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Causal Analysis of Biological Impairment in Long Creek: A Sandy-Bottomed Stream in Coastal Southern Maine

National Center for Environmental Assessment
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ABSTRACT

This case study presents results from a complex causal assessment of a biologically impaired, urbanized coastal watershed located primarily in South Portland, Maine, USA—the Long Creek watershed. This assessment serves as an example implementation of U.S. Environmental Protection Agency Stressor Identification guidance. Four specific biological effects defining impairment and seven candidate causes of impairment were chosen and evaluated at three impaired sites along Long Creek. Biological effects include (1) decreased Ephemeroptera, Plecoptera, and Trichoptera (EPT) generic richness, (2) increased percent non-insect taxa individuals relative to total macroinvertebrate abundance, (3) increased Hilsenhoff Biotic Index (HBI) score, and (4) brook trout absence. Decreased dissolved oxygen, altered flow regime, decreased large woody debris, increased temperature, and increased toxicity due to ionic strength were identified as probable causes of impairment. The implications associated with interactions among probable causes are discussed in terms of this case study and causal assessment in general.

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LIST OF ABBREVIATIONS AND ACRONYMS

CADDIS	Causal Analysis/Diagnosis Decision Information System
CCC	criterion continuous concentration (chronic)
CI	confidence interval
CMC	criteria maximum concentration (acute)
Cu	copper
CWA	Clean Water Act
ECOTOX	ECOTOXicology database (U.S. EPA)
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FPOM	fine particulate organic matter
GIS	geographic information system
HBI	Hilsenhoff Biotic Index
LC50	lethal concentration, causing death in 50% of population
LDF	linear discriminant function
LWD	large woody debris
MEDEP	Maine Department of Environmental Protection
N/A	not applicable
NCEA	National Center for Environmental Assessment
ND	not detected
NE	no evidence
NOAA	National Oceanic and Atmospheric Administration
ORD	Office of Research and Development
PAH	polycyclic aromatic hydrocarbon
Pb	lead
PCB	polychlorinated biphenyl
PPM	parts per million
PTIA	percent total impervious surface area
RBP	Rapid Bioassessment Protocol
RL	reporting limit
SOE	strength-of-evidence
S-R	stressor-response
SSD	species sensitivity distribution
ST	see text
TMDL	Total Maximum Daily Load
TSS	total suspended solids
USGS	United States Geological Survey
WQC	water quality criteria
WQS	water quality standard

FOREWORD

The National Center for Environmental Assessment (NCEA) provides this case study as an example implementation of U.S. EPA's Stressor Identification process, as presented online at the Causal Analysis / Diagnosis Decision Information System (CADDIS) Web site, http://www.epa.gov/caddis. The Long Creek case study provided U.S. EPA an opportunity to collaborate with the State of Maine and its Department of Environmental Protection. We hope this collaborative effort serves as a foundation for improving Long Creek's ecological condition, and imparts a rudimentary understanding of EPA's Stressor Identification process to Maine biologists and environmental managers.

The work herein represents a rigorous adherence to EPA's Stressor Identification guidance. Such a detailed approach may not be appropriate for all case studies; causal assessors should approach this type of analysis on a case by case basis. However, by pushing the bounds of EPA's Stressor Identification guidance with this case study, two points are worth noting: 1), we have fine tuned the on-line version of the guidance found at the CADDIS Web site, and 2) this report presents a wide range of causal assessment issues and opportunities that may arise in any given case study.

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PREFACE

U.S. EPA's National Center for Environmental Assessment, Maine Department of Environmental Protection, and Partnership for Environmental Technology Education authored this report jointly, with substantial contribution and constructive critique from U.S. EPA's Office of Research and Development and external peer reviewers. The report is intended for risk assessors, field biologists, research scientists, and environmental managers interested in learning the process and potential of U.S. EPA's Stressor Identification guidance (http://www.epa.gov/caddis/ and U.S. EPA, 2000a) by example.

The report is a causal assessment case study of a biologically impaired, urbanized coastal watershed located in Maine, USA. In accordance with U.S. EPA's Stressor Identification protocol, the report defines biological impairment, discusses candidate causes of impairment, and walks through a strength-of-evidence approach to identify probable causes. The last two chapters of the report discuss stressor interactions—in terms of general causal assessment and this case study specifically—and lessons learned upon case study completion that might be applied to future causal assessments.

The Clean Water Act (CWA) requires states to develop TMDLs for waters when current pollution controls are not stringent enough to attain or maintain compliance with adopted water quality standards. Maine's 1998 list of impaired water bodies includes Long Creek, the focus of the case study, and U.S. EPA chose the Long Creek watershed for study under CWA funding in early 1999.

The case study project team completed the majority of literature review for this report in 2005. Readers are encouraged to visit U.S. EPA's CADDIS (Causal Analysis/Diagnosis Decision Information System) Web site for state of the art causal assessment information and references (http://www.epa.gov/caddis/).

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EXECUTIVE SUMMARY

This case study presents results from a complex causal assessment of a biologically impaired, urbanized coastal watershed located primarily in South Portland, Maine, USA—the Long Creek watershed. The project team conducted this assessment using U.S. Environmental Protection Agency (EPA) Stressor Identification guidance (http://www.epa.gov/caddis/ and U.S. EPA, 2000a), which provides a useful structure for organizing available evidence and helped identify several probable causes of biological impairment.

The targeted audience for this report includes: Maine scientists and managers working to improve the environmental health of the Long Creek watershed through, for example, restoration efforts and Total Maximum Daily Load (TMDL) development; future causal assessors (scientists and managers) seeking to understand the process and potential of U.S. EPA's Stressor Identification guidance; and the scientific community as it seeks to better understand urban-related stressor interactions at impaired sites throughout the world. The Long Creek causal analysis will serve as an example for the assessment of other coastal urban areas with similar problems.

The Clean Water Act (CWA) requires states to develop TMDLs for waters when current pollution controls are not stringent enough to attain or maintain compliance with adopted water quality standards. Maine's 1998 list of impaired water bodies includes Long Creek due to decreased dissolved oxygen and unspecified non-point source pollution. Long Creek's listing partly triggered this case study. Ultimately, however, dissolved oxygen and non-point source pollution were identified among several candidate causes of impairment; causal analysis described in this report and efforts to restore the Long Creek ecosystem will likely focus on a variety of issues. The U.S. EPA chose Long Creek as an example urban watershed for study in early 1999. The project team, composed of Maine Department of Environmental Protection (MEDEP) and U.S. EPA personnel, partnered to conduct the causal analysis described herein. Results of the analysis are helping guide the MEDEP and other stakeholders in improving and managing the Long Creek watershed.

The project team conducted a site-by-site causal analysis because different patterns of biological effects were observed at different sites throughout the Long Creek watershed. The team applied biological monitoring and water quality data to the U.S. EPA Stressor Identification process to establish strength-of-evidence by impaired site, biological endpoint, and candidate cause. The team chose four effects, or specific biological endpoints, defining impairment. The team chose seven candidate causes of impairment and evaluated each cause at each of three impaired sites within the Long Creek watershed. One of the candidate causes, increased toxic substances, might more accurately be considered a causal category rather than a single stressor, as this cause includes several stressors (or sub-groups) including increased toxicity due to ionic

strength, various metals, and polycyclic aromatic hydrocarbons. Furthermore, the project team analyzed some causes in terms of acute exposure (short term duration or stormflow conditions) and chronic exposure (long term duration or baseflow conditions), based on data availability.

While other stressor identification case studies may yield single, “smoking gun,” probable causes, the Long Creek case study results point to multiple probable causes of impairment—neither scenario necessarily reflects more or less success of the stressor identification process. The case study results indicate that probable causes vary by site and biological endpoint. In summary, of the seven potential causes listed and assessed, the project team promoted the following causes of impairment from “candidate” to “probable” status: decreased dissolved oxygen, altered flow regime, decreased large woody debris, increased temperature, and increased toxicity due to ionic strength. Results indicate that some stressors impact multiple biological endpoints and others do not. Episodic toxicity from metals in stormflows may contribute to impairment at one of the sites. Due to insufficient evidence, the project team was not able to rule out increased sediment as a cause.

Urbanized watersheds are often subject to multiple, interacting causes of impairment. This is likely the case for Long Creek. This report details interacting causes of impairment in terms of general causal assessment methods and in terms of this case study. It may be beneficial to combine candidate and probable causes of impairment into groups at various points in the assessment process and to design remedial action by targeting sources of impairment common to multiple causes, such as impervious surface area.

This report concludes with a lessons-learned section, in which the project team discusses three issues specific to this study and the causal assessment process in general:

1. The project team acknowledges challenges associated with uneven evidence given data gaps and data availability.
2. The project team addresses the benefits of choosing simplified measures of biological response.
3. In terms of applying monitoring data to an assessment, the project team acknowledges the importance of forecasting data needs so that a sequential data collection plan, specific to the needs of the stressor identification process, might be implemented prior to beginning the causal assessment process.

1. INTRODUCTION

This report describes a case study of Long Creek, a biologically impaired stream located in southern coastal Maine, USA (Figure 1). Long Creek's contributing watershed is urbanized: home to industrial, commercial, and residential land uses. The Long Creek watershed showcases a wide range of topics related to resource management including the environmental implications of urban land use for coastal regions and the interactions among multiple causes linked to biological impairment.

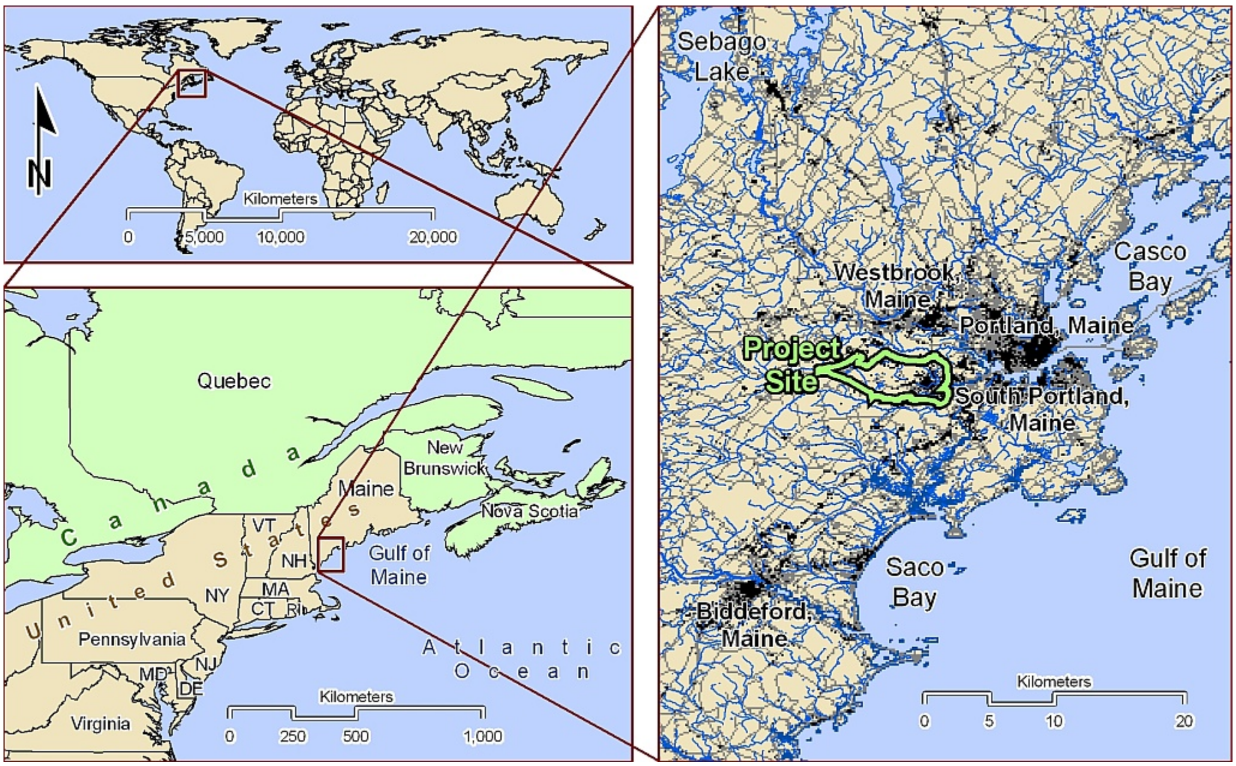

Figure 1. Project location map.

The scientific community continues to identify environmental impacts associated with urbanization (e.g.: Roy et al., 2003; Wang and Kanehl, 2003; Beach, 2002; Paul and Meyer, 2001), and the Millennium Ecosystem Assessment (2005) emphasizes the current and future importance of ecologically healthy urban environments. However, the multitude of urban-related causes of watershed impairment confounds scientists and complicates resource management. According to Wang and Kanehl (2003), urban land use is the most important factor influencing assemblages of cold water macroinvertebrates in urbanizing watersheds. Adverse changes to these assemblages may be attributed to a wide range of causes, from toxic substances to altered stormwater flow. The challenge in this assessment is pinpointing specific causal relationships, thereby providing policy makers and stakeholders a foundation for improving an urban ecosystem.

Identifying causes of urban-related biological impairment in coastal watersheds is a timely issue. Roughly 53% of U.S. residents live in coastal counties, which comprise only 17% of the country's total land area (NOAA, 1998). The National Oceanic and Atmospheric Administration (NOAA) predicts that the ratio of coastal to inland residents will remain stable as population rises (NOAA, 1998). With more coastal urbanization comes more impervious surface area, which is becoming more problematic in terms of environmental impacts and growth management (Elvidge et al., 2004). The importance of accurate causal assessment is increasing for urbanizing coastal regions.

The project team—composed of personnel from Maine Department of Environmental Protection (MEDEP), U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD), and Partnership for Environmental Technology Education—provides the following detailed causal analysis as an example for assessment of other coastal urban areas with similar problems in Maine and around the globe.

1.1. BACKGROUND

Portions of Long Creek have violated state of Maine standards for dissolved oxygen and aquatic life. The U.S. EPA chose Long Creek as an example urban watershed for study under Clean Water Act (CWA) funding (section 104-b-3, Water Quality Cooperative Agreements/Grants) in early 1999. Long Creek underwent the majority of existing commercial development approximately 35 to 40 years ago, and urban development of the area continues today. In comparison to other watersheds in the Portland, Maine area, Long Creek has a low number of landowners per acre due to more commercial development than residential areas.

1.1.1. Study Area Description

The study area for this assessment includes two watersheds: the Long Creek and Red Brook watersheds (Figure 2; Red Brook's inclusion in this case study and its use as a reference stream is discussed below). Long Creek and Red Brook flow through the municipalities of South Portland, Scarborough, Westbrook, and a small portion of Portland, Maine, eventually draining into Clark's Pond, the Fore River, Casco Bay, the Gulf of Maine, and the Atlantic Ocean. Clark's Pond and everything upstream of Clark's Pond, including Red Brook and Long Creek, are freshwater ecosystems, and the Fore River is estuarine, progressively becoming more saline until connecting to the Atlantic Ocean. Red Brook is located in a watershed adjacent to and immediately south of the Long Creek watershed. The upper reach of Red Brook provides a relatively unimpaired study site. The project team labels the upstream Red Brook site as the

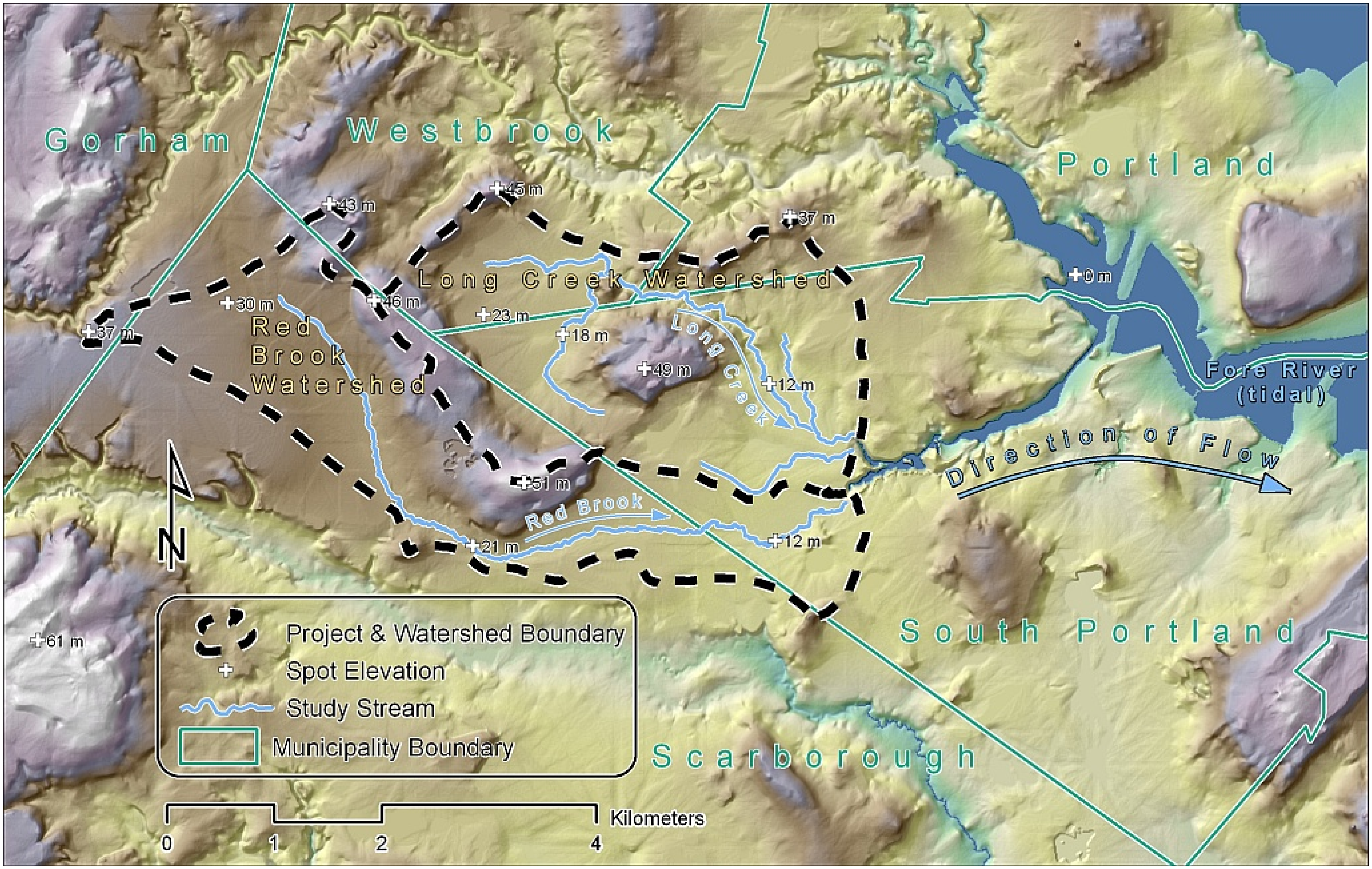

Figure 2. Elevation model of study watersheds.

Source: Map was generated using data obtained from Maine Office of Geographic Information Systems, at http://megis.maine.gov/, accessed on December 29, 2005; elevation based on USGS 1:24,000 map contours.

reference site, and the team compared conditions at Long Creek's impaired sites to the Red Brook site.

Long Creek and Red Brook are low-gradient, gently-sloped, freshwater streams, dominated primarily by very fine and medium-sized sand (i.e., 0.062-0.500 mm). Gravel and bedrock are present in isolated patches and not representative of the stream channels. The Long Creek watershed (approximately 8.9 km^2), located mainly in South Portland and Westbrook, includes an enclosed regional shopping mall (140 stores, 18 restaurants, and over 5,500 parking spaces), part of the Portland airport (Portland International Jetport, PWM), a golf course, two semiconductor manufacturing plants, office parks, residential areas, and forested areas. Long Creek was once named "Jackson Brook;" older documents and maps use this name. The Red Brook watershed (approximately 8.5 km^2), located primarily in Scarborough and South Portland, includes residential, retail, and forest land cover. Both watersheds include a stretch of the Maine Turnpike, a four-lane interstate highway, and a waste incinerator/landfill. Table 1 shows percentages of land use for each study watershed, Figure 3 shows various land use features, and Figure 4 shows the distribution of impervious surfaces throughout the study area.

Table 1. Watershed land use

Land use	Percent of watershed area: Red Brook	Percent of watershed area: Long Creek
Urban / built up	19	40
Forest	61	26
Agriculture	10	8
Barren	8	26
Surface water	2	<1

Source: Field (2005).

Portions of both study streams are physically altered beyond the level of change expected from natural geomorphologic processes. Both streams include channelized sections, and regional documents kept by the Maine Department of Inland Fisheries and Wildlife suggest that portions of both streams were relocated to accommodate commercial development and road building. U.S. Geologic Survey (USGS) topographic maps indicate that upper reaches within both watersheds were subjected to gravel mining operations, and instream detention basins exist along the upper reaches of Long Creek.

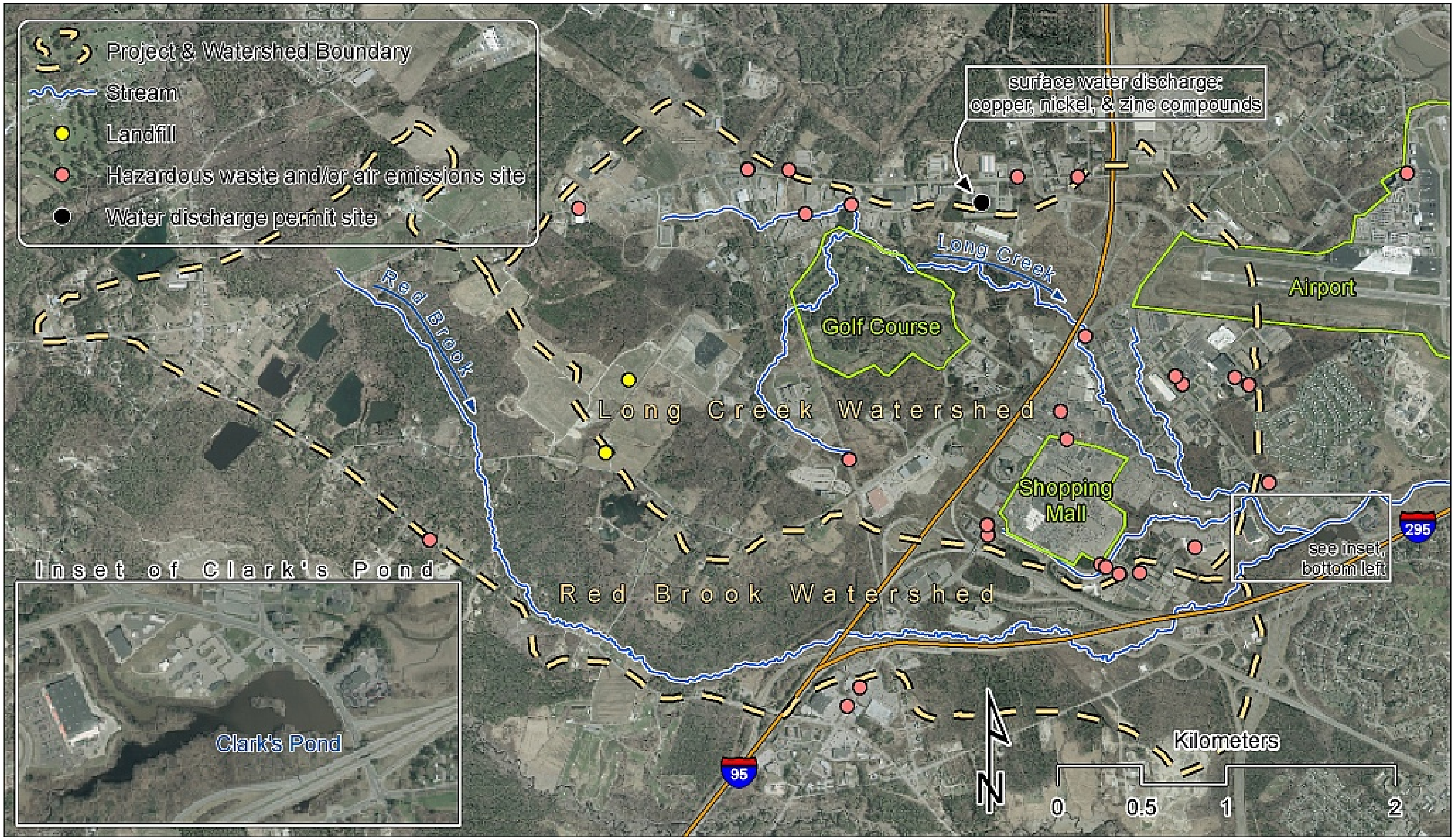

Figure 3. Land use map.

Source: Map was generated using data obtained from Maine Office of Geographic Information Systems, at http://megis.maine.gov/, accessed on December 29, 2005. The aerial photograph (basemap) was taken in April, 2001. Landfill locations are approximate, based on MEDEP (2002a). Hazardous waste, air emissions, and water discharge site information are based on U.S. EPA Envirofacts, at http://www.epa.gov/enviro/, accessed on February 14, 2006; sites include, e.g., automobile service centers, department stores, gas stations, and manufacturing corporations).

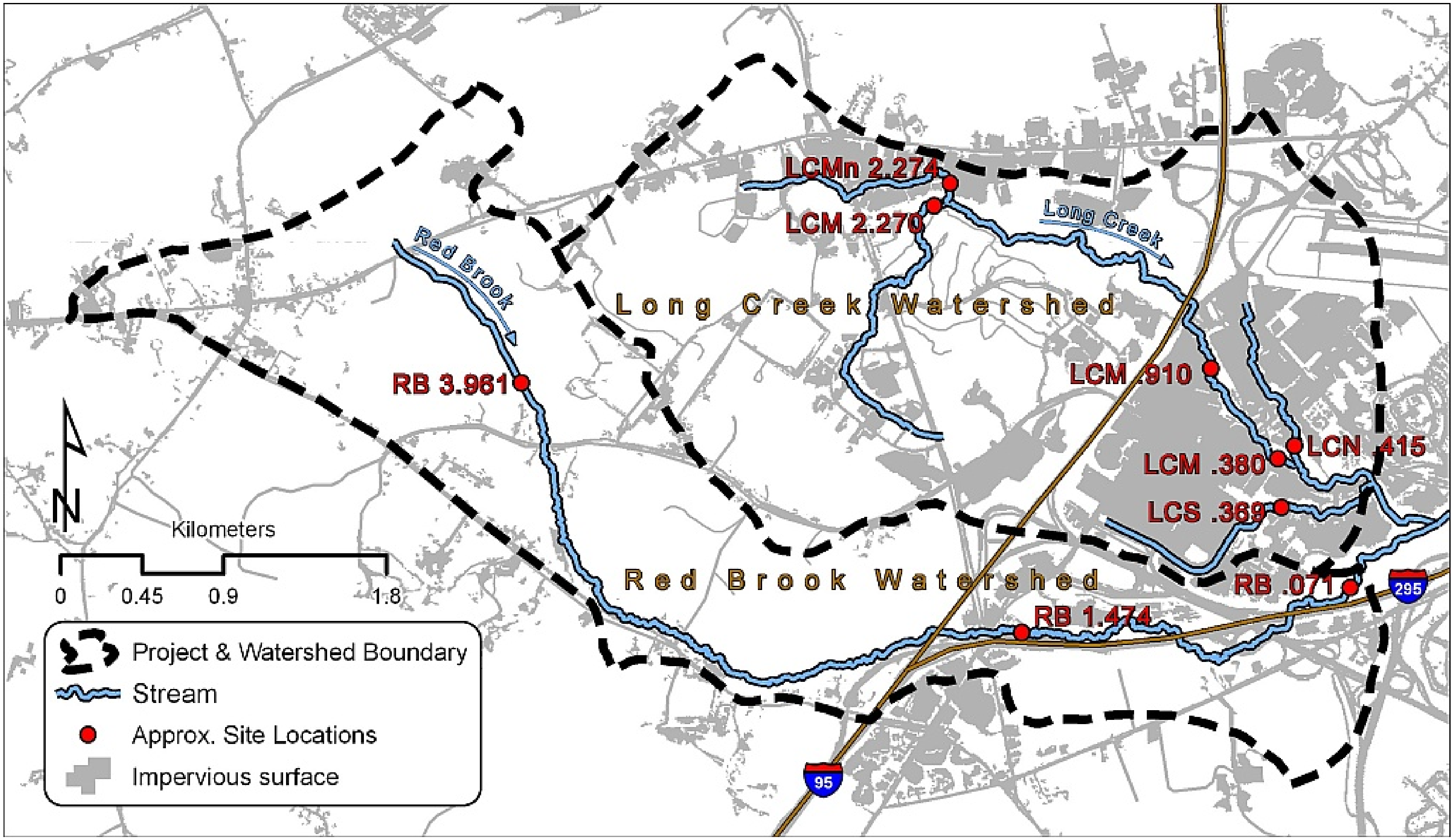

Figure 4. Impervious surface and project site locations.

Source: Map was generated using data obtained from Maine Office of Geographic Information Systems, at http://megis.maine.gov/, accessed on December 29, 2005.

1.1.2. Historical Land Use

The Long Creek and Red Brook watersheds were covered primarily by farmland and forest until the late 1960s (Seeley and Valle, 1983). Appendix A provides historic USGS maps of the project area, showing urban development as a function of time, from 1891 to 1980. Major commercial development and highway-building within the two watersheds began in the mid 1900s, and contributed to erosion and pollution of Long Creek, Red Brook, and Clark's Pond, located at the downstream confluence of the two streams (Seeley and Valle, 1983). Urban land cover of Long Creek watershed increased by 36% between 1952 and 1995, while Red Brook urban cover increased by 10% (Field, 2005). Long Creek watershed forest and agricultural land cover decreased by 10% and 34%, respectively, between 1952 and 1995, while those of Red Brook decreased by 2% and 11%, respectively (Field, 2005). Seeley and Valle (1983) note two major events leading to decreased water quality within the study watersheds and Clark's Pond: (1) construction of Interstate 295, lasting "several years," for which stabilized vegetation was removed from the Red Brook watershed and "huge amounts of fill" were relocated within the watershed and (2) construction of commercial facilities, including a regional shopping mall, industrial buildings and office buildings, with "little effort at erosion control."

Clark's Pond, an approximately 16-acre impoundment at the base of Long Creek and Red Brook, apparently existed in the 1700s but was smaller. Between that time and 1920, the area surrounding the pond—presumably including Long Creek and Red Brook watersheds—was used agriculturally, to some degree (Seeley and Valle, 1983). Sometime before 1900, a dam was constructed at the downstream end of Clark's Pond, thereby enlarging the pond, and the Cumberland County Ice Company began using the pond for harvesting ice. Ice-harvesting ended in the mid 1900s, just before the pond was stocked with trout and transformed into a sports fishery, which ceased in the 1960s, corresponding with decreased water quality (South Portland Engineering Department, 1994).

1.2. MAINE'S REGULATORY PROGRAM

The CWA requires states to adopt water quality standards (WQSs) that support designated uses for water bodies. Maine defines four surface water classes: AA, A, B, and C (MEDEP, 2002b). Each class is defined by standards describing conditions necessary to attain that class, such as minimum dissolved oxygen level. Class AA represents the highest level where "waters shall be as naturally occurs," and Class C represents the lowest attainment level for which "[d]ischarges… may cause some changes to aquatic life…" (see Appendix B for detailed class descriptions). Furthermore, the MEDEP developed numeric criteria to support narrative descriptions for aquatic life criteria as found in the Water Quality Classification Law (Davies and Tsomides, 2002). The numeric criteria are based on statistical decision models, reliant on 30 quantitative measures reflecting various aspects of benthic macroinvertebrate community health.

CWA section 303(d) requires states to develop TMDLs for waters when current pollution controls are not stringent enough to attain or maintain compliance with adopted water quality standards. Maine's 1998 303(d) list of impaired water bodies includes Long Creek because of decreased dissolved oxygen and unspecified non-point source pollution. This report focuses on determining causes of biological impairment, a necessary precursor for developing TMDLs.

1.3. TRIGGER FOR CAUSAL ANALYSIS

The MEDEP studied in detail six sites along Long Creek and three along Red Brook (Figure 4) by collecting biological, chemical, and physical data at the nine total sites[1] (see MEDEP, 2002a for a detailed description of this effort). Table 2 shows Maine's water quality class designations for the various sites and whether or not the class has been met. Macroinvertebrate data collected along the streams signal ecosystem degradation. The MEDEP found abundant numbers of brook trout in Red Brook at, and upstream of, RB 1.474 (including RB 3.961), but nowhere in Long Creek. Of the nine sites, three sites on Long Creek (LCN .415, LCM 2.270, and LCMn 2.274) did not attain their designated classes; one site on Red Brook, RB 3.961, attained Class A, the second highest possible classification (MEDEP, 2002a).

For stressor identification the project team selected the three sites not attaining designated class: LCN .415, LCM 2.270, and LCMn 2.274. The Class A site on Red Brook, RB 3.961, was used as a reference site for comparison to the three impaired Long Creek sites. All four study sites have low-gradients (less than 0.5 % slope), which is common throughout both watersheds (MEDEP, 2002a). The three non-attaining Long Creek sites represent different challenges facing parts of the Long Creek watershed and are the focus of this causal assessment.

[1] Site names consist of the stream initials ("LC" for Long Creek and "RB" for Red Brook), a branch designation for Long Creek only ("N" for the northern branch, "M" for the main branch, "Mn" for the northern branch of the main branch, and "S" for the southern branch), and the river mile, which is measured upstream from the confluence with Clark's Pond.

Table 2. Project site description and classification

Stream	Site name[a]	Watershed size		% Impervious area	Maine classification[b]	
		acres	km^2		designation	attainment
Long Creek	LCM .380	1,471	6.0	13.5	C	C
	LCM .910	1,380	5.6	10.1	C	C
	LCM 2.270[c]	670	2.7	7.1	B	C
	LCMn 2.274[c]	427	1.7	14.3	B	N
	LCN .415[c]	262	1.1	32.6	C	N
	LCS .369	361	1.5	47	C	C
	LC 0 (at Clark's Pond)	2,208	8.9	no data	no data	no data
Red Brook	RB .071	1,787	7.2	9.5	C	C
	RB 1.474	1,448	5.9	7.9	C	I
	RB 3.961[c,d] (reference site)	508	2.1	2.1	C	A
	RB 0 (at Clark's Pond)	2,112	8.5	no data	no data	no data

[a] Site names consist of the stream's initials ("LC" for Long Creek and "RB" for Red Brook), a branch designation for Long Creek only ("N" for the northern branch, "M" for the main branch, "Mn" for the northern branch of the main branch, and "S" for the southern branch), and the river mile, which is measured upstream from the confluence with Clark's Pond.
[b] Classes AA & A are the highest classifications ("natural" biological condition), C is the lowest class (represents the state's minimum environmental goals), N represents non-attainment of Class AA, A, B, or C ("degraded" biological condition), and I indicates that the class was indeterminate due to low abundance of organisms.
[c] Highlighted sites are the focus of this case study.
[d] RB 3.961 attained Class A and was designated a reference site.

1.4. REPORT FORMAT

This causal analysis adheres to U.S. EPA Stressor Identification guidance (see below). The remainder of this report addresses topics specific to that methodology, as follows:

- **Section 2 - Biological Impairment**–This section describes the foundation of the causal analysis, the specific biological effects seen at the impaired sites and how those effects were quantified.
- **Section 3 - Stressor Identification**–Section 3 describes potential stressors, assesses causal associations, and steps through strength-of-evidence (SOE) scoring for each stressor at each impaired site.
- **Section 4 - Conclusions–**Causal assessment conclusions are broken into four sub-sections: (1) similarities among impaired sites by candidate cause, (2) findings unique to each site, (3) evidence for each specific biological endpoint, and (4) overall conclusions regarding Long Creek's probable causes of impairment.
- **Section 5 - Discussion**–This section addresses two key issues surrounding conclusions drawn in the previous section: (1) the significance of interacting stressors, both for this case study and causal assessment in general, and (2) the certainty of the conclusions.
- **Section 6 - Highlights and Lessons Learned–**In this section, the team examines key lessons learned about the case study and overall stressor identification process.

The target audience of this report ranges from managers with minimal technical training in causal assessment to scientists attempting to conduct similarly complex case studies. A rudimentary knowledge of U.S. EPA's Stressor Identification guidance may assist readers. U.S. EPA's CADDIS (Causal Analysis/Diagnosis Decision Information System) Web site, located at http://www.epa.gov/caddis/, provides causal assessors with the most recent stressor identification methodology, originally adapted from the *Stressor Identification Guidance Document* (U.S. EPA, 2000a). Additionally, the CADDIS Web site provides basic information for managers interested in learning about the capabilities of this process.

To enhance this report's readability, the project team sought to minimize repetition of information among text, tables, figures, and appendices, especially in terms of numeric data. Readers seeking detailed, numeric data not found in the text will find additional data in the tables and appendices.

2. BIOLOGICAL IMPAIRMENT

The project team characterized biological impairment at each of the three Long Creek sites that did not meet designated water quality classes. Specific effects were used to determine whether different causes or intensities of stress occurred at the different study sites. Evidence that similar responses occurred throughout Long Creek might suggest a common cause and support evaluating the three sites as a single group. Observed effects can suggest inclusion of certain candidate causes as discussed in Section 3. Furthermore, recognizing specific effects often makes it easier to identify and interpret relevant evidence from scientific literature and other field studies.

2.1. ANALYSIS

An early objective of this analysis is to identify a suite of biological variables on which to focus the causal analysis. The project team sought to identify biological variables with values greatly different between the impaired and reference sites.

2.1.1. Rockbag Sampling Data

MEDEP biologists conducted macroinvertebrate rockbag sampling throughout the study area beginning August 5-6, 1999, using standard MEDEP rockbag sampling protocol (Davies and Tsomides, 2002). They placed three rock bags (7.25-kg cobble substrate, enclosed in 2.54-cm aperture mesh) in the stream channel at each site, in areas representative of the Long Creek and Red Brook watersheds and in sandy-runs with at least 79% shade from canopy cover. After a colonization period of 32 days, biologists placed a 600-μm mesh dip net downstream of each rockbag and pulled each bag into the net. The contents of each rockbag and dip net were then washed into a 600-μm sieve bucket. Biologists cleaned individual rocks by hand to ensure the capture of all sample organisms. Contents were transferred into labeled sample containers and preserved with ethyl alcohol. Rockbag sampling data are provided in Appendix C.

The project team analyzed biological effects occurring at the three study sites as follows:

- Variables contributing to Maine's linear discriminant function (LDF) model (see description below) were examined to identify responses to study site conditions.
- Species lists with associated life history attributes were examined to suggest additional variables for inclusion in the suite of specific biological effects.
- Findings from the tasks stated above were used to determine whether biological responses were sufficiently similar to support grouping the three impaired study sites and to support development of a candidate cause list.

2.1.2. Maine's Linear Discriminant Function Model

The MEDEP uses an LDF model to define attainment of WQSs. The model, an agglomerative index, incorporates approximately 30 variables associated with the invertebrate community at sampled sites (see Appendix D for variable descriptions). LDF variables include both indices and abundances of particular families or genera.

The project team disaggregated the model into its 30 component variables to determine which variables were most influential at each of the three sites. LDF model values for each impaired site were compared to corresponding values for reference site RB 3.961, and to the 5th and 95th percentile values observed at other high quality (i.e., Class A or AA), sandy-bottomed reference streams in Maine. Appendix E provides more information on the regional reference analysis and confirms the use of RB 3.961 as a reference site for this case study.

Disaggregation of the LDF model revealed at least two major findings: (1) Ephemeroptera, Plecoptera, and Trichoptera (EPT) generic richness at the three impaired sites (LCN .415 = 6; LCM 2.270 = 8; LCMn 2.274 = 7) is roughly half that of the reference site (RB 3.961 = 15) and (2) Hilsenhoff Biotic Index (HBI) scores are just above 6.0 across all three impaired sites compared with an HBI of 4.2 at the reference site (Table 3).

Table 3. Observed specific biological effects

Site	EPT richness	Percent non-insects	HBI	Brook trout
RB 3.961	15	7.8	4.2	Present
LCN .415	6	35.6	6.6	Absent
LCM 2.270	8	16.0	6.6	Absent
LCMn 2.274	7	1.4	6.2	Absent

EPT richness is often used as an indicator of stream condition (see e.g.: Wallace et al., 1996; Bednarek and Hart, 2005). While some individual taxa included under the EPT umbrella may be tolerant of particular stressors, EPT are generally more sensitive to common stressors and often provide a reasonable measure of stream condition—that is, greater EPT richness may indicate better conditions. HBI values often increase as certain aspects of stream condition decline. HBI was originally designed to assess low dissolved oxygen levels caused by organic loading in streams (Hilsenhoff, 1987), but the index often reflects the presence of other proximate stressors.

2.2. SITE-SPECIFIC DESCRIPTIONS AND BIOLOGICAL CONSIDERATIONS

The following site-specific observations are based on information from an earlier MEDEP report (2002a), lists of individual taxa observed at the four sites (Table 4; Appendix C), and expert knowledge of Maine ecosystems from authors of this document.

2.2.1. RB 3.961 (reference site)

Red Brook has a sinuous sandy-bottomed channel and an intact riparian corridor at river mile 3.961.[2] Impervious surface covers approximately 2% of the 508 acres upstream from this location. RB 3.961 was, at the time of observation, dominated by species typical of low gradient, sandy-bottomed streams in Maine.

Unlike any sites along Long Creek, abundant brook trout were observed at RB 3.961. Several organisms characterized as less tolerant of human disturbance, including the mayfly *Paraleptophlebia*, were observed at this site. The alderfly *Sialis*, not recognized as an indicator organism (Mackie, 2001), was observed as the most abundant organism at the site, comprising 13% of organisms collected. MEDEP notes, however, that no organisms stood out as dominant at this site, given that the most abundant organism observed accounted for only 13% of total abundance.

2.2.2. LCN .415 (impaired site)

The northern branch of Long Creek at river mile 0.415 is the most heavily urbanized of the three impaired study sites. Impervious surface covers approximately 33% of the 262 acres upstream of the study site. The contributing watershed includes a portion of Portland's airport, a portion of two semiconductor manufacturing plants, major roadways, retail development, and a soft drink bottling plant. The study site has a sandy-bottomed substrate and an intact riparian corridor.

The community observed at LCN .415 includes organisms typical of flowing water, but MEDEP biologists did not observe sensitive taxa at this site that were present at the reference site. Biologists found fewer organisms than would be expected and a high percentage of non-insects (relative to total macroinvertebrates). A high abundance of hyalellid amphipods was found at the site. Amphipods have short generation times, which can increase their tolerance of unstable substrate and/or frequent disturbance.

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[2] River mile measurements refer to the length of channel upstream from the Clark's Pond confluence, for both Long Creek and Red Brook.

Table 4. Dominant invertebrate taxa from rockbag samples

Class	Order	Family	Genus	HBI	FFG[a]	MOE[b]	% of total individuals at site
Site RB 3.961 (total mean abundance = 120.3)[c]							
Insecta	Megaloptera	Sialidae	*Sialis*	4	Pr	B-Cb-Cg	13
Insecta	Diptera	Chironomidae	*Tanytarsus*	6	C-F,G	Cb,Cg	12
Insecta	Diptera	Chironomidae	*Micropsectra*	7	C-G	Cb,Sp	7
Insecta	Trichoptera	Odontoceridae	*Psilotreta*	0	Sc,C-G	Sp	7
Insecta	Diptera	Chironomidae	*Stempellinella*	5	C-G	Sp	7
						sub-total	46
Site LCN .415 (total mean abundance = 62.7)[c]							
Crustacea	Amphipoda	Hyalellidae	*Hyalella*	8	Sh,G	Sw	20
Insecta	Diptera	Chironomidae	*Procladius*	9	Pr,C-G	Sp	15
Gastropoda	Limnophila	Physidae	*Physella*	8	Sc	Cg,Gl	11
Insecta	Trichoptera	Phryganeidae	*Ptilostomis*	5	Sh,Pr	Cb	7
Insecta	Trichoptera	Limnephilidae	*Limnephilus*	3	Sh,C-G	Cb,Sp,Cg	6
						sub-total	61
Site LCM 2.270 (total mean abundance = 386.0)[c]							
Insecta	Coleoptera	Elmidae	*Dubiraphia*	6	C-G,Sc	Cg,Cb	41
Insecta	Ephemeroptera	Caenidae	*Caenis*	7	C-G,Sc	Sp,Cb	16
Insecta	Diptera	Chironomidae	*Clinotanypus*	8	Pr	B	9
Pelecypoda	Veneroida	Sphaeriidae	*Sphaerium*	2	C-F	B	5
Crustacea	Isopoda	Asellidae	*Caecidotea*	8	Sh	Sp	4
						sub-total	75
Site LCMn 2.274 (total mean abundance = 97)[c]							
Insecta	Coleoptera	Elmidae	*Dubiraphia*	6	C-G,Sc	Cg,Cb	60
Insecta	Ephemeroptera	Caenidae	*Caenis*	7	C-G,Sc	Sp,Cb	9
Insecta	Diptera	Chironomidae	*Microtendipes*	6	C-F,G	Cg	8
Insecta	Diptera	Chironomidae	*Procladius*	9	Pr,C-G	Sp	5
Insecta	Diptera	Chironomidae	*Tanytarsus*	6	C-F,G	Cb,Cg	2
						sub-total	84

[a] Functional feeding group (FFG): C=Collector; F=Filterer; G=Gatherer; Pr=Predator; Sc=Scraper; Sh=Shredder (classification based on Merritt and Cummins, 1996, and project team knowledge).
[b] Mode of existence (MOE): B=Burrower; Cb=Climber; Cg=Clinger; Gl=Glider; Sp=Sprawler; Sw=Swimmer (classification based on Merritt and Cummins, 1996, and project team knowledge).
[c] Organisms collected in three rockbags over 32 days. Total mean abundance = total # of individuals from all three rockbags divided by three samples.

