A Biological, Physical, and Chemical Assessment of Two Urban Streams in Southern Maine: Long Creek & Red Brook

Volume I
Text, Figures, and Tables

December 31, 2002

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Made possible through a Clean Water Act (Section 104b3) grant from the U. S. Environmental Protection Agency.

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Acknowledgements

I would like to sincerely thank the people listed below for their assistance during this project. I could not have completed the study without them.

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Andrea Varricchione
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Susanne Meidel
Tom Danielson
Joe Glowa
Brad Autry
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Greg Beane
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Don Kale
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Susan Davies
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Susan Cormier
John Wathen
John Reynolds
Brie Begiebing
Dave Pineo
Bill Bullard
Mike Smith
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Autumn Curtis
Dave Chiappetta
Dr. J. R. Stevenson
Melissa Evers

VOLUME I

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Executive Summary

Please refer to the Glossary in Appendix K for definitions of many of the technical terms mentioned throughout this report.

This report presents the findings of a comprehensive watershed assessment of Long Creek and Red Brook, two low-gradient (gently-sloped), sandy-silty bottomed, freshwater streams that flow through the municipalities of South Portland, Scarborough, Westbrook, and a small portion of Portland, Maine into Clark's Pond, the Fore River, and eventually Casco Bay. A variety of land-uses, including retail and other commercial development, office parks, a golf course, some industrial facilities, a portion of a landfill, and some residential areas exist in the study watersheds. Long Creek, having more of its stream length flowing through urbanized areas (evidenced by greater values of percent total impervious area [PTIA[1]]), appears to be generally more stressed than Red Brook.

The alteration of the watershed landscape by the human activities just mentioned appeared to have impacted both Long Creek's and Red Brook's ecosystems to varying degrees. Those impacts included:

- Degraded water quality resulting from increased stormwater pollution (e.g., increased concentrations of metals, chloride, suspended solids, polycyclic aromatic hydrocarbons [PAHs], phosphorous, and nitrogen) and reduced dissolved oxygen concentrations
- Increased temperatures
- Altered (more flashy) patterns of stormflow and (potentially) baseflow
- Reduced/degraded streamside forest habitat and in-stream habitat quality and diversity including characteristics such as sparse streamside vegetation (trees, etc.) and shading in certain areas and apparently reduced amounts of large in-stream woody debris
- Destabilized stream geomorphology, especially in the more urbanized areas of the study watersheds.

For the most part, Long Creek and Red Brook both had a statutory water quality class designation[2] of Class C (State of Maine 2001). However, the portions of Long Creek located in Westbrook had a statutory designation of Class B (see Fig. 3.1.6). Long Creek monitoring stations located within Westbrook violated Class B dissolved oxygen standards on a number of occasions. Biological data also signaled stream ecosystem degradation in certain areas of the study watersheds. Macroinvertebrate communities, comprised largely of insects, crustaceans, and worms, generally were in worse condition in Long Creek samples than in Red Brook samples. Maine DEP water quality modeling analyses of macroinvertebrate data from the nine "rockbag"-method sampling stations had the following outcomes:

- Two Long Creek stations in Westbrook, LC-M-2.270 and LC-Mn-2.274, failed to meet their statutory designation of Class B (in fact, one site was found to be in "non-attainment" of any water quality class standards)
- One Long Creek station in South Portland, designated as Class C, was found to be in "non-attainment" of any water quality class standard
- One upper Red Brook station in Scarborough exceeded its Class C designation with a Class A model outcome.

Additionally, Long Creek had fewer pollution-sensitive macroinvertebrate species (e.g., mayflies, stoneflies, and caddisflies) in its samples than Red Brook. The fish community in the study streams showed a similar pattern. Brook trout were found to be fairly abundant at three out of four study sites in Red Brook. Conversely, brook trout were not found to exist at any of Long Creek's seven sites, even though brook trout had been documented as existing there at least as recent as the late 1960s.

Analyzing the leading causes of stream ecosystem stress throughout the watersheds, in terms of which stressors are most responsible for biological community degradation, is an ongoing process, and one that falls outside of the funded scope of this watershed assessment project. The Maine Department of Environmental Protection (MDEP) has been working with the U. S. Environmental Protections Agency's (USEPA) Office of Research and Development (ORD) and USEPA-New England to apply USEPA's stressor identification (SI) guidance (USEPA 2000) to the Long Creek data. A workshop was conducted February 26-28, 2002 with 26 participants from MDEP, Maine State Planning Office, University of Maine, Vermont Department of Environmental Conservation, USEPA-ORD, and USEPA-New England. During this preliminary workshop, SI guidance was applied to the fish portion of the aquatic life data. In subsequent working group meetings, the SI guidance will be applied to the macroinvertebrate portion of the aquatic life data, and further refinements will be made to reevaluate, prioritize, and streamline suspected causes of impairment. Results from that working group's efforts are expected to be available by the summer of 2003. A preliminary survey of the data in this report yields a fairly reliable characterization of the types of impairments affecting the biological community and suggests that watershed restoration recommendations include some or all of the following:

- Improve both stormwater quality- and quantity-control best management practices (e.g., minimize impervious surfaces throughout the watershed wherever possible, clean up potential pollutants residing on impervious surfaces as frequently as possible, construct/retrofit the stormwater release structures of stormwater detention ponds so that they are not maintaining stream flows at or above highly erosive bankfull [channel-forming] conditions longer than they normally would under natural conditions)
- Consider extending, in current municipal ordinances, the width of riparian/shoreland zoning protection beyond the minimum of 75 feet required by the State of Maine because an increase in the effectiveness of "riparian buffer benefits" such as sediment

and nutrient removal, flood mitigation, and wildlife habitat availability[3] generally is associated with an increase beyond a width of 75 feet

- Protect/enhance streamside (riparian) and floodplain forest conditions throughout the watershed (where necessary) by organizing tree plantings and bioengineering projects as well as developing more stringent controls on town shoreland (riparian zone) timber harvesting ordinances (e.g., develop "no cut zones" within 15-35 ft of streams in order to increase canopy cover to shade streams [cooler water can hold more dissolved oxygen], increase bank stability, and provide more opportunities for large woody debris to fall into the streams and become fish and macroinvertebrate habitat structures)
- Preserve the parcel of land between LC-M-1.1~ and LC-M-2.3~, believed to be within/adjacent to an open-space/clearance zone for FAA airport regulations, appeared to be one of the most contiguous, intact stream/riparian forest and floodplain complexes in the Long Creek watershed
- Minimize impervious surfaces through the use of pervious parking spaces, parking garages, and rooftop gardens/turf
- Improve in-stream habitats where necessary (e.g., strategically place large woody debris structures, where appropriate[4], in order to provide more stable habitat for macroinvertebrates, more retention devices to trap food material for microbes and macroinvertebrates, more cover for fish, and [possibly] an increased number of opportunities for stream water re-aeration)
- Evaluate the usefulness of at least two known in-stream stormwater detention basins in two reaches of Long Creek (upstream of Spring Street) and determine if they should be retrofitted, removed, or re-engineered so that stormwater is treated outside of the channel region
- Evaluate and replace as many poorly-functioning culverts as necessary with large box- (or bottomless arch-) culvert style culverts to minimize drainage plugging and increased erosion while simultaneously minimizing the amount of large woody debris needed to be removed from the system; also consider engineering and installing floodplain-sited "release" culverts in order to have channels functioning more naturally and not ponding up water behind poorly-functioning culverts
- Work with local golf courses, businesses with lawns, and homeowners to ensure that fertilizers and pesticides are only being applied to the extent that they truly are needed.

It is likely that most of the measures described above also would benefit stream ecosystems in other Maine municipalities experiencing rapid urbanization.

[1] **Impervious surfaces** were defined as areas that were impermeable and, therefore, did not allow rainfall and other precipitation to penetrate beneath the Earth's surface unless by artificial means [e.g., stormwater conveyance systems]. Examples of impervious surfaces included parking lots, roads, rooftops, driveways, etc. PTIA (or analogous measures) was used to estimate the intensity of urban land use in the study watersheds. Recently, this variable has been used by a number of studies of urban streams (Schueler 1994, Morse 2001).

[2] See Appendix H or State of Maine (2001) for definitions of the various water quality classes.

[3] Some wildlife species, such as deer, bear, and (breeding) migratory birds require widths of 100-300 ft in order to use riparian corridors as habitat (U. S. Forest Service 1997).

[4] The designs of stream restoration practices such as the placement of large woody debris need to be carefully planned and engineered as well as tailored to each site so as to not increased in-stream erosion.

Chapter 1
Introduction

Study Objectives

The objectives of the comprehensive watershed assessment were to: (1) determine the ecological conditions of two urban streams (Long Creek and Red Brook) in southern Maine, (2) improve the ability of aquatic ecosystem professionals to assess ecological conditions of urban streams, and (3) collect data and information that would help the State of Maine develop TMDLs (Total Maximum Daily Loads) for Long Creek and Red Brook and also educate local professionals and citizens about the potential impacts of urbanization on streams in Maine. (For more information about TMDLs visit <www.epa.gov/owow>.) The first and third objectives were met by completing a relatively comprehensive assessment of the local watershed conditions through monitoring of a variety of biological, physical, and chemical parameters in the study streams and their riparian corridors along with an inventory of watershed land-uses. The second and third objectives also were met because this study, completed in a state where few urban watershed studies have been conducted, contributes insights to the growing field of urban watershed science via its unique combination of biological, physical, and chemical data.

Study Area

Long Creek and Red Brook are both freshwater streams in southern Maine, above tidal influence, and tributaries to Clarks Pond, a small, relatively shallow impoundment. The Long Creek watershed above Clarks Pond (3.45 square miles) is located primarily in South Portland and Westbrook and includes the Maine Mall and its associated commercial development, a golf course, several light industrial facilities, office parks, and some forest. The Red Brook watershed drains a 3.30 square mile watershed located primarily in Scarborough and South Portland and has residential, retail, and forest land-use types. Both watersheds include a long stretch of the Maine Turnpike along with a major regional waste incinerator and associated landfill. Both Long Creek and Red Brook generally are low-gradient and, in most locations, have streambeds dominated by fine sediment size classes (i.e., sands, silts, and clays).

Maps of the study area are presented in Figures 1.1a-d and 1.2. A number of other maps showing the location of study sites, surficial geology, and land-uses which may potentially impact the study streams, are presented in section 3.1 of this report. Details about the history of the study area are discussed later in this chapter. (*Note*: Long Creek is named as such on the 1978 photo-revised Portland-West U.S.G.S. 7.5-minute topographic map, so that name was used for the stream and its three major branches, upstream of Clark's Pond, that were not a part of Red Brook. However, it must be mentioned that some older documents sometimes refer to this stream as Jackson Brook [e.g., Seeley and Valle 1983].)

Background on the Study and Regulatory Situation

The ecological conditions of the Long Creek and Red Brook watersheds apparently have been in decline for at least three decades. Water quality and sport fisheries in Clark's Pond, the impoundment at the base of the Long Creek and Red Brook watersheds, have declined in recent decades, a trend which corresponds to the development of the region into a large commercial/retail complex (e.g., the Maine Mall and associated development [South Portland Engineering Department 1995]) and which also likely reflects degradation of Long Creek and Red Brook. Degradation of stream ecosystems is a trend that is common in urbanizing watersheds. In the United States, urbanization is the second-leading cause of stream impairment after agriculture, even though the total area of urban land-use is much smaller than that of agricultural land-uses (Paul and Meyer 2001).

When 104b3 funding (Clean Water Act money administered by the USEPA) became available for the study of an urban watershed, Long Creek was chosen because it was a recently developed commercial watershed (it had been relatively undeveloped 35 years ago). Long Creek also served as a good example of what can happen in rapidly urbanizing commercial areas, a trend which is happening in several other places around the state of Maine. Also, because the watershed had very little residential development, the number of landowners per acre was rather small, meaning that any efforts to address problems were likely to have a better chance of success than in some of the more mixed-use watersheds. Red Brook was added to the project because it increased the area of study, shared some of the same problems, and also appeared to have some relatively undisturbed reaches that could be used as reference sites.

Currently, for the most part, Long Creek and Red Brook both have a statutory water quality class designation of Class C (State of Maine 2001; see also Appendix H). However, the portions of Long Creek located in Westbrook have a statutory designation of Class B (Fig. 3.1.6). Prior to this study, a number of specific problems related to water quality were known to exist within Long Creek and Red Brook. Long Creek had been included on Maine's 303(d) list of impaired waterbodies because of violations of State Water Quality Standards (WQSs) for dissolved oxygen caused by unspecified nonpoint sources of pollution. Red Brook had been on Maine's 303(d) list for contamination by PCBs (polychlorinated biphenyls) caused by unspecified nonpoint sources. (On the 1998 303(d) list, both impaired waterbodies had been scheduled for Total Maximum Daily Load (TMDL) development between 2008-2011. The schedule recently was revised and the TMDL development schedule was moved up, at least for Long Creek, due to the funding provided for this study in 1999). Maine DEP's 2002 Performance Partnership Agreement joint performance plan named Long Creek as a NPS TMDL to be worked on or completed in FY02.

Study Area History

Clark's Pond

Although the present study only examined flowing waters upstream of Clark's Pond, the history of this waterbody lends some general insight into the human activities that have occurred in the study watersheds over the years. The pond apparently had been in existence prior to European settlement of the region and probably was natural (Seeley and Valle 1983). However, a dam was constructed around 1900 at the eastern end of the pond to improve local residents' ability to harvest ice from the pond. Historically, Clark's Pond was a place for fishing, swimming, picnicking, and boating, and, up until the late 1950s, it produced high quality ice for the Greater Portland area. According to accounts from older local residents, apparently only suckers and eels were living in the pond during the 1920s and 1930s. During the 1940s, the U.S. government began funding the construction of "liberty ships" to take supplies by convoy to England. South Portland's shipyards became quite active because of this and it resulted in a large influx of people seeking work in the area, which resulted in the construction of housing projects in the Clark's Pond region. In the mid 1940s the Maine Turnpike was constructed. The first annual Clark's Pond Fishing Derby, the first derby to ever be held in Maine, happened in 1946 after the pond was stocked with trout. Other major events that occurred in the Clark's Pond watershed included the closing of the ice house and the establishment of the Bosal Foam Company in the mid-1950s, the establishment of the Maine Air National Guard station on the northern shore of Clark's Pond, the construction of I-295 in the 1960s south of Clark's Pond and adjacent to much of the lower half of Red Brook, and the construction of the Maine Mall in the late 1960s. Prior to the 1960s, almost all of the land in the watershed was farmland or forest. After that, land-uses in the watershed started to change rapidly (Seeley and Valle 1983).

In 1983, a report prepared by the South Portland Planning Department (Seeley and Valle 1983) recognized that Clark's Pond and its tributaries were becoming increasingly valuable as aesthetic and recreational resources given that urbanization was rapidly transforming the local landscape. They also noted that the stresses from erosion, sedimentation, filling of wetlands, and increased runoff pollution from impervious surfaces were beginning to degrade the water and habitat quality of Clark's Pond and its tributaries. Problematic algal blooms and abundant macrophytes in the pond were believed to be the result of increased sediment and phosphorous loads via the rapidly developing tributary watersheds. Development also was blamed for increased levels of trash in the tributaries and pond (Seeley and Valle 1983).

Long Creek - In General

A consulting firm report published in the early 1980s concluded that:

> ... the drainage region of Long Creek is an area that has undergone intensive commercial development over the past two decades. The current expansion of the Maine Mall, which is located a quarter mile to the west of the

> southern branch (*coded as LC-M in the present DEP study*), will provide an impetus for continued development in the area. Much of the wetland associated with Long Creek has been filled in order to construct new buildings, parking areas and roads. This filling activity has been a continuing process through the present and is anticipated to continue into the future (ECJCCE 1982).

Figure 1.3, taken from Seeley and Valle (1983), shows where major filling activities had occurred in the watershed up until 1983. Rapid development of the Long Creek watershed resulted in severe erosion and thus sediment pollution problems in Jackson Brook (Long Creek) (Seeley and Valle 1983). (See Figure 1.4 for a map of the study streams presented in Seeley and Valle [1983].)

Long Creek - Main Branch (LC-M)

Erosion and parking lot runoff were cited as being major problems in this branch by a study conducted in the early 1980s (Seeley and Valle 1983). There was a lot of unvegetated fill adjacent to Long Creek and between Gorham Road and the Maine Mall Road (which appears to be where the current "Mall Plaza" area plus a number of developments in the vicinity of the junction of Gorham Road and Foden Road exist). Also, the headwaters of this branch were noted as having been subjected to extensive logging operations (Seeley and Valle 1983).

Long Creek - Southern Branch (LC-S)

A tire and car-part landfill (likely pre-Maine Mall), logging activities, and parking lot runoff from the Maine Mall were cited as major problems in a 1983 study (Seeley and Valle 1983). Also, examination of photo-revised U.S.G.S. topographic maps and GIS data collected in this study indicate that this branch was relocated to facilitate expansion of the Maine Mall retail complex (pers. obs.).

Long Creek - Northern Branch (LC-N)

Erosion and parking lot runoff were cited as being major problems in this branch in a 1983 study (Seeley and Valle 1983). Additionally, in 1982, trichloroethylene (TCE), 1,1,1-trichloroethane (TCA), xylene, and other organic solvents were detected in groundwater at the Fairchild Camera and Instrument Corporation (later known as National Semiconductor). (It is not known, at this time, if the adjacent Fairchild Semiconductor is included in the affected area.) This contamination was located primarily in a region near the facility and the upper half of the northern branch of Long Creek (LC-N) (Sevee and Maher 1998). Later that year, the first known study of Long Creek, an aquatic survey, was performed by E. C. Jordan Co. Consulting Engineers [ECJCCE] (1982). In ECJCCE's study, Long Creek's branches were coded differently than they were in the present DEP study (see Table 1.1 for a comparison of the coding schemes.) ECJCCE (1982) found surface water sites to have concentrations of the following volatile organic pollutants: trichloroethylene (0.001 - 0.031 ppm), trans-1,2-dichloroethylene (0.003 - 0.009 ppm), and tetrachloroethylene (0.001 - 0.002 ppm). The highest concentrations typically were found near an outfall pipe of the Fairchild facility. Surface water sites in the northern branch of Long Creek (*LC-N*) were found to have concentrations of 0.007 and 0.003 ppm of trichloroethylene (TCE) and trans-1,2-dichloroethylene respectively (ECJCCE 1982).

Table 1.1. Comparison of study site names between a study performed in 1982 versus the present study. "LC" stands for Long Creek. Codes from the present DEP study are italicized in this study area history section to distinguish them from the 1982 study site codes.

E. C. Jordan Co. Consulting Engineers (1982)	**Present DEP Study (2002)**
LC - East Branch	Not included in study because of extremely low discharge and lack of inclusion on USGS topographic maps. Enters LC-M at approximately stream mile LC-M-0.15.
LC - South Branch	*LC-M*
LC - North Branch	*LC-N*
Not included	*LC-S*

After the pollution was detected and a few analyses were completed, a trench, filled with permeable soils was dug along Western Avenue (Rt. 9) to control off-site migration of the pollutants. A routine groundwater-, with an occasional surface-water-, sampling program was run up through (at least) 1998 to monitor the situation (Sevee and Maher 1998). In general, there has been an overall decrease in TCE concentrations since 1982. However, in 1998, concentrations were found to be at or near "human health, water, and organism criteria" (2.7 ppb) in surface water samples collected near an outfall from the plant (which is directed towards a channel headed for *LC-N*). Also, four of twenty-two wells still exceeded the clean-up goal of 75 ppb (Sevee and Maher 1998), so there still may possibly be some contamination of *LC-N* even though concentrations likely are low.

Red Brook (RB)

Construction of I-295 during the 1960s, including the removal of vegetation and the addition of fill, resulted in Red Brook becoming choked with sediment, much of which eventually entered Clark's Pond (Seeley and Valle 1983). (Note, however, that much of the brook's substrate would be expected to naturally have a higher percent composition of sands and silts based upon the geological characteristics of its watershed. For more discussion on geology and stream substrate conditions see the Results and Discussion chapters of this report.) Figure 1.3 shows where major filling activities had occurred in the watershed up until 1983. Also, parts of Red Brook were relocated to facilitate the construction of I-295 (Seeley and Valle 1983). Erosion from logging activities at the lower end of Red Brook and from unstablized slopes of the Regional

Waste Systems' (RWS) landfill balefill site, which had become severely eroded during a rainstorm, contributed significant amounts of sediment to the stream (at the time plans were in place to restablize the slope) (Seeley and Valle 1983).

Chapter 2
Methods

2.1 Land Use Analysis, Stream Walk, Watershed Survey, and Surficial Geology Investigation

1. A preliminary "stream-walk" survey of the entire length of Long Creek and Red Brook was conducted to become familiar with their channel and habitat conditions, locations of stormwater delivery outflows, and adjacent land uses. Narrative descriptions of the stream channels from headwaters to mouth were recorded. Aerial photographs were inspected to gain a broad-scale understanding of the stream and watershed conditions. As much as possible (primarily in South Portland), municipal sewer and commercial development plans were reviewed to determine areas of the streams which likely would be affected by concentrated stormflow discharge. Sampling sites for biotic, chemical, and physical parameter were chosen based upon information gathered from the evaluations described above.

2. Historical aerial photographs dating from 1976 and 1995 were obtained from the Greater Portland Council of Government, scanned on a digital scanner, and added to the final report as a visual aid in interpreting the findings. When creating GIS maps with digital orthoquad images, obtained from Maine Office of GIS and Maine DEP files, dates for these images ranged between 1996 and 1998. (*Note*: The QAPP stated that these photos would be obtained from the Cumberland County Soil and Water Conservation District.]

3. The percent total impervious area (PTIA) of the subwatershed areas above the macroinvertebrate and storm discharge sampling sites was determined using methods described in Morse (2001). Briefly, measurement of PTIA was conducted using 1995 aerial photos (described above) having a scale of 1:7,200. Catchment boundaries were delineated using the watershed divide technique (Stanford 1996) on 1:24,000 scale USGS topographic maps. After watershed divides were delineated on mylar plastic, those mylar sheets were placed over the appropriate aerial photographs and the catchment boundaries were delineated. Large and obvious expanses of impervious surfaces within the catchment (e.g., parking lots, industrial buildings, roads, etc.) were delineated and measured with a planimeter. Areas of homogenous urban / suburban intensity, as well as the total area of the catchment also were measured. The areas of homogenous urban density, including residential neighborhoods of 1, ½, ¼, and 1/8 acre lots were multiplied by an empirically derived impervious surface factor (which were ground-truthed by Morse 2001). PTIA was calculated using the following equation:

$$PTIA = \frac{\Sigma(\text{area of large impervious areas}) + (\text{areas of homogenous density X impervious factor})}{\text{catchment area}}$$

Impervious areas were defined as being parking lots, rooftops, roads, driveways, and airport runways.

4. A global positioning system (GPS) unit (Trimble model # TDC1) was used to locate major features of the study watersheds such as study site locations and major (i.e., $\geq$ 24 inches or 0.6 m) storm drain outlets. These locations were then converted to a geographic information system (GIS) "shapefile", which eventually became part of an overall GIS map project (ArcInfo 8.1) for this study. GPS data collected in 2002 for the "pollution hotspot" map (Figure 3.1.5) were collected using a Garmin 12 GPS unit.

