Maine Department of Environmental Protection (DEP) and other sources were compiled and reviewed.
- Prior data collection, analysis, and assessment information was compiled and reviewed.
- Watershed modeling information was compiled and reviewed.
- Additional data analyses were performed to understand potential impacts and develop recommendations for future work, specifically in the areas of watershed modeling and monitoring.

This TM is organized to present the analysis of available information and show how this analysis characterizes impacts within the PSW. This is followed by an evaluation and prioritization of previously identified watershed stressors and an identification of potential gaps in the watershed evaluation that need to be filled through monitoring and analysis activities. These activities will allow the establishment of key indicators of watershed improvement that can be used to establish specific goals for the Watershed Management Plan (WMP). Finally, this TM includes recommendations that will be refined through a workshop with watershed stakeholders.

Watershed Background

The PSW is a third order stream located in Bangor, Maine that is 5.2 miles long and drains an area of approximately 5,600 acres. The upper and middle portions of the watershed drain a large 300-acre emergent freshwater marsh known as Penjajawoc Marsh, the Bangor Mall, and intensely developed commercial areas on Stillwater Avenue and Hogan Road among other areas (Figure 1). The lower portion is primarily older, low-density residential development and a cemetery. The stream originates at an elevation of 200 ft above sea level and flows southeasterly to an elevation of 1.81 ft where it joins the Penobscot River, which flows into the Gulf of Maine (Penjajawoc Watershed Management Plan, 2008).

The stream has been identified as having multiple water quality problems as a result of urban stormwater, nonpoint source runoff, and habitat modification and has been determined to violate Maine's Class B water quality standards for dissolved oxygen (DO), biological criteria, and habitat, which have been set for this stream.

Previous Impairment Assessment

In 1986, each Maine stream was assigned to one of four categories by the Maine legislature. Penjajawoc Stream and its tributary, Meadow Brook, were designated as Class B streams. Class B streams are required to meet the criteria presented in Table 1 for DO, bacteria, habitat, and aquatic life (biological).

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TABLE 1
Maine Water Quality Criteria for Surface Waters

	Dissolved Oxygen Numeric Criteria	Bacteria (*E. coli*) Numeric Criteria	Habitat Narrative Criteria	Aquatic Life (Biological) Narrative Criteria
Class AA	as naturally occurs	as naturally occurs	free flowing and natural	No direct discharge of pollutants; ***as naturally occurs***
Class A	7 ppm; 75% saturation	as naturally occurs	natural	***as naturally occurs***
Class B	7 ppm; 75% saturation	64/100 ml (g.m.*) or 236/100 ml (inst.*) of human and domestic animal origin	unimpaired	Discharges ***shall not cause adverse impact*** to aquatic life in that the receiving waters shall be of sufficient quality to ***support all aquatic species indigenous to the receiving water without detrimental changes to the resident biological community***.
Class C	5 ppm; 60% saturation	126/100 ml (g.m.*) or 236/100 ml (inst.*) of human and domestic animal origin	habitat for fish and other aquatic life	Discharges ***may cause some changes*** to aquatic life, provided that the receiving waters shall be of sufficient quality to ***support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community***.

* g.m., geometric mean; inst., instantaneous level

Maine DEP's Biological Monitoring (Biomonitoring) Program conducted biomonitoring and water chemistry monitoring in the stream in 1997, 2001, 2002, 2003, and 2006. Water chemistry monitoring was conducted at four stations and biomonitoring was conducted at five. Based upon this monitoring, the stream was identified as having multiple water quality problems as a result of urban stormwater, nonpoint source runoff, and habitat modification and has been determined to violate Maine's Class B water quality standards for DO, biological criteria, and habitat. Thus, it was included on Maine DEP's impaired waters or 303(d) list (based on Section 303 of the Clean Water Act).

As a consequence of being listed as "impaired" on the "2006 Integrated Water Quality Monitoring and Assessment Report" (2006 303(d) List), EPA requires that a Total Maximum Daily Load (TMDL) be developed. Maine DEP has also developed a draft TMDL based on the impervious cover (IC) analysis methodology. The TMDL based on the impervious cover model indicated that the effects attributed to imperviousness in the watershed need to be addressed (FB Environmental Associates, 2007).

Watershed Planning Summary

In addition to the TMDL, Maine DEP has required the development of a WMP which can be implemented to address these impairment concerns. The City of Bangor, with the assistance of DEP, initiated the development of this WMP in July 2007. The planning process involved reviewing existing water quality data, integrating existing engineering and hydrology data, and soliciting and incorporating input from citizens, conservation organizations, state agencies, landowners, and business owners.

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Prior to the development of the WMP, Maine DEP completed a Stressor Identification Analysis with existing data in June 2004. The results of this analysis are presented in Table 2.

TABLE 2
Results of Maine DEP 2004 Stressor Identification Analysis for Penjajawoc Stream (Maine DEP, 2004)

Stressors	Watershed		
	Upper	**Middle**	**Lower**
Temperature	Yes - minor	Yes - possible	Yes
Nutrients	Yes - minor	Yes - possible	Yes - related to stormflow (less of a problem here)
Dissolved Oxygen	Yes - wetland main source	Yes	No (meets standards)
Conductivity	Yes	Yes - sand/silt sources	Yes - salt sources
Toxics	Yes	Yes	Yes
Sediment	No	Yes	Yes - high suspended sediment during storms (probably from Meadow Brook)
Altered Hydrology	Yes	Yes - groundwater main mitigate low baseflow syndrome	Yes - from upper reaches
Habitat	Yes	Yes	Yes - more data needed

The WMP suggested that this analysis indicates that water quality impairment in an urban stream such as the Penjajawoc is complex and that impairment is caused by multiple stressors. The summary that coincided with this analysis stated that the aquatic life impairment is likely due to urban nonpoint source pollution and habitat impairment.

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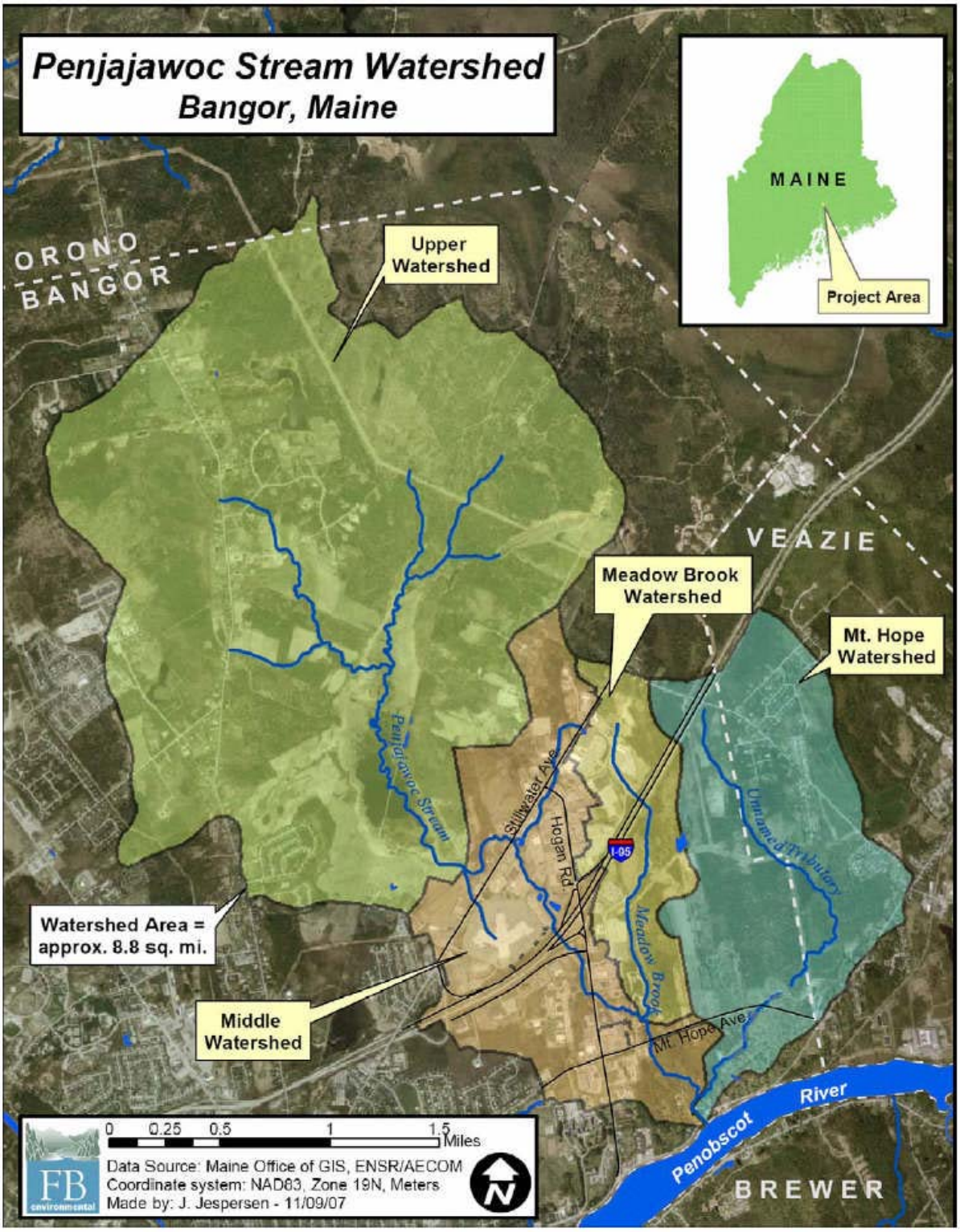

FIGURE 1
Penjajawoc Stream Watershed (from Draft Penjajawoc Stream & Meadow Brook TMDL Report, DEP 2007)

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The WMP recommends over 75 tasks in four different pollution-reduction categories, including education and prevention, stream restoration, retrofitting existing stormwater structures, and government administration. According to the WMP, it is anticipated that the plan will require up to 2 years to initiate and approximately 15-20 years to implement and that successful implementation is dependent upon several variables. Implementation is also dependent upon achieving Class B standards. If Class B standards are met before implementation is complete, the City may choose to discontinue implementation since the goal of the plan (to meet Class B standards) will have been met. In addition to the proposed implementation timeline, the WMP identifies needed partners for implementation success and potential methods for project funding; including the potential need to develop a Stormwater Utility District. The WMP indicated that further studies will be needed to evaluate the effectiveness of the plan, and that there should be planned reviews and an adaptive management approach for the implementation.

Available Data Review

Overview of Monitoring Programs

Most of the data used to assess the health of the Penjajawoc Stream and watershed were collected by Maine DEP as part of their Biomonitoring Program. Data collected as part of this program include:

- Benthic macroinvertebrate (insects and other organisms that typically live along the stream bottom and bank) sampling at stream stations using established protocols
- Wetland monitoring, including vegetation assessment at specific sites using established protocols
- Periphyton (primarily algae that grow attached to rocks and other bottom material) sampling at stream and wetland sites using established protocols
- Physical observations of habitat conditions during collection activities at biological monitoring sites
- Water quality data – field measurements and chemical analysis of samples collected

In addition, Maine DEP conducted ambient monitoring and special studies related to specific water quality issues. Since Penjajawoc Stream has been assessed as impaired primarily based on biomonitoring, water quality studies consisting of at least week-long sampling of DO, temperature, and specific conductivity at selected locations have been conducted, as well as a range of chemical analyses.

Monitoring stations for the Penjajawoc watershed are shown in Figure 2 with biomonitoring sites and water quality sites listed in Table 3. Data are available for some of these sites (not all sites were sampled during each year) for 1997, 2001, 2002, 2003 and 2006 and this is a primary source of data being assessed as part of the TM.

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TABLE 3
Summary of Monitoring Sites for Penjajawoc Stream Watershed

Site	Location	Monitoring Activity
511	Penjajawoc	biomonitoring, water quality, chlorophyll *a*
512	Penjajawoc	biomonitoring and water quality
314	Penjajawoc	biomonitoring and water quality
513	Penjajawoc	biomonitoring and water quality
315	Penjajawoc	biomonitoring and water quality
PEN1	Penjajawoc	water quality
PEN2	Penjajawoc	water quality
PEN3	Penjajawoc	water quality
PEN4	Penjajawoc	water quality
PEN5	Penjajawoc	water quality
PJ1	Penjajawoc	water quality
PJ2	Penjajawoc	water quality
PJ3	Penjajawoc	water quality
PJ4	Penjajawoc	water quality
615	Mt Hope Br	water quality, chlorophyll *a*
Mdw Br	Meadow Brook	water quality
W106	Wetland	water quality, vegetation, chlorophyll *a*

Additional monitoring is ongoing. A Volunteer Stream Team, trained and directed by Maine DEP, was created in 2007 to collect additional baseline data in the watershed before any improvement or restoration activities are conducted. These data include screening-level macroinvertebrate community sampling, flow and erosion studies, and habitat assessment using the DEP Rapid Assessment Stream Walk Technique. Maine DEP is also collecting biomonitoring and water quality data in 2008. Since the 2008 data collection and analysis is ongoing, this data has not been included in this TM.

Biomonitoring Results

Biomonitoring information for the stream stations has been collected from five sites, at least some of which have been sampled during five summer periods between 1997 and 2006. This sampling consists of deployment of artificial substrate samplers in the stream and collection of these samplers after 30 to 45 days. Past data have typically been collected during a mid-July to mid-August deployment period. Aquatic organisms present in the stream colonize these samplers. The samples are preserved and organisms are then identified to an appropriate taxonomic level (often species) and number of each present. The data are then analyzed to create a wide range of metrics. Maine DEP uses a number of statistical models to determine whether a site is attaining Class C, Class B, or Class A criteria or is in non-attainment. The statistical models used to determine attainment are based on sampling of a wide range of streams through 1998, with 373 samples used to derive the models. These samples were from minimally disturbed sites that ranged from small streams with depths less than 1 foot to large rivers with depths of over 20 feet. These re-calibrated models were put in use in 1999; 1997 data for this stream were analyzed using the pre-1999 model.

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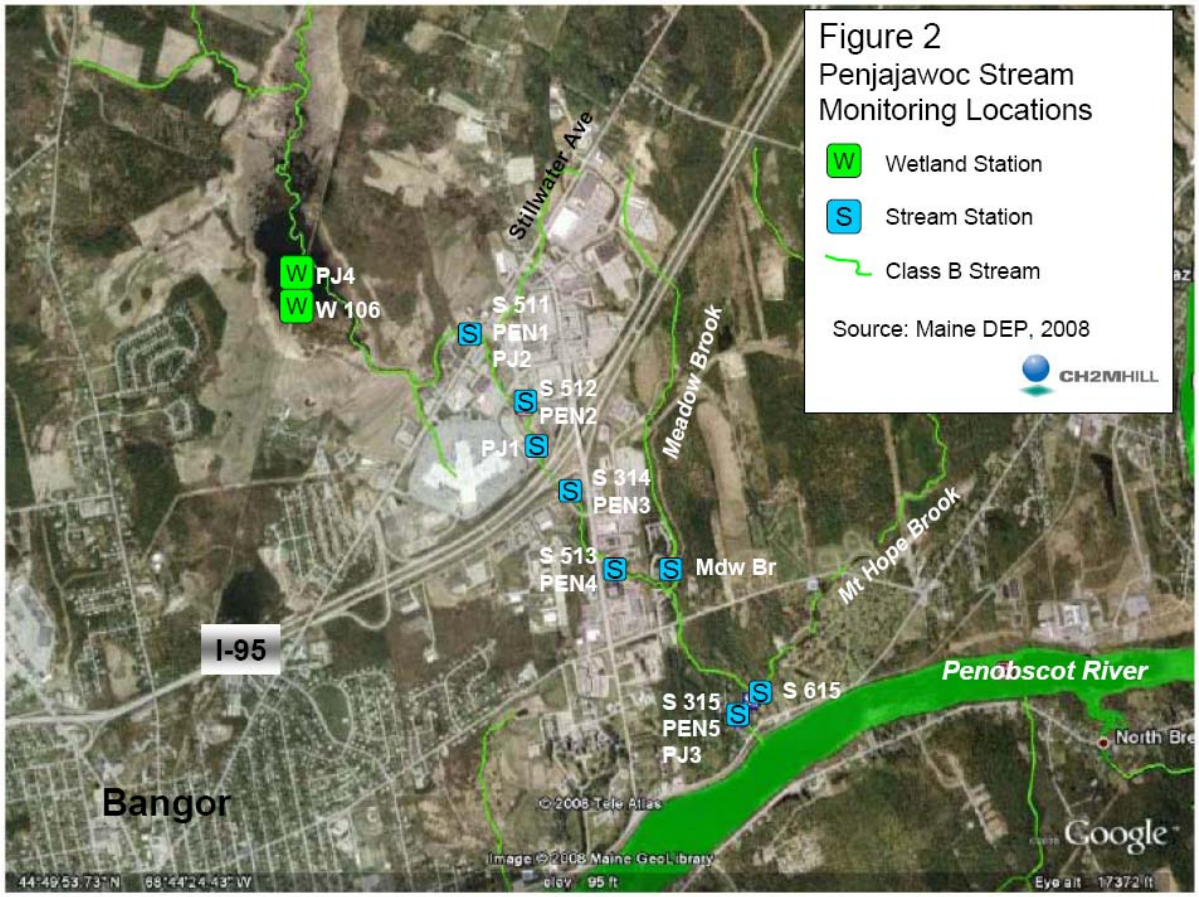

Results of biomonitoring for benthic macroinvertebrates are shown in Table 4. Station numbers correspond to those identified previously in Figure 2.

TABLE 4
Summary of Biomonitoring Results for Penjajawoc Stream

Station	Year				
	1997	2001	2002	2003	2006
511	-	NA	NA	NA	Class C
512	-	NA	NA	-	-
314	NA	NA	NA	NA	Class C
513	-	NA	NA	NA	-
315	Class B	Class B	Class C	NA	Class C
Notes:	NA = Non-Attainment Stations read from upstream to downstream				

With the exception of 2006, all of the sites in the upper and middle portions of the Penjajawoc were in non-attainment. Station 315 near the mouth of the stream was attaining Class C or B every year except 2003 when it was in non-attainment, which means the results indicated that none of the stream classifications were attained. All three sites sampled in 2006 showed attainment with Class C criteria.

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In an attempt to understand these results, precipitation information was summarized from available sources as a surrogate for a more thorough understanding of stream hydrology. The Bangor Airport gauge was selected based on its close proximity and reasonably continuous record. However, the Bangor Airport station was offline January, 1997 - March 1999, so for those months, data from the station at Orono were used. Figure 3 shows the monthly precipitation data during the sampling period, and Figure 4 shows the annual results.

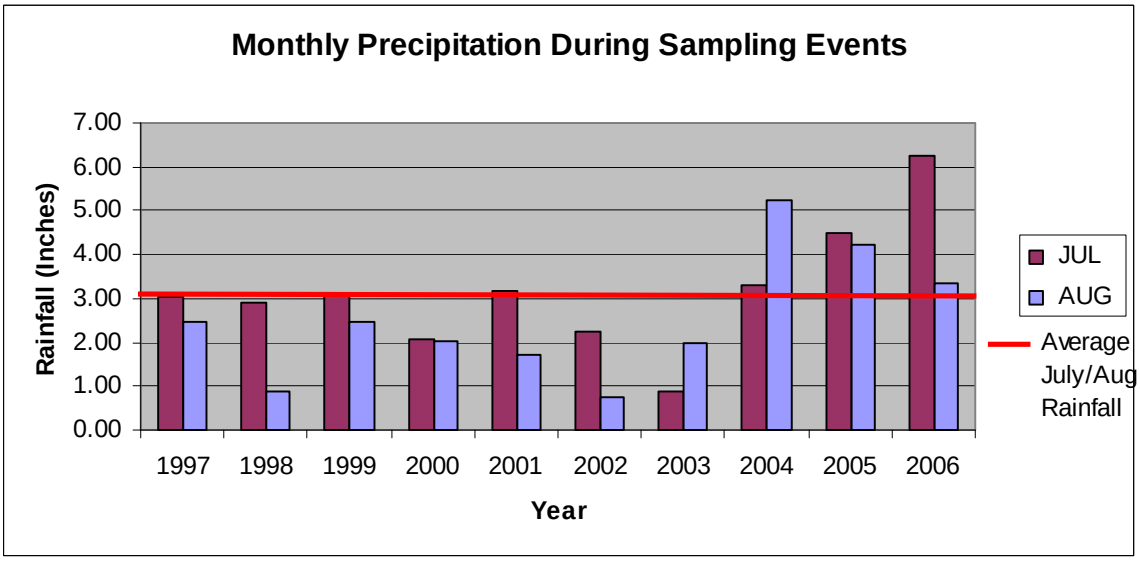

FIGURE 3
Monthly precipitation data during the months of biomonitoring from the Bangor and Orono gauges (Northeast Regional Climate Center, 2008)

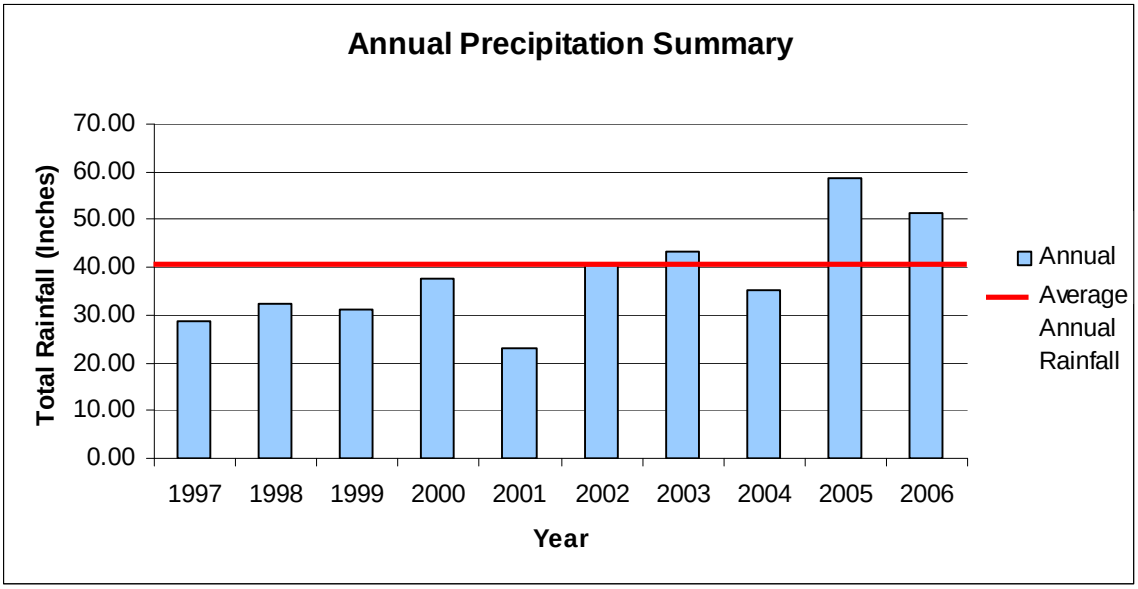

FIGURE 4
Annual precipitation from the Bangor and Orono gauges from 1997 to 2006(Northeast Regional Climate Center, 2008)

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The precipitation data may provide some useful insights for interpreting the biomonitoring results. Annual precipitation during 1997 and 2001 was well below normal, though summer precipitation was near normal during July. During these two years, upstream sites may have been in non-attainment because of low stream flow. [Note: impacts of the wetland during different hydrological conditions are discussed later in this TM]. Considering the lack of stream flow data, there is uncertainty about flow at Station 315 (near the mouth). However, it probably had sufficient flow because it received baseflow from the entire watershed and may not have been as impacted by runoff and instream source sediments and other pollutants during this year due to the lack of storm flows. This site attained Class B during these 2 years. In 2002, this site attained Class C. Annual precipitation was close to normal, but summer precipitation was extremely low. All three sites sampled in 2006 attained Class C. This was an above average year in annual and July/August precipitation. High sustained flows throughout the system may account for these results.

In order to gain insights into the biomonitoring results, the specific taxonomic results and the various metrics were examined. The results and all the graphs of year–to-year change in the metrics are included in Attachment A. Several observations were made regarding some metrics and results:

- Total mean abundance of organisms collected from the samples varies significantly between the sites and years, with 2006 having the highest abundance values for each of the sites sampled (Figure 5).

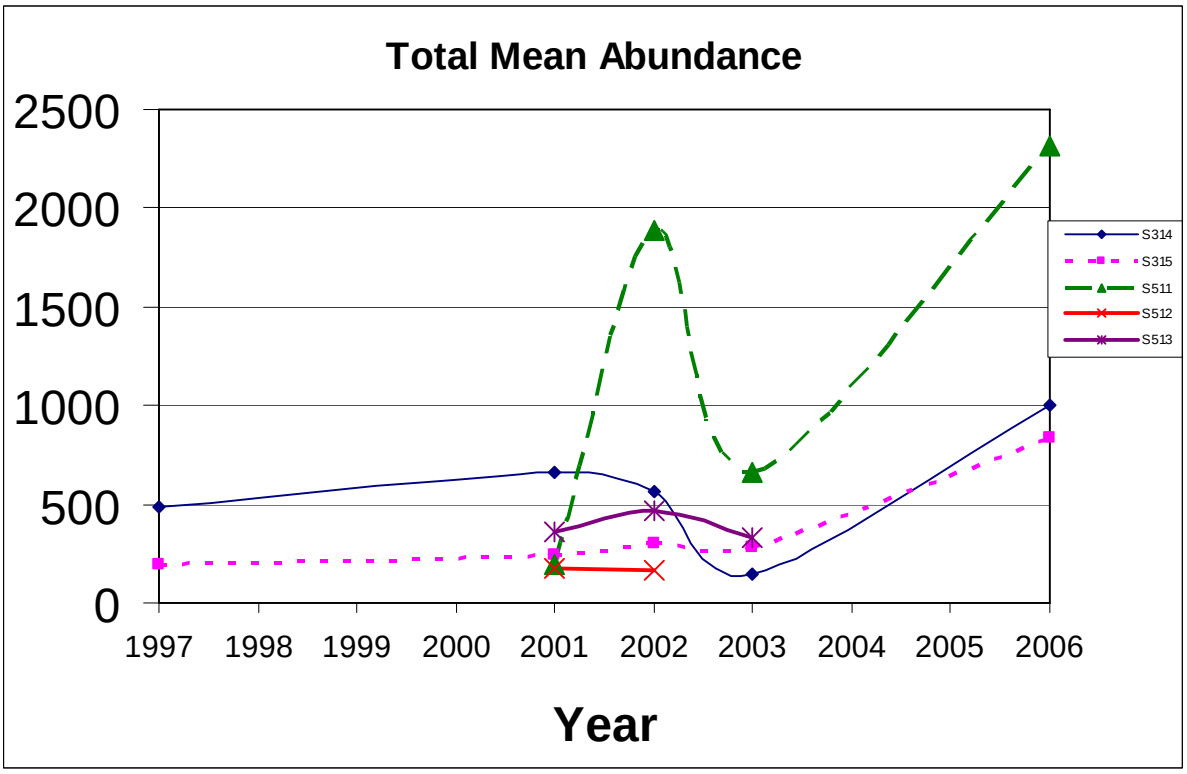

FIGURE 5
Biomonitoring Results for Penjajawoc Stream – Total Mean Abundance

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- Class A indicator groups were relatively uncommon and were identified at only two sites: Site 511 above Stillwater Avenue and Site 315 near the stream's mouth (Figure 6). No Class A groups were present at any of the sites in 2006, when all sites attained Class C.

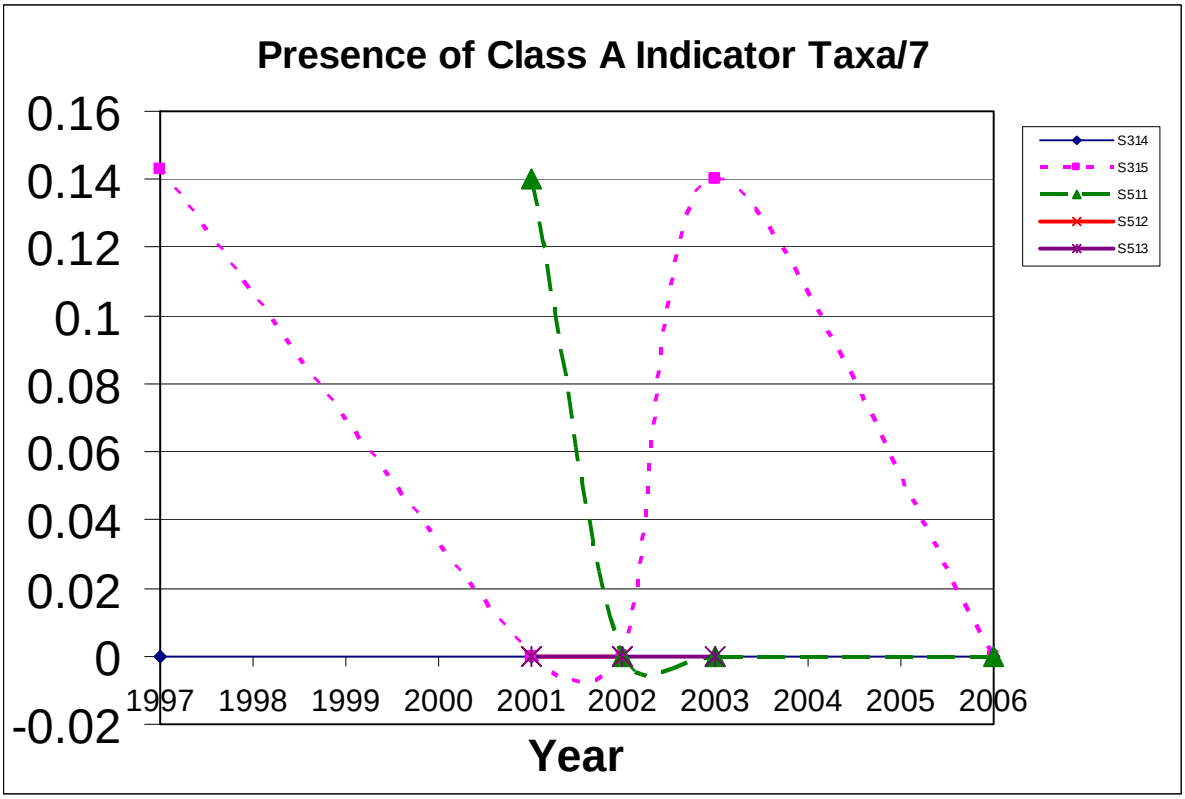

FIGURE 6
Biomonitoring Results for Penjajawoc Stream – Class A Group

- Mayflies (Ephemeroptera), an important indicator group, generally show zero or low abundance, except they become abundant at all three sites sampled in 2006 (Figure 7).
- Caddisflies (Hydropsyche), another important indicator group that is part of a broad group called Trichoptera, also show relatively low numbers and then an increase in 2006 (Figure 8).
- Stoneflies (Plecoptera), also an important indicator group, show some presence in early years but then are absent from 2002 to 2006 (Figure 9).

These metrics and others included in Attachment A show considerable variability between sites. Site 315 near the mouth tends to have the most consistent results, which is reasonable since this site does have the largest watershed area. However, its results appear to be relatively variable, presumably because of hydrological and pollutant variability in the watershed.

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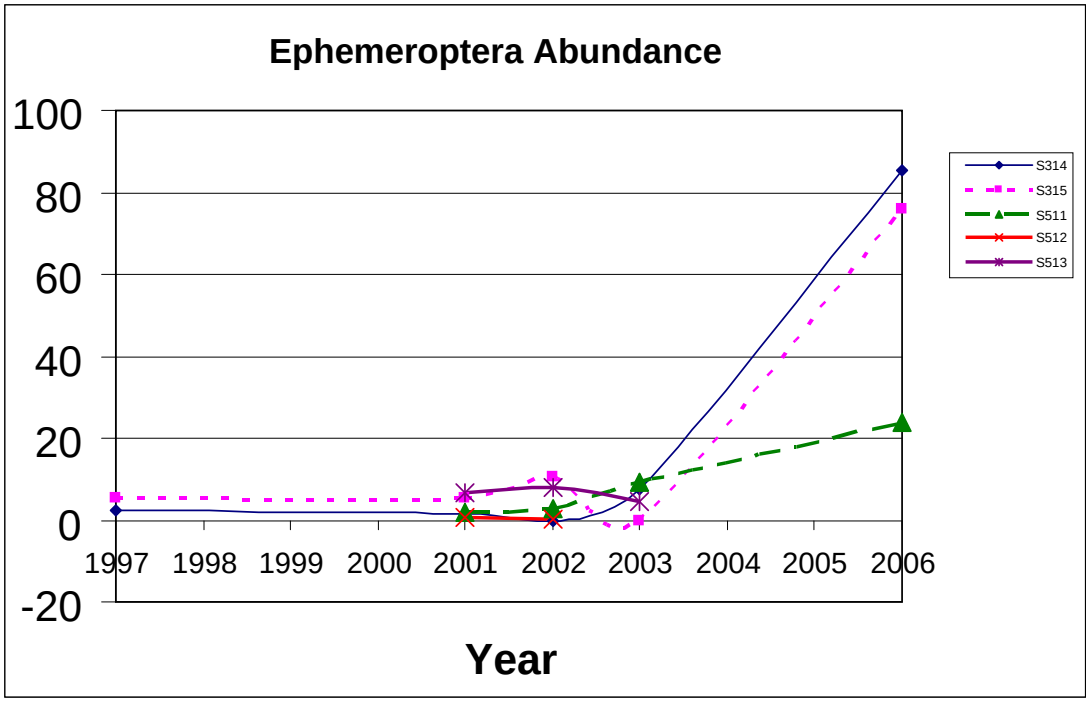

FIGURE 7
Biomonitoring results for Penjajawoc Stream – Mayfly abundance

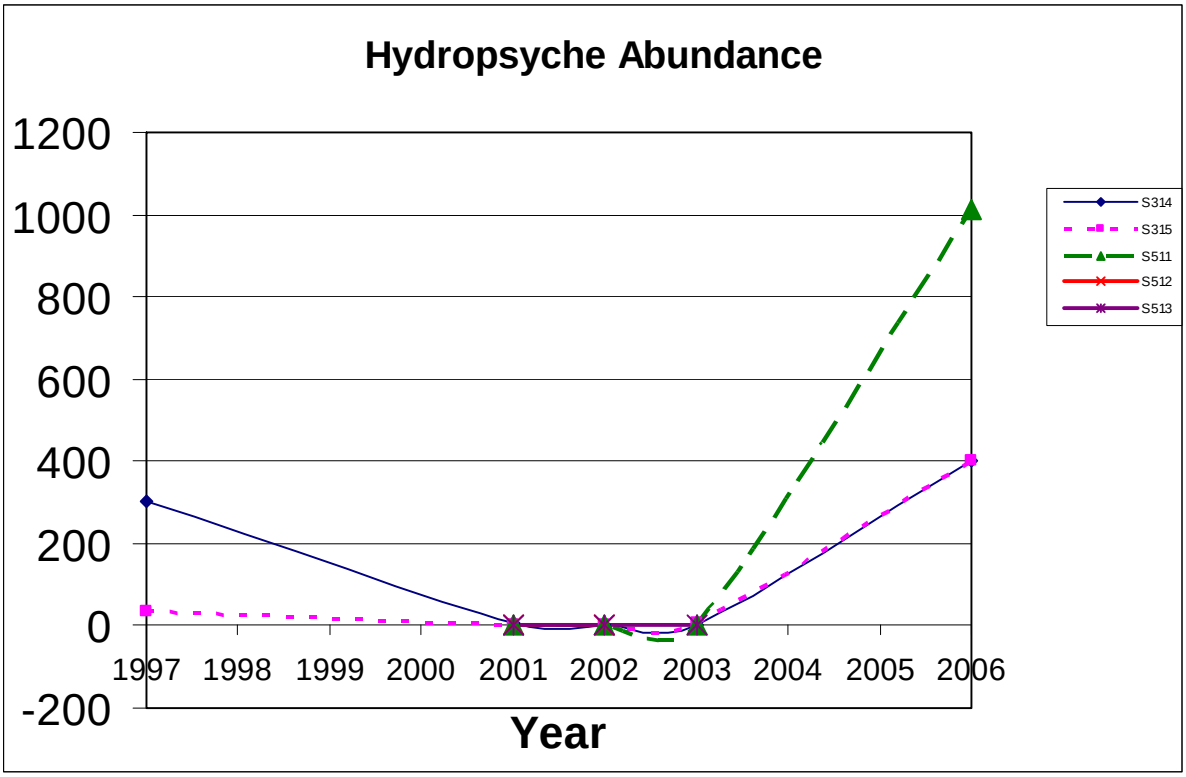

FIGURE 8
Biomonitoring results for Penjajawoc Stream – Caddis fly abundance

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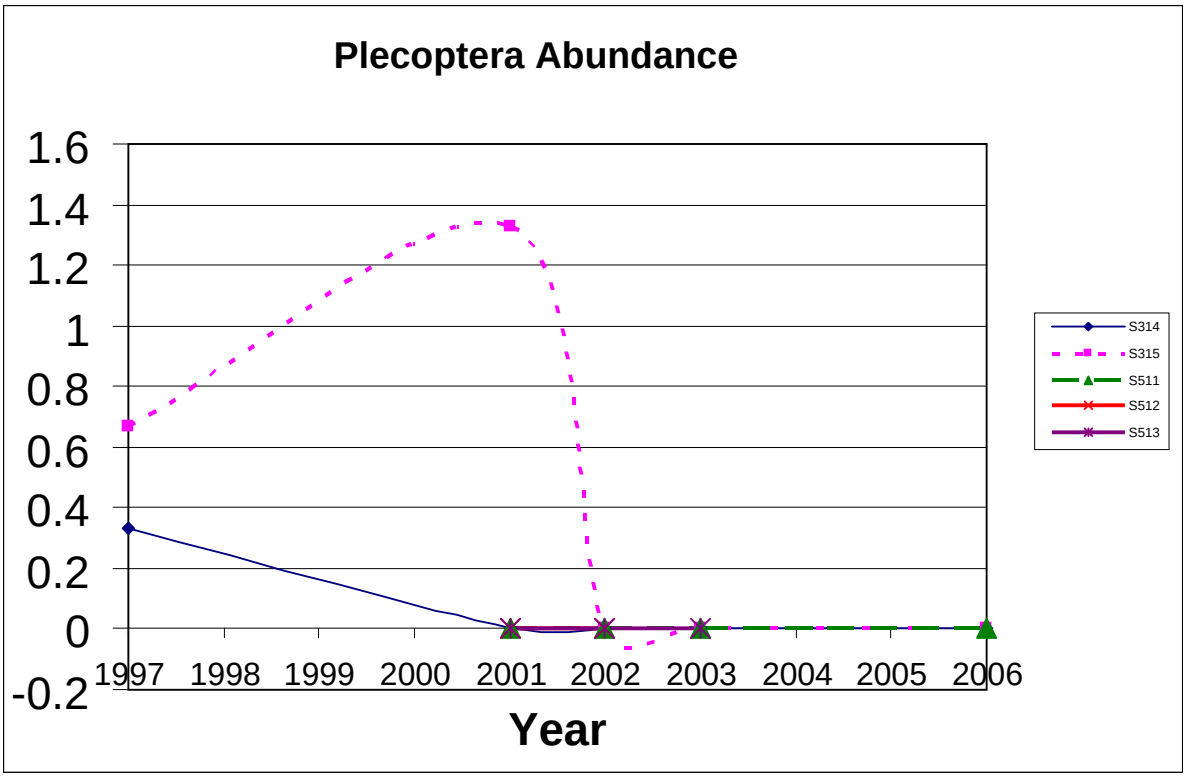

FIGURE 9
Biomonitoring results for Penjajawoc Stream –Stone fly abundance

The biomonitoring results demonstrate the impaired status of the watershed but do show that under some conditions during the last 10 years, the Penjajawoc Stream attains Class B or C criteria. However, Class B has not been attained since 2001. As indicated previously, the models used to make this determination are from a wide range of relatively undisturbed sites with a wide range in watershed size. Data from similarly sized watersheds with minimal disturbance during the same time period would be useful in interpreting the variability in the observed results.

Habitat Related Data

Qualitative assessments of habitat are recorded when macroinvertebrate samples are colleted. Parameters include land use, stream substrate composition, and canopy cover. Rubble and gravel substrates dominate the system, providing suitable habitat conditions for many macroinvertebrate species and spawning areas for fish. However, sand does become more prevalent in the middle reach, indicating that stressors such as bank erosion are affecting sediment composition and transport.

The main habitat observation is the uniform lack of canopy cover providing shade to the stream channel. Table 5 presents a summary of this qualitative variable. The benefits of a more dense canopy cover include shading to reduce the effects of photosynthesis in the stream, regulation of stream temperatures, and increased channel stability provided by the root systems of the trees.

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Open canopy is also indicative of the surrounding land uses. As shown in Figure 10, impervious area, which is a measure of urban developed land, increases (as a percentage) as one moves downstream. Figure 10 illustrates this point by showing the station locations (in upstream to downstream order from left to right) with percent imperviousness of the entire watershed from that station upstream and the size of the drainage area. [Note: These data were not compared with information available in the modeling reports.] Data on impervious cover were only estimated for 2004. Impervious cover impacts the hydrology of the watershed and, in turn, the hydraulics of the stream channel; as impervious cover increases, stormwater runoff increases and may impact the health and stability of the stream.

TABLE 5
Observed Stream Canopy during Biomonitoring

Station	Year				
	1997	2001	2002	2003	2006
511	-	Dense	Partly Open	Partly Open	Open
512	-	Dense	Partly Open		
314	Open	Open	Open	Open	Open
513	-	Open	Open	Open	-
315	Open	Open	Partly Open	Partly Open	Partly Open
Notes:	Stations read from upstream to downstream Open = up to 25 % shaded Partly Open = 25 to 75% shaded Dense = 75% to 100% shaded				

These qualitative channel descriptions are useful to paint a picture of the channel; however, limited insight can be gained because of the broadly defined variables used in the standard operating procedure (Maine DEP, 2008d). A more thorough methodology to assess riparian zones has been developed by EPA and has been adapted for use in many states. This procedure does not take long to complete in the field and can provide a more standardized and detailed picture of factors that influence the stability of a channel and the health of its biotic communities (EPA, 1999; CH2M HILL, 2001).

Water Quality Data

Dissolved Oxygen

The Class B standard for DO is 7 mg/L. Ambient water quality monitoring and monitoring conducted during benthic macroinvertebrate sampling indicate that the standard is not met at all times throughout the system. Further investigation, including additional studies to gather more data on DO fluctuations, was conducted in 2002 (see Figure 11).