2.2.3. LCM 2.270 (impaired site)

MEDEP staff describe Long Creek's main branch at river mile 2.270 as a "wooded island" along this portion of the stream, implying that there is riparian vegetation in the vicinity of the site but less vegetation above and below the site. Impervious surface covers approximately 7% of the 670 acres upstream of the study site. The contributing watershed is primarily composed of a golf course and a major roadway. An instream dam and associated upstream detention area are located approximately 0.75 miles upstream of the site.

The dominant taxa found at LCM 2.270 are well adapted to low velocity, silty habitats. Taxa found here have adaptations that could potentially enable them to withstand unstable habitat conditions. The dominant organism observed was an elmid beetle of the genus *Dubiraphia*, which can cling to vegetation and woody debris and climb out of silt. They have a plastron, which may allow them to tolerate low dissolved oxygen levels. The site's dominant mayfly, *Caenis,* is tolerant of silt, low velocity conditions, and high water temperature. A midge observed at this site, *Clinotanypus,* is often found in ponds or slow streams of variable size and quality; *Clinotanypus* lives within the sediment and prefers soft sediment and shallow, warm water.

2.2.4. LCMn 2.274 (impaired site)

Similar to LCM 2.270, site LCMn 2.274 is described as a narrow channel flowing through a "wooded island" refuge, with pond-like habitat and a predominance of fine sediments. Impervious surface (largely office parks and roadways) covers approximately 14% of the 427 acres upstream of this site.

The dominant macroinvertebrate community observed at LCMn 2.274 reflects a pond-like community, tolerant of silt and sediment effects. Absence of passive filter feeders also suggests low or no flow velocity. Over 60% of the organisms found were *Dubiraphia,* indicating low site diversity.

2.3. APPLICATION TO CAUSAL ANALYSIS

The project team selected four biological endpoints for this causal assessment:

- Decreased EPT generic richness (shown in this report as "decreased EPT richness")
- Increased percentage of non-insect taxa individuals, relative to total macroinvertebrate rockbag abundance, including both insects *and* non-insects (shown in this report as "increased percent non-insects")
- Increased HBI score
- Absence of brook trout

The EPT richness endpoint was chosen because, as described above, it is often used as an indicator of stream condition. Percent non-insects follows an opposite pattern; that is, as stream condition declines, the percentage of non-insect organisms increases. Usually, HBI values increase as stream health declines. Presence of brook trout (the fourth biological endpoint) was included because Maine stakeholders value this species, and there is a clear difference between what was observed at the reference site and the impaired sites (i.e., presence versus absence). Stakeholders consistently emphasize brook trout as a missing, yet important, component of the Long Creek ecosystem.

Table 3 provides values for the selected biological endpoints. The project team evaluated each impaired site with respect to each endpoint with one exception; LCMn 2.274 did not show an increase in percent non-insects relative to the reference site, and, therefore, LCMn 2.274 was the only impaired site not assessed in terms of the non-insect biological endpoint. Observed macroinvertebrate communities were sufficiently different among the three impaired sites such that the project team chose to conduct a separate causal analysis for each site.

Candidate causes of impairment may lead to reductions in abundance of sensitive taxa (i.e., EPT, insects relative to non-insects, pollution intolerant organisms, and brook trout) through, for example, increased mortality, decreased reproduction, increased emigration, decreased immigration, shifts in organism assemblage composition, or decreased ecosystem support of particular traits. Effects on focal taxa may result from direct or indirect impacts. For example, the taxon of concern may itself be adversely affected by a candidate cause, or it may be indirectly affected through impairment of other taxa, such as preferred prey.

3. STRESSOR IDENTIFICATION

3.1. CANDIDATE CAUSES

This section describes candidate causes of biological impairments observed at the Long Creek study sites. The project team considered the following factors in developing the list of candidate causes: land use within the Long Creek and Red Brook watersheds, common causes of biological impairment in Maine stream ecosystems, and potential linkages between causes and biological endpoints discussed in the previous section.

Observed biological effects were not specific enough to conclusively identify specific ***probable*** causes of impairment without further analysis. However, generalizations can be made to assist in developing a list of ***candidate*** causes of impairment. For example, absence of Plecoptera[3] and brook trout suggests that increased temperature might be included among candidate causes (e.g., Galli and Dubose, 1990). Presence of organisms with short life cycles suggests that flow alteration might be included as a candidate cause (e.g., Lytle and Poff, 2004).

A panel at a Long Creek workshop in 2002 developed an initial candidate cause list (Augusta, ME, February 26-28, 2002), which was refined by the project team at subsequent meetings. Seven candidate causes of impairment were eventually chosen for this assessment (causes listed in no particular order):

- increased autochthony (defined as increased on-site organic production)
- decreased dissolved oxygen
- altered flow regime (defined primarily as increased hydrologic flashiness, including decreased baseflow and increased peaks)
- decreased large woody debris
- increased sediment
- increased temperature
- increased toxic substances

Each candidate cause is discussed in greater detail in Appendix F, and individual conceptual models for each cause are presented in the Conceptual Model (CM) figures section located after the main text (CM Figures 1-10). The project team identified several anthropogenic activities (also referred to as sources of stressors in the conceptual model figures, CM Figures 1-

[3] A total of three Plecopteran individuals were found in the study area, all located at reference site RB 3.961. This gives RB 3.961 a total mean plecopteran abundance at the low end of the project team's regional reference analysis (see Appendix C).

10) in the Long Creek watershed, which may contribute to at least one candidate cause. Appendix F describes candidate causes, basic causal interactions, and sources from a *general* perspective; connections *specific* to Long Creek, among causes and effects, and probable causal interactions, are included in subsequent sections of the main text of this report.

3.2. ANALYSIS OF CAUSES

This section of the report describes how the project team used U.S. EPA's Stressor Identification process, and its strength-of-evidence (SOE) approach, to link candidate causes with the specific effects described in Section 2. The team first considered types of evidence that use data only from the case. The team examined this evidence to see if it might refute a given candidate cause with sufficient confidence to eliminate that cause from consideration. Next, evidence that uses data from outside of the case (i.e., from elsewhere) was considered. The team then evaluated each candidate cause using all available types of evidence, scored in accordance with U.S. EPA's Stressor Identification guidance.[4] Finally, the team identified additional evidence specific and important to the case study, which did not fit into the aforementioned framework.

SOE scores revealed a combination of supporting and weakening evidence across impaired sites, candidate causes, and lines of evidence. The remaining part of Section 3 does not serve as a discussion of the scoring results. Rather, results are discussed in greater detail in Section 4 (Conclusions) in the context of determining which of the ***candidate*** causes should be classified as ***probable*** causes of impairment.

MEDEP collected the majority of water chemistry and habitat quality data used to assess the candidate causes. Study-wide and site-specific data are available for watershed characteristics, baseflow and stormflow water chemistry, sediment toxicity, geomorphologic and hydrologic characteristics, and instream and riparian habitat conditions. Data collected by MEDEP, including collection and analysis techniques, can be found in MEDEP's assessment report on Long Creek and Red Brook (MEDEP, 2002a). Table 5 lists measurements used to assess each candidate cause, and Appendix G describes available measurements.

Availability of data and literature determined which types of evidence were considered. Table 6 describes the types of evidence that could be evaluated and whether endpoint-specific (EPT richness, percent non-insects, HBI, and brook trout) characterizations could be made. The project team was able to evaluate several types of evidence that use data from the case, including, spatial/temporal co-occurrence, stressor-response relationships from the field, causal pathway, and laboratory tests of site media. For types of evidence that use data from elsewhere, the team was able to evaluate mechanistically plausible cause and stressor-response relationships

[4] U.S. EPA's rules for scoring types of evidence are reviewed at the beginning of each SOE scoring table.

Table 5. Measured variables relevant to each candidate cause

Increased autochthony
aquatic vegetation
canopy shade
chlorophyll *a*
RBP score: riparian vegetative zone width
water chemistry, 2000 & 2001 stormflows: total phosphorous, ortho-phosphorous, total Kjeldahl nitrogen, nitrite, & nitrate
water chemistry, 2000 baseflows: total phosphorous, ortho-phosphorous, total Kjeldahl nitrogen, nitrite, & nitrate
Decreased dissolved oxygen
canopy shade
chlorophyll *a*
RBP scores: channel alteration & riparian vegetative zone width
water chemistry, 2000 & 2001 stormflows: total phosphorous, ortho-phosphorous, total Kjeldahl nitrogen, nitrate, & nitrite
water chemistry, 2000 baseflows: total phosphorous, ortho-phosphorous, total Kjeldahl nitrogen, nitrate, & nitrite
water quality, 2000 baseflow: dissolved oxygen
Altered flow regime
baseflow discharge
baseflow thalweg velocity
percent impervious surface
RBP scores: channel alteration, channel sinuosity, & riparian vegetative zone width
stormflow, 1994 event
stormflow, 2001 event
Decreased large woody debris (LWD)
LWD count
RBP scores: channel alteration, channel sinuosity, & riparian vegetative zone width
Increased sediment
chlorophyll *a*
muck mud
Pfankuch rating (a measure of channel stability)
percent impervious surface
RBP scores: epifaunal substrate, pool substrate, sediment deposition, channel alteration, channel sinuosity, riparian vegetative zone width, bank vegetation protection, & bank stability
sediment size
water chemistry, 1994 stormflow: TSS
water chemistry, 2000 & 2001 stormflows: TSS
water chemistry, 2000 baseflows: TSS
Increased temperature
canopy shade
percent impervious surface
RBP scores: channel alteration, channel sinuosity, & riparian vegetative zone width
temperature: weekly minimum, maximum, & mean
Increased toxic substances
sediment chemistry, 1993
sediment chemistry, 2003
sediment toxicity, 2003
water chemistry, 1992 baseflow: copper, lead, & zinc
water chemistry, 1994 stormflow: copper, lead, & zinc
water chemistry, 2000 & 2001 storm flows: cadmium, copper, lead, nickel, & zinc
water chemistry, 2000 baseflows: cadmium, chloride, copper, lead, & nickel
water chemistry, 2000 stormflow polycyclic aromatic hydrocarbons (PAHs)
water chemistry, 2001 stormflow PAHs
water chemistry, 2003 low flow: aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, silver, thallium, vanadium, & zinc
water quality, 2000 baseflow: specific conductivity & salinity

Table 6. Applicable types of evidence [a]

Type of evidence	Concept	Project applicability	Analyzed for each specific effect
Types of evidence that use data from the case:			
Spatial/temporal co-occurrence	The biological effect must be observed where and when the cause is observed, and must not be observed where and when the cause is absent.	Site-specific data used	No, generalized across all 4 endpoints
Temporal sequence	The cause must precede the biological effect.	No evidence	NA
Stressor-response relationships from the field	As exposure to the cause increases, intensity or frequency of the biological effect increases; as exposure to the cause decreases, intensity or frequency of the biological effect decreases.	Scatter plot analysis applicable across all study sites	Yes, 3 of 4 endpoints: EPT richness, % non-insects, & HBI
Causal pathway	Steps in the pathways linking sources to the cause can serve as supplementary or surrogate indicators that the cause and the biological effect are likely to have co-occurred.	Site-specific data used	No, generalized across all 4 endpoints
Evidence of exposure or biological mechanism	Measurements of the biota show that relevant exposure to the cause has occurred, or that other biological mechanisms linking the cause to the effect have occurred.	No evidence	NA
Manipulation of exposure	Field experiments or management actions that increase or decrease exposure to a cause must increase or decrease the biological effect.	No evidence	NA
Laboratory tests of site media	Controlled exposure in laboratory tests to causes (usually toxic substances) present in site media should induce biological effects consistent with the effects observed in the field.	Site-specific sediment toxicity sample analysis for 2 of 3 impaired sites: LCN .415 & LCMn 2.274	Yes, 2 of 4 endpoints: EPT richness & % non-insects
Verified predictions	Knowledge of a cause's mode of action permits prediction and subsequent confirmation of previously unobserved effects.	No evidence	NA
Symptoms	Biological measurements (often at lower levels of biological organization than the effect) can be characteristic of one or a few specific causes.	No evidence	NA

Table 6. Applicable types of evidence [a] (continued)

Type of evidence	Concept	Project applicability	Analyzed for each specific effect
Types of evidence that use data from elsewhere:			
Mechanistically plausible cause	The relationship between the cause and biological effect must be consistent with known principles of biology, chemistry and physics, as well as properties of the affected organisms and the receiving environment.	Site-specific data compared to information from elsewhere; majority of analysis applicable across all study sites	Yes
Stressor-response relationships from laboratory studies	Within the case, the cause must be at levels associated with related biological effects in laboratory studies.	Site-specific data compared to information from elsewhere	Yes
Stressor-response relationships from other field studies	At the impaired sites, the cause must be at levels sufficient to cause similar biological effects in other field studies.	Site-specific data compared to information from elsewhere	Yes
Stressor-response relationships from ecological simulation models	Within the case, the cause must be at levels associated with effects in mathematical models simulating ecological processes.	Ecological simulation models were **not** used	NA
Analogous stressors	Agents similar to the causal agent at the impaired site should lead to similar effects at other sites.	No evidence	NA
Manipulation of exposure at other sites	At similarly impacted locations outside the case sites, field experiments or management actions that increase or decrease exposure to a cause must increase or decrease the biological effect.	No evidence	NA
Evaluating multiple lines of evidence:			
Consistency of evidence	Confidence in the argument for or against a candidate cause is increased when many types of evidence consistently support or weaken it.	Site-specific analysis	Yes
Explanation of the evidence	Confidence in the argument for a candidate cause is increased when a post hoc mechanistic, conceptual, or mathematical model reasonably explains any inconsistent evidence.	Site-specific analysis	Yes

[a] Source: U.S. EPA CADDIS Web site (http://www.epa.gov/caddis/).

from laboratory and other field studies. Data are not available for several types of evidence (see Table 6), and those types of evidence will not be discussed further. Types of evidence for which data are available are discussed below and organized in detail in the SOE Tables section (SOE Tables 1-50).[5]

3.2.1. Evidence That Uses Data from the Case

3.2.1.1. *Spatial/Temporal Co-occurrence*

The project team compared data from each impaired site to reference site data for each candidate cause. Table 7 provides a summary of spatial/temporal co-occurrence data, and SOE Tables 1-3 provide the complete dataset for this line of evidence. Scores are located in SOE Tables 1-3.

The project team made comparisons between samples collected on the same day and at similar times when possible; out of sync comparisons—for example, cross-year comparisons, were not used. If water quality samples taken at a biologically-impaired Long Creek site had higher lead (Pb) concentrations than corresponding samples at the Red Brook reference site taken on the same day and at a similar time, this would be considered supporting evidence for spatial/temporal co-occurrence at the Long Creek site, and Pb would be given a positive score in the appropriate table location. Only data directly representing proximate stressors (i.e., the candidate causes) were used as evidence for spatial/temporal co-occurrence. Data representing other steps in the causal pathway and surrogate measurements were considered under other types of evidence. The project team did not discriminate between small and large measured differences among data for the purposes of scoring spatial/temporal co-occurrence; even if the difference between the impaired sites and the reference site was small, the project team still considered this supporting evidence for the purpose of scoring. However, in some situations the team qualifies small and large differences either in the “General Comments” section of the SOE tables or within the text of this report.

3.2.1.2. *Stressor-Response Relationships from the Field*

The project team developed study-wide (Long Creek and Red Brook) scatter plots to assess stressor-response relationships, which might suggest that effects increase or decrease with increasing or decreasing exposure. Appendix G provides the scatter plots, which show biological impairment endpoints (EPT richness, percent non-insects, and HBI) as a function of stressor magnitude. The brook trout endpoint was not included in this analysis, as brook trout were assessed solely in terms of presence or absence. Nine sites along Long Creek and Red

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[5] The project team attempted to convey SOE information across multiple impaired sites, candidate causes, and lines of evidence with the least amount of repetition. Nevertheless, the SOE tables included at the end of this report contain some repetition of information so that appropriate comparisons can be made for SOE-scoring purposes.

Table 7. Spatial/temporal co-occurrence data summary [a,b]

Candidate Cause	Variable, units	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
Increased autochthony	dominant aquatic vegetation, approximate % of local reach	diatoms 25%	diatoms 25%	rooted submergents & diatoms 25%	diatoms 20%
	chlorophyll *a*, mg/m^2	10.4	15.7	no data	17.5
Decreased dissolved oxygen	dissolved oxygen, mg/L	8.7 [3] (8.0-9.5)	6.3 [3] (5.3-7.8)	5.3 [3] (4.1-7.4)	5.5 [3] (4.4-6.2)
Altered flow regime	baseflow discharge/watershed area, cfs/ac	0.00073 [2] (0.00071-0.00075)	0.00055 [2] (0.00035-0.00076)	no data	no data
	storm event peak discharge/watershed area, cfs/ac	0.0035	0.1338		
	storm event volume/watershed area, ac-ft/ac	0.0041	0.0276		
	storm event duration, hours	25.4	5.5		
	storm event time to peak discharge, hours	9.4	2.3		
	mean thalweg velocity, m/s	0.10	no data		0.03
	thalweg baseflow velocity measured at 2m increments along 100m reach in site vicinity	highly variable longitudinal velocity and velocity normally above zero			low longitudinal velocity variability and velocity often equal to zero
Decreased large woody debris	LWD diameter ≥5cm, # of pieces	91	no data	37	43
	LWD diameter ≥10cm, # of pieces	39		8	12
Increased sediment	baseflow TSS, mg/L	<10 [3] (<2 - <10)	<10 [3] (3- <10)	<10 [3] (1- <10)	<10 [3] (4- <10)
	stormflow TSS, mg/L	<10-118 [9]	<10-271 [9]	no data	no data
	muck-mud, %	60	40	70	40
	RBP[c] epifaunal substrate, score & category	13 sub-optimal	13 sub-optimal	13 sub-optimal	12 sub-optimal
	RBP[c] pool substrate, score & category	10 marginal	10 marginal	10 marginal	8 marginal
	RBP[c] sediment deposition, score & category	18 optimal	11 sub-optimal	18 optimal	18 optimal

Table 7. Spatial/temporal co-occurrence data summary [a,b] (continued)

Candidate Cause	Variable, units	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
Increased temperature	weekly minimum, °C	12.9 [3] (11.4-14.0)	16.3 [3] (15.4-17.3)	17.0	13.2
	weekly maximum, °C	21.1 [3] (20.3-22.1)	22.7 [3] (21.6-24.2)	23.3	21.8
	weekly mean, °C	16.7 [3] (16.1-17.4)	19.2 [3] (18.6-20.0)	20.2	16.5
Increased toxic substances - water column samples, units in ppm or mg/L, except specific conductivity uS/cm: (not all toxic substances data are shown here, rather only values for which all 4 sites have co-occurring data; SOE tables 1 - 3 show **all** collected data)					
Ionic strength	baseflow chloride	29 [3] (26-30)	122 [3] (91-141)	99 [3] (83-124)	66 [3] (58-73)
	baseflow specific conductivity, uS/cm	129 [3] (79-155)	745 [3] (659-796)	568 [3] (491-718)	459 [3] (376-510)
Cadmium	baseflow	<0.0005 [3]	<0.0005 [3]	<0.0005 [3]	<0.0005 [3]
Copper	baseflow	<0.002 [3]	<0.002 [3]	<0.002 [3]	0.0013 [3] (<0.002-0.002)
Lead	baseflow	<0.003 [3]	<0.003 [3]	<0.003 [3]	< 0.003 [3]
Nickel	baseflow	<0.004 [3]	<0.004 [3]	<0.004 [3]	< 0.004 [3]
Zinc	baseflow	<0.005 [3]	0.014 [3] (0.013-0.015)	<0.005 [3]	0.0042 [3] (<0.005-0.005)

[a] Baseflow values shown as mean [n] (range), where more than one value available, and stormflow values shown as range [n]. (note that a range is provided for baseflow only if a toxic substance was detected).
[b] Lower thresholds of essential elements are not considered in this causal analysis.
[c] Rapid Bioassessment Protocol (RBP):

Habitat Parameter:	Score and Condition Category:
epifaunal substrate / available cover	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
pool substrate characterization	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
sediment deposition	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal

Brook, for which both endpoint and stressor data were collected, were used for this analysis; these sites include the three impaired sites and single reference site. The scatter plot analysis is not reported and scored on a site-by-site basis (see SOE Table 4), but is considered a characterization of the entire project area (both watersheds). With data from nine study sites throughout the project area, sample size is not sufficient to make judgments about individual sites or stream reaches. Rather, the project team sought only to characterize trends, if possible, across all nine sites.

The project team interpreted the scatter plots by looking for linear and curvilinear trends in the data. The team supplemented visual interpretation with statistical correlation coefficients (Appendix H). Based on available data, at least one biological endpoint appeared to correlate with stressors associated with the following candidate causes: increased autochthony, decreased dissolved oxygen, decreased large woody debris, increased temperature, and increased toxic substances, specifically ionic strength (SOE Table 4 reports SOE scores by endpoint).

Specific conductivity and chloride (often representative of ionic strength) were the only two variables for which the project team interpreted a correlation for all three assessed endpoints (EPT richness, percent non-insects, and HBI). As specific conductivity and chloride increase throughout the two study watersheds, EPT richness decreases while percent non-insects and HBI values increase.

The scatter plot analysis shows EPT richness decrease as a function of increasing percent impervious surface area. This information was *not* used for scoring this type of evidence. The project team uses impervious surface area as a surrogate measure for scoring the altered flow regime candidate cause for another type of evidence—specifically, stressor-response relationships from other studies (see Section 3.2.2). The team chose not to use surrogate measures for assessing types of evidence that only use data from the case study sites. Those types of evidence are generally considered stronger than those relying on information from outside the case study; likewise, surrogate measures are at least one step removed from the cause-and-effect relationship, and thus, introduce a weaker form of evidence.

3.2.1.3. *Causal Pathway*

The project team found supporting evidence for some causal pathway steps across all candidate causes at all three impaired sites (SOE Tables 5-11). The conceptual models (CM Figures 1-10) show causal pathways for each candidate cause. The project team scored this association with a single plus in the SOE tables, not broken down by individual biological endpoint (SOE Tables 12-18). The team used increased percent impervious surface area as a causal step for all candidate causes except increased autochthony, and percent impervious surface area was often the strongest supporting evidence within a causal pathway (e.g., for increased toxic substances).

3.2.1.4. *Laboratory Tests of Site Media*

Sediment samples were taken from the reference site and LCN .415 and LCMn 2.274 (U.S. EPA, 2004a). The samples were tested in the laboratory for toxicity to chironomids (*Chironomus tentans*) and amphipods (*Hyallela azteca*), which the project team used as surrogates for EPT and non-insects, respectively. The sediment toxicity testing laboratory determined that chironomid survivorship differences among the two impaired sites tested, the reference site, and the laboratory control were not statistically significant under laboratory conditions (U.S. EPA, 2004a). Amphipod survival, under laboratory tests, was significantly lower at both the reference site and impaired site LCN .415 than under the laboratory control; survival at LCMn 2.274, however, was similar to the control. This offers conflicting information, considering more amphipods were found at LCN .415 than at the reference site. If sediment-related toxicity at the reference site is negatively impacting amphipods, the laboratory results indicate that the same effect might be observed at LCN .415 in the field, which is not the case. The project team scored this type of evidence zero (or uncertain) for the EPT richness and percent non-insects endpoints. SOE Tables 19 and 20 show data and scores for this type of evidence.

Chironomids are generally thought to be more tolerant than EPT, and this was taken into consideration when scoring; had this dataset revealed a more significant correlation, the project team might have revisited the use of chironomids as surrogates for EPT and attempted to qualify conclusions. It should be noted that laboratory tests were conducted in controlled environments, unlike conditions found in the field, where more factors often interact and impact organism health.

3.2.2. Evidence That Uses Data from Elsewhere

3.2.2.1. *Mechanistically Plausible Cause*

Scoring for mechanistically plausible cause was similar for all three sites and yielded supporting or neutral scores for each candidate cause.[6] Some mechanisms linking cause and effect are described earlier and in Appendix F, to which the following text often refers.

The project team classified invertebrate taxa at each site according to functional feeding group and mode of existence (Merritt and Cummins, 1996). The project team then calculated relative site-specific abundance of each group (SOE Table 21). Values were compared across the reference site and impaired sites to determine if the data support increased autochthony and/or increased sediment as causes of impairment, under the mechanistically plausible cause

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[6] Unlike other types of evidence for which data are available, a separate table was not created for this type of evidence (i.e., mechanistically plausible cause); scoring is described in this section of the text for each candidate cause and each biological endpoint.

type of evidence. Relative abundance of functional feeding and mode of existence groups varied widely across the three impaired sites. In some cases, variability resulted from dominance of one or a few taxa at some subset of these sites. For example, the coleopteran *Dubiraphia* (gatherer, clinger-climber) was absent from LCN .415, but comprised 41% and 60% of total invertebrate abundance at LCM 2.270 and LCMn 2.274, respectively.

For **increased autochthony**, the project team expected to find food resource changes reflected by increases in scraping taxa and decreases in shredding taxa at impaired sites relative to the reference site. However, the data do not reflect this pattern: the highest relative abundance of scrapers is seen at the reference site, and the functional feeding group analysis does not show a clear pattern among the sites for percentage of shredders. Thus, the project team assigned a neutral score (zero; no mechanism is known) to the EPT richness endpoint across all three sites. Increased abundance of snails (non-insects) is often associated with increased autochthony, and data show that snails were found at LCN .415 and LCMn 2.274 but not at the reference site or LCM 2.270; therefore, for increased autochthony, the team scored the percent non-insects endpoint positive (single plus; plausible mechanism exists) for LCN .415 and LCMn 2.274 but neutral for LCM 2.270. HBI would be expected to increase, as it was originally designed to assess low dissolved oxygen caused by organic loading, and organic loading is often associated with increased autochthony (therefore, positive score for HBI across all three sites). The team did not find appropriate evidence to associate increased autochthony with changes in brook trout abundance.

The project team scored mechanistically plausible cause for **decreased dissolved oxygen** positive for all endpoints across all three sites. Low dissolved oxygen levels can cause asphyxiation for EPT taxa and brook trout and relative increases in tolerant non-insect taxa. HBI would be expected to increase, as it was originally designed to assess low dissolved oxygen caused by organic loading.

Altered flow regime also was scored positively for all endpoints across all three impaired sites. The project team focused on lower day-to-day baseflow conditions (a component of hydrologic flashiness) as the specific candidate cause for this type of evidence. Appendix F describes mechanisms linking EPT richness and brook trout to running water habitats. Certain non-insect taxa (e.g., oligochaetes and snails) are tolerant of lentic conditions; similarly, several taxa with high HBI tolerance values (e.g., many chironomids and oligochaetes) are less reliant on fast-flowing habitats.

Large woody debris provides habitat and cover for EPT taxa and brook trout (see Appendix F for more detailed information). A photograph taken upstream of RB 3.961 shows caddisflies attached to submerged large woody debris (Figure 5). Mechanistically plausible causes for changes in percent non-insects and HBI with respect to large woody debris are

Figure 5. Caddisflies and large woody debris under water at reference site RB 3.961. Source: MEDEP staff; photograph taken in 2004.

unknown. The project team scored EPT richness and brook trout endpoints positive and the percent non-insects and HBI endpoints neutral for large woody debris across all three sites.

For **increased sediment**, the project team might expect to see increases in suspended sediment lead to decreases in abundance of filter-feeding taxa, many of which are trichopterans. This was observed, as filterer percentage was highest at the reference site, and therefore, the team scored the EPT richness endpoint positive across all three sites. Non-insect taxa like oligochaetes often increase in abundance with increasing fine sediments, and so this endpoint received a positive score. Zweig and Rabeni (2001) indicate that HBI may be insensitive to increases in deposited sediments, and that traits associated with susceptibility to organic enrichment (as related to HBI) are often not related to traits associated with sediment deposition. The HBI endpoint received a neutral score (zero) across all three sites. Mechanisms related to increased sediment and brook trout are discussed in Appendix F; the brook trout endpoint was assigned a positive score.

The project team scored mechanistically plausible cause for **increased temperature** positive for the EPT richness and brook trout endpoints for all three sites (see Appendix F). The team could find no mechanistic information associating increased temperature with increases in percent non-insects or HBI values, so these endpoints were assigned neutral scores.

The project team scored mechanistically plausible cause the same for all **toxic substances**: positive for EPT richness and brook trout but neutral for percent non-insects and HBI. The team assumes EPT richness and brook trout are likely to decline in the presence of increased toxic substances, but the team is uncertain whether percent non-insects and HBI taxa respond positively or negatively at similar toxic substance concentrations. Thus, percent non-insects and HBI endpoints were assigned neutral scores.

3.2.2.2. *Stressor-Response Relationships from Laboratory and Other Field Studies*

SOE data and scores for stressor-response relationships from laboratory and other field studies[7] used for this case study are shown in SOE Tables 22 through 37, with a separate table for polycyclic aromatic hydrocarbons (PAHs; SOE Table 38).

Species sensitivity distributions (SSDs; Appendix I) were developed for those metals having adequate data in U.S. EPA's public-access ECOTOX database (http://www.epa.gov/ecotox). SSDs are exposure-response relationships representing distribution of species sensitivities relative to exposure to individual metals in the water column. Because variance of sensitivities to chemicals among species is often more important to ecological risk assessment than variance among individuals, SSDs have become common in ecological effects analyses in the U.S., Europe, and elsewhere (Posthuma et al., 2002; see U.S. EPA, 2005 for additional information on the generation and utility of SSDs in causal assessment).

Case study SSDs were generated using laboratory LC50 data. Since an LC50 is a concentration that kills half of the organisms in a test population, one would expect to observe a fish kill or a temporary reduction in the abundance of some species when water concentrations equal the LC50 for that species. Data used in generating SSDs do not represent specific species present at the study area. Toxicity data are generally not available for site-specific taxa due to the diversity of species occurring in the wild and the need to perform toxicity tests with well characterized organisms that can be successfully cultured in the laboratory.

For each metal, the project team selected freshwater aquatic organism tests with site-appropriate water hardness (18-60 mg $CaCO_3$/L), pH (6-8), and temperature (>15°C). It was necessary to generate SSDs with data for total metals because greater than 90% of freshwater metals data in ECOTOX are reported as total metals. Free ion or dissolved metal concentrations would be more appropriate indicators of actual toxic exposure and preferred for comparison with Long Creek dissolved metal data. However, the relative bioavailability of metals in unfiltered

[7] U.S. EPA Stressor Identification guidance (U.S. EPA, 2000a) splits stressor-response relationships that use data from elsewhere into three categories: from laboratory studies, from other field studies, and from ecological simulation models. Laboratory and other field studies were combined into one table and one type of evidence for ease of presentation in this document. Ecological simulation models were not used in this case study.

lab and natural waters differs because laboratory water contains little suspended matter. The project team did not generate SSDs for metals with sparse available toxicity data.

Separate SSDs were generated for invertebrates and fish. In comparing SSDs for different species groups, invertebrates are generally more sensitive than fish. This difference may be due to the differing life spans of the two groups: a short (acute) exposure for relatively long-lived species such as brook trout may be equivalent to a long (chronic) exposure for relatively short-lived species such as caddisflies. Data were further subdivided to generate SSDs addressing potential effects at baseflow/low flow exposures (3-30 days) and at stormflow/pulsed exposures (<30 hours). Where possible, the project team superimposed site-specific data on SSD plots (i.e., the proportion of decreased EPT richness, relative to the reference site, and site-specific observed metal concentrations). This was done to illustrate whether species reductions were plausible given site concentrations and whether the magnitude of effect observed at a given site is consistent with that suggested by the SSD.

The project team chose to use **impervious surface area** as a surrogate measure for the altered flow regime candidate cause in the context of this type of evidence—that is, stressor-response relationships from elsewhere. The use of impervious surface area, specifically increased hydrologic flashiness, allows the team to take advantage of endpoint-specific stressor-response data from other studies (see SOE Table 24).

Impervious surface is often associated with the presence of other stressors and might be used as surrogate measure for those stressors; however, of the candidate causes identified in this case study, impervious surface is the least removed from altered flow regime. That is, from a causal pathway perspective, impervious surface directly alters flow with no interim steps. Specifically, precipitation falls and impervious surface alters a watershed's hydrology. For impervious surface to increase toxic substances, for example, there must first be a source of toxic substances, the output of which may vary through time, and a mechanism by which the substances reach impervious surfaces, and then precipitation must mobilize the substances before they impair the watershed or stream. Unlike the link between impervious surface and altered flow regime, the link with increased toxic substances involves more steps.

In the context of urban hydrology, flow regime may be governed principally by two factors: (1) a watershed's contributing impervious surface area and (2) the efficiency with which water moves over land and into and through channels (e.g., Leopold, 1968). These two factors are also employed as major inputs for some hydrologic models (e.g., U.S. Army Corps of Engineers Hydrologic Engineering Center's modeling products: http://www.hec.usace.army.mil/). Measures of percent impervious surface area contributing to each stream study site are available (Table 2). More qualitative evidence from the case can be used to characterize the second factor described above, that is, hydraulic efficiency. A recent aerial photograph of the project site (dated April 2001; Figure 3) shows significantly more urbanization in the vicinity of and adjacent to Long Creek in comparison to the area of Red Brook associated with the reference site (where forested land appears instead of urban land uses). Those urban areas in the Long Creek vicinity are associated with storm drain systems and a greater density of culverts, both likely corresponding with less flow resistance (concrete and metal channels generally have lower roughness values than vegetated channels), less channel sinuosity and shorter travel times (synthetic channels are often straightened), and less sub-surface infiltration opportunities between areas of impervious surfaces and the stream channel (implications of impervious areas directly connected to streams are reviewed by Walsh et al., 2005a, b). Given that the impaired site watersheds have greater stormflow hydraulic efficiency than the reference site watershed, and accepting the simplified two-factor flow regime premise stated above, it is permissible to use impervious surface area as a surrogate measure for altered flow regime, qualitatively and conservatively.

3.2.3. Evaluation of Multiple Types of Evidence

3.2.3.1. *Consistency of Evidence*

SOE Table 39 shows U.S. EPA's scoring system for consistency of evidence. SOE Tables 40-42 provide summaries of case study scores, including consistency of evidence, with one table for each of the three impaired sites. SOE Table 43 provides only consistency of evidence scores so that the three sites can be compared.

The project team determined scores for this type of evidence by isolating individual sites, causes, and endpoints, then assessing the overall body of evidence consisting of the six types of evidence previously scored. For example, beginning with site LCN .415, going to the "Increased autochthony" column of SOE Table 40, and reviewing the scores for the EPT richness endpoint, the spatial/temporal co-occurrence and causal pathway scores (0 and +, respectively) apply across all biological endpoints, including EPT richness. EPT richness scores for stressor-response relationships from the field, mechanistically plausible cause, and stressor-response relationships from the laboratory and other field studies are 0, 0, and 0. There was no evidence to evaluate the remaining association, laboratory tests of site media, which applies only to the sediment toxicity sub-category of the increased toxic substances candidate cause. For this particular example, the evidence is ambiguous and inadequate; therefore, the team assigned a score of zero, neither supporting nor weakening the case for increased autochthony for the EPT richness endpoint.

Not all consistency of evidence scoring scenarios are as clear-cut as the above example. The project team applied several general rules of thumb while attempting to score consistency of evidence:

- NOT summing scores; for example, [0 and + and ++ and –] $\neq$ ++ or +2
- Considering confidence of scores from other types of evidence individually; for example, the team might take into account sample size for a particular type of evidence, especially when a borderline positive or negative score was assigned
- NOT considering all types of evidence with equal weight; there were exceptions, but in general, the following ranking held true for this case study (from strongest to weakest):
    1. Spatial/temporal co-occurrence
    2. Stressor-response relationships (from this case and from elsewhere) and laboratory tests of site media
    3. Mechanistically plausible cause and causal pathway
- NOT considering the overall body of evidence strong enough to assign +++ to any given endpoint; however, for situations where support was relatively strong, the team assigned ++
- Viewing this exercise as a comparative analysis within the context of the overall case study; this part of the process provided us with an opportunity to highlight findings that merit additional emphasis[8]

3.2.3.2. *Explanation of Evidence*

For the explanation of evidence association, the project team followed U.S. EPA's Stressor Identification scoring system (see SOE Table 44). SOE Tables 45-48 show complete SOE scoring tables, including all candidate causes and all types of evidence. The team did not assign scores for many of the metals because of insufficient data. Inconsistency and ambiguity among types of evidence are discussed in Section 4.

3.2.4. Additional Evidence Within the Case Study Watersheds

A previous study of Long Creek and Red Brook (South Portland Engineering Department, 1994) and aerial photographs (see Appendix A) of the two watersheds provide additional evidence for the case study. However, the project team did not include or score this evidence as part of the SOE framework because data from the previous study was not gathered in the vicinity of the case study sites, and the team was unable to interpret the aerial photographs with confidence.

3.2.4.1. *Stream Discharge*

The South Portland Engineering Department (1994) collected stream flow data during an August 18, 1994, storm. They took measurements on Long Creek and Red Brook, just upstream

[8] U.S. EPA's CADDIS Web site, http://www.epa.gov/caddis, and specifically "Step 5: Identify Probable Cause," provides additional information and advice on the comparative process of bringing together multiple lines of evidence.

of Clark's Pond. South Portland Engineering Department (1994) noted that Red Brook stormflow "lags by a couple of hours" behind Long Creek and does not show "flow increase until over 0.75″ of rain has fallen," whereas Long Creek "immediately shows a flow increase." The South Portland City Engineering Department developed a hydrograph for the storm, indicating that Long Creek has a flashier flow regime, marked by greater peak flow and greater runoff volume. The data lend support to the altered flow regime candidate cause but not specifically at the team's study sites.

3.2.4.2. *Toxic Substances*

South Portland Engineering Department (1994) conducted toxic substance sampling on Long Creek and Red Brook, just upstream of the confluence with Clark's Pond. They took water column measurements on October 5, 1992, during baseflow conditions, and on August 18, 1994, during stormflow conditions. SOE Tables 49 and 50 provide comparisons between South Portland Engineering Department (1994) measurements and measurements taken by MEDEP (2002a). Baseflow concentrations measured by South Portland Engineering Department for copper (Cu) and Pb in Long Creek are close to stressor-response benchmarks (see SOE Tables 49 and 50) and higher than those found in Red Brook. The data support the case for increased toxic substances as a cause of impairment on Long Creek but not specifically at study site locations.

3.2.4.3. *Aerial Photographs*

Aerial photographs taken in 1940, 1952, 1976, 1995, 1998, and 2001 show the confluence of Long Creek and Red Brook with Clark's Pond (Appendix A). Four of six photographs (1952, 1976, 1995, and 2001) appear to depict higher levels of suspended solid content originating from Long Creek than from Red Brook, just upstream of Clark's Pond.[9] The project team cannot pinpoint the source of the suspended solids. Is the water column cloudiness normal for Long Creek due to surficial geology and/or soil type, a result of erosion due to stormflow runoff, or specific to some other unknown event or events, such as a construction project? The data lend questionable support to the increased sediment candidate cause.

[9] The resolution and clarity of the historic aerial photographs shown in Appendix A do not allow speculation on the color difference between Long Creek and Red Brook for 1940 and 1998.

4. CONCLUSIONS

This section of the report documents conclusions of the stressor identification process based on SOE analysis. The conclusions are organized as follows:

1. Similarities across all three impaired sites as described by candidate cause, providing a watershed perspective on broad-reaching probable causes
2. Findings unique to each impaired site
3. Summaries of evidence for each specific effect or biological endpoint
4. Conclusions about the likelihood of each candidate cause contributing to Long Creek's impairment

All information found in the SOE tables (SOE Tables 1-50) is not covered in this section; rather, *key points* are highlighted. Further, the project team recognizes that some candidate causes have more complete supporting datasets than other causes; this represents a potential source of bias in the case study and will be discussed at the end of this report in Section 6.

4.1. FINDINGS CONSISTENT ACROSS ALL THREE SITES

4.1.1. Increased Autochthony—An Unlikely Cause

Chlorophyll *a* concentrations recorded at four Long Creek sites are higher than at two Red Brook sites; however, none of the six measurements were taken at the exact locations of the three impaired sites or reference site; rather, the surrogate sites are open-canopy sections of the streams. Further, the level at which chlorophyll *a* concentrations indicate shifts in basal food resources, and the transition between autochthony and allochthony, is uncertain. Site reconnaissance suggests that all three impaired sites have dominant aquatic vegetation similar to the reference site. Scatter plots show that HBI values increase with increasing Kjeldahl nitrogen and total and ortho-phosphorus concentrations; relationships with other biological endpoints analyzed (EPT richness and percent non-insects) are ambiguous. The functional feeding group analysis does not support the increased autochthony hypothesis, because the relative abundance of scrapers and filterers decreases relative to the reference site.

4.1.2. Decreased Dissolved Oxygen—A Probable Cause

Pre-dawn dissolved oxygen measurements are lower at the impaired sites than at the reference site. Scatter plots indicate that HBI values increase as dissolved oxygen decreases; relationships with other biological endpoints analyzed (EPT richness and percent non-insects) are ambiguous. All dissolved oxygen measurements from the impaired sites fall below the U.S. EPA benchmark (see SOE Table 23), with expected implications for EPT richness and brook trout; all observed levels at the impaired sites also fall below the optimum brook trout level. Minimum dissolved oxygen concentrations at the impaired sites are below or close to documented EPT 30-day LC50 values.

4.1.3. Altered Flow Regime—A Probable Cause

Available evidence indicates that the impaired watershed is impacted by increased hydrologic flashiness, characterized by greater peak storm discharges, more frequent peak discharges, and lower between-storm baseflow. The majority of evidence specifically points to decreased baseflow as a probable cause of impairment. Site reconnaissance and thalweg velocity measurements throughout the Long Creek and Red Brook watersheds indicate that Long Creek has lower baseflow and less baseflow longitudinal heterogeneity relative to the reference site on Red Brook.

The watersheds contributing to the impaired sites have higher impervious surface areas (33%, 14 %, and 7%) than the reference site (2%). If impervious surface area is used as a surrogate for altered flow regime in the stressor-response analysis that uses data from other studies (see Section 3.2.2.2), then, based on a study of Maine streams conducted by Morse et al. (2003), the project team would expect to see decreased EPT richness and brook trout, and increased percent non-insects at the impaired sites, which was indeed the case.

4.1.4. Decreased Large Woody Debris—A Probable Cause

Scatter plots show that EPT richness increases while percent non-insects and HBI values decrease with increasing large woody debris abundance. Evidence from the case was recorded as number of pieces of large woody debris along a 100-meter reach near each study site (excluding LCN .415). Evidence from other field studies indicates that large woody debris abundance is positively correlated with aquatic invertebrate abundance and diversity (Smock et al., 1989; Benke et al., 1984) and trout habitat (Neumann and Wildman, 2002; Flebbe, 1999). This evidence allowed the project team to make *qualitative* judgments regarding the case study data as part of the stressor-response analysis conducted for data from other studies. Thus, the project team assumes that greater abundance of large woody debris increases EPT richness and brook trout abundance while less large woody debris does the opposite. In a synthesis report on large woody debris, Benke and Wallace (2003) note that the significance of large woody debris for invertebrates has been documented, but that the *quantitative* role has not yet been determined; the team reached a similar conclusion while conducting this case study.

4.1.5. Increased Sediment—A Possible Cause, but Conflicting Evidence

Baseflow total suspended solids concentrations at the impaired sites are approximately the same as those taken at the reference site, and the values do not exceed levels reported to negatively affect aquatic invertebrates or brook trout. The percentages of burrowing and sprawling invertebrates, generally representative of higher deposited sediment levels, found at the impaired sites are not higher relative to the reference site, also weakening the case for this cause. Pfankuch and Rapid Bioassessment Protocol scores provide some support for this candidate cause across the impaired sites. Sediment at both the reference site and at the impaired sites is potentially fine enough to hinder brook trout egg survival, adding ambiguity to the case for this cause; if this were a primary cause of stress to brook trout, the project team would not expect to see brook trout at the reference site. Underlying differences in surficial geologies (see Appendix E) within the two case study watersheds may ultimately be responsible for differences in sediment behavior. The aerial photographs discussed in Section 3.2.4 provide weak support for this cause. Three of the five photographs appear to show a greater amount of suspended solids in Long Creek relative to Red Brook just upstream of Clark's Pond.