5. Other GIS data layers, including streams, rivers, ponds, digital USGS 7.5-minute topographic maps, etc., were obtained from the Maine Office of GIS and the Maine Department of Environmental Protection's GIS staff and were combined with GPS data collected for this study to create a variety of GIS (ArcInfo 8.1) maps for this project.

6. A survey of the watershed was performed to identify specific, priority, addressable nonpoint sources of pollution. This survey was a combination of observations made during the initial stream walk, frequent study site visits, and analysis of GIS information. Sources identified included chronic erosion problems and areas with high potential for runoff or groundwater contamination by nutrients (e.g., nitrogen and phosphorous), coliform bacteria, organic wastes (sources of biochemical oxygen demand) and toxins (e.g., metals, solvents, pesticides, and petroleum products from "hotspots" such as gas stations, underground storage tanks and landfills).

2.2 Biological Community Sampling

Periphyton

1. A quantitative technique was used to determine the sample site's potential to accumulate periphyton biomass on artificial substrate (standard bricks) (Stevenson and Bahls 1999). *Periphyton* is the community of macro- and micro-algae attached to substrates found on the bottom of aquatic ecosystems. The bricks were standardized for substrate type among the study sites so as to allow for direct comparisons. On June 12, 2000, three bricks were placed in the stream bottom at each periphyton study site (i.e., sites having an open canopy) and allowed to colonize for 4 weeks ($\pm$ 4 days). Upon return to the site, periphyton was removed from the bricks using a modified toothbrush to scrape a defined area within a PVC tube (4.2-cm internal diameter) fitted with a neoprene collar. Each scraping was 12.56 cm^2, and each "sample" was a combination of two scraped areas. The periphyton slurry was removed using an eye-dropper bulb and then emptied into labeled mason jars. Five "samples" were collected per site, for a total of 125.6 cm^2 per site. Field data sheets (Stevenson and Bahls 1999) were completed at each periphyton study site. Samples were placed on ice and returned to the laboratory. In the DEP-Portland laboratory, samples were buffered with $MgCO_3$, filtered onto 0.7 μm filters within 24 hours of collection, kept frozen in dark containers, and then analyzed for chlorophyll-*a* content by the State of Maine Health and Environmental Testing Laboratory (HETL) within 21 days (Table 2.1; Stevenson and Bahls 1999). In 1999, samples were not analyzed properly so the results were discarded. In 2000, samples were analyzed correctly except that duplicate samples were not analyzed even though they were submitted (perhaps due to miscommunication). (*Note*: This periphyton sampling technique was not the same as the protocol described in the QAPP used by Maine DEP staff in Augusta.)

2. A qualitative periphyton technique (a modification of techniques described in Stevenson and Bahls [1999]) was used to determine the species richness and composition found at each of the periphyton sites. In 1999, a procedure to proportionately sample natural substrates (fine sediments and large woody debris) for periphyton at the shaded "rockbag" macroinvertebrate sampling sites (described later) had been used. However, because chlorophyll-*a* samples had been analyzed incorrectly by the lab, these qualitative samples were discarded as well. In 2000, in the interest of saving time (because sampling of these natural substrates was time-consuming), artificial substrates (standard bricks) were used at sites having open canopies in order to encourage the maximum amount of periphyton growth possible (Table 2.1). On June 12, 2000, two bricks were placed in the stream bottom at each periphyton study site and allowed to colonize for 4 weeks (± 4 days). Upon return to the site, periphyton was removed from the bricks using a toothbrush to scrape the entire top surface of the two bricks (370.5 cm^2) into a white plastic tray. At each site, the sample slurries were washed and composited, using a squirt bottle, into a single glass mason jar (approximately 1 liter) and preserved with M3 (USEPA 1999). Preserved periphyton samples were shipped to periphyton specialist Dr. R. Jan Stevenson at Michigan State University for identification. (*Note*: At the time of this report, the data had just been received by DEP but not yet analyzed. Also, this periphyton sampling technique was not the same as the protocol described in the QAPP used by Maine DEP staff in Augusta.)

<u>Macroinvertebrates</u>

1. Standard Maine DEP "rockbag" macroinvertebrate sampling protocols (Davies and Tsomides 1997) were used at 9 study sites in the Long Creek and Red Brook watersheds. The use of rockbags standardized for substrate type both among the study sites and also with the statewide historical dataset compiled by Maine DEP. Between August 5-6, 1999, three rock bags (7.25 kg cobble substrate, 2.54 cm aperture mesh) were placed in the stream channel at each site for 4 weeks (± 4 days) in sandy-runs that were shaded more than 79% by canopy cover, the most representative habitat type of the Long Creek and Red Brook watersheds. After the

colonization period, the field technicians returned, placed a 600-μm mesh net downstream of each bag, and pulled each rockbag into the net. The contents of the rockbag and the dip-net then were washed into a 600-μm sieve bucket. Individual rocks were cleaned by hand to ensure the capture of all organisms in the sample. These contents then were washed into labeled mason jars (approximately 1-liter) and preserved with 70% ethyl alcohol. One rockbag sample was processed at a time. Macroinvertebrate/habitat field data sheets (Davies and Tsomides 1997, USEPA 1999) were completed at each macroinvertebrate rockbag sampling site.

2. A modified multi-habitat approach was used between September 22-26, 1999 to sample macroinvertebrates in all the habitat types found within the Long Creek and Red Brook drainages (U.S.E.P.A. 1997, 1999). At each of the 16 study sites where this method was used, samples of different habitat types (Table 2.1) were collected and composited into a single sample for each study site. In snag habitats, samples were collected by scraping ~630 cm^2 of woody debris (e.g., branches, logs, etc.) into a plastic tray. Also, prior to woody debris removal, a D-frame dip net was held downstream of the debris as it was lifted out of the water for sampling in order to collect any escaping organisms. For the remaining habitat types, a D-frame dip net (width: 30.5 cm) was used to collect "jab" or "kick" samples (Table 2.2; U.S.E.P.A. 1997, 1999). Each "jab" or "kick" covered a linear distance of 0.5 m (or 0.31 m^2 of total sampling area) per jab or kick. Habitats were sampled according to the proportions in which they were found at a sampling site. These proportions can be found in the "Habitat Section" of the results of this report under Table 3.6.2. Most sampling sites were sandy/silty-run type habitats, and at each of these sites the same proportions of the different habitats were sampled to help ensure comparability (e.g., 3 "snags", 2 "underneath streambanks", 2 "leaf packs", and 3 "sand" habitats at each of these sites; this totaled 2.359 m^2). This habitat information was recorded in a field notebook and on sample labels accordingly. Multi-habitat macroinvertebrate sampling occurred by moving in an upstream direction to reduce sampling site disturbance. Once collected, the contents of the dip-net or snag-material-tray were washed into a 600-μm sieve bucket. These contents were then washed into labeled Whirl-Pak bags and preserved with 70% ethyl alcohol. Macroinvertebrate/habitat field data sheets (USEPA 1999) were completed at each macroinvertebrate multi-habitat sampling site. (*Note*: This particular macroinvertebrate sampling technique was not the same as the protocol described in the QAPP used by Maine DEP staff in Augusta.)

3. Macroinvertebrate samples were sorted according to Maine Department of Environmental Protection protocols (Davies and Tsomides 1997). Macroinvertebrates were identified by Lotic, Inc (Unity, ME).

<u>Fish</u>

1. Fish communities were sampled at 9 study sites using electrofishing techniques on May 31 and June 13, 2000 (USEPA 1999). All habitats were sampled according to the relative proportions that they were found within the 200-m long study reaches. When sampling for fish took place at macroinvertebrate sampling stations, in general, approximately half of the sampling reach was located above and half of the sampling reach was located below the macroinvertebrate rockbag sampling location. Electroshocking and sampling consisted of a "shocker" technician (having two wands and a backpack shocker with pulsed DC current) and a "collector" technician (manipulating a dip net below the shocking wands). The two technicians moved simultaneously upstream and side-to-side in the channel collecting stunned fish. The collected fish were identified and measured in the field using a meter stick. Once this information was recorded, the fish were released back to the stream. Voucher specimens of each species observed in the field were preserved in 70% ethyl alcohol and kept in labeled mason jars. (*Note*: In the QAPP the preservative mentioned was 10% formalin; the change was made due to the toxicity and unavailability of formalin.) Fish/habitat field data sheets (USEPA 1999) were completed at each fish sampling site.

2.3 Water Chemistry and Suspended Solids (Baseflow and Stormflow) Sampling

1. The following definitions were used for hydrological assessment and water quality monitoring: from a planning perspective, *baseflow* (low-flow) was defined as minimum flow levels following a minimum of 14 days without rain. Two types of storms defined for this study were: a *large-quantity storm*, defined as a storm in which at least 2 inches of rain falls in 24 hours, and an *intense storm*, defined as a storm in which at least 1 inch of rain drops in less than an hour. The decision to monitor/sample was based upon conversations with the National Weather Service about the predicted quantity and duration of forecasted storms. Due to the difficulty associated with confident predictions of the weather, the lengths of time for dry periods before baseflow sampling, as well as actual intensities and durations of storm events, varied from the original QAPP definitions. The actual weather conditions for sampling are discussed in the results chapter of this report. Three baseflow sampling events and three storm sampling events were completed for this study.

2. Water quality parameters, sampling locations, sampling techniques, and analysis techniques are summarized in Table 2.1. Water quality samples were collected at the same time that stream hydrology was monitored (stormflows, baseflows) (described later).

3. In order to try to capture toxicants at their peak concentrations, grab samples were collected during the "rise to peak (streamflow)" portion of rain storms. Reference points at the monitoring sites were chosen and observed for a rise in water level at the first sign of rain. Samples were collected at the four water quality monitoring sites approximately every 30 minutes during heavy rainfall periods up to six times at each site. A cell phone was used to stay in touch with the National Weather Service to determine when increases or decreases in the intensity of the storms were expected. After samples were collected, storm hydrographs and field notes were used to select

which three samples at each site were to be analyzed in an attempt to capture the "first flush" level of toxicants.

4. The following steps, based upon the recommendations of part 1060 of Standard Methods of the Examination of Water and Wastewater (APHA et al. 1995), were followed when collecting water samples:

   Step 1. Rubber gloves were worn during water sampling to prevent sample contamination.
   Step 2. Sample containers (cubitainers for most parameters; brown glass bottles for oil and grease samples) were rinsed with stream water 3 times before collecting the actual sample.
   Step 3. "Grab" water samples were collected by immersing the cubitainer/bottle under water in the flowing-water thalweg (deepest part of a channel's cross-section) of the stream. The container was lowered to mid-depth of the stream and care was taken to not stir up sediments from the stream bottom to further ensure sample quality. For each sampling time period at each site, three grab samples were collected within 2 minutes of each other in order to have a "metals" sample, a "nutrients" sample, and a "suspended solids" sample.
   Step 4. Water samples were kept in coolers on ice until they were returned to the DEP-Portland office. To facilitate analyses for the HETL, cubitainers containing water samples for nitrogen, phosphorous, and chloride analyses were poured directly into 250-ml pre-washed bottles (and total-phosphorous samples into 55-ml flasks) before being placed back in the coolers. The remaining water samples were kept in their original cubitainers and left in the coolers. All water samples were preserved as detailed in Table 2.1.
   Step 5. Water samples were shipped to the appropriate location for analysis (see Table 2.1) within 12 hours of collection.
   Step 6. Chain-of-custody forms were completed upon delivery of the samples to the appropriate lab.

5. For most parameters, new cubitainers were used to collect water samples during baseflow and peakflow. Otherwise, "oil and grease" samples were collected in brown glass bottles prewashed and certified by ESF and supplied by Katahdin Analytical. Additional containers needed for the subsampling of total kjeldahl nitrogen and total phosphorous were washed according to HETL specifications.

6. Some water quality parameters were measured using field meters. When monitoring dissolved oxygen or pH, meters were calibrated in the filed as outlined in their operation manuals (Orion field pH / temperature meter [model 290A] and YSI field temperature / dissolved oxygen / conductivity / salinity meter [model 85]). The appropriate probes were placed on the stream bottom in the relatively fastest current areas found at each study site in order to ensure proper flow across the probe. Measurement readings were taken after the meters had stabilized (at least 5 minutes).

7. Historical water quality data was researched and used for comparisons (including pre- and post-urbanization trend analyses) with data acquired in this study. Sources of

data reports were consultant reports regarding local landfill water quality monitoring and a trichloroethane spill that occurred in 1982 near the northern branch of Long Creek, Maine DEP records, the City of South Portland's study of stormwater in Clark's Pond (South Portland Engineering Dept. 1995).

2.4 Water Temperature Monitoring

1. Temperature was monitored continuously at a number of sites throughout the study watersheds using Optic Stowaway temperature data loggers (model WTA08, Onset Corp.). The dates during which monitoring took place was dependent upon when loggers could be installed at sites, and later downloaded, primarily taking place from about July to September.

2. Temperature also was monitored during early morning water quality monitoring events and the multihabitat macroinvertebrate sampling events using a YSI field temperature / dissolved oxygen / conductivity / salinity meter (model 85) probe.

2.5 Hydrology Data Collection

1. Flow at the four storm discharge/chemistry monitoring sites was measured using ISCO “bubbler-type” flow meters (model 2870; accuracy of $\pm$0.0025 ft/ft^2 (0.0025m/m^2) from the calibration point ; ISCO 1986) placed upstream of culverts in Red Brook and the three major branches of Long Creek. Stage-discharge relationships were determined by establishing discharge-monitoring transects at the ISCO meter locations, measuring discharge with a Global Flow Probe (model FP 101/201; accuracy rating: 0.1 ft/sec [approximately 0.03 m/sec]; factory calibrated) using the USGS midsection method (Buchanon and Somers 1969) under baseflow and stormflow conditions, and then regressing ISCO meter “stage heights” against Global Flow Probe field measurements. Reference locations were chosen above “flow control” features. These features were road culverts at the three Long Creek sites. At the Red Brook site, the measurement site was located above a large pea-gravel riffle baseflow-control which was approximately 50 m upstream of a culvert. This location was chosen because of a number of debris jams and associated deep pools in the immediate area above the culvert caused a backup of channel water under baseflow conditions. These sites were photographed prior to each monitored storm event to determine the likelihood of a consistent stage-discharge relationship. If debris accumulated in front of control structures, it was removed in order to return the sites to conditions observed when the photographs were taken. At the flow monitoring sites, flow was measured at open channel locations approximately 10-15 m upstream of culverts at the southern and northern branches of Long Creek, approximately 30 m upstream of the culvert at the main stem of Long Creek, and approximately 50 m upstream of the culvert at Red Brook. Cross-sectional area was determined by running a meter-tape transect line, attached to bank pins, across the channel and using a meter stick to make water depth measurements. Permanent

reference points to which the end of ISCO "bubbler" flow meters were attached (e.g., top of a culvert, rebar markers in the stream channel, nails in a tree) were recorded using a surveyor's level and rod. Permanent flow meter locations and transects were established and surveyed to ensure flow-measurement consistency.

2. The storm discharge monitoring site on Red Brook (upstream of I-95) was used as a reference site for comparison with the more urbanized Long Creek sites because it drains a relatively low percent-impervious-surface portion of the watershed. (Not completed: Data obtained from nearby USGS gaging stations [e.g., Stroudwater River, Presumpscot River] was reviewed and analyzed to help determine historical and recent hydrological patterns for the region. This data was used for comparison with the hydrological data collected for Long Creek and Red Brook in this study.)

2.6 In-Stream and Riparian Habitat Assessment

1. In-stream and riparian habitat conditions at a number of study sites throughout the Long Creek and Red Brook watersheds were evaluated using a combination of Maine DEP and USEPA methodologies (Davies and Tsomides 1997, USEPA 1999). Detailed observations were made at the study sites and recorded on the following data sheets: "Physical Characterization / Water Quality Field Data Sheet" and "Habitat Assessment (Scoring) Field Data Sheet – Low Gradient Streams" forms (USEPA 1999) and the Maine DEP habitat evaluation form (Davies and Tsomides 1997). These forms assessed channel substrate type, flow status, alteration, and sinuosity; pool variability; bank stability and coverage by vegetation; riparian vegetative zone width; and canopy cover of the stream. The habitat scoring forms, including the definitions for the scoring questions, may be found in Appendix F. A spherical crown densiometer was used at the periphyton-sampling locations to determine local canopy cover and percent shading as follows: the number of quarter-sections of the grids that were not covered by canopy were counted; this number was multiplied by 1.04 and then subtracted from 100% to obtain the estimated canopy-cover percentage. The presence or absence and quality of buffers and other particular problem areas (i.e., parking lots adjacent to stream, stream bank failures, etc.) also were noted.

2. The term "left side" referred to the left side of the stream facing downstream and the term "right side" referred to the right side facing downstream.

3. Between November 19 and December 6, 2002, woody debris at various sites throughout the study watersheds was quantified using an adaptation of methods described in both Smock et al. (1989) and Kaufmann and Robison (1998). At the sites, 100-m reaches were delineated, which differed from Smock et al. (1989; 300-m) and Kaufmann and Robinson (1998; 20-30 times the bankfull width at sites), because time was short and the study streams were beginning to freeze over and also because consistent reach lengths between sites were desired. Smock et al. (1989) considered any wood in contact with channel sediments, having an estimated mean diameter > 5 cm, and spanning $\geq$ 25% of the channel to be a "debris dam".

Kaufmann and Robinson (1998) defined large wood debris as wood having a diameter ≥ 10 cm and having a length ≥ 1.5 m, and they required that location of the wood, or various portions of the wood, be noted on data sheets because it determined the type of large woody debris. To quantify woody debris in this study, the observer walked up the stream channel reach recording the small-end-, large-end-, and estimated-mean-diameter of any piece of wood having an estimated mean diameter > 5 cm. Length of the piece, linear tape distance where the piece was found, and percentage of the channel spanned by the piece also were recorded. Also, it was noted whether pieces were isolated or part of a debris dam matrix. Only wood pieces in contact with bankfull channel sediments were recorded in this study.

2.7 Fluvial Geomorphology Assessment

1. Stream morphology assessments were performed at a number of sites throughout the study watersheds.
   a. Channel cross-section measurements (Harrelson et al. 1994) and Rosgen channel morphology assessments (Rosgen 1994) were conducted at a number of study sites using a surveyor's level and rod, a tape measure, and, in a few instances, a GPS unit. Measurements included:

      Level I – Measurements or descriptions of:
      1. Channel shape (narrow/deep, wide shallow)
      2. Channel pattern (single thread/multiple thread/anastomosed)
      3. Sinuosity (ratio of stream length to valley length)

      Level II – Measurements of (see Rosgen 1996 for detailed method descriptions):
      4. Entrenchment ratio (calculated by measuring the ratio of the flood-prone width to bankfull width)
      5. W/D ratio (ratio of the bankfull width to bankfull depth)
      6. Slope (measured, using a surveyor's level and rod, as the drop in stream water level over a known distance)
      7. Bed material characterization (pebble counts)

      Level III – Measurements/descriptions of (using field data sheets from Rosgen 1996):
      8. Pfankuch channel stability ratings

2. Some fluvial geomorphology assessment methods in the original design of this study were not actually completed for various reasons: measurement of stream meander length, belt width, arc length, arc width, and radius of curvature (Level I;

   inability to measure these features accurately with aerial photographs due to the small size of the study streams); all measurements except for the Pfankuch channel stability ratings (Level III; time constraint issues); and scour-chain/bank pin measurements of scour and erosion (Level IV; technical problems encountered in the field). Despite this situation, a substantial amount of information still was gathered via the methods described under item "1".

Chapter 3
Results

Note: A table listing the location of quality assurance/quality control information is located in Appendix J. State of Maine water quality classification information is provided in Appendix H.

3.1 Land Use Analysis, Stream Walk, Watershed Survey, and Surficial Geology Investigation

A list of the major study sites and their "codes" is presented in Table 3.1.1. Coding was based upon approximate stream mile/distance values determined with a GIS-based map of the study watershed and GPS readings collected at the sites. The symbol "~" on stream-mile codes found on figures in this report indicates that, for a particular site, GPS data was not available at the time that stream-miles for the study sites were originally measured (mileage had to be estimated using digitized USGS 7.5 minute topographic maps and the program ArcInfo 8.1). The locations of the major biological, chemical, hydrological, and habitat monitoring sites are presented in Fig. 3.1.1.

The remaining figures in section 3.1 present findings from the synthesis of findings from an initial stream walk, an aerial photograph analysis, a watershed / "hotspot" survey, and a surficial geology (map) investigation. Many of the findings in these figures are integrated into other sections located in the "Results" chapter. However some initial comments are presented below.

The main and northern branches of Long Creek (LC-M, LC-N) primarily flow through "Presumpscot Formation" surficial geology (Fig. 3.1.2). This formation, "Pp", consists of silt, clay, and minor sand deposited on the sea floor during the late-glacial marine submergence (Thompson et al. 1997). The southern branch of Long Creek (LC-S) primarily flows through marine regressive sand deposits, or "Pmrs". These deposits consist of sand, silt, and minor gravel deposited in shallow marine waters during late-glacial regression of the sea; they may include a variety of nearshore and fluvial sediments; and they commonly occur as flat sandy areas and are likely to be underlain by marine clay-silt of the Presumpscot Formation (Thompson et al. 1997). Red Brook also primarily flows through "Pmrs", of which a large portion flows through the "Pmrs" formation just described for the Portland West Quad (Thompson et al. 1997). However, Red Brook also flows through "Pmrs" deposits in the Gorham Quad, and its group of marine regressive sand deposits have been described as being are massive to stratified and cross-stratified, well sorted brown to gray-brown sand and generally with gradational contact with (Presumpscot Formation). This group's thickness varies between 1 and 5 m and it was deposited during the regressive phase of marine submergence (Smith et al. 1999). Red Brook also flows through some "Ha" which has been described as stream alluvium, or sand silt, gravel, and organic material deposited on floodplains of modern streams in the lower 1/4th of its course (Thompson et al. 1997) (Fig. 3.1.2).

Percent total impervious area (PTIA; the percentage of land covered by impermeable surfaces such as roads, parking lots, rooftops, driveways, etc.) values determined for selected sites throughout the study watershed are presented in Figure 3.1.3 and Table 3.1.2. Above the Maine Turnpike (I-95), LC-M had values ranging from 4-14% and RB had values ranging from 2-6%. Downstream of I-95, values ranged from 46-47% (LC-S), 32-33% (LC-N), and 10-14% (LC-M) to 8-10% for RB (Fig. 3.1.3, Table 3.1.2). Growth projections, obtained from the Greater Portland Council of Governments suggest that the study watershed area will continue to experience substantial growth, both in population and in urban development, along with associated increases in impervious surface cover, over the next 20 years (Appendix I).