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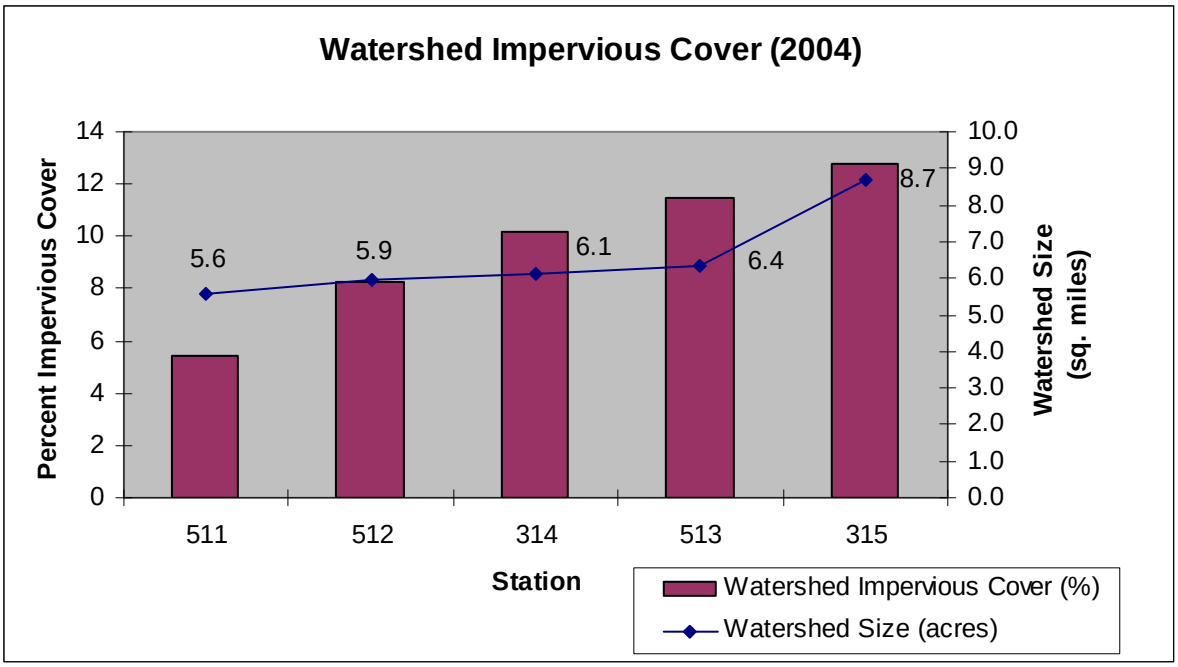

FIGURE 10
Watershed Impervious Cover and Size [based on DEP biomonitoring report information]

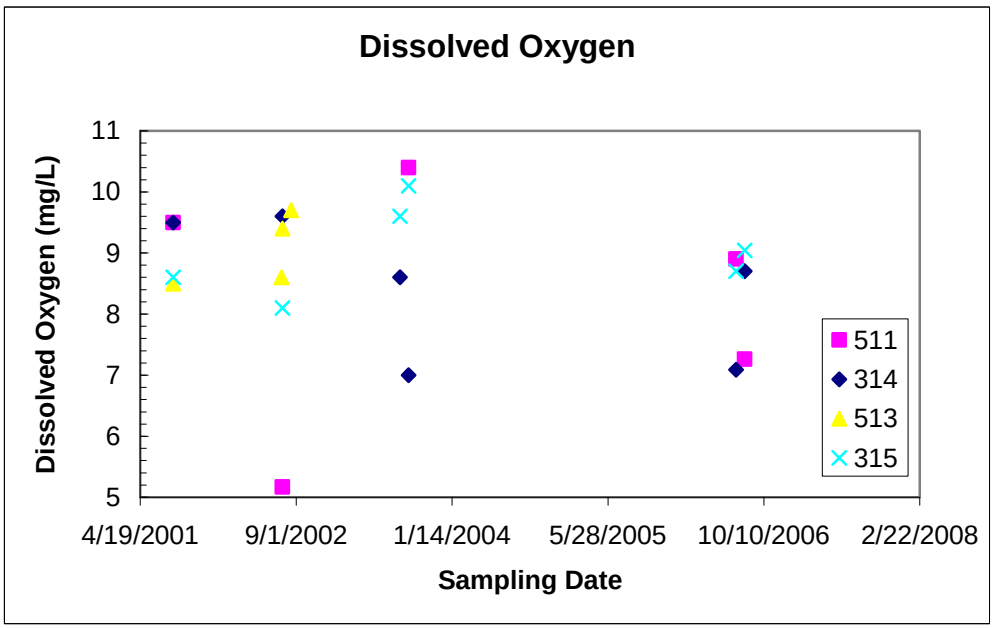

FIGURE 11
Dissolved Oxygen at biological monitoring stations

Factors that typically influence DO include temperature, stream physical characteristics and reaeration, water depth, salinity, and biological activity such as algal growth or wastewater discharges. Figure 12 presents the relationships between temperature and DO at various stations throughout the watershed, presented in order from upstream to downstream. A direct correlation between temperature and DO is not apparent, indicating that other factors are influencing DO.

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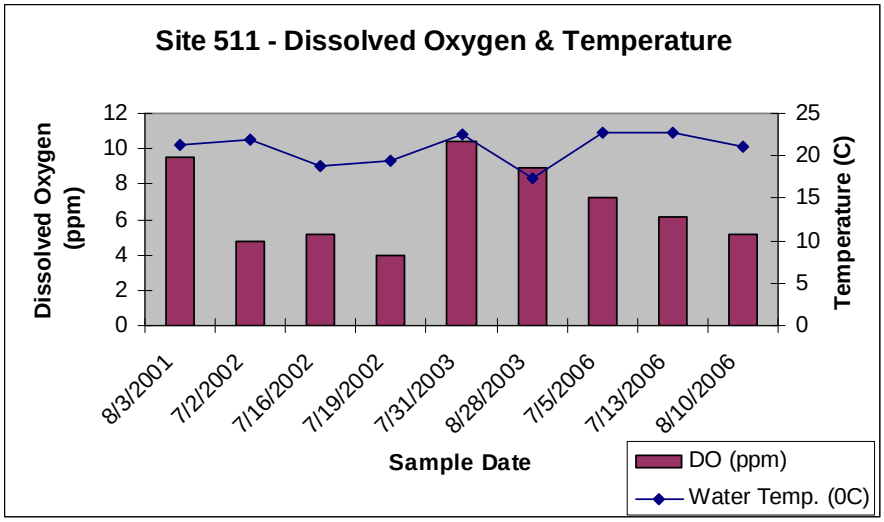

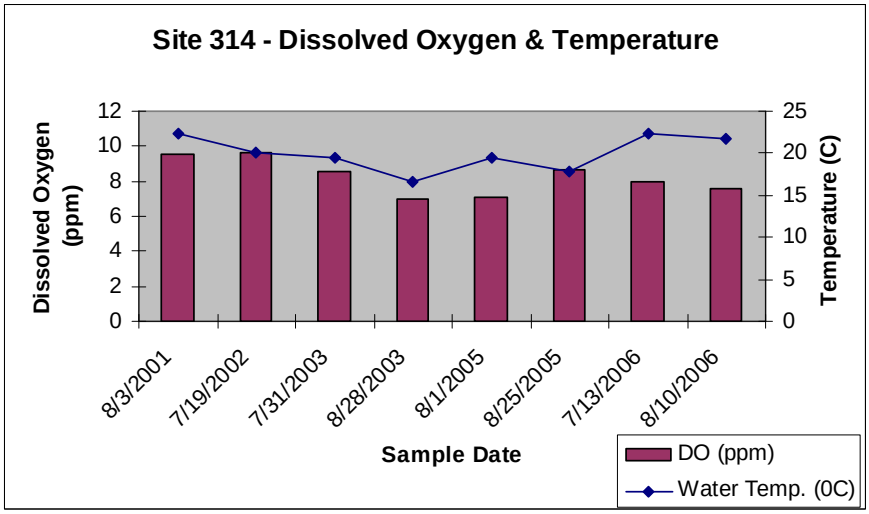

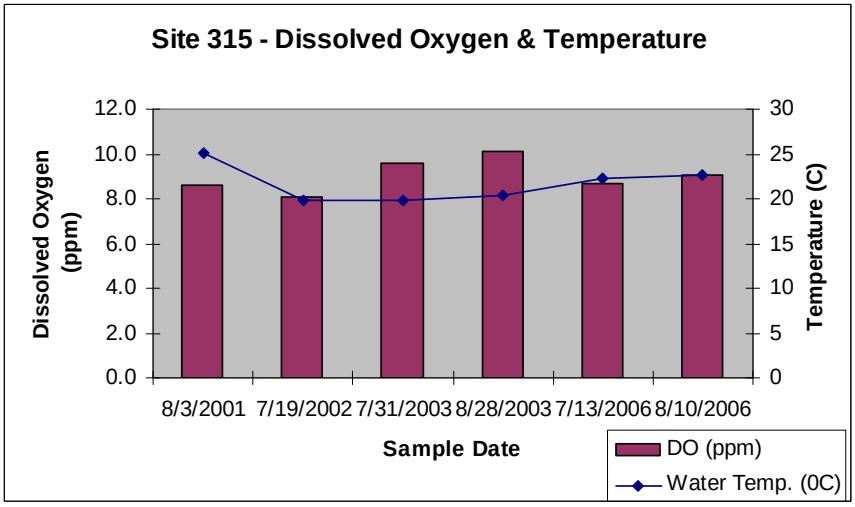

FIGURE 12
Dissolved oxygen and temperature at selected biological monitoring stations

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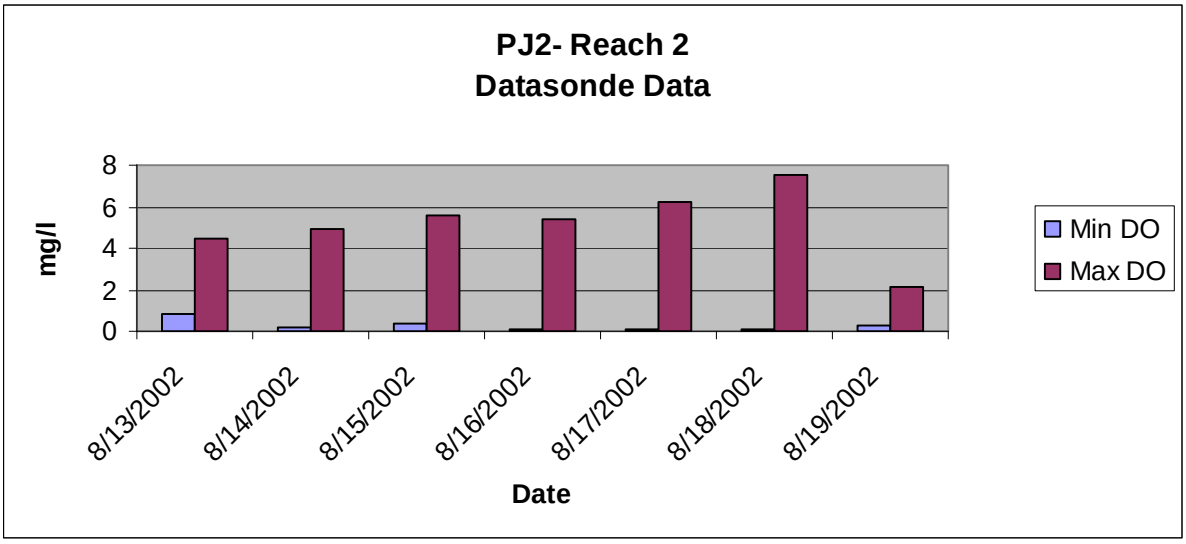
A 2002 study using continuous datasonde collection shows the temporal shifts in DO over a 24-hour period (Figure 13). This indicates influence from algal growth activity in the channel. Photosynthetic activity by algae uses sunlight for energy and creates biomass (using carbon dioxide), producing oxygen as a byproduct. At night, the algae respire, like other organisms, using oxygen and producing carbon dioxide. High DO values late in the day and low DO values at dawn are characteristic of this type of situation and apparent in the results. Subsequent periphyton (attached algae) monitoring and channel observations have recorded algal growth problems in the channel. This algal growth is attributable to many factors, mainly open canopy cover and available nutrients.



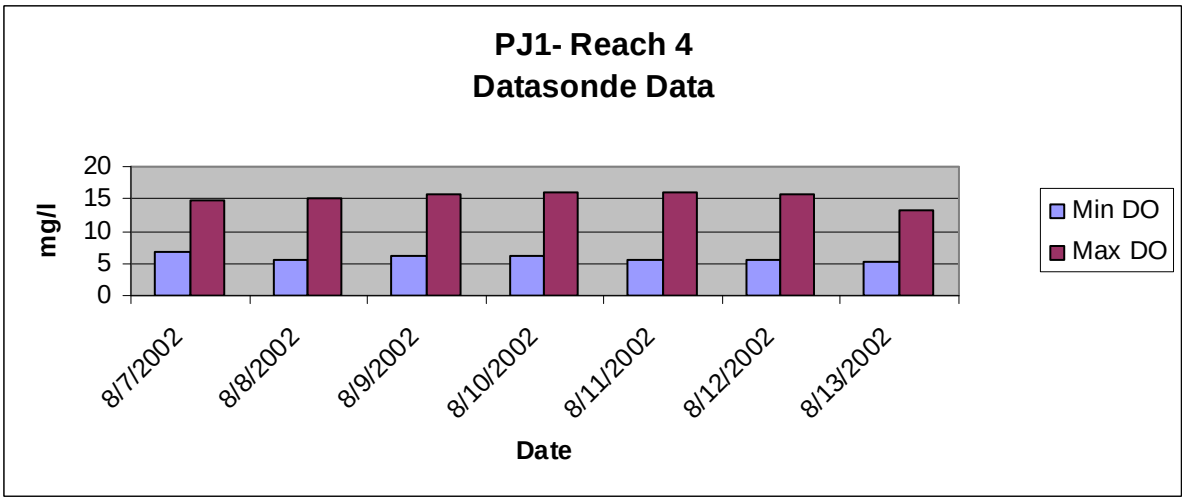


FIGURE 13
Dissolved oxygen fluctuations at selected monitoring stations

Nutrients

Water quality monitoring consistently indicates an elevated level of nutrients. Total phosphorus (TP) is highlighted here as representative of the nutrient enrichment in the watershed, as shown in Figure 14. Draft criteria for TP have been developed, with Class B set at 33 parts per billion (ppb) and Class C at 40 ppb (Maine DEP, undated). When

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compared to these draft criteria, a TP standard would often be exceeded in this watershed, especially at Station 511, which is immediately downstream of the Penjajawoc Marsh.

The large wetland upstream of Station 511 is a likely contributor to the elevated TP values at this location; other land uses in this portion of the watershed may also be contributing. Downstream values are not as elevated and TP does not appear to be exceeding draft criteria at the most downstream location, Station 315. BMPs and other measures in the middle portion of the watershed may be helping to reduce TP in runoff.

Nutrients in the system may be contributing to algal growth and should be considered a stressor on the aquatic environment and the stream's ability to maintain a healthy aquatic community.

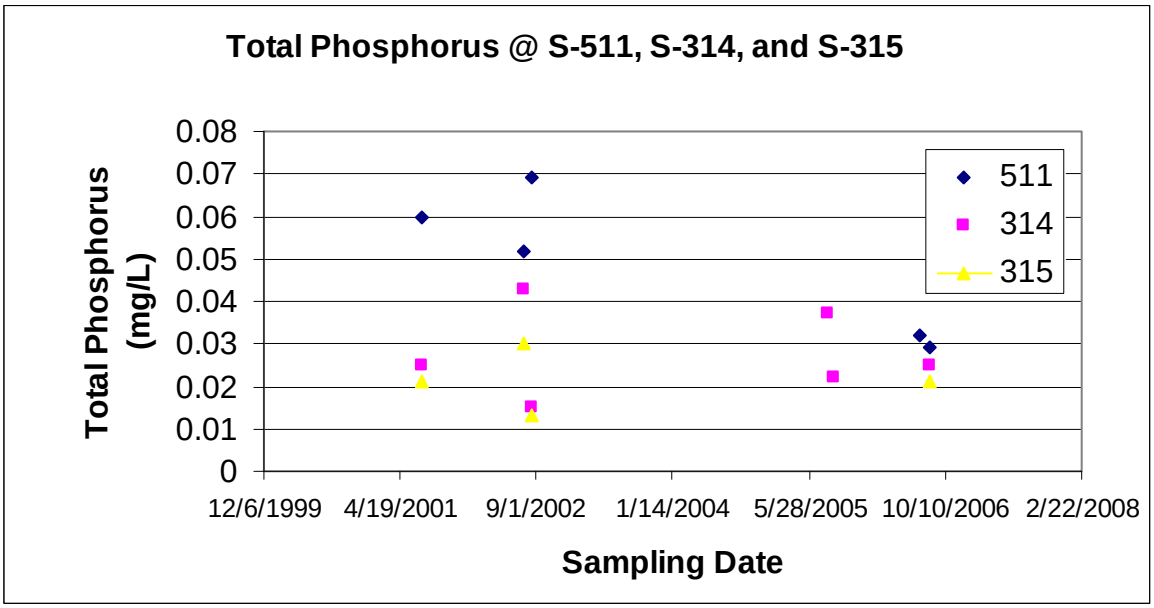

FIGURE 14
Total phosphorus at selected monitoring stations

Specific Conductivity

Specific conductivity is an important measure of water quality because the water's ability to pass a current is dependent upon dissolved solids such as salts, nitrates, sulfates, and metals. Specific conductivity is also variable based on water temperature; warmer waters have a greater specific conductivity. Dissolved salts and metals that contribute to specific conductivity may cause habitat stresses on aquatic organisms.

Throughout the watershed, specific conductivity appears to be highly variable (Figures 15 and 16). Seasonal variations are expected in this area, given applications of road salts and subsequent runoff. However, much of the monitoring data was collected in summer months and still shows considerable variability and values that are elevated beyond what is considered normal baseline values. For instance, the results from the datasonde deployment in 2002 (Figure 16) show a nearly 10-fold increase in specific conductivity from PJ2 above Stillwater Avenue to PJ1 above I-95. Background levels of specific conductivity can vary

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broadly and extensive data would need to be collected to establish a reasonable relationship between conductivity and a specific pollutant such as chloride.

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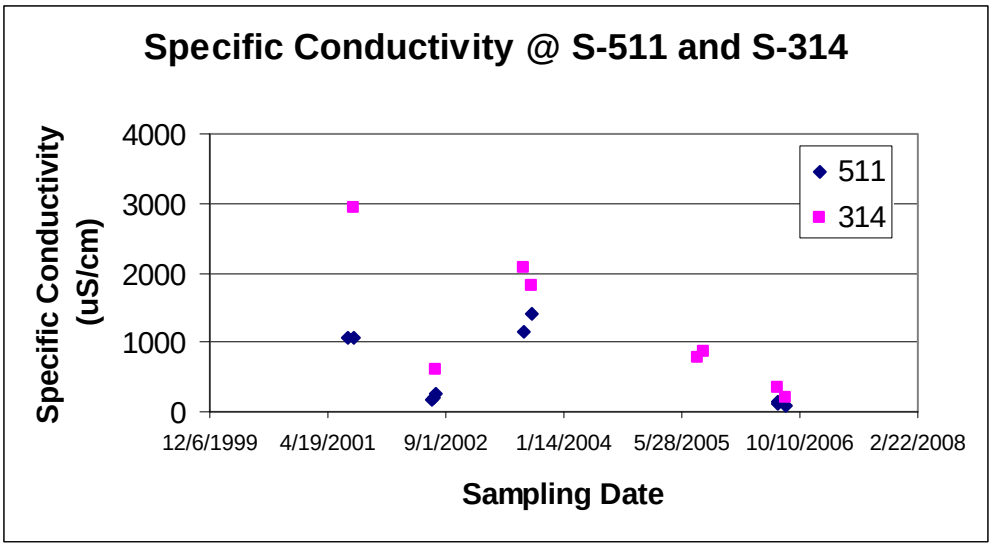

FIGURE 15
Specific conductivity sampling in the Penjajawoc watershed

Other factors are contributing to this variability, however little data is available to further assess this parameter. Possible contributors include cooling condensates entering the system and groundwater influences. Further investigation of this parameter should become part of future monitoring activities.

Other Parameters

Toxic substances such as heavy metals are likely to be present in the system; however, current monitoring programs do not include enough data to make inferences or draw conclusions. Although chloride values in 2001 and 2002 did exceed the EPA aquatic life criterion of 250 mg/L, little data are available outside this monitoring time frame to assess trends or make inferences about the causes of this impairment.

Stream temperature is recorded during all monitoring events, since it directly affects parameters such as DO and specific conductivity, as well as the health of aquatic organisms. Most of the monitoring has been conducted during July and August, when stream flows are at their lowest and corresponding stream temperatures are often at their highest. Another factor influencing stream temperature is canopy cover. Shading of the channel is an important factor in moderating temperature increases during lower flow periods. The vegetation that provides shading also provides many other benefits to a channel, improving stability and providing organic matter to the system.

Elevated stream temperatures, as shown in Figure 17, along with relatively open canopy cover are also contributing to algal growth within the system. This interaction is affecting many water quality and aquatic habitat parameters within Penjajawoc Stream.

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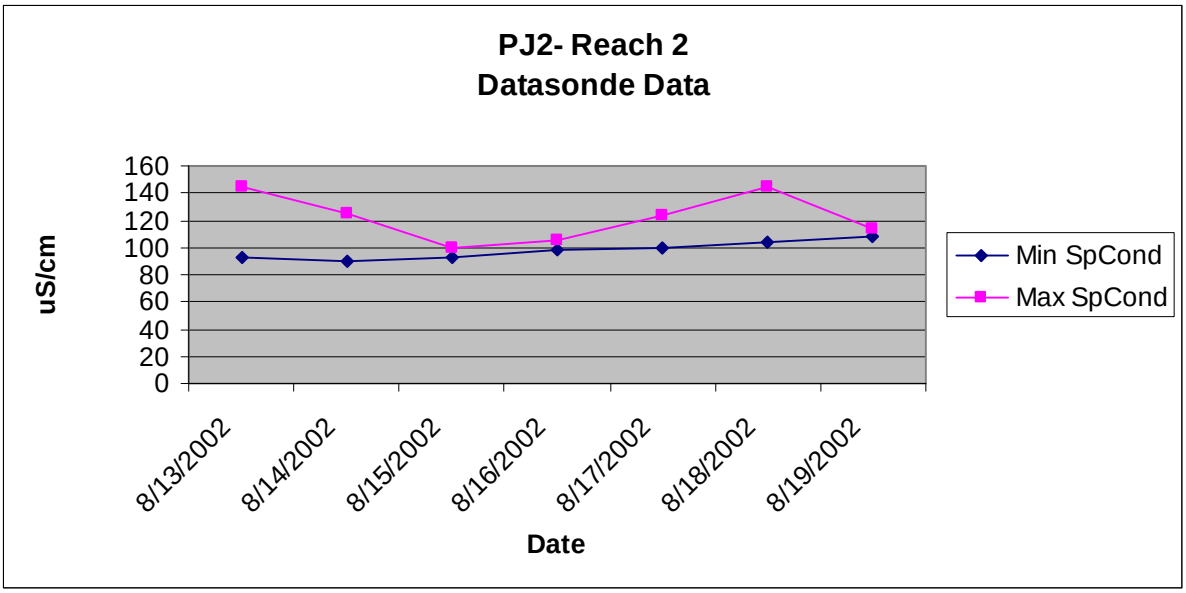

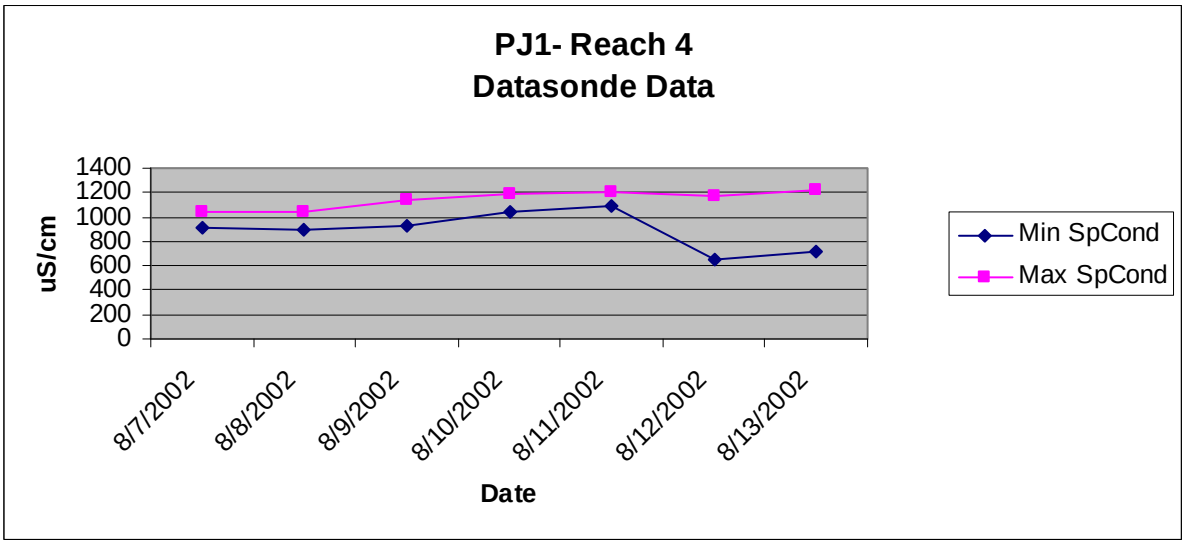

FIGURE 16
Specific conductivity measurement from datasondes in 2002

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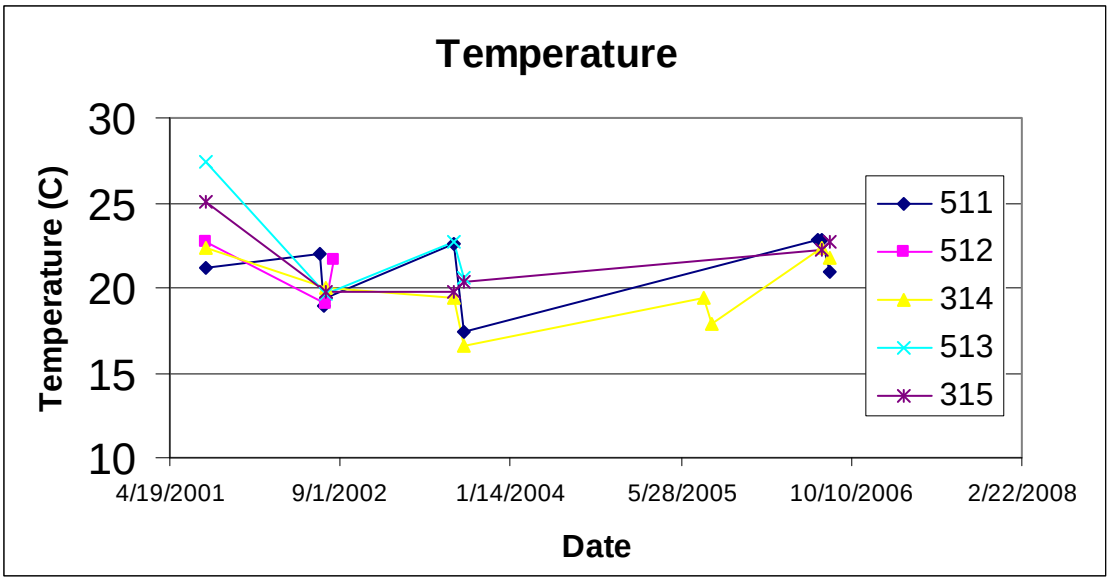

FIGURE 17
Water temperature at selected monitoring stations

Prior Modeling and Geomorphic Studies

The WMP included a summary of a number of studies that supported development of the plan. Several of these were examined during development of this TM and are highlighted below.

Modeling Studies

Tetra Tech, Inc. Modeling Study (2003)

A modeling study was conducted to support the development of a TMDL for Penjajawoc Stream with funding provided by EPA Region 1 (Tetra Tech, 2003). This study compiled baseline information on the watershed characteristics such as land use/land cover and soils and developed a watershed model using the P-8 Urban Catchment Model (Walker, 1990). The model requires hourly precipitation and daily temperature data and simulates watershed flow and pollutant transport for total suspended solids (TSS), nutrients, metals, and hydrocarbons. The model also has the capability to simulate the effects of BMPs.

The model was set up for three subwatersheds within the Penjajawoc watershed, including the upper watershed (above Stillwater Ave.), the lower watershed (including all of the areas currently drained through BMPs and including Meadow Brook), and the unnamed tributary watershed (Mt. Hope Brook) which enters the Penjajawoc Stream from the northeast near the mouth. The lower watershed was actually modeled as two areas: those draining to BMPs and those without BMPs. A "grouped performance assumption" was used for all of the BMPs. For the purposes of this modeling study, the unnamed tributary was considered a reference watershed. Pollutant concentrations input to the model for stormwater runoff were based on median event mean concentration (EMC) values from the National Urban Runoff Program (NURP) (EPA, 1983).

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The study documented altered hydrology and increased pollutant loads. From a watershed hydrology perspective, results of the study are summarized in Figures 18 and 19. Figure 18 shows that the upper and unnamed tributary watersheds have similar proportions of the annual precipitation as evaporation, baseflow, and surface runoff, with surface runoff representing less than 10 inches (or less than 25 percent) of the average 44 inches of precipitation per year. Surface runoff was estimated to represent almost 21 inches, or nearly 50 percent of the annual precipitation for the lower watershed. Annual flow duration curves were also generated for the three watersheds (Figure 19) showing the altered hydrology of the lower watershed. These curves illustrate the percent of time the flow (expressed as a flow yield per square mile) generated by that portion of the watershed is greater than a certain level. The flow duration curve for the lower (developed portion) watershed shows higher peak flow yields that the other less developed portions of the watershed and then slightly lower yields (indicating lower base flows) the remainder of the time. The model was also used to generate pollutant loads for each watershed area. As would be expected, pollutant loadings increased proportionately with the increase in surface runoff.

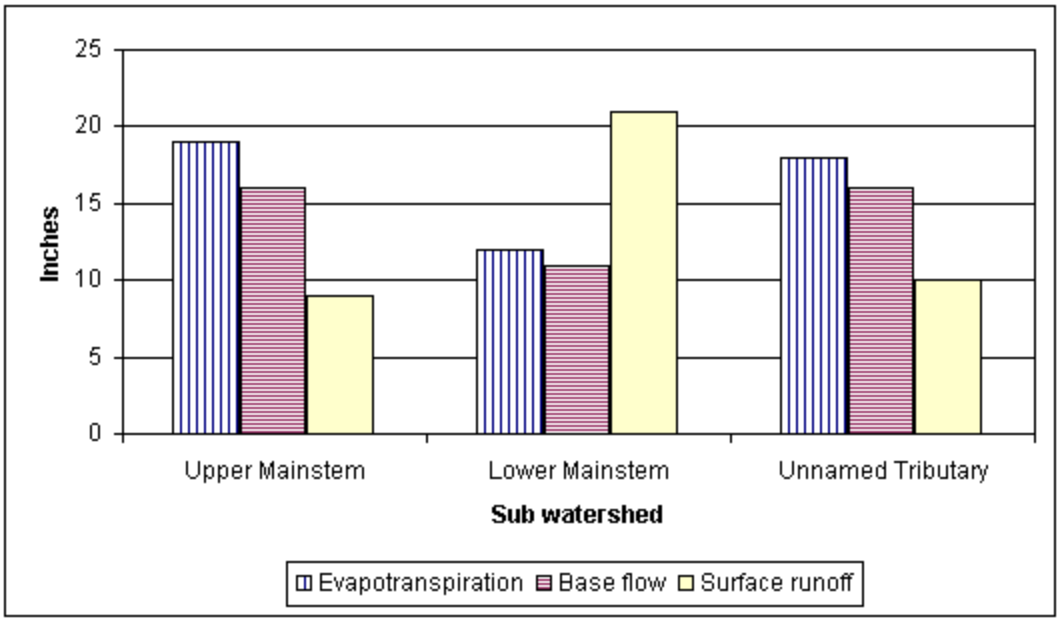

FIGURE 18
Water Balance in the sub-watersheds in the Penjajawoc. Annual average precipitation is 44 inches (from Tetra Tech, 2003)

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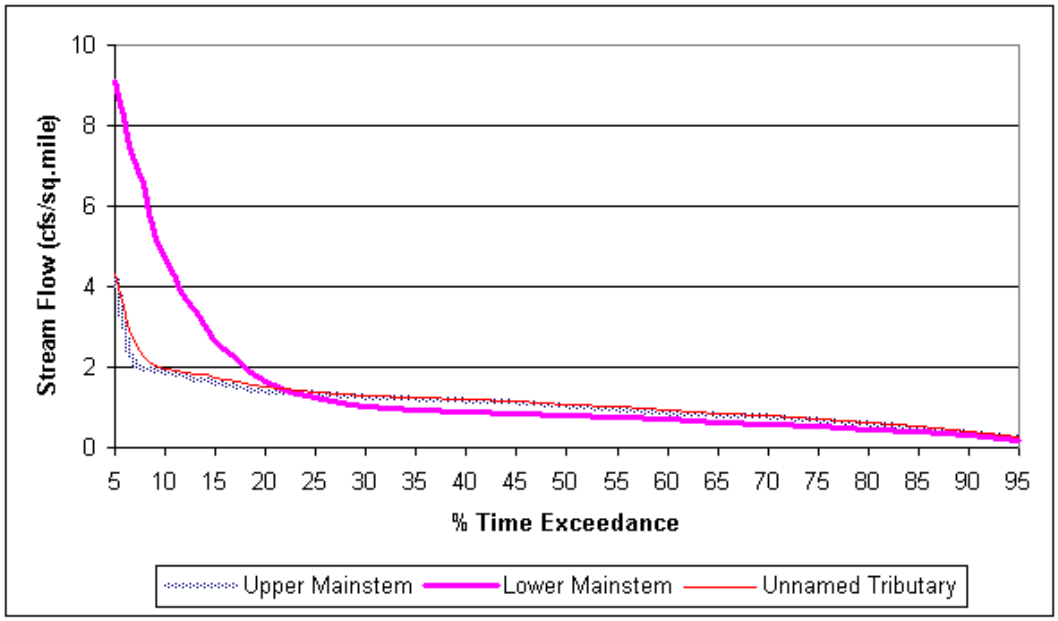

FIGURE 19
Flow duration curve generated by P-8 model for the sub-watersheds in the Penjajawoc (from Tetra Tech, 2003)

The primary limitation of this study is the lack of data for model calibration and validation. No stream flow data are available to calibrate model hydrology, and water quality data for calibration are limited. In addition, the NURP stormwater EMC values used are based on national data. Also, the metals data from NURP were collected prior to the development of clean sampling techniques and before development of new analytical methods for metals and are generally not considered valid. Finally, the data were collected prior to the complete elimination of leaded gasoline; so even if the data were valid, they would represent unrealistically high levels of lead.

This modeling is useful in that it highlights the significant increase in surface runoff when comparing the highly developed (and impervious) lower watershed with the relatively undeveloped upper watershed and unnamed tributary watershed. This modeling also showed similar hydrological response for the upper watershed and the unnamed tributary (Mt. Hope Brook) watershed. These watersheds are very different from each other, and this points to the need for data to calibrate hydrological models.

ENSR Penjajawoc Stream Storm Water Management Model (2006)

Maine DEP and the City of Bangor contracted for the development a watershed model using EPA's Storm Water Management Model (SWMM). SWMM is a dynamic rainfall-runoff model that can be used for single-event or long-term simulations. It has been used for simulation of separate and combined sewer systems with applications in urban and non-urban watersheds. SWMM includes a Runoff component that estimates surface runoff and pollutant loads generated from catchment areas and a Routing component to simulate transport of runoff through networks of pipes, channels, storage/treatment devices, etc.

SWMM uses land use/land cover and soils information similar to that of the P-8 model. However, the watershed catchment delineation is much more complex. Where there were

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basically 4 catchments simulated as part of the P-8 model, approximately 95 watershed catchment areas were simulated with SWMM based on subwatershed areas identified by Maine DEP and then further divided so that there was a separate catchment area for each BMP and area of interest (Figure 20). The model was set up for the analysis of a typical (average) rainfall year and based on an analysis of 52 years of precipitation data from Augusta, ME, 1988 was selected as the rainfall year for simulations. To model pollutant quality in runoff, the same parameters were used as in the P-8 modeling and pollutant build-up, washoff, and treatment parameters were developed to match those in the prior modeling (ENSR, 2006).

Routing hydraulics assumed a constant trapezoidal channel with a 10-foot bottom and 3:1 side slopes throughout the system. SWMM does not calculate baseflow directly in the model, and this value was estimated based on accounting for surface runoff, evapotranspiration, and precipitation abstraction, with the remainder being accounted for as baseflow.

The model was applied to the watershed and hydrology, and pollutant loads were developed based on current land use characteristics and 1988 hourly precipitation. There was no specific attempt to compare results to a reference such as the unnamed tributary watershed used in P-8 modeling, but results were provided for the watershed contributing to specific points (each point shows results for the entire watershed upstream of the specified location) as follows:

- 0+00 – Most downstream analysis point near the mouth
- 37+40 – Penjajawoc Stream at confluence with Meadow Brook
- 72+20 – Penjajawoc Stream at I-95 culvert downstream of Bangor Mall
- 100+80 – Downstream of the large headwater wetland

Figure 21 shows flow duration results for these watershed areas. The curves appear somewhat unusual, primarily because of the constant baseflow assumptions used. Also, more differences could be discerned if results were presented as an areal yield (flow per unit areas such as cfs per sq. mile), as was done in the P-8 modeling report.

The SWMM model provides a much more realistic tool for analyzing stormwater impacts because of the additional catchment detail, simulation of individual BMPs, and routing. Similar to P-8, no stream flow data are available for model calibration and validation and very limited data to judge the pollutant loading predictions. From a watershed hydrology perspective, it would be useful to devote more analysis to the baseflow issue so that it would not be a constant value for most of the year, as shown in Figure 20.

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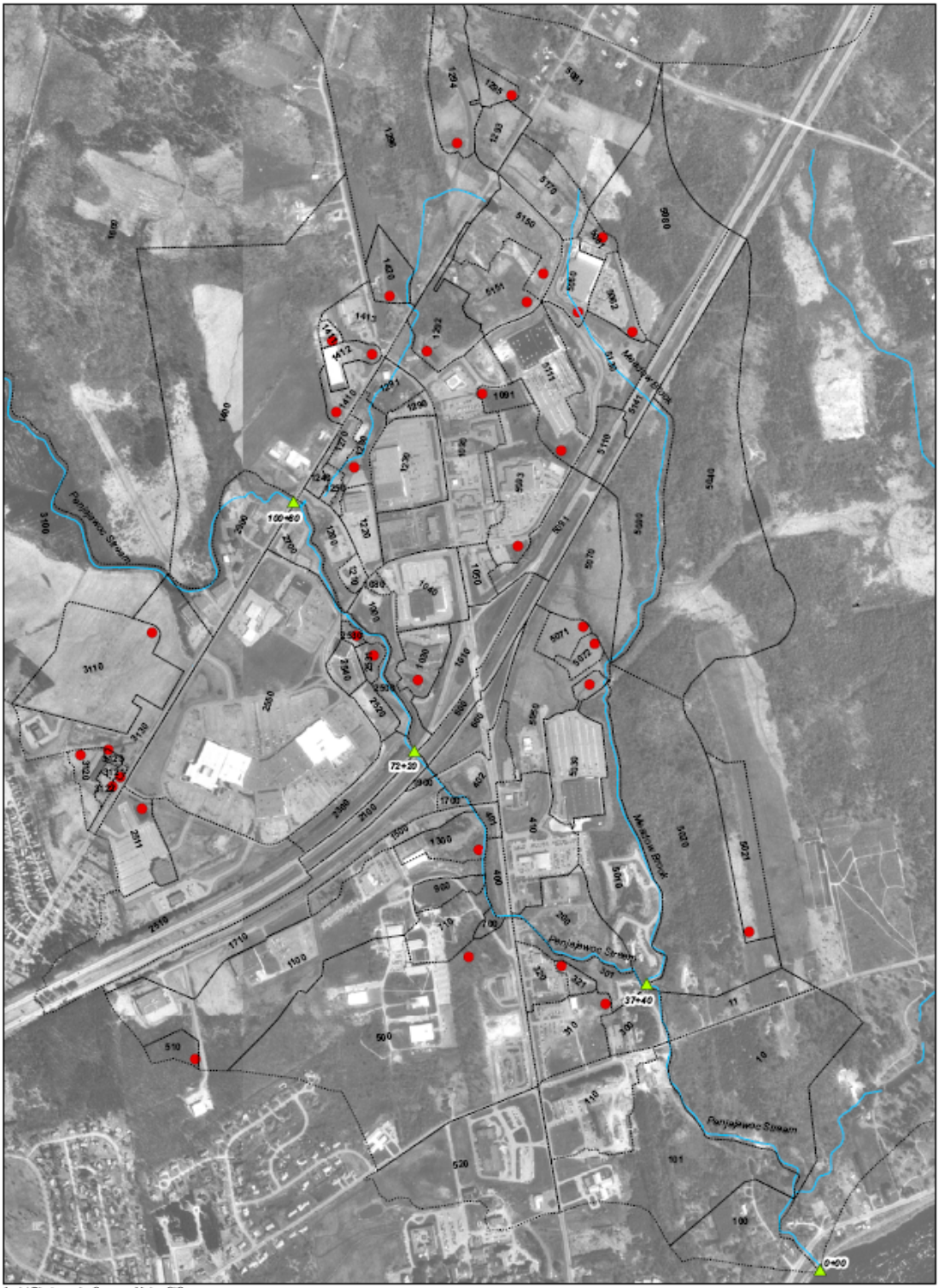

Aerial Photography Source: Maine GIS

Subwatershed Boundary

River

Stormwater Best Managment Practice

Analysis Point

N
W
E
S

0 500 1,000 2,000 Feet

FIGURE 20
Penjajawoc Stream Subwatersheds, BMP Locations and Analysis Points

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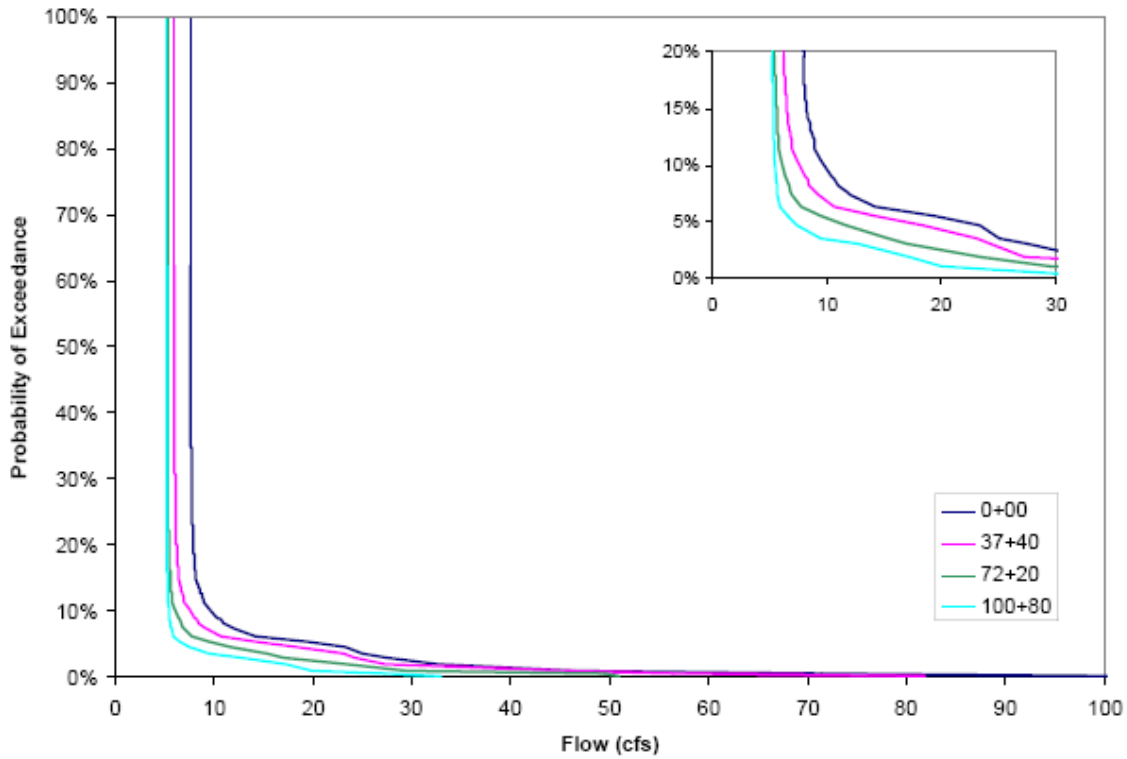

FIGURE 21
Penjajawoc Stream flow duration curves predicted by SWMM (from ENSR, 2006)
[Note: Smaller figure is a blown-up portion of the graph]

WBRC BMP Analysis (2006)

This study was targeted at analyzing specific catchments of the PSW for the purpose of developing either retrofit or new BMP conceptual designs to meet new stream protection stormwater regulations of Maine DEP (which were under development at the time of this analysis). This study used a program called Hydrocad, which is a model/design tool frequently used for the design of stormwater BMPs, and only the mainstem portion of the PSW was modeled. The study utilized the SWMM modeling (ENSR, 2006) and Geomorphic Study (Parish Geomorphic, 2006) specifically to aid in the hydrologic adjustment of Hydrocad to address baseflow and 2-year storm (bankfull) flow.