The project team acknowledges that the case study streams are sandy-bottomed (reference and impaired sites), and biological sampling data, as used by the project team, was gathered using MEDEP's standard rockbag collection techniques. The rockbag sampling mechanism may have provided refuge for some organisms not naturally present at the sites, and consequently, impacted sampling results and SOE conclusions, specifically with respect to substrate and the increased sediment candidate cause. However, while not detailed in this report, MEDEP also conducted D-frame, kicknet, multihabitat sampling of sites, which removes (or alters) the potential substrate sampling bias. Based on cursory review by project team biologists, multihabitat sampling results reflect similar biological conditions and trends as determined by the rockbag results. Information on the multihabitat sampling data can be found in MEDEP (2002a).

The project team cannot rule out increased sediment as a potential cause, likely in the form of fine bedded sediments, but the degree to, and mechanisms by which it is acting are unclear.

4.1.6. Increased Temperature—A Probable Cause

Measured temperatures at the impaired sites are higher than those measured at the reference site. Scatter plots indicate that HBI values increase with increasing maximum temperature, but relationships with other invertebrate endpoints are ambiguous. The stressor-response analysis based on data from other studies supports the case for this cause for the EPT richness and brook trout endpoints, to varying degrees among the impaired sites.

4.1.7. Increased Toxic Substances—Ionic Strength is a Probable Cause

Impervious surface area within the impaired watersheds is higher relative to the reference site, providing a potential means (that is, a step in the causal pathway) for increased stormwater concentrations of toxic substances to reach the impaired streams.

The project team cannot rule out metals and PAHs for which field data and stressor-response data, based on evidence from other studies, are sparse.

Baseflow measurements of specific conductivity and chloride are higher at the impaired sites than at the reference site, supporting the case for toxicity due to increased ionic strength. Scatter plots indicate that EPT richness decreases while HBI values and percent non-insects increase with baseflow chloride and specific conductivity. Of the scatter plots used for stressor-response relationships from the field, specific conductivity and chloride appear to show the strongest correlations, supporting the case for toxicity due to ionic strength. The observed relationship between EPT richness and specific conductivity within the study area is consistent with relationships observed throughout Maine (Figure 6) and in Florida and Kentucky (Appendix J).

There is debate among scientists as to the mechanisms responsible for biological impairment associated with ionic strength. For example, disruption of osmotic regulation, decreased bioavailability of essential elements, increased availability of toxic metal ions, increases in other particularly harmful ions, ionic composition changes, or other as yet unknown mechanisms may all affect toxicity associated with ionic strength. The project team acknowledges that teasing apart proximate stressors and interacting stressors associated with ionic strength may not be possible at this point but the team recognizes that there is significant supporting evidence to promote ionic strength from candidate to probable cause of impairment. As a probable cause, increased ionic strength at the impaired sites may not be responsible for organism mortality, but rather a shift in community structure (also see Section 4.3.2).

4.2. FINDINGS PARTICULAR TO INDIVIDUAL SITES

Table 8 summarizes findings unique to one or common between two of the three impaired sites. Stakeholders involved with management decisions may benefit by addressing watershed-wide causes of impairment and causes of impairment unique to specific locations within the project area.

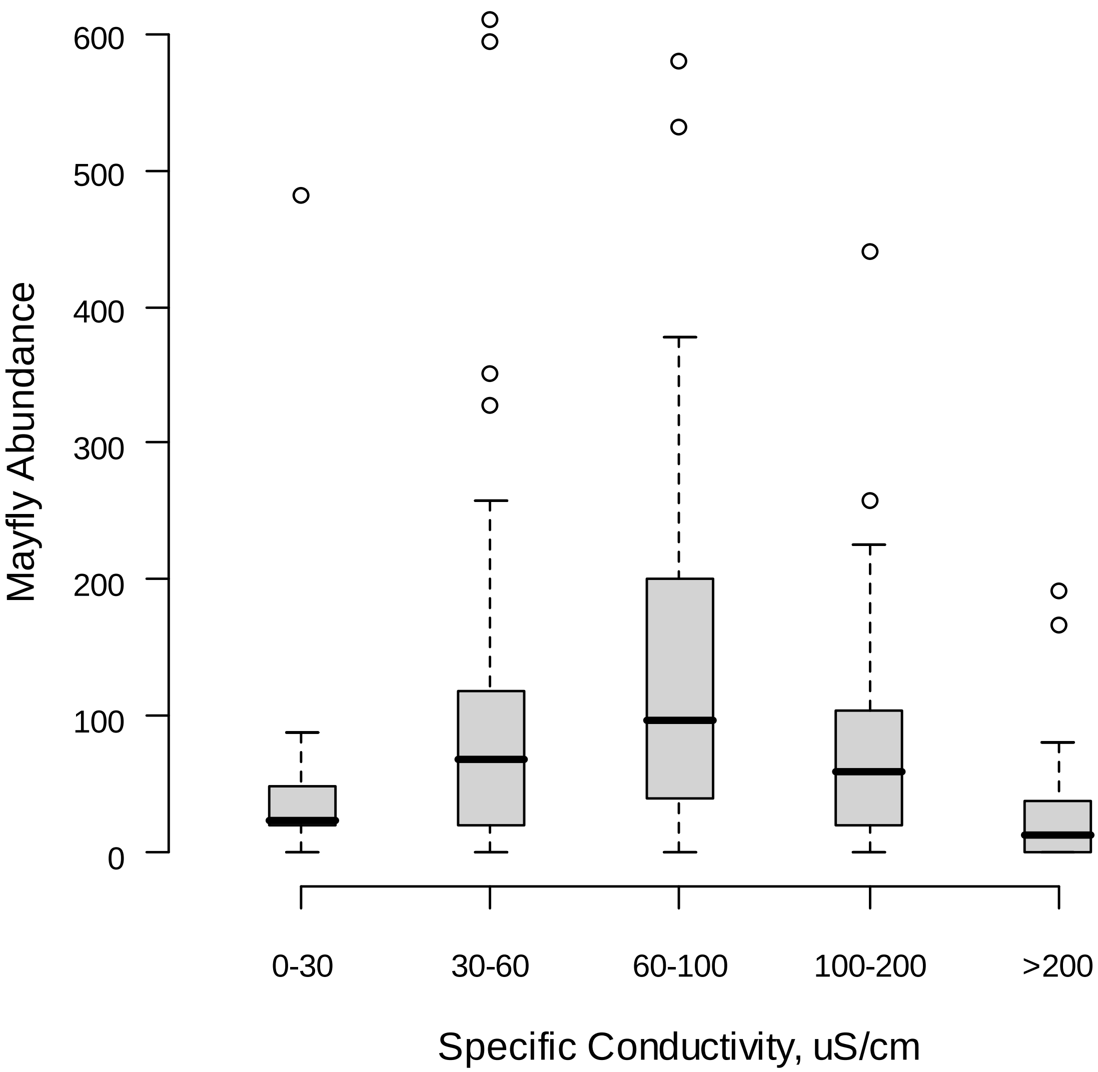

Figure 6. Maine stream mayfly abundance versus specific conductivity.

Sample size = 175
Source: Analysis and presentation of data adapted from Davies et al. (unpublished).

Table 8. Unique findings by candidate cause and site [a]

<table>
<tr><th>Candidate cause</th><th>LCN .415</th><th>LCM 2.270</th><th>LCMn 2.274</th></tr>
<tr><td>Increased autochthony</td><td>Evidence for increased autochthony at LCN .415 is ambiguous; stressor-response relationships from laboratory or other field studies show that baseflow phosphorus levels might be causing effects, but other measures are at or below benchmark criteria.</td><td colspan="2">Evidence is sparse for these two sites. Stressor-response relationships from laboratory or other field studies weaken the case for this cause because measured nutrient values are at or below benchmark criteria.</td></tr>
<tr><td>Altered flow regime</td><td>A storm event hydrograph and related analysis show that this site's hydrology has been altered (greater and more frequent peak flows and lower baseflows).</td><td>Detention upstream of this site may contribute to reduced baseflows. There is some evidence for channel alteration. Thalweg velocity measurements were not taken at the site, but those close to the site suggest that longitudinal flow heterogeneity and baseflow are low along this reach.</td><td>Baseflow velocity was lower at LCMn 2.274 relative to the reference site, and thalweg velocity measurements were often equal to zero in the vicinity of the site. Longitudinal flow heterogeneity is low in the vicinity of this site compared to the reference site. There is evidence for channel alteration and decreased large woody debris, which may be indicative of altered flow.</td></tr>
<tr><td>Decreased large woody debris</td><td>For this site specifically, the majority of support rests with the scatter plot analysis as described in the text for all three impaired sites.</td><td colspan="2">Abundance measurements for large woody debris at these two impaired sites are lower than at the reference site.</td></tr>
<tr><td rowspan="2">Increased sediment</td><td rowspan="2">Stormflow total suspended solids (TSS) concentrations are higher at LCN .415 relative to the reference site, and potentially high enough to cause decreases to invertebrate populations. Depositional “muck-mud” is, however, lower at the impaired site. RBP sediment deposition scores are lower relative to the reference site (i.e., worse at the impaired site) although substrate scores are the same. Sediment sizes are slightly higher relative to the reference site, weakening the case that fine sediments may be hindering brook trout egg survival.</td><td>Depositional “muck-mud” is higher at the impaired site.</td><td>Depositional “muck-mud” is lower at the impaired site.</td></tr>
<tr><td colspan="2">Storm event total suspended solids (TSS) data are not available for these two sites. RBP substrate and deposition scores are approximately the same relative to the reference site. As mentioned in the text for all three impaired sites and the reference site, sediments are potentially fine enough to hinder brook trout egg survival; however, while sediments at the reference site are small, sediments at these two impaired sites (LCM 2.270 & LCMn 2.274) are especially small (i.e., greater than 90% of particles are between 0.062 & 0.13 mm at the impaired sites, as opposed to 53% at the reference site).</td></tr>
</table>

Table 8. Unique findings by candidate cause and site [a] (continued)

Candidate cause	LCN .415	LCM 2.270	LCMn 2.274
Increased temperature	Watershed impervious surface area is high at this location; the project team found some literature correlating temperature and impervious surface, additional research in this area may be helpful for understanding the impact of temperature and impervious surfaces, in the context of Long Creek.	The upstream detention pond and riparian devegetation associated with the golf course may contribute to increased temperature.	Temperatures recorded at this site did not conclusively exceed those observed at the reference site. Riparian devegetation associated with the upstream office park may contribute to increased temperature.
		Rockbag sampling shows *Caenis* sp. (Ephemeroptera) as the second most abundant organism at these two sites but absent at the reference site and at LCN .415. While EPT taxa generally are more sensitive to ecosystem alterations, *Caenis* sp. is tolerant of high temperature (literature review by Galli and Dubose, 1990); however, this may be a deceptive indicator, as *Caenis* sp. is known to be tolerant of other stressors (e.g., low baseflow).	
Increased toxic substances	Stormwater measurements for concentrations of lead, zinc, copper, chloride, and PAHs are high relative to the reference site, but nothing stands out except stormflow copper. Stressor-response relationships from other studies indicate that episodic toxicity from metals, such as copper in stormflows, may reach levels capable of impacting EPT & brook trout. Sediment toxicity tests showed no decreases in survival of amphipods or midges relative to the reference site.	The stressor-response analysis does not support the case for toxicity due to metals (at least, for those sampled) in baseflow.	Sediment toxicity tests showed no decreases in survival of amphipods or midges relative to the reference site. Stressor-response relationships from other studies do not support the case for toxicity due to metals (at least, for those sampled) in baseflow.

[a] This table shows findings unique to one or two sites *only;* findings that are similar across all three impaired sites are discussed in the text (decreased dissolved oxygen is not shown here because findings were consistent across all three impaired sites).

4.3. ENDPOINT SPECIFIC FINDINGS

4.3.1. Decreased EPT Richness

Available evidence supports decreased dissolved oxygen, toxicity due to ionic strength, altered flow regime, and decreased large woody debris as probable causes for decreases in EPT richness across all three impaired sites. The project team suspects decreased dissolved oxygen and altered flow regime (specifically decreased baseflow) act jointly to decrease EPT richness at the impaired sites (see Section 5.1). More detailed discussion of ionic strength and Ephemeroptera is included in Section 4.1. Increased temperature is a probable cause for decreased EPT richness at LCM 2.270 and LCMn 2.274.

4.3.2. Increased Percent Non-insects

Increased ionic strength may be responsible for increases in percent non-insects at LCN .415 and LCM 2.270. (The project team did not analyze the third impaired site, LCMn 2.274, in terms of the percent non-insects endpoint; see Section 2.3.)

In laboratory tests conducted to determine relative salinity tolerances of various freshwater macroinvertebrates, Kefford et al. (2003) observed that macrocrustaceans (specifically Decapoda, Amphipoda, and Isopoda) were the most salt-tolerant group tested. Conversely, baetid mayflies (Ephemeroptera: Baetidae) were the most salt-sensitive group (Kefford et al., 2003). An amphipod was the most abundant organism found at LCN .415, and an isopod was the fifth most abundant organism at LCM 2.270. Only one isopod individual was found at the reference site. Figure 7 shows relative organism abundance, broken down by Kefford et al.'s (2003) salt-sensitivity categories, from all nine monitored project sites as a function of specific conductivity. Relative organism abundances plotted in Figure 7 appear to peak at some optimal specific conductivity and then decrease as the stressor increases; albeit, the sample size of the team's project site data is low. However, a similar trend can be seen throughout Maine (Figure 6). Figure 7 indicates that amphipods and isopods may be better suited to take advantage of higher conductivity (such as levels found at the impaired sites) than baetid mayflies. Overall, this evidence supports the case for increased ionic strength as a probable cause at the impaired sites. Non-insect, salt-tolerant organisms such as amphipods and isopods may be advantaged while salt-sensitive organisms are not, thereby causing overall invertebrate community shifts. Note that case study salinity levels are likely below mortality thresholds for sensitive taxa, but these levels may support certain biological preferences and/or adaptations, ultimately contributing to the observed biological conditions at the impaired sites.

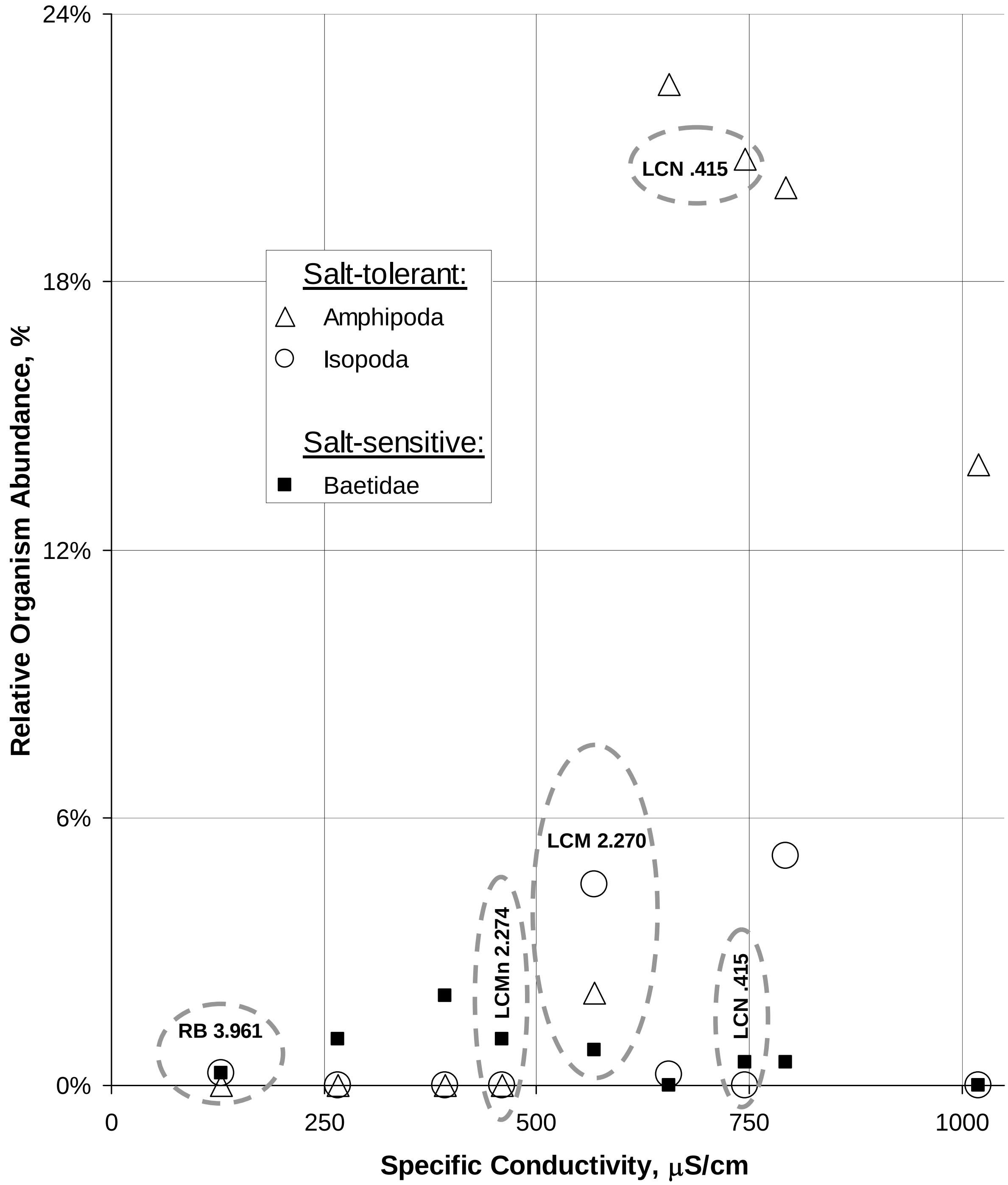

Figure 7. Relative organism abundance versus specific conductivity at project site.

Specific conductivity measured at the nine project area sites (six on Long Creek, and three on Red Brook) as a function of organisms known to be salt-tolerant and salt-sensitive, as defined by Kefford et al. (2003).

4.3.3. Increased HBI Score

Stressor-response relationships from the field (see Appendix H, scatter plots) indicate that HBI values may be responsive to a variety of variables, more so than for the EPT richness and percent non-insects endpoints. Based on available evidence, decreased dissolved oxygen is likely a primary cause for increased HBI values because HBI was designed to assess low dissolved oxygen caused by organic loading. Again, note that altered flow regime may be acting jointly with decreased dissolved oxygen (see Section 5.1).

4.3.4. Absence of Brook Trout

Decreased dissolved oxygen, altered flow regime, increased temperature, decreased large woody debris, and increased sediment are the probable causes linked to brook trout absence. According to the stressor-response analyses from other studies, temperatures are high enough and dissolved oxygen levels low enough at all three impaired sites to negatively affect brook trout. Lowered baseflow may create a situation whereby fish lack water volume and depth necessary for survival. In addition, sediment sizes at LCM 2.270 and LCMn 2.274 are potentially fine enough to hinder brook trout egg survival.

4.4. SUMMARY CONCLUSIONS

The project team did not find a single, primary cause of impairment for the Long Creek watershed or for an individual impaired site. Rather, the SOE analysis suggests several probable causes of impairment:

- Decreased dissolved oxygen
- Altered flow regime (specifically, decreased baseflow)
- Decreased large woody debris
- Increased temperature
- Increased toxic substances (specifically increased ionic strength)

These conclusions are presented by site and biological endpoint in Table 9. The importance of individual stressors varies among the impaired sites. The project team attempted to rank probable causes in order of importance for each site and endpoint in Table 9. Consistency of evidence scores (i.e., ++, +, 0, and -) weigh heavily in the team's consideration for ordering the causes in Table 9, but it is within this table that the project team employed professional judgment, based on the entire SOE analysis and all available data.

Results and analyses from this case study are helping guide the MEDEP and other stakeholders in improving and managing the Long Creek watershed.

Table 9. Probable causes of impairment [a]

Impaired site	Biological effect			
	Decreased EPT richness	**Increased % non-insects**	**Increased HBI**	**Brook trout absence**
LCN .415	increased ionic strength altered flow regime decreased dissolved oxygen decreased large woody debris	increased ionic strength altered flow regime	altered flow regime decreased dissolved oxygen	altered flow regime increased temperature decreased dissolved oxygen decreased large woody debris
LCM 2.270	decreased dissolved oxygen increased temperature increased ionic strength decreased large woody debris altered flow regime	increased ionic strength	decreased dissolved oxygen	decreased dissolved oxygen increased temperature increased sediment decreased large woody debris altered flow regime
LCMn 2.274	decreased dissolved oxygen increased temperature increased ionic strength decreased large woody debris altered flow regime	*not evaluated*	altered flow regime decreased dissolved oxygen	decreased dissolved oxygen altered flow regime increased sediment increased temperature decreased large woody debris

[a] Probable causes are listed in order, from highest to lowest importance, as judged by the project team, within each cell.

5. DISCUSSION

Two topics merit further discussion upon completing the Strength of Evidence (SOE) analysis. First, several candidate causes identified as probable causes are interrelated. Interactions are discussed from a general perspective in Appendix F, and that discussion is expanded upon here in terms of what the project team learned in the SOE analysis and in terms of implications for causal assessment in general. Second, the team discusses the certainty of its conclusions in the context of future data collection efforts that could be of value.

5.1. INTERACTING URBAN STRESSORS AND CAUSAL ASSESSMENT

Urbanized watersheds are often subject to multiple, interacting causes of impairment. Consider the following hypothetical example: decreased baseflow and water depth, two common manifestations of altered flow regime, may directly reduce suitable habitat for some organisms. Decreased baseflow may also reduce turbulence, thereby decreasing dissolved oxygen. Decreased water depth may facilitate increases in water temperature (the temperature of shallow water rises more quickly than that of deep water), thereby increasing metabolic rates in organisms. Subsequently, higher metabolic rates may increase demand for dissolved oxygen, while decreased turbulence decreases availability of dissolved oxygen. Dissolved oxygen is less soluble at both higher temperatures and higher salinity levels (or ionic strength), and when salinity climbs above favorable levels, sensitive species will spend more metabolic activity on osmoregulation, thereby limiting energy normally dedicated to other processes, such as that aimed at dealing with increased temperatures. These kinds of interactions may mislead and confound causal assessments, including the Long Creek case study. Note that in the above example, some agents, such as altered flow regime, stand alone as proximate stressors *and* serve as steps in the causal pathways of other proximate stressors.

5.1.1. Decreased Dissolved Oxygen and Altered Flow Regime

Decreased dissolved oxygen and altered flow regime, as two probable causes, may be acting as proximate stressors individually (see Section 4) at the Long Creek impaired sites. Additionally, decreased current velocity, a likely effect of decreased baseflow for Long Creek, serves as a potential step in a causal pathway leading to decreased dissolved oxygen (CM Figure 3 and Appendix F). The two causes may also be acting jointly as follows. As dissolved oxygen decreases, sensitive invertebrates may need additional current velocity so that more oxygen flows over their gills. Others have acknowledged a similar relationship among flow-dependent EPT, flow regime, and dissolved oxygen concentration (Jaag and Ambühl, 1964; Bednarek and Hart, 2005). For example, the mayflies shown in Figure 8 (*Rhithrogena* and *Baetis*) can tolerate low dissolved oxygen so long as minimum current velocities are met. Given the low velocities and decreased dissolved oxygen at the impaired Long Creek sites, it is possible that these two stressors act in concert. Further, both causes frequently appear among the probable causes shown in Table 9.

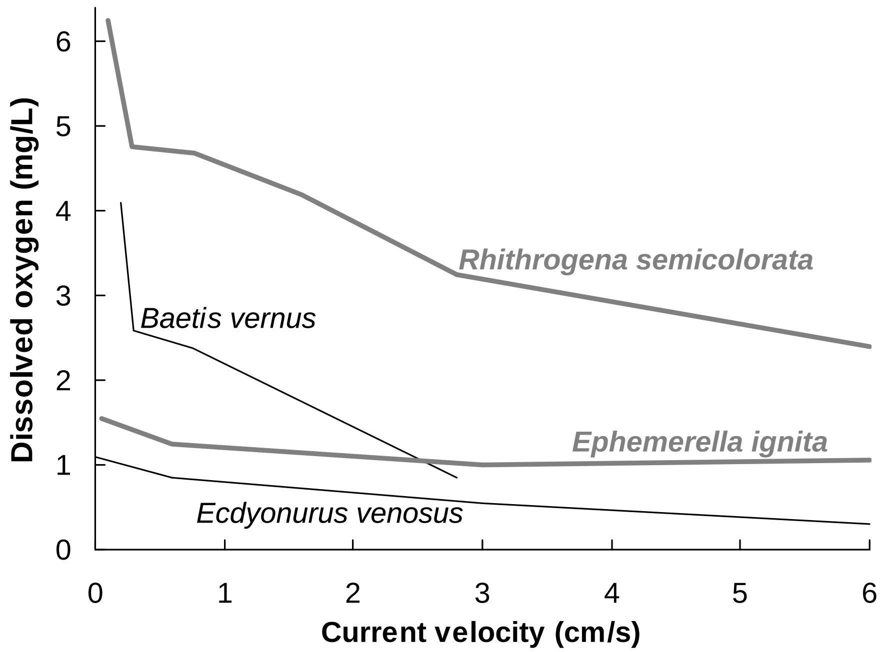

Figure 8. Impact of low dissolved oxygen & low current velocity on selected organisms.

Organism lines represent various mayfly nymphs and the point at which survival is compromised by lack of oxygen and reduced flow velocity. Source: adapted from Jaag and Ambühl (1964).

5.1.2. Increased Temperature and Decreased Dissolved Oxygen

Similar to the above interaction, increased temperature and decreased dissolved oxygen are probable causes individually (see Section 4), increased temperature is a step in a causal pathway leading to decreased dissolved oxygen (CM Figure 3 and Appendix F), *and* the two stressors may work together as follows. When temperature increases, sensitive species require additional dissolved oxygen because higher temperatures increase many coldwater organisms' investment in respiratory processes. Allan (1995) describes this connection and makes specific mention of caddisflies and stenothermic fish such as trout being susceptible to this joint interaction. The U.S. EPA ambient water quality criteria document for dissolved oxygen (U.S. EPA, 1986a) lends additional support, arguing that the two stressors may act additively or synergistically. Temperatures at Long Creek's impaired sites are at levels described by Allan (1995) as problematic, and the sites have decreased dissolved oxygen levels.

Sites within the project area with high temperatures generally have low dissolved oxygen levels (Figure 9). Stressor-response relationships from other studies show approximately equal support for both temperature and dissolved oxygen as individual causes at the Long Creek impaired sites. Purely from a water chemistry perspective, oxygen is more soluble in water at lower temperatures; considering the range of temperatures in this case study (see SOE Table 27), for example, the weekly summer maximums for RB 3.961, 21.1°C, and LCM 2.270, 23.3°C, this translates to a difference in potential oxygen solubility of approximately 0.5 mg/L (transpose temperature values to Figure 10 in order to estimate this difference in potential oxygen solubility). Given these considerations, it may be difficult, if not impossible, to discern which among the following plays a more significant role at the impaired sites:

- Increased temperature as an individual proximate stressor
- Decreased dissolved oxygen as an individual proximate stressor
    - with increased temperature as a causal pathway step
    - without temperature as a causal pathway step
- Increased temperature and decreased dissolved oxygen, working jointly

5.1.3. Other Potential Interactions

Similar to the above mentioned interactions among dissolved oxygen, flow regime, and temperature, the following interactions may also be acting at the impaired Long Creek study sites. Decreased baseflow serves as a causal agent for temperature increases by increasing the amount of time water is exposed to sunlight, and shallower flows allow heat transfer to occur more rapidly. Decreased large woody debris can reduce turbulence and aeration, thereby decreasing dissolved oxygen. Decreased large woody debris may affect sediment distribution patterns along stream bottoms, decreasing habitat heterogeneity.

Primarily based on water chemistry principles, the project team was able to limit support for two potential interactions as follows. Temperature could be presented as a causal pathway step for ionic strength because salt solubility increases as temperature increases. Figure 11 shows that project area sites with high specific conductivity generally have high temperatures. However, a much greater temperature increase is needed to significantly raise the solubility of salt in water (Figure 10). Similarly, ionic strength could serve as a causal agent for dissolved oxygen (oxygen solubility in water varies with elevation, temperature, *and* salinity); within the project area, however, there does not appear to be a correlation between the two variables (Figure 12). Furthermore, salinity values observed at project sites (all less than 700 ppm, MEDEP, 2002a) are not at levels capable of significantly decreasing or increasing the solubility of oxygen in water (Figure 10; consider "salinity = 0" appropriate for all project sites).

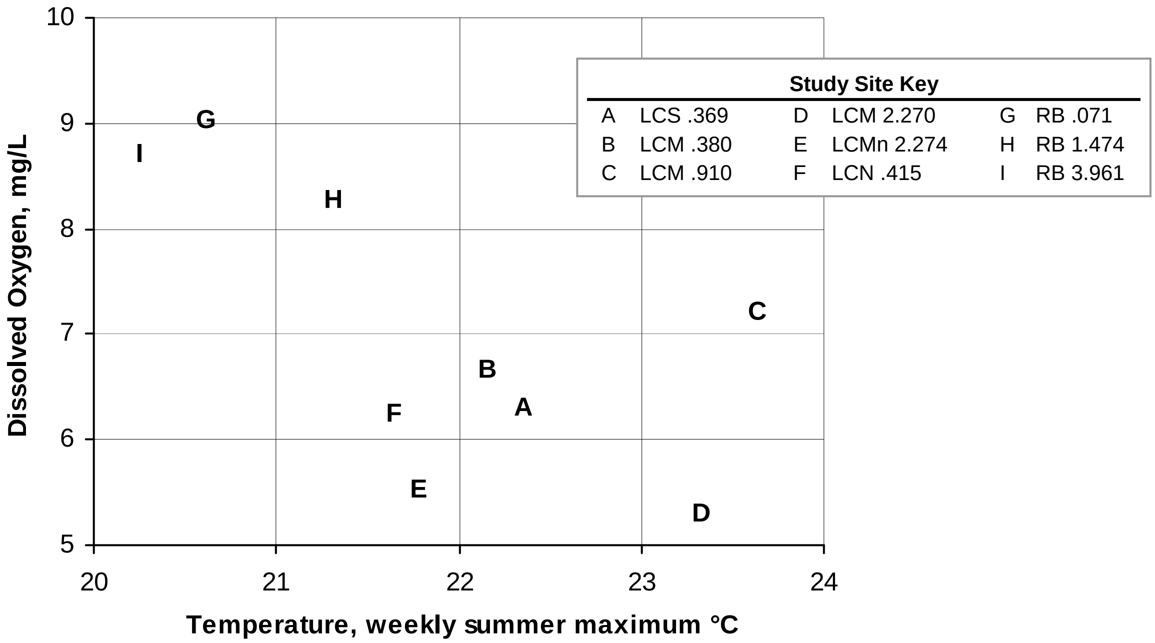

Figure 9. Dissolved oxygen versus temperature at project site.

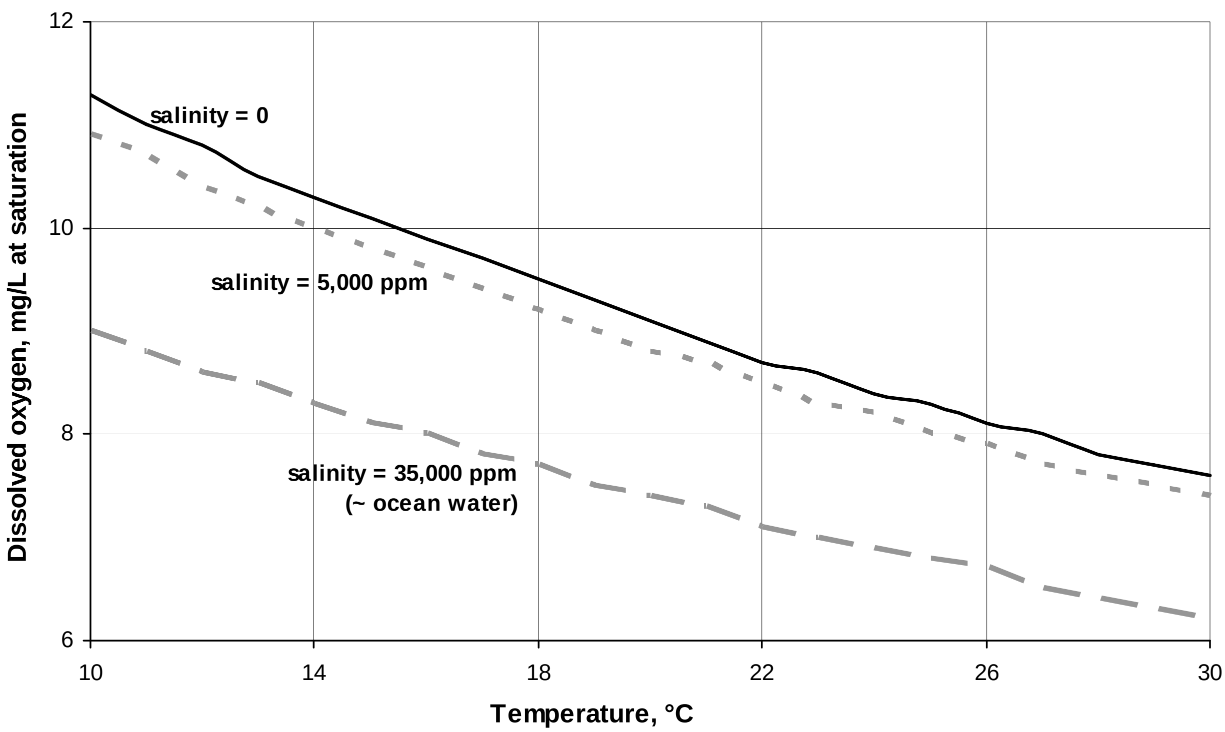

Figure 10. Oxygen solubility versus temperature at various salinities.
Source: adapted from Stickney (1979).

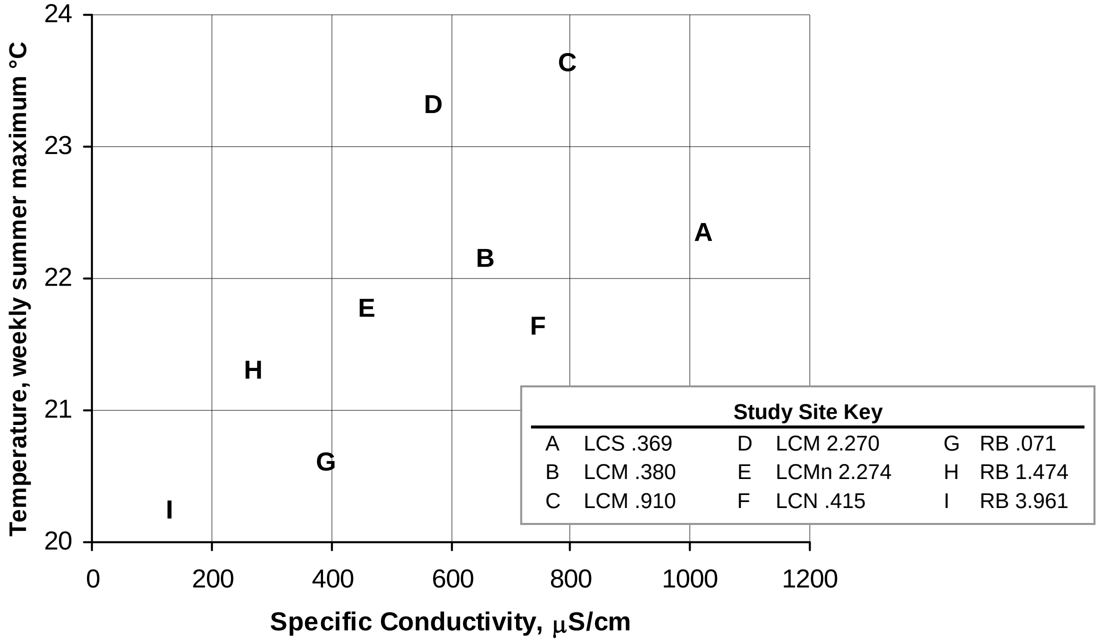

Figure 11. Temperature versus specific conductivity at project site.

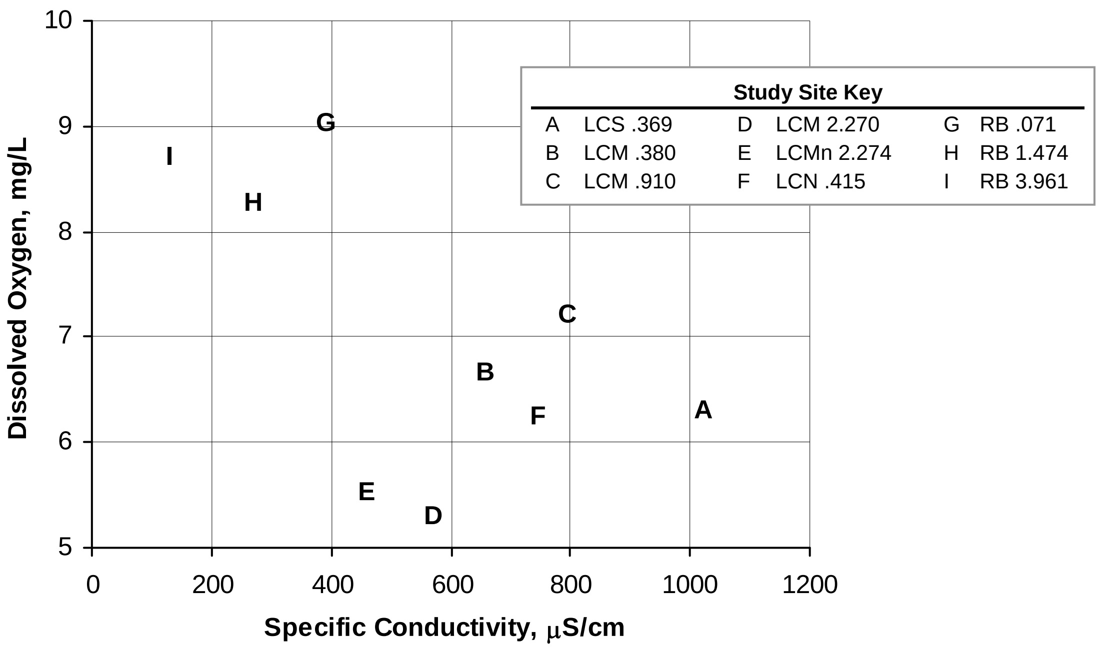

Figure 12. Dissolved oxygen versus specific conductivity at project site.

5.1.4. Negotiating Causal Interactions

Interacting candidate causes present potential challenges for causal assessment. The discussion at the end of Section 5.1.2 illustrates the difficulty in ranking one probable cause above another if the two causes are suspected to interact. The project team now introduces a potential second challenge. Take for example, three candidate causes—X, Y, and Z—which are identified and analyzed using SOE associations as described herein. Upon completion of SOE scoring, neither X nor Y stands out as probable causes of impairment, and so attention shifts to candidate cause Z, which happens to have the most supporting evidence. As individual causes, X and Y are insignificant both in the field and as determined by this hypothetical causal analysis; however, a problem may arise if X and Y are allied stressors acting jointly to cause more damage than candidate cause Z. Aside from speculating on the significance of causal interactions upon completing SOE scoring, what could the hypothetical XYZ causal analysis team do differently to accommodate potential interacting causes of impairment within their SOE analysis? The Long Creek project team was lucky in that the X and Y equivalents *do* stand out individually as probable causes of impairment, and there is no single smoking gun, or Z equivalent, that draws attention away from potential X-Y interactions.

To negotiate assessment of interacting causes, the combination of two or more causes could be analyzed separately. Along these lines, the new joint cause (e.g., "Candidate Cause #X: decreased dissolved oxygen allied with decreased baseflow") could be added as a new column in scoring tables (e.g., see SOE Tables 40-42), and a new conceptual model could be developed for the new joint cause, representing a single proximate stressor (i.e., a single square box at the bottom of a new conceptual model). However, the Long Creek project team was challenged to find relevant stressor-response relationships from other studies for joint causes. Figure 8, the only three-dimensional stressor-response relationship from another field study found appropriate for use in this case study, shows a biological response as a function of two stressors—low dissolved oxygen and low current velocity. Joint or allied candidate causes may be significant causes of impairment for Long Creek, but quantifying joint risks in comparison to individual probable causes may not be feasible (see, for example, conclusions drawn in Section 5.1.2).

Alternatively, it may be appropriate to de-emphasize ranking or comparison among individual causes and joint causes. Causes might be grouped to reduce effort spent on analyzing individual ones that ultimately cannot be prioritized due to confounding interactions. Allied stressors may also be added to candidate cause lists at the beginning of the stressor identification process. Given the complexity of interactions and potential joint impacts of candidate causes associated with this urban case study, the project team suggests that prudent remedial action target anthropogenic activities common to multiple probable causes. Impervious surface area, for example, is listed as one of the anthropogenic activity sources of all probable causes identified in this case study. Perhaps groups of causes could be combined according to common anthropogenic activities either at the beginning of the stressor identification process or during probable cause consideration. As more case studies are completed using U.S. EPA Stressor Identification guidance, it may be possible to begin new analyses with predetermined causal groups and to know specific causal interactions to watch out for, based on ecoregion (e.g., northeastern coastal zone) and general land use (e.g., urban and industrial).

Impervious surface area upstream of an impaired site may be a suitable surrogate for general urban impairment. The three impaired sites have impervious surface areas of 7%, 14%, and 33%. Morse et al. (2003) found that insect communities in Maine streams show an abrupt decline in taxonomic richness as impervious surface area increases above 6%. All three impaired sites have impervious surface areas greater than 6%. The Morse et al. (2003) study mainly focuses on the negative impact of impervious surface area on EPT taxa. Maxted (1996) noted a shift toward tolerant taxa (represented by percent non-insects and HBI values at the Long Creek study sites) at impervious surface areas of 10 to 15%. Boward et al. (1999) were unable to find brook trout in Maryland watersheds with impervious surface area levels greater than 2%. However, Meidel and MEDEP (2005) found an exception to this general trend: 23 brook trout in a Maine stream with 13% impervious surface. MEDEP staff note that this may be an anomaly because of high groundwater input of cold water in the site's vicinity, potentially creating a refuge where at least one criterion favoring brook trout is exceeded. Surrogate measures of impairment offer advantages to causal assessment, but caution must be taken to account for additional assumptions introduced by such measures.

The most immediate influences of increased impervious surface area (in northeast U.S. watersheds) may be alteration of hydrologic processes, a myriad of related impacts due to vegetation removal and increased application road salt in winter. The strongest direct evidence for altered flow regime are the single storm hydrograph for LCN .415 (Figure 13) and the thalweg flow velocities recorded along Long Creek and Red Brook (Figure 14), re-enforced by anecdotal feedback from MEDEP staff indicating that Long Creek seems to have lower baseflow relative to Red Brook during site visits. The SOE for road salt reaching the impaired sites is supported by spatial/temporal co-occurrence specific conductivity data. Figures 15 and 16 indicate that increasing impervious surface area and chloride (a common road salt constituent), respectively, correlate with increasing specific conductivity throughout the project area.

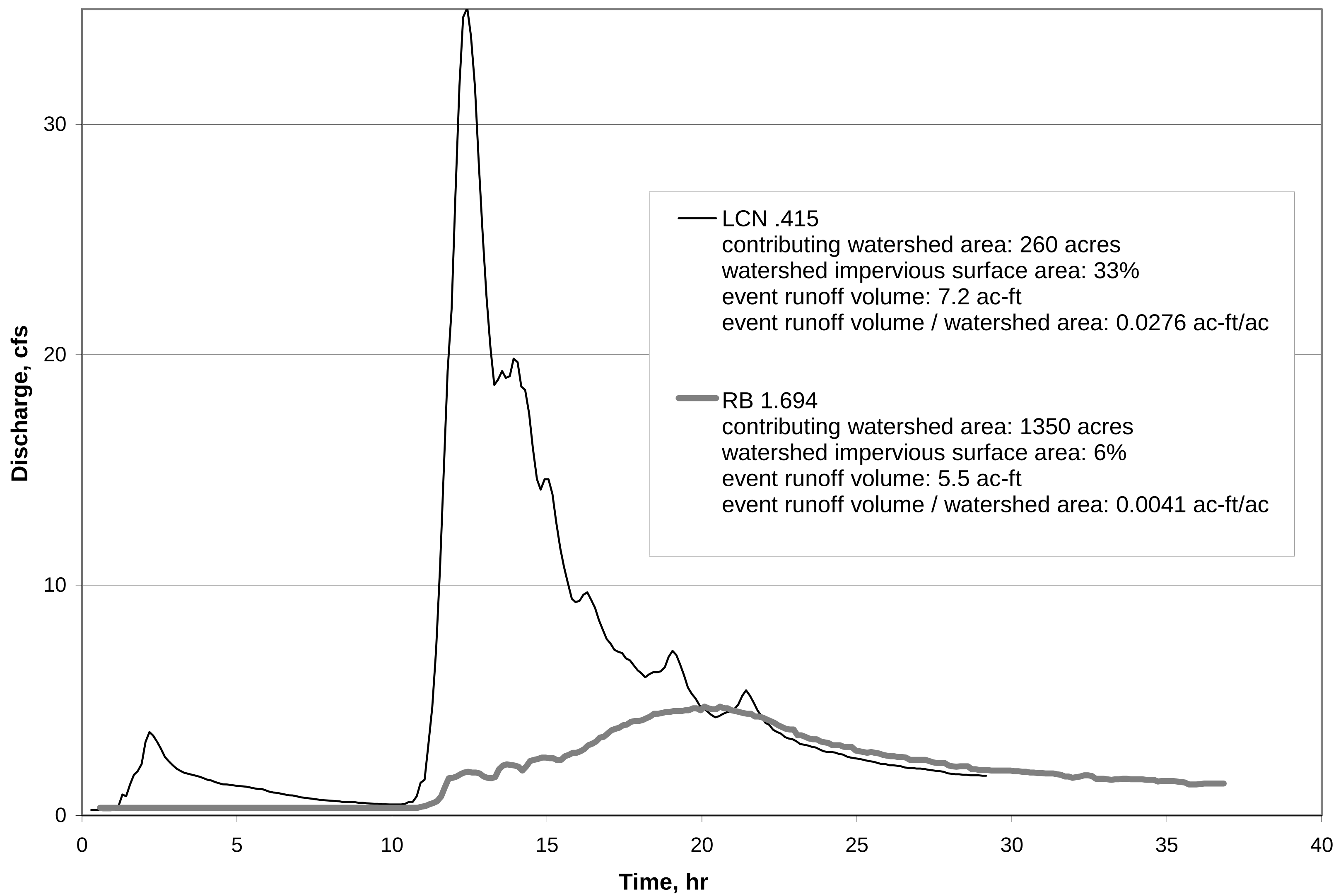

Figure 13. Storm hydrographs on Long Creek and Red Brook, September 25, 2001.