Note: Both LC-M-0.595 and LC-S-0.186 had "local PTIAs", or PTIA values for the subwatersheds located between green dots on Figure 3.1.3, of ~67%. LC-N-0.415 had a "local PTIA" of 35.6 and the short interval between RB-1.474 and RB-1.694 had a "local PTIA" of 35.1. For most of the report, however, values of PTIA that were used when talking about Red Brook and the various branches of Long Creek (LC-M, -S, and -N) were cumulative values (i.e., they took into account the entire watershed of their respective branch; Fig. 3.1.3, Table 3.1.2). However, it is important to keep in mind that on a smaller scale, land-uses varied quite a bit along the lengths of the study streams, and this variability might explain the more localized findings throughout this study.

Survey results from an initial stream habitat walk, as well as various field observations made during follow-up visits to sites, are presented in Fig. 3.1.4a-e. Many of these observations are summarized in sections presented later in the results chapter, especially in section 3.6 (In-Stream and Riparian Habitat). However, it is worth mentioning some of the major findings here. For example, in Quad I, substantial amounts of stream length were found to have relatively open canopies and a lack of shading due to historical removal of many streamside trees and shrubs (Fig. 3.1.4b). Additionally, some large stormwater control outlet and in-stream detention basin structures were documented in this quad, and they likely have an impact on the stream ecology of Long Creek. In Quad II, problem sites were more numerous, although for the most part they were documented as being only minor to moderate problems. Large stormwater inputs were noted in the upper reaches of LC-N (Fig. 3.1.4c). In Quad III, only minor problems were documented (Fig. 3.1.4d). Quad IV contained the most "severe problem" sites as well as many more minor-moderate problem areas (Fig. 3.1.4e). Some of the more severe problems included areas where some severe streambank erosion was apparent and areas where shading from trees and shrubs generally was lacking. Also, much of the stream channel in this quad apparently had been moved and/or channelized to accommodate development. Also, numerous large stormwater input structures were documented in this quad (Fig. 3.1.4e).

Pollution hotspots where pollution from automobiles and associated activities, including gas stations, car maintenance lots, and drive-thru restaurants and banks (because of idling cars), were documented throughout the study watersheds. However, the portions of Long Creek and Red Brook downstream of the Maine Turnpike (I-95) had relatively much higher numbers of these "hotspots". The section of the main branch of Long Creek (LC-M) between about stream mile 0.6 and 0.9 had the greatest number of these hotspots. And, although they tended to be apparently away from the edge of the stream channel, they likely still contributed pollutants to the stream during storms because stormwater "washed" the pavement and then headed directly towards stormwater collection systems, only to be contributed directly to the stream.

Statutory water quality classification of the study streams is presented in Fig. 3.1.6 (see also State of Maine 2001). The majority of stream reaches in this study had a statutory classification of Class C. However, sections of Long Creek located in Westbrook had a statutory classification of Class B.

3.2 Biological Community

Periphyton

Upon returning to collect periphyton samples at the study sites, it was observed that apparently not much periphyton had accumulated upon the artificial substrates. These observations were supported by the analysis of chlorophyll-*a* (Fig. 3.2.1). All mean chlorophyll-*a* values were less than 18 mg/m^2. Also, the mean chlorophyll-*a* values of both Red Brook sites were less than the values at all of the Long Creek sites. Besides those just mentioned, trends in the data were weak or puzzling. For example, when the mean chlorophyll-a values for all Long Creek and Red Brook sites were plotted against the mean percent shading (by canopy) at each site, it was found that values were greater at sites having greater amounts of shading (Fig. 3.2.2). This was an unexpected finding because periphyton sampling sites for had been selected primarily for the amount of open canopy they had relative to other sites within the watershed. The assumption had been that areas having greater exposure to sunlight would have higher rates of periphyton colonization. Further, when examining the Long Creek sites alone, there did not appear to be a relationship between the amount of open canopy and chlorophyll-a abundance. In fact, although error bars for these sites were rather large, there was a slight increase in mean chlorophyll-*a* abundance as shading increased within the Long Creek sites. The only time there was the expected drop in chlorophyll-*a* abundance with increased shading was when only the two Red Brook sites were examined (Fig. 3.2.2; shading was quantified using methods described in section 2.6). There also did not appear to be any associations between the amount of chlorophyll-*a* and percent total impervious area (PTIA) upstream of study sites, especially within Long Creek or within Red Brook (Fig. 3.2.3). However, when all the sites were examined together, the four sites (all Long Creek) having the highest PTIA also had the highest mean chlorophyll-a values (Fig. 3.2.3).

Macroinvertebrates

Results from macroinvertebrate sampling using both rockbag (artificial substrate) and multi-habitat (sampling with a D-net) techniques are presented below. Community metrics calculated for each of these data sets, and their discussion, are ordered in the same way that they are ordered in Maine DEP's computer model which determines water-body classification (Davies and Tsomides 2002). A table which provides both common and Latin names for some of the macroinvertebrate taxonomic groups commonly mentioned in this report can be found in Appendix B. Details regarding what each of the individual metrics mean can be found in Davies and Tsomides (2002).

Rockbag Results

Maine DEP water quality modeling analyses of macroinvertebrate data from the nine "rockbag"-method sampling stations had the following outcomes (Figs 3.2.4a):

- Two Long Creek stations in Westbrook, LC-M-2.270 and LC-Mn-2.274, failed to meet their statutory designation of Class B (in fact, one site was found to be in "non-attainment" of any water quality class standard);
- One Long Creek station in South Portland, designated as Class C, was found to be in "non-attainment" of any water quality class standard;
- One Red Brook station in Scarborough, designated as Class C, had too few organisms in its macroinvertebrates samples to be run correctly through the model, so it was considered to be "indeterminate";
- Three Long Creek stations and one Red Brook station in South Portland met their Class C designation;
- One upper Red Brook station in Scarborough exceeded its Class C designation with a Class A model outcome;
- *Note*: See Appendix H, State of Maine (2001), and Davies and Tsomides (2002) for water quality classification information;

Other metrics calculated from the data provided additional details about the macroinvertebrate communities collected in the samples. For example, there was no apparent trend in the "total abundance" metric except that LC-M-2.270 (adjacent to a golf course -- see more details below) had nearly double the total macroinvertebrate abundance of any other site (Fig. 3.2.4b). "Generic richness" did not display clear trends except that it was greatest at RB-3.961 (54 organisms), the forested site above Running Hill Road. The only site where insects from the order Plecoptera were found was at RB-3.961, which had an average of 1.0 stonefly per rockbag (Fig. 3.2.4b; see also Fig. 3.2.4d). As far as Ephemeroptera abundance, there was no clear trend except that LC-M-2.270 (the site adjacent to the golf course) had more than double the average number of mayflies (66.3 per rockbag) than at any other study site (Fig. 3.2.4b). The Hilsenhoff Biotic Index (a biotic index score based upon the tolerance of various species to organic stream pollution) separated all of the Red Brook sites (< 4.3; less pollution tolerant) from the Long Creek sites (> 6.1; more pollution tolerant) (Fig. 3.2.4b). The metrics "relative abundance of Chironomidae", "relative richness of Diptera taxa", and "*Hydropsyche* abundance" also did not display clear trends except that RB-3.961 and LC-S-0.369 had the greatest values for the first two metrics mentioned and also that both sites were the only two that had *Hydropsyche* present (Fig. 3.2.4c). (This is an interesting finding because the two sites are on the opposite end of the PTIA spectrum in this study.) Additionally, all of the mainstem Long Creek sites (LC-M-x) had the lowest values for "relative abundance of Chironomidae". *Cheumatopsyche* were only found at RB-1.474 (Fig. 3.2.4c).

Perlidae stoneflies were not found at any of the sites (Fig. 3.2.4d). Tanypodinae abundance did not exhibit any trends except that LC-M-2.270 had the highest value, a phenomenon consistent with some of the community metrics mentioned above (Fig. 3.2.4d). "EPT generic richness" was greater than or equal to 9 taxa at all of the Red Brook sites (RB-3.961 had the highest value [15 taxa]), while it was less than 8 or less at all of the Long Creek sites. (EPT = Ephemeroptera, Plecoptera, and Trichoptera; see Appendix B.) It was interesting to note that "EPT generic richness" increased slightly as one moved up the mainstem (LC-M-x). The "summed abundances of DMPH" did not display clear trends, although LC-M-2.270 and RB-3.961 had the highest values (Fig. 3.2.4d). (DMPH = *Dicrotendipes*, *Micropsectra*, *Parachironomus*, and *Helobedella*.) "AS" were only present at RB-3.961 and RB-1.474 (Fig. 3.2.4e). (AS = *Acroneuria* and *Stenonema.*) "Ephemeroptera-Plecoptera generic richness" did not display any clear trends except that RB-3.961 and RB-0.071 had the highest values. Only RB-3.961 and RB-0.071 had Class A indicator taxa (Fig. 3.2.4e).

Community metrics where clear trends were not apparent at all included: Shannon-Weiner Diversity (Fig. 3.2.4b), "EPT generic richness/Diptera richness" and "relative abundance of Oligochaeta" (Fig. 3.2.4c), "abundance of Chironomini" and "relative abundance of Ephemeroptera" metrics (Fig. 3.2.4d), and "summed abundances of CCTA" (Fig. 3.2.4e). (CCTA = *Cheumatopsyche*, *Cricotopus*, *Tanytarsus*, and *Ablabesmyia*.)

The rockbag data also was plotted against the total percent impervious area values for the subwatersheds above each of the sampling sites (Figs. 3.2.5a-e). For clarity and brevity purposes, any associations that were observed in these plots are summarized in Table 3.2.1.

Multi-Habitat Results

Note: Some of the multihabitat sites were subsampled (1/4th of the sample was processed) by the "sample sorters" because such a large amount of sample material was collected at those particular sites. The subsampled "sandy-silty run" sites were RB-3.961, LC-S-0.369, LC-M-0.910, and LC-M-2.270. Also, the three riffle/road debris sites (LC-M-0.533, LC-M-2.191~, and RB-1.500~) and the macrophyte/run site (LC-S-0.496) were subsampled (1/4th of sample). Additionally, although an effort was made to collect samples from the same amount of area, these data should be viewed as semi-quantitative because sampling areas were approximated in the field (see the Methods chapter for information on sampling techniques). The abundance of organisms generally was expressed as number of organisms per ~2.4 m^2. Finally, data from the "sandy-silty run" habitat sites are presented on the left-hand side of Figures 3.2.6a-f, while "riffle-road debris" and "macrophyte-sandy run" sites are presented on the right-hand side.

A clear trend was not apparent in the total abundance data except that the site which was adjacent to Sable Oakes golf course, LC-M-2.270, had a very high abundance of macroinvertebrates (1660 organisms/2.359 m^2 or 704 organisms/m^2) relative to the other sites (Fig. 3.2.6b). Riffle/road debris (channel bottom) sites all had greater macroinvertebrate abundance than any of the "sandy-silty run" sites sampled except LC-M-2.270. Clear trends also were absent from generic richness data except that, within the Red Brook "sandy-silty sites", it appeared to decrease as one progressed upstream (perhaps a result of the subsampling of RB-3.961). Plecoptera taxa were only found at RB-3.961 (8 organisms), RB-1.474 (23), RB-0.071 (2), the riffle/road debris site RB-1.500~ (132) and, interestingly, LC-N-0.850~ (1). Ephemeroptera abundance values at the "sandy-silty run" sites were as follows: the Long Creek sites were all less than 53 organisms, while the Red Brook sites were all greater than 88 organisms, with the exception of LC-M-2.270 and LC-2.191~ (riffle). The only noticeable difference found when comparing "sandy-silty run" sites with "riffle-road debris" sites was that the two greatest values were found at "riffle-road debris" sites. The Red Brook sites all had Hilsenhoff Biotic Index values less than 4.8 and, except for LC-Mw-2.896, had values that were less than all the Long Creek sites within each of the "sandy-silty" and "riffle/road debris" categories of sites (Fig. 3.2.6b).

The only apparent trend in the relative abundance of Chironomidae data was that the "riffle/road debris" sites generally had the lowest numbers of all the sites (Fig. 3.2.6c). A clear trend was not apparent in the relative richness of Diptera data. *Hydropsyche* abundance was much higher (greater than an order of magnitude) at two of the "riffle/road debris" sites than any other site. LC-M-2.191 had over three times the abundance of *Cheumatopsyche* (325 organisms/2.359 m^2) than that of any other site. Clear trends were not apparent for EPT generic richness/Diptera richness values except that the ratio increased within Red Brook as one moved upstream (within the "sandy-silty run" sites). RB-1.500~, a "riffle/road debris site", was the only site which had an EPT generic richness/Diptera richness ratio greater than 1.0 (it was 1.6). Oligochaeta worms were only found at 3 (all Long Creek sites) of the 16 sites (Fig. 3.2.6c).

Perlidae stoneflies were not found at any of the study sites (Fig. 3.2.6d). Tanypodinae abundance lacked any clear trends except that the value at LC-M-2.270 was much higher than at any of the other sites. Chironomini abundance did not display any strong trends. However, within the "sandy-silty run" sites, chironomini abundance was greater at all of the Red Brook sites except LC-S-0.369 and LC-M-2.270. The three Red Brook "sandy-silty runs" had the greatest relative abundance of Ephemeroptera values (all were between 25-30 %). The highest EPT generic richness value for Long Creek was 10 taxa (LC-N-0.850~), while all Red Brook sites ranged between 14-17 taxa. No clear trends were apparent in the summed abundance of DMPH data except that the value at

LC-M-2.270 was more than 3.3 times greater than all the other sites (Fig. 3.2.6d). Relative Plecoptera abundance was greater at all the Red Brook sites (range 4-8 %) than all the Long Creek sites (Fig 3.2.6e). In fact, the only Long Creek site where stoneflies were found was LC-N-0.850~ (3 %). The summed abundance of CCTA did not display a clear trend except that LC-M-2.191, a riffle/road debris site, had a much greater value than any of the other sites (3 - 169 % greater). AS taxa were found at all of the Red Brook sites, ranging from 1 - 164 organisms, while only 1 organism was found at any of the Long Creek sites (LC-N-0.850~). The four highest EP generic richness/14 values were found at the Red Brook sites. Class A indicator taxa were found in samples from at least one site from each of the RB (4 sites), LC-S (1), and LC-N (1) streams/tributaries (Fig. 3.2.6e).

Summary of Macroinvertebrate Data

To summarize, some of the most notable trends in the macroinvertebrate data were the following ("rb" indicates that the comment is based upon rockbag data, while "mh" indicates that the comment is based upon multihabitat data):

- Maine DEP water quality modeling analyses of macroinvertebrate data from the nine "rockbag"-method sampling stations had the following outcomes (Figs 3.2.4a) (rb):

    - Two Long Creek stations in Westbrook, LC-M-2.270 and LC-Mn-2.274, failed to meet their statutory designation of Class B (in fact, one site was found to be in "non-attainment" of any water quality class standard);
    - One Long Creek station in South Portland, designated as Class C, was found to be in "non-attainment" of any water quality class standard;
    - One upper Red Brook station in Scarborough exceeded its Class C designation with a Class A model outcome;

- RB-3.961 had the greatest generic richness and also was the only site to have stoneflies (Plecoptera -- generally one of the most stress-sensitive taxa groups) (RB-3.961 was a forested site which was observed as having the least amount of development and obvious perturbations upstream of its sampling site) (Figs. 3.2.4b, 3.2.4e) (rb);
- In the multihabitat samples, Red Brook generally had the highest generic richness (mh) (Fig. 3.2.6b). However, one of the exceptions to that trend was RB-3.961, although it might be explained by the ¼ subsampling done there (due to a large sample volume), a technique which sometimes leads to lower success of finding all the taxa present in a sample (mh). Also, in the multihabitat samples, all Red Brook sites were found to have stoneflies present. Additionally, LC-N-0.850~ stood out from all the other Long Creek sites because it was the only site found to have stoneflies (mh) (Figs. 3.2.6b, 3.2.6e). (*Note*: It also was one of the only sites in the Long Creek watershed to have a short section of pea-gravel habitat [pers. obs.]);
- Another important trend visible in both the rockbag and multihabitat data was the fact that EPT (Ephmeroptera, Plecoptera, and Trichoptera) values were always higher at

Red Brook sites than Long Creek sites. That trend was more pronounced in the multihabitat samples than the rockbag samples (Figs. 3.2.4d, 3.2.6d). (EPT is a metric that combines the numbers of three of the most stress-sensitive taxa into one measure and it commonly is used as a general indicator of relatively good stream water and/or habitat quality [Rosenberg and Resh 1993]);

- In the rockbag data, Class A indicator taxa (see Davies and Tsomides 1997) were only found at Red Brook sites, and there it was only two of the three sites (Fig. 3.2.4e). In the multihabitat samples, all of the Red Brook sites were found to have Class A indicator taxa, as well as both LC-S and LC-N each having one site with some Class A indicator taxa. No LC-M sites were ever found to have these taxa (Fig. 3.2.6e);
- The site LC-M-2.270 had lots of decomposing branches, twigs, and leaves observed in its channel. It also had the highest total- and mayfly- abundances (Fig. 3.2.4b) as well as high abundances of the beetle *Dubiraphia* (Appendix B). The site was adjacent to a golf course and its riparian zone had a higher observed percent composition of shrub-like trees (e.g., alder) than many of the other sites, which had tended to have a more even mix of taller conifers and maples along with shrubs such as alder. The apparently unusually high abundance of organic matter in the stream at this site may have been a result of pruning of riparian trees by the golf course, although there was no clear evidence that this had been the case. Regardless, large amounts of organic matter in the stream here may be overloading the stream's ability to break down the material at a rate that keeps pace with the stream's microorganisms, macroinvertebrates, and dissolved oxygen concentrations (rb & mh);
- The Hilsenhoff Biotic Index (based upon macroinvertebrate tolerance to organic pollution) separated Red Brook sites from the Long Creek sites. Although organic pollution was not assessed in this study, this finding suggests that, perhaps, Long Creek macroinvertebrate communities generally may be more tolerant of stressful conditions (overall) than Red Brook communities (rb and mh) (Fig. 3.2.4b, 3.2.6b);
- RB-3.961 and LC-S-0.038 were interesting sites because although they had the lowest and highest total percent impervious area values, respectively, they had the most similar "relative abundance of Chironomidae", "relative richness of Diptera taxa", and "*Hydropsyche* abundance" values (Fig. 3.2.4c). Both sites were located in the same area of surficial geology, which was listed as being dominated by sands (rb);

Fish

Fish taxa richness (5 taxa) was greatest at two Long Creek sites, LC-M-2.274 and LC-M-1.653~, and lowest (1 taxa) at another Long Creek site LC-Mw-2.896 (Fig. 3.2.7). Taxa richness at the Red Brook sites ranged between 2 - 3 (Fig. 3.2.7). Three basic trends were observed in the individual plots of fish taxa distribution at the study sites (Fig. 3.2.8). The first trend was that brook trout only were found at the three upstream-most Red Brook sites and not at any of the Long Creek sites. Counts were all $\geq$ 10 fish per 200 m at each of these sites. The second trend was that American eel only were found in some of the Long Creek sites and not in any of the Red Brook sites. And the third trend was that nine-spine stickleback and creek chub were found at many of the

Long Creek sites, while only being found in small numbers at the most downstream Red Brook site (Fig. 3.2.8). In most cases, trends were not obvious when fish abundance for each species was plotted against percent total impervious area (PTIA) (Fig. 3.2.9), although the abundance of brook trout declined dramatically with an increase in PTIA. (*Note*: Few Long Creek sites had comparable PTIA values.) Another, less apparent trend that appeared to be occurring within Red Brook was that there was a general increase in white suckers, nine-spine sticklebacks, and creek chubs with an increase in PTIA (Fig. 3.2.9).

3.3 Water Chemistry and Suspended Solids (Baseflow and Stormflow)

The quality assurance data for water chemistry and suspended solid parameters is presented in the table in Appendix C. Baseflow water grab samples and measures made with a water quality meter (dissolved oxygen, instantaneous temperature, specific conductivity) generally fell within QAPP-stated field duplicate criteria. Field duplicate data for the stormwater grab samples exceeded stated criteria approximately 1/3rd of the time. However, in many instances, those exceedances occurred when samples were at or near the reporting limit for that particular parameter. Accuracy and precision standards for grab samples generally fell within stated criteria. When exceptions occurred, they generally only missed quality control criteria by a few percentage points or appeared to be due to the fact that samples were near the detection/reporting limit of the laboratory for a particular parameter. Accuracy standards were met for the water quality meter measurements. Quality assurance data for PAHs and E. coli are presented in the tables in section 3.3. When available (e.g., during the second PAH sampling event field duplicate samples were collected but they were not analyzed by the lab), those QA data met QAPP criteria the majority of the time.

<u>Metals - Stormflow</u>

A number of trends were observed in the water chemistry data for metals collected during storm events (Fig. 3.3.1). First, Red Brook consistently had the lowest maximum concentration of the various metals sampled when concentrations were detected (lead, zinc, copper, nickel, and in one case, cadmium) and they were all below the water quality criteria shown in the figure (MEG [Maine Bureau of Health's Maximum Exposure Guidelines], CMC [Criterion Maximum Concentration (acute exposure)]). Second, LC-S-0.186's 3/28/00 samples generally had the highest concentrations of lead (0.09 ppm), zinc (0.27 ppm), copper (0.044 ppm), and nickel (0.03 ppm) found when looking at all three sampling dates (3/28/00, 10/18/00, and 9/25/01). Cadmium was only detected at one site (LC-M-0.595) during the 9/25/01 event. The 3/28/00 (early spring) high metal values could have been a result of the melting and runoff of stormwater from large, pollutant-laden snowpiles on parking lots in the study watersheds. Third, within the 10/00 and 9/01 events, either LC-M-0.595 or LC-N-0.585 generally had the highest concentrations of a particular metal when it was detected at any of the sites. Fourth, lead, zinc, and copper water quality criteria (either MEG or CMC) were violated in each of the three Long Creek branches (south, mainstem, and north), sometimes by a factor of 9 (LC-

S-0.186: lead, zinc) and 11.3 (LC-S-0.186: copper). And fifth, the lack of between-storm consistency regarding which site had the highest concentrations of a particular pollutant may be explained by the fact that it is likely that the actual highest concentration at each site was not sampled. Attempts had been made in the field to sample at a time that was most likely to capture the "first flush" of pollutants off of the impervious surfaces in the study watersheds. However, a lack of precise knowledge as to when the greatest intensities of rainfall were going to occur, plus travel time between the various sites, made it a difficult process. Despite this issue, samples were collected during the "rise-to-peak" periods of storms and thus it is likely that these results approximate the peak concentrations of pollutants in the watershed (Fig. 3.3.1).