The existing 25 BMPs that affect peak flows in the watershed were examined and approximately 20 of them were determined to be functioning sufficiently to be included in the analysis. Four retrofit/new BMPs were then analyzed to identify modifications needed to control the 2-year storm in accordance with the new Maine DEP criteria and for improving baseflow conditions (i.e., bypassing non-storm flows to improve stream baseflow and thermal conditions). The BMP retrofit sites analyzed includes:

- Commercial Area 1
  - BMPs included flow-splitters and two in-system underground storage tanks

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  - Benefits include control of 1- and 2-year peak flows (channel protection) and bypass of baseflow to stream, thus improving flow and thermal conditions

- Commercial Area 2 Pond Outlet
  - BMPs include modification of pond inlet to bypass baseflow to stream and modification of pond outlet to control a 1-year storm event and to change controls for 2-year and higher events
  - Benefits include control of 1- and 2-year peak flows (channel protection) and bypass of baseflow to stream, thus improving flow and thermal conditions

- Interstate I-95
  - BMPs include installation of stone-check/under-drained ditches within existing drainage swales
  - Benefits include control of 1-year peak flows, encouraging stormwater infiltration, and restoring baseflows to stream, thus improving thermal conditions

- Eastern Maine Community College
  - BMP modifications include gate valve adjustment to lower permanent pool, burying outlet pipe to cool runoff before entering the stream, and modification of outlet controls to control for 2- and 1-year events
  - Benefits include control of 1- and 2-year peak flows (channel protection) and bypass of baseflow to stream, thus improving flow and thermal conditions

The PSW was reanalyzed with the retrofit BMPs, and total peak flows at various points in the watershed were reduced substantially, as shown in Table 6. These results indicate the potential effect of the BMPs on peak flows, but additional analysis is required to determine the impact these BMPs would have on attaining water quality criteria.

TABLE 6
Peak Flow Events, Existing and Proposed following retrofit BMPs (adapted from WBRC, 2006)

Station	Description	Peak Flow of 1-year event (cfs)		Change	Peak Flow of 2-year event (cfs)		Change
		Existing	Proposed		Existing	Proposed	
0+000	Mouth of Stream	270.44	245.91	-9%	324.78	302.41	-7%
0+950	Tributary #3 confluence	270.56	246.43	-9%	321.46	303.07	-6%
3+700	Meadow Brook confluence	247.29	221.16	-11%	291.64	269.41	-8%
5+400	Hogan Rd crossing	223.77	197.34	-12%	265.17	241.78	-9%
7+250	I-95 crossing	194.52	145.94	-25%	228.02	176.91	-22%
8+900	Bangor Mall Blvd crossing	77.23	77.23	0%	92.87	92.87	0%
10+00	Stillwater Ave crossing	54.84	54.84	0%	66.43	66.45	0%
12+500	Headwater (assigned)	7.00	7.00	0%	7.00	7.00	0%

Notes: At headwater, since observed base flow represents a steady-state condition, it retained its value for the 1- and 2-year storms.

Tributary #3 is Mt. Hope Brook

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As with the prior modeling, a major limitation of this analysis is the lack of stream flow data for model calibration. The report acknowledges the lack of data for the upper watershed, Meadow Brook, and the unnamed tributary and recommends gauging of these areas. Two-year flows for these tributaries were estimated using bankfull estimates from the geomorphic study (Parish Geomorphic, 2006).

Geomorphic Studies

Penjajawoc Stream Analysis and Interpretation (Parish Geomorphic, 2006)

This study was conducted as part of the development of a WMP for the PWS. Understanding the geomorphologic processes taking place throughout the watershed is critical in managing the stressors and estimating the potential benefit(s) of proposed watershed improvements. Six reaches within the watershed were analyzed, with the plan to continue monitoring these same reaches in the future to identify changes (Figure 22). Channel changes include bank erosion, riparian zone function, substrate changes, bed scour, and fill. Bed scour and fill are also known as channel degradation or aggradation. Most channel changes result from bankfull flow events, or channel-forming flow events. These are typically 1- to 2-year storm events are responsible for most changes (Rosgen, 1996).

To monitor channel changes at the six reaches, permanent cross-section locations were established and erosion pins were installed and then revisited in 2006. While only 1 year of monitoring is currently available, inferences about channel changes and watershed influences were made.

Prior watershed manipulation (past agricultural and development practices) may be a root cause for many of the observations in the geomorphic study. The channel is responding to changes in watershed hydrology (a result of increasing uncontrolled or inadequately controlled runoff from impervious area) and an increase in sediment load evidenced by bank erosion and substrate changes. Headwater sections experienced small amounts of erosion, while an increase in sediment load was observed in the middle portion of the watershed where more development has occurred. The stream's power to transport this sediment load is lower than expected due to its over-widened size in places. Thus, accumulation of sediment is visible in the middle reaches. This section of the watershed is higher in impervious surface area, with extensive development in the area of the I-95 interchange. Stormwater runoff in this reach may also contribute significant amounts of fine sediment.

The Meadow Brook reach also shows significant downcutting of the channel and vertical stream banks. While little change was observed in the cross-sectional area between the two monitoring events, the channel cross section does paint a picture of the erosion that is occurring in the channel, contributing sediment downstream to Penjajawoc Stream.

Two sources of sediment in this system, as a result of channel instability and stormwater runoff contributions, are mobilized during smaller storm events and routed through the system. This sediment is then observed on inner point bars, or natural deposition areas, and within the channel as it is routed through the system. The sediment from degradation occurring upstream is accumulating in the lower reaches of the channel, which is an expected result of these watershed changes and normal channel processes. Another stream response to this excessive sediment transport is downstream channel widening. The study

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reports that this is also occurring in the lower reaches. The widening is a result of the channel attempting to maintain its cross-sectional area while sediment is accumulating within it. Figure 23 displays typical channel behaviors in response to sediment transport issues (Parish Geomorphic, 2006). These observations indicate there is a greater sediment load than the stream is able to route through it while still maintaining stable channel parameters.

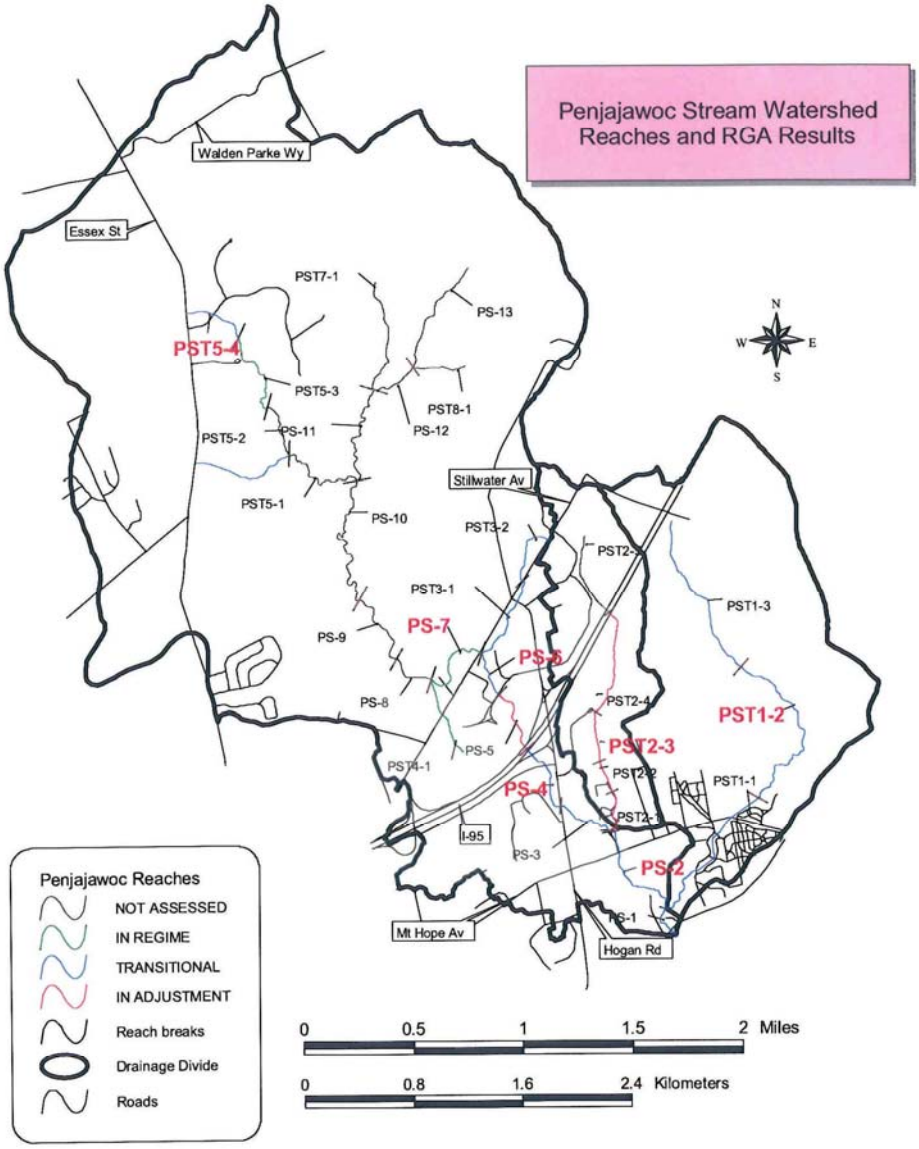

FIGURE 22
Penjajawoc Stream Geomorphic Assessment Reaches (from Parish Geomorphic, 2006)

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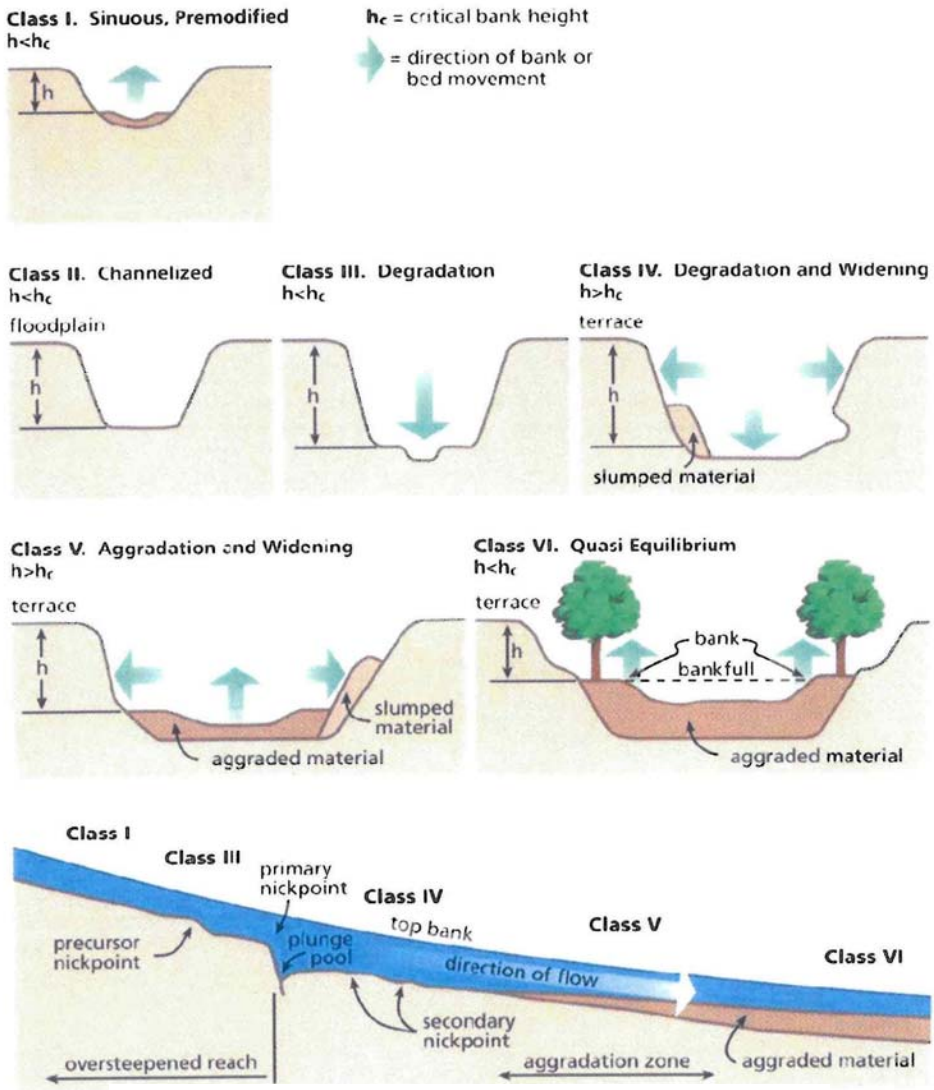

FIGURE 23
Typical Channel Evolution and Responses to Sediment Transport (from Parish Geomorphic, 2006)

To further understand the sediment loading in the system, the study used two models: the Einstein and Parker methods. However, stream flow for these models was estimated since no gauging data on the system are available. These models presented hypothetical bed load transport rates based on stream slope and substrate particle size. More accurate bed load transport calculations would be facilitated by hydrologic and hydraulic models calibrated with continuous stream flow data. Hypothetically, the upper reaches of the channel have more slope and, while contributing eroded sediment to the system, also have the ability to route it downstream more easily due to the slope. Lower reaches of a channel tend to have less slope, and less ability to route sediment; bed load hypothetically increases in these reaches and particle sizes are smaller.

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While the study authors were collecting these data, they also made observations regarding aquatic organism passage. Many of the culverts in the system have been in place for many years. The channel has evolved upstream and downstream these culverts, often resulting in a drop in elevation from the downstream end of the culvert to the channel bottom. These plunge pools can create physical barriers to fish and aquatic organisms, as many fish are not able to jump and other organisms are not able to climb into the culvert to travel upstream. Velocities within these culverts may also present barriers for passage. In recent years, the methodology for installing culverts has changed significantly. It is now recommended that culverts be bottomless or be buried in the channel to create a more natural bottom for organism passage. The study recommends further consideration of this issue during restoration planning.

The study concludes by recommending restoration priorities by reach, as summarized in Table 7. Key factors include maintaining connection of the channel with its floodplain, using grade control structures to reduce localized erosion, and using bank stabilization measures such as improving riparian zones where needed. CH2M HILL agrees that these efforts will aid in stabilizing the channel as the watershed changes, thus limiting erosion and protecting aquatic habitats.

To gain a more complete understanding of the stresses influencing this channel, including sediment loading and bank erosion, flow data are needed. This will allow more applicable and accurate modeling to be conducted, which would be extremely useful when designing improvements to the channel. It is critical to the success of any restoration project to understand the factors influencing sediment transport in a channel. If channel stability is related to runoff and urbanization, restoration must take into account the flow regime of the channel. In an urban area, flashy storm flows affect channel stability and these flows must be taken into account during design. Simply using a reference reach approach may not be sufficient to create a stable channel. This is especially true when culverts constrict flow, as has been observed in this watershed.

Stressor Comparison

In the Watershed Background section of this TM, Table 1 lists the primary stressors for the watershed that were identified through a stressor workshop led by the Maine DEP (Maine DEP, 2004). In general, the available data and background studies reviewed for this TM also point to the stressors identified in Table 1. However, for the purposes of targeting watershed management and restoration actions within the watershed, it seems appropriate to prioritize the stressors. Many of these stressors are inter-related and management/restoration activities directed at one stressor may also have a beneficial effect on others. Table 8 presents these same stressors prioritized based on the available information discussed in this TM. The following is a discussion of this prioritization of the stressors that can be used for further planning of watershed assessment and management activities.

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TABLE 7
Penjajawoc Stream Restoration Recommendations (from Parrish Geomorphic, 2006)

Restoration Site	Summary of Existing Concerns	Recommended Treatment
Mall Reach	Backwater effect, creating overly wide channel	Hydrologic modeling of system needed to understand backwater issue
	Aggradation resulting from a low gradient	Redesign channel dimension, pattern, and profile
	No diversity of aquatic habitat	Improve riparian zone
	Lack of riparian cover	
Downstream of I-95 to Hogan Rd	Upstream aggradation is leaving this section sediment-starved	Terrace channel to create a functioning floodplain
	Channel incision and widening occurring	Stabilize banks
	No connection to floodplain	Replace culvert
Meadow Brook	Degradation and widening occurring	Redesign channel dimension, pattern, and profile
	Steep gradient	Plant riparian vegetation
	Contributing fine sediment to Penjajawoc stream	Consider stormwater BMPs
Cemetery	Upstream ponds are limiting downstream sediment supply, leading to moderate erosion	Spot-treat bank erosion areas
	Ponds also affect temperature	Continue to monitor channel
Rail Trestle and Route 2 crossings	Structures pose a barrier to fish passage	Replace structures with rocky ramp structures to maintain grade but allow passage
Stillwater Ave	Aggradation occurring	Restore dimension to reduce cross-sectional areas
	Open canopy	Plant riparian vegetation

Altered Hydrology

Altered hydrology is identified as a stressor in the stressor evaluation presented in the WMP. However, in information summarized on prior studies it seems to be treated equally with other stressors for the PSW. According to CH2M HILL's assessment, altered hydrology is the most important driver to be addressed within the watershed management and restoration efforts. Furthermore, data have thus far been collected primarily to characterize the symptoms of altered hydrology, but not the altered hydrology itself.

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TABLE 8
Prioritization of Watershed Stressors

Draft Priority	Stressors	Watershed		
		Upper	Middle	Lower
1	Altered Hydrology	Yes	Yes - groundwater main mitigate low baseflow syndrome	Yes - from upper reaches
2	Habitat	Yes	Yes	Yes - more data needed
3	Conductivity	Yes	Yes - sand/silt sources	Yes - salt sources
4	Temperature	Yes - minor	Yes - possible	Yes
4	Nutrients	Yes - minor	Yes - possible	Yes - related to stormflow (less of a problem here)
4	Dissolved Oxygen	Yes - wetland main source	Yes	No (meets standards)
4	Toxics	Yes	Yes	Yes
4	Sediment	No	Yes	Yes - high suspended sediment during storms (probably from Meadow Brook)

Multiple documents and data show the effects of altered hydrology. The P-8 watershed modeling has provided information on the significant increase in surface runoff associated with changed and urbanizing land use within the watershed (Tetra Tech, 2003). Other modeling efforts support and expand upon this analysis. These modeling efforts clearly document an expected response of the watershed to changed land use. However, no watershed-specific precipitation, flow, or channel routing information has been used in these modeling efforts. Precipitation data are from adjacent watershed gauging near airports. There is no flow information for Penjajawoc Stream or its main tributaries. The P-8 modeling characterized the unnamed tributary (Mt. Hope Brook) as a potential reference area based on land cover alone, but examination of aerial land cover and visual observations indicates the significant alterations that have occurred in this watershed. The P-8 modeling uses a generalized function to delay peaks associated with flow routing and SWMM makes a generalized assumption regarding a trapezoidal channel with a 10-foot wide bottom with 3:1 slopes throughout the length of Penjajawoc Stream (ENSR, 2006). The Hydrocad modeling used information from the geomorphic study in an attempt to characterize flows up to a 2-year storm; however, they had no flow data to verify their assumptions.

Geomorphic data provide a very good baseline assessment of the current and changing gemorphometry of the stream channel. This is a symptom of the altered hydrology. Sediment transport observations are also inter-related with the altered hydrology because the increase in surface runoff delivers more fine sediment to the stream channel and also

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affects the generation of sediment within the stream channel through bank scour and down-cutting effects. The increase in surface runoff delivers more pollutants, such as nutrients and potentially toxic substances, to the stream system. The altered hydrology also affects how a stressor such as low DO impacts the system. All of these factors combined influence the aquatic communities in the stream and the ability to attain water quality criteria as measured through biomonitoring.

Developing indicators of altered hydrology and management goals for changing this alteration is a key need for this watershed management effort. The Gap Analysis section below provides additional details.

Habitat

Habitat has also been identified as a stressor within the watershed. Habitat is clearly influenced by the altered hydrology of the watershed and physical modifications that have occurred to the stream and its riparian zone to accommodate urban, as well as prior agricultural, land uses. Removal of medium and large deciduous trees along the stream bank, channel modifications as a direct result of development (relocations), and culvert and bridge structures are all direct influences on habitat. Subsequent channel modifications driven by altered hydrology also serve to alter and degrade habitat conditions. In addition, the complicating influences of beaver activity further change habitat conditions within the watershed. This impacted habitat not only influences the "home" for aquatic communities within the system, it also influences other stressors in the system such as DO and temperature. Lack of canopy (loss of shading) allows attached algae to grow and significantly influences DO levels. It also allows larger swings in stream temperature.

Available data to characterize habitat include visual observation of cover, riparian area, substrate composition, and velocity during biomonitoring. The geomorphic study also provides important information characterizing channel configuration. All of these data provide a good qualitative base to appropriately identify habitat as an important stressor.

The available habitat information is neither systematic nor robust enough for thorough design of watershed improvements. First, habitat has not been specifically defined. A thorough assessment of habitat conditions would define the area as including a specific riparian corridor, floodplain, stream channel, etc. Second, the assessment information collected with the biomonitoring information consists primarily of observations, and the review of the data reports for various sites over time indicates a number of inconsistencies. There are a number of habitat assessment protocols that have been developed, including an EPA Rapid Bioassessment Protocol (RBP) (1999), as well as several state protocols. These protocols require definition of key information and specific staff training but can produce reproducible quantitative information to assess and then manage watershed conditions.

Specific Conductivity

Specific conductivity is a measure that is an indicator of dissolved constituents in water which may be toxic to aquatic life. This is an important stressor since management activities for specific conductivity may be entirely different from those used to address altered hydrology, habitat, or pollutants.

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Review of available results indicates potential influences of road-salting practices in the watershed during the winter and potential storage of salts in BMPs and/or near-surface groundwater during the summer. Continuous specific conductivity measurements from Maine DEP sondes from upstream of Stillwater Avenue (PJ2) and downstream immediately above I-95 (PJ1) during back-to-back weeks during August 2002 show almost a 10-fold increase in specific conductivity in the areas. August 2002 was a very low rainfall month, so it can be assumed that the measurements during these 2 weeks were primarily baseflow. This consistent increase implies a significant source of dissolved constituents. Other specific conductivity measurements seem to show wide-ranging results that might also indicate condensate or other discharges that have elevated concentrations of dissolved constituents.

To aquatic life, chloride is a toxic substance. Other dissolved constituents measured by elevated specific conductivity may also be toxic. Specific conductivity needs to be more systematically characterized to discern the effects of salting activities versus those that might be associated with illicit discharges. There are some chloride measurements in the water quality data from the Penjajawoc that indicate levels in excess of suggested EPA aquatic life criteria. The systematic characterization of specific conductivity and assessment of whether this represents a potential impact to the aquatic community is important prior to development of management measures. It is also relatively unrelated to measures to manage altered hydrology and habitat.

Other Stressors

The other stressors identified in the stressor workshop are all potentially important to the ability of Penjajawoc Stream to attain water quality standards. However, they are not independent from the previously identified stressors of altered hydrology and habitat. Also, efforts to manage these stressors may be primarily linked to management efforts for hydrology and habitat. The following section briefly discusses the other stressors.

Sediment

Sediment has been identified as an important stressor to the system and is frequently cited as the pollutant that impacts the most miles of streams throughout the United States (EPA, 2008). In the Penjajawoc, sediment impacts seem to be related to both (1) potential inputs from stormwater from impervious surface and construction sites and (2) geomorphological changes within the channel system.

Available data do not seem to indicate extremely high levels of either suspended sediment (as measured by TSS) or turbidity. There are no direct water quality criteria for sediment or turbidity. The geomorphic study did a very good job of characterizing potential sediment transport issues in the Penjajawoc, including areas of degradation and aggregation.

Sediment management, while important, seems highly related to source control measures for construction sites, as well as controls necessary for management of altered hydrology. Also, channel generation of sediment may be managed through a combination of hydrologic controls and restoration activities designed to stabilize stream banks. Sediment issues are an important consideration in watershed management but are linked through management of other stressors.

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Nutrients

Elevated nutrient levels in a stream system can promote attached algal growth, which directly influences DO levels. They are also a source of organic enrichment to the system that influences the types of aquatic communities present. Excessive attached algae growth can also be an aesthetic concern.

The ability of nutrients to impact streams is highly influenced by habitat conditions. Shaded streams have less algal growth because of reduced sunlight. Stream depth also influences how nutrient effects are exhibited.

Data for Penjajawoc Stream indicate TP levels that are in the range of or above proposed stream criteria (Maine DEP, undated). The highest concentrations of TP, which are consistently above these criteria, were recorded upstream of Stillwater Avenue in the area influenced by the large wetland system. Downstream measurements of TP show lower levels.

For the urbanized areas, control measures to manage altered hydrology are moderately to extremely effective in managing TP levels. Even stormwater detention devices may provide TP removals in the 20 to 40 percent range (CWP, 2000), whereas low-impact development (LID) measures may be as much as 80 percent effective in managing TP depending on design criteria. There is no way of managing nutrients in stormwater that is not linked to management of altered hydrology.

In addition, the high TP levels downstream of the wetland system also imply that some of the nutrient issue may be natural and/or related to historical agricultural activities in the watershed. The relative influence of these nutrients should be considered in assessing the necessary nutrient controls implemented in conjunction with management of altered hydrology.

Dissolved Oxygen

DO levels in Penjajawoc Stream are clearly below the water quality standards, particularly in the area downstream of the wetland and in the middle portion of watershed. DO levels seem to consistently meet criteria in the area approaching the mouth of the system. While low DO levels are an important stressor, they appear to be naturally occurring downstream of the wetland. The movement of this low DO water and reaeration are highly dependent on hydrological conditions. Daily variations in DO from very low to supersaturated conditions are a function of nutrient levels, shading, and hydrological conditions. There are no significant sources of oxygen demanding materials to the system, so management of DO is highly linked to management of altered hydrology and habitat conditions. The role of natural variations resulting from the wetland should not require management.

Toxic Substances

Toxic substances are listed as a stressor in the stressor evaluation. Sediment, nutrients, metals, and hydrocarbons are frequently identified sources of contaminants associated with stormwater runoff. Little or no water quality data are available regarding metals and hydrocarbons. Also, many stormwater BMPs are highly effective at reducing metals and hydrocarbons in runoff.

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Watershed management measures for potentially toxic substances (other than salt) should be directed at source control measures typically required as part of Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) stormwater programs. These include public information and education regarding disposal of potentially hazardous substances, hot lines and other means for observing and reporting problematic waste management activities, and monitoring activities associated with illicit discharges.

Consensus on Stressor Prioritization

The proposed prioritization of watershed stressors in Table 8 was presented for stakeholder discussion at a Watershed Stressors and Modeling meeting in February 2009. Full meeting notes are attached in Appendix C. The group reached consensus that altered hydrology should be the highest priority because the lack of hydrologic data does not allow for a systematic analysis with habitat and chemistry data. Habitat was selected as the second highest priority stressor with all other stressors rated in equal priority following habitat. It was also agreed that more data was needed before specific remedies to address these stressors could be implemented. It was noted that while altered hydrology would be the highest prioritized stressor, opportunities to easily or inexpensively address other stressors, specifically nutrients and toxics, should not be overlooked while collecting hydrologic data.

Gap Analysis

Chartered Stakeholder Process

There has been an informal stakeholder process for the Penjajawoc watershed, convened by Maine DEP and the City. The stakeholders have assisted with issues such as the stressor workshop and the WMP development. As the TMDL and WMP were developed, there were some concerns about the adequacy of representation of potentially affected parties within the stakeholder group. At the first workshop (Attachment B), there was considerable discussion about the need for a defined stakeholder process that was chartered so that the stakeholders were properly identified and so that roles and responsibilities were fully defined. After that workshop, there was an effort to develop a charter for watershed stakeholders; however, this effort was not completed until the Bangor City Council was engaged in designation of stakeholders. At this time, the City Council is completing its designation of stakeholders which can guide the further evolution of watershed management efforts in the PSW.

Indicators of Impairment

The single biggest potential gap in the watershed assessment and management activities to date is agreement on the key indicators of watershed impairment and the establishment of specific targets for improvements in these indicators. At present, all of the stressors appear to be given equal weight in terms of potential contribution to the impairment of the PSW. The WMP identifies a wide range of potential activities to address the stressors, as well as to provide for comprehensive implementation of the NPDES Phase 2 Stormwater Program. However, stakeholder review and agreement on management indicators and targets to address watershed impairment has not been accomplished.

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Despite the long experience with stormwater management in North America and the comprehensive Maine requirements, these requirements are typically based on performance criteria, which are in turn based on a technology approach similar to secondary treatment for publicly owned treatment works. These technology-based approaches provide an indication of appropriate stormwater management approaches to address aquatic life impairment in urbanized watersheds. There is considerable ongoing research in this area, including several applicable projects being funded by the Water Environment Research Foundation (WERF), such as:

- Bioassessment: A Tool for Managing Aquatic Life Uses for Urban Streams (WERF #01WSM3)
- Distinguishing the Relative Influence of Habitat and Water Quality on Aquatic Biota (WERF #98WSM1)
- Physical Effects of Wet Weather Flows on Aquatic Habitats (WERF #00WSM4)
- Protocols for Studying Wet Weather Impacts and Urbanization Patterns (WERF #03WSM3)
- Linking BMP Systems Performance to Receiving Water Protection to Improve BMP Selection and Design (WERF #SW1R06)

Despite this ongoing research, there is no specific approach applicable to all watersheds. Therefore, many watershed management approaches, as well as aquatic life impairment-based TMDL approaches, typically develop an indicator or indicators of watershed impairment, and then establish targets for these indicators for watershed management and restoration based on available watershed monitoring, modeling, and assessment information through a stakeholder involvement process. Often these targets represent a compromise between (1) best available information to move forward with watershed management activities and (2) extensive long-term monitoring and studies to provide better information. This compromise is brokered through a stakeholder process where stakeholders can appropriately weigh the various issues. Targets established in this way can then be used for the initial round of watershed management activities. Further monitoring and assessment activities in conjunction with ongoing stakeholder involvement are used to adjust or adaptively manage the process over time. Figure 24 shows an example of a watershed planning process incorporating adaptive management.

There are several examples of watershed planning processes that have established specific indicators and targets but fewer examples where this has been done based on an aquatic life impairment-based TMDL. A comprehensive review of these studies is beyond the scope of this TM, but review of a few studies illustrates the point.

In Mecklenburg County, North Carolina, hydrologic and water quality modeling with HSPF was used to establish a range of indicators for management of watersheds. Initial modeling and review with stakeholders were used to establish targets for suspended sediment, TP, and zinc (as a metal indicator for stormwater runoff). Targets of 600 lbs/acre-year of suspended sediment and 0.3 to 0.5 lb/acre-year (absent point sources) were established for various watersheds to address impairment (Tetra Tech, 2001). These loading factors were considered to address both hydrological and pollutant effects of urban stormwater inputs. A

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later study also established targets for these same watersheds for hydrological measures to protect stream channels to guide LID and other stormwater management efforts. These analyses included an examination of the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) measurements in conjunction with geomorphic stream assessments to establish criteria to control instream sediment sources (Tetra Tech, 2005). These targets were used as a basis for local watershed planning efforts to develop recommendations for new development and retrofit measure throughout major portions of Mecklenburg County (CH2M HILL, 2003).

Two recent studies used flow duration relationships as a means of establishing targets used to develop stormwater management performance criteria for retrofits and new development. As part of a project for the Great Lakes Protection Fund, watersheds in Michigan and Wisconsin were evaluated in conjunction with groups of watershed stakeholders. These watersheds were selected because of ongoing watershed management activities and active stakeholder groups. The approach involved development of fisheries-based flow duration curves and determination of stormwater management target volumes to achieve the flow regime target to support the indicator fish species. Figure 24 illustrates the concept of this approach (Medina, 2007). Another study used a similar approach to compare the ability of various stormwater management approaches to manage the flow regime as measured by shear stress duration curves for stream channels. This analysis showed LID approaches more closely replicate the original regime (Ibendahl, 2008).

Selection of Indicators

In the previous sections, a prioritization of stressors was proposed based on the available watershed monitoring and other studies. This prioritization (shown in Table 8) needs to be endorsed and/or modified by the watershed stakeholders. Assuming there is agreement on the prioritization of stressors as presented previously, management indicators could be developed for the key stressors as discussed below. This could be modified based on the approach agreed upon by stakeholders.

Altered Hydrology

Currently, there are requirements for stormwater management for new and redevelopment based on the Chapter 500 rules. The basic and general stormwater requirements include stormwater management measures to reduce pollutants in stormwater, measures to protect stream channels from increased frequency and duration of channel erosive flows, and measures to mitigate temperature effects. In addition to the basic and general requirements, there are also additional requirements for specific watershed situations, including

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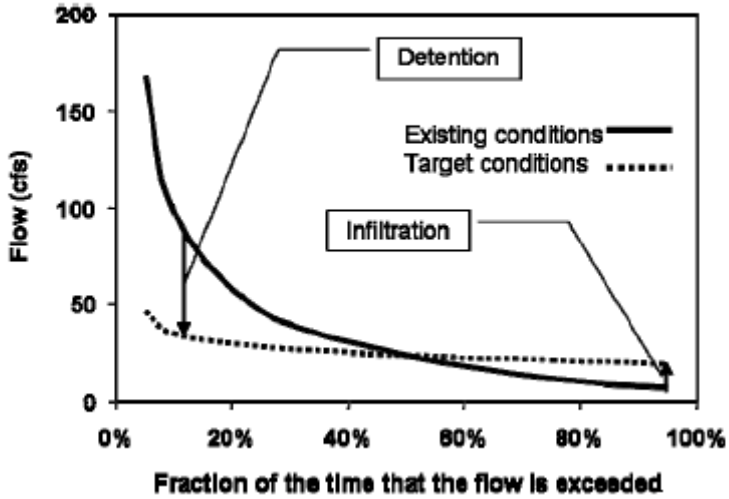

FIGURE 24
Conceptual depiction of the effects of stormwater BMPs in matching ecological flow targets by reducing peak flows and increasing base flows (from Medina, 2007)

phosphorus standards for lake watersheds, an urban impaired streams standard, and a flooding standard. The urban impaired stream standard requires either a compensation fee or mitigation of stormwater impacts for development meeting certain requirements. This standard does provide an exception for redevelopment by not requiring stormwater management for existing impervious cover except in limited situations.

While addressing stormwater controls for new impervious cover, these requirements primarily prevent the impacts associated with increased stormwater from becoming worse and can only make marginal improvements to the existing impairment situation from redevelopment, potentially through the mitigation requirements in the rules. The Hydrocad analysis conducted by WBRC indicated that retrofit BMPs, conceptually designed in accordance with Chapter 500 rules, could substantially reduce 1- and 2- year peak flows, which are important from a channel protection standpoint (WBRC, 2006). However, since no targets for success have been established, the benefit of these BMPs in addressing impairment cannot be evaluated. In addition, the Hydrocad model, as well as other modeling analyses, was developed with no data for calibration of the hydrological response of the watershed. As a result, there is considerable uncertainty in the actual benefits that would be accomplished with these BMPs.

To address this gap, the following steps are recommended:

1. Stakeholders should review the pertinent information and select potential hydrological indicators for watershed management. An approach to setting targets for these indicators should also be identified.

2. Based on the indicators, the applicability of watershed models should be reviewed, including those previously applied, and a model should be selected for moving forward. [Note: model selection should also consider other stressors of concern, such as habitat indicators, pollutants, etc. so that a multi-purpose model can be selected]

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3. A hydrological data collection effort should be implemented in the watershed, including precipitation and flow gauging stations. [Note: this can be done in conjunction with Recommendation 1 and even short-term data, such as 3 months of precipitation and flow measurements, can provide increased confidence in the model]
4. A calibrated watershed model should be developed and analyses conducted to support quantification of indicators and development of targets.
5. Results should be reviewed with stakeholders, and indicators and targets should be selected for watershed management. [Note: this process may identify other issues so the approach may need to be adaptive, with the establishment of interim targets, to be validated/modified by subsequent analyses.]

Habitat

Habitat is clearly an important stressor to address; however, much of the information to assess habitat is qualitative, as discussed previously. While the geomorphic information provided is more quantitative and concepts have been identified for improving channel stability (Parish Geomorphic, 2006), moving forward with channel improvements should be in conjunction with development of a better understanding of watershed hydrology through gauging and the development of a hydrological model for the watershed. As mentioned previously, flashy storm flows affect channel stability in an urbanizing area and these flows must be taken into account during design. Simply using a reference reach approach may not be sufficient to create a stable channel. This is especially true when culverts constrict flow, as has been observed in this watershed.

It seems that development of better habitat information to assess the watershed could move forward concurrently with efforts to develop a better understanding of watershed hydrology. While a specific protocol and approach to managing the data are recommended, this assessment of habitat can be accomplished using trained watershed volunteers. In Atlanta, all of the watersheds in the City were evaluated for habitat conditions using trained Ameri-Corps volunteers (CH2M HILL, 1999). These volunteers were trained to use an EPA RBP-based method and provided valuable information for the City's watershed management assessments. Mecklenburg County used a similar approach but developed their own habitat assessment protocols and mapped the City using summer interns (CH2M HILL, 2001).

Habitat improvements, particularly improved shading and temperature moderation provided by stream canopy, have been identified as an important factor associated with other water quality stressors, such as productivity-driven DO fluctuations. Efforts to improve riparian areas need to be coordinated with stream channel stability and restoration efforts. Since these efforts require better hydrological data and a calibrated model, there is a good opportunity to conduct a more detailed habitat assessment, which could be coordinated with watershed interest groups.

Others Stressors

As mentioned previously, specific conductivity is a stressor as it relates to salt and other dissolved constituents. From a watershed improvement standpoint, it seems reasonable to continue to monitoring and assess specific conductivity to determine the role of salting

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practices or potentially illicit discharges in the variability that has been identified. Control of specific conductivity, and the dissolved constituents it indicates, is primarily achieved through source control measures that are independent of the efforts to address hydrology and habitat.

As previously indicated, CH2M HILL believes that impacts associated with other stressors are primarily related to altered hydrology and/or habitat conditions and their improvement can be accomplished through control of the other stressors. More specific data may change this conclusion.

Conclusions and Recommendations

The PSW has been appropriately identified as being impaired, based primarily on monitoring programs of Maine DEP. Additional studies related to watershed modeling, geomorphic conditions, and conceptual BMP retrofits have provided valuable insight and information related to the nature of hydrological, pollutant loading, and stream channel conditions in the watershed. Clearly, the efforts to move forward with a comprehensive watershed–based management program are appropriate. Such improvements can begin to stabilize portions of the watershed that are currently deteriorating and improve the situation until the system continually meets water quality standards.

While some data are clearly available to assess impairment of the watershed, additional data are needed to fully understand how the watershed is responding hydrologically. This is extremely useful in terms of interpreting water quality and biomonitoring results, and necessary for the establishment of indicators and targets to measure watershed improvement. Also, a thorough understanding of watershed hydrology is essential to having sufficient confidence in models used as a basis to design improvements, especially when those improvements need to be integrated within the watershed to establish a geomorphically stable pattern and profile of the stream. A stable stream channel is an important element of improved habitat conditions and is necessary so that riparian improvements to stabilize bank conditions, provide canopy to the stream, etc., can mature over time to also aid in the overall efforts to restore the stream channel.

Based on the information reviewed in this TM, there are several recommendations to support the overall watershed management efforts for the PSW. These are organized into stakeholder involvement, monitoring program, and modeling/analysis recommendations. A framework for a watershed program workplan is also provided.