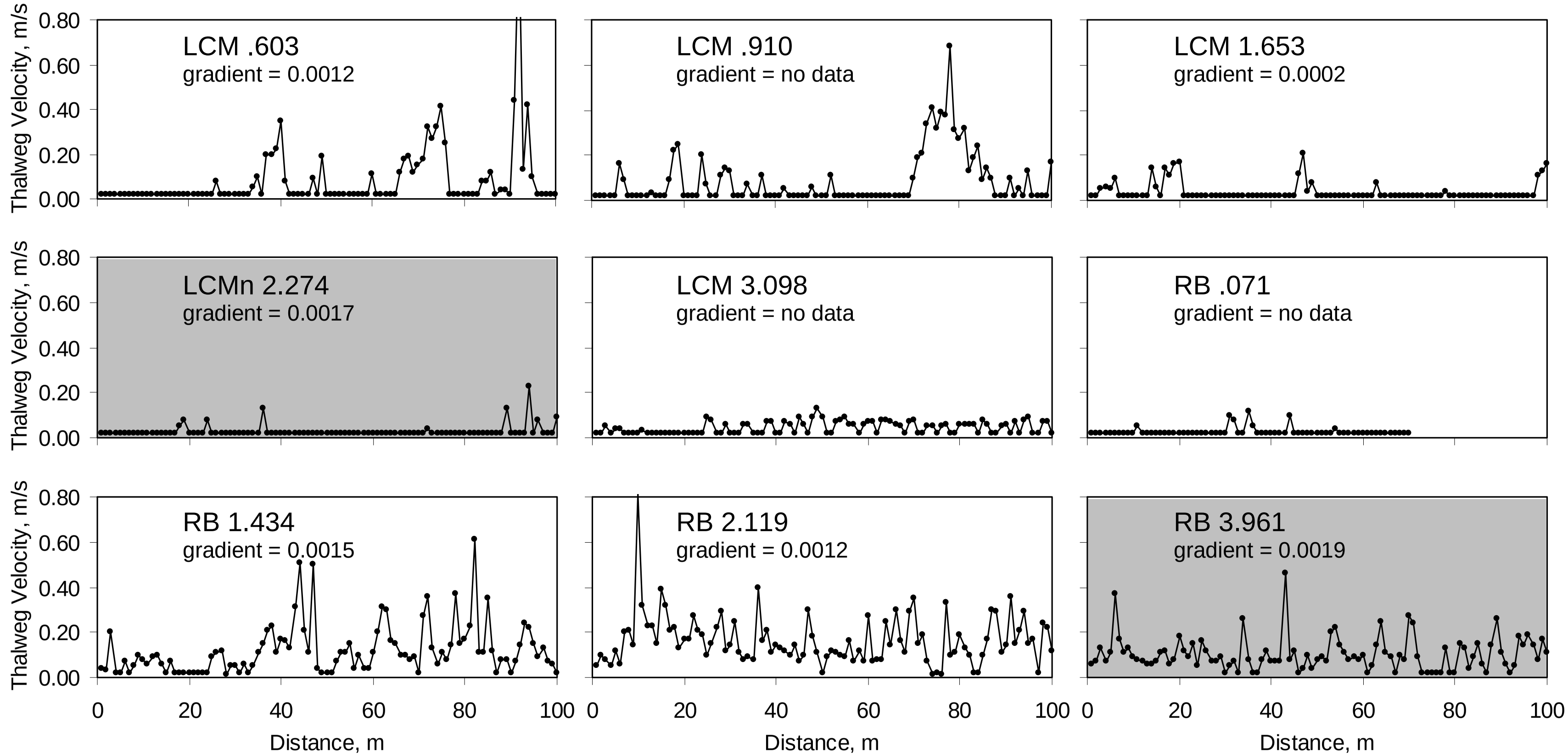

Figure 14. Baseflow thalweg velocity measurements throughout project site.

Measurements were taken at 2-m intervals in the vicinity of the site; gradients are expressed in feet/feet.
Highlighted plots/sites are the focus of this case study.
Source: MEDEP (2002a).

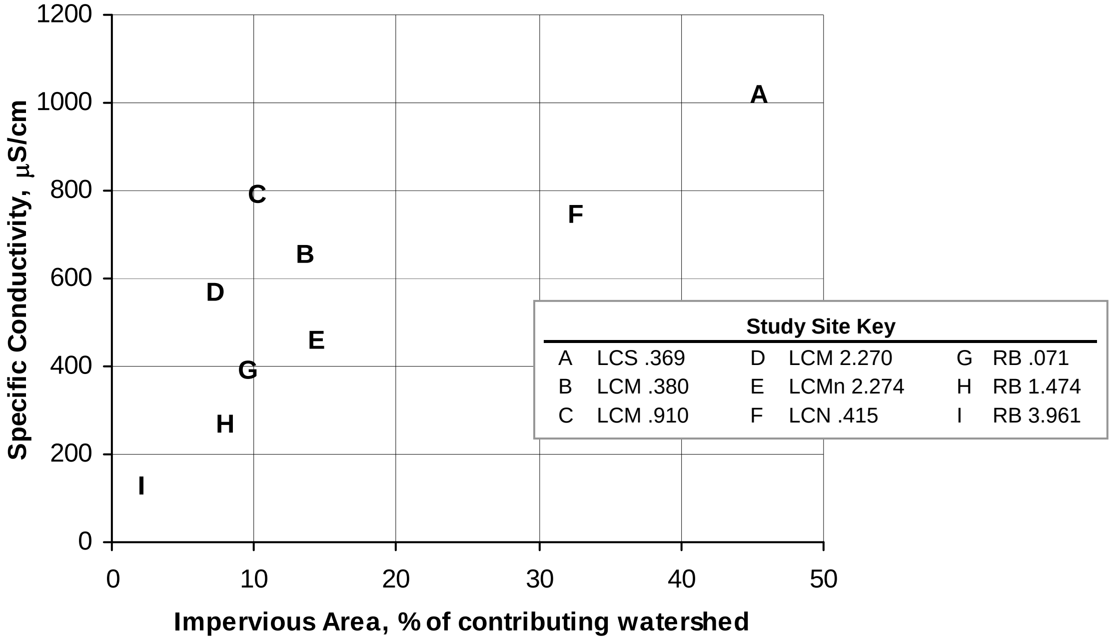

Figure 15. Specific conductivity versus impervious area at project site.

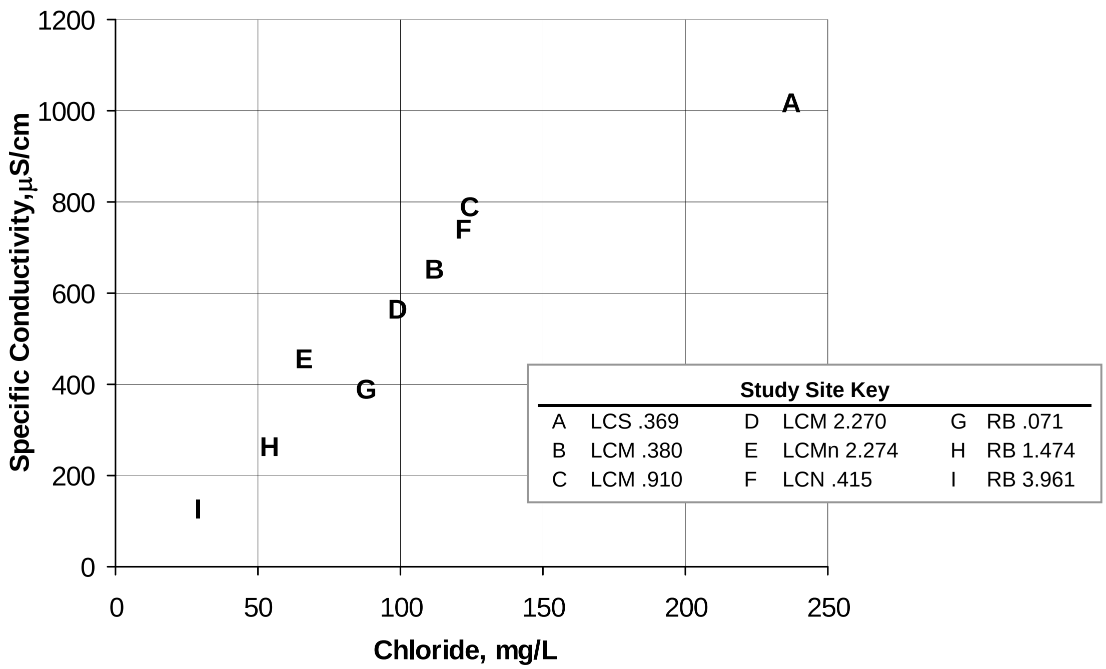

Figure 16. Specific conductivity versus chloride at project site.

5.2. CONFIDENCE IN CONCLUSIONS

> *"All scientific work is incomplete—whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we already have, or to postpone the action that it appears to demand at a given time."*
>
> —Sir Bradford Hill, 1965

The project team lists multiple probable causes of impairment in Section 4. Lack of evidence may have prevented promotion of one probable cause over another, in terms of significance for a particular study site. As discussed in Section 5.1, isolating individual urban-related candidate causes may not be possible or necessary. Unlike some other stressor identification case studies (refer to the CADDIS Web site, http://www.epa.gov/caddis, for examples), this report points to multiple candidate causes with little distinction among causes regarding significance to the project site. For the benefit of decision makers, however, the project team circumvents this issue by emphasizing anthropogenic activities or sources common to multiple stressors, such as impervious surface area, thereby empowering future efforts aimed at improving the Long Creek and Maine ecosystems.

Ultimately, the project team is confident in the conclusions as they are. Some readers may prefer a single, "smoking gun" cause of impairment. This was not determined for the Long Creek case study, nor for any given Long Creek study site. This, however, does not reflect poorly on the stressor identification process as a tool in and of itself, nor implementation of the process for this particular case study. Rather, there are simply multiple probable causes of impairment at the case study sites.

The project team concludes that some level of uncertainty is inherent to causal assessment, perhaps especially for urban ecosystems. That said, and in no way negating the high level of confidence in the conclusions already drawn, much of the remaining uncertainty for this case study may be explained by two factors:

- Lack of sufficient case-specific data collected at the project's reference and impaired sites, including measurements of biological conditions and/or stressors such as stormflow water quality observations
- Lack of research needed to understand case-specific data including, for example, stressor-response relationships based on data from elsewhere, regional reference criteria, and/or literature and information about candidate causes

5.2.1. Case-Specific Data and Research Needs

The project team compiled a robust data set specific to the case study including both the impaired sites and other sites throughout the Long Creek and Red Brook watersheds; nevertheless, this causal analysis could have been strengthened by additional data including:

- **Flow regime or hydrology data –** Historical stream flow time series data measured at the reference and impaired sites may have provided valuable information about the impacts of altered flow regime.
- **Total suspended solids measurements –** Available baseflow suspended sediment data are sparse and some measurements may not meet MEDEP quality control criteria; additional stormflow suspended sediment data taken throughout the project area would have been desirable.
- **Pesticide measurements –** The project team did not test for herbicides, fungicides, or insecticides; this may have been especially valuable downstream of intensive landscaping efforts such as in the vicinity of golf courses.
- **Stormflow metal concentrations –** These data are limited to surrogate sites for LCN .415 and the reference site, and the data indicate that episodic toxicity from Cu is a possible cause of impairment. It might benefit the study to have stormflow metal concentration samples from more locations.

5.2.2. Research Needed To Understand Case-Specific Data

Large woody debris – Decreased large woody debris is listed as a probable cause of impairment. However, stressor-response relationships from elsewhere were used to support this cause directionally. Specifically, the project team was unable to compare large woody debris numbers or thresholds from the literature to those data collected at the study sites, and, therefore, the team supported the conclusions qualitatively by showing that more large woody debris would be helpful for EPT and brook trout at the impaired sites based on general research about the importance of large woody debris. A reasonable amount of site data exists but research needed to quantitatively understand the data does not. It would be helpful to have more quantitative stressor-response information related to specific mechanisms through which this proximate stressor impacts biological endpoints (e.g., large woody debris substrate for EPT taxa, cover for fish, and physical source of aeration/dissolved oxygen). Regional baseline data may also be of value.

Brook trout habitat – Knowledge of historic brook trout habitat is limited for the case study area and the state of Maine; it would be valuable to know what the historic and/or best-case scenarios of brook trout habitat are for the case study region, taking into consideration variables such as surficial geology and the life cycle of brook trout, both of which may be relevant to this case study.

Relationship between stream temperature and impervious surface – There does not appear to be a clear correlation between temperature and impervious surface area within the project area (Figure 17). However, Morse (2001) discusses several causal pathways linking impervious surface and temperature in his literature review of the subject, specific to the northeastern U.S. Additional research regarding the mechanisms of this linkage may be valuable for this and other studies.

Ionic strength and winter sanding, salting, and plowing – Recent studies in Northeastern U.S. show that road salting threatens freshwater ecosystems (Kaushal et al., 2005). The project team found supporting evidence for increased ionic strength as a candidate cause in the Long Creek watershed, and roads within the watershed are salted during winter, but data from outside the case study appears weak in this area. Considering the potentially contentious topic of decreasing winter road salt applications to minimize salinization of freshwater streams, more research on methods and impacts of winter road maintenance techniques may benefit causal assessments and help managers devise alternatives.

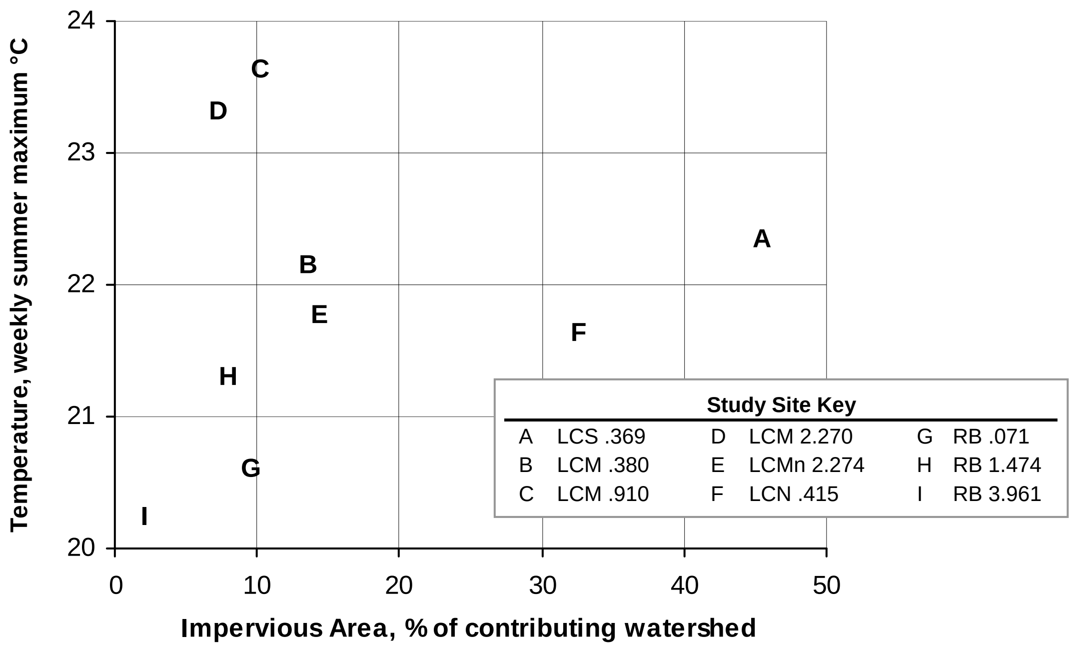

Figure 17. Temperature versus impervious area at project site.

6. LESSONS LEARNED

6.1. UNEVEN EVIDENCE—ADDRESS POTENTIAL BIASES

Some candidate causes evaluated in this case study have more supporting data than others. For example, the project team does not have spatial/temporal co-occurrence data for altered flow regime and decreased large woody debris for *all* three impaired sites. The team discusses other specific data gaps in Section 5.2. Uneven data sets among candidate causes have the potential to impact Strength of Evidence (SOE) scoring; the U.S. EPA Stressor Identification consistency of evidence association scoring system (see SOE Table 39) differentiates +++ versus +, and - - - versus - indicating that a single + or - be assigned if "few" types of evidence are available. Caution should be taken where uneven evidence may impact SOE scores.

The project team attempts to remove bias related to uneven evidence among causes by discussing the relative strengths and weaknesses of the data primarily when drawing conclusions about probable causes in Section 4. The team also acknowledges data gaps in Section 5.2, further qualifying the strength of the team's results. SOE scores are not a final judgment; the scores must be put into context when conclusions are drawn, thereby providing causal assessment teams an opportunity to revisit potential causes, making sure causes are not overlooked simply because certain data were not collected.

6.2. BIOLOGICAL ENDPOINTS—CHOOSE SIMPLER MEASURES

The project team identified effects, or biological endpoints, representing a wide range of complexity. The brook trout endpoint is the simplest; the team relates the response as a binary variable, indicating presence or absence of a single species. The next simplest is the EPT richness endpoint, for which a generic count from three insect orders is used. The percent non-insects endpoint is more complicated because of its relativity to insect abundance; further, it is less descriptive in terms of not knowing which specific non-insects are relatively more or less abundant than specific insects or other non-insects. The HBI index is the most complicated variable. HBI is calculated by multiplying the abundance of observed organisms by assigned tolerance values, specific to organic pollution, summing the products, and dividing by the total number of individuals.

Simplified specific effects may be of greater benefit to causal assessment than more complicated variables such as percentages and indices. The complexities and unknowns associated with the percent non-insects and HBI endpoints as mentioned above may have been avoided by identifying more specific endpoints. Furthermore, the project team's endpoints overlap to some degree; for example, the project team may be double counting some organisms with the use of HBI and EPT. Consider also that a biotic index, such as HBI, may be responding to multiple stressors, not solely stress related to the index's focus (i.e., organic pollution for

HBI). This phenomenon appears to be demonstrated by the scatter plot analysis described earlier in the report (see HBI specific summary in Section 4). The team recommends future causal assessors select endpoint variables that are as specific as possible.

6.3. MULTI-STAGE CAUSAL ANALYSIS—STRATEGIZE IN ADVANCE

This causal assessment may have been conducted more efficiently and the results determined with more certainty if data collection had proceeded in two stages, with biological monitoring conducted first (perhaps as a scaled back effort), followed by thorough water quality, habitat, and biological monitoring at specific sites, rather than one large-scale data collection effort. The project team recognizes that this is not always possible; for the Long Creek case study, data were collected as part of a previous study and at sites that were not included in this causal assessment because the sites met class designations. U.S. EPA Stressor Identification guidance provides a basis for designing such a two-stage analysis. The guidance recommends determining biological impairments before causal analysis begins; actual causal analysis might proceed alongside and potentially guide water quality data collection efforts.

Several steps aimed at increasing efficiency and certainty of results might be conducted *between* the two stages mentioned above.

Choice of sites – Reference and impaired sites to be studied should be determined prior to stressor data collection. For the Long Creek case study, this may have helped to concentrate time spent in the field on sites of primary concern and avoid data gaps among candidate causes. If multiple potential study sites are appropriate for a particular case study but a limited number of sites will be studied, sites may be strategically chosen to take advantage of existing historical data. For example, if a watershed or site has historic stream gage and precipitation records associated with it or presently operating gages, this may be a good location to focus collection of stressor data.

Analysis of biological monitoring data – Functional feeding group, mode of existence, and indicator species analyses may provide case study teams with clues about what is and is not happening in their study areas and help direct the types of stressor data to be collected at the study sites.

Determination of specific biological effects or endpoints – It may be possible to group reference or impaired sites with similar attributes. Results from this causal assessment may have been strengthened with little additional effort if sites with similar types and levels of impairment had been grouped; grouped sites also may share other attributes, such as location within a watershed (e.g., elevation and contributing watershed size). Grouping sites may have strengthened stressor data if some values could be averaged among similar sites and compared collectively to a reference site value or an average value derived from a group of similar reference sites.

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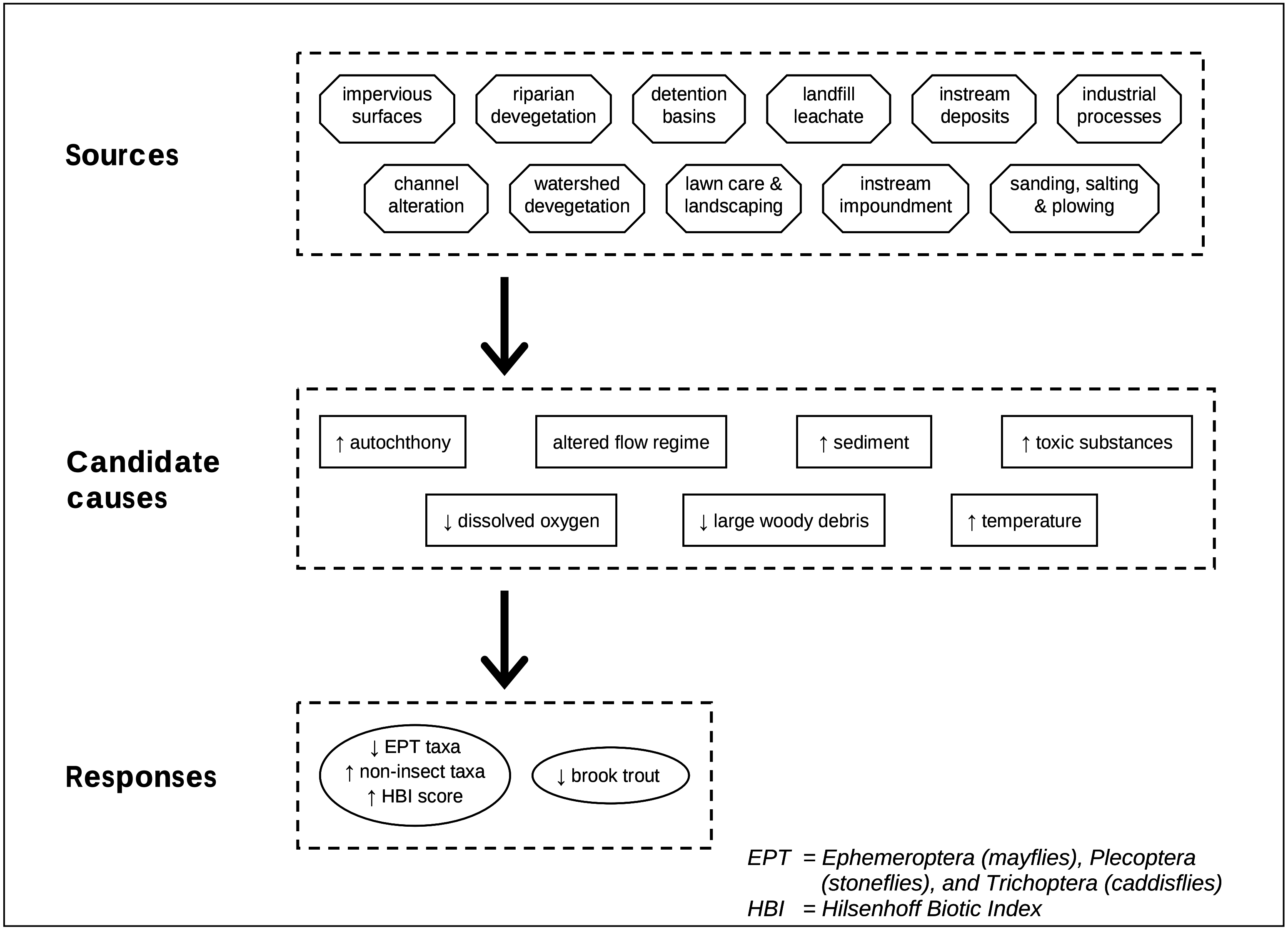
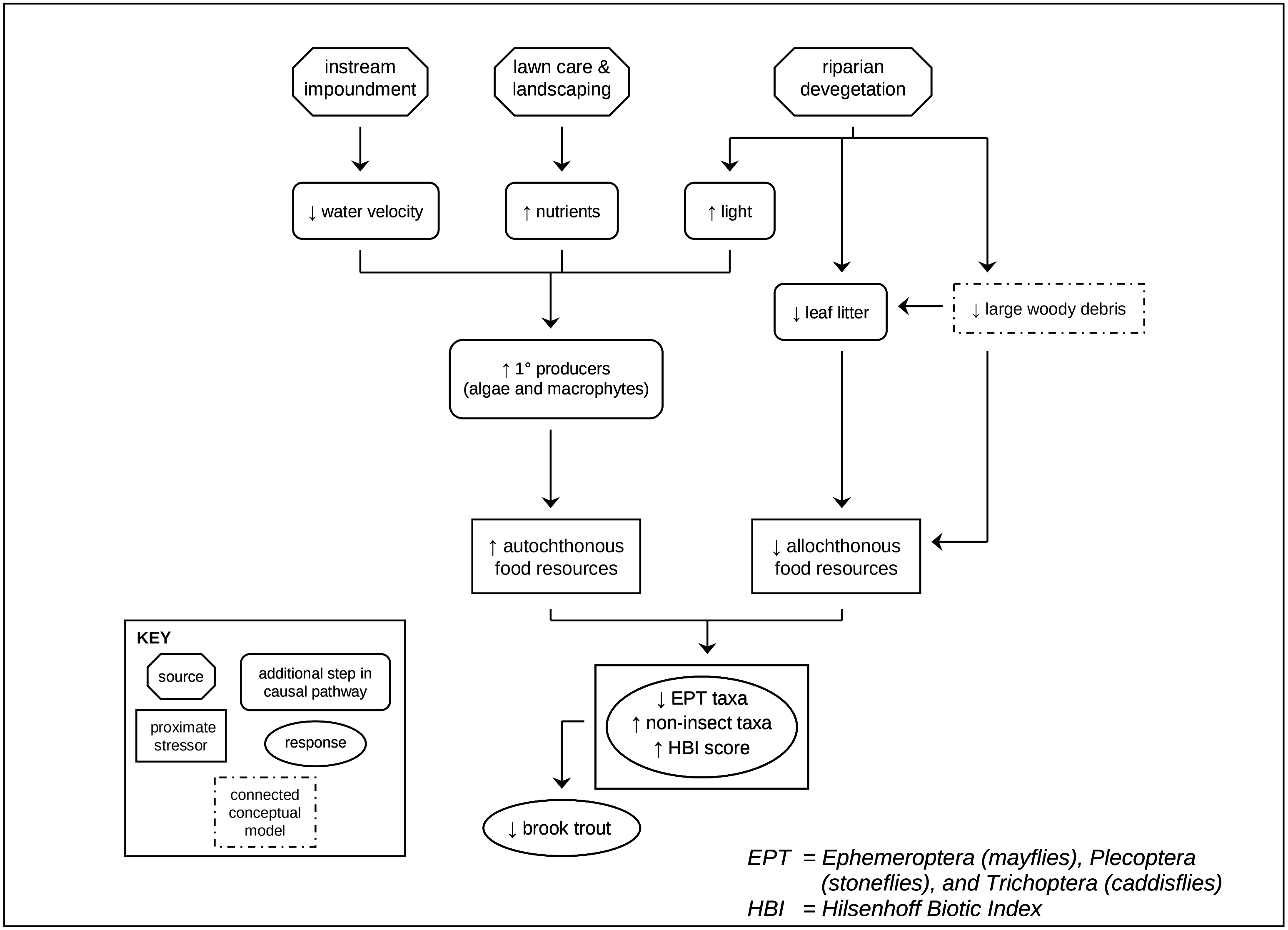
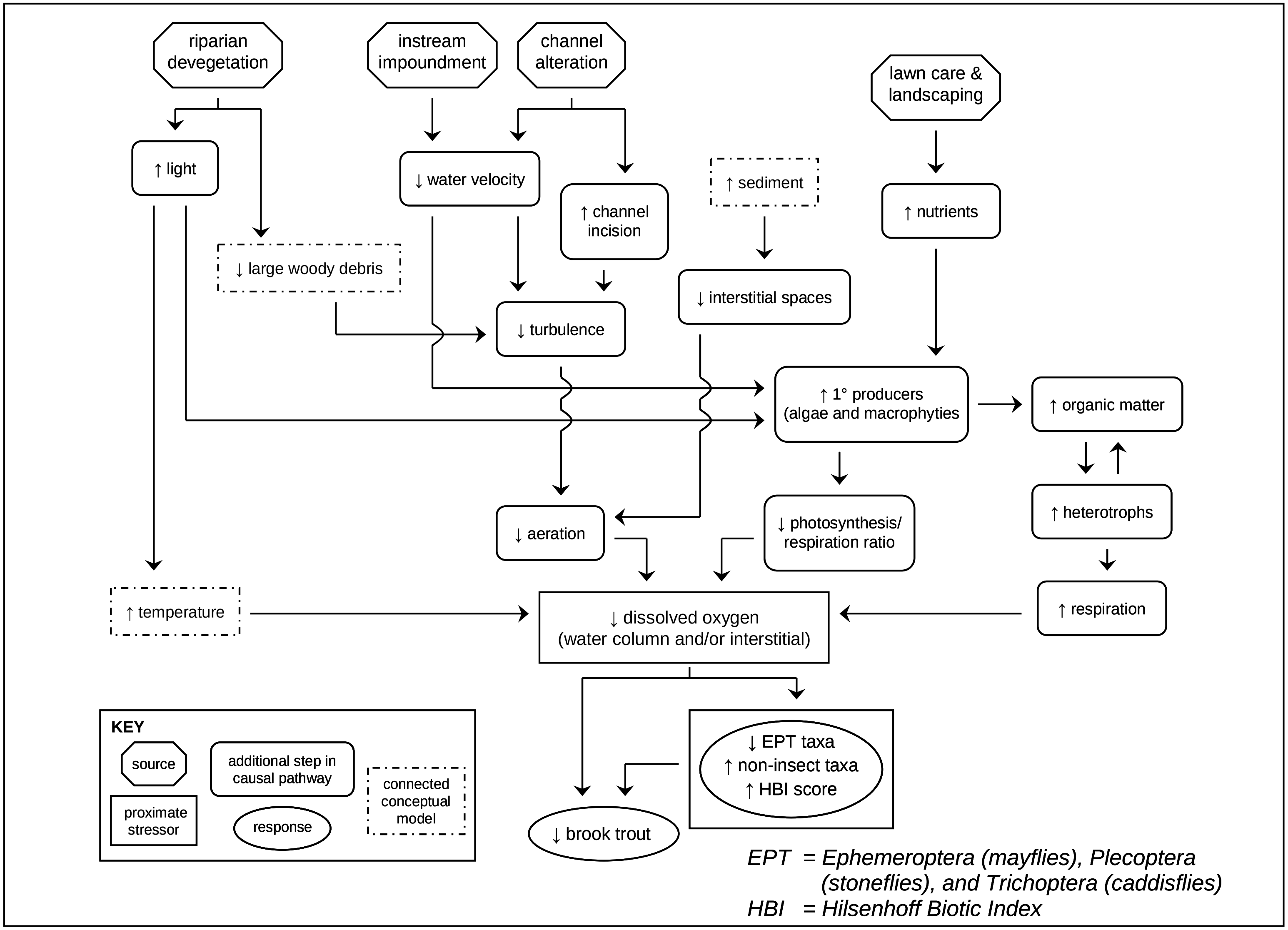


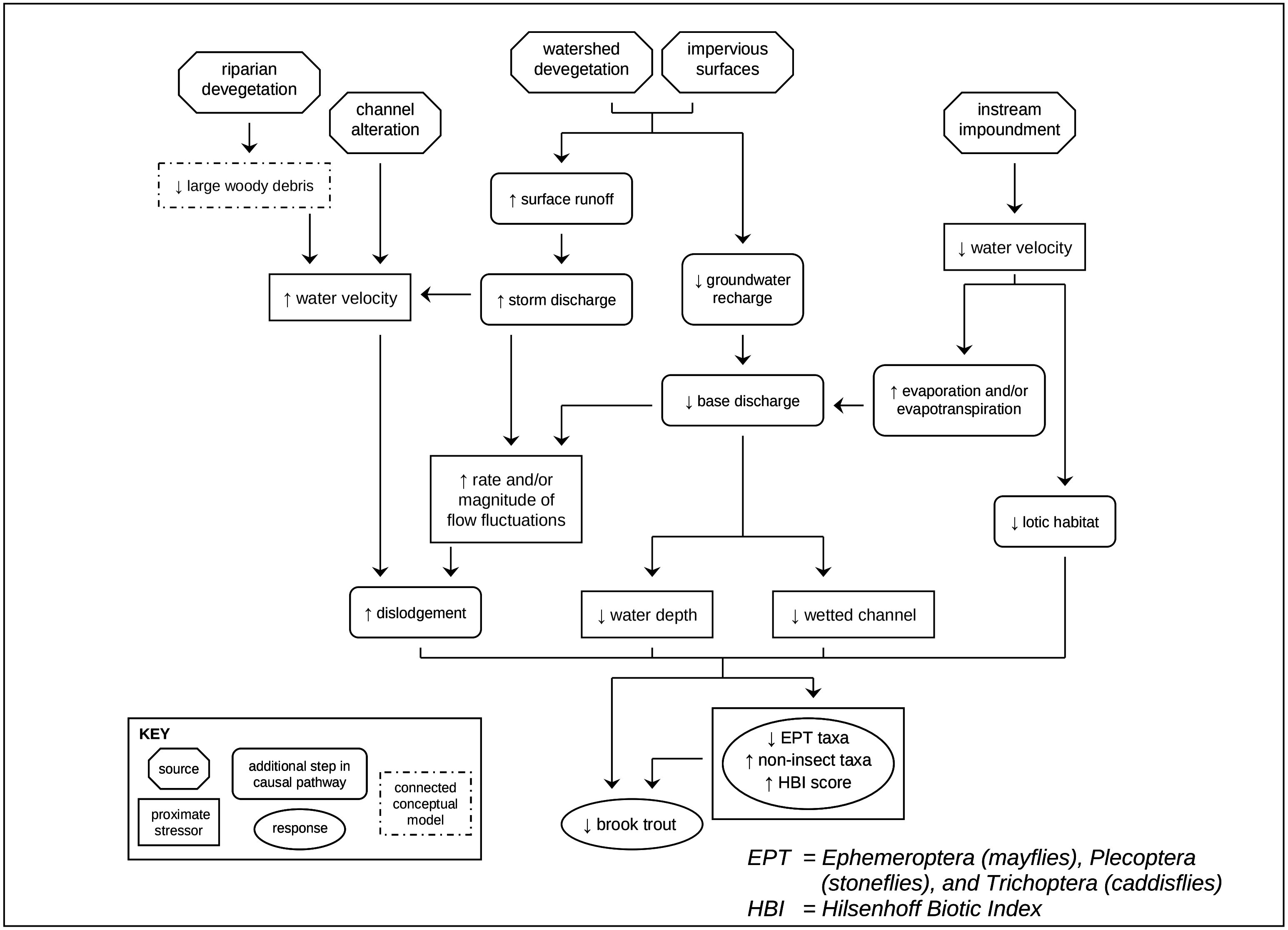
CM Figure 1. Case study conceptual model elements.



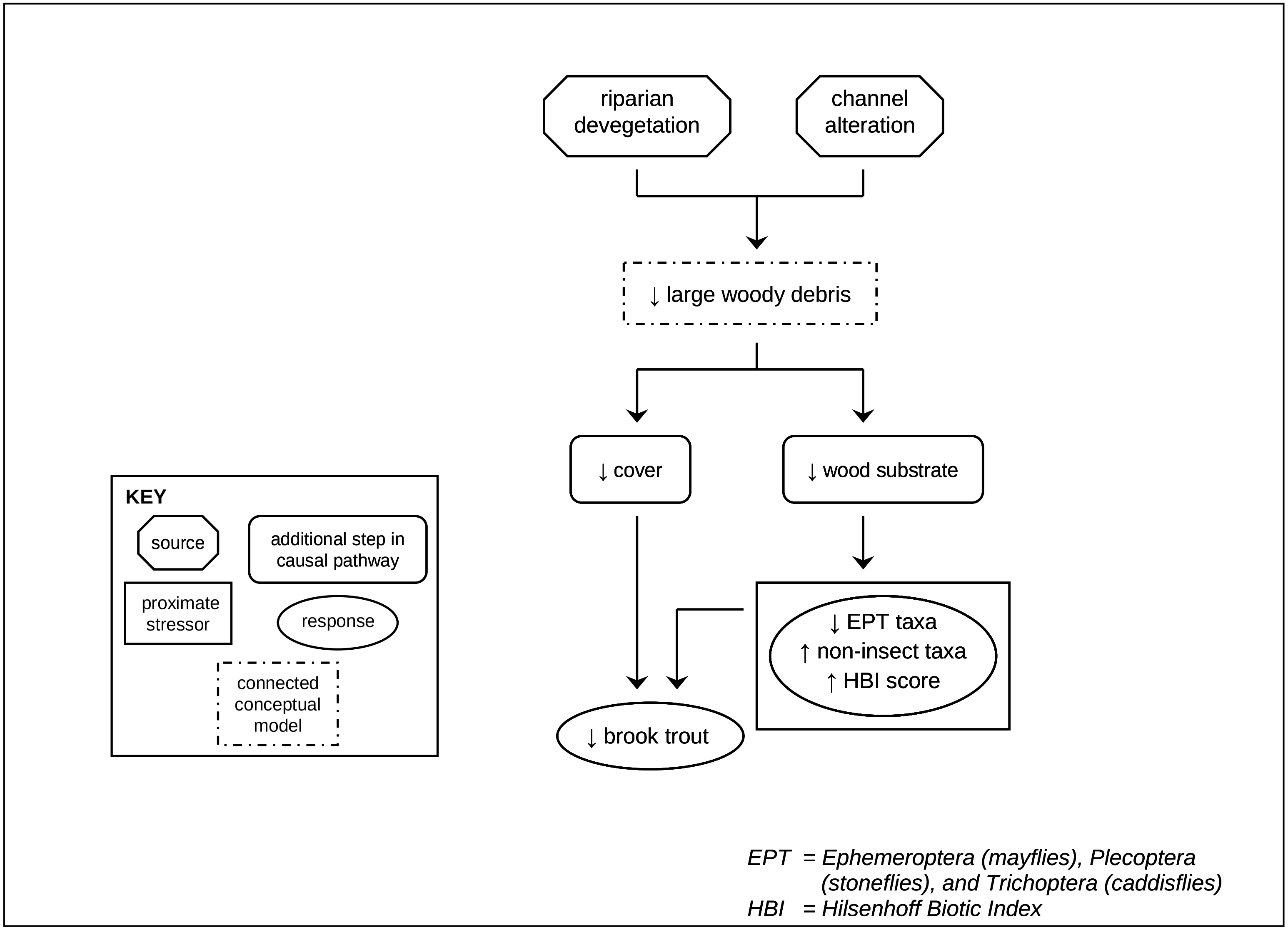
CM Figure 2. Increased autochthony conceptual model.



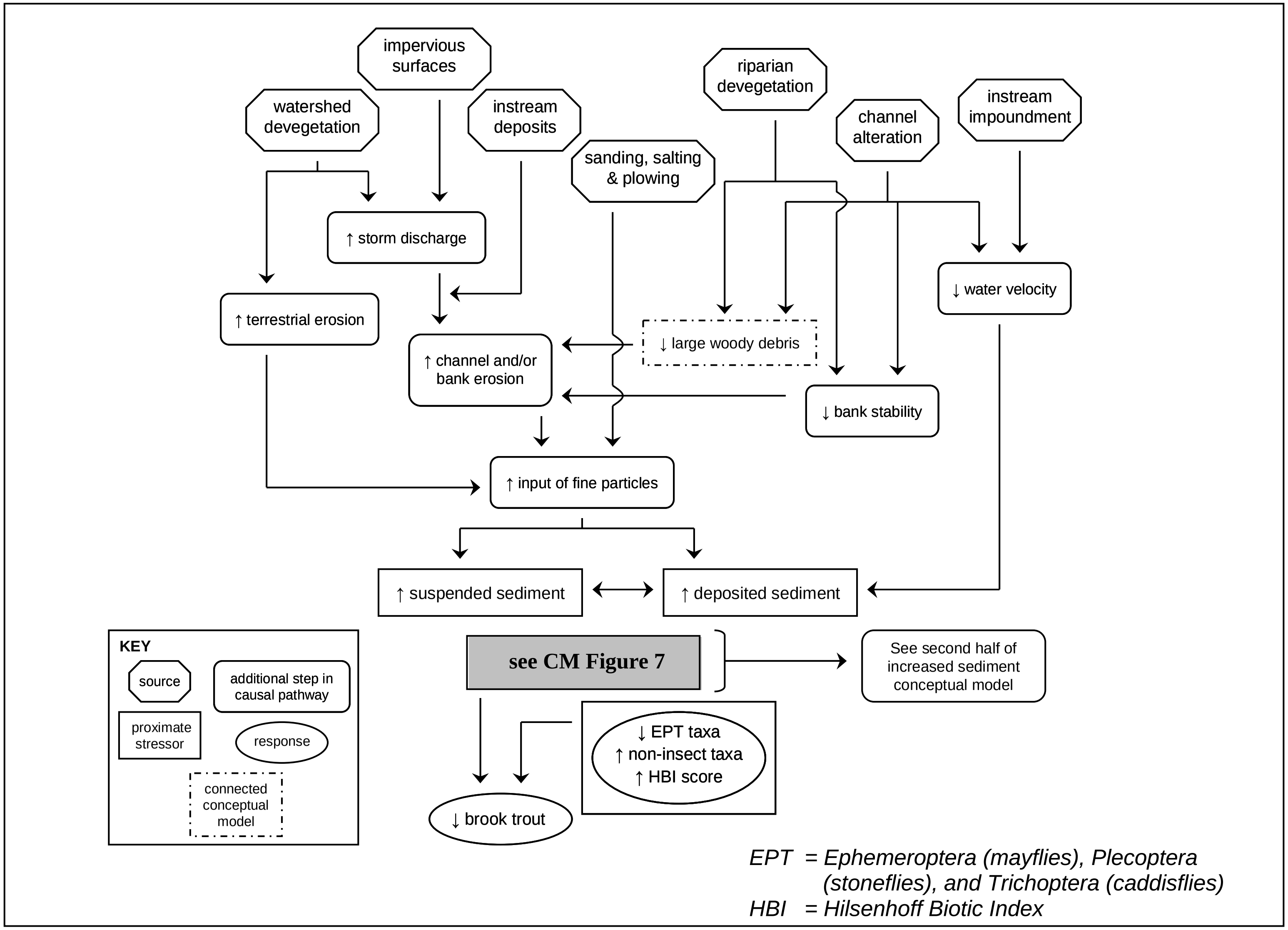
CM Figure 3. Decreased dissolved oxygen conceptual model.