Nutrients & Suspended Solids - Stormflow

When compared with trends in stormflow metals, the trends for nutrients and suspended solids were less clear. As with the stormflow metals, LC-S-0.186 had the highest concentration of most of the parameters found in Figure 3.3.2 (total phosphorous, total kjeldahl nitrogen, chloride, and total suspended solids) when examining the three stormflow events. Trends within the ortho-phosphorous and $NO_2 + NO_3$ data were much more complex. First, relative to the September 2001 and October 2000 sampling dates, the March 2000 concentrations were quite low. This suggests that a large proportion of phosphorous and nitrogen in the stream was not in a biologically-reactive state. This likely was the case because it was early spring (March) and there was still snow on the ground throughout much of the watershed, which suggests that biological processing of organic matter on the watershed floor and in the stream was occurring at slow, winter-time rates, as compared to autumn-time rates when organic matter was more readily available and temperatures were warmer. Additionally, maximum concentrations of ortho-phosphorous at LC-S-0.186 were lower than in LC-M or LC-N, which may have been due to less amounts of forest land cover in its watershed. As with metals at all of the sites, RB-1.694 generally had the lowest concentrations of the nutrients, chloride, and suspended solids plotted in Figure 3.3.2. However, the maximum concentrations of these materials in Red Brook tended to be more in the range of the Long Creek sites with these parameters than it did with the metals data. (Note: Water quality criteria indicator lines were not visible in these plots either because they were higher than the concentrations found in this study or they were not available.)

Metals - Low Flow

Figures 3.3.3 and 3.3.4 present low-flow metal concentrations sampled throughout the study watershed on 8/6/00, 8/23/00, and 9/19/00. Figure 3.3.3 presents the data using the same y-axes as those used in the stormwater plot (Fig. 3.3.1), while Figure 3.3.4 uses y-axes that are more closely scaled to concentrations found at low flow. Overall, metal concentrations at low flow were relatively much lower than those found under stormwater conditions. Lead, cadmium, and nickel were not detected in any of the samples. Concentrations of zinc and copper were found in low flow samples, however they were all below CCC (Criterion Continuous Concentration [chronic exposure]) water quality criteria. LC-N-0.585 had the highest zinc concentrations (0.013 - 0.015 ppm).

LC-S-0.369 and LC-Mn- 2.274 had the highest (and only) copper measurements at 0.002 ppm each.

Note: Mercury was detected only once ($2x10^{-4}$ ppm) during this study, and it was at RB-3.961. This value was three orders of magnitude greater than the MEG criteria of $2x10^{-7}$ ppm. More than likely, this value was a result of field or lab error. However, the mercury might possibly have been in the stream due to atmospheric deposition. Or the mercury could have come from the landfill that was nearby this site, although it was believed that this sampling site was upstream of the influence of groundwater upwelling areas that may be influenced by the landfill. After the sample collection period of the study had passed, it was learned that mercury sample collection and analysis techniques used in this study were not what currently is regarded as being acceptable (i.e., very rigorous "clean techniques" now required for mercury sampling were not used in this study).

Nutrients & Suspended Solids - Low Flow

Figures 3.3.5 and 3.3.6 present low-flow nutrient and suspended solid concentrations sampled throughout the watershed on the same dates as "low-flow" metals. As with the metals data, Figure 3.3.5 presents the data using the same y-axes as used in the stormwater plots (Fig. 3.3.2), while Figure 3.3.6 uses y-axes that are more closely scaled to concentrations found at low flow. Total phosphorous, $NO_2 + NO_3$, and total suspended solids were much lower than values measured during storm events. Total kjeldahl nitrogen concentrations were approximately half or less than the maximum concentrations found during storm conditions. Interestingly, both ortho-phosphorous and chloride levels generally were in the range of stormflow conditions. For ortho-phosphorous, this was likely was due to large amounts of in-stream leaf litter being processed by microbes and dissolution processes upstream of many of the baseflow sampling sites. The fact that chloride levels generally were in the range of stormwater values was unexpected. These high concentrations may have been due to either soil type, or more likely, many years of road salting practices on roads and parking lots. LC-S-0.369 even exceeded CCC water quality criteria levels at concentrations of 245 and 243 ppm during the two August sampling dates.

Polycyclic Aromatic Hydrocarbons (PAHs)

Concentrations of PAHs in composite samples collected during two storm events, 10/23/00 and 9/25/01, are listed in Table 3.3.1. Within the 10/23/00 data, one can see that PAHs were not detected in LC-S-0.186 nor RB-1.694 samples. At sites LC-N-0.585 and LC-M-0.595, 13 and 10, respectively, of 16 USEPA priority PAH compounds were detected. Of the compounds that were found at LC-M-0.595, they were all greater than or equal to concentrations found at LC-N-0.585. (*Note*: The 10/23/00 actually refers to the PAH analysis date; the sampling occurred on 10/18/00.)

Within the 9/25/01 storm, which had a larger amount of rainfall (discussed later), RB-1.694 still did not have any PAH compounds detected. However, although it always had the lowest concentrations of PAHs of the three Long Creek sites, LC-S-0.186 had 10 of the 16 USEPA priority compounds detected, which was in contrast to an absence of any detections during the previous storm. LC-N-0.585 had 11 compounds present and LC-M-0.595 had 12. LC-M-0.595 had the highest concentrations of PAHs during the 9/25/01 storm. Concentrations of PAHs during the 9/25/01 storm generally were three times greater (or more) than concentrations measured during the 10/23/00 storm.

Oil and Grease

Generally, most oil and grease samples collected during stormflow conditions did not have concentrations greater than the “practical quantitation level (PQL)” of 5.0 mg/L (Tables 3.3.2.a-b). Exceptions to this trend included one baseflow sample (LC-S-0.186, 8/23/00, 5.8 mg/L) and a number of samples collected during the 10/18/00 storm. LC-S-0.186, LC-N-0.585, and RB-1.694 all had at least 2 of 3 sample concentrations falling between 5.0 and 8.6 mg/L, although LC-M-0.595 did not have any concentrations above 5.0 mg/L (the PQL).

Although attempts were made to keep the samples stored between the recommended 2.0-6.0 ^{o}C, samples often were brought to the analysis laboratory at temperatures cooler, and occasionally higher, than the recommended temperature. Temperature maintenance was difficult because ice-packed coolers had to be used instead of refrigeration due to the large amount of space needed to store the glass bottle containers. Despite temperature inconsistencies, the data likely are close to actual conditions because samples were dropped off at the lab within 24 hours of collection and because samples were preserved with H_2SO_4 at the time of sampling.

Escherichia coli Bacteria

Escherichia coli bacteria were found to be fairly abundant in water samples collected on two low-flow days (9/19/00 and 10/3/00) and on one stormy day (10/18/00) (Table 3.3.3). The Maine standards for *E. coli*, set by Maine DEP, state that between May 15 and September 30, the number of E. coli of human origin may not exceed a geometric mean of 142 per 100 ml or an instantaneous level of 949 per 100 ml for Class C waters. The methods used in this study did not differentiate between *E. coli* of human-origin and non-human-origin. However, there were a number of cases where standards might have been violated if the *E. coli* were of human origin. These included LC-S-0.186, LC-M-0.910, LC-N-0.585, and RB-0.071 on a low-flow day (9/19/00) and LC-S-0.186, LC-M-0.595, and LC-N-0.585 on a stormy day (10/18/00). Given that very recently genetic techniques for determining the species-origin of E. coli have become more readily available, the findings of this study suggest that there may be some hotspots in these study watersheds worth investigating further with these techniques.

Dissolved Oxygen

The first notable trend observed in the percent saturation of dissolved oxygen data was that the three Red Brook sites always exceeded Class B standards (75% saturation) whenever data was available (Fig. 3.3.7). Long Creek never exceeded Class B standards except on September 23rd, during afternoon hours, a period of the day when photosynthesis often has the opportunity to pump oxygen into a water body. Long Creek sites LC-M-2.270 and LC-Mn-2.274, which both had statutory water quality designations of Class B, violated those standards a number of times (Fig. 3.3.7).

Long Creek did not violate Class C standards (where data were available) during the mid-afternoon sampling on September 23, 1999. However, Long Creek did violate Class C standards on certain dates at the following sites: LC-M-2.270~ and LC-N-0.585 (June 15, 2000 - early morning); LC-S-0.369, LC-M-1.653 [just barely at 59.5%], LC-M-2.270~, LC-M-2.754, LC-Mn-2.274~, and LC-N-0.585 (September 1, 2000 - early morning); and LC-Mn-2.754~ (September 30, 2000). (*Note*: "Early morning" represents a sampling period between 4:00 and 7:20 am.) Many Long Creek sites experienced at least some dissolved oxygen problems at various times of the year. The sites most consistently exhibiting problems were in the upper half of the watershed of LC-M. These sites were downstream of a poorly-shaded reach near the Colonel Westbrook Industrial Park (LC-Mn-2.274~), an in-stream detention basin filled with macrophytes emergent and submergent (LC-M-2.754), and a golf course where certain areas near the stream were sparsely-shaded. The water in all of these areas was slow-moving and the stream channels lacked riffles and pieces of large woody debris, habitat structures which may have increased re-aeration rates (see the habitat section for more information about the habitat characteristics in this study). When sites which did have riffles (or accumulations of road debris in their channel) were included in the percent saturation of dissolved oxygen analysis, it became apparent that, at least, on September 23, 1999 (mid-afternoon), these sites had the highest values of any of the sites (Fig. 3.3.8).

Dissolved oxygen concentrations (mg/L; Fig. 3.3.9) showed many of the same trends which were observed for percent saturation (Fig. 3.3.7). Red Brook never had values below Class B standards (7 mg/L) (where data were available). Surprisingly, September 30, 2000 concentrations (early morning) exceeded September 23, 1999 (mid-afternoon) values at six of the nine sites. This occurrence probably was explained mostly by much lower water temperatures (generally a 4^{o}C difference) found on the September 30, 2000 early morning sampling (Fig. 3.3.11) because cooler waters have a greater capacity to hold dissolved oxygen (Allan 1995). Long Creek violated Class B standards at sites LC-M-2.270 and LC-Mn-2.274 on a number of occasions. Long Creek also violated Class C standards on certain dates at the following sites (where data are available): LC-M-2.270~ (June 15, 2000 - early morning) and LC-S-0.369, LC-M-2.270~, LC-M-2.754, and LC-Mn-2.274~ (September 1, 2000 - early morning). Again, the sites most consistently exhibiting problems were the LC-M sites in the upper half of the watershed, most likely for the same reasons as mentioned earlier. Interestingly, the uppermost site in the LC-M watershed, LC-Mn-3.224~, a site in a relatively undisturbed, forested section of the stream, had a reasonably high dissolved oxygen (7.1 mg/L) on September 30, 2000, but not as high as expected given the adjacent land-use. This might be explained by the fact that the stream actually emerged from a spring (as groundwater) about 50 m upstream of the sampling point.

Specific Conductivity

Specific conductivity at all of the Red Brook sites was always below 400 μS/cm (Fig. 3.3.10). The uppermost Red Brook site, RB-3.961, was always < 156 μS/cm. Specific conductivity at the site ~ 50 m downstream of a spring, LC-Mn-3.224~, was 89 μS/cm. Except in a few instances (LC-M-0.595: 9/23/99; LC-Mn-2.274: 9/23/99 & 6/15/00), all Long Creek sites generally had specific conductivity readings greater than 400 μS/cm. LC-S-0.369 and LC-N-0.585 always had values greater than 809 and 655 μS/cm, respectively. These generally high values at the Long Creek sites may be explained by surficial geology characteristics, but more than likely, they are a result of nonpoint source pollution entering the system from nearby land-use practices (road salting and sanding, construction and its associated sediment pollution, etc.). The unusually high value at LC-M-2.754 (1336 μS/cm) could have been a result of either an upstream in-stream stormwater pond or perhaps even leachate from a nearby landfill (further study would be needed to determine this scenario) (Fig. 3.3.10). (Procedural error could have been the reason too, although the measurement was double-checked in the field to support the initial reading.)

3.4 Water Temperature

Spot temperature readings (Fig. 3.3.11) were most useful when trying to interpret dissolved oxygen percent saturation data. Other than that, no clear trends were obvious in the data. Continuous data logger information (discussed below) was more helpful in determining trends. However, it is interesting to note that when these spot measurements were made, three out of the four measurement dates they were made before 7 am. Water temperatures at the sites then generally were about the same. However, as one sees later, mean and maximum weekly water temperatures exhibited much more variability between sites. This most likely was due to either the varied amounts of shade provided by riparian vegetation at the various sites or the proximity of hot pavement next to some sites, which may have heated runoff waters during summer thunderstorms.

Minimum Weekly Temperatures - 1999

A couple of trends were visible in the minimum weekly water temperature data for 1999 (Fig. 3.4.1). First, sites located in the upper reaches of both Long Creek (LC-Mn-2.714 and LC-Mn-2.274) and Red Brook (RB-3.961) typically had the lowest minimum weekly temperatures when comparing sites within a particular week. These sites all were generally below more shaded stretches of stream and they also had smaller volumes of water relative to downstream sites, which likely explains their lower minimum temperatures. One exception to this was LC-M-0.432, which was a downstream site with a greater volume of water than the upstream sites, but which also flowed through a fair amount of relatively shaded of stream. Second, there were some visible cooling-down (post- 7/31/99 and 9/11/99) and warming-up periods visible in the data.

Maximum Weekly Temperatures - 1999

The first trend obvious in the weekly maximum temperature plot was that the Red Brook sites almost always had the lowest temperatures and they always were < 24 °C and often < 22 °C (Fig. 3.4.2). These sites were located below/within relatively shaded reaches and they were sites which appeared to have greater inputs of water via groundwater versus surface runoff when compared with some of the warmer Long Creek sites. Field observations of less dramatic declines in flow in Red Brook during the warm summer months lent support to this notion (pers. obs.). Five other sites, LC-N-0.415, LC-S-0.369, LC-M-0.432, LC-Mn-2.274, and LC-Mn-2.714, located below/within relatively shaded reaches, also typically had some of the lower temperature values and were always below 24.2 °C. In general, the remaining seven sites, all in LC-S, LC-M, and LC-Mn, had the highest weekly maximum temperatures often were > 23°C and, in the cases of LC-S-0.496, LC-S-0.400~, LC-M-0.910, and LC-Mn-2.400~, ranged between 26 - 29.3°C.

Mean Weekly Temperatures - 1999

Weekly mean temperature trends were similar to those found for weekly maximum temperatures, although not as dramatic (likely a result of the cooling effect of nighttime air temperatures at all the sites) (Fig. 3.4.3). Temperatures at the Red Brook sites all generally were lower than most of the Long Creek sites, and they were always lower than 21 °C and often < 19 °C. A few Long Creek sites that were below/within relatively shaded areas, LC-S-0.369, LC-M-0.432, LC-N-0.415, LC-Mn-2.274, and LC-Mn-2.714, consistently had relatively low weekly mean temperatures. The remaining sites, a number of LC-S and downstream LC-M- sites plus LC-M-2.270, which was downstream of a golf course, had the highest weekly mean water temperatures. Their temperatures generally were > 19 °C and, for three of the weeks sampled, ranged between 20 - 23.5 °C.

Minimum Weekly Temperatures - 2000

Generally, weekly minimum water temperatures at the majority of the sites ranged between 14 - 18 °C, with Red Brook sites and an upper-watershed site of Long Creek (downstream of/within a shaded area; LC-Mn-2.714) tending to have the lowest temperatures (Fig. 3.4.4). One notable exception to this pattern was LC-Mn-3.224~, a site which was ~ 50 m downstream from Long Creek emerged from spring. (Incidentally, at the time of the study, if one walked up a small hill ~ 200 m from this spring, one could find a surface water flow emerging from another spring, which appeared to be the "true" point of origin. The point which was ~ 50 m upstream of the temperature site actually appeared to be an outflow/spring of the stream after it had gone completely underground for about 200 m.) This site, which was in a dense forest area with lots of shading, appeared to be very close to groundwater conditions, which explains why the temperatures here often were 6 - 8.5 °C cooler than the other sites. After moving about 30 m downstream of this site, the stream was observed to have been diverted 90 °

into a ditch which redirected the stream around a parcel of land (and a dirt road), through an instream stormwater detention (fairly dry) pond that was sparsely vegetated with small riparian trees and eventually towards the Colonel Westbrook Industrial Park. These stream modifications apparently explained why water temperatures rose dramatically in this stretch of stream.

Maximum Weekly Temperatures - 2000

The most apparent trend in these data was the large difference (18 ^{o}C) between LC-Mn-3.224~ and the rest of the sites (Fig 3.4.5). Other trends here were similar to those found in the 1999 data. LC-S- generally had the highest temperatures, sometimes reaching as high as 28.4 ^{o}C.

Mean Weekly Temperatures - 2000

The most apparent trend in these data was the large difference (11 ^{o}C) between LC-Mn-3.224~ and the rest of the sites (Fig. 3.4.6). LC-S- generally had the highest temperatures, sometimes reaching as high as 21.6 ^{o}C. LC-Mn-2.370~ generally had the same (or slightly lower) temperatures as LC-S-0.470. This site (LC-Mn-2.370~) was below a stretch of the stream flowing through the Colonel Westbrook Industrial Park complex where riparian trees were quite sparse. Other trends here were similar to those found in the 1999 data.

Temperature Data Summary

Water temperature data was only available for a select number of sites throughout the watershed. However, in the study design, an attempt was made to choose fairly representative sites. Also, actual stream shading provided by riparian forests along the length of the streams was not quantified for many sites in this study, although if it had, it would have a given a picture of the representativeness of the water temperature data. However, despite these issues, this study did conduct a preliminary stream walk along the majority of the length of all the stream reaches involved in this study, plus visual observations were made of aerial photographs covering the study area. These observations have led the author to conclude that a fairly greater proportion of the riparian zone (and its canopy) along the length of Red Brook have been allowed to remain fairly intact and provide shade to the stream than along the length of Long Creek. This suggests that the water temperature data plotted in the figures in this section are fairly representative of true conditions found throughout Red Brook and Long Creek. Fortunately, for Long Creek, there still are some portions of land through which it flows that have somewhat intact riparian zones. These areas ought to become the building blocks of any form of restoration which may occur within the Long Creek watershed and the areas of Red Brook which should receive careful attention and protection.

3.5 Hydrology

Storm event and low-flow sampling conditions for this study are summarized in Table 3.5.1. Figures 3.5.1 - 3.5.8 present hydrographs of discharge data collected during the three storms, and Table 3.5.2 lists the time it took LC-S, LC-M, and RB to reach peak discharge during each of the storms. (*Note*: Often at least one of the ISCO flow meters would have technical problems in the field. In order to maintain storm-storm consistency, the malfunctioning meter typically was moved to LC-N so that a working meter could be used at one of the other sites.) Each storm had unique characteristics, varying in time of year, intensity, and duration (Table 3.5.1). The March 28-29, 2000 storm took place during a time when there was still snow on the ground in certain areas of the study watersheds. The October 18-19, 2000 and September 25-26, 2001 storms took place during autumn. At that time, flows were much lower than those seen during the March 2000 storm. Relative to the two Long Creek sites, the stage at Red Brook barely even rose during the course of the storm. This fact probably was due to the fact that Red Brook had a lot more forested land and less acreage of impervious surfaces (i.e., a lower PTIA value), which would have resulted in more of the precipitation being absorbed into the ground and either becoming groundwater or being lost to the atmosphere via evapotranspiration by vegetation. Additionally, drought conditions were occurring/lingering for all the sites during September 2001, which also probably contributed to the much lower discharges seen during at least that autumn sampling period (Figures 3.5.1 - 3.5.8). The data in Table 3.5.2 provide some information regarding the degree of "flashiness" in the hydrologies of these three sites. LC-S was more flashy (rising to peak flow faster, dropping from peak flow faster) than the other two streams. This stream also had the largest PTIA value, an indicator of the intensity of urban land-use. LC-M, having a lower PTIA value displayed hydrology patterns that were intermediate to LC-S and RB. (*Note*: LC-M did have a region between LC-M-0.595 and -0.910 that had a "local PTIA" of 67%, which may have explained why it almost reached peak discharge at about the same time that LC-S did during the September 2001 storm.) Red Brook, on the other hand, always had a gentle "rise to" and "fall from" peak during the storms.

Figure 3.5.9 (draft) presents "runoff:rainfall amount" ratios calculated for the March and October 2000 storms. All the sites had higher runoff:rainfall ratios during the March storm than the October storm. This likely was a result of two factors: the March 2000 storm occurred while there still were some portions of the study watersheds that had some snow-cover and the October 2000 storm occurred at the tail-end of the summer low-flow, high-evapotranspiration period of the year. Red Brook consistently had the lowest ratios, which probably was a result of low PTIA values. In Figure 3.5.10, discharge (low-flow) data were plotted against watershed area (at the point of measurement). Trends in this plot suggest that the sites with higher PTIA values had lower discharge:watershed area ratios, especially as watershed area increases (e.g., compare RB-1.694 versus LC-M-0.595). When the ratio of discharge (low-flow) to watershed area (to standardize for area) was plotted against PTIA, trends generally were unclear (Figure 3.5.11). Below a PTIA of 15%, there was a downward trend, but above 15%, trends were unclear. Interestingly, RB values at both RB-3.961 and RB-1.964 each had quite similar values during both the August and September 2000 sampling events, while Long Creek displayed no clear trends. The most recent precipitation event that occurred prior to low-flow sampling may have been a factor.

3.6 In-Stream and Riparian Habitat

Table 3.6.1 lists the nine major biota sampling sites for this study. These were sites where all the "rockbag" (plus some of the "multihabitat") macroinvertebrate and fish sampling occurred. Many of the other types of monitoring/surveying, including habitat, temperature, fluvial geomorphology, and baseflow water chemistry, also took place at these sites. Both Long Creek and Red Brook are tributaries to the Fore River. These sampling sites were located in South Portland, Westbrook, and Scarborough, and stream order ranged from 1st to 2nd order, according to USGS 7.5' topographic maps. Stream gradient, according to measurements made off of these topographic maps, ranged between 0.17 - 0.52%. At both LC-S-0.369 and RB-1.474, one of the three rockbags left there to be colonized had about 60% of its volume covered by sand (which probably moved during a storm event during the rockbag colonization period) (Table 3.6.1).

"Multihabitat" macroinvertebrate sampling was done at all the sites where "rockbag" samples were collected (Table 3.6.2). At these sites, the same habitats were sampled in the same proportions (3 snag, 2 under-bank, 2 leafpack, and 3 sand habitat D-net samples) in order to increase the comparability of results between these sites. Other sites, which had different habitat types such as riffle or "road debris/rubble" habitats or "sandy-runs with lots of macrophytes" type habitat were included in order to increase the range of habitats sampled in this study (Table 3.6.2).

Qualitative stream bottom substrate and aquatic vegetation information was collected by using the USEPA's Rapid Bioassessment Protocols (USEPA 1999) and is presented in Table 3.6.3. Because the data sheets had only vague explanations for the "organic substrate components" section, and because it stated that it did not necessarily have to add up to 100%, this measure was used to estimate the percentage of stream channel in each study reach which had detritus (coarse particulate organic matter or "CPOM"), muck-mud (fine particulate organic matter or "FPOM"), and/or marl present on the stream bottom. No site was found to have obvious marl deposits present, which is not a surprise for a stream in the northeastern United States, where streams often have a relatively low concentration of calcium carbonate. Detritus was found to be common at most sites throughout the study watersheds. Sites having 20% or less of their stream bottom with obvious accumulations of CPOM included LC-M-0.380, LC-M-0.533 (a riffle/road debris area), LC-M0.603, LC-M-3.098, LC-N-0.585, LC-N-0.850~, and RB-1.474 (over 1/3rd of the sites where it was measured). All sites had at least 10%. The only site having 80% or more of its stream bottom covered by CPOM was LC-Mw-2.896. FPOM was a little more difficult to estimate in the field, but at 8 of the 18 total sites it was not found (in any easily-observable quantities). Sites which had percentages of stream reach having observable FPOM on 70% or greater of their stream reach's bottom included LC-M-2.270, a site below a golf course, and RB-1.474, a wooded area below Maine Mall Road.