Stakeholder Process

In this TM, an active role for stakeholders or a potential sub-group of the stakeholders is recommended for making decisions regarding adaptive approaches to managing the watershed. CH2M HILL recommends that the specific role of stakeholders and any subgroups be identified and that a stakeholder charter describing this role be developed. This approach has been used in many other watershed planning efforts and can be used to describe the group structure, the goals of the representatives, the “stake” of individual members, sub-groups, meeting expectations, and proper procedures for communications. These types of charters describe how stakeholders are involved with watershed management process and guide how the group should interact.

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During the course of this assessment and two workshops regarding the information contained in this TM, progress has been made in transitioning from an informal group of stakeholders to a formal stakeholder group with members designated by the City Council of Bangor. Designation of this stakeholders group is in progress at the time of completion of this TM. A balanced stakeholder group with endorsement by the City will allow watershed management efforts to proceed and further allow adaptive approaches as the City staff, DEP, and stakeholders develop a better understanding of the watershed as more data are collected and watershed improvements are implemented.

Monitoring Program

Hydrologic Monitoring

The primary source of data of any watershed program is hydrologic monitoring. From a long-term standpoint, CH2M HILL believes one permanent flow gauging station is necessary in the watershed to begin developing a record of hydrologic response of the watershed to land use changes over time. The exact location of this flow gauge would depend on a number of factors and discussions with stakeholders but should probably be in the central portion of the watershed, somewhere between I-95 and the confluence of Penjajawoc Stream and Meadow Brook.

In addition, two shorter-term gauging locations should be established for monitoring during non-winter conditions. Preliminary candidate locations would be on Penjajawoc Stream above Stillwater Avenue and Meadow Brook. The hydrology of the upper watershed is very different from that of the lower watershed because of the more rural land use and the considerable storage and detention provided by the wetlands. Understanding this hydrology will be important for any watershed modeling effort. The Meadow Brook sub-watershed is undergoing development and seems to be experiencing water quality and channel stability issues. Hydrologic data will assist in evaluating and determining appropriate corrective actions for this problem.

Precipitation data for the watershed are also important, especially during the period when temporary gauging is underway, to provide data for hydrologic model calibration and verification. Two recording gauges are recommended; one would be permanent and the other would operate during the temporary flow monitoring, primarily during non-winter months. In addition, long-term precipitation monitoring is an element that could be incorporated into the volunteer stream team effort.

Water Quality and Biological Monitoring

The overall monitoring program moving forward is not well documented. As mentioned previously, there have been a variety of biomonitoring, water quality and special studies (data sondes) ongoing in 2008 and conducted by DEP and the volunteer stream team. DEP seems to have a plan for continued watershed monitoring but documentation for this plan has not been identified. Likewise, the volunteer stream team effort has involved routine training and frequent sampling. A description and workplan for this effort have not been developed (personal communication with Mark Whiting/DEP, 2008). A draft quality assurance/quality control (QA/QC) plan was started and never finalized. Maine DEP is in the process of developing guidance including QA for stream team efforts.

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While available historical data have allowed an evaluation of watershed impairment, a concise description of planned watershed monitoring activities over the next 2 to 5 years should be developed and maintained. In this way, stakeholders and other interested parties will be able to quickly see what monitoring activities are planned and be able to suggest changes to address specific issues.

Finally, data quality associated with a volunteer stream team effort will always have some uncertainty associated with data reliability. From the available information, it appears that Meadow Brook monitoring is accomplished only by the stream team. Also, the Mount Hope Brook only appears to have an algae station by DEP. These streams are important components of the watershed and there should be overlap between the DEP and stream team efforts so that data can be compared.

Modeling/Data Evaluation

This TM has suggested a prioritization of stressors and some approaches to development of indicators and management targets. This approach needs to be implemented in conjunction with stakeholders. Once the stakeholders have agreed on indicators of impairment and a plan to move forward with development of watershed targets, a modeling approach for the watershed can be developed. The prior modeling effort represents a range – from broad modeling of the entire watershed using P-8 to detailed modeling of the stormwater system and BMPs using SWMM and Hydrocad. Each of these models has some utility and all of them lack hydrologic data for calibration and verification.

Models have various strengths and weaknesses. However, a recommendation on modeling needs to be based upon stakeholder discussion of the impairment description in this TM, agreement on the prioritization of stressors, and development of indicators for watershed management. A suggested process for selecting hydrologic and water quality models is outlined below:

- Identify stakeholders
- Define selection criteria (include data availability)
- Assign weights to criteria
- Propose suite of potential models
- Score models according to criteria
- Select model

Identify Stakeholders

Stakeholder identification is important to the model selection process because the model will be used to support the stakeholder goal setting process. By properly identifying all stakeholders, all goals for the watershed management program as well as the necessary selection criteria will be identified. This will result in the best model to support the objectives of the program.

City Council of Bangor is in the process of designating a formal stakeholder group. This group is ideal for establishing goals for a watershed modeling program and can provide guidance to the subsequent modeling effort or a sub-committee can be designated to track and support this effort.

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Define Selection Criteria

In defining the selection criteria, the goal should be to make the model as simple as possible to achieve the defined objectives with the available monitoring data. Such a model provides a representative characterization of the physical problem and is able to be calibrated with monitoring data. This type of model is recommended over others based on simulation processes that can not be adequately calibrated. Calibration is important for achieving stakeholder support because it gives stakeholders confidence in the model results. Keeping the model as simple as possible to achieve the desired results leads to the most cost-effective model option, ensuring that valuable financial resources are not expended for capabilities not needed to achieve the program objectives.

In defining the selection criteria, it is important that the criteria be consistent with available data for the watershed. If model selection criteria are developed without consideration of available data, it is possible that a model could be selected that requires data that are limited or not available for the watershed. This would likely result in inaccurate results from the modeling effort and/or the need to collect additional data and rerunning of the model. This scenario would cause the use of additional resources and delay the modeling results and the progress of the watershed management program.

Examples of potential model selection criteria include:

- Fitness to the problem
  - Screening vs. planning
  - Urban, rural, or mixed use
  - Output (hydrographs, runoff volumes, baseflows, pollutant loads)
  - Temporal scale (small vs. large storms)
  - Spatial scale (large vs. small watersheds)
  - Continuous simulation vs. single event
- Management objectives
  - Can it simulate management measures?
- Project constraints
  - Collection of additional monitoring data, time, money, user skills
- Pre- and post-processors, decision support
  - Can data required to assess key information be quickly summarized for decision making
- Technical support
  - Lack of strong technical support for some public models
- Availability (public vs. proprietary)
  - Software cost and licensing fees for proprietary models
- Longevity (short term vs. "living" model)
  - Will the model need to be updated periodically and do appropriate technical resources exist to support the effort?

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Assign Weights to the Selection Criteria

It is important that the selection criteria for the model be weighted by relative importance of the criteria to provide the information needed to make decisions for the watershed management program. For example in the PSW, altered hydrology has been identified as the primary stressor by the stakeholder group and the watershed has some unique hydrologic characteristics, such as the largely undeveloped headwater area with significant wetland areas. Baseflow and storm flow characteristics are both important for understanding issues related to impairment and in identifying solutions to restoring a more natural hydrological regime. This would indicate that the model's ability to predict base flow and storm flow would be a higher weighted criteria than the model's ability to predict water quality concentrations. Another potential criterion where weighting may influence the model selection may be cost to purchase the model and ongoing license fees. If cost is important because of limitations to the modeling budget, cost of the model may receive a high weighting leading to the selection of a public domain model that meets all of the other selection criteria but is less expensive than a proprietary model that equally meets the selection criteria, even though the latter may have other advantages. If water quality data are sparse, then a model that yields pollutant loads instead of concentrations will be better suited to the available data and the weights will reflect it.

Propose Suite of Potential Models

At this point in the model selection process, the model criteria have been defined and weighted and can be presented to a modeling consultant to propose a suite of potential models. Selecting a modeling consultant should be based upon the consultant's knowledge and experience with a broad range of models as well as the consultant's willingness to consider several models in the model evaluation.

While the criteria for the Penjajawoc hydrologic and water quality models have not yet been defined, the following list of models is a potential starting point:

- Public domain
  - Storm Water Management Model (SWMM)
  - Hydrologic Simulation Program Fortran (HSPF)
  - Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (P8)
  - Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS)-Hydrology only
  - Parameter-elevation Regressions on Independent Slopes Model (PRISM) – Hydrology only
  - Generalized Watershed Loading Function (GWLF)
- Proprietary
  - Source Loading and Management Model (WinSLAMM)
  - HydroCAD – Hydrology only
  - Inter-connected Pond Routing (ICPR) Model– Hydrology only
  - MIKE SHE
  - InfoWorks RS
  - SWMM variants (PC-SWMM.NET, XP-SWMM)

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Score Models According to Criteria

Scoring each model according to the selection criteria and their relative weights provides an objective evaluation of the models for the stakeholders. Once the scoring is completed, the modeling consultant should present the results to the stakeholders with an explanation of how the highest ranked models could be applied to the Penjajawoc watershed. This presentation should also present any data gaps or limitations from the existing data set that would impact the accuracy or precision of the results from the highest ranked models. The consultant should also identify what data will be needed for calibration and verification of the highest ranked models so that decisions can be made about on-going monitoring efforts.

Model Selection

Once all of the potential models have been scored and any additional data needs have been identified, a model should be selected by the stakeholders in cooperation with the modeling consultant. It is important that the stakeholders reach consensus on the model selection to foster trust and buy-in on the results produced by the modeling effort.

Proposed Work Plan

A work plan is critical to the success of a comprehensive watershed-based management program. The work plan should clearly define the goals of the program, what activities need to be completed to achieve the goals, and how program success will be measured. It is important to clearly define in the work plan which agency or entity is responsible for each element of the work plan. This clarification will ensure that all activities are cooperative among the agencies and entities involved and not duplicative, utilizing resources that could be used to implement other watershed activities or improvements. It is also important to clearly define the schedule and duration of the work plan activities as multiple aspects of the work plan may need to be completed concurrently. Table 9 includes a framework for a work plan including major items which should be included.

The work plan should be revisited on scheduled intervals to evaluate whether or not goals have been achieved. If goals have been achieved, the work plan can be updated to place a higher priority on other goals that have not yet been achieved. If the highest priority goals have not yet been achieved, the evaluation criteria should be reviewed to determine if progress is being made or if the approach needs to be revised to better achieve the highest priority goals. This process will make the work plan adaptable.

TABLE 9
Work Plan Tasks

Task/Sub-Task	Description	Schedule/Duration	Responsible Agency/Entity
I. Establish Watershed Goals	The stakeholder group should establish a set of goals to be achieved through the implementation of the workplan. The goals should be measureable and set for a specific timeframe so that progress and work plan effectiveness can be evaluated.	Within 3 months of the establishment of the stakeholder charter.	
II. Monitoring			
II.A. Data Collection Plan	Set sampling/data collection protocols,	Within 3 months of the	

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Task/Sub-Task	Description	Schedule/Duration	Responsible Agency/Entity
	schedule, QA/QC	establishment of watershed goals.	
II.B. Hydrologic Monitoring			
Permanent Flow Gauge	The permanent flow gauges will provide hydrologic data for modeling and decision making. The permanent gauges will provide long-term data.		
Temporary Flow Gauges	The temporary flow gauges will provide hydrologic data for modeling and decision making. These gauges will not be needed to provide a long-term data history.		
Permanent Precipitation Gauges	The precipitation gauges will provide data for the hydrologic modeling.		
II.C. Water Quality & Biological Monitoring			
Develop plan for ongoing DEP and Streamteam monitoring	Includes development of QA/QC program		
Develop plan for additional monitoring for Meadow Brook and Mt. Hope Brook			
II.D. Evaluation of Monitoring Efforts	Presentation of results including a summary of QA/QC activities as well as a review of the monitoring plan and recommended changes.		
III. Modeling			
III.A. Selection of Hydrologic Model	Develop model criteria, select model consultant		
III.B. Hydrologic Modeling	Model results, model calibration, model verification		
IV. Stakeholder Process			
IV.A. Establish Stakeholder Charter	Set the rules and processes for stakeholder involvement in the watershed workplan. Establish collective ownership and accountability for goals and tasks.	Initial action & annual revisiting of improvement goals	
IV.B. Identify and Establish Needed Stakeholder Sub-Groups	Sub-groups may be needed to evaluate specific issues in more detail than can be effectively completed by a larger stakeholder group. These groups will study and distill information and present to the larger stakeholder group for consideration.	Initial action & quarterly reporting from sub-group to determine if activated are completed or need to continue.	

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Task/Sub-Task	Description	Schedule/Duration	Responsible Agency/Entity
IV.C. Reporting on Progress			
Reporting on Work Plan Implementation Progress	This will report on progress toward completing action items, but not progress toward goals.	Quarterly with annual revisiting of work plan to adjust schedule if needed.	
Reporting on Status Towards Watershed Goals	Will include regular revisiting of the work plan to determine if adaptation is necessary to achieve goals.	Quarterly with annual revisiting of work plan effectiveness	

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Attachment A

Penjajawoc Stream Watershed Biomonitoring Data

Biomonitoring Metrics – Station S314

Variable No.	Variable Name	1997	2001	2002	2003	2006
1	Total Mean Abundance	490.3333	661.33	564	146.67	1004
2	Generic Richness	33	40	24	40	35
3	Plecoptera Mean Abundance	0.3333	0	0	0	0
4	Ephemeroptera Mean Abundance	2.3333	1.33	0	7.33	85.33
5	Shannon-Weiner Generic Diversity	2.3953	3.38	2.79	3.96	3.18
6	Hilsenhoff Biotic Index	4.0952	7.11	6.33	5.14	4.44
7	Relative Abundance - Chironomidae	0.0136	0.1	0	0.01	0.1
8	Relative Generic Richness Diptera	0.1515	0.4	0.08	0.13	0.31
9	*Hydropsyche* Abundance	301.4776	5.33	0	0.67	402.43
11	*Cheumatopsyche* Abundance	28.8557	0	0	0	18.91
12	EPT Generic Richness/ Diptera Generic Richness	2.8	0.38	1	1.8	0.64
13	*Relative Abundance - Oligochaeta*	0.0014	0.04	0	0	0.02
15	Perlidae Mean Abundance (Family Functional Group)	0.3333	0	0	0	0
16	Tanypodinae Mean Abundance (Family Function Group)	missing	20	0	0	2.74
17	Chironomini Abundance (Family Functional Group)	1	0	1.33	1	46.61
18	Relative Abundance Ephemeroptera	0.0048	0	0	0.05	0.08
19	EPT Generic Richness	14	6	2	9	7
21	Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	missing	1.33	0	3.33	0
23	Relative Generic Richness - Plecoptera	0.0303	0	0	0	0
25	Sum of Abundances: *Cheumatopsyche Cricotopus, Tanytarsus, Ablabesmyia*	33.189	18.67	0	0.33	35.36
26	Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	0.6667	0	0	0	0
28	EP Generic Richness/14	0.4286	0.07	0	0.36	0.14
30	Presence of Class A Indicator Taxa/7	missing	0	0	0	0

Biomonitoring Metrics – Station S315

Variable No.	Variable Name	1997	2001	2002	2003	2006
1	Total Mean Abundance	198.6667	243	302.33	279.33	840
2	Generic Richness	28	69	47	49	32
3	Plecoptera Mean Abundance	0.6667	1.33	0	0	0
4	Ephemeroptera Mean Abundance	5.3333	5.33	10.67	0	76
5	Shannon-Weiner Generic Diversity	3.4455	4.8	3.15	3.79	2.97
6	Hilsenhoff Biotic Index	3.2762	5.17	3.95	5.36	4.5
7	Relative Abundance - Chironomidae	0.0638	0.23	0.08	0.22	0.24
8	Relative Generic Richness Diptera	0.2857	0.36	0.26	0.37	0.38
9	*Hydropsyche* Abundance	32.7857	4.18	0	7.22	401.42
11	*Cheumatopsyche* Abundance	21.2143	11.49	2.33	36.11	41.24
12	EPT Generic Richness/ Diptera Generic Richness	1.25	0.64	0.83	0.56	0.92
13	*Relative Abundance - Oligochaeta*	0.005	0.07	0	0.06	0
15	Perlidae Mean Abundance (Family Functional Group)	0.6667	0.67	0	0	0
16	Tanypodinae Mean Abundance (Family Function Group)	1.6667	6.67	1.09	5.33	4.05
17	Chironomini Abundance (Family Functional Group)	missing	3.33	6.15	2	82.43
18	Relative Abundance Ephemeroptera	0.0268	0.02	0.04	0	0.09
19	EPT Generic Richness	10	16	10	10	11
21	Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	missing	2	6.33	0.33	0
23	Relative Generic Richness - Plecoptera	0.0357	0.04	0	0	0
25	Sum of Abundances: *Cheumatopsyche Cricotopus, Tanytarsus, Ablabesmyia*	22.2143	36.16	13.91	82.78	61.51
26	Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	0.6667	0.67	0	0	0
28	EP Generic Richness/14	0.1429	0.43	0.29	0	0.21
30	Presence of Class A Indicator Taxa/7	0.1429	0	0	0.14	0

Biomonitoring Metrics – Station S511

Variable No.	Variable Name	2001	2002	2003	2006
1	Total Mean Abundance	194	1888	664	2318.67
2	Generic Richness	35	37	33	47
3	Plecoptera Mean Abundance	0	0	0	0
4	Ephemeroptera Mean Abundance	2	2.67	9.33	24
5	Shannon-Weiner Generic Diversity	2.88	3.07	3.01	3.09
6	Hilsenhoff Biotic Index	6.92	6	6.76	4.69
7	Relative Abundance - Chironomidae	0.33	0.72	0.21	0.32
8	Relative Generic Richness Diptera	0.46	0.38	0.24	0.4
9	*Hydropsyche* Abundance	0	2.67	0	1014.36
11	*Cheumatopsyche* Abundance	0	20	0	97.64
12	EPT Generic Richness/ Diptera Generic Richness	0.38	0.36	1	0.58
13	*Relative Abundance - Oligochaeta*	0	0	0.02	0.01
15	Perlidae Mean Abundance (Family Functional Group)	0	0	0	0
16	Tanypodinae Mean Abundance (Family Function Group)	3.5	16.6	8	12.29
17	Chironomini Abundance (Family Functional Group)	51	140.31	25.33	270.4
18	Relative Abundance Ephemeroptera	0.01	0	0.01	0.01
19	EPT Generic Richness	6	5	8	11
21	Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	1	279.12	0	191.19
23	Relative Generic Richness - Plecoptera	0	0	0	0
25	Sum of Abundances: *Cheumatopsyche Cricotopus, Tanytarsus, Ablabesmyia*	3	75.82	85.33	101.74
26	Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	0	0	0	1.33
28	EP Generic Richness/14	0.07	0.07	0.21	0.29
30	Presence of Class A Indicator Taxa/7	0.14	0	0	0

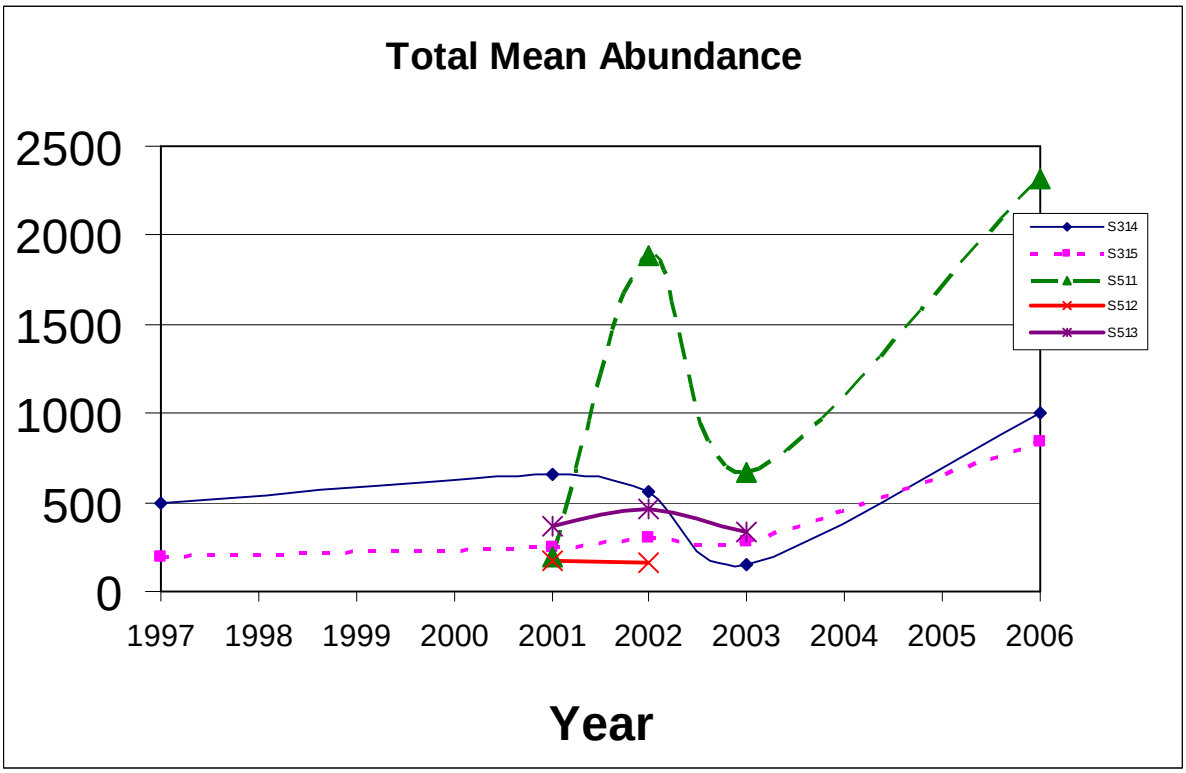
Biomonitoring Metrics – Station S512

Variable No.	Variable Name	2001	2002
1	Total Mean Abundance	174	162.67
2	Generic Richness	66	47
3	Plecoptera Mean Abundance	0	0
4	Ephemeroptera Mean Abundance	0.67	0.33
5	Shannon-Weiner Generic Diversity	4.69	3.5
6	Hilsenhoff Biotic Index	6.36	6.75
7	Relative Abundance - Chironomidae	0.35	0.25
8	Relative Generic Richness Diptera	0.45	0.34
9	*Hydropsyche* Abundance	0	0.33
11	*Cheumatopsyche* Abundance	0.67	0.33
12	EPT Generic Richness/ Diptera Generic Richness	0.3	0.38
13	*Relative Abundance - Oligochaeta*	0.04	0.02
15	Perlidae Mean Abundance (Family Functional Group)	0	0
16	Tanypodinae Mean Abundance (Family Function Group)	18.77	1.74
17	Chironomini Abundance (Family Functional Group)	3.02	0.7
18	Relative Abundance Ephemeroptera	0	0
19	EPT Generic Richness	9	6
21	Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	13.41	5.07
23	Relative Generic Richness - Plecoptera	0	0
25	Sum of Abundances: *Cheumatopsyche Cricotopus, Tanytarsus, Ablabesmyia*	5.69	1.72
26	Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	0	0
28	EP Generic Richness/14	0.14	0.07
30	Presence of Class A Indicator Taxa/7	0	0

Biomonitoring Metrics – Station S513

Variable No.	Variable Name	2001	2002	2003
1	Total Mean Abundance	364	462.67	329.33
2	Generic Richness	37	36	45
3	Plecoptera Mean Abundance	0	0	0
4	Ephemeroptera Mean Abundance	6.67	8	4.33
5	Shannon-Weiner Generic Diversity	2.91	3.25	3.57
6	Hilsenhoff Biotic Index	5.67	5.86	4.75
7	Relative Abundance - Chironomidae	0.16	0.35	0.04
8	Relative Generic Richness Diptera	0.38	0.36	0.24
9	*Hydropsyche* Abundance	0	0	2.67
11	*Cheumatopsyche* Abundance	1.33	0	5.67
12	EPT Generic Richness/ Diptera Generic Richness	0.43	0.54	0.91
13	*Relative Abundance - Oligochaeta*	0.03	0.01	0.2
15	Perlidae Mean Abundance (Family Functional Group)	0	0	0
16	Tanypodinae Mean Abundance (Family Function Group)	22.89	17.18	4.11
17	Chironomini Abundance (Family Functional Group)	12.88	4.69	1.71
18	Relative Abundance Ephemeroptera	0.02	0.02	0.01
19	EPT Generic Richness	6	7	10
21	Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	1.43	1.56	0
23	Relative Generic Richness - Plecoptera	0	0	0
25	Sum of Abundances: *Cheumatopsyche Cricotopus, Tanytarsus, Ablabesmyia*	15.64	135.89	11.15
26	Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	0	0	0
28	EP Generic Richness/14	0.14	0.21	0.29
30	Presence of Class A Indicator Taxa/7	0	0	0

Graphs


Total Mean Abundance
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1500
1000
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1999
2000
2001
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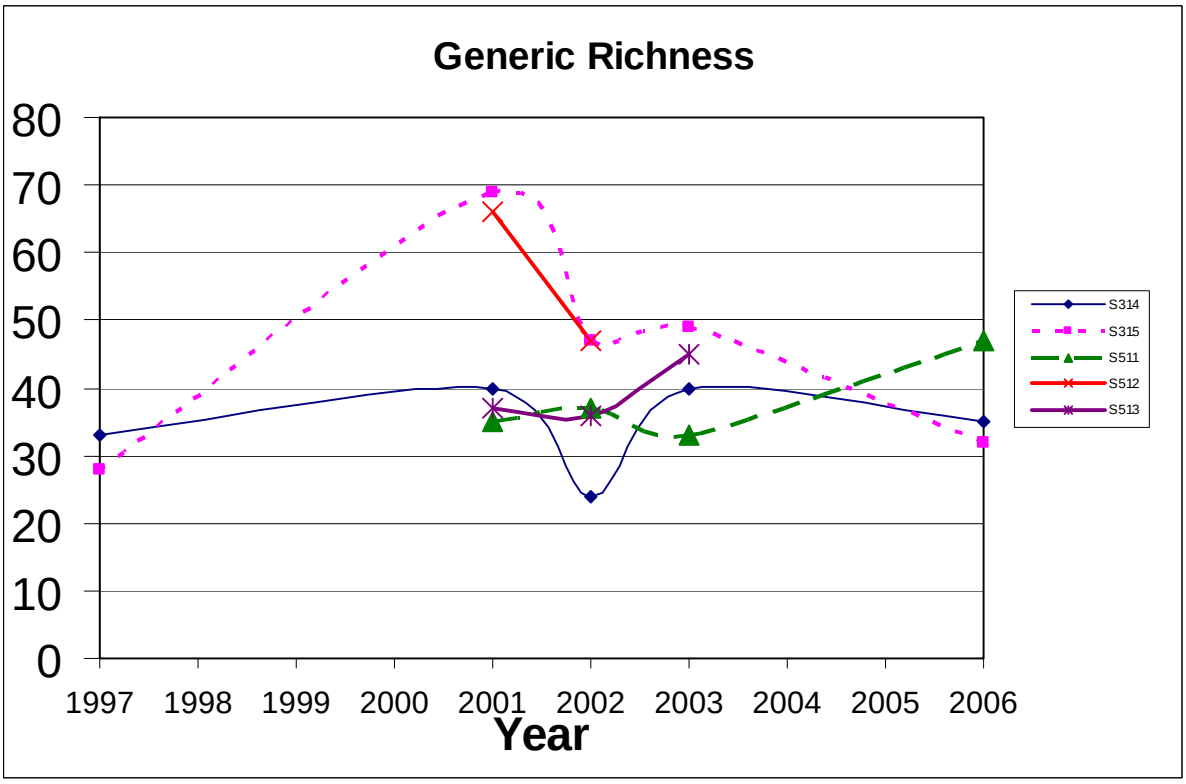
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513


Generic Richness
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70
60
50
40
30
20
10
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1999
2000
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S315
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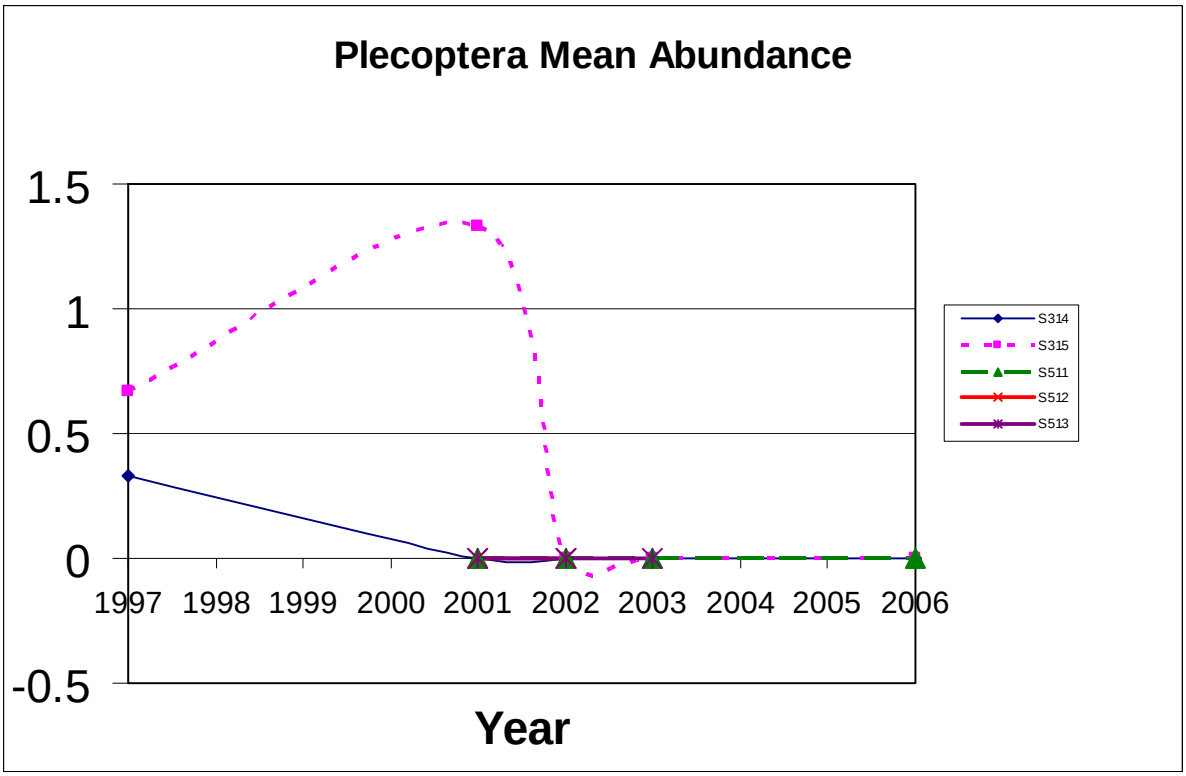
S513


Plecoptera Mean Abundance
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1
0.5
0
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1998
1999
2000
2001
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2003
2004
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S314
S315
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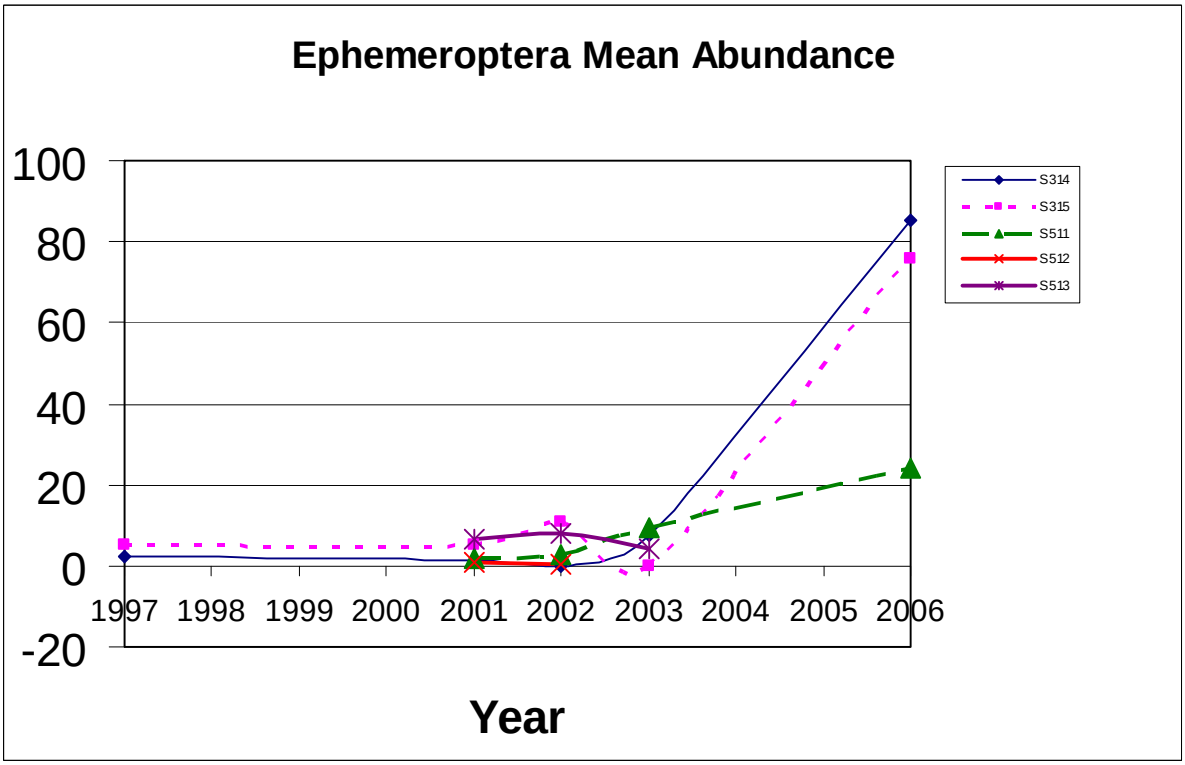
S512
S513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80
60
40
20
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2000
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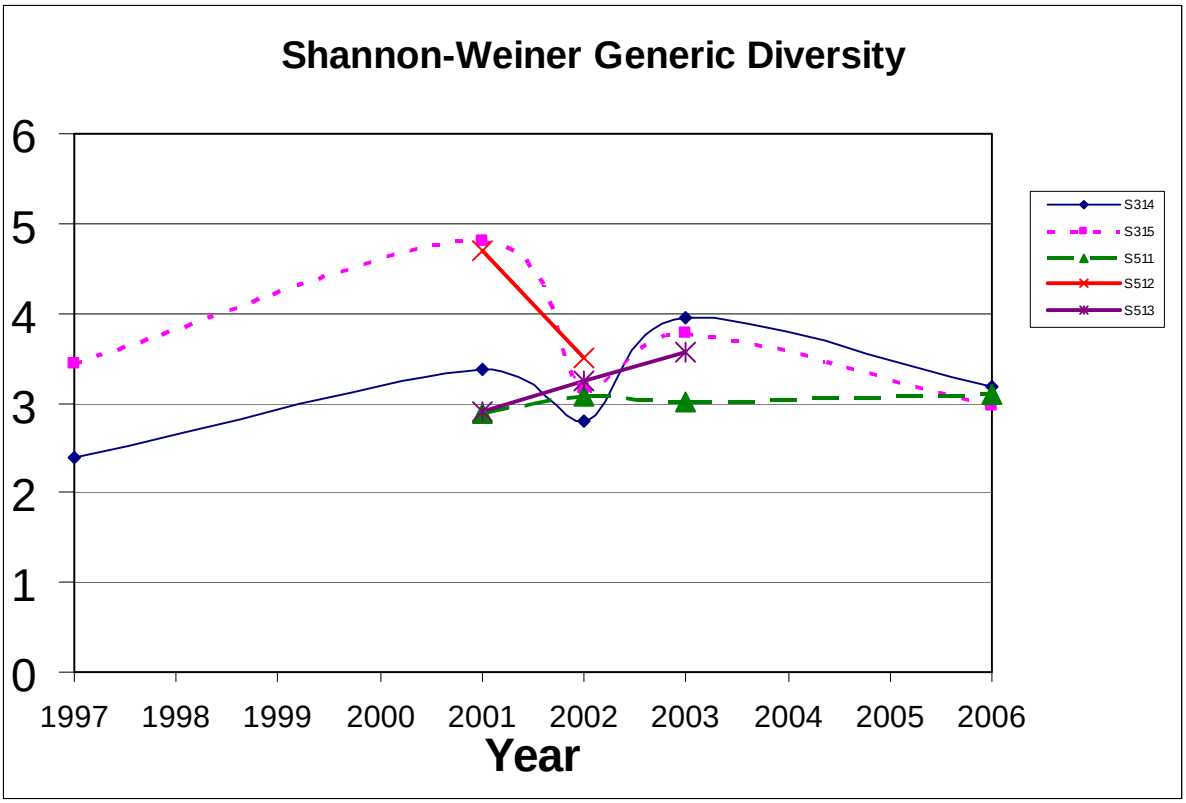
S512
S513


Shannon-Weiner Generic Diversity
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5
4
3
2
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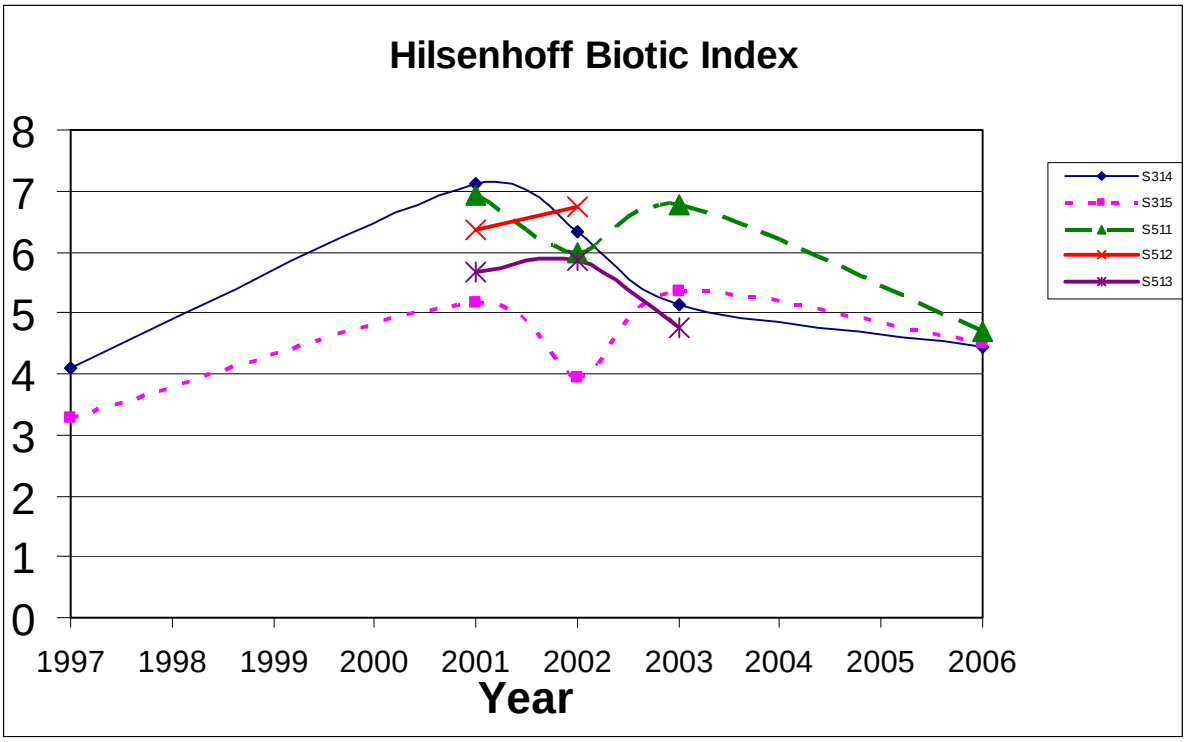
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513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8
7
6
5
4
3
2
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2003
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2005
2006
Year
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S315
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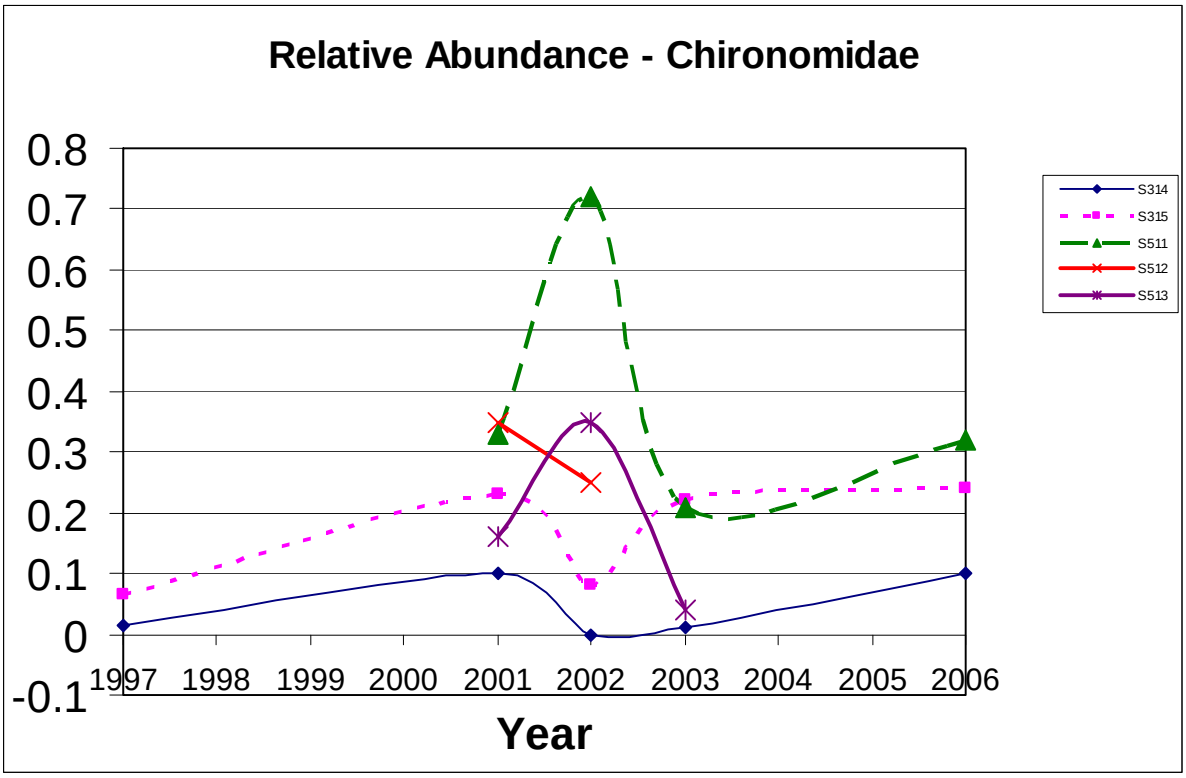
S512
S513