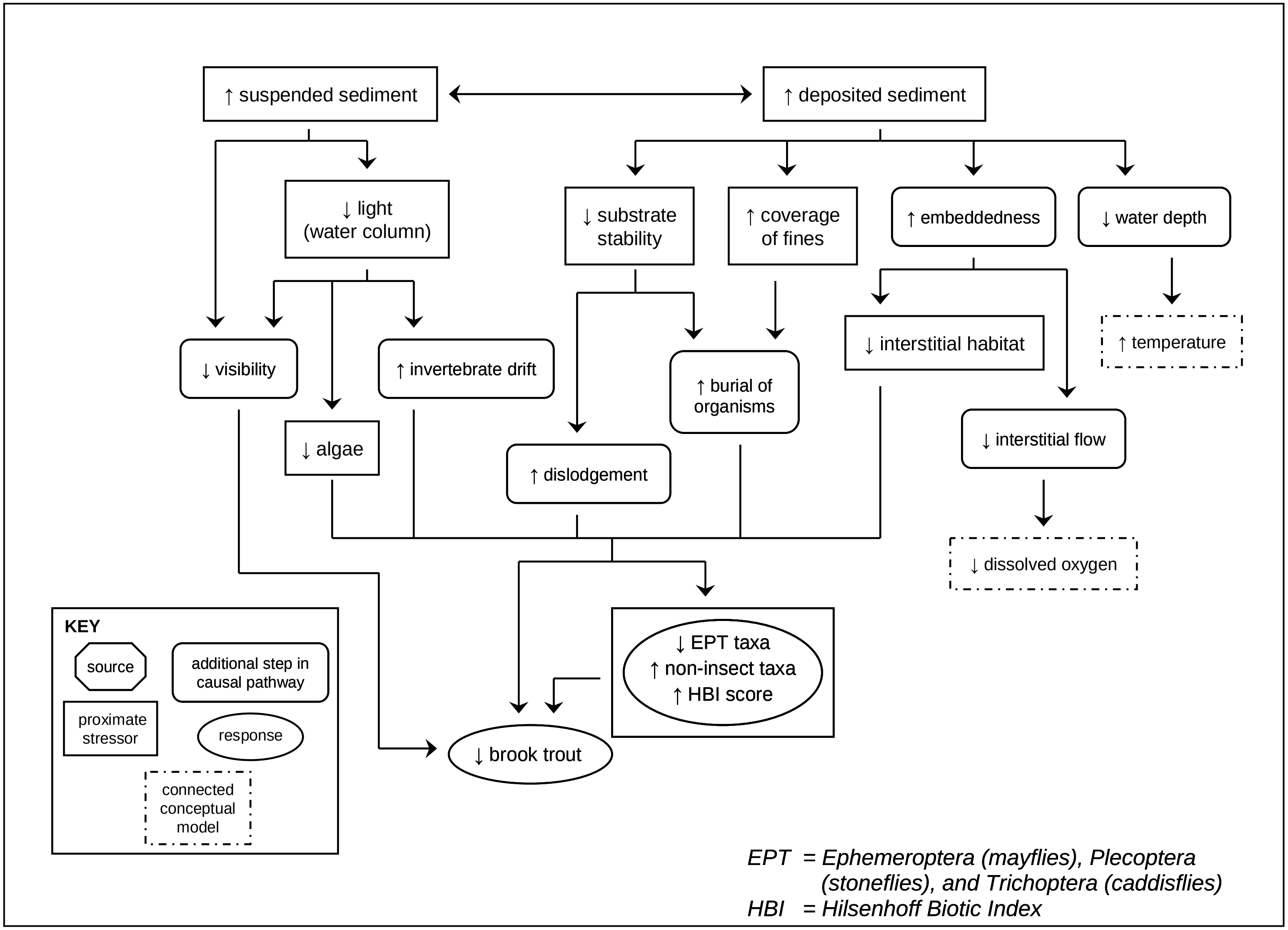
CM Figure 4. Altered flow regime conceptual model.



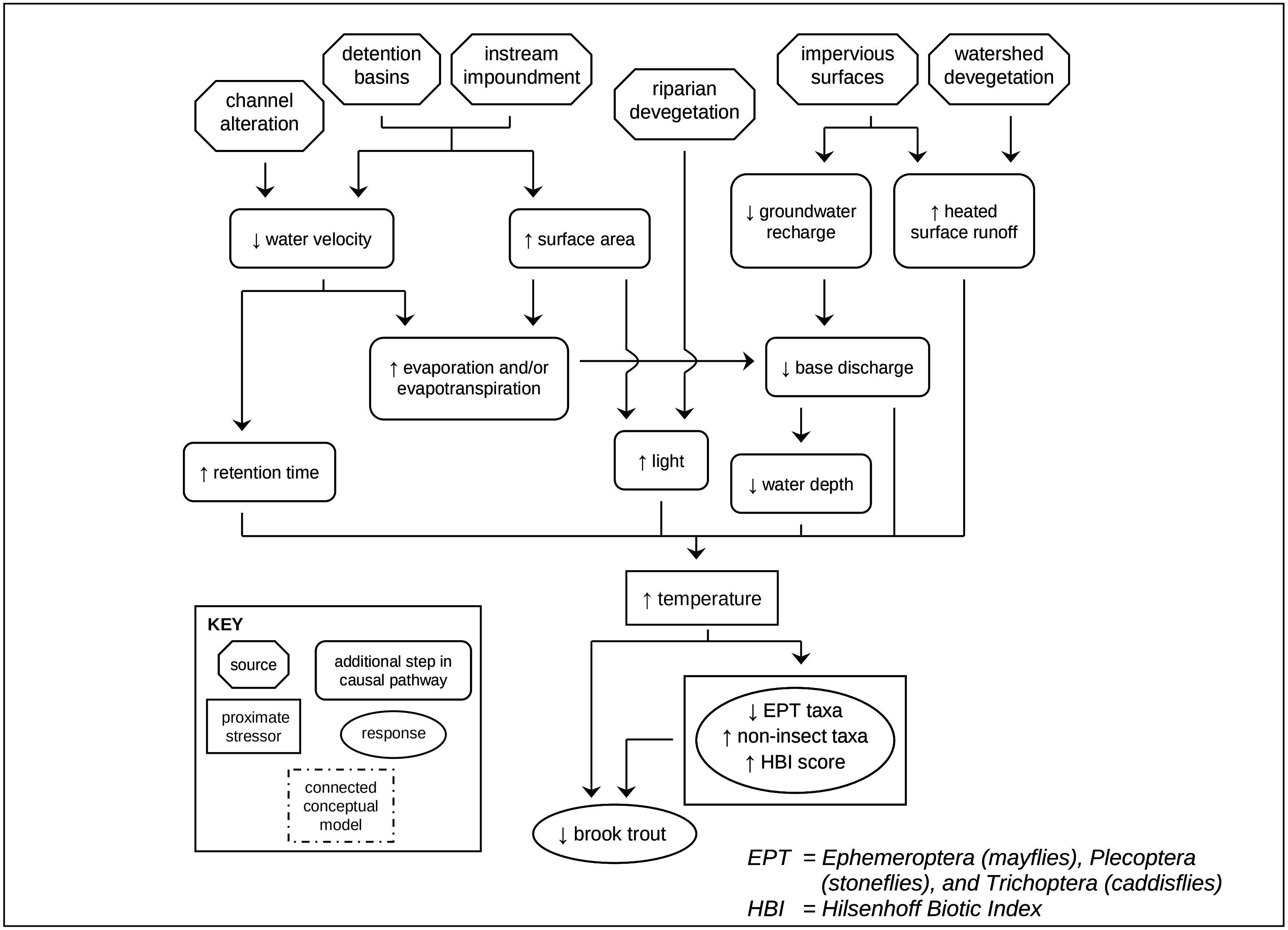
CM Figure 5. Decreased large woody debris conceptual model.



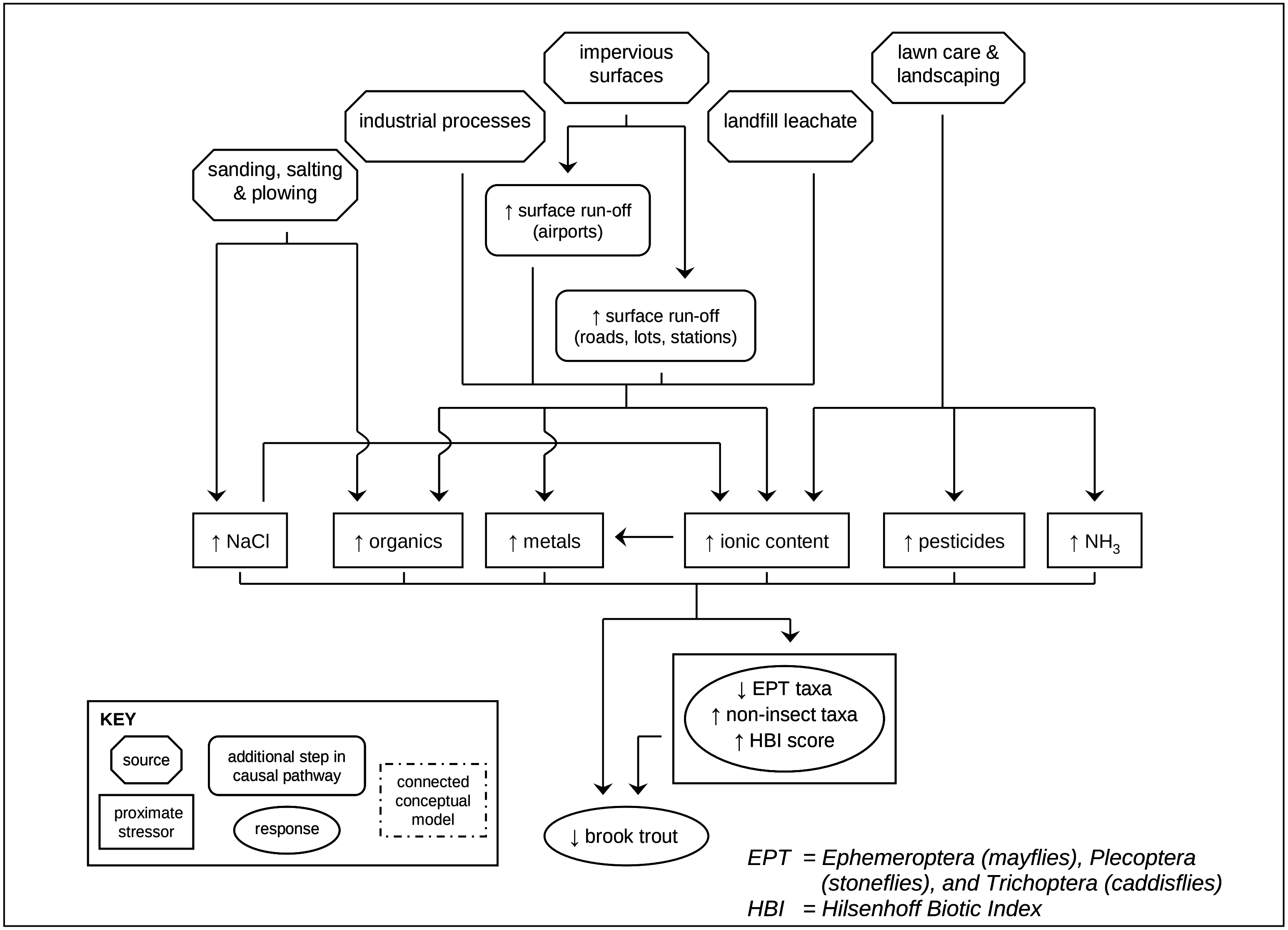
CM Figure 6. Increased sediment, first half of conceptual model.



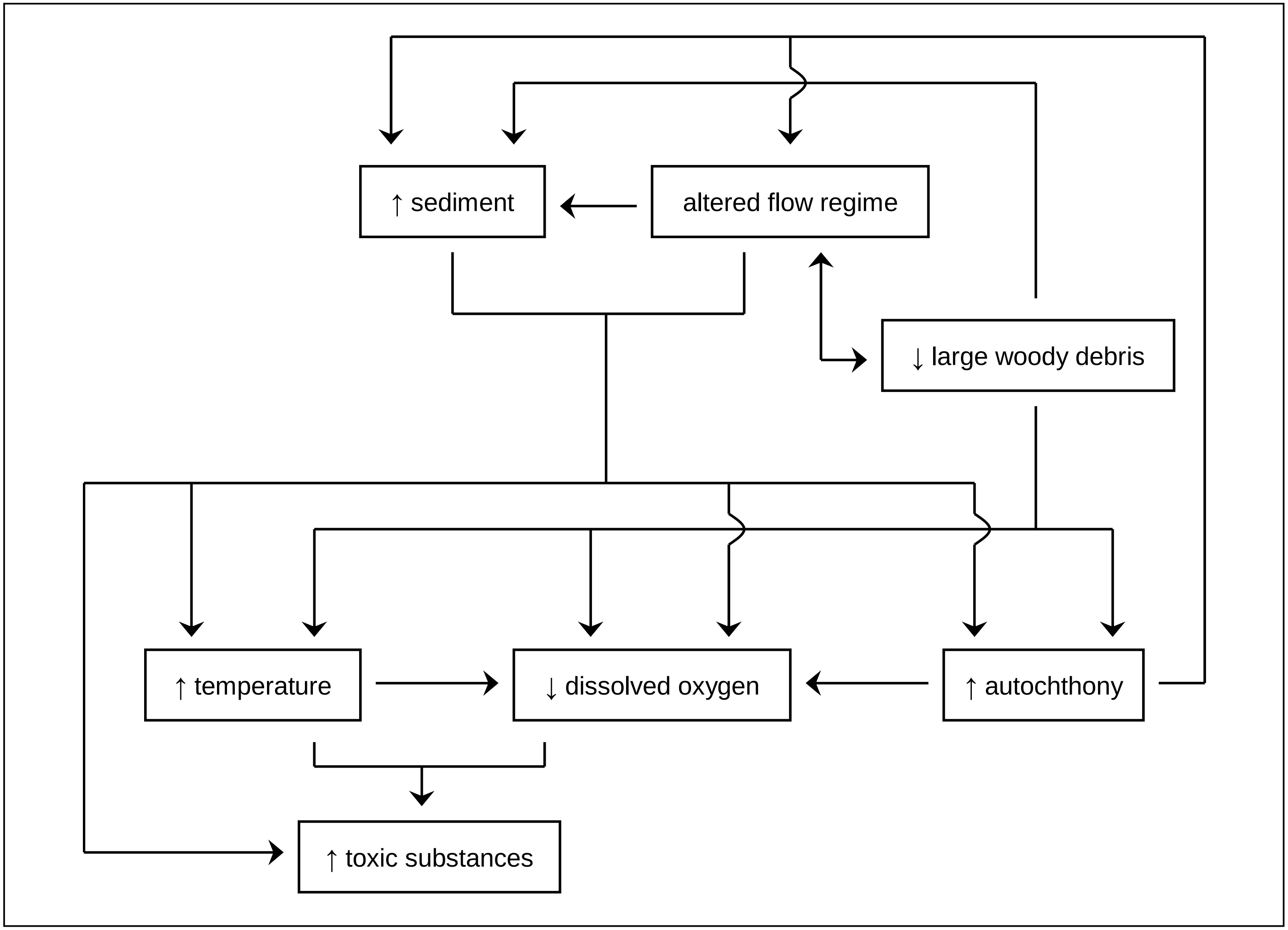
CM Figure 7. Increased sediment, second half of conceptual model.



CM Figure 8. Increased temperature conceptual model.



CM Figure 9. Increased toxic substances conceptual model.



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SOE Table 1. Spatial / temporal co-occurrence at LCN .415

Strength of evidence (SOE) scoring system for spatial / temporal co-occurrence
+ The effect occurs where or when the candidate cause occurs OR the effect does not occur where or when the candidate cause does not occur
0 It is uncertain whether the candidate cause and the effect co-occur
- - - The effect does not occur where or when the candidate cause occurs OR the effect occurs where or when the candidate cause does not occur
R The effect does not occur where and when the candidate cause occurs OR the effect occurs where or when the candidate cause does not occur and the evidence is indisputable
NE No evidence.

Candidate Cause	Variable, units	RB 3.961	LCN .415	Difference	SOE score	Comments
Increased autochthony	dominant aquatic vegetation, estimated % of local reach	diatoms 25%	diatoms 25%	0	0	The higher chlorophyll *a* measurement at LCN .415 was not considered strong enough to merit a positive score, given the similarity in dominant aquatic vegetation.
	chlorophyll *a*, mg/m^2	10.4	15.7	51%		
Decreased dissolved oxygen	dissolved oxygen, mg/L	8.7 [3] (8.0 - 9.5)	6.3 [3] (5.3 - 7.8)	-28%	+	
Altered flow regime	baseflow discharge / watershed area, cfs/ac	0.00073 [2] (0.00071 - 0.00075)	0.00055 [2] (0.00035 - 0.00076)	-25%	+	The baseflow data suggest that less groundwater recharge may be occurring at the impaired site, although this is based on 2 samples only. The 4 storm flow variables indicate that the impaired site responds to storm runoff with flashier discharge than the reference site (also see Figure 13).
	storm event peak discharge / watershed area, cfs/ac	0.0035	0.1338	3716%		
	storm event volume / watershed area, ac-ft/ac	0.0041	0.0276	578%		
	storm event duration, hours	25.4	5.5	-78%		
	storm event time to peak discharge, hours	9.4	2.3	-76%		
Decreased large woody debris	no LWD data at impaired site				NE	

Candidate Cause	Variable, units	RB 3.961	LCN .415	Difference	SOE score	Comments
Increased sediment	baseflow TSS, mg/L	< 10 [3] (< 2 - < 10)	< 10 [3] (3 - < 10)	≈ 0	+	The positive score is based on storm flow TSS and the RBP sediment deposition score. The project team recognizes that other variables listed indicate similarity between the two sites, and the muck mud variable indicates better conditions at the impaired site; as such, the positive score is borderline and, based on ambiguities, this cause could have been given a score of zero. Note that some TSS data did not meet MEDEP quality standards.
	storm flow TSS, mg/L	< 10 - 118 [9]	< 10 - 271 [9]	130%		
	muck-mud, %	60	40	-33%		
	RBP epifaunal substrate, score & category	13 sub-optimal	13 sub-optimal	0		
	RBP pool substrate, score & category	10 marginal	10 marginal	0		
	RBP sediment deposition, score & category	18 optimal	11 sub-optimal	LCN .415 worse than RB 3.961		
Increased temperature	weekly minimum, °C	12.9 [3] (11.4 - 14.0)	16.3 [3] (15.4 - 17.3)	27%	+	
	weekly maximum, °C	21.1 [3] (20.3 - 22.1)	22.7 [3] (21.6 - 24.2)	7%		
	weekly mean, °C	16.7 [3] (16.1 - 17.4)	19.2 [3] (18.6 - 20.0)	15%		
Increased toxic substances						
Water column sampling (units in ppm or mg/L, except specific conductivity uS/cm):						
Ionic strength	baseflow chloride	29 [3] (26 - 30)	122 [3] (91 - 141)	324%	+	
	storm flow chloride	17 - 57 [9]	15 - 296 [9]	419%		
	low flow calcium	6.8	67	885%		
	low flow magnesium	2.2	17	673%		
	baseflow specific conductivity, uS/cm	129 [3] (79 - 155)	745 [3] (659 - 796)	476%		
Cadmium	baseflow	< 0.0005 [3]	< 0.0005 [3]	ND	+	The Cadmium positive score is considered borderline; due to ambiguity, this could have been scored zero. Only 1 of 9 storm samples at the impaired site registered positive for cadmium (0.0007 ppm), & cadmium was not detected in any other measurement.
	low flow	< 0.0002	< 0.0002	ND		
	storm flow	< 0.0005 [9]	< 0.0005 - 0.0007 [9]	> 0		

Candidate Cause	Variable, units	RB 3.961	LCN .415	Difference	SOE score	Comments
Copper	baseflow	< 0.002 [3]	< 0.002 [3]	ND	+	
	low flow	contaminated sample		NA		
	storm flow	< 0.002 - 0.003 [9]	0.002 - 0.018 [9]	500%		
Lead	baseflow	< 0.003 [3]	< 0.003 [3]	ND	+	
	low flow	< 0.0002	< 0.0002	ND		
	storm flow	< 0.003 - 0.004 [9]	0.003 - 0.031 [9]	675%		
Nickel	baseflow	< 0.004 [3]	< 0.004 [3]	ND	+	
	low flow	0.00045	0.0032	611%		
	storm flow	< 0.004 [9]	< 0.004 - 0.013 [9]	> 0		
Zinc	baseflow	< 0.005 [3]	0.014 [3] (0.013 - 0.015)	> 0	+	
	low flow	< 0.005	0.0064	> 0		
	storm flow	0.008 - 0.024 [9]	0.043 - 0.14 [9]	483%		
Aluminum	**low flow**	0.045	0.006	-87%	- - -	
Antimony		< 0.0005	< 0.0005	ND	0	
Arsenic		< 0.0005	0.00098	> 0	+	
Barium		0.0054	0.021	289%	+	
Beryllium		< 0.0002	< 0.0002	ND	0	
Chromium		< 0.0005	0.0032	> 0	+	
Cobalt		0.00085	0.0029	241%	+	
Iron		0.091	0.14	54%	+	
Manganese		0.025	0.37	1380%	+	
Molybdenum		< 0.0005	0.00092	> 0	+	
Selenium		< 0.001	< 0.001	ND	0	
Silver		< 0.0002	< 0.0002	ND	0	
Thallium		< 0.0005	< 0.0005	ND	0	
Vanadium		0.0003	0.00082	173%	+	

Candidate Cause	Variable, units	RB 3.961	LCN .415	Difference	SOE score	Comments
Polycyclic aromatic hydrocarbons (PAHs) water column sampling (ppm or mg/L):						
Acenaphthene	**storm flow PAH samples are from two events, occurring on 10/23/2000 and 9/25/2001. values and differences shown at right are separated by "&" to distinguish between the two storm events PAHs were tested for but not detected for either storm event at the reference site (surrogate site RB 1.694)**		0.0001 & < 0.0001	> 0 & ND	+	
Acenaphthylene			< 0.00005 & < 0.0001	ND & ND	0	
Anthracene			0.0002 & < 0.0001	> 0 & ND	+	
Benzo(a) anthracene			0.0001 & 0.00033	> & > 0	+	
Benzo(a) pyrene			0.0001 & 0.00048	> 0 & > 0	+	
Benzo(b) fluoranthene			0.0002 & 0.00111	> 0 & > 0	+	
Benzo(ghi) perylene			0.0001 & 0.0005	> 0 & > 0	+	
Benzo(k) fluoranthene			< 0.00005 & 0.00029	ND & > 0	+	
Chrysene			0.0002 & 0.0008	> 0 & > 0	+	
Dibenzo(a,h) anthracene			< 0.00005 & 0.00011 (note that RL = 0.0002)	ND & ND	0	
Fluoranthene			0.0005 & 0.0016	> 0 & > 0	+	
Fluorene			0.0001 & < 0.0001	> 0 & ND	+	
Indeno (1,2,3-cd) pyrene			0.0001 & 0.00056	> 0 & > 0	+	
Naphthalene			0.0001 & < 0.0001	> 0 & ND	+	
Phenanthrene			0.00025 & 0.00067	> 0 & > 0	+	
Pyrene			0.0003 & 0.00115	> 0 & > 0	+	

Candidate Cause	Variable, units	RB 3.961	LCN .415	Difference	SOE score	Comments
Sediment sampling (mg/kg):						
Antimony	**one sediment sample taken on 10/10/2003**	< 10	< 10	ND	0	Toxicity tests were conducted using these sediment samples; for results and related information, see the Stressor-Response analysis.
Arsenic		< 20	< 20	ND	0	
Barium		43	41	-5%	- - -	
Beryllium		< 1.0	< 1.0	ND	0	
Cadmium		< 3.0	< 3.0	ND	0	
Chromium		6.3	18	186%	+	
Cobalt		5.5	8.2	49%	+	
Copper		3.2	6.3	97%	+	
Lead		14	13	-7%	- - -	
Nickel		< 6.0	10	> 0	+	
Selenium		< 10	< 10	ND	0	
Silver		< 3.0	< 3.0	ND	0	
Thallium		< 20	< 20	ND	0	
Vanadium		9.2	24	161%	+	
Zinc		32	54	69%	+	

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].
(Note that a range is provided for baseflow only if a toxic substance is detected.)

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Lower thresholds of essential elements are not considered in this causal analysis.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
epifaunal substrate / available cover	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
pool substrate characterization	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
sediment deposition	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal

SOE Table 2. Spatial / temporal co-occurrence at LCM 2.270

Strength of evidence (SOE) scoring system for spatial / temporal co-occurrence
+ The effect occurs where or when the candidate cause occurs OR the effect does not occur where or when the candidate cause does not occur
0 It is uncertain whether the candidate cause and the effect co-occur
- - - The effect does not occur where or when the candidate cause occurs OR the effect occurs where or when the candidate cause does not occur
R The effect does not occur where and when the candidate cause occurs OR the effect occurs where or when the candidate cause does not occur and the evidence is indisputable
NE No evidence.

Candidate Cause	Variable, units	RB 3.961	LCM 2.270	Difference	SOE score	Comments
Increased autochthony	dominant aquatic vegetation, % of local reach	diatoms 25%	rooted submergents and diatoms 25%	0	0	The minor reported difference in dominant aquatic vegetation was not clear enough to change the score from zero.
Decreased dissolved oxygen	baseflow, mg/L	8.7 [3] (8.0 - 9.5)	5.3 [3] (4.1 - 7.4)	-39%	+	
Altered flow regime	no appropriate data to represent flow conditions at the impaired site (e.g., velocity or discharge)				NE	
Decreased large woody debris	LWD diameter ≥ 5cm, # of pieces	91	37	-59%	+	
	LWD diameter ≥ 10cm, # of pieces	39	8	-79%		
Increased sediment	baseflow TSS, mg/L	< 10 [3] (< 2 - < 10)	< 10 [3] (1 - < 10)	≈ 0	0	The small difference in muck mud between the two sites does not provide enough evidence over the other variables, which are essentially equal at both sites; therefore, this was scored zero. Note that some TSS data did not meet MEDEP quality standards.
	muck-mud, %	60	70	17%		
	RBP epifaunal substrate, score, and category	13 sub-optimal	13 sub-optimal	0		
	RBP pool substrate, score and category	10 marginal	10 marginal	0		
	RBP sediment deposition, score, and category	18 optimal	18 optimal	0		

Candidate Cause	Variable, units	RB 3.961	LCM 2.270	Difference	SOE score	Comments
Increased temperature	weekly minimum, °C	13.1	17.0	29%	+	
	weekly maximum, °C	20.3	23.3	15%		
	weekly mean, °C	16.6	20.2	22%		
Increased toxic substances						
Water column sampling (units in ppm or mg/L, except specific conductivity uS/cm):						
Ionic Strength	baseflow chloride	29 [3] (26 - 30)	99 [3] (83 - 124)	241%	+	
	baseflow specific conductivity, uS/cm	129 [3] (79 - 155)	568 [3] (491 - 718)	340%		
Cadmium	baseflow	< 0.0005 [3]	< 0.0005 [3]	ND	0	
Copper	baseflow	< 0.002 [3]	< 0.002 [3]	ND	0	
Lead	baseflow	< 0.003 [3]	< 0.003 [3]	ND	0	
Nickel	baseflow	< 0.004 [3]	< 0.004 [3]	ND	0	
Zinc	baseflow	< 0.005 [3]	< 0.005 [3]	ND	0	

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].
(Note that a range is provided for baseflow only if a toxic substance is detected.)

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Lower thresholds of essential elements are not considered in this causal analysis.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
epifaunal substrate / available cover	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
pool substrate characterization	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
sediment deposition	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal

SOE Table 3. Spatial / temporal co-occurrence at LCMn 2.274

Strength of evidence (SOE) scoring system for spatial / temporal co-occurrence
- \+ The effect occurs where or when the candidate cause occurs OR the effect does not occur where or when the candidate cause does not occur
- 0 It is uncertain whether the candidate cause and the effect co-occur
- \- - - The effect does not occur where or when the candidate cause occurs OR the effect occurs where or when the candidate cause does not occur
- R The effect does not occur where and when the candidate cause occurs OR the effect occurs where or when the candidate cause does not occur, and the evidence is indisputable
- NE No evidence.

Candidate Cause	Variable, units	RB 3.961	LCMn 2.274	Difference	SOE score	Comments
Increased autochthony	dominant aquatic vegetation, % of local reach	diatoms 25%	diatoms 20%	-20%	0	The higher diatom observation at the reference site counteracts the higher chlorophyll *a* measurement at the impaired site; uncertainty yielded a score of zero.
	chlorophyll *a*, mg/m^2	10.4	17.5	68%		
Decreased dissolved oxygen	baseflow, mg/L	8.7 [3] (8.0 - 9.5)	5.5 [3] (4.4 - 6.2)	-37%	+	Dissolved oxygen data were collected approximately 10cm above the stream bottom; therefore, these values may be more applicable to fish habitat than benthic invertebrate habitat.
Altered flow regime	mean thalweg velocity, m/s	0.10	0.03	-73%	+	Flow regime differences between the two sites cannot be characterized by mean velocity alone. Flow heterogeneity adds support for a positive score (also see Figure 14).
	baseflow velocity measured at 2m increments along 100m reach in site vicinity	highly variable longitudinal channel velocity and normally above zero	low longitudinal velocity variability and often equal to zero	qualitative support of cause		
Decreased large woody debris	LWD diameter ≥ 5cm, # of pieces	91	43	-53%	+	
	LWD diameter ≥ 10cm, # of pieces	39	12	-69%		

Candidate Cause	Variable, units	RB 3.961	LCMn 2.274	Difference	SOE score	Comments
Increased sediment	baseflow TSS, mg/L	< 10 [3] (< 2 - < 10)	< 10 [3] (4 - < 10)	≈ 0	0	The difference in muck mud between the two sites does not provide enough evidence over the other variables, which are essentially equal at both sites; therefore, this was scored zero. Note that some TSS data did not meet MEDEP quality standards.
	muck mud, %	60	40	-33%		
	RBP epifaunal substrate, score, and category	13 sub-optimal	12 sub-optimal	0		
	RBP pool substrate, score and category	10 marginal	8 marginal	0		
	RBP sediment deposition, score, and category	18 optimal	18 optimal	0		
Increased temperature	weekly minimum, °C	13.1	13.2	0%	+	The weekly maximum is higher, and this value may be more important that the others (see Stressor-Response analysis); therefore, while the minimum and mean values for the two sites are relatively similar, a positive score was still given.
	weekly maximum, °C	20.3	21.8	8%		
	weekly mean, °C	16.6	16.5	0%		
Increased toxic substances						
Water column sampling (units in ppm or mg/L, except specific conductivity uS/cm):						
Ionic Strength	baseflow chloride	29 [3] (26 - 30)	66 [3] (58 - 73)	128%	+	
	low flow calcium	6.8	31.5	363%		
	low flow magnesium	2.2	11	400%		
	baseflow specific conductivity, uS/cm	129 [3] (79 - 155)	459 [3] (376 - 510)	256%		
Cadmium	baseflow	< 0.0005 [3]	< 0.0005 [3]	ND	0	
	low flow	< 0.0002	< 0.0002	ND		
Copper	baseflow	< 0.002 [3]	0.0013 [3] (< 0.002 - 0.002)	ND	0	
	low flow	contaminated sample		NA		

Candidate Cause	Variable, units	RB 3.961	LCMn 2.274	Difference	SOE score	Comments
Lead	baseflow	< 0.003 [3]	< 0.003 [3]	ND	0	
	low flow	< 0.0002	< 0.0002	ND		
Nickel	baseflow	< 0.004 [3]	< 0.004 [3]	ND	+	
	low flow	0.00045	0.0019	322%		
Zinc	baseflow	< 0.005	0.0042 [3] (< 0.005 - 0.005)	ND	0	
	low flow	< 0.005	< 0.005	ND		
Aluminum	low flow	0.045	0.019	-58%	- - -	
Antimony		< 0.0005	< 0.0005	ND	0	
Arsenic		< 0.0005	0.00235	> 0	+	
Barium		0.0054	0.011	104%	+	
Beryllium		< 0.0002	< 0.0002	ND	0	
Chromium		< 0.0005	0.00205	> 0	+	
Cobalt		0.00085	0.000555	-35%	- - -	
Iron		0.091	0.22	142%	+	
Manganese		0.025	0.092	268%	+	
Molybdenum		< 0.0005	0.000385	ND	0	
Selenium		< 0.001	< 0.001	ND	0	
Silver		< 0.0002	< 0.0002	ND	0	
Thallium		< 0.0005	< 0.0005	ND	0	
Vanadium		0.0003	0.000695	132%	+	

Candidate Cause	Variable, units	RB 3.961	LCMn 2.274	Difference	SOE score	Comments
Sediment sampling (mg/kg):						
Antimony	**one sediment sample taken on 10/10/2003**	< 10	< 10	ND	0	Toxicity tests were conducted using these sediment samples; for results and related information, see the Stressor-Response analysis.
Arsenic		< 20	< 20	ND	0	
Barium		43	38	-12%	- - -	
Beryllium		< 1.0	< 1.0	ND	0	
Cadmium		< 3.0	< 3.0	ND	0	
Chromium		6.3	16.5	162%	+	
Cobalt		5.5	6.95	26%	+	
Copper		3.2	6.25	95%	+	
Lead		14	7.5	-46%	- - -	
Nickel		< 6.0	10.5	> 0	+	
Selenium		< 10	< 10	ND	0	
Silver		< 3.0	< 3.0	ND	0	
Thallium		< 20	< 20	ND	0	
Vanadium		9.2	20	117%	+	
Zinc		32	58.5	83%	+	

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].
(Note that a range is provided for baseflow only if a toxic substance is detected.)

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Lower thresholds of essential elements are not considered in this causal analysis.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
epifaunal substrate / available cover	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
pool substrate characterization	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
sediment deposition	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal

SOE Table 4. Stressor-response relationships from the field

Strength of evidence (SOE) scoring system for stressor-response relationship in the field

+ + A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, and the gradient is in the expected direction.
+ A weak effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, OR a strong effect gradient is observed relative to exposure to the candidate cause, at non-spatially linked sites, and the gradient is in the expected direction.
0 An uncertain effect gradient is observed relative to exposure to the candidate cause
- An inconsistent effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, OR a strong effect gradient is observed relative to exposure to the candidate cause, at non-spatially linked sites, but the gradient is not in the expected direction.
- - A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, but the relationship is not in the expected direction.
NE no evidence.

Reasoning and Comments	SOE score Endpoint	SOE score Score
Increased autochthony Scatter plots for nutrients and aquatic vegetation were used to determine stressor-response relationships for autochthony. Weak positive gradients are seen between HBI and the following nutrients: total Kjeldahl nitrogen, total phosphorus, and ortho-phosphorus. Correlations for the other biological endpoints and other variables remain uncertain.	EPT richness % non-insects HBI	0 0 +
Decreased dissolved oxygen Scatter plots for dissolved oxygen (percent saturation and concentration) show weak correlation between decreasing HBI and increasing dissolved oxygen. Relationships for other biological endpoints are uncertain. However, EPT may be increasing with increasing dissolved oxygen; the project team chooses to score this zero (uncertain) but recognizes this as a borderline situation and that additional data may add support to the correlation, thus supporting the case for this cause.	EPT richness % non-insects HBI	0 0 +
Altered flow regime Appropriate stressor-response data from the project site are not available for direct analysis of this cause; therefore, NE scores were given.	EPT richness % non-insects HBI	NE NE NE
Decreased large woody debris Scatter plot data are sparse but support the case for this cause. EPT and large woody debris are positively correlated. Additionally, HBI appears to decrease as large woody debris increases.	EPT richness % non-insects HBI	+ 0 +
Increased sediment Substrate particle size, bank stability, and Rapid Bioassessment Protocol (RBP) variables were considered for this candidate cause. Noticeable relationships between the variables and biological endpoints were unclear. Weak correlations between RBP variables and biological endpoints did not merit positive scores.	EPT richness % non-insects HBI	0 0 0

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
Increased temperature		
Weekly minimum, maximum, and mean temperature and canopy shade variables are used for this candidate cause. EPT appears to decrease and HBI appears to increase as weekly maximum temperature increases. There is a weak correlation between decreasing HBI and increasing canopy shade. Relationships between remaining variables and biological endpoints remain uncertain.	EPT richness % non-insects HBI	+ 0 +
Increased toxic substances		
ionic strength		
EPT decreases as chloride and specific conductivity increase. Non-insects appear to increase as chloride and specific conductivity increase, although the relationship is weak-to-borderline for chloride. HBI increases as chloride and specific conductivity increase.	EPT richness % non-insects HBI	+ + +
zinc		
Scatter plot correlations between zinc and the biological endpoints are uncertain.	EPT richness % non-insects HBI	0 0 0

SOE Table 5. Causal pathway - Data - Increased autochthony

Steps in causal pathway, units	RB 3.961	LCN .415 Value	LCN .415 Difference	LCM 2.270 Value	LCM 2.270 Difference	LCMn 2.274 Value	LCMn 2.274 Difference
RBP riparian vegetative zone width, score and category	10 optimal	6.5 sub-optimal	<	4 marginal	<	7 sub-optimal	<
baseflow total phosphorus, ppm	0.009 [3] (0.008 - 0.010)	0.048 [3] (0.040 - 0.061)	433%	0.025 [3] (0.020 - 0.028)	174%	0.030 [3] (0.024 - 0.035)	230%
baseflow ortho-phosphorus, ppm	0.003 [3] (0.002 - 0.004)	0.009 [3] (0.004 - 0.017)	238%	0.008 [3] (0.006 - 0.010)	200%	0.005 [3] (0.002 - 0.007)	88%
baseflow total nitrogen, ppm	0.310 [3] (0.280 - 0.350)	0.617 [3] (0.610 - 0.620)	99%	0.513 [3] (0.420 - 0.600)	66%	0.457 [3] (0.330 - 0.540)	47%
baseflow total kjeldahl nitrogen, ppm	0.167 [3] (0.100 - 0.200)	0.300 [3] (0.300 - 0.300)	80%	0.467 [3] (0.400 - 0.500)	180%	0.400 [3] (0.300 - 0.500)	140%
baseflow nitrate + nitrite, ppm	0.143 [3] (0.100 - 0.180)	0.317 [3] (0.310 - 0.320)	121%	< 0.047 [3] (0.02 - < 0.20)	-67%	< 0.057 [3] (0.03 - < 0.20)	-60%
storm flow total phosphorus, ppm	0.011 - 0.074 [9]	0.044 - 0.320 [9]	332%	NE	NA	NE	NA
storm flow ortho-phosphorus, ppm	< 0.001 - 0.005 [9]	< 0.001 - 0.015 [9]	200%	NE	NA	NE	NA
storm flow total nitrogen, ppm	0.330 - 0.800 [9]	0.520 - 1.670 [9]	109%	NE	NA	NE	NA
storm flow total Kjeldahl nitrogen, ppm	0.2 - 0.7 [9]	0.4 - 1.3 [9]	86%	NE	NA	NE	NA
storm flow nitrate + nitrite, ppm	0.03 - 0.25 [9]	0.12 - 0.82 [9]	228%	NE	NA	NE	NA
LWD diameter ≥ 5cm, # of pieces	91	NE	NA	37	-59%	43	-53%
LWD diameter ≥ 10cm, # of pieces	39	NE	NA	8	-79%	12	-69%
mean thalweg velocity, m/s	0.10	NE	NA	NE	NA	0.0273	-73%
shaded canopy, %	90.9	88.1	-3%	81.4	-10%	90.8	0%

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

difference calculation

- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
riparian vegetative zone width	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal

SOE Table 6. Causal pathway - Data - Decreased dissolved oxygen

Steps in causal pathway, units	RB 3.961	LCN .415		LCM 2.270		LCMn 2.274	
		Value	Difference	Value	Difference	Value	Difference
RBP channel alteration, score and category	20 optimal	17 optimal	≈ 0	14 sub-optimal	<	14 sub-optimal	<
RBP riparian vegetative zone width, score and category	10 optimal	6.5 sub-optimal	<	4 marginal	<	7 sub-optimal	<
baseflow total phosphorus, ppm	0.009 [3] (0.008 - 0.010)	0.048 [3] (0.040 - 0.061)	433%	0.025 [3] (0.020 - 0.028)	174%	0.030 [3] (0.024 - 0.035)	230%
baseflow ortho-phosphorus, ppm	0.003 [3] (0.002 - 0.004)	0.009 [3] (0.004 - 0.017)	238%	0.008 [3] (0.006 - 0.010)	200%	0.005 [3] (0.002 - 0.007)	88%
baseflow total nitrogen, ppm	0.310 [3] (0.280 - 0.350)	0.617 [3] (0.610 - 0.620)	99%	0.513 [3] (0.420 - 0.600)	66%	0.457 [3] (0.330 - 0.540)	47%
baseflow total kjeldahl nitrogen, ppm	0.167 [3] (0.100 - 0.200)	0.300 [3] (0.300 - 0.300)	80%	0.467 [3] (0.400 - 0.500)	180%	0.400 [3] (0.300 - 0.500)	140%
baseflow nitrate + nitrite, ppm	0.143 [3] (0.100 - 0.180)	0.317 [3] (0.310 - 0.320)	121%	< 0.047 [3] (0.02 - < 0.20)	-67%	< 0.057 [3] (0.03 - < 0.20)	-60%
storm flow total phosphorus, ppm	0.011 - 0.074 [9]	0.044 - 0.320 [9]	332%	NE	NA	NE	NA
storm flow ortho-phosphorus, ppm	< 0.001 - 0.005 [9]	< 0.001 - 0.015 [9]	200%	NE	NA	NE	NA
storm flow total nitrogen, ppm	0.330 - 0.800 [9]	0.520 - 1.670 [9]	109%	NE	NA	NE	NA
storm flow total Kjeldahl nitrogen, ppm	0.2 - 0.7 [9]	0.4 - 1.3 [9]	86%	NE	NA	NE	NA
storm flow nitrate + nitrite, ppm	0.03 - 0.25 [9]	0.12 - 0.82 [9]	228%	NE	NA	NE	NA
chlorophyll *a* , mg/m^2	10.4	15.7	51%	NE	NA	17.5	68%
LWD diameter ≥ 5cm, # of pieces	91	NE	NA	37	-59%	43	-53%
LWD diameter ≥ 10cm, # of pieces	39	NE	NA	8	-79%	12	-69%
shaded canopy, %	90.9	88.1	-3%	81.4	-10%	90.8	0%

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
channel alteration	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
riparian vegetative zone width	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal

SOE Table 7. Causal pathway - Data - Altered flow regime

Steps in causal pathway, units	RB 3.961	LCN .415		LCM 2.270		LCMn 2.274	
		Value	Difference	Value	Difference	Value	Difference
RBP channel alteration, score, and category	20 optimal	17 optimal	≈ 0	14 sub-optimal	<	14 sub-optimal	<
RBP channel sinuosity, score, and category	16 optimal	9 marginal	<	14 sub-optimal	<	12 sub-optimal	<
RBP riparian vegetative zone width, score, and category	10 optimal	6.5 sub-optimal	<	4 marginal	<	7 sub-optimal	<
LWD diameter ≥ 5cm, # of pieces	91	NE	NA	37	-59%	43	-53%
LWD diameter ≥ 10cm, # of pieces	39	NE	NA	8	-79%	12	-69%
percent impervious surface	2.1	32.6	1452%	7.1	238%	14.3	581%

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
channel alteration	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
channel sinuosity	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
riparian vegetative zone width	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal

SOE Table 8. Causal pathway - Data - Decreased large woody debris

Steps in causal pathway, units	RB 3.961	LCN .415		LCM 2.270		LCMn 2.274	
		Value	Difference	Value	Difference	Value	Difference
RBP channel alteration, score, and category	20 optimal	17 optimal	≈ 0	14 sub-optimal	<	14 sub-optimal	<
RBP channel sinuosity, score, and category	16 optimal	9 marginal	<	14 sub-optimal	<	12 sub-optimal	<
RBP riparian vegetative zone width, score, and category	10 optimal	6.5 sub-optimal	<	4 marginal	<	7 sub-optimal	<

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
channel alteration	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
channel sinuosity	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
riparian vegetative zone width	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal

SOE Table 9. Causal pathway - Data - Increased sediment

Steps in causal pathway, units	RB 3.961	LCN .415		LCM 2.270		LCMn 2.274	
		Value	Difference	Value	Difference	Value	Difference
RBP channel alteration, score, and category	20 optimal	17 optimal	≈ 0	14 sub-optimal	<	14 sub-optimal	<
RBP channel sinuosity, score, and category	16 optimal	9 marginal	<	14 sub-optimal	<	12 sub-optimal	<
RBP riparian vegetative zone width, score, and category	10 optimal	6.5 sub-optimal	<	4 marginal	<	7 sub-optimal	<
RBP bank vegetative protection, score, and category	10 optimal	10 optimal	0	7 sub-optimal	<	8 sub-optimal	<
RBP bank stability, score, and category	9 optimal	7 sub-optimal	<	8.5 optimal	≈ 0	9 optimal	≈ 0
Pfankuch, score	93	105	13%	NE	NA	111	19%
LWD diameter ≥ 5cm, # of pieces	91	NE	NA	37	-59%	43	-53%
LWD diameter ≥ 10cm, # of pieces	39	NE	NA	8	-79%	12	-69%
percent impervious surface	2.1	32.6	1452%	7.1	238%	14.3	581%

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
channel alteration	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
channel sinuosity	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
bank stability	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal
bank vegetative protection	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal
riparian vegetative zone width	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal

SOE Table 10. Causal pathway - Data - Increased temperature

Steps in causal pathway, units	RB 3.961	LCN .415		LCM 2.270		LCMn 2.274	
		Value	Difference	Value	Difference	Value	Difference
RBP channel alteration, score, and category	20 optimal	17 optimal	≈ 0	14 sub-optimal	<	14 sub-optimal	<
RBP channel sinuosity, score, and category	16 optimal	9 marginal	<	14 sub-optimal	<	12 sub-optimal	<
RBP riparian vegetative zone width, score, and category	10 optimal	6.5 sub-optimal	<	4 marginal	<	7 sub-optimal	<
shaded canopy, %	90.9	88.1	-3%	81.4	-10%	90.8	0%
percent impervious surface	2.1	32.6	1452%	7.1	238%	14.3	581%

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

difference calculation
- the majority of differences are expressed as a percent = [(impaired value - reference value) / reference value] * 100%;
- differences between Rapid Bioassessment Protocol (RBP) values are shown as greater or less than the reference value based on RBP qualitative condition categories (see further below);
- differences between two ranges of values are calculated using the maximum values.