Information about the inorganic substrate components gathered from pebble counts done at a number of sites throughout the watershed is presented in detail in the fluvial geomorphology section (3.7) of this report. Slightly anaerobic sediment conditions were observed at LC-S-0.496 (below stormwater inputs draining the Maine Mall and nearby developments), LC-M-2.270 (an area below a golf course), LC-M-0.603, LC-M-3.098, and LC-N-0.850~. A slight presence of oils on substrate was observed at LC-N-0.850~ and LC-M-1.653. Deposits of sludge, sawdust, paper fiber, and relict shells were not observed. As far as aquatic vegetation, diatoms were assumed to be present at many of the sites, but taxonomic data for periphyton samples remain unavailable at this point. Rooted submergent macrophytes were observed at a few locations, but the only sites where they were found to be present in more than 25% of the study reach were LC-S-0.496 (an apparently channelized stretch of stream below the Maine Mall parking lots, associated development, and drainage ditches), LC-M-1.653 (downstream of a golf course), and LC-M-3.098 (Table 3.6.3). There possibly were other sites with macrophytes in the study streams, but there are no more documented sites at this time.

Table 3.6.4 summarizes data on riparian zone and water quality observations at sampling sites in the study watersheds. At most sites, trees were the dominant type of riparian vegetation. Exceptions included LC-M-2.270 (below Sable Oakes golf course), LC-M-0.533 (an area which apparently had been channelized and which had much of its floodplain filled in), and LC-N-0.850~ (an area through which a powerline had been cut years ago). Rockbag macroinvertebrate sampling sites had canopies which provided shading ranging from 79 (LC-M-0.910) - 93 (RB-1.474) %. E. C. Jordan Co. Consulting Engineers (1992) noted that the primary vegetation near the streams and wetlands included maple, alder, ferns, mosses, and various small bushes and grasses. Additionally, they noted that higher, drier areas, commonly had pine trees, maple trees, and raspberry bushes. Field observations made during the present study agreed with those findings (pers. obs.). Additional information about riparian zone conditions is presented later in this report.

For water quality observations using the USEPA (1999) RBP data sheets, odors were not observed (Table 3.6.4). A slight presence, or “flecks”, of water surface oils were observed at 8 of 19 study sites, which may have been a result of (orange) iron bacteria in most cases, and in the downstream sites, occasionally may have been a result of petroleum waste washing off of parking lots. Long Creek water was slightly turbid to turbid at 13 of its 16 sites, while Red Brook waters were stained (tea color) at 2 of its 3 sites and slightly turbid at its most downstream site (Table 3.6.4).

At the study sites, average stream water width ranged between 0.8 and 5 m, while average streamwater depth ranged between 0.2 and 0.6 m (Table 3.6.5). Five of 19 sites were observed to have riffles. This was not a representative proportion of habitats based upon field observations during the initial stream “walk”. The true percentage of the study streams having riffles was probably closer to 5 - 10% of the total stream mileage. Where the rockbags were sampled, stream water widths ranged between 1.23 and 5 m, while water depths ranged between 0.17 and 0.39 m. Due to very slow water, velocities at the rockbags were estimated, by watching flecks of organic matter float by, and they ranged between 0.4 and 0.8 cm/sec (Table 3.6.5). Plots of velocities, measured every 2-m as the observer walked up the thalweg of the channel, show the different types of flow environments encountered at sites under low-flow conditions (Fig. 3.6.1). The most noticeable trend in the data was that the upper-most 3 (of the 4) Red Brook sites exhibited much more variability in flow velocities as one moved up the channel when compared to the lowest Red Brook site and all the Long Creek sites. Many of the Long Creek sites, as well as the lowest Red Brook site, often had long stretches of water where no measurable velocities were recorded (sometimes as long as 47 m).

Land uses near the sites were mostly "commercial/(retail)" downstream of the Maine Turnpike and a mix of forest, golf course, commercial/industrial park upstream of the Maine Turnpike (Table 3.6.6). Portions of all three Long Creek branches appeared to have been channelized. Further, applications for channel relocation permits kept by the Maine Department of Inland Fisheries and Wildlife suggested that a significant proportion of Long Creek downstream of the Turnpike (and some of the upstream) portions of this stream may have been channelized or relocated. In Red Brook, only the region around RB-1.474 appeared to have had some channel relocation due to the construction of the Scarborough Connector highway. An in-stream detention basin / impoundment located at LC-M-2.875 appeared to have been constructed to detain stormwater leaving from some upstream industrial parks, but that is not a certainty. An in-stream detention basin also apparently exists at approximately LC-Mn-3.000~. Table 3.6.7 lists the aquatic organisms observed when performing habitat analyses. There were no clear trends except that fish were only observed in Long Creek upstream of stream mile 2.20 and that macrophytes were observed at only a few locations.

Habitat Scoring

Quite a range of habitat conditions were found among the study sites during this study (Table 3.6.8). In 1999, the nine major "biota" sampling sites were assessed and scored using USEPA (1999) Rapid Bioassessment Protocols for low-gradient streams. These sites had originally been selected for having characteristics that appeared to be consistent with those most commonly found in relatively undisturbed reaches throughout the watershed: being a forested and relatively shaded site (although at some sites those patches of woods were fairly small and isolated patches), having a sandy-silty substrate, and having a predominantly "run/glide" type habitat. This was done in order to reduce confounding variables when later attempting to interpret the biological data. (Copies of blank habitat scoring sheets may be found in Appendix F.) The top three sites, in terms of overall habitat scores, were RB-3.961 (1), LC-M-0.910 (2), and RB-0.071 (3), while the lowest three sites were LC-M-2.270~ (7), LC-M-0.380 (8), and LC-S-0.369 (9). Overall, none of the sites had plentiful stable substrate or pool diversity. Also, a number of sites had riparian buffers $\leq$ 12 m (~40 ft) on at least one side of the stream: LC-M-0.910, LC-M-2.270~, LC-Mn-2.274~, and LC-N-0.415 (1999 - major biota sampling sites) and LC-M-0.603, LC-N-0.595, and LC-N-0.850~ (2000 - some additional sites where scoring was done). (*Note*: It is assumed that much of the development in this area was constructed prior to the existence of current DEP regulations which require 75-ft-wide shoreland zoning protection areas on small streams.) Further, during trips out to various locations in the watershed, additional areas were observed to have habitat problems (pers. obs.). Much of this information is documented in the "problem area" map (Fig. 3.1.4a-e) and in Appendix L (Photographs). Some of these areas included extensive areas of channel relocation / channelization / ditching, especially in the upper halves of LC-S and LC-N plus near LC-M-0.533, significant removal of riparian vegetation (especially at various locations upstream of LC-M-2.200~, as well as the existence of in-stream stormwater detention basins (LC-M-2.875 and near LC-M-2.8~).

Large Woody Debris

Large woody debris (LWD) has been cited in the literature (discussed later) as playing a vital role in stream ecology, especially that of low-gradient, sandy streams. However, LWD surveys were not included in the original design of this study. Nevertheless, observations made in the field during repeated visits to study sites suggested that Red Brook sites generally had more LWD present in its channel than Long Creek (pers. obs.). Additionally, past (heavy) timber harvesting activities in the watershed (Seeley and Valle 1983, pers. obs.) may help explain why there appeared to be a general scarcity of LWD, especially pieces larger than branches, in all the study streams.

The two Red Brook sites had more woody debris in general, as well as more pieces having a mean diameter $\geq$ 20 cm, than Long Creek sites (Fig. 3.6.2, Table 3.6.9). Woody debris also appeared to generally be more evenly distributed at the Red Brook sites compared to the Long Creek sites. The even, relatively large abundance of wood at the Red Brook sites probably was a result of the fairly undisturbed wooded areas adjacent to the stream channels. The two Long Creek stream sections where wood was either completely absent (LC-Mn-2.600~) or fairly scarce (LC-M-0.533) flowed through areas where riparian/streamside areas had been substantially altered. LC-Mn-2.600~ flowed through an area with relatively few riparian trees. This channel section also looked as though it may have been channelized or even moved from its original location to accommodate development of office/industrial parks. LC-M-0.533 flowed through a section where there apparently had been a lot of floodplain filling adjacent to the stream. Here, storm/floodwaters were confined to a fairly deep channel with no evident floodplain, so stream power here during storms likely moved the majority of woody debris to downstream segments. The other Long Creek sites did have woody debris. However, these remaining sites flowed through fairly wooded sections, which likely was the source of much of the wood. Also, the Long Creek sites towards the bottom of the watershed (e.g., LC-M-0.595, LC-M-0.380), which were below substantial inputs of stormwater and numerous serious streambank erosion areas, tended to have wood piled up in clumps rather than evenly distributed pieces of wood and dams. (Note: Statistics to verify whether these differences were significant could not be generated because only one survey was conducted per site.)

3.7 Fluvial Geomorphology

Table 3.7.1 summarizes the fluvial geomorphology data collected for this study. This data, obtained from channel cross-section surveys and pebble counts, includes width of the flood-prone area, bankfull width, entrenchment ratio, mean bankfull depth, width/depth ratio, slope, sinuosity, "D50" substrate particle size class, and Rosgen (1996) channel classification.

It is worth noting that Rosgen's classification is meant for natural stream and river systems, and this study was conducted in a primarily urban landscape. When streams are not easily classified, it may be a signal that the channel is out of equilibrium due to a disturbance (e.g., increased flows or sediment inputs, etc.) and currently is changing to a new form. Some information about his classification scheme is presented in Appendix G (after the pebble count information). Excellent primer fact sheets on this classification and other basic geomorphology information can be at North Carolina Cooperative Extension Service's website (http://www.ncsu.edu/sri/fact_sheets.htm). "Natural Channel Processes" and "Application of the Rosgen Stream Classification System in North Carolina" are the recommended fact sheets.

Channel Type Classifications

Based upon channel cross-section measurement, field observations, and verbal descriptions in Rosgen (1996), it appears as though the natural (pre-settlement) channel form for both Long Creek and Red Brook were either "E5" or "E6" channels. Field data and the reasoning behind why it is believed that these channels were E5 or E6 are discussed below. E5 and E6 channels generally are single-threaded (as opposed to having multiple channels), are slightly entrenched (entrenchment equals the ratio of the width of the flood-prone area : bankfull width), have a very low width/depth ratio, have a very high sinuosity (the degree of curviness or "s-shape" of the planform of the channel), have slopes less than 0.02 (< 2%), and have stream bottoms comprised primarily of sand (E5) or silt and clay (E6) (Rosgen 1996).

All the Red Brook sites were classified as being either truly an E5 or E6 channel (RB-1.434) or being an E5 or E6 channel after making the allowable (Rosgen 1996) adjustments (e.g., $\pm$ 0.2 units for sinuosity values, etc.) (RB-2.119 and RB-3.961). Based upon field observations, the majority of Red Brook upstream of the Turnpike (I-95) appeared to be in a relatively stable state given that there is a fairly high degree of stream sinuosity, density of riparian tree cover, and apparent streambank stability there. Additionally, it was observed that, generally, these portions of the stream had access to floodplains during high flows, thereby reducing some of the potential stresses on the streambanks and channel bottom during flood conditions. Below the Turnpike and Maine Mall Rd., the stream channel appeared to have remained in fairly good condition, although some signs of stress and instability were apparent. This was especially apparent when the stream ran close to the "Scarborough Connector" interstate section. This likely was due to increased stormwater runoff associated with commercial development along

Maine Mall Road and the Turnpike along with the hardening of portions of the streambanks near the Scarborough Connector.

In the Long Creek watershed, the extensive network of roads near the streams, the encroachment of filling and construction activities within the historical floodplains in many areas, and the diversion of many stretches of the stream into ditches or through in-stream detention ponds made it very challenging to find what were believed to be relatively-unaltered stretches of stream channels. One exception to this trend was a section sandwiched between the I-95 Turnpike at its downstream end, the Colonel Westbrook Park complex at its upstream end, and an area of land bordered by the Sable Oakes golf course, a Portland Public Works facility, and a land parcel that had been cleared for Portland International Jetport safety reasons. In other words, this section includes the stream reaches in the vicinity of LC-M-1.653 (± approx. ¼ mile). Relative to other parts of the watershed, this area had a fairly wide riparian zone. This section of stream also appeared to have fairly easy access to its floodplain during floods as opposed to having steep banks and an incised, entrenched channel, which generally would allow floodwaters to be dissipated on floodplains and not threaten channel stability rather than be trapped between steep streambanks and cause the channel to downcut and/or overwiden during storm events. There were some impervious surface areas, mostly office parks, upstream of this reach, and there also were occasional signs of some apparent streambank degradation, but overall the reach appeared to be in a relatively good condition. This section was classified as being E5 without making any adjustments (per Rosgen 1996) (Table 3.7.1). Four cross-section sites in the Long Creek watershed classified out as either E5 or E6 after making allowable adjustments (per Rosgen 1996). Prior to making measurement adjustments, issues at those sites included: sinuosity values not being high (sinuous) enough, which probably was due to straightening / channelization of the stream for development purposes (direct impacts) or due to alteration of watershed hydrology through an increase in impervious surfaces and, possibly, resultant channel destabilization overwidening, and downcutting activities (indirect impacts) (see Schumm et al. 1984 for more information on channel evolution models). These “marginal” sites included LC-N-0.595, LC-Mn-2.274, LC-S-0.220, and LC-S-0.369. The remaining four Long Creek sites were sites that had missed the E category by two or more parameters (e.g., sinuosity, entrenchment, etc.), and they likely were exhibiting signs of channel evolution in response to an altered hydrology or channel straightening associated with urbanization of the local watersheds. (*Note*: Although cross-sections were spread out throughout the study area, and also that an attempt was made to be representative, the number of cross-section sites in this study was not considered exhaustive or complete.)

Pfankuch Channel Stability Evaluations

For the Pfankuch assessments in general, it appeared as though the "poor" and "very poor" scores were mostly a result of channel bottom characteristic scores which, in many cases, was primarily sand and silt dominated beds (Table 3.7.2). This may be the case when comparing sites in these streams to sites in other streams around the state and country that have a much greater presence of larger size substrate particles. Those larger particle-type stream bottoms often are much more stable systems than are sand and clay dominated systems. Also, the "overall" scores did not reflect the fact that all of the study sites had either "excellent" or "good" vegetative bank cover. This is likely due to the fact that the weight of the vegetative bank scores had a much lower range of values than did the channel bottom characteristic scoring. Another factor that commonly scored in the "poor" category and which heavily influenced overall scores was bank rock content. At the majority of the sites, banks were comprised primarily of sands and clays which, did not appear to be very resistant to high flows except some areas which had exposed lenses of solid clay. The site which appeared to be the least disturbed and the most stable, RB-3.961, had either "excellent" or "good" scores for all the upper bank and lower bank characteristics, except bank rock content, including mass wasting, vegetative bank protection, and cutting. As for the remaining locations, there were a number of sites (11 out of 21 total sites) which had either "excellent" or "good" ratings for the mass wasting category plus often had "excellent" or "good" scores in most of the other upper and lower bank categories, although not as consistently as RB-3.961. These sites included LC-S-0.369, LC-S-0.496, LC-M-0.910, LC-Mw-2.896, LC-M-3.098, LC-Mn-3.224, LC-N-0.404, LC-N-0.850~ RB-0.071, RB-1.434, and RB-2.119.

The only site to receive a "good" overall Pfankuch score was LC-S-0.496. This site was a reach upstream both Maine Mall area stormwater detention ponds and outfalls. This channel section apparently had been carved out into a straight channel and lined with lots of trees (based upon field observations and photocorrections on USGS topographic maps). The fact that this section was upstream, instead of downstream from, two large detention ponds probably explains this apparently high degree of stability. At LC-M-1.663~, the stream is approaching a steep wooded bank at a sharp angle, so the bank area immediately adjacent to the stream is very steep and eroding. The tree roots in this bank are providing a lot of short-term bank stability. Note that office & industrial parks upstream of this area may be contributing to altered hydrology and channel de-stabilization in this area (Table 3.7.2).

Chapter 4
Discussion

4.1 Biological Community

Note: Some brief comments about the biological communities are presented in this first section (4.1) of the discussion. However, because the condition of these communities was the greatest concern in this study, comments about the health of Long Creek's and Red Brook's communities, with respect to findings about stream water quality, habitat, etc., are integrated into the remaining sections of the discussion where applicable.

Periphyton

The authors of a 1983 study were surprised to find low chlorophyll levels in Clark's Pond, which they attributed to light-blocking characteristics of high suspended solid levels in the Pond (Seeley and Valle 1983). Interestingly, chlorophyll levels for the streams in this study did not appear to be terribly high even though the land use was primarily urban development, at least in Long Creek. For example, in this study mean chlorophyll-*a* values collected in mid-July ranged between approximately 14-18 mg/m^2 for Long Creek and 5-11 mg/m^2 for Red Brook. In a small Massachusetts river flowing through primarily agricultural land (but with riparian shading), mid-July mean values ranged from approximately 11-40 mg/m^2 (Sumner and Fischer 1979). For additional perspective, one can look at Bigg's (1995) study of periphyton sampling done, during all seasons of the year, in 16 New Zealand stream sites that ranged from unenriched to enriched nutrient status. Chlorophyll-*a* values in that study ranged between approximately 0.5 and 900 mg/m^2, so it appears as though Long Creek and Red Brook were at the low end of the spectrum of periphyton abundance. Of course, season is a very important driver in stream periphyton communities, as these organisms respond to variations in daily amounts of sunlight and temperature (Allan 1995). For example, the dominance of communities by various algal groups changes with season (e.g., diatoms tend to be most abundant in the winter, spring, early summer, and autumn, while other groups such as green and blue-green algae tend to peak in the summer). Algal communities on the substrate sampled in July in the present study appeared to be primarily comprised of diatom taxa. Interestingly, filamentous green algae, and occasionally blue-green algae, sometimes were observed in the field late in the summer and early autumn. Filamentous green algae were only observed to be growing on large rock substrate (typically riprap) or on concrete culvert bottoms; they never were observed on sandy or silty habitats, likely due to the instability of these substrate types during storm flows.

Invertebrates

Benthic macroinvertebrate sampling was a major component of this study, therefore, discussion about these communities is integrated into the sections below. A table listing the common names of many of the macroinvertebrate orders mentioned in this report may be found in Appendix B.

Fish

At least until the late 1960s, brook and brown trout populations were sustained in Red Brook and Long Creek (Seeley and Valle 1983, Maine Department of Inland Fisheries records). Only warmwater fish (kilifish and sunfish) were observed, during visual surveys, in the northern (*LC-N*) and eastern branches of Long Creek, while no fish were observed in the southern branch (*LC-M in the present study*) in a 1982 reconnaissance. The authors did acknowledge that sampling with electrofishing techniques, in addition to the visual observations they made, likely would have increased the species of fish observed during their study (E. C. Jordan Co. Consulting Engineers 1982). Records indicate that the last time brook trout were stocked in Red Brook was 1974, so the current existing population is believed to be a self-sustaining population (Francis Brautigan, Maine Dept. Inland Fisheries & Wildlife, pers. comm.).

4.2 Land Use Analysis, Watershed Survey, Stream Walk, and Surficial Geology Investigation

Percent total impervious area (PTIA) is not actually the causative factor behind stream health decline. Rather, PTIA is an integrative measure of the cumulative factors associated with urbanization that affect the biological, chemical, and physical conditions of streams and rivers (Arnold and Gibbons 1996). There is a general lack of mechanistic studies that determine whether factors such as physical habitat, water quality, or food web disturbances are the cause of biological degradation in urban streams (Paul and Meyer 2001). The difficulty associated with pinpointing exact mechanisms responsible for urban stream degradation may be a result of the inherent variability associated within stream systems and land-use characteristics (Morse 2001) and the multivariate nature of urban impacts on streams (see review in Paul and Meyer 2001). For example, a study in New Hampshire found that concentrations of a number of metals, PAHs, nutrients (nitrogen and phosphorous), and oil/grease were 2 -14 times greater in storm drain system stormwater from a commercial/ business/residential watershed than from a residential watershed (Comstock 1997).

It is worth noting that although impervious surfaces are not the mechanism of degradation, they are directly linked to the degradation because they often, for example, collect and accumulate pollutants derived from sources such as leaky vehicles and the atmosphere, which then are easily washed off during storms and rapidly delivered to aquatic systems (Schueler 1994a). More details about increased pollutant loads and altered hydrologies associated with impervious surfaces are discussed later in this report, particularly in sections 4.3 and 4.5.

Numerous studies, and reviews of those studies, have found many measures of stream health, including changes in hydrology, water quality, habitat (e.g., attachment sites for macroinvertebrates, feeding and spawning areas for fish, refugia for all aquatic organisms), and biodiversity, begin to significantly degrade after PTIA reaches levels greater than 10 - 20% (Schueler 1994a, Paul and Meyer 2002) or 5 - 25% (Morse 2001). Many studies have found 10% to be the threshold value. Schueler (1994a) proposed a classification scheme based upon PTIA where stream watersheds having PTIA values between 1-10%, 11-25%, and 26-100% are classified as being "stressed", "impacted", and "degraded", respectively. Using Schueler's (1994a) categories to characterize the majority of stream length of each of the study stream branches, RB, LC-M, and LC-S/LC-N would have been classified as being "stressed", "impacted", and "degraded", respectively. Also, because a significant stretch of the lower half of LC-M was found to have a "local PTIA" of 67%, one might have further classified that particular stretch as being "degraded" (Fig 3.1.3 and Table 3.1.2). The particulars of the physical, chemical, and biological impacts mentioned above are presented later in the discussion.

Periphyton and Macrophytes

As urbanization expands in stream watersheds, the diversity of algal communities tends to decrease while biomass tends to increase due to increased nutrient and light levels. However, in some cases, shifting bed sediments, frequent bed disturbance, increased turbidity, and increased levels of pollutants (e.g., metals, herbicides) may decrease algal biomass (see review in Paul and Meyer 2001). In this study, biomass, as evidenced by chlorophyll-*a* values, appeared to generally increase with increases in PTIA (Fig. 3.2.3), although there were not enough data points for regression analysis. The existing data, though, did not appear to show a strong linear trend associated with PTIA. More samples would be needed before any serious conclusions could be made. Fertilizers associated with golf course greens and the lawns of businesses and residences, along with the phosphorous that typically is associated with winter sand runoff, may explain the relatively higher chlorophyll-*a* values in Long Creek.

Not much is known about macrophyte communities in urban watersheds, although it is known that in certain parts of the country, introduced exotic species have caused decreases in the presence of native macrophyte species (see review in Paul and Meyer 2001). Macrophytes were only observed occasionally in this study and they generally appeared to be confined to areas where there were large openings in the riparian zone. One place where there was serious concern about macrophyte growth was the area within and below what appeared to be an in-stream stormwater detention basin at LC-M-2.875~. The abundant emergent macrophytes within and the abundant submergent macrophytes below the basin may be largely responsible for low dissolved oxygen measurements made during early-morning sampling, probably due to high respiration rates occurring overnight (even though dissolved oxygen contribution via photosynthesis during daylight hours may be significant).