Relative Abundance - Chironomidae
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0.4
0.3
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S314
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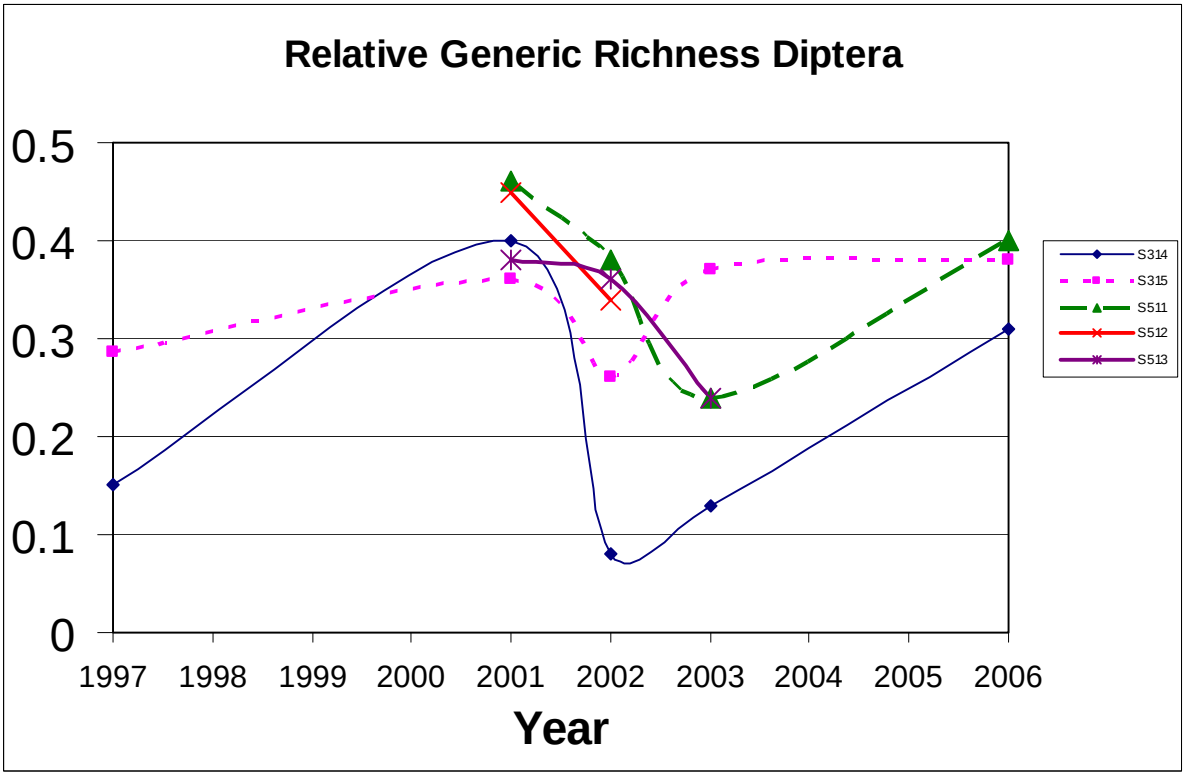
Relative Generic Richness Diptera
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0.4
0.3
0.2
0.1
0
1997
1998
1999
2000
2001
2002
2003
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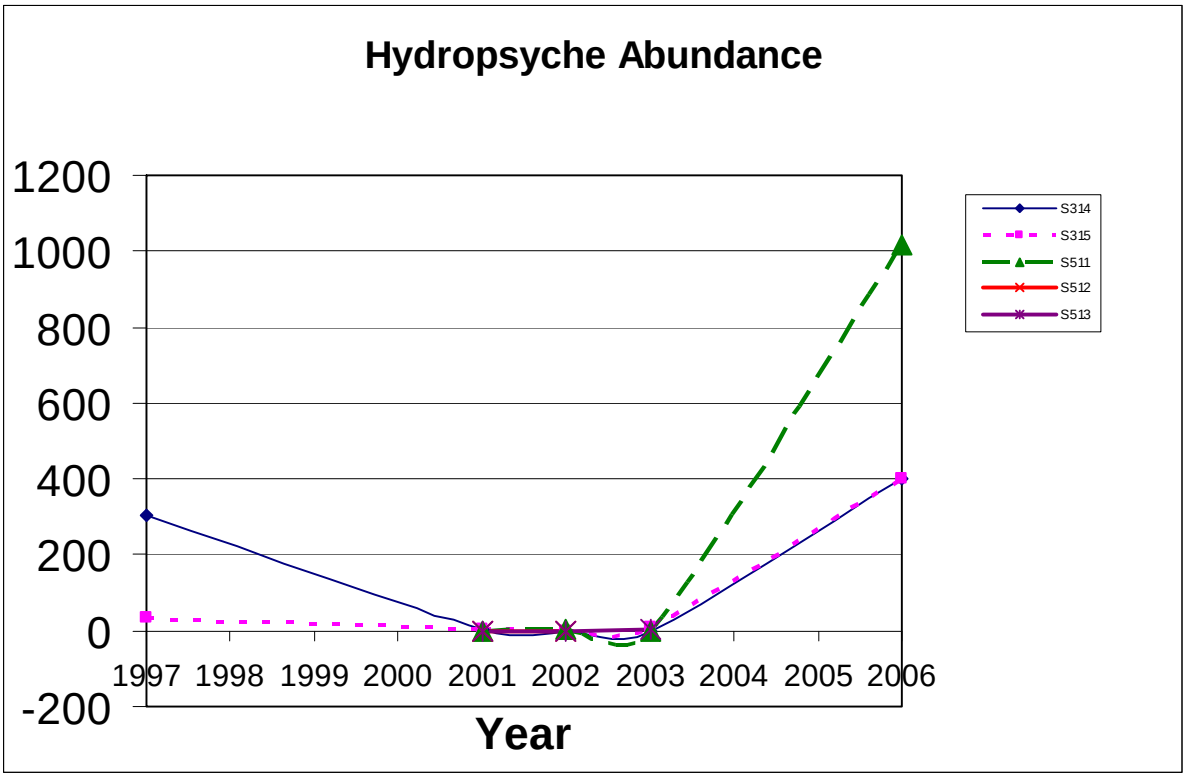
S314
S315
S511
S512
S513


Hydropsyche Abundance
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1000
800
600
400
200
0
-200
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
Year
S314
S315
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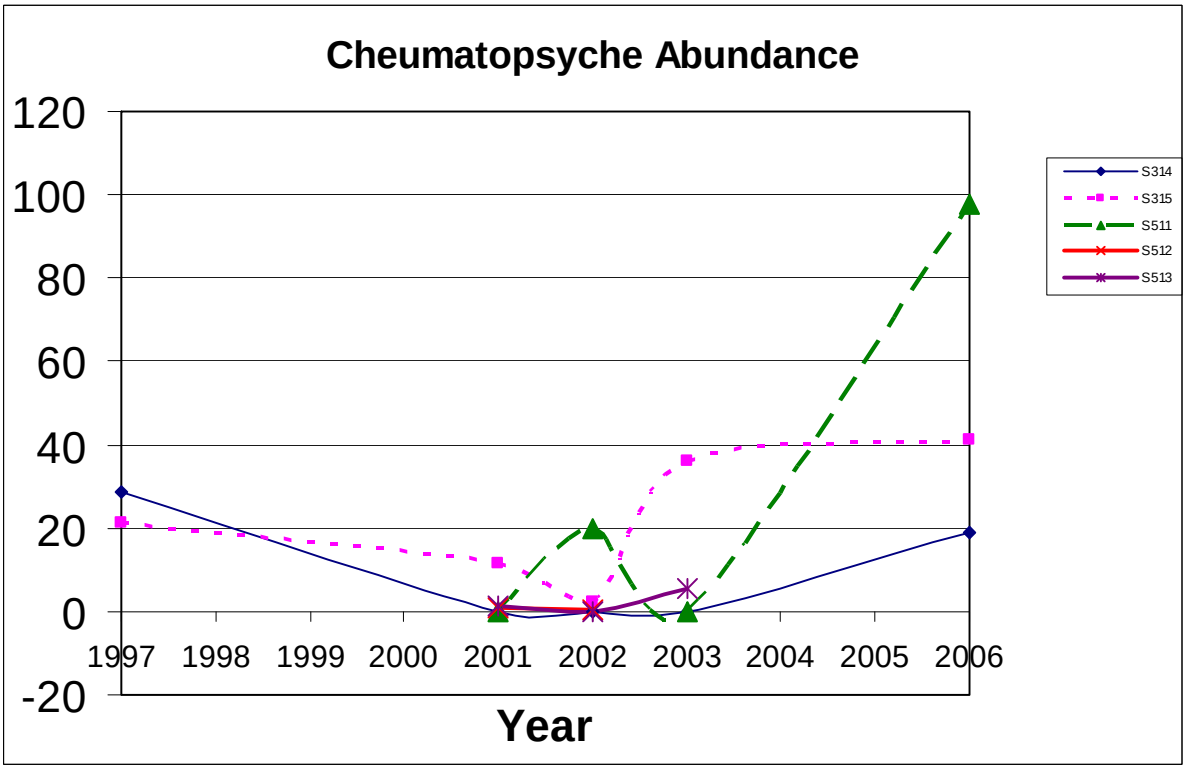
S512
S513


Cheumatopsyche Abundance
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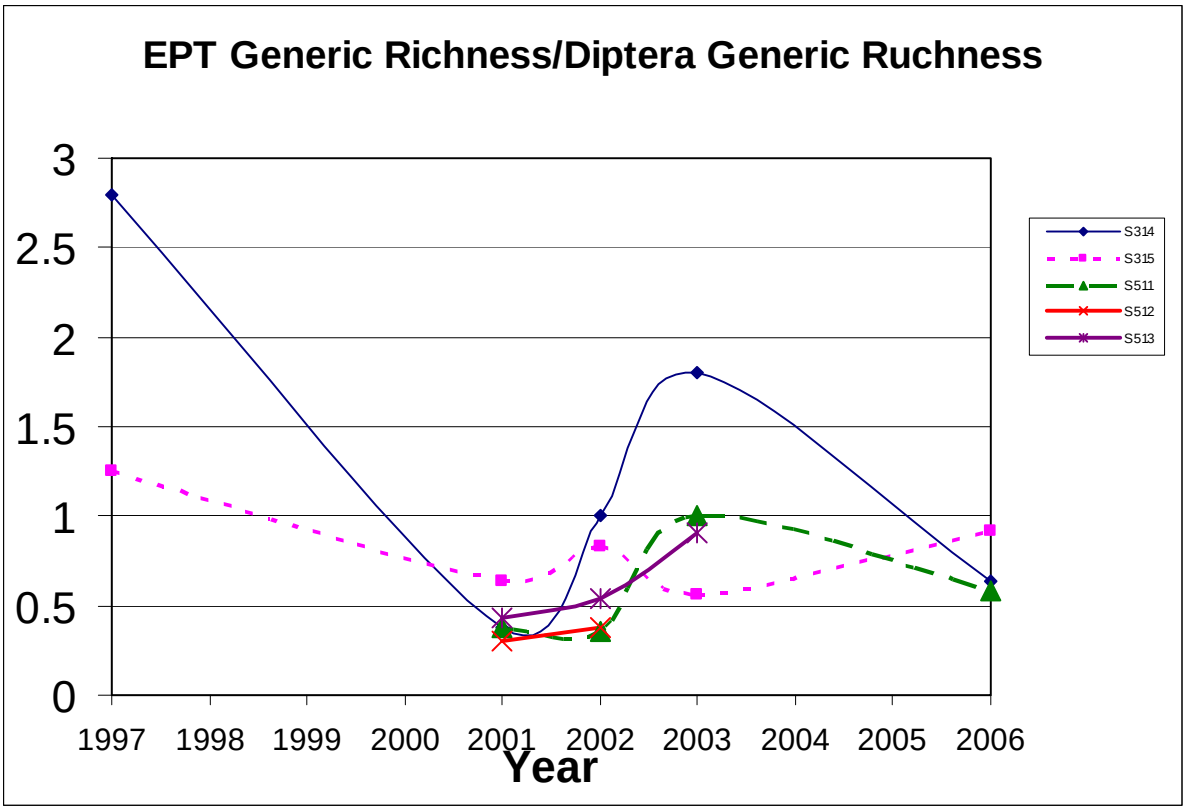
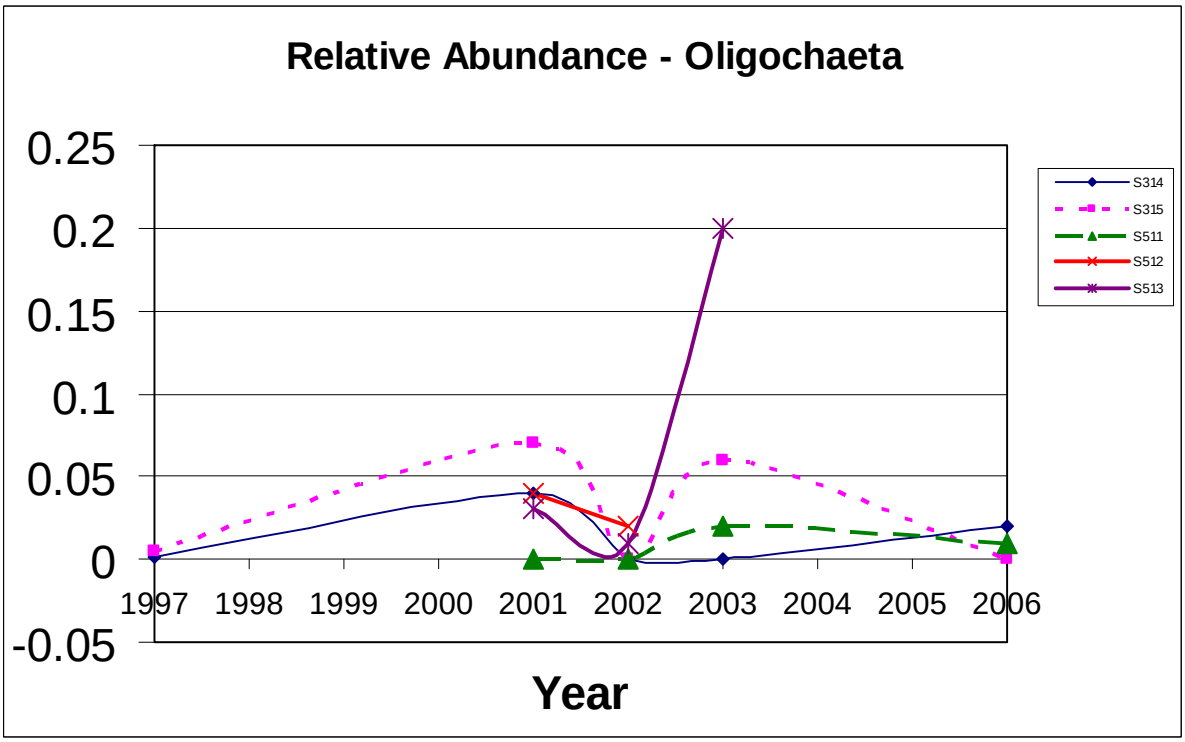
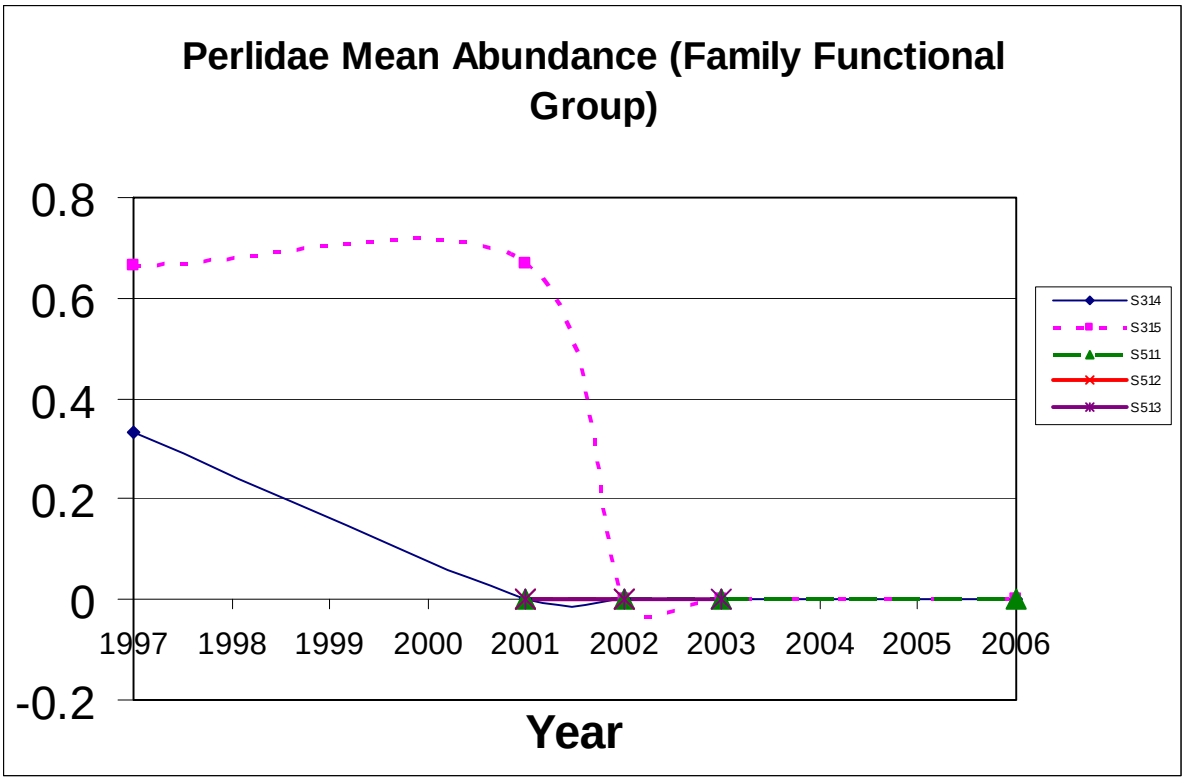
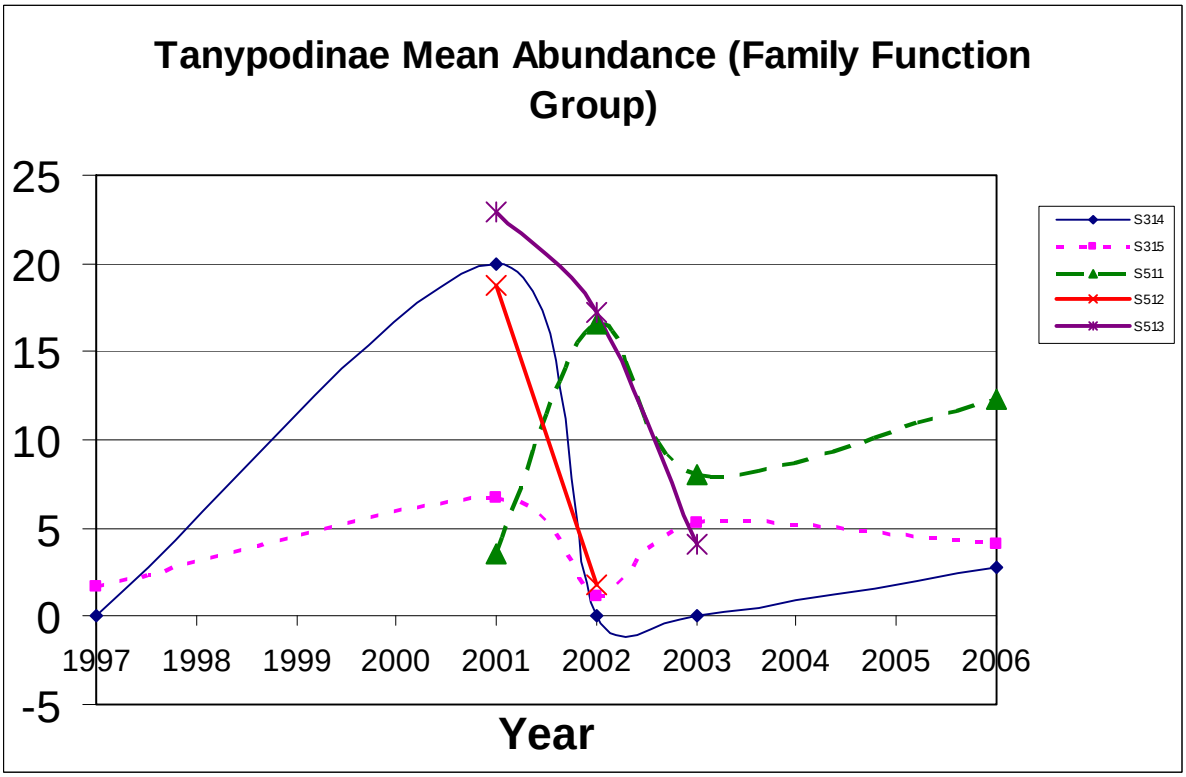
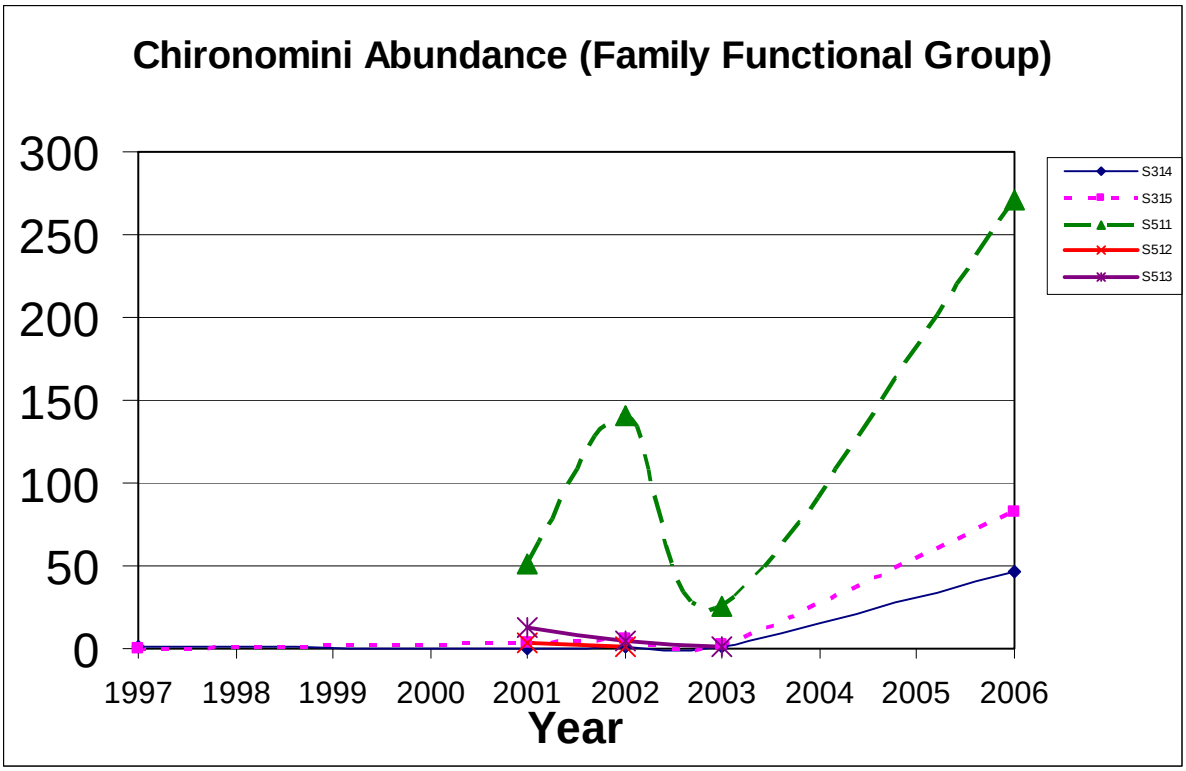
100
80
60
40
20
0
-20
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
Year
S314
S315
S511
S512
S513

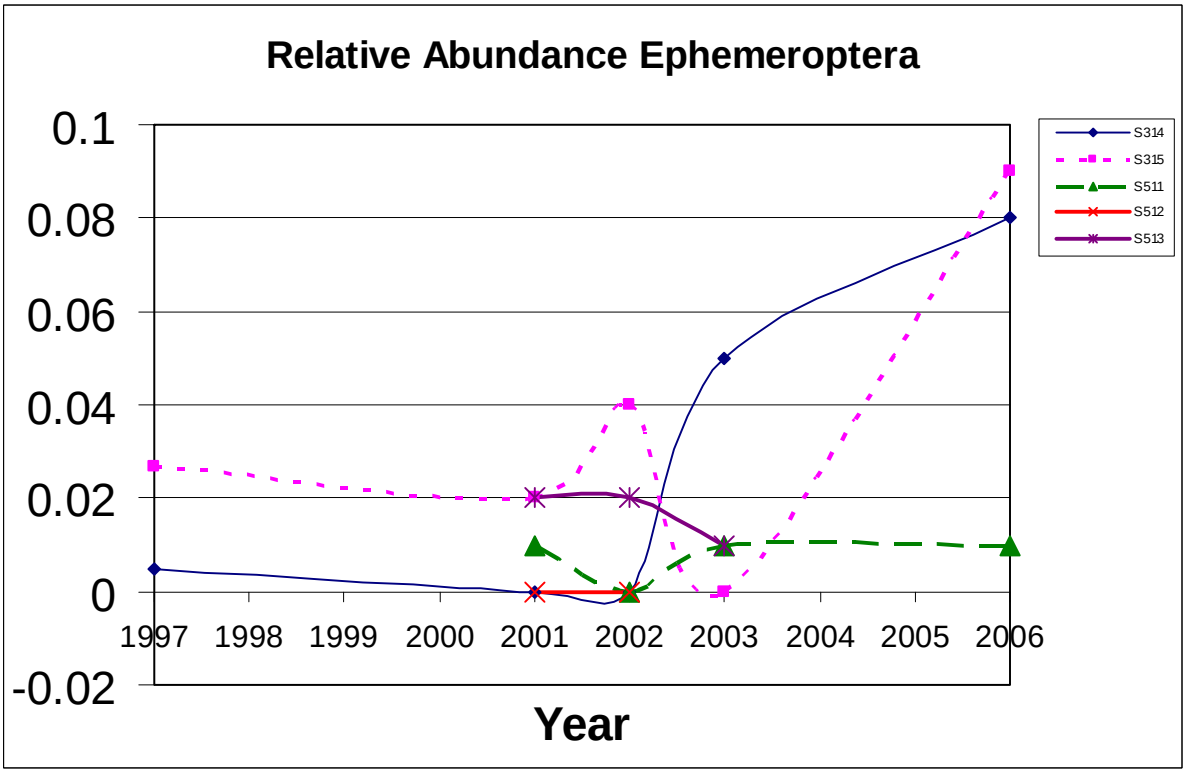

EPT Generic Richness/Diptera Generic Ruchness
3
2.5
2
1.5
1
0.5
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

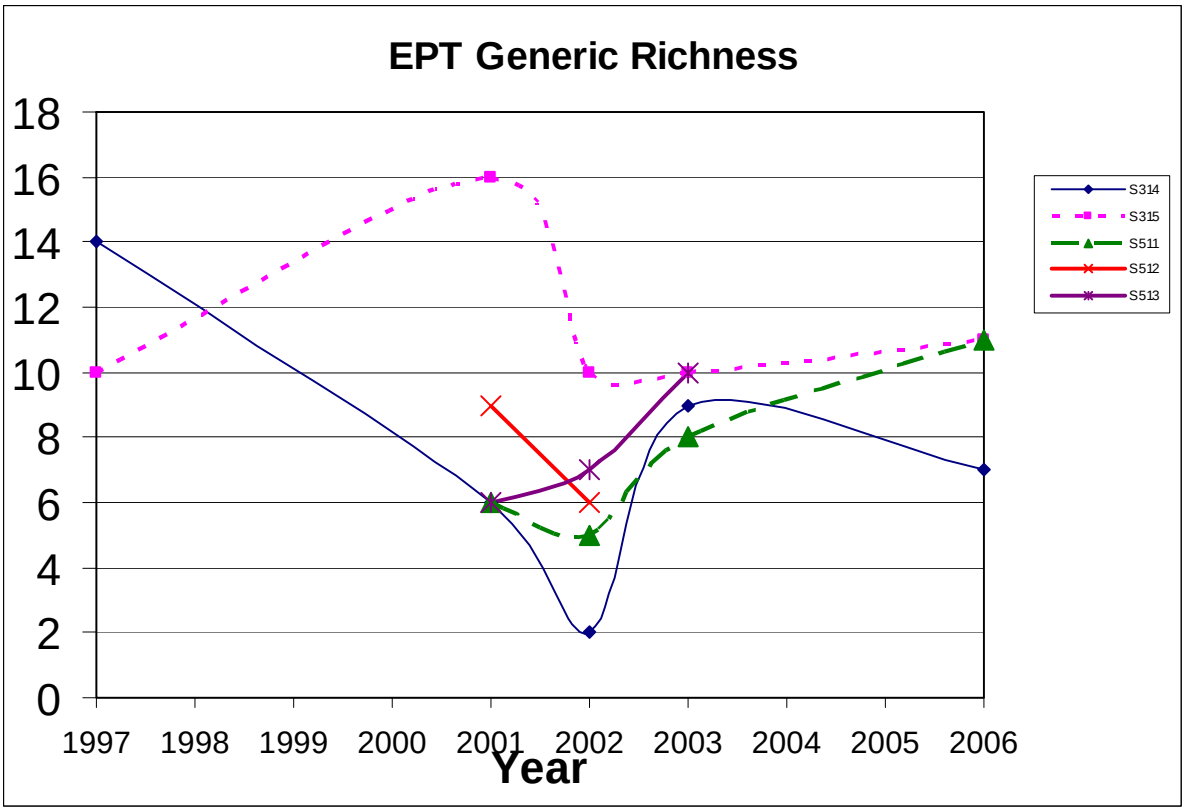

Relative Abundance - Oligochaeta
0.25
0.2
0.15
0.1
0.05
0
-0.05
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

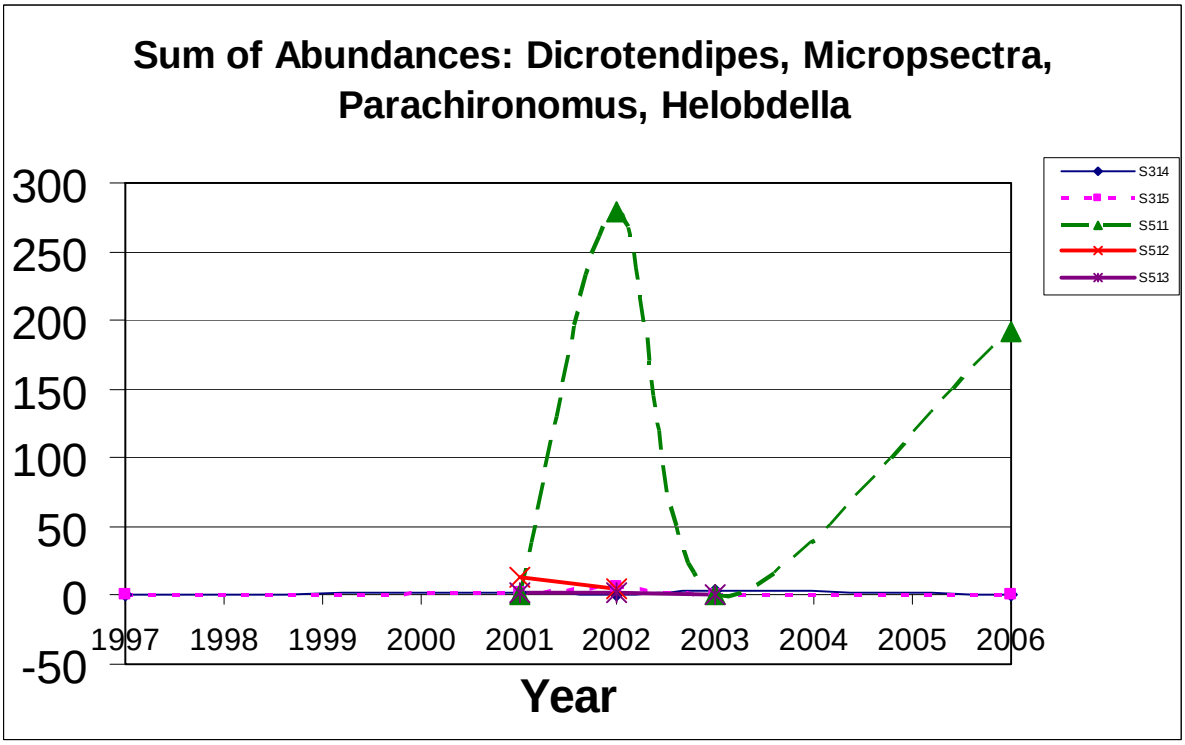

Perlidae Mean Abundance (Family Functional Group)
0.8
0.6
0.4
0.2
0
-0.2
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

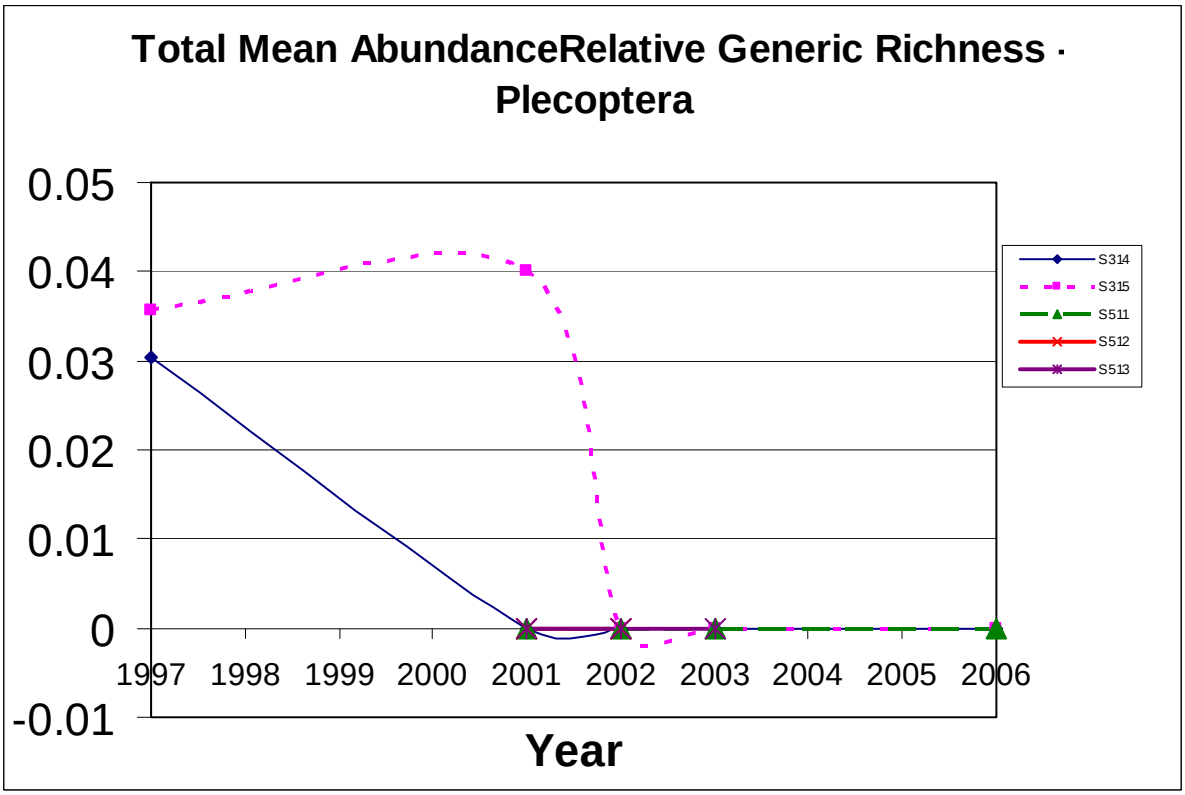

Tanypodinae Mean Abundance (Family Function Group)
25
20
15
10
5
0
-5
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

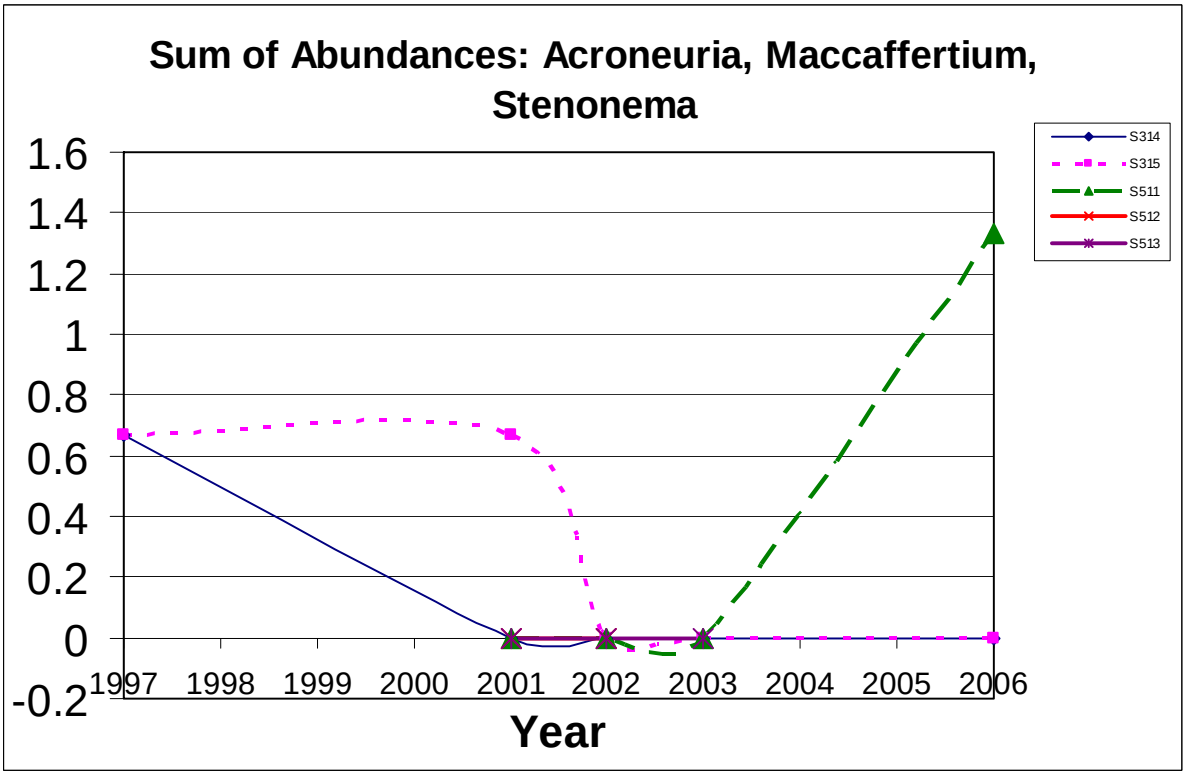

Chironomini Abundance (Family Functional Group)
300
250
200
150
100
50
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

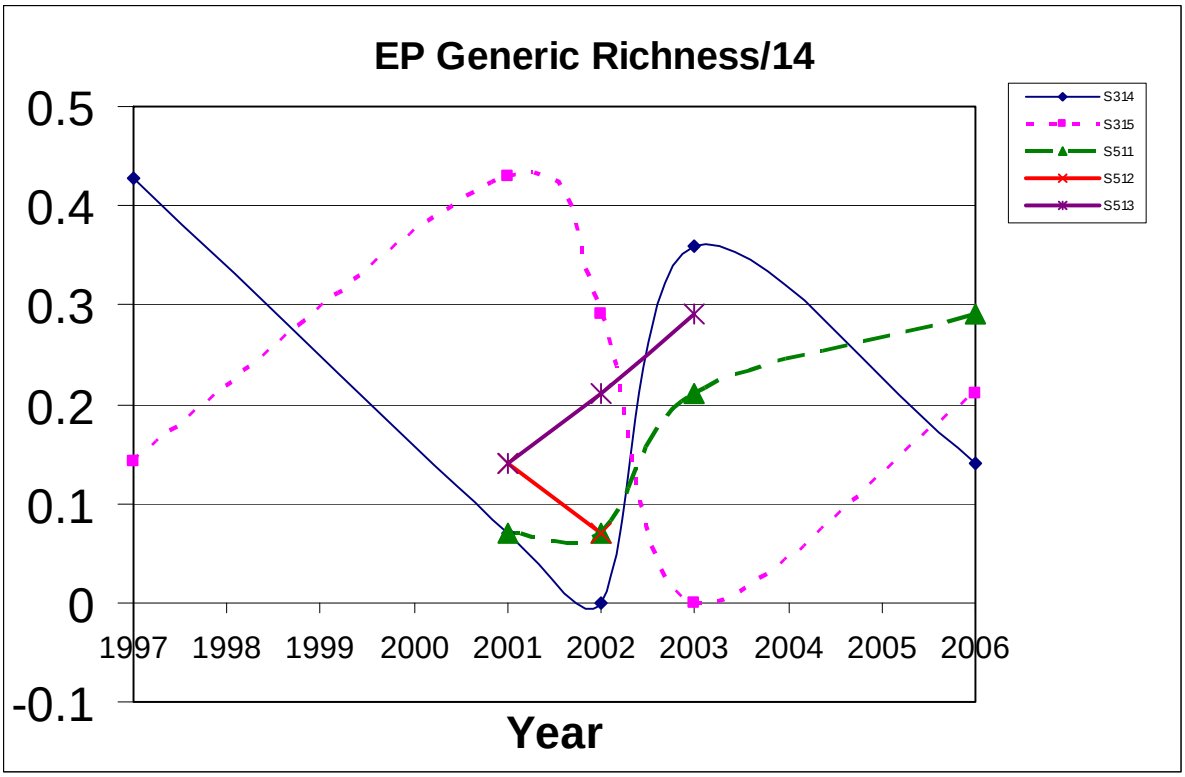

Relative Abundance Ephemeroptera
0.1
0.08
0.06
0.04
0.02
0
-0.02
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

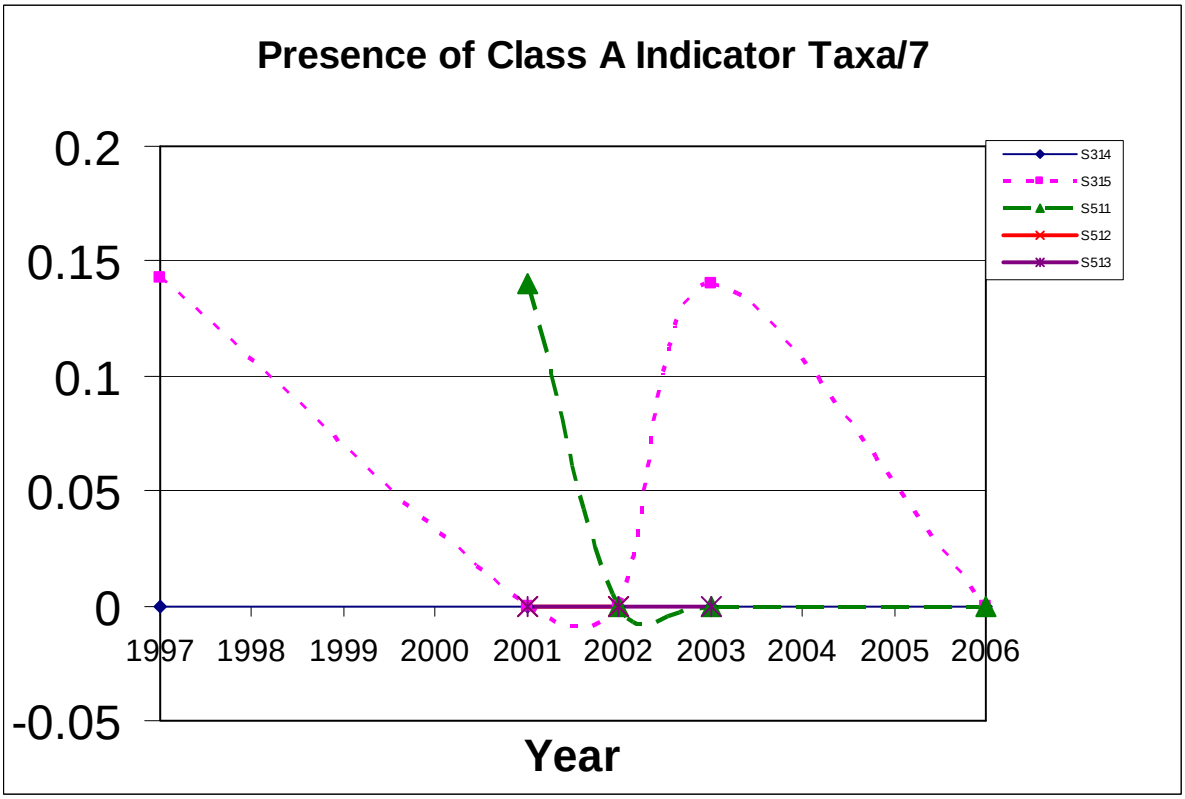

EPT Generic Richness
18
16
14
12
10
8
6
4
2
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513


Sum of Abundances: Dicrotendipes, Micropsectra, Parachironomus, Helobdella
300
250
200
150
100
50
0
-50
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513


Total Mean AbundanceRelative Generic Richness - Plecoptera
0.05
0.04
0.03
0.02
0.01
0
-0.01
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513


Sum of Abundances: Acroneuria, Maccaffertium, Stenonema
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513


EP Generic Richness/14
0.5
0.4
0.3
0.2
0.1
0
-0.1
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513


Presence of Class A Indicator Taxa/7
0.2
0.15
0.1
0.05
0
-0.05
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
S314
S315
S511
S512
S513

Attachment B

Minutes and Presentation Information from Workshop No. 1 – October 9, 2008

Penjajawoc Stream Watershed Stakeholder Workshop

ATTENDEES:

Chet Bigelow/Sewall
Jeff Dennis/MEDEP
Mary Ellen Dennis/MEDEP
Melissa Evers/MEDEP
James Gerety/Bangor Mall
Bruce Grantham/LOTIC
Andy Hamilton/Eaton Peabody
Joyce B. Hedlund/Eastern Maine Community College
Ed Logue/MEDEP
Brad Medling/Bangor Mall
Art Morgan/City of Bangor
John Murphy/City of Bangor
Beth Nagusky/MEDEP
Paul Nicklas/City of Bangor
Lucy Quinby/Stakeholder
Jim Ring/City of Bangor
Mark Ward/City of Bangor
Wendy Warren/City of Bangor
Tim Woodcock/Eaton Peabody
Barbara Arter
George Elliott

FROM: Bill Kreutzberger/CH2M HILL
Becky Weig/CH2M HILL

DATE: October 23, 2008

On Thursday October 9, 2008 a stakeholder workshop was held at Bangor City Hall to review the data summary and recommendation made by CH2M HILL in its draft technical memorandum (TM) *Penjajawoc Stream Watershed Analysis and Options for Refining Management Recommendations* and to discuss options and next steps for Penjajawoc watershed management. The following is a summary of the items presented and the discussions that followed.