Rapid Bioassessment Protocol (RBP)

Habitat Parameter	Score and Condition Category
channel alteration	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
channel sinuosity	0-5 poor, 6-10 marginal, 11-15 sub-optimal, 16-20 optimal
riparian vegetative zone width	0-2 poor, 3-5 marginal, 6-8 sub-optimal, 9-10 optimal

SOE Table 11. Causal pathway - Data - Increased toxic substances

		LCN .415		LCM 2.270		LCMn 2.274	
Steps in causal pathway, units	**RB 3.961**	**Value**	**Difference**	**Value**	**Difference**	**Value**	**Difference**
percent impervious surface	2.1	32.6	1452%	7.1	238%	14.3	581%

SOE Table 12. Causal pathway - Scores - Increased autochthony

Strength of evidence (SOE) scoring system for causal pathway

- ++ Data show that all steps in at least one causal pathway are present.
- \+ Data show that some steps in at least one causal pathway are present.
- 0 Data show that the presence of all steps in the causal pathway is uncertain.
- \- Data show that there is at least one missing step in each causal pathway.
- \- - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway.

Reasoning and Comments	SOE score
Site LCN .415 Evidence for some causal steps - All measured nutrients are greater at the impaired site than at the reference site, which could lead to increases in primary producers, thereby potentially increasing autochthony. Riparian devegetation, evidenced by the RBP riparian vegetation variable, could decrease allochthony, thereby increasing autochthony; however, there is no evidence for intermediate steps within that particular causal pathway. Ambiguous evidence - Shaded canopy values at the impaired and reference sites are almost identical, which weakens the case for the increased light pathway. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+
Site LCM 2.270 Evidence for some causal steps - Most measured nutrients are greater at the impaired site than at the reference site, which could lead to increases in primary producers and potential increases in autochthony. Riparian devegetation, evidenced by the RBP riparian vegetation variable, leads to decreased LWD, for which there is evidence, thereby potentially decreasing allochthony and increasing autochthony; also, riparian devegetation could lead to increases in light, which is evidenced by the lower canopy shade percentage, thereby increasing primary producers and increasing autochthony. Ambiguous evidence - Measured nitrate plus nitrite at the site is lower than at the reference site; this contradicts the increased nutrients causal step. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+
Site LCMn 2.274 Evidence for some causal steps - Most measured nutrients are greater at the impaired site than at the reference site, which could lead to increases in primary producers and potential increases in autochthony. Riparian devegetation, evidenced by the RBP riparian vegetation variable, leads to decreased LWD, for which there is evidence, thereby potentially decreasing allochthony and increasing autochthony. There is evidence for decreased channel velocity at the site, which could increase primary producers. Ambiguous evidence - Measured nitrate plus nitrite at the site is lower than at the reference site; this contradicts the increased nutrients causal step. Shaded canopy values at the impaired and reference sites are almost identical, which weakens the case for the increased light pathway. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 13. Causal pathway - Scores - Decreased dissolved oxygen

Strength of evidence (SOE) scoring system for causal pathway
- ++ Data show that all steps in at least one causal pathway are present
- + Data show that some steps in at least one causal pathway are present
- 0 Data show that the presence of all steps in the causal pathway is uncertain
- - Data show that there is at least one missing step in each causal pathway
- - - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway

Reasoning and Comments	SOE score
Site LCN .415 Evidence for some causal steps - All measured nutrients are greater at the impaired site than at the reference site, which could lead to increases in primary producers, resultant disruptive shifts in the photosynthesis/respiration balance, and potential decreases in dissolved oxygen. Ambiguous evidence - There is some evidence for riparian devegetation (lower RBP riparian vegetative zone width), but given the high shaded canopy value at the impaired site and its similarity to the reference condition, this causal pathway is probably not a factor. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+
Site LCM 2.270 Evidence for some causal steps - Most measured nutrients are greater at the impaired site than at the reference site, which could lead to increases in primary producers, resultant disruptive shifts in the photosynthesis/respiration balance, and potential decreases in dissolved oxygen. The low RBP riparian vegetation score lends evidence to increased riparian devegetation, leading to decreased LWD, for which there is also evidence, and this could reduce turbulence and aeration. The low RBP riparian vegetation score lends support to the increased light causal pathway, which is further supported by a lower shaded canopy percentage at the impaired site. Turbulence and aeration may also be reduced by channel alteration, as evidenced by the RBP scores. Ambiguous evidence - Measured nitrate plus nitrite at the site is lower than at the reference site; this contradicts the increased nutrients causal step. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Reasoning and Comments	SOE score
Site LCMn 2.274 Evidence for some causal steps - Most measured nutrients are greater at the impaired site than at the reference site, which could lead to increases in primary producers, resultant disruptive shifts in the photosynthesis/respiration balance, and potential decreases in dissolved oxygen. The low RBP riparian vegetation score lends support to increased riparian devegetation, leading to decreased LWD, for which there is also evidence, and this could reduce turbulence and aeration. Turbulence and aeration may also be reduced by channel alteration, as evidenced by the RBP scores. Ambiguous evidence - Measured nitrate plus nitrite at the site is lower than at the reference site; this contradicts the increased nutrients causal step. Shaded canopy values at the impaired and reference sites are almost identical, which weakens the case for the increased light pathway. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 14. Causal pathway - Scores - Altered flow regime

Strength of evidence (SOE) scoring system for causal pathway

- ++ Data show that all steps in at least one causal pathway are present
- + Data show that some steps in at least one causal pathway are present
- 0 Data show that the presence of all steps in the causal pathway is uncertain
- - Data show that there is at least one missing step in each causal pathway
- - - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway

Reasoning and Comments	SOE score
Site LCN .415 Evidence for some causal steps - The high percent impervious surface within this watershed likely results in a more flashy hydrologic system—that is, a system with higher storm discharges and lower day-to-day base discharge—potentially leading to organism dislodgement and decreased base water depth and base wetted channel. Decreased channel sinuosity, a form of channel alteration evidenced by the RBP analysis, and riparian devegetation, evidenced by the RBP riparian vegetative zone width variable, could increase the potential for greater flow velocities and dislodgement of organisms. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+
Sites LCM 2.270 & LCMn 2.274 Potential pathways - Percent impervious surface within these watersheds likely results in more flashy hydrologic systems—that is, systems with higher storm discharges and lower day-to-day base discharge—potentially leading to organism dislodgement and decreased base water depth and base wetted channel. Riparian devegetation and channel alteration, evidenced by the RBP analysis and decreases in LWD, could increase the potential for greater flow velocities and dislodgement of organisms. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 15. Causal pathway - Scores - Decreased large woody debris

Strength of evidence (SOE) scoring system for causal pathway

- ++ Data show that all steps in at least one causal pathway are present
- \+ Data show that some steps in at least one causal pathway are present
- 0 Data show that the presence of all steps in the causal pathway is uncertain
- \- Data show that there is at least one missing step in each causal pathway
- \- - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway

Reasoning and Comments	SOE score
Sites LCN .415, LCM 2.270, & LCMn 2.274	
Evidence for some causal steps - The RBP analysis lends evidence to riparian devegetation, channel alteration, and decreased cover. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 16. Causal pathway - Scores - Increased sediment

Strength of evidence (SOE) scoring system for causal pathway

++ Data show that all steps in at least one causal pathway are present
+ Data show that some steps in at least one causal pathway are present
0 Data show that the presence of all steps in the causal pathway is uncertain
- Data show that there is at least one missing step in each causal pathway
- - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway

Reasoning and Comments	SOE score
Site LCN .415 Evidence for some causal steps - The high PTIA within this watershed could increase storm discharges, resulting in increased channel and/or bank erosion—thereby increasing potential sediment sources. Channel alteration and riparian devegetation, evidenced by the RBP qualitative scores for channel sinuosity and riparian vegetative width zone, may decrease bank stability, for which there is also evidence—specifically, a lower RBP bank stability qualitative score and a higher Pfankuch score—leading to increased bank erosion and potential sediment sources. Ambiguous evidence - The RBP bank vegetative protection qualitative score is optimal for both sites, which weakens the case for increased riparian devegetation leading to erosion. The pathway including decreased velocity, allowing settling/deposition, is uncertain because the sub-optimal score for RBP channel sinuosity may indicate increased flow velocity at the impaired site. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+
Site LCM 2.270 Evidence for some causal steps - The PTIA within this watershed could increase storm discharges, resulting in increased channel and/or bank erosion—thereby increasing potential sediment sources. Channel alteration and riparian devegetation, evidenced by the RBP qualitative scores for channel sinuosity and riparian vegetative width zone, may decrease bank stability, leading to increased bank erosion and potential sediment sources. Reduced riparian vegetation, evidenced by the RBP vegetative zone width and bank vegetative protection, may decrease LWD, which is lower at this site, thereby increasing erosion and further input of sediment. Ambiguous evidence - The RBP bank stability qualitative score is optimal for both sites, which weakens the case for the causal pathway beginning with channel alteration and causing bank instability, leading to bank erosion. The pathway including decreased velocity allowing settling/deposition is uncertain because the sub-optimal score for RBP channel sinuosity may indicate increases in flow velocity at the impaired site. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Reasoning and Comments	SOE score
Site LCMn 2.274 Evidence for some causal steps - The PTIA within this watershed could increase storm discharges, resulting in increased channel and/or bank erosion—thereby increasing potential sediment sources. Channel alteration and riparian devegetation, evidenced by the RBP qualitative scores for channel sinuosity and riparian vegetative width zone, may decrease bank stability, leading to increased bank erosion and potential sediment sources. Reduced riparian vegetation, evidenced by the RBP vegetative zone width and bank vegetative protection, may decrease LWD, which is lower at the site, thereby increasing erosion and further input of sediment. Ambiguous evidence - The RBP bank stability qualitative score is optimal for both sites, which weakens the case for the causal pathway beginning with channel alteration. Bank instability leading to bank erosion is not evident. However, the higher Pfankuch score at the impaired site supports decreased bank stability. The pathway including decreased velocity, allowing settling/deposition, is uncertain because the sub-optimal score for RBP channel sinuosity may indicate increases in flow velocity at the impaired site, while the actual velocity measured at the site is lower than at the reference site. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 17. Causal pathway - Scores - Increased temperature

Strength of evidence (SOE) scoring system for causal pathway
- ++ Data show that all steps in at least one causal pathway are present
- \+ Data show that some steps in at least one causal pathway are present
- 0 Data show that the presence of all steps in the causal pathway is uncertain
- \- Data show that there is at least one missing step in each causal pathway
- \- - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway

Reasoning and Comments	SOE score
Site LCN .415 Evidence for some causal steps - The high PTIA within this watershed may hinder soil infiltration thereby decreasing groundwater recharge and base discharge and, in turn, keeping flow above ground exposed to light and ambient air temperature (warmer than underground) and lowering base flow water depths, which may increase the rate of water-warming on summer days. Ambiguous evidence - The increased light pathway resulting from riparian devegetation is not supported by the relatively high shaded canopy value. The pathway including decreased velocity, allowing longer retention time, and/or evaporation/evapotranspiration, is uncertain because the sub-optimal score for RBP channel sinuosity may indicate increases in flow velocity at the impaired site. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+
Site LCM 2.270 Evidence for some causal steps - The PTIA within this watershed may hinder soil infiltration thereby decreasing groundwater recharge and base discharge and, in turn, keeping flow above ground exposed to light and ambient air temperature (warmer than underground) and lowering base flow water depths, which may increase the rate of water-warming on summer days. The shaded canopy percentage at the impaired site is lower than the reference and may be evidence for further temperature increases due to increased light exposure. Ambiguous evidence - The pathway including decreased velocity, allowing longer retention time and/or evaporation/evapotranspiration, is uncertain because the sub-optimal score for RBP channel sinuosity may indicate increases in flow velocity at the impaired site. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Reasoning and Comments	SOE score
Site LCMn 2.274 Evidence for some causal steps - The PTIA within this watershed may hinder soil infiltration thereby decreasing groundwater recharge and base discharge and, in turn, keeping flow above ground exposed to light and ambient air temperature (warmer than underground) and lowering base flow water depths, which may increase the rate of water-warming on summer days. Ambiguous evidence - The increased light pathway resulting from riparian devegetation is not supported by the relatively high shaded canopy value. The pathway including decreased velocity, allowing longer retention time and/or evaporation/evapotranspiration, is uncertain because the sub-optimal score for RBP channel sinuosity may indicate increases in flow velocity at the impaired site; this is confounded, however, with the lower baseflow velocity measured at the impaired site. SOE scoring - The project team did not eliminate any causal pathways, and there is evidence for some steps.	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 18. Causal pathway - Scores - Increased toxic substances

Strength of evidence (SOE) scoring system for causal pathway

- ++ Data show that all steps in at least one causal pathway are present
- \+ Data show that some steps in at least one causal pathway are present
- 0 Data show that the presence of all steps in the causal pathway is uncertain
- \- Data show that there is at least one missing step in each causal pathway
- \- - - Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway

Reasoning and Comments	SOE score
Sites LCN .415, LCM 2.270, and LCMn 2.274	
Evidence for some causal steps - Primary evidence consists of high watershed PTIA in conjunction with known industrial and commercial land uses.	
SOE scoring - There is no evidence regarding specific surface run-off characteristics, pertaining to toxic substances (beyond that which was used for spatial co-occurrence evidence). The project team did not eliminate any causal pathways, and there is evidence for some steps (sources only).	+

Causal pathway tables are closely tied to the conceptual models developed for each candidate cause. Refer to conceptual model figures in the main report to see how relevant variables and comments for each candidate cause, as shown above, correspond to specific causal steps and pathways.

SOE Table 19. Laboratory tests of site media (sediment toxicity) - Data

	Percent survival, after 10 days exposure to sediment				
Organism	**Lab Control**	**RB 3.961**	**LCN .415**	**LCM 2.270**	**LCMn 2.274**
C. tentans **(chironomid)**	87.5	88.3	87.1	NE	92.5
H. azteca **(amphipod)**	100.0	81.3	85.0	NE	96.3

SOE Table 20. Laboratory tests of site media (sediment toxicity) - Scores

Strength of evidence (SOE) scoring system for laboratory tests of site media

+ + + Laboratory tests with site media show clear biological effects that are closely related to the observed impairment
+ Laboratory tests with site media show ambiguous effects OR clear effects that are not closely related to the observed impairment
0 Laboratory tests with site media show uncertain effects
- Laboratory tests with site media show no toxic effects that can be related to the observed impairment
NE no evidence.

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
Site LCN .415		
The project team used the chironomid (*C. tentans*) and amphipod (*H. azteca*) laboratory specimens as surrogates for EPT and non-insects, respectively. Chironomid survivorship differences among the two impaired sites tested, the reference site, and the laboratory control were not found to be statistically significant; therefore, EPT was given a score of zero. Amphipod survival was significantly lower at both the reference and impaired sites than under the laboratory control; therefore, the sediment's effect on amphipods is uncertain.	EPT richness	0
	% non-insects	0
	HBI	NE
	brook trout	NE
Site LCM 2.270		
Sediment sampling laboratory tests were not conducted for this site.	EPT richness	NE
	% non-insects	NE
	HBI	NE
	brook trout	NE
Site LCN 2.274		
The project team used the chironomid (*C. tentans*) laboratory specimen as a surrogate for EPT. Chironomid survivorship differences among the two impaired sites tested, the reference site, and the laboratory control were not found to be statistically significant; therefore, EPT was given a score of zero.	EPT richness	0
	HBI	NE
	brook trout	NE

10-day laboratory exposure does not accurately represent site conditions, where longer term exposures to sediment are likely.

SOE Table 21. Mechanistically plausible cause (functional feeding and mode of existence groups)

Group	Study Site Percent			
	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
Functional feeding:				
filterers	18.3	1.1	10.8	10.3
gatherers	18.6	16.5	60.7	71.8
predators	36.6	30.9	18.2	13.1
scrapers	17.2	13.3	3.3	1.4
shredders	7.8	34.6	6.7	2.7
Mode of existence:				
burrower-sprawlers	57.9	38.3	33.9	19.2
swimmers	5.3	22.9	2.9	2.1
clingers	6.4	5.9	47.6	70.1
climbers	27.7	18.6	3.5	7.6

SOE Table 22. Stressor-response relationship from elsewhere - Data - Increased autochthony

Variable, units	Stressor-Response Benchmark Description	Value	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
chlorophyll *a*, mg/m^2	reduced invertebrate diversity (Nordin, 1985)	100	10.4	15.7	NE	17.5
	eutrophy risk range (U.S. EPA, 2000b, summary document)	100 - 200				
baseflow total nitrogen, ppm	EPA reference for ecoregion XIV, 59, northeastern coastal zone (U.S. EPA, 2000c)	0.57	0.310 [3] (0.280 - 0.350)	0.617 [3] (0.610 - 0.620)	0.513 [3] (0.420 - 0.600)	0.457 [3] (0.330 - 0.540)
	eutrophy risk range (U.S. EPA, 2000b, summary document)	1.5				
baseflow total Kjeldahl nitrogen, ppm	EPA reference for ecoregion XIV, 59, northeastern coastal zone (U.S. EPA, 2000c)	0.30	0.167 [3] (0.100 - 0.200)	0.300 [3] (0.300 - 0.300)	0.467 [3] (0.400 - 0.500)	0.400 [3] (0.300 - 0.500)
baseflow nitrate + nitrite, ppm	EPA reference for ecoregion XIV, 59, northeastern coastal zone (U.S. EPA, 2000c)	0.31	0.143 [3] (0.150 - < 0.20)	0.317 [3] (0.310 - 0.320)	< 0.047 [3] (0.02 - < 0.20)	< 0.057 [3] (0.03 - < 0.20)
baseflow total phosphorus, ppm	deleterious effects on fish communities (Miltner & Rankin, 1998)	0.06	0.009 [3] (0.008 - 0.010)	0.048 [3] (0.040 - 0.061)	0.025 [3] (0.020 - 0.028)	0.030 [3] (0.024 - 0.035)
	EPA reference for ecoregion XIV, 59, northeastern coastal zone (U.S. EPA, 2000c)	0.024				
	eutrophy risk range (U.S. EPA, 2000b, summary document)	0.035 - 0.075				

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

SOE Table 23. Stressor-response relationship from elsewhere - Data - Decreased dissolved oxygen

Variable, units	Stressor-Response Benchmark		RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
	Description	Value				
minimum dissolved oxygen, mg/L	U.S. EPA (1986a) fresh and cold water aquatic life criteria	8.0	8.0 [3] (8.0 - 9.5)	5.3 [3] (5.3 - 7.8)	4.1 [3] (4.1 - 7.4)	4.4 [3] (4.4 - 6.2)
	30-day LC50 values for four different EPT organisms (Nebeker, 1972)	4.4 - 5.0 [4]				
	optimum level for brook trout, where temperature is above 15˚C (Raleigh, 1982)	9				
	minimum acceptable temporary brook trout level (Mills, 1971 as cited in Raleigh, 1982)	5				

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

SOE Table 24. Stressor-response relationship from elsewhere - Data - Altered flow regime

Variable, units	Stressor-Response Benchmark		RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
	Description	Value				
impervious surface area, %	abrupt decline in taxonomic richness, specifically EPT, and an increase in non-insects, specifically gastropods (Morse et al., 2003)	6	2.1	32.6	7.1	14.3
	shift to tolerant species (Maxted et al., 1996)	10 - 15				
	brook trout not found (Boward et al., 1999)	2				

SOE Table 25. Stressor-response relationship from elsewhere - Data - Decreased large woody debris

Variable, units	Stressor-Response Benchmark		RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
	Description	Value				
LWD diameter ≥ 5 cm, # of pieces	aquatic invertebrate productivity 3 to 4 times higher for submerged wooden substrates or snags than for sandy or muddy benthic habitats (Benke et al., 1984; applies to EPT endpoint)	N/A - analysis conducted qualitatively	91	NE	37	43
	debris dam abundance positively correlated with macroinvertebrate abundance and relative abundance of shredders to biomass (Smock et al., 1989; applies to EPT endpoint)					
----------			----------	----------	----------	----------
LWD diameter ≥ 10cm, # of pieces	in high gradient mountain streams, trout nearly always occupied pools with at least 2 pieces of woody debris (Flebbe 1999)		39	NE	8	12
	LWD contributes to wild trout habitat (Neumann and Wildman, 2002)					

SOE Table 26. Stressor-response relationship from elsewhere - Data - Increased sediment

Variable, units	Stressor-Response Benchmark		RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
	Description	Value				
baseflow TSS, mg/L	exposure causing 40 - 60% aquatic invertebrate mortality and severe habitat degradation at greater than 1,000 hours duration (similar to baseflow condition) (mean [n] (range), from literature review, Newcombe and MacDonald, 1991)	33 [4 studies] (8 - 77)	< 10 [3] (< 2 - < 10)	< 10 [3] (3 - < 10)	< 10 [3] (1 - < 10)	< 10 [3] (4 - < 10)
	exposure causing reduction in brook trout growth rate at durations greater than 1,000 hours (similar to baseflow condition) (mean [n] (range), from literature review, Newcombe and MacDonald, 1991)	45 [3 studies] (12 - 100)				
storm flow TSS, mg/L	exposure causes decreased invertebrate population at approximately 24 hours duration (similar to storm event) (Gammon, 1970 as cited in Newcombe and MacDonald, 1991)	53 - 92	< 10 - 118 [9]	< 10 - 271 [9]	NE	NE
sediment size, mm	sediment diameter potentially fine enough to hinder brook trout egg survival and early development (Argent and Flebbe, 1999)	0.43 - 0.85	53% of particles @ 0.062 - 0.13 & 35% @ 0.25 - 0.5	45% of particles @ 0.062 - 0.13 & 29% @ 0.25 - 0.5	100% of particles @ 0.062 - 0.13	92% of particles @ 0.062 - 0.13

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

SOE Table 27. Stressor-response relationship from elsewhere - Data - Increased temperature

Variable, units	Stressor-Response Benchmark		RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
	Description	Value				
	severe stress to most cold-water organisms (literature review by Galli and Dubose, 1990)	21				
	generalized optimum for EPT (literature review by Galli and Dubose, 1990)	< 17				
temperature, weekly maximum, °C	50% mortality for *Baetis rhodani* , *Baetis tenax* , and *Caenis sp* . (Ephemeroptera), respectively (literature review by Galli and Dubose, 1990)	21.1, 21.3, & 26.7	21.1 [3] (20.3 - 22.1)	22.7 [3] (21.6 - 24.2)	23.3	21.8
	generalized physiological optimum for stenotherms (trout and other coldwater fish) (literature review by Galli and Dubose, 1990)	< 20.0				
	95th percentile brook trout tolerance limit (Eaton et al., 1995)	22.3				

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].

SOE Table 28. Stressor-response relationship from elsewhere - Data - Increased toxic substances

Variable (ppm or mg/L)	Flow	Stressor-Response Benchmark: Description	Stressor-Response Benchmark: Value	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
Ionic strength, water column sampling							
calcium	low	*not available*		6.8	67	NE	31.5
chloride	base	EPA CCC	230	29 [3] (26 - 30)	122 [3] (91 - 141)	99 [3] (83 - 124)	66 [3] (58 - 73)
	storm	EPA CMC	860	17 - 57 [9]	15 - 296 [9]	NE	NE
magnesium	low	*not available*		2.2	17	NE	11
salinity	base	range of 48-hr LC50 values for various salt combinations tested on *Ceriodaphnia* (Mount et al., 1997)	250 - 5700	67 [3] (0 - 100)	367 [3] (300 - 400)	267 [3] (200 - 400)	200 [3]
specific conductivity, uS/cm	base	EPT effects based on interpretation of statewide data from Maine (Davies and MEDEP, 2005; Fig. 6), Florida (Florida Department of Environmental Protection, 2005; Appendix J), and Kentucky (Pond, 2004; Appendix J)	100 - 200	129 [3] (79 - 155)	745 [3] (659 - 796)	568 [3] (491 - 718)	459 [3] (376 - 510)
		presence of amphipods in place of EPT might be indicative of higher conductivity, as amphipods are more tolerant (Kefford et al., 2003)	NA				
Elements, water column sampling							
aluminum	low	EPA CCC	0.087	0.045	0.006	NE	0.019
arsenic	low	invertebrate SSD, LC50 for 10% of species	0.66	< 0.0005	0.00098	NE	0.00235
		chordate SSD, LC50 for 10% of species	0.71				
		EPA CCC	0.15				
cadmium	base	EPA CCC	0.00025	< 0.0005 [3]	< 0.0005 [3]	< 0.0005 [3]	< 0.0005 [3]
	low			< 0.0002	< 0.0002	NE	< 0.0002
	storm	invertebrate SSD, LC50 for 10% of species	0.032	< 0.0005 [9]	< 0.0005 - 0.0007 [9]	NE	NE
		chordate SSD, LC50 for 10% of species	0.35				
		EPA CMC	0.002				

Variable (ppm or mg/L)	Flow	Stressor-Response Benchmark Description	Value	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
chromium	low	invertebrate SSD, LC50 for 10% of species	0.17	< 0.0005	0.0032	NE	0.00205
		chordate SSD, LC50 for 10% of species	7.3				
copper	base	invertebrate SSD, LC50 for 10% of species	0.008	< 0.002 [3]	< 0.002 [3]	< 0.002 [3]	0.0013 [3] (< 0.002 - 0.002)
		chordate SSD, LC50 for 10% of species	0.015				
		EPA CCC	0.009				
	storm	invertebrate SSD, LC50 for 10% of species	0.013	< 0.002 - .003 [9]	0.002 - 0.018 [9]	NE	NE
		chordate SSD, LC50 for 10% of species	0.061				
		EPA CMC	0.013				
iron	low	EPA CCC	1.0	0.091	0.14	NE	0.22
lead	base	EPA CCC	0.0025	< 0.003 [3]	< 0.003 [3]	< 0.003 [3]	< 0.003 [3]
	low			< 0.0002	< 0.0002	NE	< 0.0002
	storm	EPA CMC	0.065	< 0.003 - .004 [9]	0.003 - 0.031 [9]	NE	NE
nickel	base	invertebrate SSD, LC50 for 10% of species	0.61	< 0.004 [3]	< 0.004 [3]	< 0.004 [3]	< 0.004 [3]
		chordate SSD, LC50 for 10% of species	2.9				
		EPA CCC	0.052				
	low	*use baseflow S-R values immediately above*		0.00045	0.0032	NE	0.0019
	storm	invertebrate SSD, LC50 for 10% of species	1.9	< 0.004 [9]	< 0.004 - 0.013 [9]	NE	NE
		chordate SSD, LC50 for 10% of species	6.2				
		EPA CMC	0.47				
selenium	low	EPA CCC	0.005	< 0.001	< 0.001	NE	< 0.001
zinc	base	invertebrate SSD, LC50 for 10% of species	0.087	< 0.005 [3]	0.014 [3] (0.013 - 0.015)	< 0.005 [3]	0.0042 [3] (< 0.005 - 0.005)
		chordate SSD, LC50 for 10% of species	0.14				
		EPA CCC	0.12				
	low	*use baseflow S-R values immediately above*		< 0.005	0.0064	NE	< 0.005
	storm	invertebrate SSD, LC50 for 10% of species	0.45	.008 - .024 [9]	0.043 - 0.14 [9]	NE	NE
		chordate SSD, LC50 for 10% of species	1.9				
		EPA CMC	0.12				

Variable (ppm or mg/L)	Flow	Stressor-Response Benchmark Description	Stressor-Response Benchmark Value	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274
antimony	low	*--- see text ---*		< 0.0005	< 0.0005	NE	< 0.0005
barium				0.0054	0.021		0.011
beryllium				< 0.0002	< 0.0002		< 0.0002
cobalt				0.00085	0.0029		0.000555
manganese				0.025	0.37		0.092
molybdenum				< 0.0005	0.00092		0.000385
silver				< 0.0002	< 0.0002		< 0.0002
thallium				< 0.0005	< 0.0005		< 0.0005
vanadium				0.0003	0.00082		0.000695

All values displayed in ppm or mg/L, unless otherwise noted.

Base and low flow values shown as mean [n] (range), where more than one value available, and storm flow values shown as range [n].
(Note that a range is provided for baseflow only if a toxic substance is detected.)

EPA CCC and CMC from U.S. EPA, 2004b.

SOE Table 29. Stressor-response relationship from elsewhere - Scores - Increased autochthony

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.
- - The observed relationship between exposure and effects in the case does not even qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.
NE no evidence.

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
Site LCN .415 The chlorophyll *a* site observation is approximately one order of magnitude less than benchmark values found in the literature. Total nitrogen levels at the impaired sites fall below the level for eutrophy risk, and all nitrogen measures are relatively close to the regional reference condition. While chlorophyll *a* and nitrogen values tend to weaken the case for increased autochthony, phosphorus values provide evidence for the cause. Specifically, baseflow total phosphorus is in the range where fish effects and/or eutrophication might be seen, and mean total site phosphorous was twice that of the regional reference value. S-R support for this cause is unclear, as the supporting evidence both weakens and supports.	EPT richness % non-insects HBI brook trout	0 0 0 0
Site LCM 2.270 Total nitrogen and phosphorus levels at the site fall under the level for eutrophy risk, and all nitrogen and phosphorus measures are relatively close to the regional reference condition values. Baseflow total phosphorus is below the range where fish effects might be seen. S-R data weaken the case for this cause. The project team score EPT and brook trout negatively because signs of increased autochthony are not significant; furthermore, a minor increase in autochthony would be expected to slightly benefit some organisms such as EPT and brook trout. HBI was also scored negatively because it was designed to reflect nutrient loading. Scoring for non-insects was unclear.	EPT richness % non-insects HBI brook trout	- 0 - -
Site LCMn 2.274 The chlorophyll *a* site observation is approximately one order of magnitude less than benchmark values found in the literature. Total nitrogen and phosphorus site levels fall under the level for eutrophy risk, and all nitrogen and phosphorus measures are relatively close to the regional reference condition values. Baseflow total phosphorus is below the range where fish effects might be seen. S-R data refutes this cause. The project team scores EPT and brook trout negatively because signs of increased autochthony are not significant; furthermore, a minor increase in autochthony would be expected to slightly benefit some organisms such as EPT & brook trout. HBI was also scored negatively because it was designed to reflect nutrient loading.	EPT richness HBI brook trout	- - -

SOE Table 30. Stressor-response relationship from elsewhere - Scores - Decreased dissolved oxygen

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.
- - The observed relationship between exposure and effects in the case does not even qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.
NE no evidence.

Reasoning and Comments	SOE score Endpoint	Score
Site LCN .415		
The minimum measured dissolved oxygen value (5.3 mg/L) and the range of values are less than the EPA criteria (8.0 mg/L) and optimum brook trout level (9 mg/L). We consider this supporting evidence for the case (positive score) for EPT taxa and brook trout, but it is unclear how non-insects and HBI would respond to these dissolved oxygen levels.	EPT richness	+
	% non-insects	0
	HBI	0
	brook trout	+
Site LCM 2.270		
The minimum measured dissolved oxygen value (4.1 mg/L) and the range of values are less than the EPA criteria (8.0 mg/L) and optimum brook trout level (9 mg/L). The range of observed values also dips into the 30-day LC50 range for EPT and goes below the temporary brook trout minimum (5 mg/L). We consider this supporting evidence for the case (positive score) for EPT taxa and brook trout, but it is unclear how non-insects and HBI would respond to these dissolved oxygen levels.	EPT richness	+
	% non-insects	0
	HBI	0
	brook trout	+
Site LCMn 2.274		
The minimum measured dissolved oxygen value (4.4 mg/L) and the range of values are less than the EPA criteria (8.0 mg/L) and optimum brook trout level (9 mg/L). The range of observed values also goes below the temporary brook trout minimum (5 mg/L). We consider this supporting evidence for the case (positive score) for EPT taxa and brook trout, but it is unclear how non-insects and HBI would respond to these dissolved oxygen levels.	EPT richness	+
	HBI	0
	brook trout	+

SOE Table 31. Stressor-response relationship from elsewhere - Scores - Altered flow regime

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.

+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.

0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.

- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.

- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.

NE no evidence.

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
Site LCN .415		
Percent impervious surface is greater than all S-R benchmark values related to multiple endpoints. (See text for discussion on percent impervious surface as a conservative and qualitative surrogate for altered flow regime.)	EPT richness	+
	% non-insects	+
	HBI	0
	brook trout	+
Site LCM 2.270		
Percent impervious surface is greater than all S-R benchmark values related to multiple endpoints. (See text for discussion on percent impervious surface as a conservative and qualitative surrogate for altered flow regime.)	EPT richness	+
	% non-insects	+
	HBI	0
	brook trout	+
Site LCMn 2.274		
Percent impervious surface is greater than all S-R benchmark values related to EPT and brook trout. (See text for discussion on percent impervious surface as a conservative and qualitative surrogate for altered flow regime.)	EPT richness	+
	HBI	0
	brook trout	+

SOE Table 32. Stressor-response relationship from elsewhere - Scores - Decreased large woody debris

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.

+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.

0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.

- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.

- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.

NE no evidence.

Reasoning and Comments	SOE score Endpoint	Score
Site LCN .415		
LWD was not measured at LCN .415.	EPT richness	NE
	% non-insects	NE
	HBI	NE
	brook trout	NE
Site LCM 2.270		
Relevant S-R data indicates that increased abundance or presence of LWD supports macroinvertebrate and wild trout abundance. This evidence directionally and qualitatively supports the case for this cause for the EPT and brook trout endpoints.	EPT richness	+
	% non-insects	NE
	HBI	NE
	brook trout	+
Site LCMn 2.274		
Relevant S-R data indicates that increased abundance or presence of LWD supports macroinvertebrate and wild trout abundance. This evidence directionally and qualitatively supports the case for this cause for the EPT and brook trout endpoints.	EPT richness	+
	HBI	NE
	brook trout	+

SOE Table 33. Stressor-response relationship from elsewhere - Scores - Increased sediment

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.

+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.

0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.

- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.

- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.

NE no evidence.

Reasoning and Comments	SOE score Endpoint	Score
Site LCN .415 Baseflow TSS levels do not appear high enough to impact invertebrates or brook trout (note, however, that the invertebrate S-R value is based on 40-60% mortality; it's difficult to know what effects might be seen at the impaired site's TSS levels). Storm flow site measurements fall within the range of effects for invertebrates, and sediment diameters are fine enough to impact early stages of brook trout development, but note that reference site sediment sizes are similar. The S-R data both weaken and support the case for this cause; therefore, zeros were assigned to all scores, indicating ambiguity.	EPT richness % non-insects HBI brook trout	0 0 0 0
Site LCM 2.270 Baseflow TSS levels do not appear high enough to impact invertebrates or brook trout (note, however, that the invertebrate S-R value is based on 40-60% mortality; it's difficult to know what effects might be seen at the impaired site's TSS levels). Sediment diameters are fine enough to impact early stages of brook trout development, and so the brook trout endpoint was scored positive. Zeros were assigned to the other endpoint scores, indicating uncertainty.	EPT richness % non-insects HBI brook trout	0 0 0 +
Site LCMn 2.274 Baseflow TSS levels do not appear high enough to impact invertebrates or brook trout (note, however, that the invertebrate S-R value is based on 40-60% mortality; it's difficult to know what effects might be seen at the impaired site's TSS levels). Sediment diameters are fine enough to impact early stages of brook trout development, and so the brook trout endpoint was scored positive. Zeros were assigned to the other endpoint scores, indicating uncertainty.	EPT richness HBI brook trout	0 0 +

Note that some TSS data did not meet MEDEP quality standards (MEDEP, pers comm, 2005).

SOE Table 34. Stressor-response relationship from elsewhere - Scores - Increased temperature

Strength of Evidence scoring system for plausible effect given stressor-response relationships
+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.
- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.
NE no evidence.

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
Site LCN .415		
The mean weekly maximum temperature exceeds most, and the range exceeds all S-R benchmark values, except *Caenis* sp. LC50. The S-R evidence supports positive scores for EPT and brook trout, but it is unclear how non-insects and the HBI might respond to the site's temperatures.	EPT richness % non-insects HBI brook trout	+ 0 0 +
Site LCM 2.270		
The mean weekly maximum temperature exceeds all S-R benchmark values, except the *Caenis* sp. LC50. The site's second most dominant organism, *Caenis* sp., is tolerant of high temperatures. In contrast, Caenidae were not found at the reference site. The S-R evidence supports positive scores for EPT and brook trout, but it is unclear how non-insects and the HBI might respond to the site's temperatures.	EPT richness % non-insects HBI brook trout	+ 0 0 +
Site LCMn 2.274		
The mean weekly maximum temperature exceeds most of the S-R benchmark values listed. The site's second most dominant organism, *Caenis* sp., is tolerant of high temperatures. In contrast, Caenidae were not found at the reference site. The S-R evidence supports positive scores for EPT and brook trout, but it is unclear how non-insects and the HBI might respond to the site's high temperatures.	EPT richness HBI brook trout	+ 0 +

SOE Table 35. Stressor-response relationship from elsewhere - Scores - Increased toxics at LCN .415

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.
- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.
NE no evidence.

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
ionic strength		
Chloride site values are below EPA CCC and CMC benchmarks. Salinity values are within the range of LC50 observations, and the specific conductivity range indicates effects to EPT for which we gave a positive score. Further supporting evidence comes from the most dominant species at LCN .415, an amphipod, a salt tolerant non-insect (Kefford et al., 2003), and for this we also gave a positive score. Evidence is unclear for HBI and brook trout. Note that salinity measurements were calculated using specific conductivity—internal to the YSI 85 field data logger; therefore, as a secondary or indirect measure, salinity is not used in other SOE considerations but is used here only for comparison to literature.	EPT richness % non-insects HBI brook trout	+ + 0 0
aluminum, arsenic, chromium, iron, nickel, and selenium		
All observed site values fall below EPA CCC and CMC values (applies to all but chromium). All measured values at the site fall below the 10% SSD thresholds (applies to arsenic, chromium, and nickel). This weakens the case for effects on EPT and brook trout, but evidence is unclear for non-insects and HBI, which could benefit from some level of these substances.	EPT richness % non-insects HBI brook trout	- 0 0 -
cadmium and lead		
Measured values at the site fall below the 10% SSD thresholds for cadmium. The baseflow reporting limits for cadmium and lead are greater than corresponding EPA CCC values; therefore, while cadmium and lead were not detected in baseflow samples, they could still exceed CCC values. 1 of 9 storm samples at the impaired site registered positive for cadmium (0.0007 ppm), and cadmium was not detected in any other measurement. For these two substances there is no supporting evidence, but neither can be ruled out.	EPT richness % non-insects HBI brook trout	0 0 0 0
copper		
1 of 9 storm event copper samples exceeded the invertebrate SSD 10% threshold and the EPA CMC, and 1 of 9 equaled those two criteria; this adds supporting evidence to the EPT and brook trout endpoints, but evidence for non-insects and HBI is unclear.	# EPT taxa % non-insects HBI brook trout	+ 0 0 +

Reasoning and Comments	SOE score Endpoint	Score
zinc		
All measured zinc values at the site fall below the 10% SSD thresholds. Baseflow & low flow values fall below the EPA CCC. 1 of 9 storm event zinc samples exceeds the EPA CMC value, and 1 of 9 equaled the CMC value. S-R evidence both weakens and supports the case for zinc as a cause; therefore, the project team scored all endpoints zero (unclear)	EPT richness	0
	% non-insects	0
	HBI	0
	brook trout	0
antimony, barium, beryllium, cobalt, manganese, molybdenum, silver, thallium, and vanadium		
No appropriate S-R evidence could be applied to these remaining substances.	EPT richness	NE
	% non-insects	NE
	HBI	NE
	brook trout	NE

SOE Table 36. Stressor-response relationship from elsewhere - Scores - Increased toxics at LCM 2.270

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.
- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.
NE no evidence.

Reasoning and Comments	SOE score Endpoint	SOE score Score
ionic strength		
Baseflow chloride is below the EPA CCC. Salinity values are within the range of LC50 observations, and the specific conductivity range indicates effects to EPT for which we gave a positive score. Further supporting evidence comes from the fifth most dominant species at the site, an isopod, a salt tolerant non-insect (Kefford et al., 2003), and for this we also gave a positive score. Evidence is unclear for HBI and brook trout. Note that salinity measurements were calculated using specific conductivity—internal to the YSI 85 field data logger; therefore, as a secondary or indirect measure, salinity is not used in other SOE considerations but is used here only for comparison to literature.	EPT richness % non-insects HBI brook trout	+ + 0 0
cadmium and lead		
The baseflow reporting limits for cadmium and lead are greater than corresponding EPA CCC values; therefore, while cadmium and lead were not detected in baseflow samples, they could still exceed CCC values. For these two substances, there is no supporting evidence, but neither can be ruled out.	EPT richness % non-insects HBI brook trout	0 0 0 0
copper, nickel, and zinc		
Copper, nickel, and zinc were not detected in baseflow samples, and the reporting limits fall below corresponding EPA CCC values and the 10% SSD thresholds; therefore, the S-R data weaken the case for copper, nickel, and/or zinc as causes. Note that we do not have storm flow data for copper at this site, unlike LCN .415, where storm samples tested positive for copper levels above the CCC and SSD 10% threshold but baseflow did not. Based on the data we do have for the three substances, EPT and brook trout receive negative scores, and impacts are unclear for non-insects and HBI.	EPT richness % non-insects HBI brook trout	- 0 0 -

SOE Table 37. Stressor-response relationship from elsewhere - Scores - Increased toxics at LCMn 2.274

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies.
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies.
- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies or the quantitative differences are very large.
NE no evidence.

Reasoning and Comments	SOE score: Endpoint	SOE score: Score
ionic strength		
Baseflow chloride is below the EPA CCC, and salinity is below the LC50 range. The specific conductivity range indicates effects to EPT for which we gave a positive score. Evidence is unclear for HBI and brook trout. Note that salinity measurements were calculated using specific conductivity—internal to the YSI 85 field data logger; therefore, as a secondary or indirect measure, salinity is not used in other SOE considerations but is used here only for comparison to literature.	EPT richness HBI brook trout	+ 0 0
aluminum, arsenic, chromium, copper, iron, nickel, selenium, and zinc		
All observed site values fall below EPA CCC values (applies to all but chromium). All measured values at the site fall below the 10% SSD thresholds (applies to all but aluminum, iron, and selenium). Note that we do not have storm flow data for copper at this site, unlike LCN .415, where storm samples tested positive for copper levels above the CCC and SSD 10% threshold but baseflow did not. Based on the data we do have for these substances, EPT and brook trout receive negative scores, and impacts are unclear for HBI.	EPT richness HBI brook trout	- 0 -
cadmium and lead		
The baseflow reporting limits for cadmium and lead are greater than corresponding EPA CCC values; therefore, while cadmium and lead were not detected in baseflow samples, they could still exceed CCC values. For these two substances, there is no supporting evidence, but neither can be ruled out.	EPT richness HBI brook trout	0 0 0
antimony, barium, beryllium, cobalt, manganese, molybdenum, silver, thallium, and vanadium		
No appropriate S-R evidence could be applied to these remaining substances.	EPT richness HBI brook trout	NE NE NE

SOE Table 38. Stressor-response relationship from elsewhere - Increased PAH's at LCN .415

Strength of Evidence scoring system for plausible effect given stressor-response relationships

+ + The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments or from other field studies
+ The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments or from other field studies
0 The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments or from other field studies is ambiguous.
- The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments or from other field studies
- - The observed relationship between exposure and effects in the case does not qualitatively agree with stressor-response relationships in controlled laboratory experiments or from other field studies o the quantitative differences are very large.
NE no evidence.