Invertebrates

Benthic macroinvertebrates are useful as integrative indicators of the effects of a wide range of stresses on aquatic systems. They are relatively immobile and are exposed to both chronic and acute levels of pollutants in streams. The diversity, species composition, and abundance of organisms in these communities often help scientists to understand the conditions of stream ecosystems. For example, aquatic insects belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) tend to be most rich and abundant in unstressed stream systems, while higher proportions of oligochaetes, isopods, and some insects in the Diptera order often are more dominant in stressed systems (Rosenberg and Resh 1993, USEPA 1999).

Invertebrates have been examined more than any other group of biota when it comes to urban stream studies. Among these studies, typical trends associated with increases in urban land-use within watersheds include decreased diversity (in response to temperature regime changes and increased toxin, silt, and nutrient loading), decreased abundance (in response to toxins and siltation), and increased abundance (in response to inorganic and organic nutrient loading). Decreased abundances tended to be evident in the sensitive orders (Ephemeroptera, Plecoptera, and Trichoptera), while increased abundances tended to be prevalent in the more tolerant organism groups such as Chironomidae (order: Diptera), oligochaetes, and certain gastropods (see review in Paul and Meyer 2001).

Morse (2001) conducted a study that examined the relationships between macroinvertebrate communities, stream habitat and water quality, and watershed land-use characteristics on 20 streams varying in urban land-use intensity throughout central and southern Maine, primarily in the vicinity of Bangor, Anson/Madison, Augusta, and South Portland. The total range of PTIA for streams that Morse examined was 1-31%, and the four streams in the South Portland/Portland vicinity included Minnow Brook (3% PTIA), Trout Brook (14%), Long Creek (calculated as 16% in Morse's study and at approximately the same location calculated as being 14% in this study), and Barberry Creek (22%). How various stream habitat and water quality parameters differed as a function of increasing PTIA is discussed in sections 4.3 and 4.6.

Using criteria in Plafkin (1986), Morse (2001) concluded that a PTIA value of 6% separated streams that appeared to be "unimpacted" (< 6%) from streams that appeared to be "moderately- to severely-impacted" (≥ 6%). He found total taxonomic richness and EPT taxonomic richness to be higher in the "unstressed" streams compared to those that were "stressed". At levels of PTIA ≥ 6%, both total taxonomic richness and EPT richness generally declined with increasing PTIA, although the negative trend was not significant between sites within the restricted range of 6-27%. The site having a PTIA of 31% had the lowest total taxa richness and EPT richness during both spring and fall sampling seasons. (The exception there was total taxa richness in the fall where a site having a PTIA of 22% had slightly lower values than the site with a PTIA of 31%.) The 31% PTIA site was the only one to be described as "severely impacted". Interestingly, while Morse (2001) found that densities of a number of sensitive, pollution-intolerant taxa decreased as PTIA levels increased across streams, he also found some moderately-sensitive taxa to be relatively unaffected by increasing PTIA values (e.g., *Acerpenna* [Ephemeroptera], *Paracapnia* and *Allocapnia* [Plecoptera], *Optioservus* and *Stelmis* [Coleoptera], *Hydropsyche* and *Cheumatopsyche* [Trichoptera], and Orthocladiinae [Diptera], and Oligochaeta). Neither physical habitat nor water quality parameters indicated what the mechanism was for degradation of the macroinvertebrate community (Morse 2001).

In this study, similar changes were observed in the rockbag macroinvertebrate samples as PTIA values changed. These communities, despite meeting at least Class C standards (State of Maine 2001), generally appeared to be more stressed at the Long Creek sites based upon examination of the individual metrics presented in Figs. 3.2.5a-f. For example, metrics such as Plecoptera abundance, Hilsenhoff Biotic Index, EPT generic richness, summed abundances of "D,M,P,H", summed abundances of "A,S", dominant Class A taxa, and presence of Class A taxa all showed at least a weak transition towards more degraded communities as PTIA values increased (Figs. 3.2.5a-f, Table 3.2.1). Further, Table 3.2.2 lists taxonomic composition differences between the reference Red Brook site (RB-3.961) and the Long Creek sites. The lack of really strong trends associated with increases in PTIA may be explained by the fact that, even though they had generally lower PTIA values than downstream sites, many areas of Long Creek above I-95 still had apparently been subjected to intensive land uses in the past or present. As mentioned earlier, prior to the late 1960s, most of the study area was farmland and forest. After that, land-uses in the region began to change dramatically (Seeley and Valle 1983). In addition to increases in PTIA, agriculture, channelization, in-stream detention basins, a landfill, and timber harvesting/riparian zone thinning (for business site development, office parks, a golf course, a powerline, and general landscaping) had seriously altered near-stream and in-stream habitat conditions which may explain why biological communities generally appeared degraded in the upstream (above I-95) reaches as well as the downstream (very high PTIA) reaches.

<u>Fish</u>

Paul and Meyer (2001) cited a review of Ohio EPA's large database of land use and fish abundance data from around Ohio where the following predictions were made for fish: between 0-5% urban land-use sensitive species are lost, between 5-15% habitat degradation occurs and functional feeding groups (e.g., benthic invertivores) are lost, and above 15% increased in-stream toxicity and organic nutrient enrichment result in severe degradation of fish fauna. Reviewing other literature, Paul and Meyer (2001) found that as the percentage of land being impervious increases, in general, responses include one or all of the following: fish diversity decreases, relative abundance of tolerant taxa increases, indices of biotic integrity decreases. Above 10% impervious surface cover, fish communities begin to dramatically degrade and, beyond 15%, fish communities remain degraded.

In this study, the fish data (focusing on brook trout) fell approximately within the ranges reported by Ohio EPA (see Paul and Meyer 2001), with brook trout only being found at sites (all Red Brook sites) having PTIA values ranging between 2 - 8%. In Long Creek, where fish sampling sites had PTIA values ranging between 7 - 47%, brook trout were not found. The fact that brook trout were not found at the 7% PTIA site may be explained by some of the degraded channel/riparian conditions just mentioned for macroinvertebrates.

4.3 Water Chemistry and Suspended Solids (Baseflow and Stormflow)

As watersheds urbanize, there generally is an increase in the level of pollutants in streams including dissolved ions, suspended solids, hydrocarbons, metals, and oxygen-depleting substances. These increases often are attributed to effluent from wastewater treatment plants (not believed to be an issue in the present study watersheds) and/or a variety of nonpoint sources such as impervious surfaces, lawns, illicit septic-waste discharge connections, and leaking sewer systems (see review in Paul and Meyer 2001). Figures 3.1.4a-e present a summary of observations of potential nonpoint sources of pollution. The following section describes these pollutants, and their effect on aquatic ecosystems, in more detail. (*Note*: A landfill exists up in the upper portion of the study watersheds. At this time, it is not understood what potential impacts, if any, that land use may be having on the water quality of the study streams.)

Toxins

Metals

Elevated metal concentrations in the water column and sediments commonly are found in urban streams. Table 4.1a lists common metal pollutants and some of their typical sources. Besides industrial sources, automobiles, and the impervious surfaces upon which they are driven and parked, are major contributors of these metals (see review in Paul and Meyer 2001). As much as 75% of heavy metals entering surface waters in the United States can be traced to traffic-related sources (Tsihrintzis and Hamid 1997 as cited in Woodcock 2002). Interestingly, a study in New Hampshire estimated that 41 and 11% of zinc and nitrate/nitrite-nitrogen, respectively, entering stormwater was coming from atmospheric (precipitation) sources (Comstock 1997). Additional problematic metals in urban watersheds, coming from a variety of sources, include mercury, cadmium, arsenic, iron, boron, cobalt, silver, strontium, rubidium, antimony, scandium, molybdenum, lithium, and tin (see review in Paul and Meyer 2001). When stream organisms undergo chronic exposure to metal contamination, which can be present in both the water column and sediments, the results can be bioaccumulation of metals, reduced abundances, loss of sensitive species, and reduction of diversity (see reviews in Morse 2001, Paul and Meyer 2001, Woodcock 2002). Woodcock (2002) found whole-community macroinvertebrate production rates (biomass/m^2/year) in

Goosefare Brook (Saco, Maine) to decrease dramatically over a gradient of increasing metal concentration.

From 1993-1994, the South Portland City Engineering Department conducted sediment and water column sampling of various metals and total suspended solids at three locations, one near Clark's Pond dam and one each where Long Creek and Red Brook flowed into the pond. According to the report, copper, lead, and zinc concentrations all were well below federal drinking water standards. Table 4.1b provides a comparison between metal concentrations found in the South Portland Engineering study (1994) and the present study. Samples collected during the September 2001 storm (present study) appeared to be approximately within the range of the 1994 study, while March 2000 storm values (present study) generally were much higher in Long Creek in the present study than the 1994 values. This probably is due, in part, to accumulation of metals in the parking lots and snow piles over the course of the winter, during which there was not much runoff. In comparison, when examining a number of streams in the Puget Sound lowland area of Washington state ranging in PTIA from 2-61%, Horner et al. (1997) found that mean stormwater concentrations of zinc (over 3 storms) were all less than 0.011 ppm for streams having PTIA < 10%, while concentrations for streams ranging between 14-61% PTIA generally increased with increasing PTIA and were 1.3-5.5 times higher than in streams with a PTIA < 10%.

Interestingly, in the 1994 South Portland study, sediment samples analyzed for metals were found to have concentrations ranging from 5,000 - 50,000 times greater than surface water grab samples during either low-flow or storm event conditions (South Portland Engineering Department 1994). Some research suggests that metal toxicity is most strongly exerted through the riverbed (see review in Paul and Meyer 2001). Sampling sediments for metal concentrations in the present study might have added greater insight into the potential for metal toxicity in the Long Creek and Red Brook ecosystems. There is a possibility that high metal concentrations in the sediments of these systems is limiting the types of macroinvertebrate and fish species that may inhabit Long Creek and Red Brook. These types of analyses ought to be considered in future studies. Upcoming stressor identification workgroup analyses hopefully will determine the potential impact of these metal concentrations on the aquatic organisms.

<u>Polychlorinated Biphenyls (PCBs), Polycyclic Aromatic Hydrocarbons (PAHs), and Oil/Grease</u>

A number of organic contaminants frequently are detected in urban streams. Even though their use in manufacturing has been outlawed because of their carcinogenic effects, polychlorinated biphenyls (PCBs) are quite stable and they are still being found in high concentrations in different regions of the country (see review in Paul and Meyer 2001). Even though Red Brook is supporting a self-sustaining brook trout population, there still is concern about this population because fish samples have been found to be contaminated with PCBs (Maine DEP 1996) which may possibly be linked to a site, located a few hundred feet from Red Brook at approximately RB-3.0, that historically was contaminated with electrical transformer waste and related debris. The debris and upper layers of soil, since that time, have been removed although there may still be residual contamination in local groundwaters.

Polycyclic aromatic hydrocarbons (PAHs) are another large class of organic compounds, which includes natural aromatic hydrocarbons. There also are many synthetic aromatic hydrocarbons, including organic solvents, which are used in various industrial operations and which can reach urban streams via industrial effluent or episodic spills (see review in Paul and Meyer 2001). Another major source of human-created PAHs is the incomplete combustion or leakage of fossil fuels (e.g., automobile gasoline; see review in Woodcock 2002). In urban watersheds there can be many areas which produce significantly greater loadings of hydrocarbons (and trace metals) than other areas. Schueler (1994d) termed these areas as "hotspots" and stated that they often are linked to places where vehicles are fueled, serviced, and/or parked. Citing a study by Schueler and Shepp (1993), Schueler (1994d) ranked samples collected from oil grit separators underneath five types of hotspots in the metro-Washington, D. C. area from (#1) gas stations (the worst sites), (#2) convenience stores, (#3) all-day parking lots, (#4) streets, to (#5) residential parking in terms of general ranking of concentrations of total-phosphorous, total organic carbon, hydrocarbons, cadmium, chromium, copper, lead, and zinc in "separator pool" water and sediments. Other potential hotspot areas may include vehicle maintenance areas, bus depots, fast-food restaurant "drive-thrus", and other types of parking lots (see review in Schueler 1994d). Gas stations were found to be extremely significant hotspots for hydrocarbons. For example, 37 and 19 potentially-toxic compounds were found in gas station oil grit separator sediment and water column samples, respectively. Many of these pollutants were PAHs thought to be harmful to both humans and aquatic organisms. Based upon the research it also was suggested that oil grit separators were fairly ineffective water quality protection devices due to frequent resuspension of sediments and associated pollutants, insufficient volume capacity, poor internal geometry, and lack of maintenance (see review in Schueler 1994d).

Petroleum-based aliphatic hydrocarbon pollution (e.g., oil), often a result of leaky automobiles, is common in urban streams. Eighty-five percent of the 29 million gallons of oil that enters the ocean around North America each year comes from polluted rivers and runoff resulting from leakage from cars, trucks, airplanes, small boats, and jet skis, as well as from contaminants in wastewater. Less than 8% comes from tanker and pipeline spills (National Research Council 2002). The potential "hotspots" documented in Fig. 3.1.5 likely are contributing, cumulatively, pollutants such as petroleum to Long Creek, Red Brook, and downstream waterbodies such as Clark's Pond, the Fore River, and Casco Bay. These "hotspots" need to be targeted for improved best management practices during any future restoration plans.

Nutrients, Other Ions, and Suspended Sediments

Total Suspended Solids

Because total suspended solids (TSS) can have a great impact upon in-stream habitat, and because they often are related to watershed erosion problems, TSS, erosion, sedimentation, and the direct effects of sediment upon biota are discussed in section 4.6, In-Stream Habitat (Erosion & Sedimentation) below. TSS also can indirectly impact stream ecosystems because of the nutrients commonly associated with them - please see below for more information.

Nutrients and Other Ions

Nutrient pollution was cited as being the most widespread form of water quality degradation by the USEPA in 1998. Nitrogen and phosphorous were blamed as being the primary causes of eutrophication in the United States (USEPA 1998). Reviews in Paul and Meyer (2001) and Woodcock (2002) stated that urbanization generally leads to increases in the addition of phosphorous and nitrogen pollution to streams through soil erosion, road sanding, fertilizer applications, illicit discharges, and leaking sewers. They also stated that chloride levels often are elevated in urban streams due to the common practice of deicing roads with sodium chloride. Other ions that also generally are elevated in urban streams include calcium, sodium, potassium, and magnesium (see reviews in Paul and Meyer 2001, Woodcock 2002).

Among his 20 study streams, Morse (2001) found NO_3-N concentrations to significantly increase with increasing PTIA (after a few outliers were removed). Long Creek was found to have a concentration of ~0.1 mg/L (Morse 2001). Total phosphorous was not detected (detection limit: > 0.038 mg/L) in most of Morse's study streams, including Long Creek (Morse 2001). Total-phosphorous, total Kjeldahl nitrogen (TKN), and NO_2+NO_3 measurements made by Guay (2002) were fairly comparable to values observed during storms in this study in LC-S, given the unique characteristics of each storm sampled (Table 4.2). However, one notable exception was an intense storm (FG-ut [#4]), where values of TSS, total-phosphorous, and TKN were all 3.4 - 4.5 times higher than any levels found in LC-S. As mentioned earlier, this may have been the result of large amounts of road sand, debris, and associated nutrients remaining on impervious surfaces, as well as any remaining fall leaf litter, up until the time the storm occurred (springtime; May 2001). The one outlier for Long Creek, 20 ppm of NO_2+NO_3 (present study), may have been the result of a piece of detritus in the sample.

In general, eutrophication did not appear to play a major role in degrading Long Creek or Red Brook. This may be due in large part to the fact that the majority of substrate materials (sands and silts) in Long Creek and Red Brook appeared to be fairly unstable (e.g., during high flows) and thus are not suitable habitats for the establishment of significant communities of periphyton. There were occasional small stretches where some macrophytes were observed, but they tended to be restricted to areas underneath large openings in the canopy. Even when relatively large and stable substrate (bricks) were placed in relatively open-canopy sections of the stream, generally little growth of periphtyon occurred. However, as discussed earlier, these bricks were placed in the stream during June, and it was noticed in the field that occasional growth of strands of periphyton occurred later in the year (around August) in areas where stable substrate such as road debris and riprap had fallen or been placed in the stream channel (pers. obs.). Primary areas where macrophyte/periphyton growth was observed included: areas of riprap in the stream, especially above or below culverts and stormwater outflows in the LC-S branch; some open canopy areas downstream of LC-M-1.6~; and downstream of an in-stream detention basin (at LC-M-2.875) above Spring Street. Fish kills due to eutrophication-related depletion of dissolved oxygen did not appear to be a major issue as concentrations often were not observed below 5 mg/L in either stream, even during stressful, early morning, late summer days. Still, the dissolved oxygen levels at some upstream stations in Long Creek were fairly low, with concentrations sometimes below 5 mg/L. These stressed environments might explain the apparent absence of brook trout and sensitive macroinvertebrate taxa in Long Creek. Due to the nutrient loads being generated in Long Creek and Red Brook, eutrophication may be more of an issue for downstream bodies of water such as the Clark's Pond impoundment, which was noted as having some problems by Seeley and Valle (1983), and potentially the Fore River and Casco Bay.

Specific Conductivity

Morse (2001) observed that as PTIA increased, average specific conductivity significantly increased. He also found that when both total and EPT richness were correlated against the physical habitat and water quality parameters in his study, specific conductivity consistently had the strongest relationships with the two richness measures (r^2 values: total richness = 0.72[fall], 0.82[spring]; EPT richness = 0.64[fall], 0.74[spring]). This is a useful finding because increased specific conductivity values indicate an increase in dissolved ions in the water column, which may reflect an increase in the amount of pollutants in water bodies. However, this measure does not indicate which specific ions (e.g., nutrients) or pollutants (e.g., metals) are increasing.

Under (pre-storm) low flow conditions at various times during the year, Guay (2002) found specific conductivity values in an urban tributary to Frost Gully Brook (having a PTIA of about 40%) that ranged between 282-791 μS/cm with a mean of 563 μS/cm. Guay attributed the high (low-flow condition) values to intensive road salting practices in the watershed. In this study, LC-S-0.186 (having a PTIA of 47%), was found during the summer and fall to have values ranging between 978-1042 μS/cm with a mean of 1020 μS/cm. These values also may have been influenced by road salting activities. One potential reason for these high values may be that road salt is persisting in the watershed, even during summer baseflow periods. Snow melt and storm events may be washing this salt into nearby lawns and wetlands where it may be infiltrating into the groundwater and then slowly reemerging into the stream during the summer.

Golf Courses

The sampling design of the present study allocated only a moderate amount of effort towards examining potential chemical impacts from the golf course in the Long Creek watershed, primarily due to budget and time constraints. Although some sampling sites were located near golf course areas, they were not intended to directly monitor golf course effects because they also potentially included contributions from other land-uses upstream of the golf course. Also, samples were not analyzed for pesticides, chemicals which can have serious impacts on aquatic ecosystems. However, since golf course land-use represents a significant portion of the study watersheds, it is worth including this topic in the discussion. Typically, large amounts of fertilizer, pesticides, fungicides, and other chemicals need to be applied to golf courses in order to maintain vigorous and attractive greens. In some cases, these rates exceed those that are applied to agricultural cropland, and they have the potential to significantly contaminate surface and groundwater resources, although data are somewhat limited (Schueler 1994b). A three-year study of four golf courses located on top of sandy soils of glacial origin near Cape Cod, MA found 10 out of 17 applied pesticides in groundwater monitoring wells (Schueler 1994c). Although these pesticides were not detected at levels considered to be above health guidance concentrations (except chlordane, a chemical that had been banned 12 years prior to the study), the study postulated that there might be potential for long-term effects on aquatic biota. Additionally, nitrate nitrogen levels were found to be at levels comparable to intensive agricultural areas, averaging 1-6 mg/L and occasionally exceeding 10 mg/L, and they were thought to have the potential to cause eutrophication in coastal waters or in nitrogen-sensitive waters. It should be noted that other types of land-uses, such as business and residential lawns, also can contribute pesticides and fertilizers to streams (see review in Schueler 1994c).

Other Pollutants

Examples of pollutants which were not sampled in the present study, but if they had been found may have helped explain biological conditions in the study watersheds, include things such as pesticides, volatile organic carbon compounds, etc. Pesticides frequently are detected in urban streams and they often exceed concentration guidelines designed to protect aquatic biota. Sources may include lawns, both residential and commercial, gardens, and golf courses (as mentioned above; see review in Paul and Meyer 2001). Some recent studies suggest that hospital effluent may contribute pollutants such as antibiotics, genotoxic chemotherapeutic drugs, and narcotics (see review in Paul and Meyer 2001) -- another unknown in this study.

Escherichia coli and Other Bacteria

Bacteria and other microbes are found to occur naturally in streams and many species are important to stream ecosystem processes such as decomposition of organic matter (Allan 1995). However, urban streams tend to have relatively high bacteria densities, especially after storms (see review in Paul and Meyer 2001), which can result in shellfish bed closures (Schueler 1994a). Sources of bacteria may include wastewater treatment plants and combined sewer overflows (not believed to be an issue in the study watersheds), chronic sewer leaks, and illicit discharges (see review in Paul and Meyer 2001), as well as pet and wildlife fecal matter. Guay (2002) found fecal coliform bacteria levels to be quite high in a 40% PTIA urban stream in Freeport, Maine. There are no known sources of sanitary waste entering Clark's Pond so it is likely that fecal bacteria counts are, at least in part, attributable to wildlife (South Portland Engineering Department 1994). Additionally, the sampling in this study did not differentiate between human- and wildlife-associated *E. coli*, so the results remain primarily inconclusive, although some "flags" have been raised. There may be some septic systems or illicit discharges, as well as pet waste, issues in the Long Creek and Red Brook watersheds that warrant further investigation. Future efforts may be aided by recently developed techniques that use RNA (genetic coding) analyses to differentiate between human- and wildlife-associated bacteria.

Iron-oxidizing bacteria often are abundant in urban streams, especially where reduced metals emerge as part of anoxic groundwater or stormwater system outflows (see review in Paul and Meyer 2001). Orange mats believed to be this type of bacteria were found in various places throughout the study watersheds, most notably in the vicinity of LC-N-0.595, an area where it is believed the floodplain was buried under piles of fill. (Some trash, such as concrete blocks and iron rebar, was observed to be mixed in with the fill.) The author of this study is unaware of any problems associated with iron-oxidizing bacteria, as they are found to sometimes occur naturally in streams.