The workshop was opened by Art Morgan from the City of Bangor. Mr. Morgan introduced Bill Kreutzberger from CH2M HILL who facilitated the workshop. The agenda for the workshop is attached to this meeting summary. Bill Kreutzberger reviewed the planned objectives of the workshop and asked the workshop participants to identify their objectives for the workshop. The objectives identified by the participants were:

- A step-by-step process for monitoring
- Understanding of data completion and possibility of attaining Class B
- A collective understanding of what we have and what we need to do and how to get the best results for the money invested.
- A defined stakeholder process
- Consensus on the science and next steps

Following the identification of the workshop objectives, Bill Kreutzberger presented an overview of the draft TM. The first topic covered was a review of the watershed characteristics. This included how the watershed was characterized in the different models of the watershed and the gaps in these characterizations. One item discussed was the fact that the existing models were not calibrated. Attendees wanted to know what calibration

was and why it was important. It was explained that these models use precipitation and temperature to predict flow and real data is needed to check the model's accuracy.

The next topic was a review of monitoring results from the watershed. Bill Kreutzberger presented a summary of the biomonitoring, water quality, habitat, and geomorphology data for the watershed. The participants discussed that the nutrients from the wetland in the upper portion of the watershed are mostly uncontrollable. From the data summary, it appears that these impacts are worse in dry years and better in wet years, which may be due to dilution. In wet years, the wetland is almost acting like a stream. Nutrient criteria in Maine are still draft. The proposed limits are 0.033 mg/L for phosphorus and 0.04 mg/L for nitrogen. In 2002, there was a condensate discharge (below station PJ1) that was about one-half of the stream flow. This affected conductivity, but not at the reaches presented. None of the other well know contaminants of urban stormwater were ate concentrations of concern. Jeff Dennis from Maine Department of Environmental Protection (MEDEP) stated that these contaminants would show up in storm event data but there has been no storm monitoring in the watershed. Melissa Evers from MEDEP stated that there is some metals data for the Penjajawoc watershed for both base flow and storm flow. Maine has adopted all Environmental Protection Agency (EPA) metals water quality criteria.

There were a number of other comments from the participants on the data review:

- Melissa Evers of MEDEP stated that the results presented for the Penjajawoc watershed are consistent with other urban streams in Maine. Bill Kreutzberger stated that what he typically sees is urbanization starting at the ridgeline (headwaters).
- Wendy Warren from the City of Bangor asked if other states wait for better hydrologic data in the watershed before implementing improvements. Bill Kreutzberger stated that other watersheds do usually wait on good hydrologic data before starting restoration activities. This is very important if redesigning the stream channel. This also needs to account for future land use and not just current conditions.
- There are references to ponds in reports about the watershed; does this refer to natural ponds or detention/retention? In the Penjajawoc watershed reports it is referring to detention/ retention ponds, but there are also some beaver ponds in some areas.

The next topic covered was a review of stressors in the watershed. There was a stressor workshop held by MEDEP in 2004 that identified the stressors believed to be impacting the watershed. Bill Kreutzberger presented a proposed prioritization of these stressors for the watershed and asked the participants to discuss and comment on the prioritization. It was suggested that it might be good to separate out the Mt. Hope Brook and Meadow Brook subwatersheds in the stressor prioritization.

Jim Ring from the City of Bangor noted that temperature appears to be a lesser factor upstream and greater factor downstream and that this seems backwards given that the upper reaches are wide open and shallow near the marsh. Jeff Dennis stated that the stream is pretty well shaded after Petco. Also, the stressor analysis was also based only on bugs and what stresses them and this is why there was more stress in the lower reached of the watershed. Jim Ring asked if shading is better in the lower watershed than the middle of the watershed. Jeff Dennis stated that there are pretty open sections in both reaches. Melissa Evers stated that Meadow Brook is so cold it is almost like groundwater when it enters

Penjajawoc Stream and this impacts temperature in the lower section. There is not a lot of data on the Mt. Hope subwatershed.

Wendy Warren asked why habitat is included as a stressor if its rating is subjective. All the other stressors listed affect habitat. Could numbers be placed in the stressor table rather than yeses and maybes? Jeff Dennis stated that the purpose of stressor workshop was to evaluate how each of the stressors was affecting the bugs. Altered hydrology is probably best addressed first because other stressors such temperature, dissolved oxygen (DO), nutrients, metals, and sediment can be improved from this work.

George Elliott asked what the issue was with high temperature. Bill Kreutzberger stated that if this to be a cold water fishery (Jeff Dennis said it would be for a class B stream such as the Penjajawoc Stream) needs to be close to 20^0C. Jeff Dennis stated that MEDEP would be happy with temperature of 22^0C and lower.

Bill Kreutzberger stated that the data review identified that there are impairments and that they next portion of the workshop would be to discuss what we want to affect as we move to watershed management.

Andy Hamilton stated that there is an EPA methodology for evaluating habitat that has not been used to date in the watershed. Bill Kreutzberger stated that the EPA methodology has not yet been used in the watershed, but that the issues of open canopy and lack of woody debris are well identified. There is more habit data that was collected as part of the geomorphology study that wasn't included in the draft TM. MEDEP will make this data available for inclusion in the final TM. Melissa Evers stated that it is hard to put habitat in neat package.

Andy Hamilton asked that given the warmer temperatures in upper reaches, what are the water quality objectives with respect to temperature and trying to establish a cold-water fishery? Jeff Dennis stated that warmer temperatures are expected out of the wetland. A Class B stream needs to support trout and stoneflies and DEP wants to see the Penjajawoc Stream get back to that natural setting, which will mostly require shading.

Andy Hamilton stated that he was not aware of any trout fisheries that start in a wetland. With beavers colonizing in the watershed as well, we need to be sensible in what try to accomplish in the watershed. Jeff Dennis stated that there are some Class B streams that start in open wetlands.

Lucy Quinby asked where on Penjajawoc Stream do we think the stream starts to meet target temperature? Melissa Evers stated that in high flow years temperature values are probably fine right from the marsh. In low flow years, this would not be the case. A minor temperature excursion is not a big deal, but elevated temperatures over long periods (days) stress the biology. Lucy Quinby stated that she has heard many complaints about the bog and wants to know what the temperature target should be with the bog taken into consideration. Bill Kreutzberger stated that to the extent that the bog is a natural system, any deviations are not violations. Lucy Quinby stated that upstream on Land Trust preserve everything is fine coming out of a smaller bog. MEDEP stated that it is assumed that the reason for this is consistent good flow, rocks for reaeration and good shading. They believe that this would be the same if the conditions were the same below the big bog.

Barbara stated that we have yet to discuss the importance of groundwater and springs. She believes that we should not be making assumptions until we figure this out. These cold-water inputs can occur anywhere along the stream. The term habitat is an open-ended term. It is made up of all the parameters put together. We need to think about putting the stream back to its natural ecosystem. Bill Kreutzberger stated that it would be good to discuss if there are differences in wetland types between the two bogs in the watershed.

The next topic was a discussion of gaps for watershed assessment information. The participants identified the following data gaps:

- Flow data (there is some with temperature data for Birch Stream)
- Local precipitation monitor (15 minute recoding gauge)
- Flow baseline/stream survey for purposes of identifying additional groundwater inputs (under drains) or retrofit to the Mall pond. We would need to know groundwater quality before these were done.
- Illicit discharge detection program.

Barbara Arter thought that there is a fair amount of data on the Penjajawoc Stream and wondered how it compares to other impaired streams in Maine. The MEDEP states that compared to other Maine streams it is data rich. Bill Kreutzberger noted that for all the data there is no flow or hydrology data. A stakeholder noted that Penjajawoc Stream being more data rich than other streams is not a useful comparison, as we need to address the requirements for this stream per the legislature. Is there confidence that the missing flow data is not important or do we need it? Jeff Dennis stated it would be great to have it and to calibrate a flow model, but just setting the target is no guarantee that the stream will be Class B. The process will be iterative. Iterations can be small and not go beyond where you need to go or can be aggressive and be sure you will meet target and not have to go back and do more. Bill Kreutzberger noted that attainment in urban streams is a moving target because of development. There is no formula to meet biological classification. Right now, we do not know what is a little or what is a lot in terms of measures of success.

Jim Ring suggested that the group identify what gaps there are and then decide if they are significant in terms of what we are trying to address. Flow data and calibration of hydrology models is important in order to do lasting stream restoration. This data could be collected short term and added to over time. Bill Kreutzberger stated that there is going to be a sequence to restoration activities because we do not want to plant trees if there needs to be bank stabilization.

Bill Kreutzberger asked the attendees to discuss management indicators for the watershed. For example, in Virginia sediment was the first indicator and then other indicators were focused on. For Penjajawoc Stream, it appears that hydrology will be the first indicator. The attendees identified the following implications for the watershed management plan:

- We need to have a method to measure impacts, probably flow duration curves.
- Need to be careful of being too focused on flow; it is not the only indicator.
- What is the impact of erratic flow on the biological community?
- Need to understand the natural condition of Penjajawoc stream so that we do not try to stop something that occurs naturally for this stream.

Melissa Evers asked if Rouge River like flow-durations curves be done for Penjajawoc Stream with the existing SWMM model. Bill Kreutzberger stated that the Rouge River modeling was done in HSPF.

For habitat assessment, a number of states have methods to quantitatively assess habitat. The EPA method comes up with a number. This may need to be done for Penjajawoc Stream.

The next topic was a discussion of next steps. Concerning monitoring, Melissa Evers stated that the Quality Assurance Project Plan (QAPP) for the Stream Team monitoring was almost complete.

For modeling, Art Morgan stated that it would be helpful if models selected were models that the local engineering community is comfortable with. Bill Kreutzberger stated that HydroCAD is a tool and BMP design model. There is now a watershed Infoworks model much like for wastewater collection and water distribution.

The group discussed that there are multiple monitoring station naming plans. Barbara stated that there is a reason why there is different station naming. The Stream Team data is different from other monitoring data.

Barbara stated that there is an opinion to view each subwatershed as a discharge. It needs to be cool, have pollutants removed, and it needs to have flow control. This is another way that the stakeholders may want to approach this. If this can be done on experimental basis on some sites it could be monitored and studied. Art Morgan stated that this is being done. The City is talking to some people about doing riparian repairs right below I-95. Andy Hamilton stated that this is an opportunity is to put some of these projects together with data to educate ourselves about what is going to work. The big issue will be funding in lean times. Barbara stated that we do not want to make the process too complicated.

Bruce Grantham from Lotic stated that the current Penjajawoc biological community is in response to current conditions. We are trying to add to the community not change the community. What are missing are organisms that require colder, more consistent, larger sustained flows throughout the year. An aspect of the target may be to do literature reviews to see what the sensitive taxa need and make that an initial target. A consistent community of stoneflies needs specific conditions to survive. Shading and cooling temperatures will aid this process but the stream is going to need higher sustained flows over a longer period of time. A participant asked if there proper vegetation for reproduction.

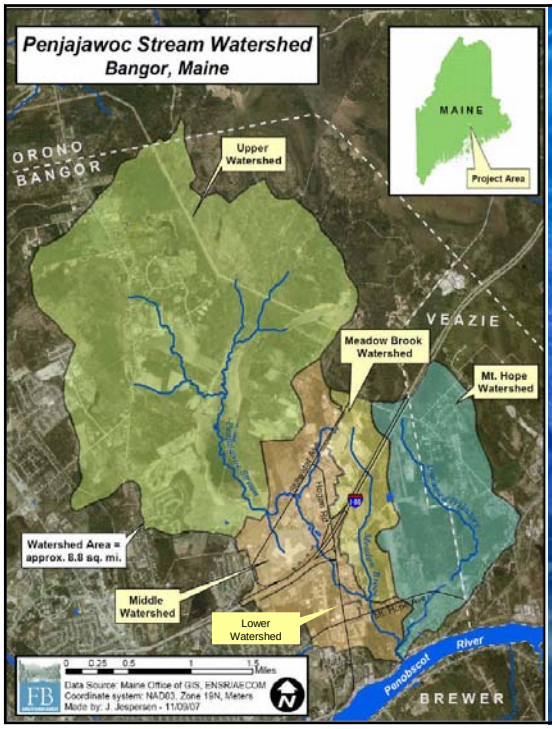
Wendy Warren asked if we comparing a half-mile stream to a river?

Andy Hamilton asked what do we think the next steps are and what are the chances that the City will continue this work? He likes Bill Kreutzberger's recommendation to get flow information and continue monitoring. He also wanted to know what happens after the TM is finalized in terms of the stakeholder process? Art Morgan stated that the group needs to come to consensus on the three indicators (hydrology, habitat, conductivity).

Jim Ring asked for more discussion from stakeholders about the best/most efficient process for moving forward. Art Morgan stated that we need to provide guidance on stakeholder

process as suggested in the draft TM. This would be on the agenda for another workshop. Lucy Quinby stated that the City has a tradition of bringing together diverse groups and opinions, such as with the Mall Marsh Commission. Bill Kreutzberger stated that we have examples of stakeholder charters for the group to look at. Andy Hamilton stated that the charter needs to have a policy on how to sunset the stakeholder group once the objectives are achieved. The stakeholder group may want to get a stormwater utility district on the table soon with regards to how this process will be funded. Jim Ring stated that the City is already proceeding with updating a 1990s stormwater utility report.

James Gerety of Bangor Mall stated that he definitely thinks there needs to be another workshop, especially since we are very focused and heading in a direction at this workshop. Bill Kreutzberger stated that early next week he and Art Morgan would talk through the workshop notes and develop some ideas about next steps. Then they will send suggestions to the rest of the group.



Penjajawoc Stream Watershed Analysis and Options Workshop

October 9, 2008

Workshop Overview

- Introductions
- Purpose of the workshop
- Overview of Technical Memorandum (TM)
- Watershed characteristics
- Monitoring results
- Stressor review
- Watershed assessment gaps
- TM Recommendations review
- Implications for WMP
- Next Steps

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Purpose of the Workshop

- Develop a mutual understanding of the problem issues in the Penjajawoc
  - *Through review of prior studies*
  - *Through review of available data*
- Review and prioritize stressors
- Reach agreement on information gaps
- Determine appropriate actions as we begin implementing the Watershed Plan

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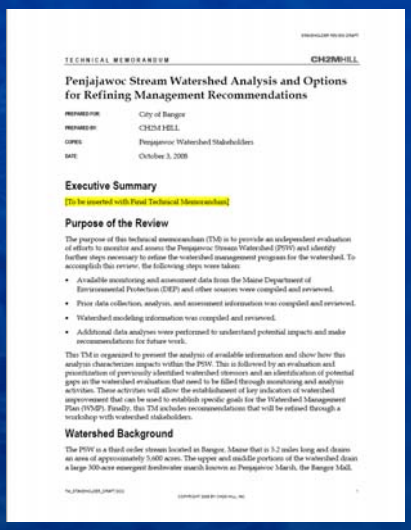
Overview of Technical Memorandum

- Purpose
- Watershed Background
- Monitoring Results
- Prior Modeling and Geomorphic Studies
- Stressor Comparison
- Gap Analysis
- Conclusions and Recommendations



TECHNICAL MEMORANDUM CH2MHILL

Penjajawoc Stream Watershed Analysis and Options for Refining Management Recommendations

PREPARED FOR: City of Bangor
PREPARED BY: CH2M HILL
COPIES: Penjajawoc Watershed Stakeholders
DATE: October 3, 2008

Executive Summary

[To be inserted with Final Technical Memorandum]

Purpose of the Review

The purpose of this technical memorandum (TM) is to provide an independent evaluation of efforts to monitor and assess the Penjajawoc Stream Watershed (PSW) and identify further steps necessary to refine the watershed management program for the watershed. To accomplish this review, the following steps were taken:

- Available monitoring and assessment data from the Maine Department of Environmental Protection (DEP) and other sources were compiled and reviewed.
- Prior data collection, analysis, and assessment information was compiled and reviewed.
- Watershed modeling information was compiled and reviewed.
- Additional data analyses were performed to understand potential impacts and make recommendations for future work.

This TM is organized to present the analysis of available information and show how this analysis characterizes impacts within the PSW. This is followed by an evaluation and prioritization of previously identified watershed stressors and an identification of potential gaps in the watershed evaluation that need to be filled through monitoring and analysis activities. These activities will allow the establishment of key indicators of watershed improvement that can be used to establish specific goals for the Watershed Management Plan (WMP). Finally, this TM includes recommendations that will be refined through a workshop with watershed stakeholders.

Watershed Background

The PSW is a third order stream located in Bangor, Maine that is 5.2 miles long and drains an area of approximately 5,600 acres. The upper and middle portions of the watershed drain a large 300-acre emergent freshwater marsh known as Penjajawoc Marsh, the Bangor Mall.

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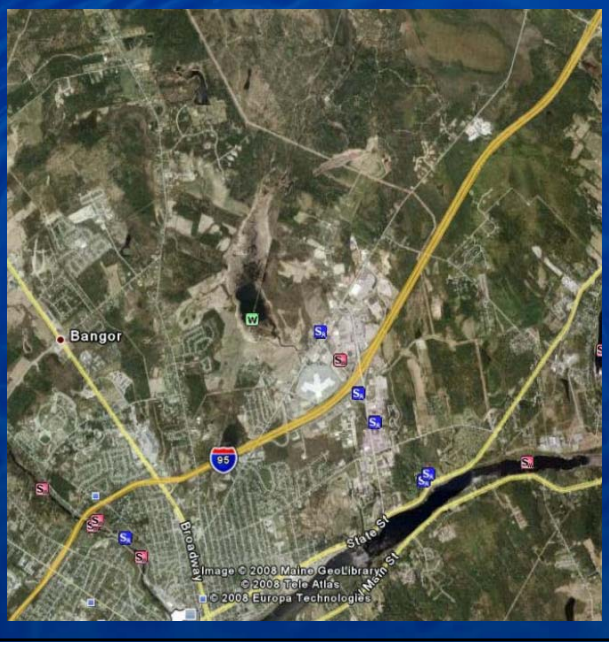
Watershed Characteristics



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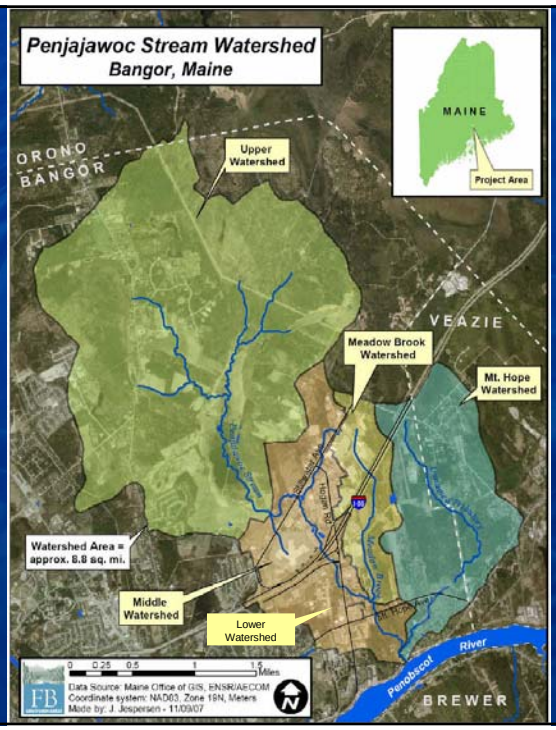

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Watershed Modeling Studies

- P-8 Modeling - Tetra Tech
- Storm Water Management Model (SWMM) – ENSR
- Hydrocad - WBRC

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P-8 Model

- Simple model for evaluating hydrological and water quality issues
- Watershed described as 3 catchment areas and modeled as 4
  - *Developed areas divided into those w and w/o BMPs*
- Uses hourly rainfall
  - *30 years analyzed at high level and 10 used for detailed analysis*

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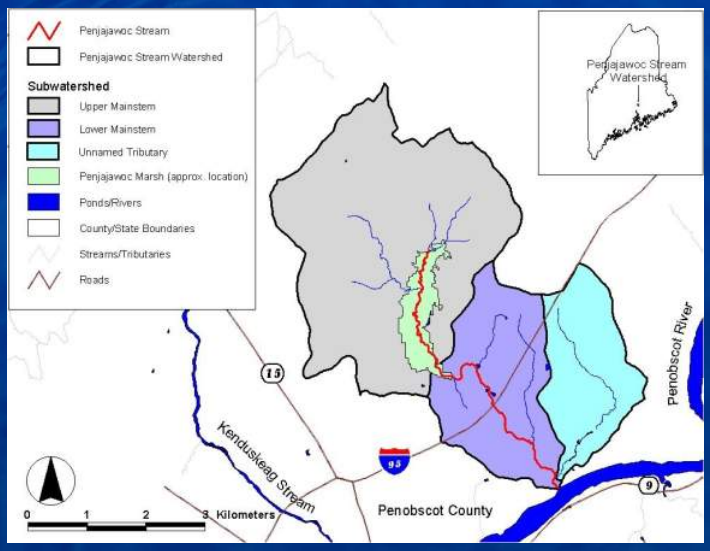
P-8 Modeling



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Sub-watershed Characteristics

LAND USE	UPPER PENJAJAWOC		LOWER PENJAJAWOC*		UNNAMED TRIBUTORY	
	Area (acres)	Percentage	Area (acres)	Percentage	Area (acres)	Percentage
Forest	2,143	71%	228	17%	484	51%
Grasslands/Field	490	16%	154	12%	232	24%
Cropland	44	1%	6	0%	19	2%
Clear/Partial Cuts	158	5%	20	1%	28	3%
Residential/Commercial	122	4%	796	60%	142	15%
Highways/Parking	0	0%	101	8%	12	1%
Abondoned Field	21	1%	14	1%	15	2%
Scrub-shrub	30	1%	5	0%	6	1%
Wetland/Water	25	1%	14	1%	13	1%
Total	3,032		1,337		952	

WATERSHED	AREA (ACRES)	PERCENT IMPERVIOUS[1]		PERVIOUS CURVE NO.[2]
Upper	3,032	10		73
Lower (w/ BMP)	42	60		73
Lower (w/o BMP)	1,337	37		74
Unnamed	952	5		72

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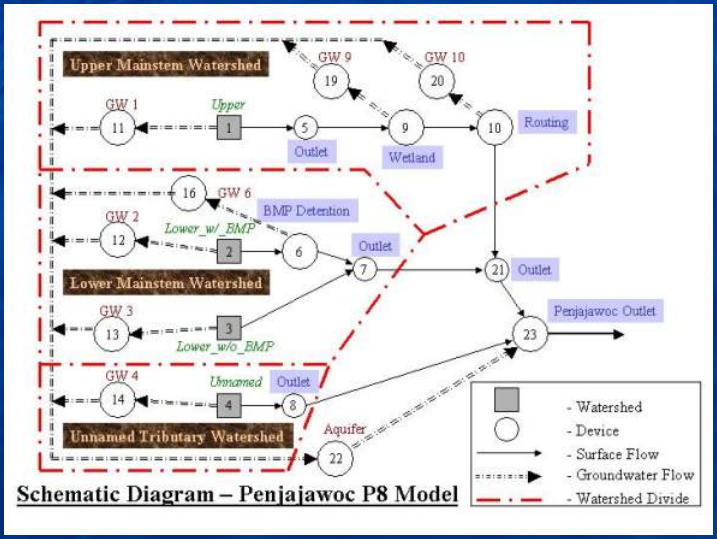
Model Schematic



Schematic Diagram – Penjajawoc P8 Model

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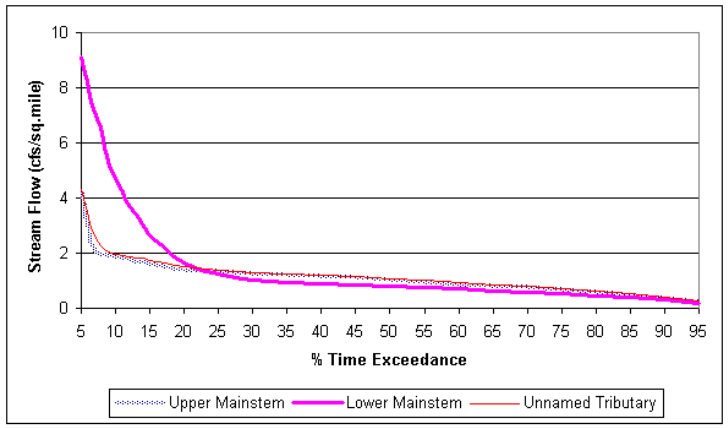
Hydrological Characterization

WATERSHED	UPPER (REF.)	LOWER (IMPAIRED)	UNNAMED (REF.)
95% exceedance flow (cfs/mi^2) – Low Flow	0.26	0.19	0.26
50% exceedance flow (cfs/mi^2) – Median Flow	1.06	0.80	1.08
5% exceedance flow (cfs/mi^2) – High Flow	4.12	9.11	4.37



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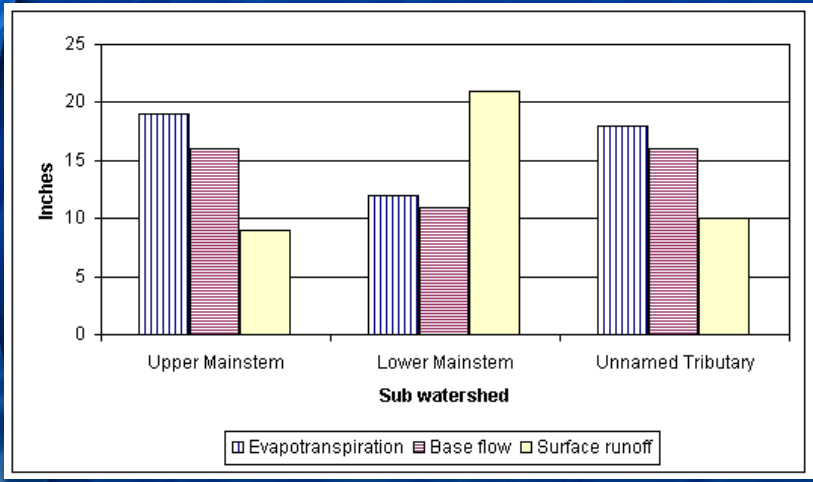
P-8 Hydrological Characterization



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P-8 Modeling

- Reasonable overview of changed watershed hydrology
  - *Upper watershed and Mt. Hope Brook show similar hydrology*
- No calibration
  - *Hydrology based on area precipitation and accepted concepts*
  - *Pollutant loading based on NURP information*

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SWMM Modeling

- Well accepted model stormwater model for urban areas
- Runoff and routing components of the model
- More detailed breakdown of watershed catchments
  - *95 in SWMM versus 4 in P-8*
- Used hourly precipitation
  - *1988 precipitation used as typical year*

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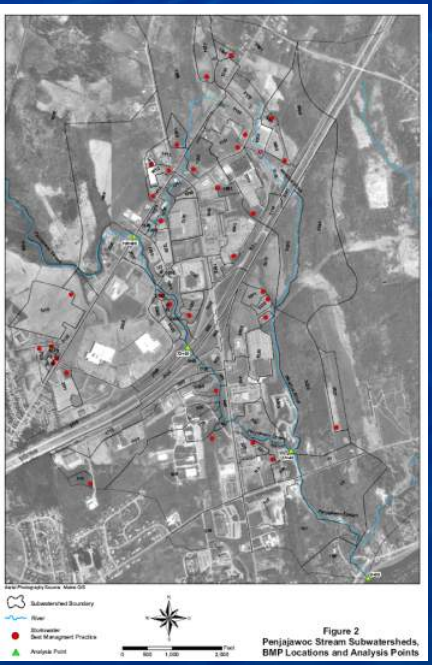
SWMM Catchment Areas



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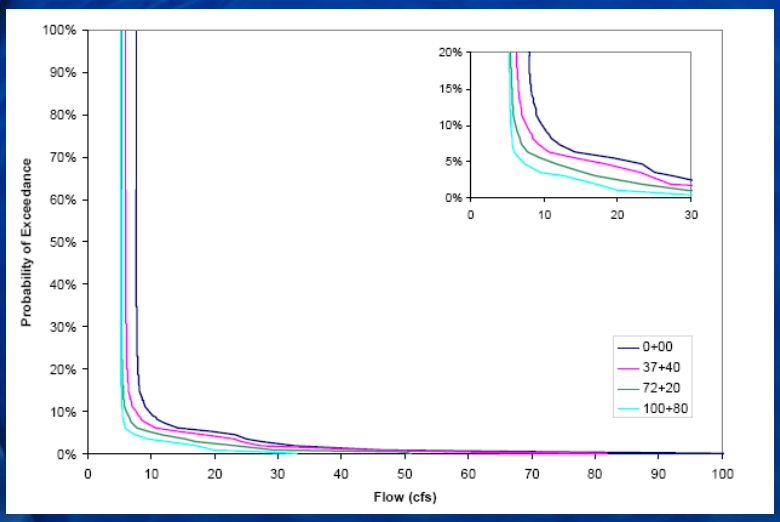
SWMM Hydrological Characterization



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SWMM Modeling

- Provided more detailed characterization of developed areas
- Model designed as a stormwater model
  - *Predicts runoff from developed areas well*
  - *Inadequately predicts baseflow – especially from undeveloped areas*
- Results presented provided little additional understanding of watershed
  - *Model could be built-upon*
- No model calibration

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Monitoring Results

- Monitoring Overview
- Biomonitoring results
- Habitat results
- Water quality results
- Geomorphic Study
- Ongoing efforts

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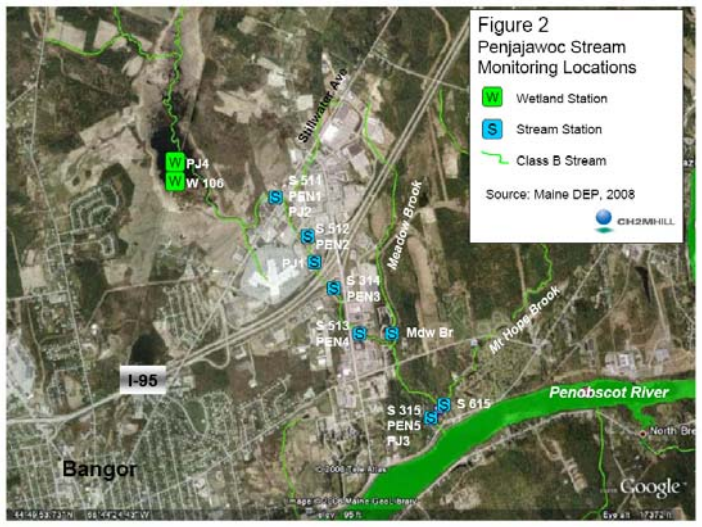
Monitoring Stations for Penjajawoc Watershed



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Penjajawoc Monitoring Sites

Site	Location	Monitoring Activity
511	Penjajawoc	biomonitoring, water quality, chlorophyll *a*
512	Penjajawoc	biomonitoring and water quality
314	Penjajawoc	biomonitoring and water quality
513	Penjajawoc	biomonitoring and water quality
315	Penjajawoc	biomonitoring and water quality
PEN1	Penjajawoc	water quality
PEN2	Penjajawoc	water quality
PEN3	Penjajawoc	water quality
PEN4	Penjajawoc	water quality
PEN5	Penjajawoc	water quality
PJ1	Penjajawoc	water quality
PJ2	Penjajawoc	water quality
PJ3	Penjajawoc	water quality
PJ4	Penjajawoc	water quality
615	Mt Hope Br	water quality, chlorophyll *a*
Mdw Br	Meadow Brook	water quality
W106	Wetland	water quality, vegetation, chlorophyll *a*

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What is Biomonitoring?

- Sampling stream for aquatic organisms
- Organisms present compared to reference data set
- Statistical analysis to determine attainment with water quality criteria

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Maine Water Quality Criteria

	Dissolved Oxygen Numeric Criteria	Bacteria (*E. coli*) Numeric Criteria	Habitat Narrative Criteria	Aquatic Life (Biological) Narrative Criteria
Class AA	as naturally occurs	as naturally occurs	free flowing and natural	No direct discharge of pollutants; ***as naturally occurs***
Class A	7 ppm; 75% saturation	as naturally occurs	natural	***as naturally occurs***
Class B	7 ppm; 75% saturation	64/100 ml (g.m.*) or 236/100 ml (inst.*) of human and domestic animal origin	unimpaired	Discharges ***shall not cause adverse impact*** to aquatic life in that the receiving waters shall be of sufficient quality to ***support all aquatic species indigenous to the receiving water without detrimental changes to the resident biological community***.
Class C	5 ppm; 60% saturation	126/100 ml (g.m.*) or 236/100 ml (inst.*) of human and domestic animal origin	habitat for fish and other aquatic life	Discharges ***may cause some changes*** to aquatic life, provided that the receiving waters shall be of sufficient quality to ***support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community***.