Polycyclic Aromatic Hydrocarbon (PAH)	Storm, 10/18/00 1.1" over 21 hrs			Storm, 9/25/01 1.7" over 24 hrs												
ALL units are µg/ml	**LCN .585**	**RB 1.694**	**RL**	**LCN .585**	**RB 1.694**	**RL**	U.S. EPA, 2004d[A]	U.S. EPA, 1986b (Goldbook)	Eisler, 1987	ECOTOX[B]	SOE sub-score	British Columbia, 1993	Canada, 2003 (fresh-water aquatic life)	SOE sub-score	**SOE score**
Acenaph-thene	0.10	nd	0.05	nd	nd	0.1	data for human consume only	<= 1,700 & 520 acute and chronic freshwater, respectively	not listed	1280 (tox)	-	6 chronic	5.8	-	**- -**
Acenaph-thylene	nd	nd	0.05	nd	nd	0.1	listed, but no data	not listed	not listed	not listed	NE	not listed	no data	NE	**NE**
Anthracene	0.20	nd	0.05	nd	nd	0.1	data for human consume only	not listed	info not pertinent	95 (tox)	-	4 chronic & 0.1 phototox	0.012	+	**0**
Benzo(a) anthracene	0.10	nd	0.05	0.33	nd	0.1	data for human consume only	not listed	LC87 (6mo) bluegill @ 1,000	not listed	-	0.1 chronic & phototox	0.018	+	**0**
Benzo(a) pyrene	0.10	nd	0.05	0.48	nd	0.1	data for human consume only	not listed	LC50 (96hr) sandworm @ >1,000	not listed	-	0.01 chronic	0.015	+	**0**
Benzo(b) fluoranthene	0.20	nd	0.05	1.11	nd	0.1	data for human consume only, but nps shows 300 marine acute LEC	not listed	info not pertinent, but listed many times	not listed	NE	not listed, but pending ref to 0.01 (NPS 1997)	no data	+	**0**
Benzo(ghi) perylene	0.10	nd	0.05	0.5	nd	0.2	listed, but no data	not listed	LC50 (96hr) sandworm @ >1,000	not listed	-	not listed	not listed	NE	**0**
Benzo(k) fluoranthene	nd	nd	0.05	0.29	nd	0.1	data for human consume only, but nps shows 300 marine acute LEC	not listed		not listed	NE	not listed, but pending ref to 0.01 (NPS 1997)	no data	+	**0**
Chrysene	0.20	nd	0.05	0.8	nd	0.1	data for human consume only	not listed	LC50 (96hr) sandworm @ >1,000	not listed	-	insufficient data	no data	NE	**0**

Polycyclic Aromatic Hydrocarbon (PAH) ALL units are µg/ml	Storm, 10/18/00 1.1" over 21 hrs			Storm, 9/25/01 1.7" over 24 hrs			U.S. EPA, 2004d[A]	U.S. EPA, 1986b (Goldbook)	Eisler, 1987	ECOTOX[B]	SOE sub-score	British Columbia, 1993	Canada, 2003 (fresh-water aquatic life)	SOE sub-score	SOE score
	LCN .585	**RB 1.694**	**RL**	**LCN .585**	**RB 1.694**	**RL**									
Dibenzo(a,h) anthracene	nd	nd	0.05	0.11	nd	0.2	data for human consume only	not listed	LC50 (96hr) sandworm @ >1,000	not listed	-	not listed	no data	NE	**0**
Fluoran-thene	0.50	nd	0.05	1.6	nd	0.1	data for human consume only	<= 3,980 acute freshwater, and <= 40 and 16 acute and chron, respectively, saltwater	LC50 (96hr) sandworm 500	38 (feeding) - 200 (tox)	-	4 chronic & 0.2 phototox	0.04	+	**0**
Fluorene	0.10	nd	0.05	nd	nd	0.1	data for human consume only	not listed	LC50s (various orgs, 96hr) 320 - 5,600	not listed	-	12 chronic	3.0	-	**- -**
Indeno (1,2,3-cd) pyrene	0.10	nd	0.05	0.56	nd	0.2	data for human consume only	not listed		not listed	NE	not listed	no data	NE	**NE**
Naphthalene	0.10	nd	0.05	nd	nd	0.1	listed, but no data	<= 2,300 and 620 acute and chronic freshwater, respectively	LC50 (10d) copepod @ 50, and LC50s (various orgs, 24-96 hr) 920 - 150,000	1,700 (behavior) - 3,700 (physiol-ogy)	-	1 chronic	1.1	-	**- -**
Phenan-threne	0.25	nd	0.05	0.67	nd	0.1	listed, but no data	not listed	LC50 (24hr) grass shrimp @ 370, and LC50 (96hr) sandworm 600	340 (tox)	-	0.3 chronic	0.4	+	**0**
Pyrene	0.30	nd	0.05	1.15	nd	0.1	data for human consume only	not listed		1,020 (tox)	-	0.02 phototox	0.025	+	**0**

[A]Source (U.S. EPA, 2004d) lists only human health consumption criteria for some PAHs.
[B]ECOTOX database (ECOTOXicology, located at: http://www.epa.gov/ecotox/).

SOE Table 39. Consistency of evidence scoring system

Finding	Interpretation	Score
All available types of evidence support the case for the candidate cause.	This finding convincingly supports the case for the candidate cause.	+ + +
All available types of evidence weaken the case for the candidate cause.	This finding convincingly weakens the candidate cause.	- - -
All available types of evidence support the case for the candidate cause, but few types are available.	This finding somewhat supports the case for the candidate cause, but is not strongly supportive because coincidence and errors may be responsible.	+
All available types of evidence weaken the case for the candidate cause, but few types are available.	This finding somewhat weakens the case for the candidate cause, but is not strongly weakening because coincidence and errors may be responsible.	-
The evidence is ambiguous or inadequate.	This finding neither supports nor weakens the case for the candidate cause.	0
Some available types of evidence support and some weaken the case for the candidate cause.	This finding somewhat weakens the case for the candidate cause but is not convincing because a few inconsistencies may be explained.	-

Source: U.S. EPA CADDIS (http://www.epa.gov/caddis/).

SOE Table 40. Strength of Evidence summary scoring at LCN .415

Biological endpoint **Candidate cause**	**Types of evidence that use data from the case**			**Types of evidence that use data from elsewhere**		
	Spatial/temporal co-occurrence	**Stressor-response relationships from the field**	**Causal pathway**	**Mechanistically Plausible Cause**	**Stressor-response relationships from laboratory or other field studies**	**Consistency of Evidence**
EPT richness						
Increased autochthony	0	0	+	0	0	0
Decreased dissolved oxygen	+	0	+	+	+	+
Altered flow regime	+	NE	+	+	+	+ +
Decreased large woody debris	NE	+	+	+	NE	+
Increased sediment	+	0	+	+	0	+
Increased temperature	+	+	+	+	+	+
Increased ionic strength	+	+	+	+	+	+ +
% non-insects						
Increased autochthony	0	0	+	+	0	0
Decreased dissolved oxygen	+	0	+	+	0	+
Altered flow regime	+	NE	+	+	+	+ +
Decreased large woody debris	NE	0	+	+	NE	0
Increased sediment	+	0	+	+	0	+
Increased temperature	+	0	+	0	0	+
Increased ionic strength	+	+	+	0	+	+ +
HBI						
Increased autochthony	0	+	+	+	0	+
Decreased dissolved oxygen	+	+	+	+	0	+
Altered flow regime	+	NE	+	+	0	+
Decreased large woody debris	NE	+	+	+	NE	+
Increased sediment	+	0	+	0	0	+
Increased temperature	+	+	+	0	0	+
Increased ionic strength	+	+	+	0	0	+
Brook trout						
Increased autochthony	0	NE	+	0	0	0
Decreased dissolved oxygen	+	NE	+	+	+	+
Altered flow regime	+	NE	+	+	+	+ +
Decreased large woody debris	NE	NE	+	+	NE	+
Increased sediment	+	NE	+	+	0	+
Increased temperature	+	NE	+	+	+	+
Increased ionic strength	+	NE	+	+	0	+

NE = No evidence
Complete summary tables, including toxic substances and all lines of evidence, are located in the appendices.

SOE Table 41. Strength of Evidence summary scoring at LCM 2.270

	Types of evidence that use data from the case			Types of evidence that use data from elsewhere		
Biological endpoint **Candidate cause**	**Spatial/temporal co-occurrence**	**Stressor-response relationships from the field**	**Causal pathway**	**Mechanistically Plausible Cause**	**Stressor-response relationships from laboratory or other field studies**	**Consistency of Evidence**
EPT richness						
Increased autochthony	0	0	+	0	-	-
Decreased dissolved oxygen	+	0	+	+	+	+ +
Altered flow regime	NE	NE	+	+	+	+
Decreased large woody debris	+	+	+	+	+	+ +
Increased sediment	0	0	+	+	0	0
Increased temperature	+	+	+	+	+	+ +
Increased ionic strength	+	+	+	+	+	+ +
% non-insects						
Increased autochthony	0	0	+	0	0	0
Decreased dissolved oxygen	+	0	+	+	0	+
Altered flow regime	NE	NE	+	+	+	+
Decreased large woody debris	+	0	+	+	NE	+
Increased sediment	0	0	+	+	0	0
Increased temperature	+	0	+	0	0	+
Increased ionic strength	+	+	+	0	+	+ +
HBI						
Increased autochthony	0	+	+	+	-	0
Decreased dissolved oxygen	+	+	+	+	0	+
Altered flow regime	NE	NE	+	+	0	0
Decreased large woody debris	+	+	+	+	NE	+
Increased sediment	0	0	+	0	0	0
Increased temperature	+	+	+	0	0	+
Increased ionic strength	+	+	+	0	0	+
Brook trout						
Increased autochthony	0	NE	+	0	-	-
Decreased dissolved oxygen	+	NE	+	+	+	+ +
Altered flow regime	NE	NE	+	+	+	+
Decreased large woody debris	+	NE	+	+	+	+
Increased sediment	0	NE	+	+	+	+
Increased temperature	+	NE	+	+	+	+
Increased ionic strength	+	NE	+	+	0	+

NE = No evidence
Complete summary tables, including toxic substances and all lines of evidence, are located in the appendices.

SOE Table 42. Strength of Evidence summary scoring at LCMn 2.274

Biological endpoint Candidate cause	Types of evidence that use data from the case: Spatial/temporal co-occurrence	Stressor-response relationships from the field	Causal pathway	Types of evidence that use data from elsewhere: Mechanistically Plausible Cause	Stressor-response relationships from laboratory or other field studies	Consistency of Evidence
EPT richness						
Increased autochthony	0	0	+	0	-	-
Decreased dissolved oxygen	+	0	+	+	+	+ +
Altered flow regime	+	NE	+	+	+	+
Decreased large woody debris	+	+	+	+	+	+ +
Increased sediment	0	0	+	+	0	0
Increased temperature	+	+	+	+	+	+ +
Increased ionic strength	+	+	+	+	+	+ +
% non-insects						
Increased autochthony	The % non-insects biological endpoint was not assessed at site LCMn 2.274. See text for more information.					
Decreased dissolved oxygen						
Altered flow regime						
Decreased large woody debris						
Increased sediment						
Increased temperature						
Increased ionic strength						
HBI						
Increased autochthony	0	+	+	+	-	0
Decreased dissolved oxygen	+	+	+	+	0	+
Altered flow regime	+	NE	+	+	0	+
Decreased large woody debris	+	+	+	+	NE	+
Increased sediment	0	0	+	0	0	0
Increased temperature	+	+	+	0	0	+
Increased ionic strength	+	+	+	0	0	+
Brook trout						
Increased autochthony	0	NE	+	0	-	-
Decreased dissolved oxygen	+	NE	+	+	+	+ +
Altered flow regime	+	NE	+	+	+	+
Decreased large woody debris	+	NE	+	+	+	+
Increased sediment	0	NE	+	+	+	+
Increased temperature	+	NE	+	+	+	+
Increased ionic strength	+	NE	+	+	0	+

NE = No evidence
Complete summary tables, including toxic substances and all lines of evidence, are located in the appendices.

SOE Table 43. Consistency of evidence summary for all three impaired sites

Biological endpoint **Candidate cause**	**LCN .415**	**LCM 2.270**	**LCMn 2.274**
	Impaired site		
EPT richness			
Increased autochthony	0	-	-
Decreased dissolved oxygen	+	+ +	+ +
Altered flow regime	+ +	+	+
Decreased large woody debris	+	+ +	+ +
Increased sediment	+	0	0
Increased temperature	+	+ +	+ +
Increased ionic strength	+ +	+ +	+ +
% non-insects			
Increased autochthony	0	0	The % non-insects biological endpoint was not assessed at site LCMn 2.274. See text for more information.
Decreased dissolved oxygen	+	+	
Altered flow regime	+ +	+	
Decreased large woody debris	0	+	
Increased sediment	+	0	
Increased temperature	+	+	
Increased ionic strength	+ +	+ +	
HBI			
Increased autochthony	+	0	0
Decreased dissolved oxygen	+	+	+
Altered flow regime	+	0	+
Decreased large woody debris	+	+	+
Increased sediment	+	0	0
Increased temperature	+	+	+
Increased ionic strength	+	+	+
Brook trout			
Increased autochthony	0	-	-
Decreased dissolved oxygen	+	+ +	+ +
Altered flow regime	+ +	+	+
Decreased large woody debris	+	+	+
Increased sediment	+	+	+
Increased temperature	+	+	+
Increased ionic strength	+	+	+

Complete summary tables are located in the appendices.

SOE Table 44. Explanation of evidence scoring system

Finding	Interpretation	Score
There is a credible explanation for any negative inconsistencies or ambiguities in an otherwise positive body of evidence that could make the body of evidence consistently supporting.	This finding can save the case for a candidate cause that is weakened by inconsistent evidence; however, without evidence to support the explanation, the cause is barely strengthened.	+ +
There is no explanation for the inconsistencies or ambiguities in the evidence.	This finding neither strengthens nor weakens the case for a candidate cause.	0
There is a credible explanation for any positive inconsistencies or ambiguities in an otherwise negative body of evidence that could make the body of evidence consistently weakening.	This finding further weakens an inconsistent case; however, without evidence to support the explanation, the cause is barely weakened.	-

Source: U.S. EPA CADDIS (http://www.epa.gov/caddis/)

SOE Table 45. Strength of evidence complete scoring at LCN .415

Type of Evidence	Biological endpoint	Candidate Cause						Increased toxic substances																					
									water column																				
		Increased autochthony	Decreased dissolved oxygen	Altered flow regime	Decreased large woody debris	Increased sediment	Increased temperature	Ionic strength	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium	Silver	Thallium	Vanadium	Zinc	PAHs	Sediment toxicity[A]
Types of evidence that use data from the case																													
Spatial/temporal co-occurrence	NA	0	+	+	NE	+	+	+	- - -	0	+	+	0	+	+	+	+	+	+	+	+	+	0	0	0	+	+	ST	ST
Stressor-response relationships from the field	EPT richness	0	0	NE	+	0	+	+	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0	NE	NE
	% non-insects	0	0	NE	0	0	0	+	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0	NE	NE
	HBI	+	+	NE	+	0	+	+	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0	NE	NE
Causal pathway	NA	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Laboratory tests of site media	EPT richness	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0
	% non-insects	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0
Types of evidence that use data from elsewhere																													
Mechanistically plausible cause	EPT richness	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	% non-insects	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HBI	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	brook trout	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Stressor-response relationships from laboratory or other field studies	EPT richness	0	+	+	NE	0	+	+	-	NE	-	NE	NE	0	-	NE	+	-	0	NE	NE	-	-	NE	NE	NE	0	0	NE
	% non-insects	0	0	+	NE	0	0	+	0	NE	0	NE	NE	0	0	NE	0	0	0	NE	NE	0	0	NE	NE	NE	0	0	NE
	HBI	0	0	0	NE	0	0	0	0	NE	0	NE	NE	0	0	NE	0	0	0	NE	NE	0	0	NE	NE	NE	0	0	NE
	brook trout	0	+	+	NE	0	+	0	-	NE	-	NE	NE	0	-	NE	+	-	0	NE	NE	-	-	NE	NE	NE	0	0	NE
Multiple Lines of Evidence																													
Consistency of evidence	EPT richness	0	+	+ +	+	+	+	+ +	-	0	-	0	0	0	-	0	+	-	0	+	0	-	-	0	0	0	+	0	0
	% non-insects	0	+	+ +	0	+	+	+ +	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	+	0	0
	HBI	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	+	0	0
	brook trout	0	+	+ +	+	+	+	+	-	0	-	0	0	0	-	0	+	-	0	+	0	-	-	0	0	0	+	0	0
Explanation of the evidence	EPT richness	0	+ +	+ +	+ +	+ +	+ +	+ +	-	ST	ST	ST	ST	ST	ST	ST	+ +	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	0	0
	% non-insects	0	+ +	+ +	+ +	+ +	+ +	+ +	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	0	0
	HBI	0	+ +	+ +	+ +	+ +	+ +	+ +	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	0	0
	brook trout	0	+ +	+ +	+ +	+ +	+ +	+ +	-	ST	ST	ST	ST	ST	ST	ST	+ +	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	0	0

NE = No evidence; ST = See text

[A] Sediment toxicity laboratory results include individual metal concentrations found in the sediment samples; however, given lack of S-R information relevant to this type of data and given that the species survivorship information does not indicate support for this cause, we do not break this column down by individual contaminants found in sediment samples.

SOE Table 46. Strength of Evidence complete scoring at LCM 2.270

Type of Evidence	Biological endpoint	Increased autochthony	Decreased dissolved oxygen	Altered flow regime	Decreased large woody debris	Increased sediment	Increased temperature	Ionic strength	Cadmium	Copper	Lead	Nickel	Zinc
		Candidate Cause							Increased toxic substances *water column*				
Types of evidence that use data from the case													
Spatial/temporal co-occurrence	NA	0	+	NE	+	0	+	+	0	0	0	0	0
Stressor-response relationships from the field	EPT richness	0	0	NE	+	0	+	+	NE	NE	NE	NE	0
	% non-insects	0	0	NE	0	0	0	+	NE	NE	NE	NE	0
	HBI	+	+	NE	+	0	+	+	NE	NE	NE	NE	0
Causal pathway	NA	+	+	+	+	+	+	+	+	+	+	+	+
Types of evidence that use data from elsewhere													
Mechanistically plausible cause	EPT richness	0	+	+	+	+	+	+	+	+	+	+	+
	% non-insects	0	+	+	+	+	0	0	0	0	0	0	0
	HBI	+	+	+	+	0	0	0	0	0	0	0	0
	brook trout	0	+	+	+	+	+	+	+	+	+	+	+
Stressor-response relationships from laboratory or other field studies	EPT richness	-	+	+	+	0	+	+	0	-	0	-	-
	% non-insects	0	0	+	NE	0	0	+	0	0	0	0	0
	HBI	-	0	0	NE	0	0	0	0	0	0	0	0
	brook trout	-	+	+	+	+	+	0	0	-	0	-	-
Multiple Lines of Evidence													
Consistency of evidence	EPT richness	-	+ +	+	+ +	0	+ +	+ +	0	-	0	-	-
	% non-insects	0	+	+	+	0	+	+ +	0	0	0	0	0
	HBI	0	+	0	+	0	+	+	0	0	0	0	0
	brook trout	-	+ +	+	+	+	+	+	0	-	0	-	-
Explanation of the evidence	EPT richness	-	+ +	+ +	+ +	0	+ +	+ +	ST	-	ST	-	-
	% non-insects	0	+ +	+ +	+ +	0	+ +	+ +	ST	ST	ST	ST	ST
	HBI	-	+ +	+ +	+ +	0	+ +	+ +	ST	ST	ST	ST	ST
	brook trout	-	+ +	+ +	+ +	+ +	+ +	+ +	ST	-	ST	-	-

NE = No evidence; ST = See text

SOE Table 47. Strength of Evidence complete scoring at LCMn 2.274

Type of Evidence	Biological endpoint	Candidate Cause																										
								Increased toxic substances																				
								water column																				
		Increased autochthony	Decreased dissolved oxygen	Altered flow regime	Decreased large woody debris	Increased sediment	Increased temperature	Ionic strength	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium	Silver	Thallium	Vanadium	Zinc	Sediment toxicity[A]
Types of evidence that use data from the case																												
Spatial/temporal co-occurrence	NA	0	+	+	+	0	+	+	- - -	0	+	+	0	0	+	- - -	0	+	0	+	0	+	0	0	0	+	0	ST
Stressor-response relationships from the field	EPT richness	0	0	NE	+	0	+	+	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0	NE
	HBI	+	+	NE	+	0	+	+	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0	NE
Causal Pathway	NA	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Laboratory tests of site media	EPT richness	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0
Types of evidence that use data from elsewhere																												
Mechanistically plausible cause	EPT richness	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	HBI	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	brook trout	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Stressor-response relationships from laboratory or other field studies	EPT richness	-	+	+	+	0	+	+	-	NE	-	NE	NE	0	-	NE	-	-	0	NE	NE	-	-	NE	NE	NE	-	NE
	HBI	-	0	0	NE	0	0	0	0	NE	0	NE	NE	0	0	NE	0	0	0	NE	NE	0	0	NE	NE	NE	0	NE
	brook trout	-	+	+	+	+	+	0	-	NE	-	NE	NE	0	-	NE	-	-	0	NE	NE	-	-	NE	NE	NE	-	NE
Multiple Lines of Evidence																												
Consistency of evidence	EPT richness	-	+ +	+	+ +	0	+ +	+ +	-	0	-	0	0	0	-	0	-	-	0	+	0	-	-	0	0	0	-	0
	HBI	0	+	+	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0
	brook trout	-	+ +	+	+	+	+	+	-	0	-	0	0	0	-	0	-	-	0	+	0	-	-	0	0	0	-	0
Explanation of the evidence	EPT richness	-	+ +	+ +	+ +	0	+ +	+ +	-	ST	ST	ST	ST	ST	ST	ST	-	ST	ST	ST	ST	ST	ST	ST	ST	ST	-	0
	HBI	-	+ +	+ +	+ +	0	+ +	+ +	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	0
	brook trout	-	+ +	+ +	+ +	+ +	+ +	+ +	-	ST	ST	ST	ST	ST	ST	ST	-	ST	ST	ST	ST	ST	ST	ST	ST	ST	-	0

NE = No evidence; ST = See text

[A] Sediment toxicity laboratory results include individual metal concentrations found in the sediment samples; however, given lack of S-R information relevant to this type of data and given that the species survivorship information does not indicate support for this cause, we do not break this column down by individual contaminants found in sediment samples.

SOE Table 48. Consistency of evidence complete scoring for all three impaired sites

Type of Evidence	Biological endpoint	Increased autochthony	Decreased dissolved oxygen	Altered flow regime	Decreased large woody debris	Increased sediment	Increased temperature	Ionic strength	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium	Silver	Thallium	Vanadium	Zinc	PAH's	Sediment toxicity
		Candidate Cause																											
								Increased toxic substances																					
								water column																					
LCN .415																													
Consistency of Evidence	EPT richness	0	+	+ +	+	+	+	+ +	-	0	-	0	0	0	-	0	+	-	0	+	0	-	-	0	0	0	+	0	0
	% non-insects	0	+	+ +	0	+	+	+ +	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	+	0	0
	HBI	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	+	0	0
	brook trout	0	+	+ +	+	+	+	+	-	0	-	0	0	0	-	0	+	-	0	+	0	-	-	0	0	0	+	0	0
LCM 2.270																													
Consistency of Evidence	EPT richness	-	+ +	+	+ +	0	+ +	+ +	NE	NE	NE	NE	NE	0	NE	NE	-	NE	0	NE	NE	-	NE	NE	NE	NE	-	NE	NE
	% non-insects	0	+	+	+	0	+	+ +	NE	NE	NE	NE	NE	0	NE	NE	0	NE	0	NE	NE	0	NE	NE	NE	NE	0	NE	NE
	HBI	0	+	0	+	0	+	+	NE	NE	NE	NE	NE	0	NE	NE	0	NE	0	NE	NE	0	NE	NE	NE	NE	0	NE	NE
	brook trout	-	+ +	+	+	+	+	+	NE	NE	NE	NE	NE	0	NE	NE	-	NE	0	NE	NE	-	NE	NE	NE	NE	-	NE	NE
LCMn 2.274																													
Consistency of Evidence	EPT richness	-	+ +	+	+ +	0	+ +	+ +	-	0	-	0	0	0	-	0	-	-	0	+	0	-	-	0	0	0	-	NE	0
	HBI	0	+	+	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	NE	0
	brook trout	-	+ +	+	+	+	+	+	-	0	-	0	0	0	-	0	-	-	0	+	0	-	-	0	0	0	-	NE	0

NE = No evidence

[A] Sediment toxicity laboratory results include individual metal concentrations found in the sediment samples; however, given lack of S-R information relevant to this type of data and given that the species survivorship information does not indicate support for this cause, we do not break this column down by individual contaminants found in sediment samples.

SOE Table 49. Water column metal observations study comparison - Low flow

Study	South Portland Engineering		MEDEP				
Metal	LC 0	RB 0	LCN .585	LCM .595	LCMn 2.274	LCS .186	RB 1.694
Copper, ppm	0.008	0.005	<0.002	<0.002	0.002	0.002	<0.002
Lead, ppm	0.005	<0.001	<0.003	<0.003	<0.003	<0.003	<0.003
Zinc, ppm	0.025	0.025	0.015	<0.005	0.005	0.007	0.009

Adapted from MEDEP (2002a) Table 4.1b.

SOE Table 50. Water column metal observations study comparison - Stormflow

Study	South Portland Engineering		MEDEP							
	LC 0	RB 0	LCN .585		LCM .595		LCS .186		RB 1.694	
Metal	Aug-94	Aug-94	Mar-00	Sep-01	Mar-00	Sep-01	Mar-00	Sep-01	Mar-00	Sep-01
Copper, ppm	0.007	0.008	0.018	0.013	0.021	0.015	0.044	0.007	<0.002	0.003
Lead, ppm	0.003	0.009	0.031	0.015	0.052	0.025	0.9	0.007	0.003	0.004
Zinc, ppm	0.05	0.07	0.14	0.12	0.2	0.11	0.27	0.062	0.024	0.023

Adapted from MEDEP (2002a) Table 4.1b.

APPENDICES

APPENDIX A
HISTORIC MAPS

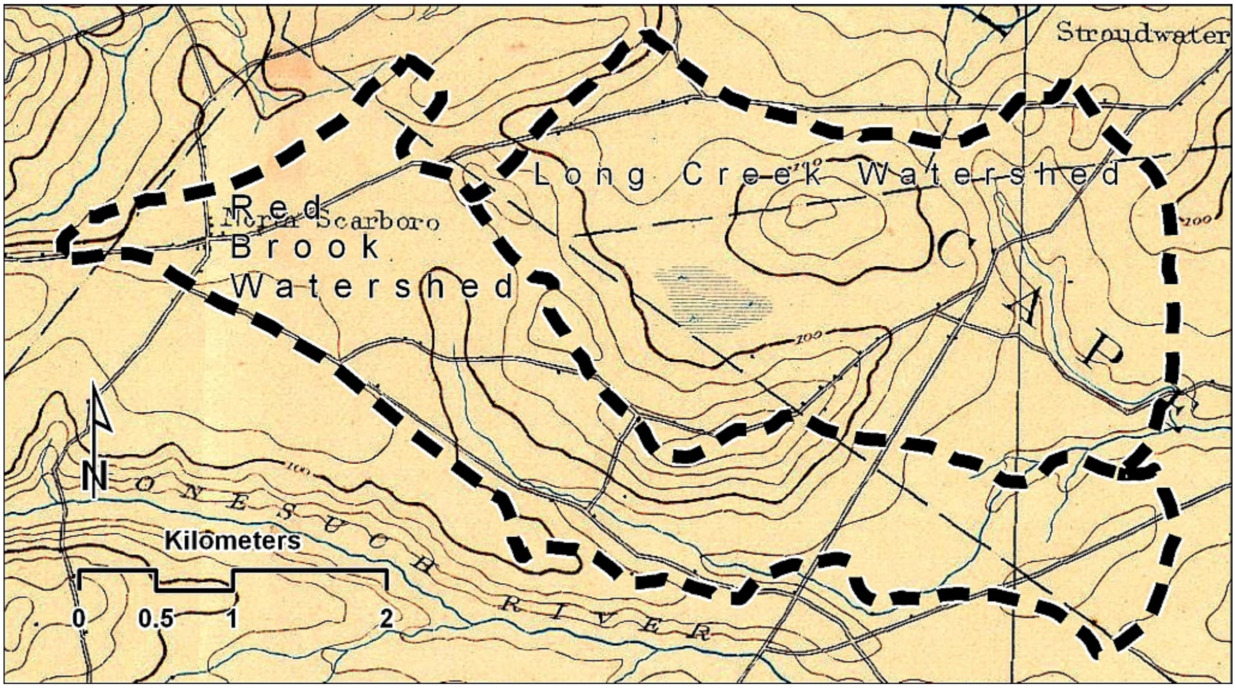

Figure A-1. Historic USGS map – 1891.
Dashed line is approximate location of superimposed case study watershed boundaries.

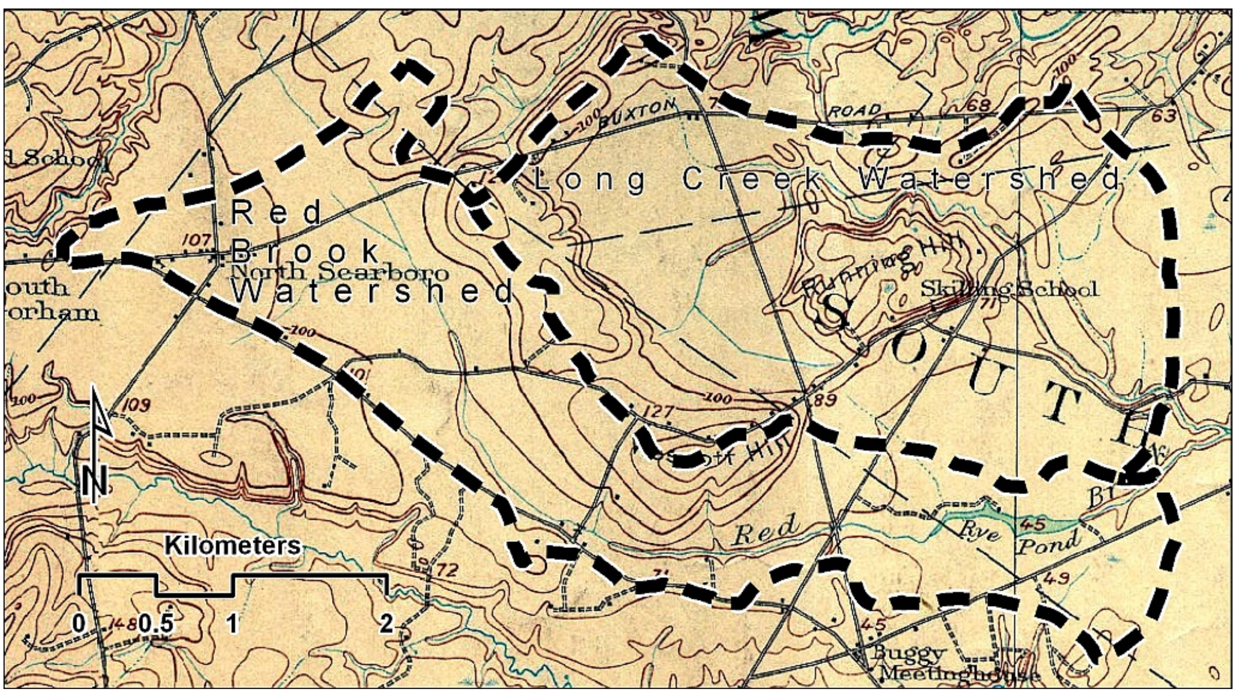

Figure A-2. Historic USGS map – 1916.
Dashed line is approximate location of superimposed case study watershed boundaries.

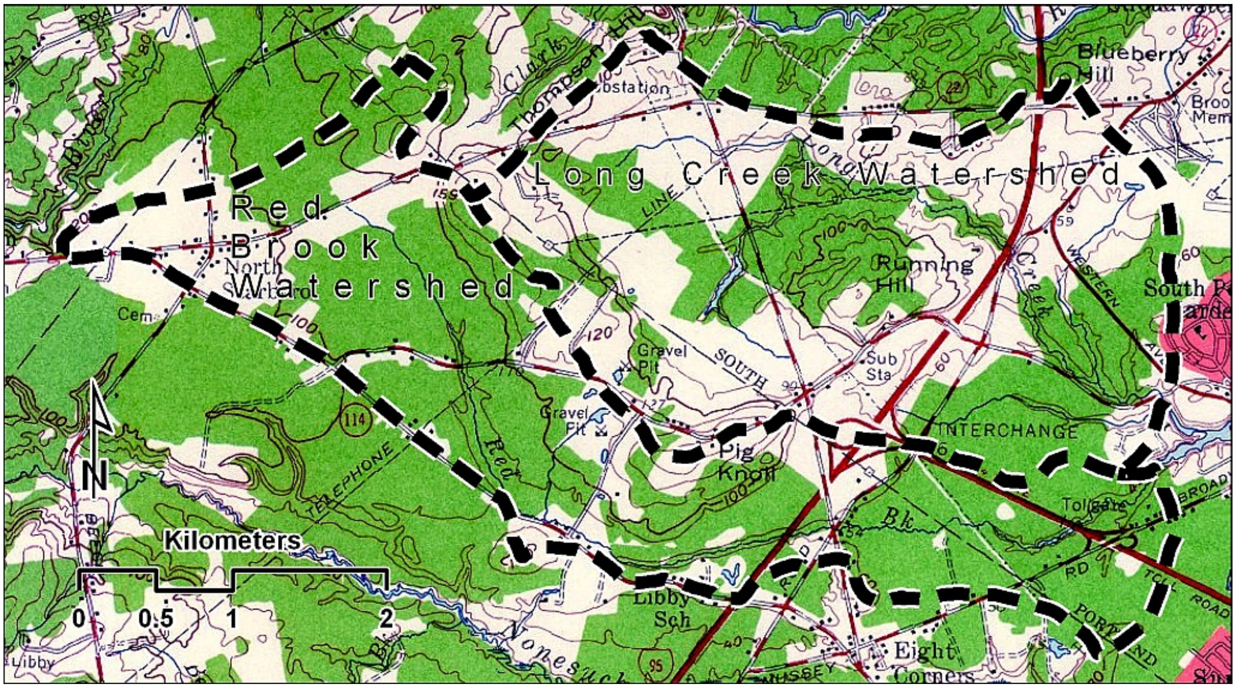

Figure A-3. Historic USGS map – 1957.
Dashed line is approximate location of superimposed case study watershed boundaries.

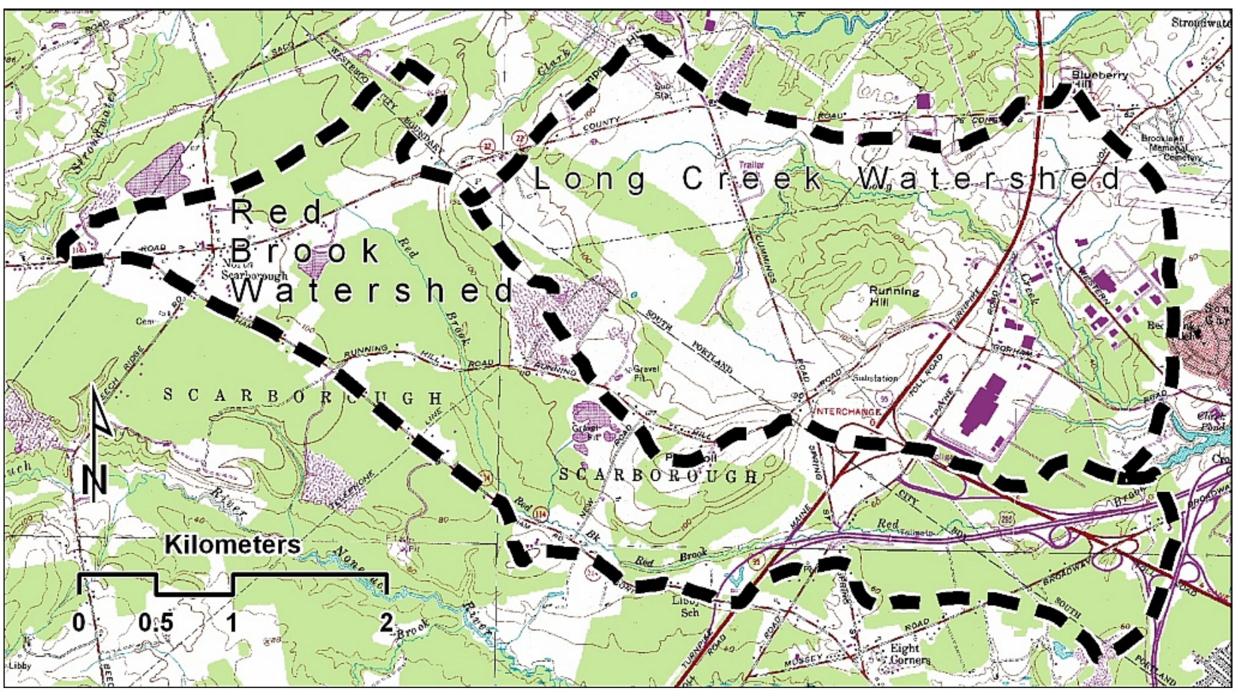

Figure A-4. Current USGS map – circa 1980s.
Dashed line is approximate location of superimposed case study watershed boundaries.

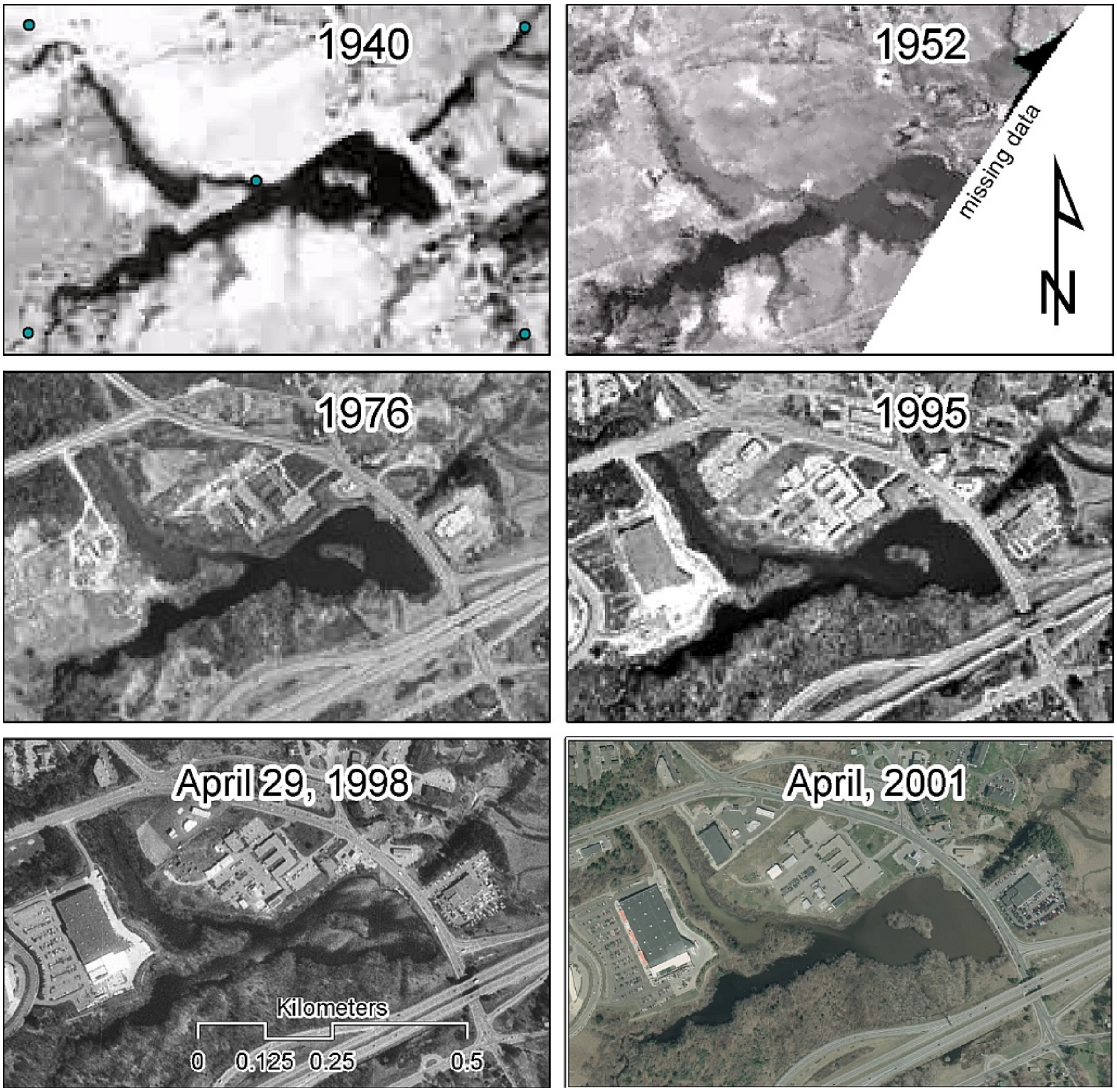

Figure A-5. Clark's Pond – Confluence of Long Creek and Red Brook.
Source: 1940 and 1952 aerial photographs from Field (2005); 1976 and 1995 aerial photographs from Greater Portland Council of Governments, at http://www.gpcog.org/, accessed in 2005; 1998 (USGS Digital Orthophoto Quadrangle) and 2001 aerial photographs from Maine Office of Geographic Information Systems, at http://megis.maine.gov/, accessed on December 29, 2005.

APPENDIX B
MAINE'S WATER QUALITY CLASSIFICATION LAW

The following is a copy of Maine's water quality classification law: Title 38, Chapter 3, Article 4-A, Section 465, Standards for classification of fresh surface waters, last updated December 1, 2004. This documentation can be accessed at the Maine State Legislature Web site: http://janus.state.me.us/legis/

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§465. Standards for classification of fresh surface waters (CONTAINS TEXT WITH VARYING EFFECTIVE DATES)

The department shall have 4 standards for the classification of fresh surface waters which are not classified as great ponds. `[1989, c. 890, Pt. A, §40 (aff); Pt. B, §61 (amd).]`

1. Class AA waters. Class AA shall be the highest classification and shall be applied to waters which are outstanding natural resources and which should be preserved because of their ecological, social, scenic or recreational importance. `[2003, c. 574, §1 (amd).]`

A. (TEXT EFFECTIVE UNTIL CONTINGENCY: See Title 38, section 470-E) Class AA waters shall be of such quality that they are suitable for the designated uses of drinking water after disinfection, fishing, recreation in and on the water and navigation and as habitat for fish and other aquatic life. The habitat shall be characterized as free flowing and natural.

`[1985, c. 698, §15 (new).]`

A. (TEXT EFFECTIVE ON CONTINGENCY: See Title 38, section 470-E) Class AA waters must be of such quality that they are suitable for the designated uses of drinking water after disinfection, fishing, agriculture, recreation in and on the water, navigation and as habitat for fish and other aquatic life. The habitat must be characterized as free-flowing and natural.

`[2003, c. 227, §1 (amd); §9 (aff).]`

B. The aquatic life, dissolved oxygen and bacteria content of Class AA waters shall be as naturally occurs.

`[1985, c. 698, §15 (new).]`

C. Except as provided in this paragraph, there may be no direct discharge of pollutants to Class AA waters.

(1) Storm water discharges that are in compliance with state and local requirements are allowed.

(2) A discharge to Class AA waters that are or once were populated by a distinct population segment of Atlantic salmon as determined pursuant to the United States Endangered Species Act of 1973, Public Law 93-205, as amended, is allowed if, in addition to satisfying all the requirements of this article, the applicant, prior to issuance of a discharge license, objectively demonstrates to the department's satisfaction that the discharge is necessary, that there are no other reasonable alternatives available and

that the discharged effluent is for the purpose of and will assist in the restoration of Atlantic salmon and will return the waters to a state that is closer to historically natural chemical quality.

(a) The department may issue no more than a total of 3 discharge licenses pursuant to this subparagraph and subsection 2, paragraph C, subparagraph (2).

(b) A discharge license issued pursuant to this subparagraph may not be effective for more than 5 years from the date of issuance.

[2003, c. 574, §1 (rpr).]

2. Class A waters. Class A shall be the 2nd highest classification. [2003, c. 574, §2 (amd).]

A. (TEXT EFFECTIVE UNTIL CONTINGENCY: See Title 38, section 470-E) Class A waters shall be of such quality that they are suitable for the designated uses of drinking water after disinfection; fishing; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; and navigation; and as habitat for fish and other aquatic life. The habitat shall be characterized as natural.

[1985, c. 698, §15 (new).]

A. (TEXT EFFECTIVE ON CONTINGENCY: See Title 38, section 470-E) Class A waters must be of such quality that they are suitable for the designated uses of drinking water after disinfection; fishing; agriculture; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; navigation; and as habitat for fish and other aquatic life. The habitat must be characterized as natural.

[2003, c. 227, §2 (amd); §9 (aff).]

B. The dissolved oxygen content of Class A waters shall be not less than 7 parts per million or 75% of saturation, whichever is higher. The aquatic life and bacteria content of Class A waters shall be as naturally occurs.

[1985, c. 698, §15 (new).]

C. Except as provided in this paragraph, direct discharges to these waters licensed after January 1, 1986 are permitted only if, in addition to satisfying all the requirements of this article, the discharged effluent will be equal to or better than the existing water quality of the receiving waters. Prior to issuing a discharge license, the department shall require the applicant to objectively demonstrate to the department's satisfaction that the discharge is necessary and that there are no other reasonable alternatives available. Discharges into waters of this classification licensed prior to January 1, 1986 are allowed to continue only until practical alternatives exist.

(1) This paragraph does not apply to a discharge of storm water that is in compliance with state and local requirements.

(2) This paragraph does not apply to a discharge to Class A waters that are or once were populated by a distinct population segment of Atlantic salmon as determined pursuant to the United States Endangered Species Act of 1973, Public Law 93-205, as amended, if, in addition to satisfying all the requirements of this article, the applicant, prior to issuance of a discharge license, objectively demonstrates to the department's satisfaction that the discharge is necessary, that there are no other reasonable alternatives available and that the discharged effluent is for the purpose of and will assist in the restoration of Atlantic salmon and will return the waters to a state that is closer to historically natural chemical quality.