<u>Summary of Water Chemistry and Suspended Solids Discussion (Except Dissolved Oxygen Issues)</u>

All the Long Creek branches, which were sampled downstream of significant amounts of impervious surfaces and other urban/suburban land use activities, had relatively high concentrations of metals, nutrients, chloride, suspended solids, and PAHs compared to Red Brook, which was sampled below a region having a relatively low PTIA value. The highest concentration of a given parameter during the course of this study was not always found in the same branch, but rather in different branches during different storms. Regardless of these inconsistencies, LC-S, the site with the highest PTIA, was the site found to have the highest one-time (across all storms) concentration of each pollutant except cadmium, orthophosphorous, and PAHs. In some instances, concentrations of pollutants were found to exceed certain water quality criteria (e.g., lead, zinc, copper, chloride) at some of the Long Creek sampling sites (LC-S, LC-M, LC-N) (criteria for PAH levels have not been obtained yet). This occurred under storm conditions for the metals, and these concentrations may not have lasted long enough to cause serious damage to the biological communities. On the other hand, low-flow chloride concentrations in LC-S, may be a chronic problem for biota. Note, however, that it is important to keep in mind that this study only gathered samples from the water column. This study did not assess the potential impact to biota of chronic exposure to pollutant loads in the sediments. Such information may be worth considering in the future given that the South Portland Engineering Department (1994) found metals to exist in concentrations that were 5,000 - 50,000 times greater than what they found in surface water grab samples during either low-flow or storm event conditions. It is important to note that although pulses of high concentrations of pollutants (i.e., acute exposure) can be very detrimental to biological communities, stream biota commonly are more often impacted by long-term chronic exposure to pollutants than by short-term, acute exposures (see review in Morse 2001).

The Long Creek and, to some extent, lower Red Brook, watershed is downstream of substantial amounts of impervious surfaces. These surfaces are driven-, idled-, refueled-, salted-, and parked-upon continuously throughout the year. Pollution from leaky cars; fragments from brake pads, tires, and other automobile parts; atmospheric deposition; and trash appears to potentially have plenty of opportunities to be deposited on these impervious surfaces. Once deposited, these materials can be readily swept up and carried down through the stormwater collection system to the study streams, Clark's Pond, the Fore River, and eventually Casco Bay. (*Note*: More discussion about suspended solids is presented later.)

Probably the most important finding was that Red Brook had relatively low concentrations of all the metals, nutrients, chloride, PAHs, and suspended solids measured in this study, both during storm-flow and low-flow conditions. This appeared to be related to the relatively low proportion, compared with Long Creek, of its watershed being covered by impervious surfaces (parking lots, roads, driveways and their associated automobiles; rooftops; etc.), lawns, golf greens, and the pollutants commonly are associated with those land-uses. This fact may be part of the overall explanation of why biological communities (e.g., macroinvertebrates and especially brook trout) were in better conditions in Red Brook than the three Long Creek branches. This fact also suggests that there may still be time to protect the sensitive aquatic life that still exists in Red Brook.

<u>Dissolved Oxygen</u>

Low dissolved oxygen concentrations commonly are a problem in urban streams. Causes of decreased dissolved oxygen levels can be attributed to factors such as increased biological oxygen demand (BOD) (or chemical oxygen demand) from organic pollution in wastewater discharges and organically-enriched sediments, which can even sometimes result in fish kills (see reviews in Morse 2001, Paul and Meyer 2001). Some of the more likely causes of low dissolved oxygen in the study watersheds include the following: first, unnaturally high levels of algae/macrophyte growth and decay (due to nutrient-enriched waters) can cause stream ecosystem respiration processes to exceed inputs of dissolved oxygen from photosynthesis and re-aeration which then results in a net lowering of stream dissolved oxygen concentrations (see Allan 1995, Morse 2001). Second, other major controls on dissolved oxygen levels include temperature and turbulence (colder water can hold more dissolved oxygen; more turbulent waters can dissolve more oxygen through physical action) (Allan 1995). Commonly, 5 mg/L is identified as the threshold level for healthy biological communities, while 2 mg/L is required for maintaining any aerobic life in streams (see review in Morse 2001). Morse (2001) observed that as PTIA increased, average low-flow, pre-dawn dissolved oxygen concentrations significantly decreased. Still, even though Morse's study streams ranged between 1-31% PTIA, he rarely saw dissolved oxygen levels drop below 5 mg/L.

As mentioned earlier, despite the fact that LC-S had the highest PTIA value and often the highest pollutant (e.g., nutrient) concentrations, it had a sizable stretch of riprap-armored stream bottom (~ 20 m) and tree cover/shading (~ 300 m) upstream of its biological and water quality sampling stations. The riprap-lined channel was wide and shallow, and the rough rocks made the water more turbulent, which thus likely increased re-aeration of the stream water, and the shading likely kept waters cooler than they would have been under an open canopy. Also, cold water has a greater capacity to retain dissolved oxygen than does warm water (Allan 1995). These factors may have combined to keep dissolved oxygen levels higher in that stretch and, thus, also produce macroinvertebrate communities that apparently were less stressed than many of the LC-M (especially upstream) sites that had some or all of these conditions: stretches where riparian vegetation was sparse, detention basins built in/around the channel which were filled with abundant emergent and/or submergent macrophytes, or, in general, an overall lack of in-stream habitat structures that would have served to generate more turbulence in the stream, thus increasing re-aeration rates.

4.4 Water Temperature

Note: See also the in-stream and riparian habitat section (4.6) below.

Urbanization can result in the alteration of the thermal regime of streams due to a variety of reasons including: reduced canopy cover due to riparian forests being thinned or cleared for development and landscaping purposes, increased local air temperatures due to the “heat island effect” (from densely developed urban areas), increased presence of man-made ponds, and reduced recharge of groundwaters due to reduced precipitation infiltration in urban watersheds (see reviews in Schueler 1994a, Morse 2001, Paul and Meyer 2001). A study of five streams in Long Island found that mean summer temperatures were 5-8^{o}C warmer and mean winter temperatures were 1.5-3^{o}C cooler in urbanized streams than forested reference streams. Further, summertime storms resulted in increased temperature pulses 10-15^{o}C warmer than forested streams, which were attributed to runoff from heated impervious surfaces. These temperature alterations were attributed to man-made ponds, clearcutting in the riparian zone, increases in the volume of urban runoff and a reduction in groundwater (Pluhowski 1970). In the Maryland Piedmont, Galli (1991) found in a study of five headwater streams, which differed in the amount of impervious cover that they had in their watershed, that the urban streams had mean temperatures that consistently were warmer than a forested reference stream. Golf courses also may be contributors to stream water warming if numerous warm “water-hazards” are in contact with nearby streams (either during baseflow or stormflow), or if substantial amounts of riparian clearing has occurred for aesthetic or game-play reasons (Schueler 1994b, pers. obs.).

Changes in stream temperatures can affect things such as leaf processing rates, and organism life histories (see review in Paul and Meyer 2001), as well as damage or kill aquatic organisms (Galli 1991, McCullough 1999). Temperatures less than 17 ^{o}C generally have been considered to be above the optimum for many stoneflies, mayflies, and caddisflies; stoneflies, as a group, generally are the least temperature tolerant. Further, temperatures exceeding 21 ^{o}C have been found to severely stress most coldwater organisms (Galli 1991). McCullough (1999) conducted a substantial review of the literature pertaining to the influence of temperature on salmonids (the family fish to which brook trout belong). In studies where laboratory experiments were performed, various temperatures were observed to be harmful to brook trout at different life stages (Table 4.3). For eggs and alevin, temperatures ranging between 1.5-9.0 ^{o}C were considered to be optimum, while temperatures warmer than 15-18 ^{o}C were considered to be very detrimental. Limited information was available on juveniles, although in one experiment, when young brook trout were acclimatized to 24 ^{o}C and then were subjected to a temperature of 25.5 ^{o}C, only half of them had survived past seven days. A temperature of 9 ^{o}C was found to be optimum for spawning, while temperatures warmer than 16-19 ^{o}C were considered detrimental. (*Note*: Since brook trout spawning occurs in the late fall in Maine, this may not be an issue.) Studies examining field observation data were more clear with respect to temperature thresholds. Of the studies reviewed, the range of upper limit temperatures for brook trout was between 19-25.6 ^{o}C, with most upper limits falling between 20-22 ^{o}C. The most interesting study cited by McCullough (1999) was that of Eaton et al. (1995) where they analyzed a large national database of brook trout presence/absence data and weekly mean temperatures and found the 95th percentile thermal tolerance temperature value to be 22.3 ^{o}C (Table 4.3). Also of interest were laboratory studies on the competitive abilities of brook trout, brown trout, and creek chub, with a size range of 107-165 mm fork length, in constant temperature environments ranging from 3-26 ^{o}C. A transition in the competitive ability of trout was detected at 22-24 ^{o}C which reflected the replacement of trout by creek chubs (Taniguichi et al. 1998 as cited in McCullough 1999). In the present study, creek chubs were found at many sites, including the most downstream Red Brook site, but they were not found at the upper three Red Brook sites. Brook trout, on the other hand, were only found at the three upper Red Brook sites. As far as disease is concerned, temperatures in the range of 12.8-15 ^{o}C appear to be the least problematic for salmonids in resisting diseases overall (see review in McCullough 1999).

A number of Long Creek sites were found to have fairly high water temperatures during summer months, while Red Brook sites generally had the lowest temperature (except the LC-Mn site ~ 40 m downstream from where it emerged from a groundwater seep), which may explain, in part, why brook trout were absent from Long Creek. If one uses a mean weekly temperature of 22^{o}C as the upper thermal tolerance level for brook trout in this study, in 1999, a few sites exceeded 22^{o}C for a couple of weeks (the majority of Long Creek sites repeatedly had weekly maximum temperatures that exceeded 22^{o}C. In 2000, mean weekly temperatures approached or equaled, but did not exceed 22 ^{o}C at any sites (about half the Long Creek sites had maximum weekly temperatures that exceeded 22^{o}C). Even if brook trout are not being killed by the higher water temperatures in Long Creek, it is likely that they prefer the temperatures in Red Brook and, because Long Creek and Red Brook are connected via Clark's Pond, they probably either migrate to or stay in Red Brook. These high temperatures may be an important factor reducing the health of both fish and macroinvertebrate populations, especially in the upper reaches of Long Creek. Any future preservation/restoration efforts ought to seriously consider preserving existing areas where riparian forests are fairly intact and then enhancing/restoring areas where these streamside vegetation are degraded.

4.5 Hydrology

Hydrologic regime is a master variable in streams, influencing channel form, biological assemblages, and ecosystem processes (Minshall 1988). Changes in the hydrologic regime of urbanizing watersheds can be the source of the most significant ecological changes for urban streams (see reviews in Morse 2001, Paul and Meyer 2001). Changes in hydrologic regimes of urbanizing watersheds include altered patterns of runoff, increased runoff volume, decreased lag time between the peaks of storms and peaks in local stream discharge, increased peak flows (with a shift towards a more sharply-angled rising and falling limb than found in streams in non-urban watersheds), and an increased number of storms reaching or exceeding bankfull stage (the stage at which the most channel erosion and channel shaping occurs). These changes usually are attributed to increases in PTIA (which reduce the infiltration capability of the landscape) and drainage density (because stormwater conveyance systems such as ditches and storm sewers typically are constructed in urban areas and they are more efficient at delivering runoff to receiving waters) in urban watersheds (see reviews in Morse 2001, Paul and Meyer 2001). To illustrate these potential changes in hydrologic regime, Schueler (1994a) calculated the amounts of runoff that would be generated during a 1 inch storm on a 1 hectare area of land of two different types of land-uses. A typical parking lot, having a runoff coefficient (R_v) of 0.95 and an unpaved meadow, having a R_v of 0.06 would produce approximately 230,000 and 25,000 liters of runoff respectively, nearly a 10-fold difference (Schueler 1994a).

There has been some mention in the literature that urbanization of watersheds, and the associated increases in impermeable land surfaces, can lead to an overall decrease in urban stream baseflows due to reduced infiltration of precipitation into the groundwater, although research on this topic has been limited and findings have been mixed (see reviews in Schueler 1994a, Morse 2001, Paul and Meyer 2001). One example was a study of a number of streams near Vancouver, Canada, having a range of PTIA of 4-77%. There, summer baseflow was uniformly low when PTIA was > 40% (Finkenbine et al. 2000). One confounding variable believed to be responsible for inconsistent observations in the literature is the type of impervious surface being examined. Different types of impervious surfaces can act differently during storm events. For instance, while impervious surfaces in commercial areas (rooftops, roads, parking lots, etc.) and transportation corridors tend to divert stormwater directly to local waterways, impervious surfaces in residential areas such as rooftops often divert water onto relatively more pervious surfaces like lawns (Schueler 1994a).

In the South Portland Engineering study (1994) mentioned earlier, it was found that while low-flow discharges appeared to be approximately equal to each other, during a 0.67" storm in July 1992 approximately 75% of the total flow entering Clark's Pond was from the Long Creek drainage, with the remaining 25% coming from Red Brook and other sources. Long Creek flows started to rise before Red Brook flows did. This difference was attributed to the greater amount of commercial development and associated impervious areas in the Long Creek drainage (South Portland Engineering Department 1994). In the present study, an increasing "flashiness" (rate of rise to/drop off from peak discharge) of the hydrology of the streams generally increased as PTIA increased from RB (lowest PTIA) to LC-S (highest PTIA). The relatively "flashy" hydrologies observed in Long Creek appeared to be having a strong influence on the delivery of pollutants, the stability of its channels, and the stability of its fish and macroinvertebrate habitats (and, hence, the integrity of those communities) as mentioned in other sections of this discussion. Dealing with hydrology problems likely will be a high priority in any restoration strategy which likely will include items such as improved stormwater quantity controls and an evaluation of the sizing of culverts in the watersheds.

4.6 In-Stream and Riparian Habitat

The fact that Long Creek and Red Brook are low-gradient, primarily-sandy, coastal streams forces one to view them in a slightly different context than many other streams in Maine, which tend to have steeper slopes and coarser substrate materials. When this study was designed, insight on these low-gradient, nontidal, coastal streams was gleaned from work that had been done within the Middle Atlantic Coastal Plain Ecoregion, which stretches from southern Georgia up to Cape Cod, Massachusetts, to help tailor sampling methods to what were viewed as more appropriate techniques (USEPA 1997, 1999). The description of streams from that work appeared to match habitat conditions found in Long Creek and Red Brook, even though they are slightly out of the range mentioned in that work. For instance, "streams of the coastal plain typically have velocities less than 0.5 fps, sandy or muddy substrates, and few riffle areas ... coastal plain streams have received relatively little attention from scientists, the public, and government agencies for a variety of reasons including their typically small size, which reduces the number of opportunities for swimming and fishing. Plus, they often have soft, muddy bottoms and are surrounded by wetlands, making them difficult to traverse on foot" (USEPA 1997). These concepts need to be kept in mind as one reviews the habitat and geomorphology data because much of current stream science is built upon streams that flow over coarse substrates.

Erosion and Sedimentation

In-stream and bank erosion and sedimentation are natural processes in streams and rivers (Rosgen 1994, Allan 1995). However, human activities can greatly alter the rates and volumes of these processes. Examples of ways that human activities can introduce excessive amounts of sediment into streams include construction activities, unpaved roads, "street dust" (common minerals and organic material derived from soils in the watershed and deposited on roads), channelization, and road crossings with areas of exposed soil (Woodcock 2002).

In their review, Wood and Armitage (1997) summarized the common ways in which fine sediment impacts biota in streams and rivers. Fine sediment suspension and deposition affects periphyton and aquatic macrophytes by: (1) reducing the penetration of light and, as a result, reducing photosynthesis and primary productivity within the stream; (2) reducing the organic content of periphyton cells; (3) damaging macrophyte leaves and stems due to abrasion; (4) preventing attachment to the substrate of algal cells. In heavily impacted streams, periphyton and aquatic macrophytes may be smothered and/or eliminated by sediment.

Fine sediment suspension and deposition affects benthic invertebrates by: (1) altering substrate composition and changing the suitability of the substrate for some taxa; (2) increasing drift due to sediment deposition or substrate instability; (3) affecting respiration due to the deposition of silt on respiratory structures or low oxygen concentrations associated with silt deposits; and (4) affecting feeding activities by impeding filter feeding due to an increased in suspended sediment concentrations, reducing the food value of periphyton, and reducing the density of prey items (Wood and Armitage 1997). Pools are particularly affected by sedimentation, and invertebrate communities within these habitats often are degraded. Sedimentation results in an increased proportion of the stream bottom consisting of unstable sediments (which favors taxa such as Chironomidae (Diptera) and oligochaete worms. Also, increased sedimentation reduces the availability of refugial space, and invertebrates are more prone to drift (i.e., enter the water column in order to be carried to downstream locations) during flood conditions (see review in Paul and Meyer 2001).

Fine sediment suspension and deposition affects fish communities by: (1) adversely acting on the fish swimming in the water by either reducing their rate of growth, reducing their tolerance to disease or killing them, (lethal concentrations primarily kill by clogging gill rakers and gill filaments); (2) reducing the spawning habitat (by reducing gravel permeability and intergravel flow of oxygenated water) and hindering the development of fish eggs, larvae, and juveniles; (3) modifying the natural migration patterns of fish; (4) reducing the abundance of food available to fish because primary production and invertebrate production has been reduced (see above); and (5) affecting the efficiency of hunting, particularly in the case of visual feeders (Wood and Armitage 1997).

In contrast to the situations mentioned above where urban streams often are being degraded by excessive amounts of fine sediment pollution, urban streambeds (15-77% PTIA) near Vancouver, Canada, were found to have less fine material than rural streambeds (4-7% PTIA) (Finkenbine et al. 2000). Because a range of stream slopes were included in that study, and because streams having higher stream slopes are expected to have greater competence to transport coarse-sized materials, only streams having slopes $\leq$ 2% slopes were compared. Thus the authors attributed increased bed coarsening to increased peak velocities in the urban streams. The authors also noted that the stream watersheds had been developed approximately 20 years prior to the study and thus were out of the early phases of urban stream evolution (first, a post-construction, high watershed erosion/sediment-input phase and then an altered hydrology/increased in-stream channel erosion and enlargement phase) and into a later phase where the streams had adjusted to their new/altered/urban hydrologies and also where high sediment loads were not as much of a problem so the streams had begun a process of streambed coarsening (Finkenbine et al. 2000). The heavily urbanized reaches of Long Creek and Red Brook appear as though they may be in the second phase, although rates of (unnatural) sedimentation were difficult to assess in the field because of the general fine sediment nature of the study streams.

Sediment toxicity also can be responsible for the degradation of invertebrate communities in urban streams, resulting either from direct exposure to contaminated bed materials or ingestion of toxin-contaminated organic material found on top of or within sediments. As mentioned earlier, sedimentation can degrade and alter the benthic invertebrate community, which in turn, affect the abundance of benthic-feeding fish. Sediment toxicity also is presumed to be responsible for degradation of fish communities (see reviews in Morse 2001, Paul and Meyer 2001).

In an urbanized branch (~ 40% PTIA) of Frost Gully Brook ("FGB"; Freeport, Maine), generally, "first flush" total suspended solid (TSS) values found in various storms there (Guay 2002) appeared to have been fairly similar to maximum values found in the most urbanized branch of Long Creek (LC-S-0.186; PTIA = 47%) (Table 4.2) in the present study. One intense storm (0.25" in 2.5 hours) in the urban branch of FGB, however, did have a TSS value that was ~ 4.5 times greater than any value found in LC-S. High turbidity values for FGB-urban branch, 2432 NTU (the highest measured during the study), reaffirmed that there was a large load of suspended solids in the stream at that time. It is uncertain why that particular event and location had such a high TSS value, although it did occur in May, a time when there still was a fair amount of residual road sand in the watershed. Overall, better water quality in the relatively forested reference branch of FGB compared to the urbanized branch of FGB was attributed to lower amounts of impervious surfaces, wide stream buffers, and better stormwater detention practices (Guay 2002).

A study of the Clark's Pond/Long Creek/Red Brook watersheds in 1983 found there to be high suspended solids/turbidity levels in the waterbodies all of the time, but especially during and following storm events. This situation was attributed to unnaturally high erosion and sedimentation rates due to unstabilized fill sites, uncontrolled/poorly controlled construction projects in the Long Creek watershed area downstream of I-95, and from highway runoff (ECJCCE 1982, Seeley and Valle 1983). Also, limited sampling of total and dissolved phosphorous revealed high concentrations and suggested that parking lot runoff was a major contributor [note: actual figures were not presented in the report] (Seeley and Valle 1983). Another study found TSS concentrations in dry weather background samples consistently below the minimum detectable limit (4 mg/L) at sites near Clark's Pond's dam and the mouths of the two tributaries Long Creek and Red Brook (South Portland Engineering 1994). The authors believed that colloidal solids or fine clay particles were responsible for the pond's continuous brown color. During an 1.79" storm over a 15 hour period in August 1994, maximum TSS concentrations were found to be approximately 100 and 125 mg/L in Long Creek and Red Brook respectively, although the 125 mg/L appeared to be an outlier for Red Brook with 60 mg/L appearing to be closer to the "true" value. Generally higher values in Long Creek were attributed to construction of commercial areas in the Long Creek watershed (South Portland Engineering Department 1994).

Both Morse (2001) and Seeley and Valle (1983) made notes about relatively high TSS concentrations and turbidity levels, even during low flow conditions. Additionally, this study generally found fairly high TSS concentrations, especially during storm events. Field observations found, under low-flow conditions, Long Creek to generally appear to be more turbid than Red Brook. This may, as both Morse (2001) and Seeley and Valle (1983) mentioned, be attributable to the relatively common occurrence of construction activities in the watershed. However, this low-flow turbidity phenomenon also may be due to the high clay content of the surficial geology in the watershed and the relatively long period of time it takes for very fine particles to settle out after storm events.

Morse (2001) observed that, in general, as PTIA increased, low-flow TSS concentrations significantly increased. As an interesting aside, it is worth noting that Long Creek, which had an intermediate PTIA value (16%) relative to his other study streams, had a value (~10.7 mg/L) that was > 2 times higher than any of the other sites, so Morse removed it as an outlier for his statistical analyses (all water quality samples had been collected at least 48 hours after any precipitation). In streams, total suspended solid concentrations are considered low when they are < 10 mg/L and high when they are > 100 mg/L (see review in Morse 2001). In the present study, during baseflow conditions, all of Long Creek and Red Brook's TSS sample concentrations were < 10 mg/L. Further, TSS concentrations were not even detected in any of the Red Brook samples. Conversely, under storm conditions in March 2000, maximum TSS concentrations exceeded 100 mg/L in Red Brook and 270 mg/L in all the Long Creek branches. However, maximum TSS concentrations during the two fall storms generally were lower and only exceeded 100 mg/L in the LC-M and LC-N branches. Therefore, suspended sediment loads generally appeared fairly high in Long Creek, especially during the spring, which may be a result of runoff from road sanding, construction activities, land degradation of riparian ecosystems. However, it was not understood what proportion of TSS was coming from outside of the stream (i.e., the importance of land-use activities versus in-stream sediment capture and suspension). This analysis may be necessary in modeling efforts, although it may prove to be difficult.