* g.m., geometric mean; inst., instantaneous level

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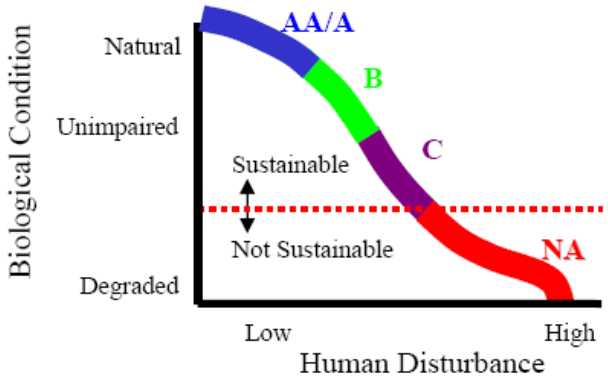
Biological Condition for Water Quality Classifications

Fig. 2. Maine's Aquatic Life Management Classes



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Biomonitoring Results

Station	Year				
	1997	2001	2002	2003	2006
511	-	NA	NA	NA	Class C
512	-	NA	NA	-	-
314	NA	NA	NA	NA	Class C
513	-	NA	NA	NA	-
315	Class B	Class B	Class C	NA	Class C

Notes: NA = Non-Attainment
Stations read from upstream to downstream

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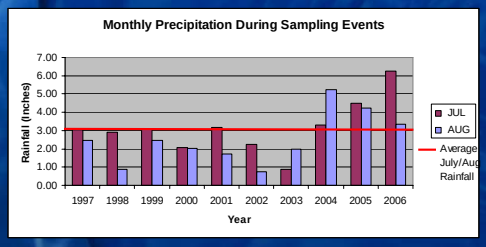
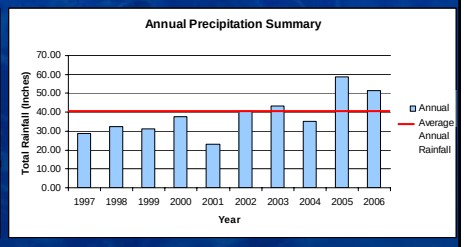
Biomonitoring Results and Precipitation

Station	Year				
	1997	2001	2002	2003	2006
511	-	NA	NA	NA	Class C
512	-	NA	NA	-	-
314	NA	NA	NA	NA	Class C
513	-	NA	NA	NA	-
315	Class B	Class B	Class C	NA	Class C

Notes: NA = Non-Attainment
Stations read from upstream to downstream





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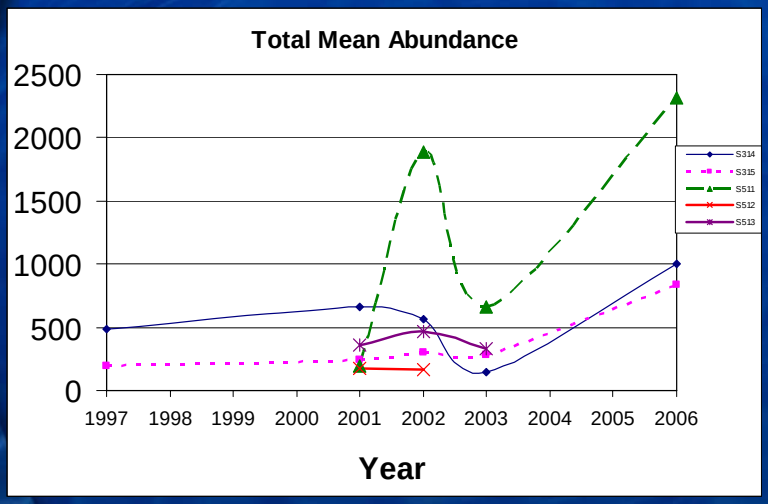
Biomonitoring Metrics



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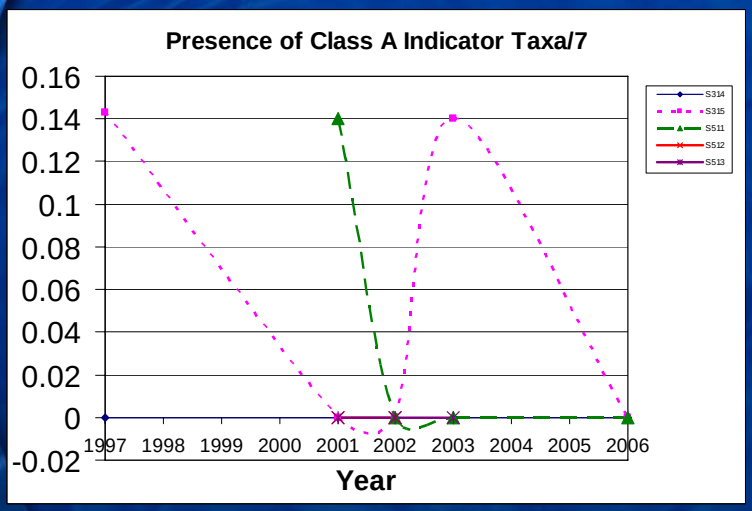
Biomonitoring Metrics



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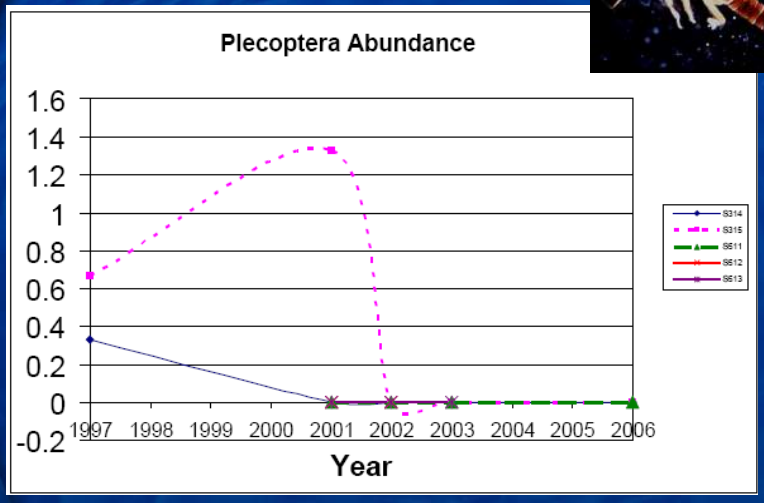
Biomonitoring Metrics



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Habitat Monitoring

- Qualitative assessments during biomonitoring
- Parameters include
  - *land use*
  - *canopy cover*
  - *bottom substrate compositions*
  - *others*

Canopy

Station	Year				
	1997	2001	2002	2003	2006
511	-	Dense	Partly Open	Partly Open	Open
512	-	Dense	Partly Open		
314	Open	Open	Open	Open	Open
513	-	Open	Open	Open	-
315	Open	Open	Partly Open	Partly Open	Partly Open

Notes: Stations read from upstream to downstream
Open = up to 25 % shaded
Partly Open = 25 to 75% shaded
Dense = 75% to 100% shaded

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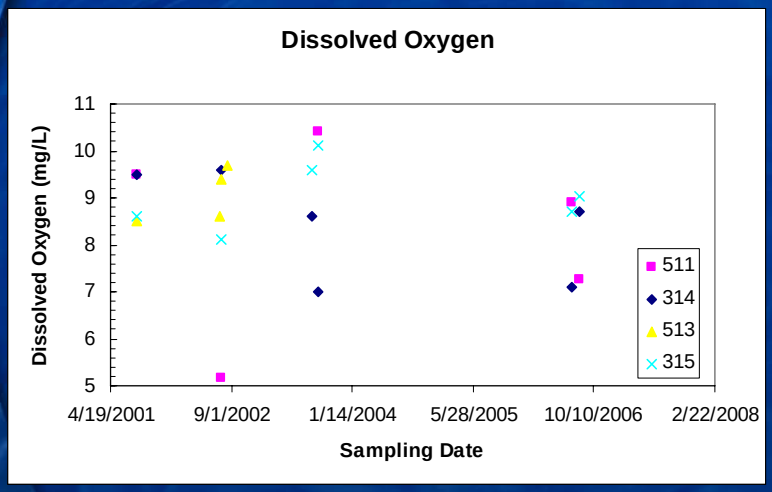
Water Quality – Dissolved Oxygen



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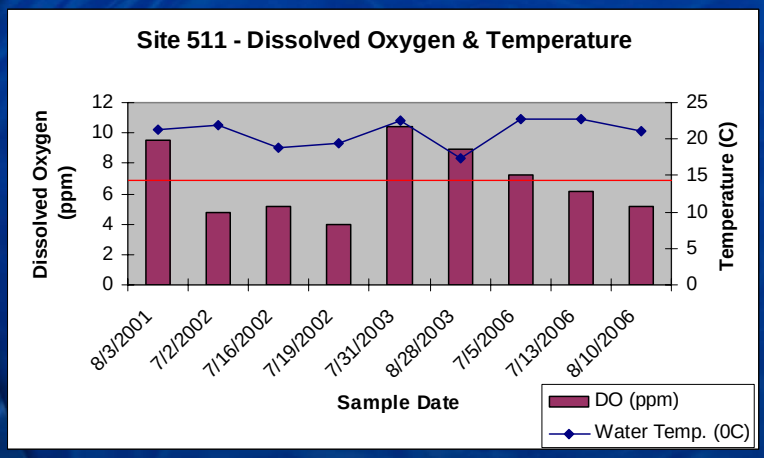
Water Quality – Dissolved Oxygen



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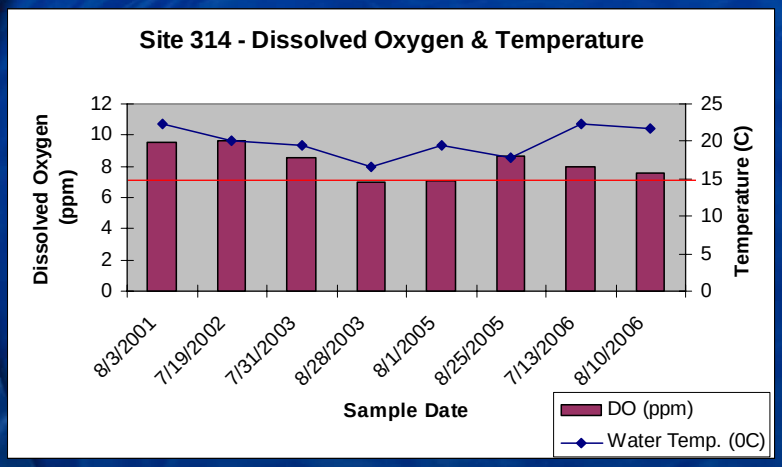
Water Quality – Dissolved Oxygen



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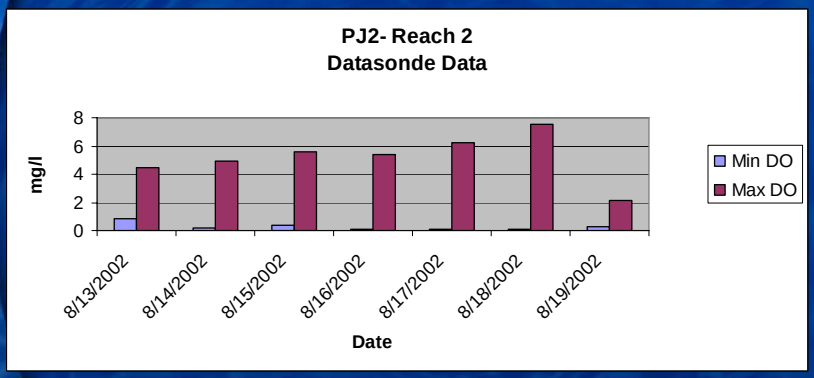
Water Quality – Dissolved Oxygen



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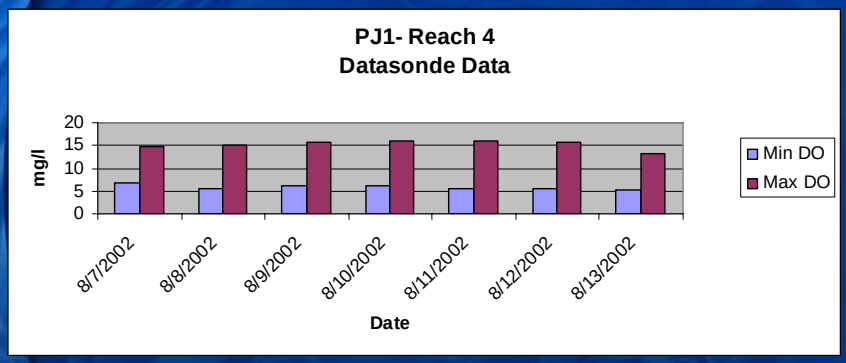
Water Quality – Dissolved Oxygen



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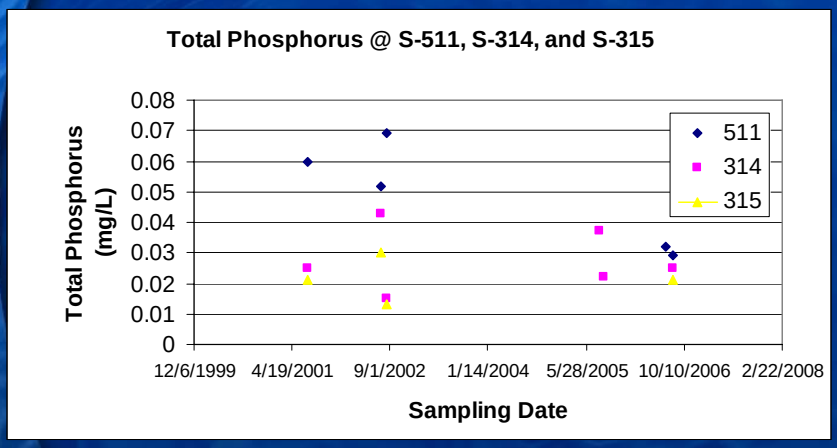
Water Quality - Nutrients



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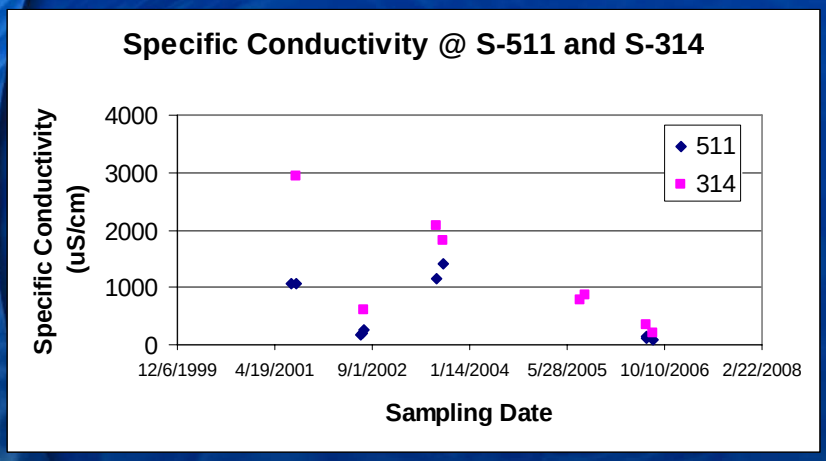
Water Quality - Conductivity



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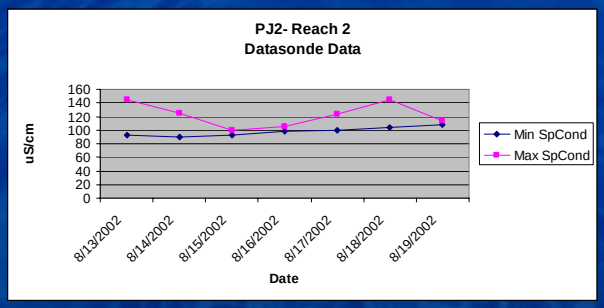
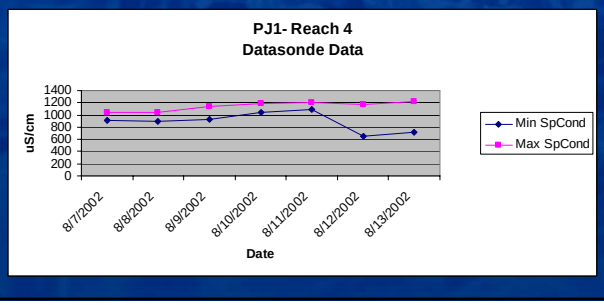
Water Quality - Conductivity





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Water Quality – Other Parameters

- Limited water quality data
- Several parameters well know contaminant in urban stormwater
  - *Sediment – Turbidity*
  - *Nutrients*
  - *Metals*
  - *Hydrocarbons*

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Geomorphic Conditions

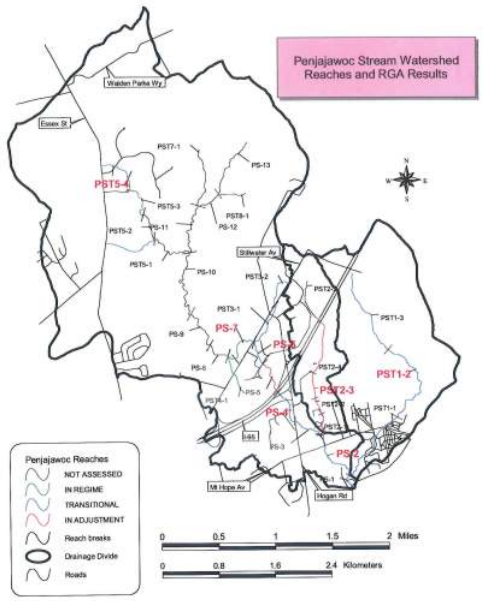

Figure 1. Location map with identified reaches.

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Geomorphic Conditions

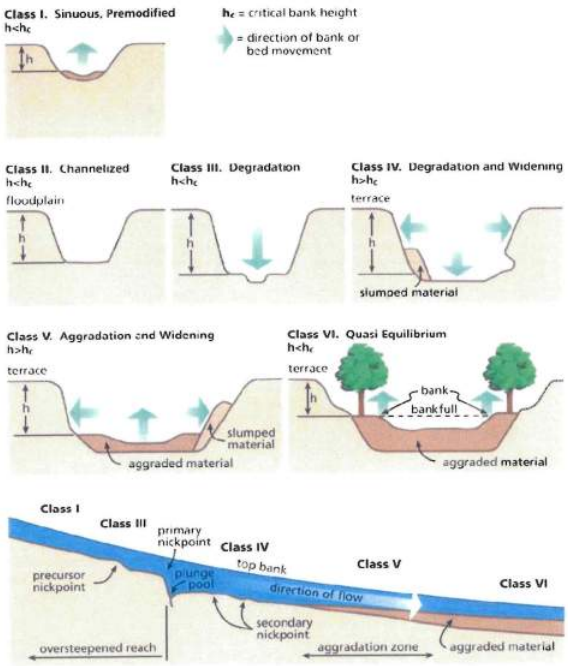

Figure 3. Channel Evolution Model (source: USDA 1998)

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Geomorphic Conditions - Barriers

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Geomorphic Conditions

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Stressor Workshop

Results of Maine DEP 2004 Stressor Identification Analysis for Penjajawoc Stream (Maine DEP, 2004)

Stressors	Watershed		
	Upper	Middle	Lower
Temperature	Yes - minor	Yes - possible	Yes
Nutrients	Yes - minor	Yes - possible	Yes - related to stormflow (less of a problem here)
Dissolved Oxygen	Yes - wetland main source	Yes	No (meets standards)
Conductivity	Yes	Yes - sand/silt sources	Yes - salt sources
Toxics	Yes	Yes	Yes
Sediment	No	Yes	Yes - high suspended sediment during storms (probably from Meadow Brook)
Altered Hydrology	Yes	Yes - groundwater main mitigate low baseflow syndrome	Yes - from upper reaches
Habitat	Yes	Yes	Yes - more data needed

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Stressor Discussion

Priority	Stressors	Watershed		
		Upper	Middle	Lower
1	Altered Hydrology	Yes	Yes - groundwater main mitigate low baseflow syndrome	Yes - from upper reaches
2	Habitat	Yes	Yes	Yes - more data needed
3	Conductivity	Yes	Yes - sand/silt sources	Yes - salt sources
4	Temperature	Yes - minor	Yes - possible	Yes
4	Nutrients	Yes - minor	Yes - possible	Yes - related to stormflow (less of a problem here)
4	Dissolved Oxygen	Yes - wetland main source	Yes	No (meets standards)
4	Toxics	Yes	Yes	Yes
4	Sediment	No	Yes	Yes - high suspended sediment during storms (probably from Meadow Brook)

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Afternoon Session

- Watershed assessment gaps
- TM Recommendations review
- Implications for WMP
- Next Steps

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Watershed Assessment Gaps

- Indicators of impairment
- Others

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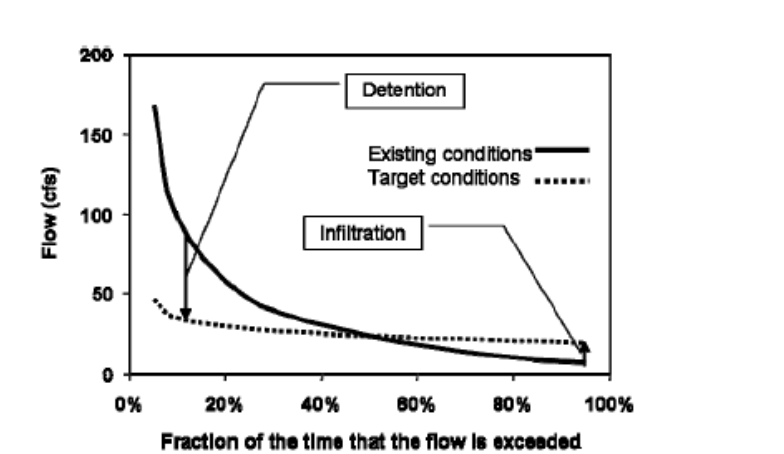
Indicators of Impairments – Altered Hydrology



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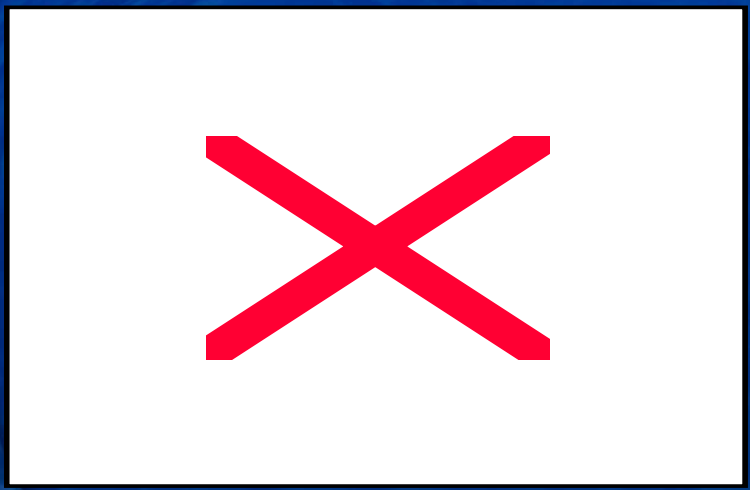
Indicators of Impairments – Altered Hydrology



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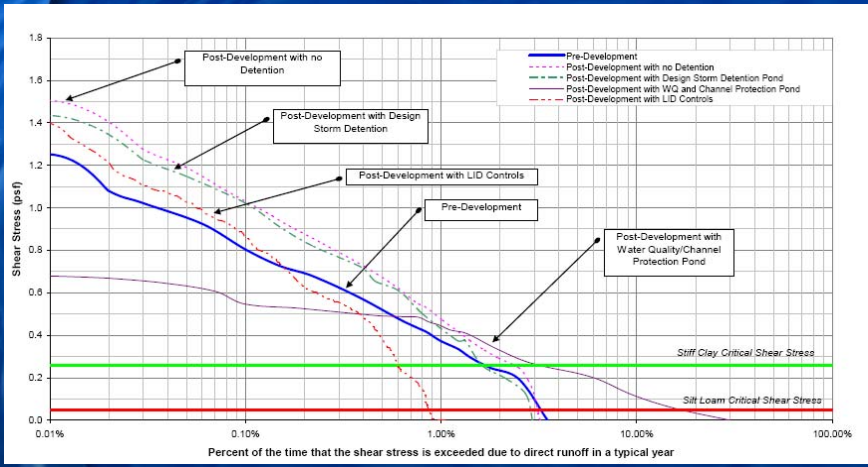
Indicators of Impairments – Altered Hydrology



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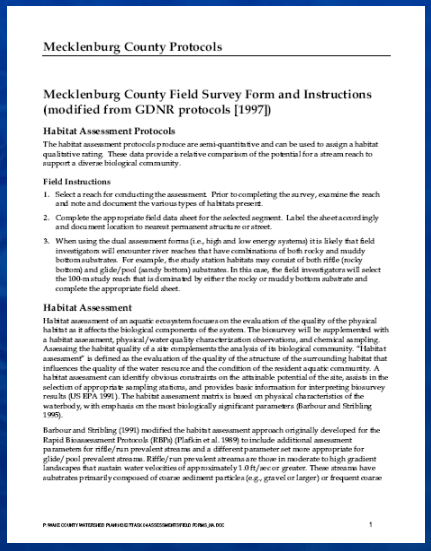
Indicators of Impairments - Habitat

- Numerous habitat assessment methods have been developed
- Several based on EPA RBP Method
- Objective information to assess habitat



Mecklenburg County Protocols

Mecklenburg County Field Survey Form and Instructions (modified from GDNR protocols [1997])

Habitat Assessment Protocols

The habitat assessment protocols produce are semi-quantitative and can be used to assign a habitat qualitative rating. These data provide a relative comparison of the potential for a stream reach to support a diverse biological community.

Field Instructions

1. Select a reach for conducting the assessment. Prior to completing the survey, examine the reach and note and document the various types of habitats present.
2. Complete the appropriate field data sheet for the selected segment. Label the sheet accordingly and document location to nearest permanent structure or street.
3. When using the dual assessment forms (i.e., high and low energy systems) it is likely that field investigators will encounter river reaches that have combinations of both rocky and muddy bottom substrates. For example, the study station habitats may consist of both riffle (rocky bottom) and glide/pool (sandy bottom) substrates. In this case, the field investigators will select the 100-m study reach that is dominated by either the rocky or muddy bottom substrate and complete the appropriate field sheet.

Habitat Assessment

Habitat assessment of an aquatic ecosystem focuses on the evaluation of the quality of the physical habitat as it affects the biological components of the system. The biosurvey will be supplemented with a habitat assessment, physical/water quality characterization observations, and chemical sampling. Assessing the habitat quality of a site complements the analysis of its biological community. "Habitat assessment" is defined as the evaluation of the quality of the structure of the surrounding habitat that influences the quality of the water resource and the condition of the resident aquatic community. A habitat assessment can identify obvious constraints on the attainable potential of the site, assists in the selection of appropriate sampling stations, and provides basic information for interpreting biosurvey results (US EPA 1991). The habitat assessment matrix is based on physical characteristics of the waterbody, with emphasis on the most biologically significant parameters (Barbour and Stribling 1995).

Barbour and Stribling (1991) modified the habitat assessment approach originally developed for the Rapid Bioassessment Protocols (RBPs) (Plafkin et al. 1989) to include additional assessment parameters for riffle/run prevalent streams and a different parameter set more appropriate for glide/pool prevalent streams. Riffle/run prevalent streams are those in moderate to high gradient landscapes that sustain water velocities of approximately 1.0 ft/sec or greater. These streams have substrates primarily composed of coarse sediment particles (e.g., gravel or larger) or frequent coarse

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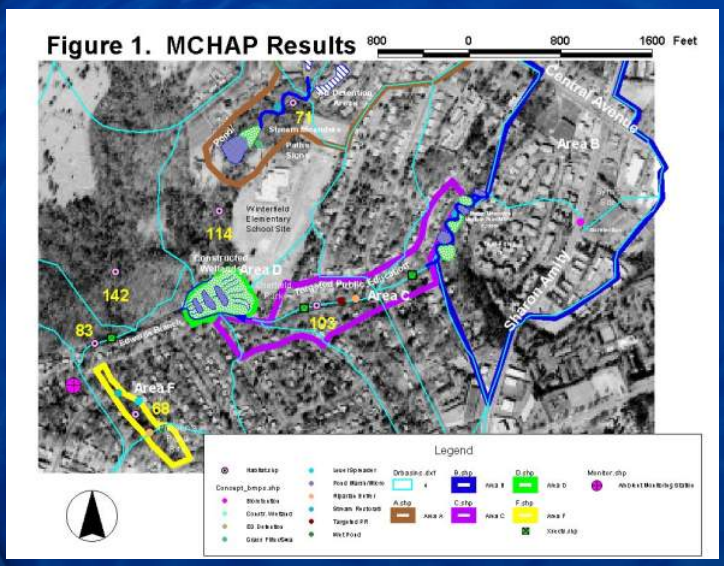
Indicators of Impairments - Habitat



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Recommendations

- Monitoring
  - *Hydrological data*
  - *Monitoring plan*
    - *Goals*
    - *Description/Responsibilities*
    - *QA/QC*
- Modeling
  - *Linking indicators to watershed changes*
- Stakeholder Process
- Others

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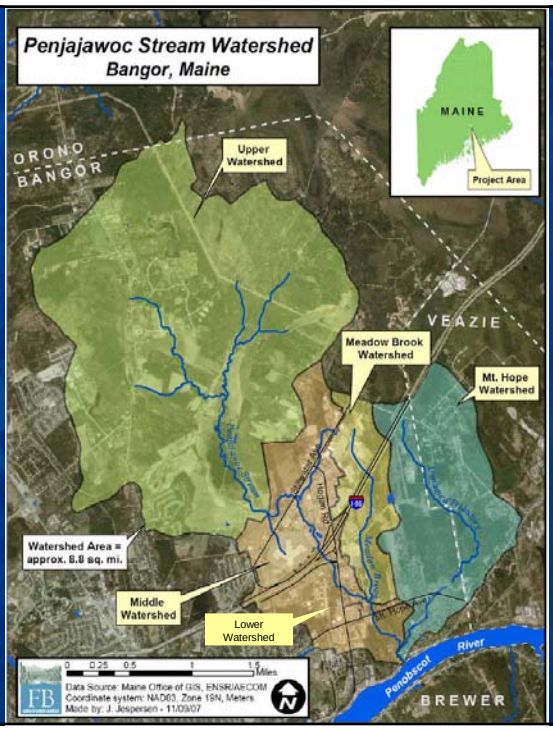
Hydrological Monitoring



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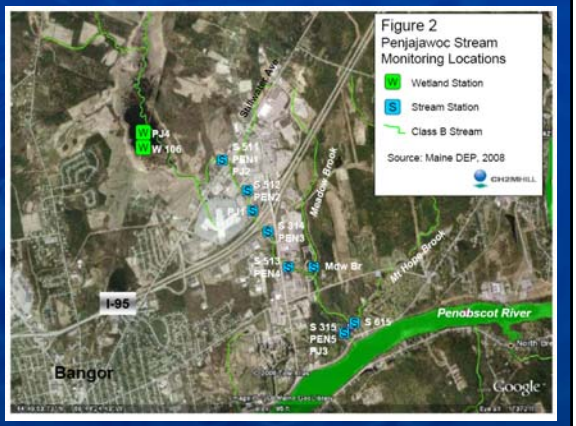
Monitoring Plan

- Monitoring plan
  - *Goals*
  - *Description*
  - *Maps*
  - *Responsibilities*
  - *QA/QC*



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Volunteer Stream Team Monitoring

Penjajawoc Stream, Bangor
Stream Team Sites

Meters
0 1,000 2,000

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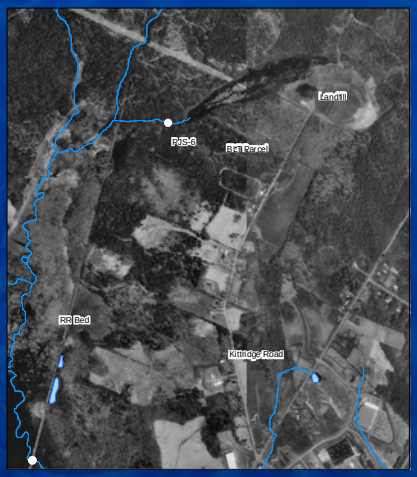
Volunteer Stream Team Monitoring



Penjajawoc Stream, Bangor Land Trust Site

Meters
0 480 960

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Volunteer Stream Team Monitoring

Meadow Brook, Bangor at Evergreen Woods
Conductivity Measurements of 7/10/2008
by Mark Whiting, Maine DEP

Meters
0 170 340

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Modeling Needs

- Dependent on hydrological data
- Model selection driven by key indicators
- Modeling support many key activities
  - *Stakeholder goal setting*
  - *BMP retrofit design*
  - *Stream restoration design*

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Hydrocad Modeling

- Hydrocad is a tool often used for BMP design
- Analysis used P-8, SWMM and Geomorphic Study information
- Evaluated functionality of existing BMPs
  - *Determined 20 of 25 were sufficiently functional to be included*
- Focused on conceptual design of retrofit BMPs
  - *Bypassing baseflow – Thermal protection*
  - *Channel protection peak flow control*

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Predicted Effectiveness of 4 BMPs for Peak Flow Reduction

Station	Description	Peak Flow of 1-year event (cfs)		Change	Peak Flow of 2-year event (cfs)		Change
		Existing	Proposed		Existing	Proposed	
0+000	Mouth of Stream	270.44	245.91	-9%	324.78	302.41	-7%
0+950	Tributary #3 confluence	270.56	246.43	-9%	321.46	303.07	-6%
3+700	Meadow Brook confluence	247.29	221.16	-11%	291.64	269.41	-8%
5+400	Hogan Rd crossing	223.77	197.34	-12%	265.17	241.78	-9%
7+250	I-95 crossing	194.52	145.94	-25%	228.02	176.91	-22%
8+900	Bangor Mall Blvd crossing	77.23	77.23	0%	92.87	92.87	0%
10+00	Stillwater Ave crossing	54.84	54.84	0%	66.43	66.45	0%
12+500	Headwater (assigned)	7.00	7.00	0%	7.00	7.00	0%

Notes: At headwater, since observed base flow represents a steady-state condition, it retained its value for the 1- and 2-year storms.
Tributary #3 is Mt. Hope Brook

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Hydrocad Modeling

- Developed concepts for retrofit BMPs
  - *Showed effectiveness of peak flow reduction*
  - *Developed design concepts*
  - *Preliminary cost information*
- No model calibration
- Context of flow reduction unknown
  - *Are the reductions significant versus needed improvements*

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Implications for WMP

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Next Steps

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Attachment C

Minutes and Presentation Information for Workshop No. 2 – February 27, 2009

PENJAJAWOC STREAM WATERSHED
STRESSORS and MODELING MEETING
MEETING SUMMARY
February 27, 2009

INTRODUCTIONS

Participants introduced themselves and included; Mark Ward, Lucy Quimby, Mark Whiting, Paul Nicklas, Andy Hamilton, Dan Belyea, Jeff Dennis, Dan Wellington, Wendy Warren, Art Morgan, Ray Cota, Tim Woodcock, Bill Kreutzberger (remote).

PURPOSE OF THE WORKSHOP

Bill described the purpose of the meeting was to develop a mutual understanding of problems/issues in the Penjajawoc through review of prior studies and available data, and to review and prioritize stressors, to reach agreement on assessment gaps, and to determine appropriate actions as we begin implementing a watershed management plan.

REVIEW OF THE DRAFT TECHNICAL MEMORANDUM

The Draft Technical Memorandum provided a review of existing monitoring results, prior modeling studies, stressor comparison, and a gap analysis. Bill highlighted some of the points from the technical memorandum.

The following models have been previously developed for study of the watershed:

- P8 Modeling (Tetra Tech) provided a reasonable overview of change in hydrology. No calibration, based upon precipitation & pollutant load formulas.
- SWMM modeling (ENSR) is a well accepted model for urban areas as it predicts runoff from urban areas, but inadequately predicts base flow especially in undeveloped areas. It provided a detailed overview of catchments that could be built. The model had not been calibrated to real data.
- Hydrocad (WBRC) – focused on peak events, not calibrated with real, data.

The following monitoring results were summarized in the technical memorandum:

- DEP bio-monitoring – assesses stream for abundance of aquatic organisms, and uses statistical analysis to determine how much the sample resembles the reference set of organisms.
- Maine Water Quality Criteria also includes habitat, dissolved oxygen, and bacteria Results.
- In comparing attainment to precipitation , we see that 2003 was a year of non-attainment for all stations, a very dry summer. Wet years achieve class C in some stations and Class B at mouth of stream.
- Qualitative assessments of habitat are noted during rock basket assessments that include notes of land use, canopy cover, bottom substrate and other parameters.
- Biomonitoring reflected Plecoptera abundance down in 2002 – no stone flies even at upstream station.
- Data sondes provided dissolved oxygen information. Note that added nutrients, and lack of canopy can add to DO fluctuations.
- Data sondes reflected high conductivity – even in summer.

- Limited water quality data, but some pollutants are known to be present in urban surface water
- Geomorphic conditions were documented in the Parish analysis. It documented barriers, and known changes in hydrology.
-

STRESSOR REVIEW/PRIORITIZATION

Bill noted that in the last meeting we reviewed the stressors and relative prioritization, but we ended the meeting not really knowing if we had a consensus. The mission of this workshop is to determine what we need to know MOST to know that the actions we take will have an effect on the watershed. The stressors identified and prioritized in the TM included:

1) Altered hydrology – including high peak flows and duration of high peaks, and low base flow. If we reduce hydrologic load, we generally see a reduction in the amount of toxics and pollutants.
2) Habitat – including canopy, stream geomorphology, stream corridor, and riparian conditions. Bill noted that EPA has a methodology to rate the habitat based upon these. When people are monitoring, they should be trained to collect habitat information as well to provide a good baseline of habitat conditions.
3) Conductivity - A measure of inputs of dissolved solids such as metals and chlorides. There may be other sources than road salt such as historic condensate discharges. Chlorides are toxic at certain levels. Road salt generally moves through water systems pretty quickly. The stream team is indicating that in some areas we are seeing high salt beyond normal expected seasons.

Comment: Cautioned about choosing altered hydrology as highest priority. If nutrients and toxics are discounted, we may miss an opportunity for less expensive fixes that do not account for altered hydrology.
Response: We need to understand altered hydrology first and then habitat, but that doesn't mean we can't simultaneously install inexpensive practices that will influence toxics. Those areas identified in Parish's report that do not need hydrology addressed can be focused on nutrients and toxics.
Question: Which priority do we know the least about?
Answer: We probably know the least about altered hydrology. We have models but they were not based on real data. For a comprehensive watershed approach, we need hydrology and habitat data and systematic analysis. We do have more information with regard to biological data, but this is the <u>response</u> (or symptom) of the problem, not the <u>cause</u> of the problem.

The group reached consensus that regarding data collection we can list Hydrology as #1 and Habitat #2 and the rest of the stressors can be all rated #3. There was agreement that these prioritized stressors were important in that we need much more information before we could pick definitive remedies to address these stressors

Note: Hydrology is the easiest and quickest data that we could gather. Flow data allows you to accurately see flows in streams in relationship to storm events and baseline data. The City will be releasing an RFP for installation of data loggers and

collection of the data for analysis soon. This data will allow us to generate more meaningfully calibrated models.

MODELING OVERVIEW

Selection should be based upon key indicators. Models can support different activities such as goal setting, BMP design, restoration design, or to predict response to future land use changes. Important considerations when choosing a model are picking a model that fits the problem, picking a model as simple as possible, but not simpler. Making sure it represents the existing physical system; that it is cost effective; and consistent with existing data or data that can be collected. Make sure the predictions are both precise and accurate. Consider that it is relatively easy to develop a model for hydrology, but difficult and less reliable to model ecological response, or measure water quality.

GAP ASSESSMENT

In selecting the proper model(s) we need to determine what information is lacking that we want to gather. In our case, we know that we need to figure out what is impacting the biota. We know we have altered hydrology that we need to improve. The monitoring that has already been done is best used for assessment – to tell us where we're at, but we need more diagnostic testing in parallel with understanding better hydrology. We need to model for the worst case scenario. Data is most consistent during the dry summer months. Need to look at some additional biological characterization to understand why we're getting the ratings such as no class B or class C at upper stream segment – likely due to the Marsh affect.

Comment: Jeff Dennis noted this is normal in streams beneath wetlands and marshes, and is NOT considered a violation. The distance from the marsh to where the stream recovers is determined on a case by case basis.

Comment: Perhaps a paired watershed approach would be useful. A paired watershed would be one with similar soils, similar sized watershed, and similar hydrologic characteristics. Suggest breaking up the watershed into portions, and finding a similar stream to match a portion of the watershed. Jeff Dennis agreed to look into the DEP databanks to see if there is a similar situation to that of Penjajawoc with a marsh at the headwaters of a stream, but that is not developed. This could be used as a "control" to compare with.

CHOOSING A MODEL FOR PENJAJAWOC

Public Domain models – Two that are often used SWMM and HSPF;
SWMM is great for urban areas storm sewers, emphasis on water quality, not hydrology.
HSPF is a good model where there is both rural and urban situations, such as in the Penjajawoc.

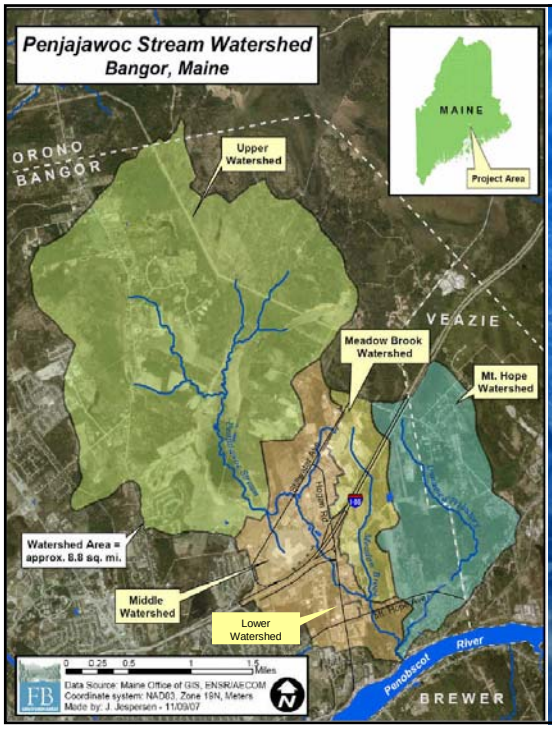
We need to think about whether or not the model can simulate our management measures. Need to have the ability to take the data so it can be analyzed and communicated to others. Pre and post processing costs should be considered. Another consideration is longevity – it should be supported and available into the future.

When hiring a model consultant – you would ask the consultant to compare cost vs. benefit and what data we have. The consultant would assist in the model selection process, which is to define selection criteria, weight the selection criteria, propose suite of potential models, score models according to criteria, and select a model.
Comment: Jeff Dennis noted that if we have 5 to 7 years of experience (assessment data) we will know how the stream is responding more so than a HSPF model would tell us.
Note: Models are a prediction tool, not an assessing tool. Given water detention ability of the marsh, there may be value in monitoring flow in an area above the marsh. There is a place that would be suitable near the RR tracks, but it is on private property. If you have a flow meter above the marsh, it may make it less important which model is used.

MONITORING PLAN
Hydrological Monitoring – Data and Temp and Flow is needed and is in the works to begin collecting. Biological characterization monitoring we do is pass/fail, but does not assess how close we are to meeting our goals. A diagnostic approach is required.
We should consider what additional sampling we could use for diagnostics, and provide some reference metrics to compare so we can tell if we are improving or not. EPA uses an alternative method, called the Rapid bio-assessment protocol (RBP). DEP has problems with the Rapid bio-assessment that EPA uses. The current DEP method puts out an artificial substrate – colonization over an artificial substrate during a month, not necessarily measuring what is in the habitat of the stream, however, it does provide reproducible standardized information for comparison purposes statewide. Having a better reference to a paired watershed would provide us better information to compare to. This would be helpful in making conclusions to what are the factors.

NEXT STEPS
- **CH2MHill – wrap up the deliverables, and pull together a work plan, including a comprehensive monitoring plan with roles and responsibilities, preliminary modeling recommendations, and recommendation for moving forward with a modeling consultant**
- **Get additional advice from Benthic expert on how to get a better understanding of what is going on (diagnostics).**
- **DEP will look for a similar stream for comparison.**

Post meeting notes for clarification: CH2MHill will make preliminary recommendations for a modeling tool that will be useful in developing indicators of altered hydrology through the development of flow duration curves or other applicable methodology. The preliminary assessment is that HSPF might be a more applicable public domain model than some of the others for this watershed because of the mixed rural and urban land use - and it is better at handling baseflow conditions. However, the selection of the modeling tool should be done in concert with the consultant selected to assist the City with this effort. In addition, the City is interested in having a tool at the end of this process that can be used to analyze future situations and aid in adaptive implementation of the watershed management efforts. Our final recommendation will not be just to consider HSPF - but will focus on the specific modeling needs for the watershed.



Penjajawoc Stream Watershed Workshop:

Stressor Prioritization and Monitoring-Modeling Workplan

February 27, 2009

Workshop Overview

- Introductions
- Purpose of the second workshop
- Review of the previous workshop data review
- Stressor review/Prioritization
- Watershed assessment gaps
- Modeling overview
- Monitoring Plan
- Implications for WMP
- Next Steps

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Purpose of the Workshop

- Develop a mutual understanding of the problem issues in the Penjajawoc
  - *Through review of prior studies*
  - *Through review of available data*
- Review and prioritize stressors
- Reach agreement on information gaps
- Discuss monitoring and modeling approaches
- Determine appropriate actions as we begin implementing the Watershed Plan

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Purpose of the Workshop

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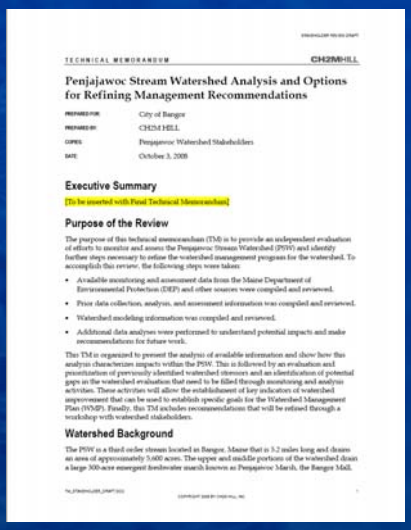
Overview of Technical Memorandum

- Purpose
- Watershed Background
- Monitoring Results
- Prior Modeling and Geomorphic Studies
- Stressor Comparison
- Gap Analysis
- Conclusions and Recommendations



TECHNICAL MEMORANDUM CH2MHILL

Penjajawoc Stream Watershed Analysis and Options for Refining Management Recommendations

PREPARED FOR: City of Bangor
PREPARED BY: CH2M HILL
COPIES: Penjajawoc Watershed Stakeholders
DATE: October 3, 2008

Executive Summary

[To be inserted with Final Technical Memorandum]

Purpose of the Review

The purpose of this technical memorandum (TM) is to provide an independent evaluation of efforts to monitor and assess the Penjajawoc Stream Watershed (PSW) and identify further steps necessary to refine the watershed management program for the watershed. To accomplish this review, the following steps were taken:

- Available monitoring and assessment data from the Maine Department of Environmental Protection (DEP) and other sources were compiled and reviewed.
- Prior data collection, analysis, and assessment information was compiled and reviewed.
- Watershed modeling information was compiled and reviewed.
- Additional data analyses were performed to understand potential impacts and make recommendations for future work.

This TM is organized to present the analysis of available information and show how this analysis characterizes impacts within the PSW. This is followed by an evaluation and prioritization of previously identified watershed stressors and an identification of potential gaps in the watershed evaluation that need to be filled through monitoring and analysis activities. These activities will allow the establishment of key indicators of watershed improvement that can be used to establish specific goals for the Watershed Management Plan (WMP). Finally, this TM includes recommendations that will be refined through a workshop with watershed stakeholders.

Watershed Background

The PSW is a third order stream located in Bangor, Maine that is 5.2 miles long and drains an area of approximately 5,600 acres. The upper and middle portions of the watershed drain a large 300-acre emergent freshwater marsh known as Penjajawoc Marsh, the Bangor Mall.