Riparian Vegetation: Shading and Large Woody Debris

Urban streams commonly have greater rates of riparian vegetation clearing, especially of trees, than non-urban streams (see review in Morse 2001). Riparian deforestation associated with urbanization reduces food availability (e.g., leaves and twigs), affects water temperatures, and results in the loss of a system which removes a substantial amount of sediments, nutrients, and toxins from stormwater runoff (see review in Paul and Meyer 2001). (*Note*: Section 4.4 of this document reviews many of the temperature issues associated with urbanization.) A study of streams entering the Puget Sound, Washington, found that invertebrate bioassessment metrics decreased/degraded sharply with increases in the amount of impervious surface cover. Interestingly, streams having greater amounts of riparian forest cover in their watersheds always had higher benthic indices of biotic integrity scores at a given level of impervious surface cover, which suggested that riparian forests may help buffer streams from urban impacts. The authors did note, however, that above 45% PTIA all stream invertebrate communities were degraded regardless of whether riparian zones were intact or not. The authors also noted that when stormwater systems were designed to bypass riparian buffers, many of the benefits associated with them were lost (Horner et al. 1997). Riparian forests also may ameliorate urban impacts to fish communities up to a certain point (see review in Paul and Meyer 2001).

During the initial stream walk and subsequent visits to areas through the watershed, a number of locations were observed to have areas of sparse, thinned, or potentially cleared trees, shrubs, and other vegetation as Long Creek flowed through business parks and other commercial zones, lots apparently cleared for development, a golf course, a powerline clearing, and two in-stream stormwater detention basins (see Figs. 3.1.4a-e). In most cases it was assumed likely that these stream reaches had been shaded by stands of streamside trees and shrubs prior to human settlement. This assumption was based upon the common presence of adjacent/nearby woodlands, including the Red Brook region, as well as reports about intensive historical logging in the watershed (Seeley and Valle 1983). However, it must be noted that some difficulty was encountered in the field in a few areas where the observer could not tell whether a treeless/shrubless area should naturally be only vegetated by emergent aquatic macrophytes (e.g., cattails) or if these areas previously had been used for agriculture or timber harvesting (especially upstream of LC-M-2.200~). Therefore, it is recommended that if a riparian forest restoration project is desired in the watershed, there should be a follow-up survey of those identified problem areas to ascertain the potential success of reestablishing streamside forests or shrub stands.

In many streams, large woody debris plays a vital role in ecosystem functions and processes including providing and trapping organic materials for consumption by microbes and macroinvertebrates, providing stable attachment sites for microbes and macroinvertebrates, trapping sediments, and aiding in the formation of critical habitats such as pools for fish (see reviews in Harmon et al. 1986, Allan 1995, Finkenbine et al. 2000). Cover is vital to the survival of trout because it provides shelter from predators and strong currents. Although cover may be present in the form of boulders in the streambed and overhanging banks, it also may present in the form of riparian vegetation (canopy), rootwads, and fallen large woody debris (Cushing and Allan 2001).

In low gradient streams and rivers, woody debris dams and snags often provide the only stable substrate within the channel (Smock et al. 1989). Smock et al. (1989) conducted a study of two low-gradient streams in the coastal plain of Virginia: Buzzards Branch and Colliers Creek. Colliers Creek was rather different in character from Long Creek and Red Brook so it will not be discussed here. Buzzards Branch, however, appeared to be fairly similar to Long Creek and, especially, Red Brook, although it was located at a much lower latitude, and thus it existed in a generally warmer climate. Buzzards Branch had a shifting sand substrate with areas of silt and sand occurring near the banks, an average gradient of 0.08%, an annual mean discharge of 0.080 m^3/s (range = 0.006 - 0.264 m^3/s), an annual mean water temperature of 16^oC (range = 4^o - 27^o), an annual pH of 5.7, an average bankfull width of 2.5 m, an average water depth of 0.25 m, a full canopy and shading, a meandering channel, it had been logged 52 years prior to the study, and it was a blackwater stream. Table 3.9 shows a comparison between the findings of Smock et al. (1989) in Buzzards Branch and the rapid survey in the present study (conducted in November 2002) which used a combination/adaptation of methods used by both Smock et al. (1989) and the USEPA EMAP protocols (Kaufmann and Robison 1998) so that the data would be comparable with other studies.

In Buzzards Branch, 73% of the total stored organic matter was > 1.6 cm in diameter. Debris dams appeared crucial to retaining/storing organic matter important to ecosystem functioning such as leaves (Smock et al. 1989), which are known to be a food source for many microbes and macroinvertebrates, organisms which often are a significant component of fish diets (Allan 1995). In Buzzards Branch, when dam frequencies were experimentally manipulated, a 5-fold increase in dam abundance (approximating an expected frequency under a 200-year post-timber-harvest scenario's abundance of dams) relative to current dam abundances resulted in a 6-11 fold increase in organic matter storage in experimental stream reaches. Macroinvertebrate densities were found to be 5-10 times higher in debris dam habitats than sandy sediment habitats, apparently due to their relatively long-term structural stability. Also, macroinvertebrate density and biomass were significantly correlated with leaf storage in dams (Smock et al. 1989). Other studies have found wood to be a preferred substrate over sand for benthic macroinvertebrates (see reviews in Smock et al. 1989, Allan 1995).

Degraded food quality (e.g., organic matter) has been implicated as degrading urban stream biological communities in some studies (see review in Morse 2001). Urbanization has been documented to reduce the quantity, quality, and retention of transported organic matter in streams, a fact that could limit secondary (e.g., invertebrate) production. Also, studies in Georgia and New Zealand found the decay of organic matter to be more rapid in suburban and urban streams relative to forested reference streams, which may have been a result of greater physical abrasion and fragmentation of leaves associated with higher stormflows in the non-reference streams (see review in Paul and Meyer 2001).

Because urbanization is occurring in other parts of Maine, many of which have a different topography than coastal Maine, it is worth mentioning that debris dams probably are even more important, in terms of organic matter retention, in high- to mid-gradient streams (Bilby and Likens 1980, Allan 1995). For example, in a high-gradient New Hampshire stream, 75% of the stream's organic matter was found in debris dams. Experimental removal of debris dams in a 175-m stretch of that stream resulted in a 2.5-times increase in total organic matter export (Bilby and Likens 1980).

Harvesting of mature streamside trees, a practice frequently associated with watershed urbanization, often results in a reduction of large woody debris inputs and debris dam formation which can lead to an increased simplification of stream channels (Allan 1995, Dolloff 1998). Historical records indicate that wood was much more abundant in stream channels in pre-settlement times than today (Cushing and Allan 1995). In a study of a number of streams near Vancouver, Canada, ranging in PTIA from 4-77%, large woody debris patterns were indiscernible while in all streams with a PTIA >

20% large woody debris was scarce. The latter observation was believed to be a result, in large part, of increased harvesting of riparian trees associated with increased urbanization. The authors also noted that a large number of stream crossings in urban areas also can result in plugged culverts due to debris pile-ups, where wood often is removed in order to facilitate watershed drainage and reduce flooding problems behind the culvert. The authors also noted that a healthy riparian zone and abundant large woody debris appeared to stabilize streambanks (Finkenbine et al. 2000). A survey of numerous streams in the Puget Sound lowland area of Washington state found that while large woody debris densities frequently were greater than 300 pieces/km in streams having PTIA $\leq$ 9, those densities never were greater than 300 pieces/km for streams having PTIA > 9%. The two exceptions to that were one streams which had been subjected to wood additions for fisheries management purposes and another where an undersized culvert had prevented the downstream movement of wood debris (Horner et al. 1997). Finally, higher shear stresses that occur during periods of channel adjustment to altered (urban) hydrologies (e.g., higher peak flows associated with greater PTIA) have been known to be capable of washing out large amounts of large woody debris (Booth et al. 1997).

As mentioned above, a number of studies have documented the importance of large woody debris to streams, including low-gradient, sandy streams. However, also as mentioned earlier, during site visits in this study there appeared to, first, be a number of reaches where riparian corridors obviously had either been degraded or partially/wholly cleared, and second, where riparian corridors were populated by trees and shrubs, it was noted that timber harvesting appeared to have removed many of the potential sources of LWD (i.e., large, mature trees). Regarding the riparian areas where historical land-use management was less obvious, there were some sites where old tree stumps near the stream channel were apparent, but in other sections, although there were no obvious stumps, there were other, more subtle visual cues that suggested historical harvesting of large, streamside trees. This should be treated as anecdotal evidence and not concrete facts, although Seeley and Valle (1983) indicated that substantial timber harvesting had been occurring at least around the early 1980s. Initial observations made in the field during repeated visits to sites noted a general lower abundance of LWD in Long Creek relative to Red Brook. Later, woody debris surveys of representative sites conducted during November/December 2002 in the study watersheds provided additional evidence (Fig. 3.6.2, Table 3.9) suggesting that, relative to the upper reaches of Red Brook, many reaches of Long Creek had lower, and perhaps insufficient, amounts of large woody debris to provide enough habitat diversity in the form of stable attachment sites for both periphyton and macroinvertebrates as well as cover for fish in order to maintain healthy and diverse biological communities.

With respect to habitat conditions, average stream velocities measured in glides of a number of streams varying in the amount of PTIA were found to generally decrease with increasing PTIA (Finkenbine et al. 2000). This study found that Long Creek, which at many sites had higher PTIA values than Red Brook, had a number of sites where stream where velocities were below the detection limit. This may be a result of lowered baseflow discharges caused by reduced infiltration of precipitation in a watershed that had a lot of impervious surfaces, although more investigation would be required to prove/disprove this "altered hydrology" hypothesis. A "habitat" hypothesis regarding the diversity of velocities also was generated during field work conducted at various sites in the study watersheds. During measurements of the diversity of flow velocities, it was observed that woody debris sometimes appeared to help with the re-aeration of stream waters, especially at sites in Red Brook, where woody debris was fairly abundant. For example, pieces of wood such as limbs or branches that were emerging from underneath the water surface sometimes created turbulence at the water surface, which appeared to be helping re-aerate local stream waters. Since there were very few observed riffles in the study streams, this type of re-aeration may play an important role in the dissolved oxygen balance of Red Brook and Long Creek.

Habitat Assessment Challenges

Morse (2001) observed in his 20 Maine study streams that as PTIA increased, habitat quality, average riparian width, channel stability, and median substrate particle size significantly decreased, while average bank erosion significantly increased. Morse (2001), after reviewing the literature, concluded that the highest quality of stream habitat in the northeast was reflected by streams having > 50% cobble substrate and a large number of riffles. Because the present study regards Long Creek and Red Brook as coastal, low-gradient streams that have stream bottoms naturally dominated by sands and silts, there likely will be some differences in the interpretation of the habitat quality of these streams. This study focused on the entire lengths of Long Creek and Red Brook rather than the single Long Creek reach which Morse (2001) included in his assessment (he was constrained by time and the number of streams he had to sample). The reach which Morse sampled in his study was, what is believed in the present study, to have been uncharacteristic of most of the length of Long Creek because it appeared to have been a riffle created by humans during road/culvert construction (e.g., channel armoring with riprap; see the photo of LC-M-0.533, "below Foden Rd." [Appendix L-11]). Also, Morse had used riffles as a common sampling habitat throughout his study to help him rule out that factors as explaining differences in communities among streams.

As indicated by a brief review of numerous stream alteration permits located at the Maine Department of Inland Fisheries office in Gray, ME, Long Creek, and Red Brook to an extent, apparently have had numerous sections of their stream lengths (and associated floodplains) relocated, channelized, filled, or armored with riprap. This occurrence has also been observed in the field (per. obs.) and in some of the literature (e.g., ECJCCE 1982). These channel and floodplain alterations made habitat assessments fairly challenging because they created complex habitat situations. For example, in some locations riprap was observed in the stream channel. This often benefited the stream by creating a more turbulent flow situation, which likely increased dissolved oxygen concentrations through aeration. However, this riprap often also appeared to created a more simplified habitat condition and also act as a fish migration barrier during low flow conditions. This riprap also likely was placed in the channel to stabilize the stream below large stormwater detention ponds. Therefore, these situations generally implied that during storm events these stream sections were poor habitat because they were subjected to intense stormflows and they rarely provided good cover for fish.

Brook trout are generally thought to require gravels between about the size of a pea or a walnut for spawning (reproduction) (Karas 1997; Paul Christman, Maine Atlantic Salmon Federation, pers. comm.; Francis Brautigan, Maine Dept. Inland Fisheries & Wildlife, pers. comm.). Pea gravels (important for brook trout spawning) or larger, coarse substrate were observed infrequently in this study. This may be explained by a number of reasons including: much of the valley material in the study watersheds consists of fine materials such as sands and clays (see section 3.1), the streams are fairly flat and appear to have relatively low stream power, and erosion and sedimentation apparently was high at least during the 1970s and 1980s (Seeley and Valle 1983). However, the amount of channel alteration mentioned above may partially explain the relatively small amounts of this type of habitat.

The rapid habitat assessments performed in this study had some limitations associated with them. Even though many of the sites had riparian buffers with widths greater than 10-m within their study reach, habitat scoring did not take into account habitat conditions upstream of a particular study reach. Thus, sites which had fairly intact riparian vegetation conditions locally may actually have been downstream of areas lacking riparian vegetation, large amounts of impervious surfaces, or stormwater systems outlets. Hence, site habitat scoring in this study should be viewed with some caution. Also, this study likely did not sample the full range of habitat conditions found in the watershed because the sites were purposely chosen for having the best possible conditions for a general region. This was done so that when analyses and comparisons were made, one could rule out local habitat conditions (e.g., shading, substrate characteristics, morphological features, etc.) as possible factors controlling the character of that site's biological community.

4.7 Fluvial Geomorphology

It generally is believed in fluvial geomorphology and urban stream science that streams adjust their channel dimensions in response to long-term changes in sediment supply and bankfull discharge. Urbanization often can have profound effects on stream channel morphology (see reviews in Schueler 1994a, Morse 2001, Brown and Caraco 2001, Paul and Meyer 2001). A common chronology in urban watersheds is to begin with a "construction phase", where numerous parcels in the watershed are developed. This phase results in an aggradation response-phase within the stream channels as sediment is washed off the watershed during large, episodic floods. This phase is followed by the "erosional phase", where stream channel cross-sectional area is increased (i.e., widening and/or deepening) to accommodate larger, more frequent bankfull ("channel-forming/altering") discharges resulting from the increased amounts of impervious surfaces in the watershed. This phase typically results in increased frequency of bank failures and catastrophic erosion (Paul and Meyer 2001). Other consequences of changes in urban stream hydrology and geomorphology may include changes in pool-riffle spacing, substrate (stream bottom) characteristics, velocity profiles, hyporheic/parafluvial region dynamics, and the ecological processes associated with those parts of stream channels (see reviews in Schueler 1994a, Morse 2001, Paul and Meyer 2001). Some studies have seen evidence of channel enlargement occurring in watersheds having PTIA's as low as 10, 6, 4, and even 2 % (Paul and Meyer 2001).

Streamside/riparian vegetation helps maintain channel stability because its root networks help stabilize streambanks (Rosgen 1996, U. S. Forest Service 1997). Large woody debris can function as a retentive structure and also lower the effective stream gradient. It also reduces stream power, both by lowering stream gradient and increasing channel roughness, thus lowering the stream's erosion potential (see review in Morse 2001). Easy access of floodwaters (generally the 1.5-year storm or larger) to floodplains is important because energy is dissipated by the roughness of riparian vegetation rather than being trapped inside incised walls and causing excessive downcutting, and also because floodplains temporarily store flood waters, thereby reducing flood-induced damage downstream (U. S. Forest Service 1997).

It is probably safe to suggest that the relocation, floodplain/wetland-filling, and riparian zone alteration activities of certain portions of Long Creek and Red Brook (described in ECJCCE 1982, Seeley and Valle 1983, and pers. obs.) have had an impact on many of their physical attributes including basic geomorphology, channel stability, channel entrenchment, access to the floodplain during floods, and, to some extent, stream substrate conditions. The hydrology of the three branches of Long Creek especially below I-95 appear to have been substantially altered as PTIA values have increased over the years. (Some visual observations suggested that lower Red Brook below I-95 also was experiencing similar changes, although it was not studied in the present study.) Significant portions of these streams appear to still be in a process of downcutting (entrenching) and widening, which became apparent when comparing Long Creek Rosgen classification values, which often failed to meet the expected E5/E6 channel type, with mid-upper-reach Red Brook values. Pfankuch measurements also indicated that many of the study stream reaches were unstable. (*Note*: Another type of classification of channels that commonly is used by fluvial geomorphologists is the channel evolution model [Schumm et al. 1984]. Scientists use this model to assess at which stage of evolution channels are in, especially if they are in watersheds where land uses have changed. Knowing which stage various reaches of Long Creek and Red Brook are in [e.g., stable, incising, widening, re-establishing a new equilibrium, etc.] might prove useful when a restoration plan is being created for the study watersheds.) Important considerations to make when designing a restoration plan for the study watersheds will be to reduce deviation from the natural hydrology pattern of the watershed and to preserve/restore access of floodwaters to floodplains so that their high energies may be dissipated on forested floodplains rather than induce further channel downcutting.

Chapter 5
Conclusions and Recommendations
(DRAFT)

Analyzing the leading causes of stream ecosystem stress throughout the watersheds, in terms of which stressors are most responsible for biological community degradation, is an ongoing process, and one that falls outside of the funded scope of this watershed assessment project. The Maine Department of Environmental Protection (MDEP) has been working with the U. S. Environmental Protections Agency's (USEPA) Office of Research and Development (ORD) and USEPA-New England to apply USEPA's stressor identification (SI) guidance (USEPA 2000) to the Long Creek data. A workshop was conducted February 26-28, 2002 with 26 participants from MDEP, Maine State Planning Office, University of Maine, Vermont Department of Environmental Conservation, USEPA-ORD, and USEPA-New England. During this preliminary workshop, SI guidance was applied to the fish portion of the aquatic life data. In subsequent working group meetings, the SI guidance will be applied to the macroinvertebrate portion of the aquatic life data, and further refinements will be made to reevaluate, prioritize, and streamline suspected causes of impairment. Results from that working group's efforts are expected to be available by the summer of 2003. A preliminary survey of the data in this report yields a fairly reliable characterization of the types of impairments affecting the biological community and suggests that watershed restoration recommendations include some or all of the following:

- Improve both stormwater quality- and quantity-control best management practices (e.g., minimize impervious surfaces throughout the watershed wherever possible, clean up potential pollutants residing on impervious surfaces as frequently as possible, construct/retrofit the stormwater release structures of stormwater detention ponds so that they are not maintaining stream flows at or above highly erosive bankfull [channel-forming] conditions longer than they normally would under natural conditions)
- Consider extending, in current municipal ordinances, the width of riparian/shoreland zoning protection beyond the minimum of 75 feet required by the State of Maine because an increase in the effectiveness of "riparian buffer benefits" such as sediment and nutrient removal, flood mitigation, and wildlife habitat availability[1] generally is associated with an increase beyond a width of 75 feet
- Protect/enhance streamside (riparian) and floodplain forest conditions throughout the watershed (where necessary) by organizing tree plantings and bioengineering projects as well as developing more stringent controls on town shoreland (riparian zone) timber harvesting ordinances (e.g., develop "no cut zones" within 15-35 ft of streams in order to increase canopy cover to shade streams [cooler water can hold more dissolved oxygen], increase bank stability, and provide more opportunities for large

woody debris to fall into the streams and become fish and macroinvertebrate habitat structures)
- Preserve the parcel of land between LC-M-1.1~ and LC-M-2.3~, believed to be within/adjacent to an open-space/clearance zone for FAA airport regulations, appeared to be one of the most contiguous, intact stream/riparian forest and floodplain complexes in the Long Creek watershed
- Minimize impervious surfaces through the use of pervious parking spaces, parking garages, and rooftop gardens/turf
- Improve in-stream habitats where necessary (e.g., strategically place large woody debris structures, where appropriate[2], in order to provide more stable habitat for macroinvertebrates, more retention devices to trap food material for microbes and macroinvertebrates, more cover for fish, and [possibly] an increased number of opportunities for stream water re-aeration)
- Evaluate the usefulness of at least two known in-stream stormwater detention basins in two reaches of Long Creek (upstream of Spring Street) and determine if they should be retrofitted, removed, or re-engineered so that stormwater is treated outside of the channel region
- Evaluate and replace as many poorly-functioning culverts as necessary with large box- (or bottomless arch-) culvert style culverts to minimize drainage plugging and increased erosion while simultaneously minimizing the amount of large woody debris needed to be removed from the system; also consider engineering and installing floodplain-sited "release" culverts in order to have channels functioning more naturally and not ponding up water behind poorly-functioning culverts
- Work with local golf courses, businesses with lawns, and homeowners to ensure that fertilizers and pesticides are only being applied to the extent that they truly are needed.

It is likely that most of the measures described above also would benefit stream ecosystems in other Maine municipalities experiencing rapid urbanization.

[1] Some wildlife species, such as deer, bear, and (breeding) migratory birds require widths of 100-300 ft in order to use riparian corridors as habitat (U. S. Forest Service 1997).

[2] The designs of stream restoration practices such as the placement of large woody debris need to be carefully planned and engineered as well as tailored to each site so as to not increased in-stream erosion.

Chapter 6
Local Partnerships and Other Outreach

The following list summarizes efforts made, and anticipated to be made, by the author of this report in order to build partnerships between the Maine Department of Environmental Protection and various members of the towns through which Long Creek and Red Brook flow and also to educate members of these communities about the impacts of urbanization on local stream ecosystems:

Past Efforts

• May 3, 2001
Presented preliminary findings of the watershed assessment at the Maine Water Conference.

• May 23, 2002
Presented preliminary findings of the watershed assessment at the NEWIPCC Nonpoint Source Pollution Conference.

• June 19, 2002
Presented preliminary findings of the watershed assessment at the State of the Bay (Casco Bay) Conference.

• April 18, 2002
Presented preliminary findings of the watershed assessment to South Portland's Pollution Abatement Officer (Pat Cloutier).

• June 18, 2002
Attended a meeting of the Interlocal Stormwater Working Group (comprised primarily of Greater Portland area municipalities and Cumberland County Soil & Water Conservation District staff) to see where the group was at in terms of dealing with local stormwater issues. At that meeting, the group appeared to be primarily focused on revising and completing their Stormwater Phase II general permit documentation. Recent emails (as of December 24, 2002) of updates and agenda items for recent meetings have suggested that this subject is still their primary focus. The group is submitting their documentation in March 2003. See "Spring & Summer 2003" below for more information about efforts to reach out to this group.

• August 26, 2002
Presented preliminary findings of the watershed assessment to South Portland's City Council, Pollution Abatement Officer (Pat Cloutier), and Planning Department Director (Charles Hauser).

• August 27, 2002
Newspaper article about the assessment published in the Portland Press Herald.

Anticipated Upcoming Efforts

• Spring & Summer 2003
  - Complete the stressor identification analyses and summary report/recommendations (beyond the scope of funding for this project).
  - Launch efforts to make members of the Interlocal Stormwater Working Group and other local municipal officials fully aware of the watershed assessment and the availability of having a presentation of the assessment done for them at city council meetings and other types of outreach events. This presentation also will be available to other Maine towns experiencing urbanization trends.
  - Begin attempts to organize a stakeholder group process to create and implement a restoration project for the Long Creek and Red Brook watersheds. Local town officials, business owners, and conservation groups will be targeted during recruitment attempts.

Chapter 7
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