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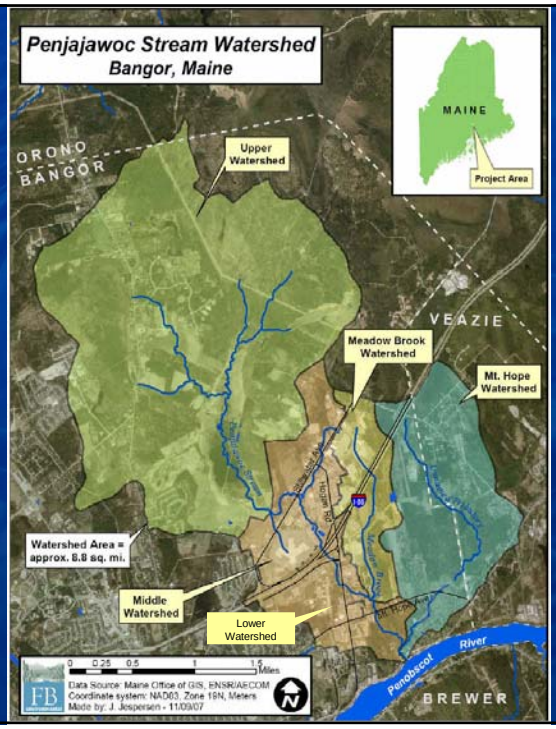

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Watershed Modeling Studies

- P-8 Modeling - Tetra Tech
- Storm Water Management Model (SWMM) – ENSR
- HydroCAD - WBRC

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P-8 Modeling

- Reasonable overview of changed watershed hydrology
  - *Upper watershed and Mt. Hope Brook show similar hydrology*
- No calibration
  - *Hydrology based on area precipitation and accepted concepts*
  - *Pollutant loading based on NURP information*

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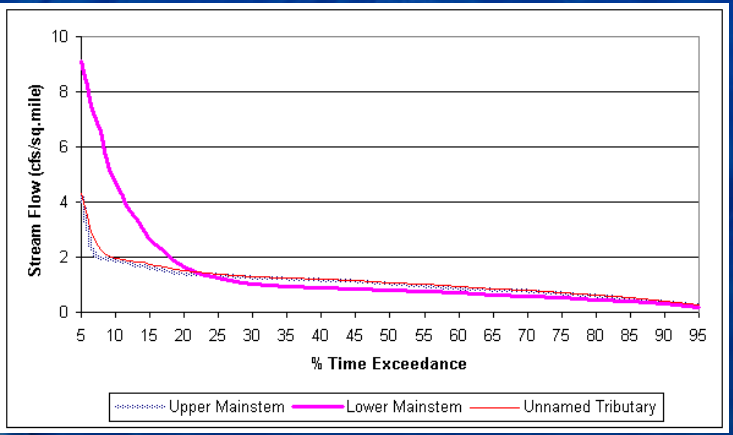
Hydrological Characterization

WATERSHED	UPPER (REF.)	LOWER (IMPAIRED)	UNNAMED (REF.)
95% exceedance flow (cfs/mi^2) – Low Flow	0.26	0.19	0.26
50% exceedance flow (cfs/mi^2) – Median Flow	1.06	0.80	1.08
5% exceedance flow (cfs/mi^2) – High Flow	4.12	9.11	4.37



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SWMM Modeling

- Provided more detailed characterization of developed areas
- Model designed as a stormwater model
  - *Predicts runoff from developed areas well*
  - *Inadequately predicts baseflow – especially from undeveloped areas*
- Results presented provided little additional understanding of watershed
  - *Model could be built-upon*
- No model calibration

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HydroCAD Modeling

- Developed concepts for retrofit BMPs
  - *Showed effectiveness of peak flow reduction*
  - *Developed design concepts*
  - *Preliminary cost information*
- No model calibration
- Context of flow reduction unknown
  - *Are the reductions significant versus needed improvements*

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Monitoring Results

- Monitoring Overview
- Biomonitoring results
- Habitat results
- Water quality results
- Geomorphic Study
- Ongoing efforts

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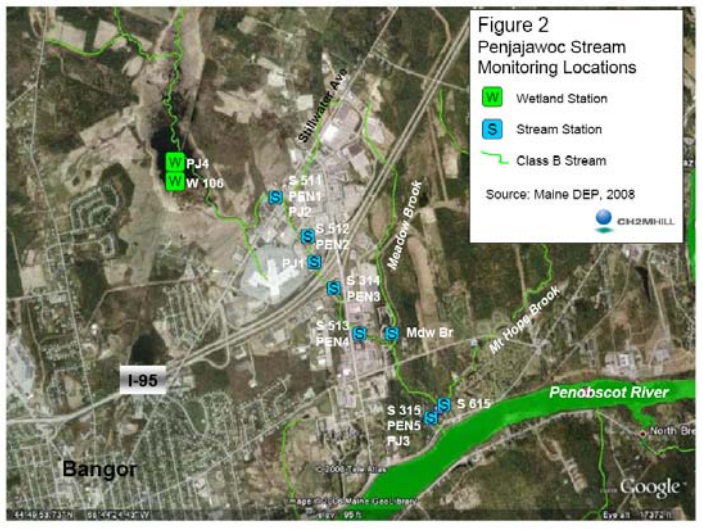
Monitoring Stations for Penjajawoc Watershed



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What is Biomonitoring?

- Sampling stream for aquatic organisms
- Organisms present compared to reference data set
- Statistical analysis to determine attainment with water quality criteria

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Maine Water Quality Criteria

	Dissolved Oxygen Numeric Criteria	Bacteria (*E. coli*) Numeric Criteria	Habitat Narrative Criteria	Aquatic Life (Biological) Narrative Criteria
Class AA	as naturally occurs	as naturally occurs	free flowing and natural	No direct discharge of pollutants; ***as naturally occurs***
Class A	7 ppm; 75% saturation	as naturally occurs	natural	***as naturally occurs***
Class B	7 ppm; 75% saturation	64/100 ml (g.m.*) or 236/100 ml (inst.*) of human and domestic animal origin	unimpaired	Discharges ***shall not cause adverse impact*** to aquatic life in that the receiving waters shall be of sufficient quality to ***support all aquatic species indigenous to the receiving water without detrimental changes to the resident biological community***.
Class C	5 ppm; 60% saturation	126/100 ml (g.m.*) or 236/100 ml (inst.*) of human and domestic animal origin	habitat for fish and other aquatic life	Discharges ***may cause some changes*** to aquatic life, provided that the receiving waters shall be of sufficient quality to ***support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community***.

* g.m., geometric mean; inst., instantaneous level

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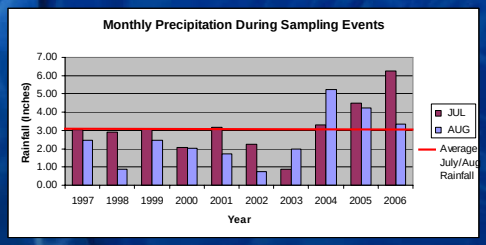
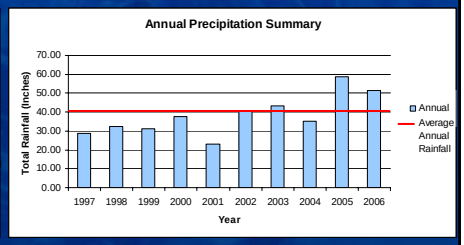
Biomonitoring Results and Precipitation

Station	Year				
	1997	2001	2002	2003	2006
511	-	NA	NA	NA	Class C
512	-	NA	NA	-	-
314	NA	NA	NA	NA	Class C
513	-	NA	NA	NA	-
315	Class B	Class B	Class C	NA	Class C

Notes: NA = Non-Attainment
Stations read from upstream to downstream





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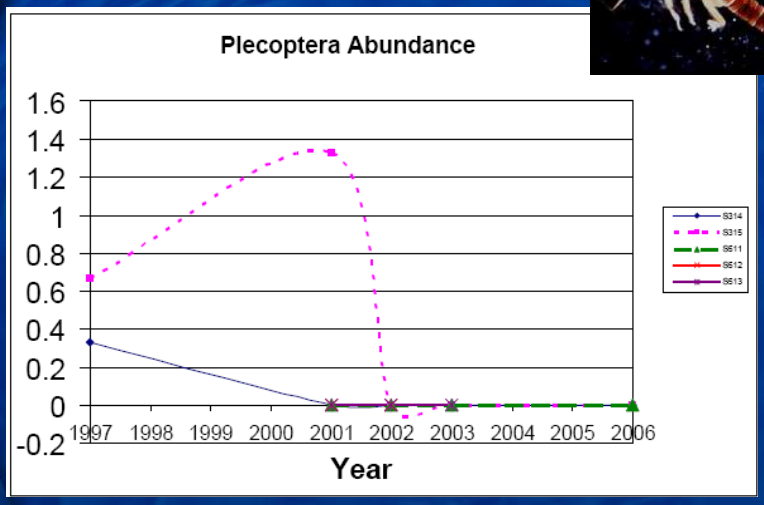
Biomonitoring Metrics



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Habitat Monitoring

- Qualitative assessments during biomonitoring
- Parameters include
  - *land use*
  - *canopy cover*
  - *bottom substrate compositions*
  - *others*

Canopy

Station	Year				
	1997	2001	2002	2003	2006
511	-	Dense	Partly Open	Partly Open	Open
512	-	Dense	Partly Open		
314	Open	Open	Open	Open	Open
513	-	Open	Open	Open	-
315	Open	Open	Partly Open	Partly Open	Partly Open

Notes: Stations read from upstream to downstream
Open = up to 25 % shaded
Partly Open = 25 to 75% shaded
Dense = 75% to 100% shaded

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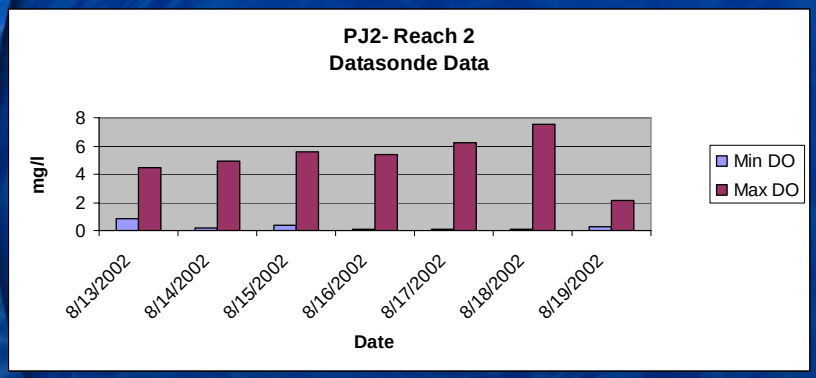
Water Quality – Dissolved Oxygen



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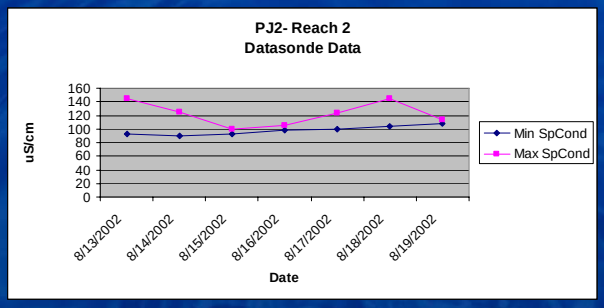
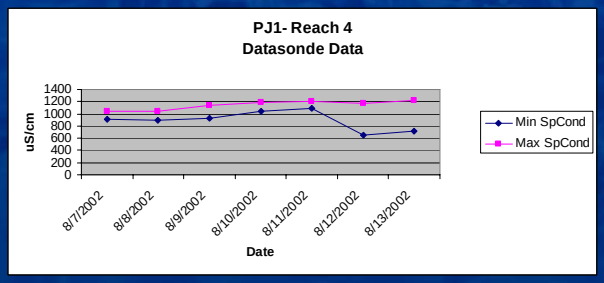
Water Quality - Conductivity





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Water Quality – Other Parameters

- Limited water quality data
- Several parameters well know contaminants in urban stormwater
  - *Sediment – Turbidity*
  - *Nutrients*
  - *Metals*
  - *Hydrocarbons*

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Geomorphic Conditions

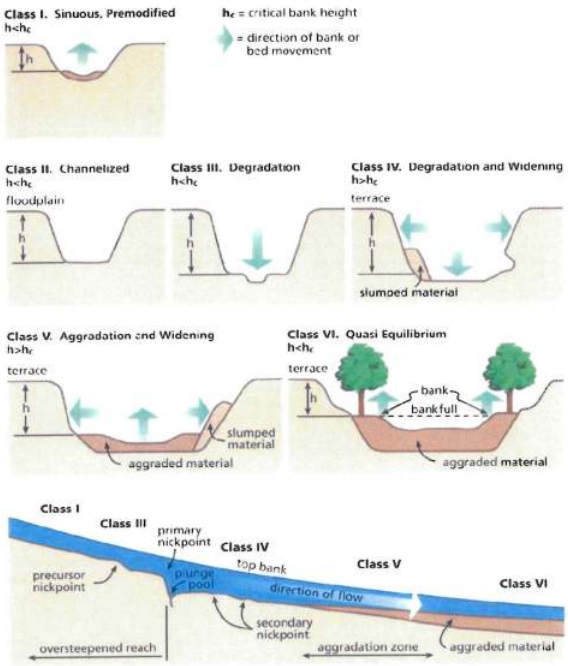

Figure 3. Channel Evolution Model (source: USDA 1998)

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Geomorphic Conditions - Barriers

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Geomorphic Conditions

Restoration Site	Summary of Existing Concerns	Recommended Treatment
Mall Reach	Backwater effect, creating overly wide channel	Hydrologic modeling of system needed to understand backwater issue
	Aggradation resulting from a low gradient	Redesign channel dimension, pattern, and profile
Downstream of I-95 to Hogan Rd	No diversity of aquatic habitat	Improve riparian zone
	Lack of riparian cover	
	Upstream aggradation is leaving this section sediment-starved	Terrace channel to create a functioning floodplain
Meadow Brook	Channel incision and widening occurring	Stabilize banks
	No connection to floodplain	Replace culvert
	Degradation and widening occurring	Redesign channel dimension, pattern, and profile
	Steep gradient	Plant riparian vegetation
	Contributing fine sediment to Penjajawoc stream	Consider stormwater BMPs
Cemetery	Upstream ponds are limiting downstream sediment supply, leading to moderate erosion	Spot-treat bank erosion areas
	Ponds also affect temperature	Continue to monitor channel
Rail Trestle and Route 2 crossings	Structures pose a barrier to fish passage	Replace structures with rocky ramp structures to maintain grade but allow passage
Stillwater Ave	Aggradation occurring	Restore dimension to reduce cross-sectional areas
	Open canopy	Plant riparian vegetation

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Stressor Workshop

Results of Maine DEP 2004 Stressor Identification Analysis for Penjajawoc Stream (Maine DEP, 2004)

Stressors	Watershed		
	Upper	Middle	Lower
Temperature	Yes - minor	Yes - possible	Yes
Nutrients	Yes - minor	Yes - possible	Yes - related to stormflow (less of a problem here)
Dissolved Oxygen	Yes - wetland main source	Yes	No (meets standards)
Conductivity	Yes	Yes - sand/silt sources	Yes - salt sources
Toxics	Yes	Yes	Yes
Sediment	No	Yes	Yes - high suspended sediment during storms (probably from Meadow Brook)
Altered Hydrology	Yes	Yes - groundwater main mitigate low baseflow syndrome	Yes - from upper reaches
Habitat	Yes	Yes	Yes - more data needed

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Stressor Prioritization – Need for Information

Priority	Stressors	Watershed		
		Upper	Middle	Lower
1	Altered Hydrology	Yes	Yes - groundwater main mitigate low baseflow syndrome	Yes - from upper reaches
2	Habitat	Yes	Yes	Yes - more data needed
3	Conductivity	Yes	Yes - sand/silt sources	Yes - salt sources
4	Temperature	Yes - minor	Yes - possible	Yes
4	Nutrients	Yes - minor	Yes - possible	Yes - related to stormflow (less of a problem here)
4	Dissolved Oxygen	Yes - wetland main source	Yes	No (meets standards)
4	Toxics	Yes	Yes	Yes
4	Sediment	No	Yes	Yes - high suspended sediment during storms (probably from Meadow Brook)

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Stressor Discussion

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Watershed Assessment Gaps

- Indicators of impairment
  - *Altered hydrology*
  - *Habitat*
- Biological characterization
  - *What needs to change to achieve Class B?*
    - *Class B has not been achieved at upstream station*

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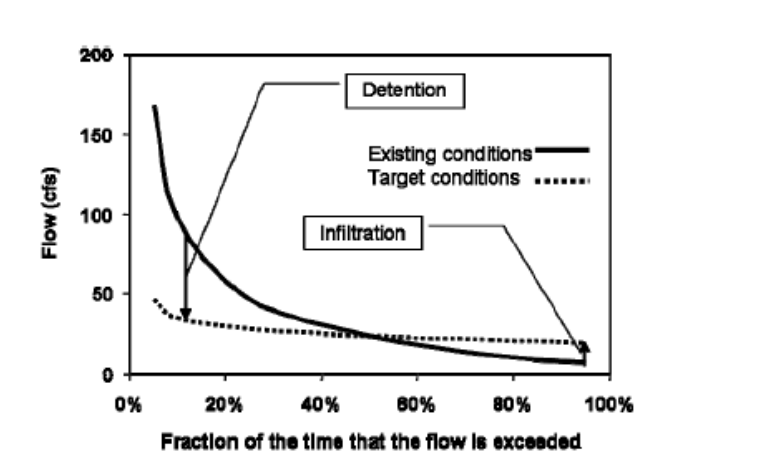
Indicators of Impairments – Altered Hydrology



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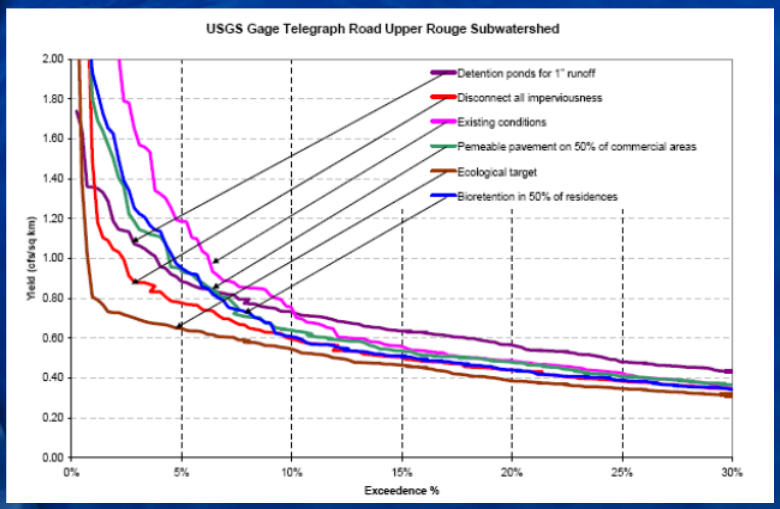
Indicators of Impairments – Altered Hydrology



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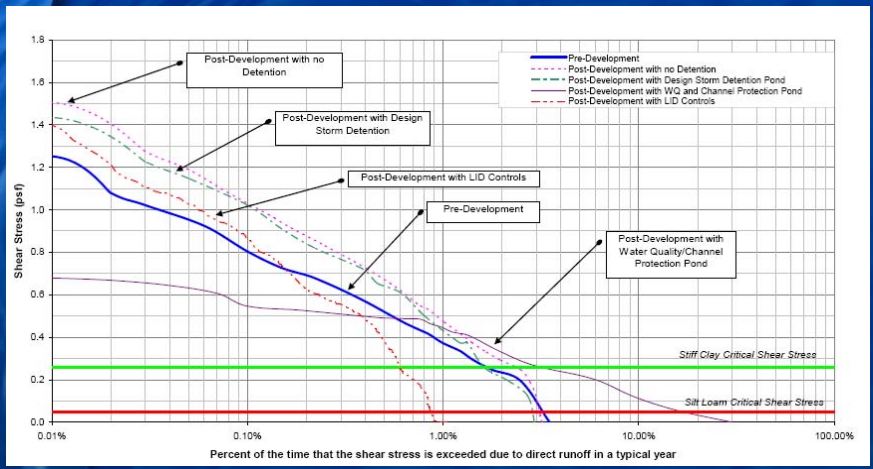
Indicators of Impairments – Altered Hydrology



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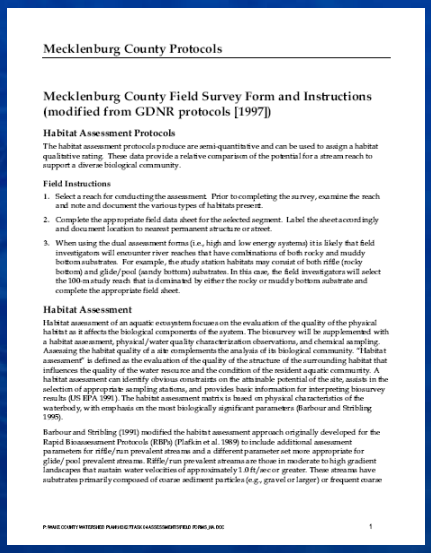
Indicators of Impairments - Habitat

- Numerous habitat assessment methods have been developed
- Several based on EPA RBP Method
- Objective information to assess habitat



Mecklenburg County Protocols

Mecklenburg County Field Survey Form and Instructions (modified from GDNR protocols [1997])

Habitat Assessment Protocols

The habitat assessment protocols produce are semi-quantitative and can be used to assign a habitat qualitative rating. These data provide a relative comparison of the potential for a stream reach to support a diverse biological community.

Field Instructions

1. Select a reach for conducting the assessment. Prior to completing the survey, examine the reach and note and document the various types of habitats present.
2. Complete the appropriate field data sheet for the selected segment. Label the sheet accordingly and document location to nearest permanent structure or street.
3. When using the dual assessment forms (i.e., high and low energy systems) it is likely that field investigators will encounter river reaches that have combinations of both rocky and muddy bottom substrates. For example, the study station habitats may consist of both riffle (rocky bottom) and glide/pool (sandy bottom) substrates. In this case, the field investigators will select the 100-m study reach that is dominated by either the rocky or muddy bottom substrate and complete the appropriate field sheet.

Habitat Assessment

Habitat assessment of an aquatic ecosystem focuses on the evaluation of the quality of the physical habitat as it affects the biological components of the system. The biosurvey will be supplemented with a habitat assessment, physical/water quality characterization observations, and chemical sampling. Assessing the habitat quality of a site complements the analysis of its biological community. "Habitat assessment" is defined as the evaluation of the quality of the structure of the surrounding habitat that influences the quality of the water resource and the condition of the resident aquatic community. A habitat assessment can identify obvious constraints on the attainable potential of the site, assists in the selection of appropriate sampling stations, and provides basic information for interpreting biosurvey results (US EPA 1991). The habitat assessment matrix is based on physical characteristics of the waterbody, with emphasis on the most biologically significant parameters (Barbour and Stribling 1995).

Barbour and Stribling (1991) modified the habitat assessment approach originally developed for the Rapid Bioassessment Protocols (RBPs) (Plafkin et al. 1989) to include additional assessment parameters for riffle/run prevalent streams and a different parameter set more appropriate for glide/pool prevalent streams. Riffle/run prevalent streams are those in moderate to high gradient landscapes that sustain water velocities of approximately 1.0 ft/sec or greater. These streams have substrates primarily composed of coarse sediment particles (e.g., gravel or larger) or frequent coarse

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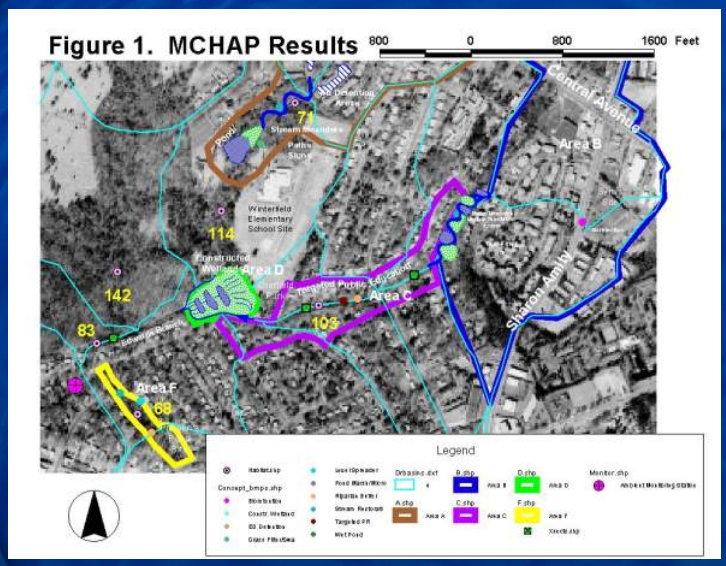
Indicators of Impairments - Habitat



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Workshop Overview

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Modeling Needs

- Dependent on hydrological data
- Model selection driven by key indicators
- Modeling support many key activities
  - *Stakeholder goal setting*
  - *BMP retrofit design*
  - *Stream restoration design*

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Critical Issues in Modeling

- Rules of modeling
  - *1st most important rule*
  - *2nd most important rule*
- Predictive ability of models
- Modeling objectives
- Data requirements
- Model selection process

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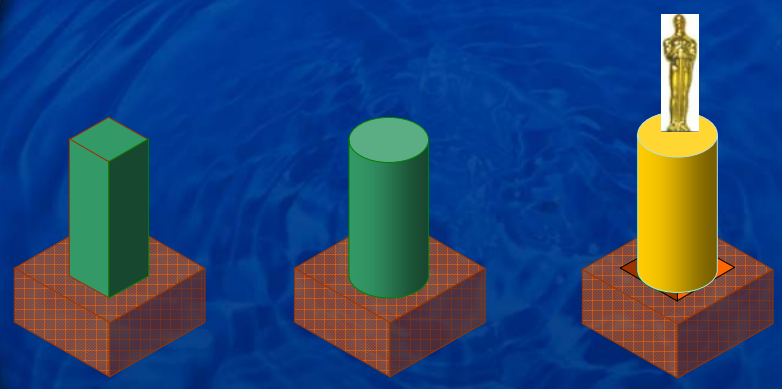
The 1st Most Important Rule: The Round-Peg-Square-Hole Syndrome



Model that fits the problem

Model that does not fit the problem

Problem fitted to the model

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The 2nd Most Important Rule

- Make the model as simple as possible but not simpler
  - *Maintains representativeness of the physical problem*
  - *Cost effective*
  - *Consistent with available data*

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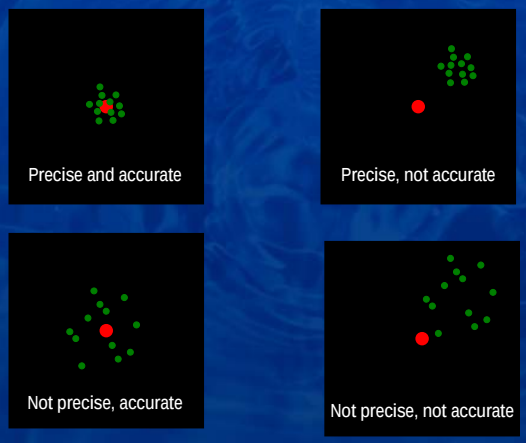
Predictive Ability of Models

- Precision vs. accuracy



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Predictive Ability of Models

- Reliability of predictions: state of the science

More reliable

Less reliable

Hydrology

Water quality

Ecology

less data

less difficult

more data

very difficult

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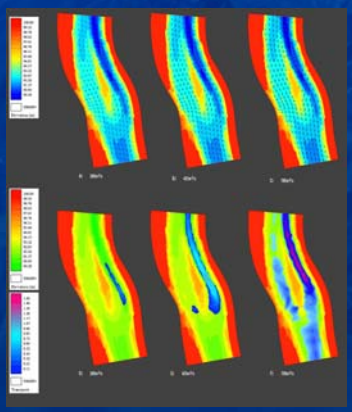
Predictive Ability of Models

- It's not about the pretty pictures



Source: USGS

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Model Calibration and Validation

- A reality check (literally)
  - *Select a measured data set (calibration data set)*
  - *Adjust input parameters to attain closest match to measured data*
  - *Select another data set (validation data set)*
  - *Verify that the model replicates the validation data set*
- Calibration data set sometimes available
- Validation data set seldom available

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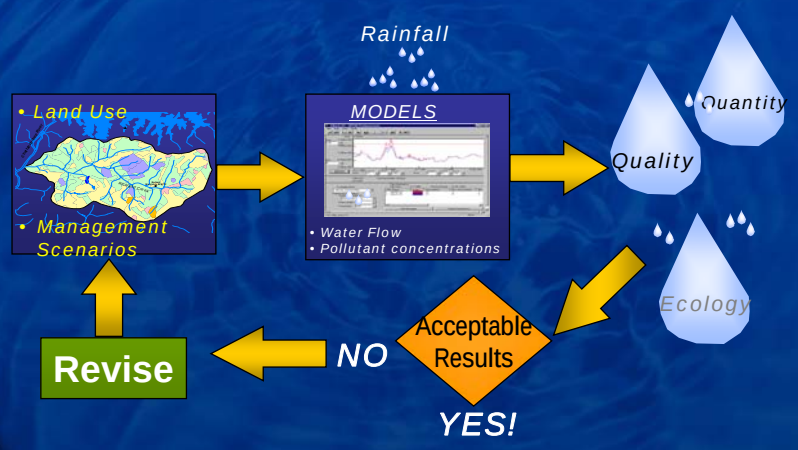
Models help evaluate watershed protection strategies



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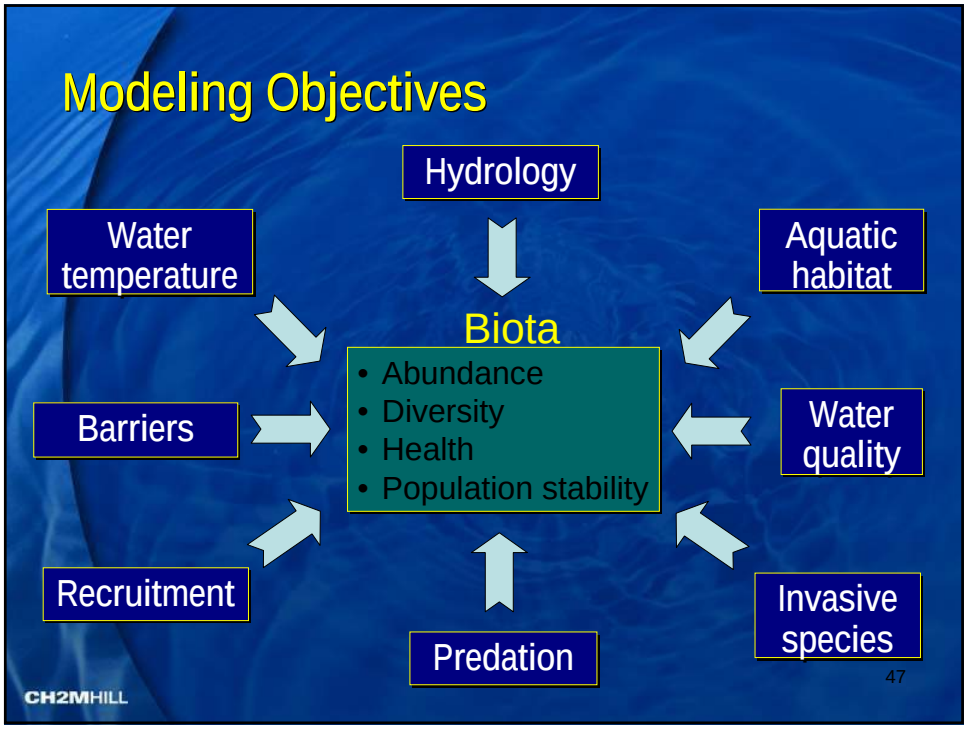
Modeling Objectives
Hydrology
Water temperature
Aquatic habitat
Biota
• Abundance
• Diversity
• Health
• Population stability
Barriers
Water quality
Recruitment
Invasive species
Predation
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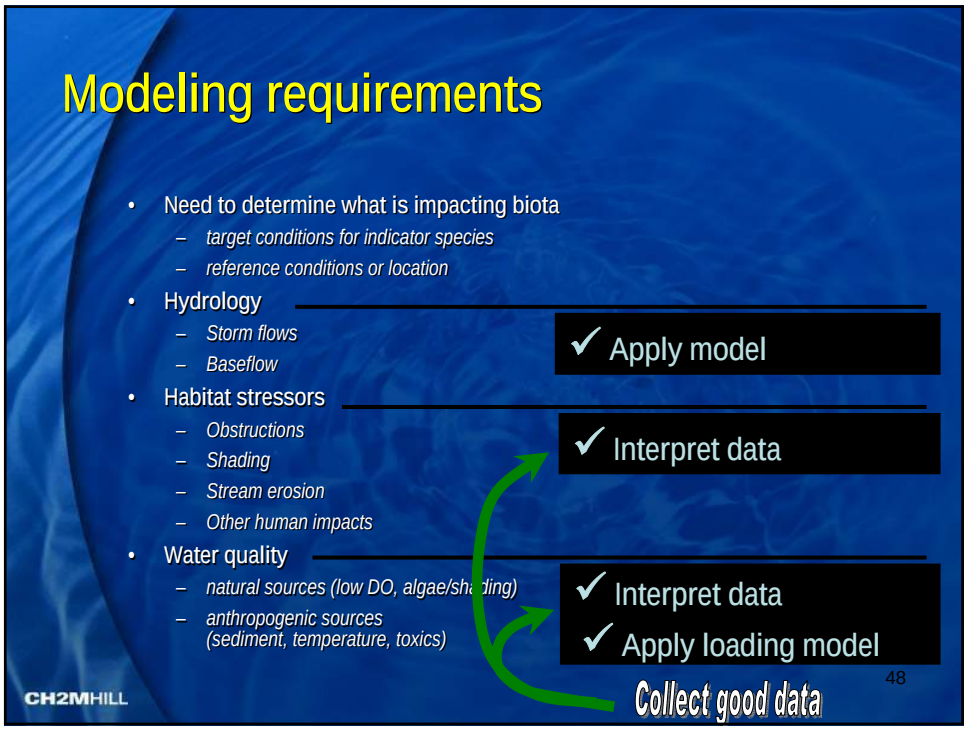
Modeling requirements
• Need to determine what is impacting biota
– target conditions for indicator species
– reference conditions or location
• Hydrology
– Storm flows
– Baseflow
• Habitat stressors
– Obstructions
– Shading
– Stream erosion
– Other human impacts
• Water quality
– natural sources (low DO, algae/shading)
– anthropogenic sources (sediment, temperature, toxics)
✓ Apply model
✓ Interpret data
✓ Interpret data
✓ Apply loading model
Collect good data
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Data Requirements for Hydrologic Modeling

- Watershed data (terrain, stream network, other water features)
- Soils map
- Land use, land cover map for current and future conditions
- Rainfall record
- Streamflow records (for calibration)

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What if data are not available?

- Garbage in … (get good data!)
- Start with hydrology
- Adaptive modeling
- Before-after scenarios
- Paired watersheds

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Caveats of Hydrologic Modeling

- Most models focused on extreme events
- Weak baseflow modeling
- Some models are very complex
- Continuous simulation vs. single events
- Rainfall data are often coarse
- Model users vs. modelers

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Some Available Models

- Public domain
  - *Storm Water Management Model (SWMM)*
  - *Hydrologic Simulation Program Fortran (HSPF)*
  - *Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (P8)*
  - *Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS)*
  - *Parameter-elevation Regressions on Independent Slopes Model (PRISM)*
  - *Generalized Watershed Loading Function (GWLF)*
- Proprietary
  - *Source Loading and Management Model (SLAMM)*
  - *HydroCAD*
  - *Inter-connected Pond Routing (ICPR) Model*
  - *MIKE SHE*
  - *InfoWorks RS*
  - *SWMM variants (PC-SWMM.NET, XP-SWMM)*

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Model Selection Factors

- Fitness to the problem
  - *Screening vs. planning*
  - *Urban, rural, or mixed use*
  - *Output (storm flows, baseflow)*
  - *Temporal scale (small vs. large storms)*
  - *Spatial scale (large vs. small watersheds)*
  - *Continuous simulation vs. single event*
- Management objectives
  - *Can it simulate management measures?*
- Project constraints
  - *Data, time, money, user skills*
- Pre- and post-processors, decision support
- Technical support
- Availability (public vs. proprietary)
- Longevity (short term vs. "living" model)

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Current Penjajawoc Models

- SWMM
  - *Suitable for urban areas (storm sewers)*
  - *Undeveloped areas require extra care*
  - *Weak baseflow capabilities*
  - *Continuous simulation*
- P8
  - *Emphasis on water quality, not hydrology*
  - *Weak channel routing and baseflow generation*
  - *Continuous simulation*
- HydroCAD
  - *Emphasis on storage facility design*
  - *Single event*
  - *Emphasis on large storms*
  - *No baseflow*

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Model Selection Process

- Identify stakeholders
- Define selection criteria (include data availability!)
- Assign weights to criteria
- Propose suite of potential models
- Score models according to criteria
- Select model

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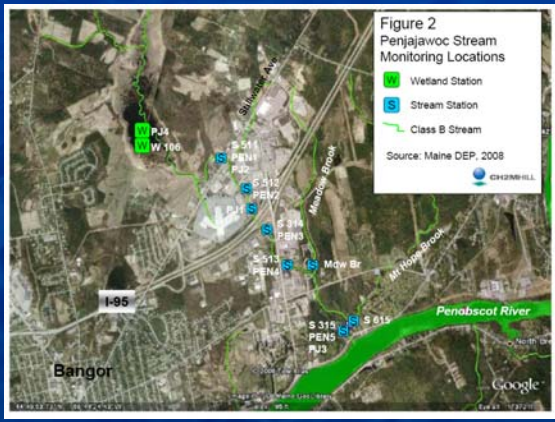
Monitoring Plan

- Monitoring plan
  - *Goals*
  - *Description*
  - *Maps*
  - *Responsibilities*
  - *QA/QC*



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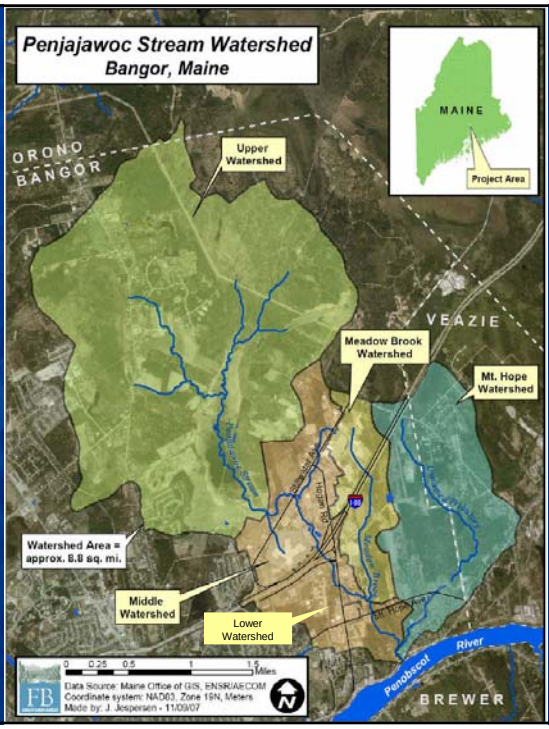
Hydrological Monitoring



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Need for Additional Biological Characterization

- What needs to change to achieve Class B?
  - *Class B has not been achieved at upstream station*
- Current Biological monitoring
  - *Assessment oriented*
  - *Diagnostic approach is required*

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Biological Characterization Considerations

- Additional sampling
- Consideration of additional sampling methods
  - *Quantitative and qualitative*
- Selection of a reference watershed
  - *Similar watershed size*
  - *Physiographic area*
  - *Areas with minimal impacts*
- Different use of metrics
  - *Expressed as % of reference*

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Advantages of Additional Biological Characterization

- Increased understanding of aquatic system
  - *Affects of watershed size*
  - *Potential marsh influences (similar influences in reference watershed)*
  - *Habitat influences (which are partially avoided through artificial substrate samplers)*
  - *Other factors necessary to support Class B*

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Volunteer Stream Team Monitoring

Penjajawoc Stream, Bangor Stream Team Sites

Meters
0 1,000 2,000

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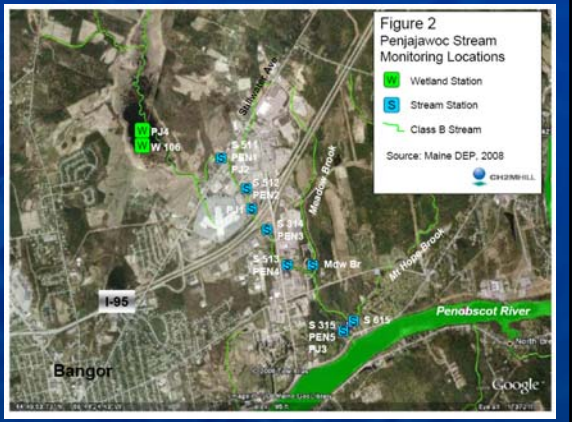
Monitoring Plan

- Monitoring plan
  - *Goals*
  - *Description*
  - *Maps*
  - *Responsibilities*
  - *QA/QC*



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Implications for WMP

Discussion

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Next Steps

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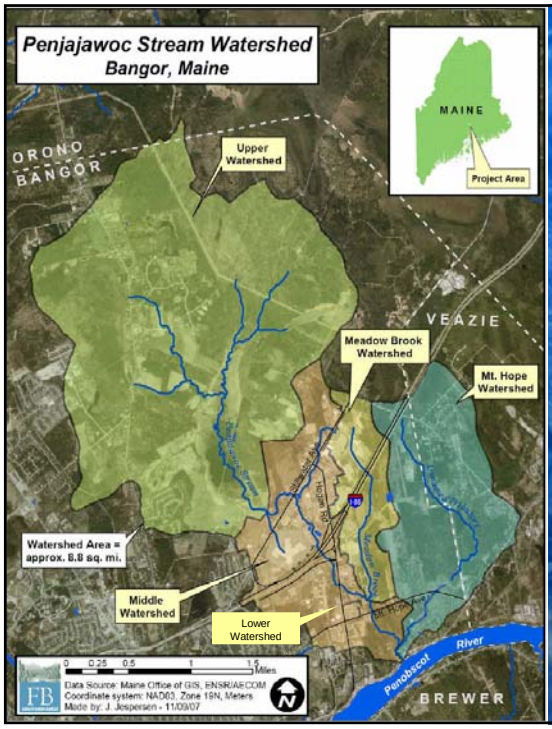

Penjajawoc Stream Watershed Workshop:

Stressor Prioritization and Monitoring-Modeling Workplan

February 27, 2009