(a) The department may issue no more than a total of 3 discharge licenses pursuant to this subparagraph and subsection 1, paragraph C, subparagraph (2).

(b) A discharge license issued pursuant to this subparagraph may not be effective for more than 5 years from the date of issuance.

[2003, c. 574, §2 (rpr).]

D. Storm water discharges to Class A waters must be in compliance with state and local requirements.

[2003, c. 318, §4 (new).]

E. Material may not be deposited on the banks of Class A waters in any manner that makes transfer of pollutants into the waters likely.

[2003, c. 318, §4 (new).]

3. Class B waters. Class B shall be the 3rd highest classification. [1985, c. 698, §15 (new); 2003, c. 227, §3 (amd); §9 (aff).]

A. (TEXT EFFECTIVE UNTIL CONTINGENCY: See Title 38, section 470-E) Class B waters shall be of such quality that they are suitable for the designated uses of drinking water supply after treatment; fishing; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; and navigation; and as habitat for fish and other aquatic life. The habitat shall be characterized as unimpaired.

[1985, c. 698, §15 (new).]

A. (TEXT EFFECTIVE ON CONTINGENCY: See Title 38, section 470-E) Class B waters must be of such quality that they are suitable for the designated uses of drinking water supply after treatment; fishing; agriculture; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; navigation; and as habitat for fish and other aquatic life. The habitat must be characterized as unimpaired.

[2003, c. 227, §3 (amd); §9 (aff).]

B. The dissolved oxygen content of Class B waters shall be not less than 7 parts per million or 75% of saturation, whichever is higher, except that for the period from October 1st to May 14th, in order to ensure spawning and egg incubation of indigenous fish species, the 7-day mean dissolved oxygen concentration shall not be less than 9.5 parts per million and the 1-day minimum dissolved oxygen concentration shall not be less than 8.0 parts per million in identified fish spawning areas. Between May 15th and September 30th, the number of Escherichia coli bacteria of human origin in these waters may not exceed a geometric mean of 64 per 100 milliliters or an instantaneous level of 427 per 100 milliliters.

[1985, c. 698, §15 (new).]

C. Discharges to Class B waters shall not cause adverse impact to aquatic life in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous to the receiving water without detrimental changes in the resident biological community.

[1985, c. 698, §15 (new).]

4. Class C waters. Class C shall be the 4th highest classification. [2003, c. 664, §1 (amd).]

A. (TEXT EFFECTIVE UNTIL CONTINGENCY: See Title 38, section 470-E) Class C waters shall be of such quality that they are suitable for the designated uses of drinking water supply after treatment; fishing; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; and navigation; and as a habitat for fish and other aquatic life.

[1985, c. 698, §15 (new).]

A. (TEXT EFFECTIVE ON CONTINGENCY: See Title 38, section 470-E) Class C waters must be of such quality that they are suitable for the designated uses of drinking water supply after treatment; fishing; agriculture; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; navigation; and as a habitat for fish and other aquatic life.

[2003, c. 227, §4 (amd); §9 (aff).]

B. The dissolved oxygen content of Class C water may be not less than 5 parts per million or 60% of saturation, whichever is higher, except that in identified salmonid spawning areas where water quality is sufficient to ensure spawning, egg incubation and survival of early life stages, that water quality sufficient for these purposes must be maintained. In addition, in order to provide additional protection for growth of indigenous fish, dischargers that were issued final discharge licenses or water quality certificates prior to March 16, 2004 that are based on a 6.5 parts per million dissolved oxygen criterion must continue to be licensed using a temperature of 24 degrees centigrade or the ambient temperature of the water body, whichever is lower. Final discharge licenses and water quality certificates not based on a 6.5 parts per million dissolved oxygen criterion prior to March 16, 2004 must be based on a 6.5 parts per million dissolved oxygen criterion at a temperature of 22 degrees centigrade or the ambient temperature of the water body, whichever is lower. Between May 15th and September 30th, the number of Escherichia coli bacteria of human origin in these waters may not exceed a geometric mean of 142 per 100 milliliters or an instantaneous level of 949 per 100 milliliters. The board shall adopt rules governing the procedure for designation of spawning areas. Those rules must include provision for periodic review of designated spawning areas and consultation with affected persons prior to designation of a stretch of water as a spawning area.

[2003, c. 664, §1 (amd).]

C. Discharges to Class C waters may cause some changes to aquatic life, provided that the receiving waters shall be of sufficient quality to support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community.

[1985, c. 698, §15 (new).]

PL 1985, Ch. 698, §15 (NEW).
PL 1989, Ch. 890, §A40,B61-63 (AMD).
PL 1999, Ch. 243, §8 (AMD).
PL 2003, Ch. 227, §1-4 (AMD).
PL 2003, Ch. 227, §9 (AFF).
PL 2003, Ch. 318, §3,4 (AMD).
PL 2003, Ch. 574, §1,2 (AMD).
PL 2003, Ch. 664, §1 (AMD).

APPENDIX C
MACROINVERTEBRATE ROCKBAG SAMPLING DATA

The following table provides rockbag sampling data for Long Creek and Red Brook. MEDEP biologists conducted sampling beginning August 5-6, 1999, using three rockbags over a 32-day colonization period. See the main text for information on how the data was used in this analysis. For general information about the data, refer to MEDEP (2002a).

				Reference site	Impaired sites			Other Long Creek & Red Brook sites				
Class	Order	Family	Genus	RB 3.961	LCN .415	LCM 2.270	LCMn 2.274	LCS .369	LCM .380	LCM .910	RB .071	RB 1.474
Non-Insects:												
Arachnida	Acari	Hydrachnidae		0	0	0	0	0	0	0	2	0
Arachnida	Acari	Hygrobatidae	*Hygrobates*	0	0	0	0	0	0	0	1	0
Arachnida	Acari	Lebertiidae	*Ferrissia*	0	0	0	0	0	0	4	0	0
Crustacea	Amphipoda			0	0	8	0	0	0	0	0	0
Crustacea	Amphipoda	Crangonyctidae	*Crangonyx*	0	1	0	0	0	73	52	0	0
Crustacea	Amphipoda	Hyalellidae	*Hyalella*	0	38	16	0	60	23	65	0	0
Crustacea	Cladocera			0	0	0	0	0	0	7	0	0
Crustacea	Isopoda	Asellidae	*Caecidotea*	1	0	52	0	0	1	30	0	0
Gastropoda				0	0	0	0	7	0	0	0	0
Gastropoda	Limnophila	Ancylidae	*Ferrissia*	0	0	0	0	0	5	0	1	0
Gastropoda	Limnophila	Physidae	*Physa*	0	0	0	3	0	0	1	0	0
Gastropoda	Limnophila	Physidae	*Physella*	0	21	0	0	10	0	0	0	0
Gastropoda	Limnophila	Physidae		0	1	0	0	0	0	0	1	0
Gastropoda	Limnophila	Planorbidae		0	0	0	0	0	0	1	1	0
Gastropoda	Mesogastropoda	Valvatidae	*Valvata*	0	0	0	0	0	0	4	2	0
Gastropoda	Mollusca	Planorbidae	*Gyraulus*	0	0	0	0	8	0	0	0	0
Gastropoda	Basommatophora	Planorbidae	*Helisoma*	0	0	0	0	3	0	0	0	0
Hirudinea	Arhynchobdellida	Erpobdellidae	*Erpobdella*	0	0	0	0	1	0	0	0	0
Hirudinea	Arhynchobdellida	Erpobdellidae		0	0	0	1	0	1	2	0	0
Hirudinea	Rhynchobdellida		*Rhynchobdellida*	0	0	1	0	0	7	0	0	0
Hirudinea	Rhynchobdellida	Glossiphoniidae	*Glossiphonia*	0	4	1	0	0	0	6	0	1
Hirudinea	Rhynchobdellida	Glossiphoniidae	*Helobdella*	4	0	26	0	0	0	5	0	1
Hirudinea	Rhynchobdellida	Glossiphoniidae	*Placobdella*	0	0	0	0	0	0	1	0	0
Hydrozoa	Hydroida			0	0	0	0	0	2	2	0	0
Oligochaeta	Lumbriculida	Lumbricidae		0	0	1	0	0	0	0	0	0
Oligochaeta	Lumbriculida	Lumbriculidae	*Stylodrilus*	4	0	0	0	0	2	0	0	0
Oligochaeta	Lumbriculida	Lumbriculidae		0	0	0	0	3	0	0	0	0

Class	Order	Family	Genus	Reference site RB 3.961	Impaired sites LCN .415	LCM 2.270	LCMn 2.274	Other Long Creek & Red Brook sites LCS .369	LCM .380	LCM .910	RB .071	RB 1.474
Oligochaeta	Tubificida	Enchytraeidae		0	1	0	0	0	0	0	0	0
Oligochaeta	Tubificida	Naididae	*Chaetogaster*	2	0	0	0	0	0	0	0	0
Oligochaeta	Tubificida	Tubificidae	*Limnodrilus*	0	0	3	0	0	0	0	0	0
Oligochaeta	Tubificida	Tubificidae		0	0	19	0	8	0	0	0	0
Pelecypoda	Veneroida	Sphaeriidae	*Pisidium*	14	1	0	0	18	0	0	0	0
Pelecypoda	Veneroida	Sphaeriidae		3	0	0	0	3	0	0	0	0
Pelecypoda	Veneroida	Sphaeriidae	*Sphaerium*	0	0	58	0	0	0	14	0	0
			Non-insect sub-total:	**28**	**67**	**185**	**4**	**121**	**114**	**194**	**8**	**2**
Insects:												
Insecta	Coleoptera	Dytiscidae	*Deronectes*	0	0	0	0	2	3	0	0	0
Insecta	Coleoptera	Dytiscidae	*Dytiscus*	0	0	0	1	0	0	0	0	0
Insecta	Coleoptera	Elmidae	*Ancyronyx*	0	0	0	0	0	0	2	0	0
Insecta	Coleoptera	Elmidae	*Dubiraphia*	0	0	478	175	1	32	111	2	15
Insecta	Coleoptera	Elmidae		0	0	0	0	0	0	0	0	1
Insecta	Coleoptera	Elmidae	*Macronychus*	0	1	0	0	0	2	0	0	0
Insecta	Coleoptera	Elmidae	*Optioservus*	0	0	0	1	0	0	37	0	0
Insecta	Coleoptera	Elmidae	*Oulimnius*	0	0	0	0	0	1	0	0	0
Insecta	Coleoptera	Elmidae	*Promoresia*	0	1	0	0	2	0	0	0	0
Insecta	Coleoptera	Elmidae	*Stenelmis*	0	0	16	0	0	2	9	0	0
Insecta	Coleoptera	Haliplidae	*Haliplus*	0	0	0	0	0	0	1	0	0
Insecta	Coleoptera	Psephenidae	*Ectopria*	0	2	0	0	0	0	0	0	0
Insecta	Collembola			0	0	0	0	1	0	0	0	0
Insecta	Diptera			0	0	0	0	2	0	0	0	0
Insecta	Diptera	Ceratopogonidae	*Bezzia/Palpomyia*	0	0	0	0	1	0	0	0	0
Insecta	Diptera	Ceratopogonidae	*Culicoides*	0	0	1	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Ablabesmyia*	2	4	1	4	28	0	0	4	0
Insecta	Diptera	Chironomidae	*Apsectrotanypus*	1	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Brundiniella*	3	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Chironomus*	0	0	2	0	15	0	0	0	0
Insecta	Diptera	Chironomidae	*Clinotanypus*	0	0	104	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Conchapelopia*	3	0	0	0	1	0	0	0	0
Insecta	Diptera	Chironomidae	*Cricotopus*	0	0	0	0	0	0	3	0	0
Insecta	Diptera	Chironomidae	*Cryptochironomus*	0	0	0	0	3	0	0	0	0
Insecta	Diptera	Chironomidae	*Cryptotendipes*	0	0	0	0	0	0	0	1	0
Insecta	Diptera	Chironomidae	*Dicrotendipes*	0	2	10	2	2	0	1	0	0
Insecta	Diptera	Chironomidae	*Heterotrissocladius*	2	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Hudsonimyia*	0	0	0	0	0	1	0	0	0

				Reference site	Impaired sites			Other Long Creek & Red Brook sites				
				RB	LCN	LCM	LCMn	LCS	LCM	LCM	RB	RB
Class	Order	Family	Genus	3.961	.415	2.270	2.274	.369	.380	.910	.071	1.474
Insecta	Diptera	Chironomidae	*Kiefferulus*	0	0	0	0	0	2	0	0	0
Insecta	Diptera	Chironomidae	*Labrundinia*	1	1	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Macropelopia*	18	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Meropelopia*	2	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Micropsectra*	27	5	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Microtendipes*	0	0	37	22	0	0	1	9	7
Insecta	Diptera	Chironomidae	*Natarsia*	1	3	11	0	34	3	0	1	0
Insecta	Diptera	Chironomidae	*Parachironomus*	0	0	0	0	0	1	0	0	0
Insecta	Diptera	Chironomidae	*Parakiefferiella*	2	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Paralauterborniella*	4	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Paramerina*	3	6	1	2	0	4	1	1	0
Insecta	Diptera	Chironomidae	*Parametriocnemus*	6	0	0	0	1	0	0	0	1
Insecta	Diptera	Chironomidae	*Phaenopsectra*	0	1	0	0	20	0	0	0	2
Insecta	Diptera	Chironomidae	*Polypedilum*	13	0	1	0	31	0	3	1	1
Insecta	Diptera	Chironomidae	*Procladius*	8	29	21	14	3	0	0	1	1
Insecta	Diptera	Chironomidae	*Psectrotanypus*	0	1	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Rheotanytarsus*	3	0	0	0	0	8	0	5	1
Insecta	Diptera	Chironomidae	*Stempellina*	0	0	10	0	0	21	2	0	0
Insecta	Diptera	Chironomidae	*Stempellinella*	26	0	0	0	0	14	0	7	4
Insecta	Diptera	Chironomidae	*Tanytarsus*	42	0	23	5	18	5	122	30	4
Insecta	Diptera	Chironomidae	*Thienemanniella*	0	9	0	2	1	0	0	0	0
Insecta	Diptera	Chironomidae	*Thienemannimyia*	3	0	5	0	12	32	0	0	4
Insecta	Diptera	Chironomidae	*Trissopelopia*	2	0	0	0	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Xylotopus*	0	0	0	0	1	0	0	0	0
Insecta	Diptera	Chironomidae	*Zavrelia*	0	0	0	1	0	0	1	0	0
Insecta	Diptera	Chironomidae	*Zavrelimyia*	9	2	0	1	0	0	0	0	0
Insecta	Diptera	Chironomidae	*Nanocladius*	0	0	0	0	1	0	0	0	0
Insecta	Diptera	Chironomidae	*Orthocladius*	0	0	0	0	5	0	0	0	0
Insecta	Diptera	Chironomidae	*Paratanytarsus*	0	0	0	0	7	0	0	0	0
Insecta	Diptera	Chironomidae	*Paratendipes*	0	0	0	0	1	0	0	0	0
Insecta	Diptera	Culicidae	*Anopheles*	0	0	0	1	0	0	0	0	0
Insecta	Diptera	Empididae		1	0	0	0	0	0	0	0	0
Insecta	Diptera	Empididae	*Hemerodromia*	0	0	0	0	1	0	0	0	0
Insecta	Diptera	Tabanidae	*Chrysops*	3	2	0	0	6	2	0	0	0
Insecta	Diptera	Tabanidae		0	0	6	0	0	53	0	0	0
Insecta	Diptera	Tipulidae	*Limnophila*	0	0	0	0	0	0	0	0	1
Insecta	Diptera	Tipulidae	*Pilaria*	1	0	0	0	0	0	0	0	0
Insecta	Diptera	Tipulidae	*Pseudolimnophila*	1	0	0	0	0	0	0	0	0

				Reference site	Impaired sites			Other Long Creek & Red Brook sites				
				RB	LCN	LCM	LCMn	LCS	LCM	LCM	RB	RB
Class	Order	Family	Genus	3.961	.415	2.270	2.274	.369	.380	.910	.071	1.474
Insecta	Diptera	Tipulidae	*Tipula*	1	0	0	0	0	3	0	0	0
Insecta	Ephemeroptera	Baetidae	*Acerpenna*	1	0	0	0	0	0	0	0	0
Insecta	Ephemeroptera	Baetidae		0	1	9	1	0	0	1	4	1
Insecta	Ephemeroptera	Baetidae	*Cloeon*	0	0	0	2	0	0	2	0	0
Insecta	Ephemeroptera	Caenidae	*Caenis*	0	3	190	26	43	62	67	1	0
Insecta	Ephemeroptera	Ephemerellidae	*Eurylophella*	0	0	0	0	0	0	0	4	0
Insecta	Ephemeroptera	Heptageniidae	*Heptageniidae*	1	0	0	0	0	0	0	0	0
Insecta	Ephemeroptera	Heptageniidae	*Stenonema*	8	0	0	0	0	0	0	0	2
Insecta	Ephemeroptera	Leptophlebiidae		6	0	0	0	0	0	0	0	0
Insecta	Ephemeroptera	Leptophlebiidae	*Paraleptophlebia*	12	0	0	0	0	0	0	57	10
Insecta	Hemiptera	Gerridae	*Gerris*	0	0	0	1	0	0	0	0	0
Insecta	Hemiptera	Veliidae	*Microvelia*	0	3	0	0	0	0	0	0	0
Insecta	Hemiptera	Veliidae	*Veliidae*	0	0	0	0	0	0	0	0	0
Insecta	Megaloptera	Corydalidae	*Nigronia*	1	5	0	0	0	2	1	2	12
Insecta	Megaloptera	Sialidae	*Sialis*	46	0	8	2	29	11	0	2	6
Insecta	Odonata	Aeshnidae	*Aeshna*	0	3	0	0	5	7	0	0	0
Insecta	Odonata	Aeshnidae		0	0	0	4	0	0	4	0	0
Insecta	Odonata	Aeshnidae	*Boyeria*	3	0	0	4	1	1	2	2	0
Insecta	Odonata	Calopterygidae		7	0	0	0	0	0	0	3	0
Insecta	Odonata	Calopterygidae	*Calopteryx*	0	1	1	0	0	4	0	1	7
Insecta	Odonata	Coenagrionidae	*Argia*	0	0	1	0	13	0	0	0	0
Insecta	Odonata	Coenagrionidae		0	0	3	0	0	0	2	0	0
Insecta	Odonata	Coenagrionidae	*Enallagma*	0	0	0	0	0	2	0	0	0
Insecta	Odonata	Cordulegastridae	*Cordulegaster*	5	0	0	0	0	0	0	0	0
Insecta	Odonata	Gomphidae	*Lanthus*	1	0	0	0	0	0	0	0	0
Insecta	Odonata	Libellulidae	*Sympetrum*	0	0	0	1	0	0	0	0	0
Insecta	Plecoptera	Leuctridae	*Leuctra*	3	0	0	0	0	0	0	0	0
Insecta	Trichoptera	Calamoceratidae	*Heteroplectron*	1	0	0	0	0	0	0	0	0
Insecta	Trichoptera	Dipseudopsidae	*Phylocentropus*	1	0	7	2	16	4	0	3	7
Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*	0	0	0	0	0	0	0	0	2
Insecta	Trichoptera	Hydropsychidae	*Diplectrona*	1	0	0	0	0	0	0	0	0
Insecta	Trichoptera	Hydropsychidae	*Hydropsyche*	2	0	0	0	1	0	0	0	0
Insecta	Trichoptera	Hydroptilidae	*Oxyethira*	0	0	0	0	0	0	0	2	0
Insecta	Trichoptera	Leptoceridae		0	0	1	0	0	0	0	0	0
Insecta	Trichoptera	Leptoceridae	*Mystacides*	0	9	0	0	0	11	9	40	0
Insecta	Trichoptera	Leptoceridae	*Oecetis*	0	0	20	5	1	1	3	0	1
Insecta	Trichoptera	Limnephilidae	*Glyphopsyche*	0	0	0	0	0	1	0	0	0
Insecta	Trichoptera	Limnephilidae		0	0	1	0	0	0	0	0	0
Insecta	Trichoptera	Limnephilidae	*Limnephilus*	3	12	0	5	1	0	0	0	2

Class	Order	Family	Genus	Reference site	Impaired sites			Other Long Creek & Red Brook sites				
				RB 3.961	LCN .415	LCM 2.270	LCMn 2.274	LCS .369	LCM .380	LCM .910	RB .071	RB 1.474
Insecta	Trichoptera	Limnephilidae	*Psychoglypha*	5	0	0	0	0	0	0	0	0
Insecta	Trichoptera	Limnephilidae	*Pycnopsyche*	6	0	0	0	0	0	0	0	0
Insecta	Trichoptera	Molannidae	*Molanna*	0	0	3	0	0	0	1	0	1
Insecta	Trichoptera	Odontoceridae	*Psilotreta*	27	0	0	0	0	16	0	0	0
Insecta	Trichoptera	Phryganeidae	*Oligostomis*	5	0	0	0	0	0	0	0	0
Insecta	Trichoptera	Phryganeidae		0	0	0	0	1	0	0	0	0
Insecta	Trichoptera	Phryganeidae	*Ptilostomis*	0	14	1	3	0	3	2	0	3
Insecta	Trichoptera	Polycentropodidae		0	1	0	0	0	0	0	0	0
Insecta	Trichoptera	Polycentropodidae	*Polycentropus*	0	0	0	0	0	0	0	6	0
Insecta	Trichoptera	Psychomyiidae	*Lype*	0	0	0	0	0	0	0	2	0
			Insect sub-total:	**333**	**121**	**972**	**287**	**311**	**314**	**388**	**191**	**96**
			Total (non-insects + insects):	**361**	**188**	**1157**	**291**	**432**	**428**	**582**	**199**	**98**
			Total mean abundance (total / 3 samples):	**120.3**	**62.7**	**385.7**	**97.0**	**144.0**	**142.7**	**194.0**	**66.3**	**32.7**
			% non insects:	**7.8%**	**35.6%**	**16.0%**	**1.4%**	**28.0%**	**26.6%**	**33.3%**	**4.0%**	**2.0%**

APPENDIX D
MAINE'S LINEAR DISCRIMINANT FUNCTION MODEL VARIABLES

The following 30 linear discriminant function (LDF) model variable descriptions are copied directly from Davies and Tsomides (2002). Further information about the LDF model can be found in Davies and Tsomides (2002).

1 **Total Mean Abundance**

Count all individuals in all replicate samples from one site and divide by the number of replicates to yield mean number of individuals per sample.

2 **Generic Richness**

Count the number of different genera found in all replicates from one site.

Counting rules for Generic Richness:

a) All population counts at the species level will be aggregated to the generic level.

b) A family level identification which includes no more than one taxon identified to the generic level is counted as a separate taxon in generic richness counts.

c) A family level identification with more than one taxon identified to generic level is not counted towards generic richness. Counts are to be divided proportionately among the genera that are present.

d) Higher level taxonomic identifications (Phylum, Class, Order) are not counted toward generic richness unless they are the only representative.

e) Pupae are ignored in all calculations.

3 **Plecoptera Mean Abundance**

Count all individuals from the order Plecoptera in all replicate samplers from one site and divide by the number of replicates to yield mean number of Plecopteran individuals per sampler.

4 **Ephemeroptera Mean Abundance**

Count all individuals from the order Ephemeroptera in all replicate samplers from one site and divide by the number of replicates to yield mean number of Ephemeropteran individuals per sampler.

5 **Shannon-Wiener Generic Diversity (Shannon and Weaver, 1963)**

After adjusting all counts to genus following counting rules in Variable 2:

$$\overline{d} = \frac{c}{N}\left(N \log_{10} N - \sum n_i \log_{10} n_i\right)$$

where: $\overline{d}$ = Shannon-Wiener Diversity
c = 3.321928 (converts base 10 log to base 2)
N = Total abundance of individuals
n_i = Total abundance of individuals in the i^{th} taxon

6 **Hilsenhoff Biotic Index (Hilsenhoff, 1987)**

$$HBI = \sum \frac{n_i a_i}{N}$$

where: HBI = Hilsenhoff Biotic Index
n_i = number of individuals in the i^{th} taxon
a_i = tolerance value assigned to that taxon
N = total number of individuals in sample with tolerance values.

7 **Relative Chironomidae Abundance**

Calculate the mean number of individuals of the family Chironomidae, following counting rules in Variable 4, and divide by total mean abundance (Variable 1).

8 **Relative Diptera Richness**

Count the number of different genera from the Order Diptera, following counting rules in Variable 2, and divide by generic richness (Variable 2).

9 ***Hydropsyche* Mean Abundance**

Count all individuals from the genus *Hydropsyche* in all replicate samplers from one site, and divide by the number of replicates to yield mean number of *Hydropsyche* individuals per sampler.

10 **Probability (A + B + C) from First Stage Model**

Sum of probabilities for Classes A, B, and C from First Stage Model.

11 ***Cheumatopsyche* Mean Abundance**

Count all individuals from the genus *Cheumatopsyche* in all replicate samplers from one site and divide by the number of replicates to yield mean number of *Cheumatopsyche* individuals per sampler.

12 **EPT - Diptera Richness Ratio**

EPT Generic Richness (Variable 19) divided by the number of genera from the order Diptera, following counting rules in Variable 2. If the number of genera of Diptera in the sample is 0, a value of 1 is assigned to the denominator.

13 **Relative Oligochaeta Abundance**

Calculate the mean number of individuals from the Order Oligochaeta, following counting rules in Variable 4, and divide by total mean abundance (Variable 1).

14 **Probability (A + B) from First Stage Model**

Sum of probabilities for Classes A and B from First Stage Model.

15 **Perlidae Mean Abundance (Family Functional Group)**

Count all individuals from the family Perlidae (Appendix C-3) in all replicate samplers from one site and divide by the number of replicates to yield mean number of Perlidae per sampler.

16 **Tanypodinae Mean Abundance (Family Functional Group)**

Count all individuals from the subfamily Tanypodinae (Appendix C-3) in all replicate samplers from one site and divide by the number of replicates to yield mean number of Tanypodinae per sampler.

17 **Chironomini Mean Abundance (Family Functional Group)**

Count all individuals from the tribe Chironomini (Appendix C-3) in all replicate samplers from one site and divide by the number of replicates to yield mean number of Chironomini per sampler.

18 **Relative Ephemeroptera Abundance**

Variable 4 divided by Variable 1.

19 **EPT Generic Richness**

Count the number of different genera from the Order Ephemeroptera (E), Plecoptera (P), and Trichoptera (T) in all replicate samplers, according to counting rules in Variable 2, generic richness.

20 **Variable Reserved**

21 **Sum of Mean Abundances of: *Dicrotendipes, Micropsectra, Parachironomus* and *Helobdella***

Sum the abundance of the 4 genera and divide by the number of replicates (as performed in Variable 4).

22 **Probability of Class A from First Stage Model**

Probability of Class A from First Stage Model.

23 **Relative Plecoptera Richness**

Count number of genera of Order Plecoptera, following counting rules in Variable 2, and divide by generic richness (Variable 2).

24 **Variable Reserved**

25 **Sum of Mean Abundances of *Cheumatopsyche, Cricotopus, Tanytarsus* and *Ablabesmyia***

Sum the number of individuals in each genus in all replicate samplers and divide by the number of replicates (as performed in Variable 4).

26 **Sum of Mean Abundances of *Acroneuria* and *Stenonema***

Sum the number of individuals in each genus in all replicate samplers and divide by the number of replicates (as performed in Variable 4).

27 **Variable Reserved**

28 **Ratio of EP Generic Richness**

Count the number of different genera from the order Ephemeroptera (E), and Plecoptera (P) in all replicate samplers, following counting rules in Variable 2, and divide by 14 (maximum expected for Class A).

29 **Variable Reserved**

30 **Ratio of Class A Indicator Taxa**

Count the number of Class A indicator taxa as listed in Appendix C-2 that are present in the community and divide by 7 (total possible number).

APPENDIX E
REGIONAL REFERENCE ANALYSIS

Red Brook site RB 3.961 was chosen as the reference site for this case study. The project team developed a regional reference library, as described in this appendix, to confirm that RB 3.961 is a suitable reference site.

<u>Methods</u>

The regional reference library includes Maine streams with sandy-bottoms, Class A surface water quality designations, and surficial geology similar to that of the case study streams; this translates to 23 sites from 10 different streams. The project team compared each MEDEP Linear Discriminant Function (LDF; see Appendix B of this report and Tsomides and Davies, 2002) model variable distribution associated with the regional reference library to corresponding observed measurements from the three impaired Long Creek sites, the Red Brook reference site, and five additional sites also from the two watersheds (these nine total sites were not included in the regional reference library).

A statistically significant relationship was found (Kruskal-Wallis test) between surficial geology and 3 of 23 LDF model variables: 07 Relative Chironomidae Abundance, 09 *Hydropsyche* Mean Abundance, and 16 Tanypodinae Mean Abundance. Therefore, for these three variables, the comparison with Long Creek and Red Brook sites is conducted by surficial geology type. Three surficial geology types are represented within the case study and regional reference library, primarily including Pp[10] and Pmrs[11] (type Ha[12] is the third type, located only at site RB .071); therefore, variables 07, 09, and 16 were broken down into three different analyses—Pp sites, Pmrs sites, and the combination thereof. For the remaining 20 LDF variables, we do not distinguish on the basis of surficial geology type.

Table C-1 compares 5th, 25th, 75th, and 95th percentiles of the regional reference library range to Long Creek and Red Brook site-specific values for each LDF variable. Percentiles were used for the comparison because reference stream data is not normally distributed, and many variables have a value of zero. Highlighted values fall outside the percentile range. Figures C-1 – C-30

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[10] Pp, or Presumpscot Formation, consists of fine-grained silt and clay with minor marine fossils and dropstones deposited in deeper, quiet water during the marine submergence of the coastal zone (Thompson et al., 1997).
[11] Pmrs, or Marine regressive sand deposits, consists of sand deposited in marine waters during regression of the sea from the coastal zone. Sand is commonly interbedded with fine-grained sediments of the Presumscot Formation (Thompson et al., 1997).
[12] Ha, or Stream alluvium, consists of silt, sand, and gravel, comprising modern flood plains (Thompson et al., 1997).

graphically display information from Table C-1. The table and the figures show 30 total comparisons, representing the 23 LDF model variables, three of which are further broken down by surficial geology type (Pp, Pmrs, and the combination of Pp and Pmrs).

Results and discussion

For 15 of the LDF model variables, at least one case study site falls above the 95th percentile or below the 5th percentile. These variables are usually associated with overall low abundance (4 of the 8 non-reference sites), low abundance of Plecoptera (8 of 8 non-reference sites), or absence of Class A indicator taxa (8 of 8 non-reference sites).

All sites in Long Creek have HBI values that are above the 95th percentile of the regional reference HBI value (and above the Red Brook sites). Four sites, LCN .415, LCMn 2.274, RB .071, and RB 1.474, have low total abundance. Three sites (including case study reference site RB 3.961) have Oligochaeta at a level significantly higher than the reference condition. Of the 24 reference sites, six have oligochaetes present, so the presence does not prevent sites from attaining Class A. However, oligochaetes are not dominant at any of those reference sites. All sites except the reference site in this case study (RB 3.961) have low EPT richness and no Plecoptera individuals. However, in the reference streams there are sites showing 0.33 Plecoptera (1 individual averaged over 3 rockbags). In the reference streams, there are some sites that attain Class A and have very low numbers of Plecoptera individuals per sample (Capisic 0.67, Frost Gulley 0.67, Cascade 0.67, and West Brook 0.33). Note that Plecoptera impacts multiple variables in the LDF model (12, 19, 23, 28, and minor influence on 30).

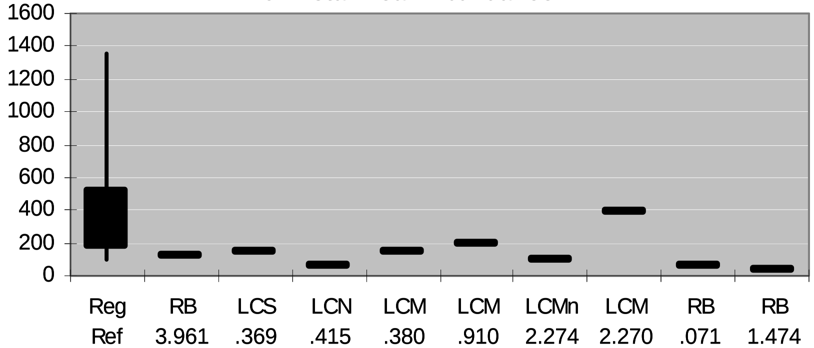
RB 3.961 represents the regional reference sites quite well. Most LDF variable values for RB 3.961 fall between the 25th and 75th percentiles of the regional reference condition. This regional reference analysis, on-site reconnaissance of the Red Brook and Long Creek watersheds, and general knowledge of the project team about Maine stream ecosystems and reference sites confirms RB 3.961 as a reasonable reference site for this case study.

Table E-1. Regional reference and case study LDF model data

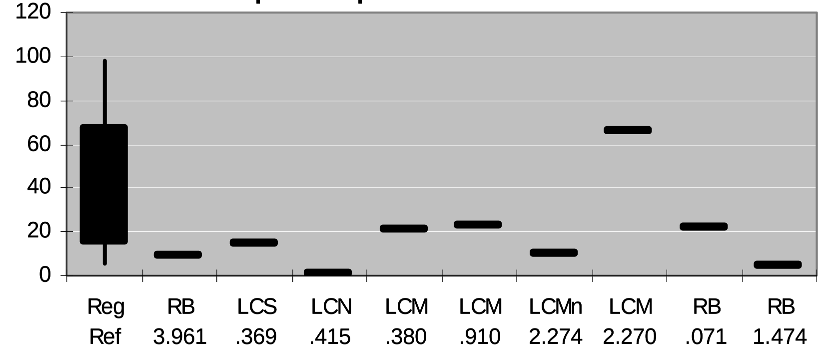
	Study site	Geology	Total Mean Abundance	Generic Richness	Plecoptera Mean Abundance	Ephemeroptera Mean Abundance	Shannon-Wiener Generic Diversity	Hilsenhoff Biotic Index (HBI)	Relative Chironomidae Abundance	Relative Chironomidae Abundance (Pp)	Relative Chironomidae Abundance (Pmrs)	Relative Diptera Richness	*Hydropsyche* Mean Abundance	*Hydropsyche* Mean Abundance (Pp)	*Hydropsyche* Mean Abundance (Pmrs)	*Cheumatopsyche* Mean Abundance	EPT - Diptera Richness Ratio	Relative Oligochaeta Abundance	Perlidae Mean Abundance	Tanypodinae Mean Abundance	Tanypodinae Mean Abundance (Pp)	Tanypodinae Mean Abundance (Pmrs)	Chironomini Mean Abundance	Relative Ephemeroptera Abundance	EPT Generic Richness	Sum of Mean Abundances of *Dicrotendipes, Micropsectra, Parachironomus, & Helobdella*	Relative Plecoptera Richness	Sum of Mean Abundances of *Cheumatopsyche, Cricotopus, Tanytarsus, & Ablabesmyia*	Sum of Mean Abundances of *Acroneuria & Stenonema*	Ratio of EP Generic Richness	Ratio of Class A Indicator Taxa	Tricoptera Richness
LDF model variable			01	02	03	04	05	06	07	07	07	08	09	09	09	11	12	13	15	16	16	16	17	18	19	21	23	25	26	28	30	
Regional reference		5th %	101.6	23.6	0.7	5.4	3.04	3.14	0.10	0.08	0.41	0.27	0.0	0.0	0.0	0.0	0.36	0.00	0.00	0.0	0.0	7.0	0.0	0.03	11.0	0.0	0.03	0.0	0.0	0.36	0.14	3.3
Regional reference		25th %	165.2	44.0	1.0	14.3	3.69	3.80	0.34	0.19	0.48	0.40	0.2	8.0	0.0	0.0	0.51	0.00	0.00	4.2	2.2	11.2	5.7	0.06	13.5	2.2	0.03	3.2	0.5	0.43	0.29	8.5
Regional reference		50th %	280.0	56.0	4.7	44.3	4.2	4.3	0.4	0.4	0.5	0.4	8.0	20.0	0.2	0.0	0.7	0.0	0.0	11.1	5.0	18.5	27.5	0.1	19.0	6.5	0.0	11.9	8.0	0.6	0.3	10.0
Regional reference		75th %	527.2	68.0	11.3	67.5	4.68	4.70	0.54	0.49	0.61	0.52	78.5	153.8	0.6	3.2	0.92	0.01	0.00	20.0	14.4	33.3	68.4	0.19	22.5	22.1	0.05	21.4	26.9	0.75	0.29	11.0
Regional reference		95th %	1354.2	74.9	37.9	97.8	4.92	5.32	0.67	0.62	0.70	0.63	421.8	531.1	17.5	68.9	2.07	0.01	1.20	39.6	27.5	50.2	180.5	0.24	24.0	50.9	0.09	79.4	61.0	0.93	0.43	13.9
Case study reference	**RB 3.961**	Pmrs	121.0	54.0	1.0	9.3	4.79	4.22	0.50		0.50	0.50	0.7		0.7	0.0	0.56	0.02	0.00	11.9		11.9	5.6	0.08	15.0	10.4	0.02	14.6	2.7	0.43	0.14	9.0
Case study impaired sites	**LCN .415**	Pp	62.7	32.0	0.0	1.3	4.00	6.64	0.34	0.34		0.38	0.0	0.0		0.0	0.50	0.01	0.00	15.3	15.3		1.0	0.02	6.0	2.3	0.00	1.3	0.0	0.14	0.00	4.0
Case study impaired sites	**LCM 2.270**	Pp	386.0	36.0	0.0	66.3	3.20	6.60	0.20	0.20		0.39	0.0	0.0		0.0	0.57	0.02	0.00	47.7	47.7		16.9	0.17	8.0	12.1	0.00	8.0	0.0	0.14	0.00	6.0
Case study impaired sites	**LCMn 2.274**	Pp	97.0	27.0	0.0	9.7	2.49	6.16	0.18	0.18		0.37	0.0	0.0		0.0	0.70	0.00	0.00	7.0	7.0		8.0	0.10	7.0	0.7	0.00	3.0	0.0	0.21	0.00	4.1
Other Long Creek & Red Brook sites	**LCS .369**	Pmrs	144.3	44.0	0.0	14.3	4.52	6.74	0.43		0.43	0.48	0.3		0.3	0.0	0.29	0.03	0.00	25.9		25.9	24.2	0.10	6.0	0.7	0.00	15.3	0.0	0.07	0.00	5.0
Other Long Creek & Red Brook sites	**LCM .380**	Pp	143.0	40.0	0.0	20.7	4.13	6.51	0.20	0.20		0.28	0.0	0.0		0.0	0.55	0.00	0.00	7.0	7.0		3.7	0.14	6.0	0.3	0.00	17.7	0.0	0.07	0.00	5.0
Other Long Creek & Red Brook sites	**LCM .910**	Pp	194.0	38.0	0.0	23.3	3.61	6.38	0.23	0.23		0.21	0.0	0.0		0.0	0.88	0.00	0.00	0.3	0.3		1.7	0.12	7.0	2.0	0.00	41.7	0.0	0.21	0.00	4.1
Other Long Creek & Red Brook sites	**RB .071**	Ha	66.3	31.0	0.0	22.0	3.53	3.64	0.30			0.32	0.0			0.0	0.90	0.00	0.00	2.3			3.7	0.33	9.0	0.0	0.00	11.3	0.0	0.29	0.14	5.0
Other Long Creek & Red Brook sites	**RB 1.474**	Pmrs	33.0	26.0	0.0	4.3	4.11	4.01	0.26		0.26	0.38	0.0		0.0	0.7	0.90	0.00	0.00	1.7		1.7	3.5	0.13	9.0	0.3	0.00	2.1	0.7	0.21	0.00	6.0

Highlighted cells fall outside 5th and 95th percentile range.

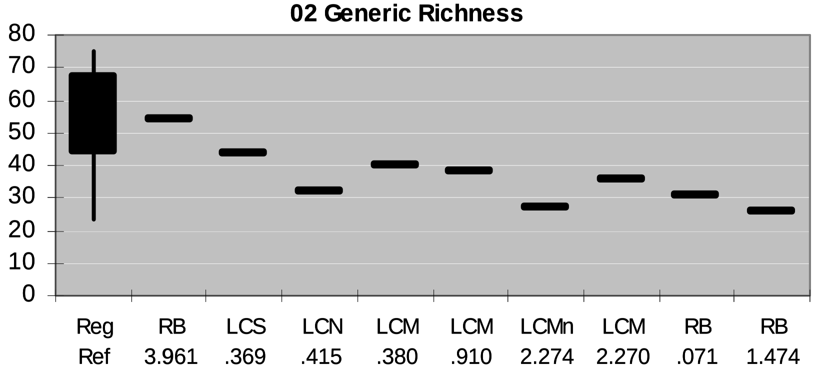
01 Total Mean Abundance



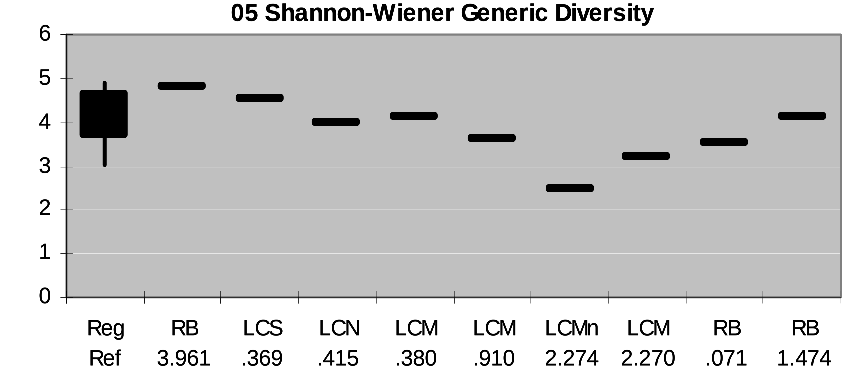
04 Ephemeroptera Mean Abundance



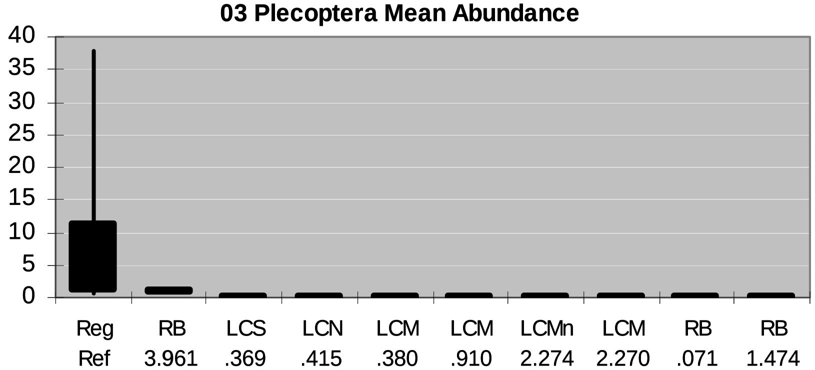
02 Generic Richness



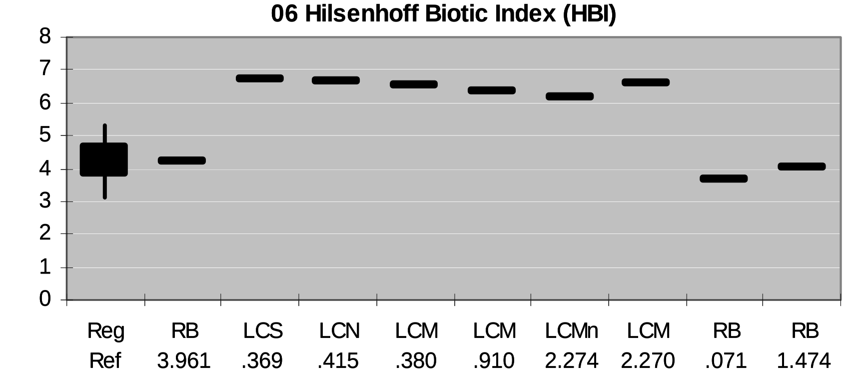
05 Shannon-Wiener Generic Diversity



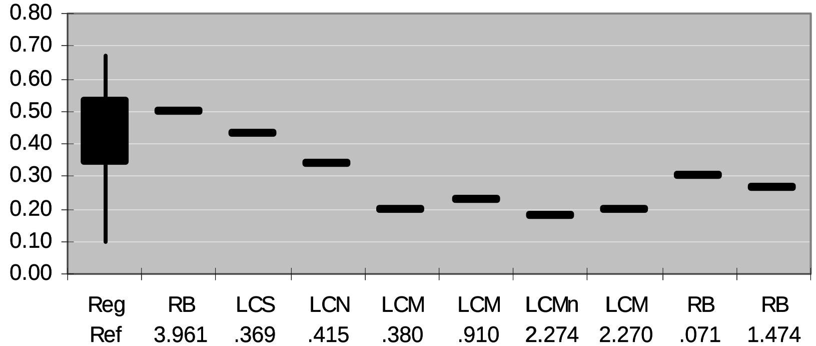
03 Plecoptera Mean Abundance



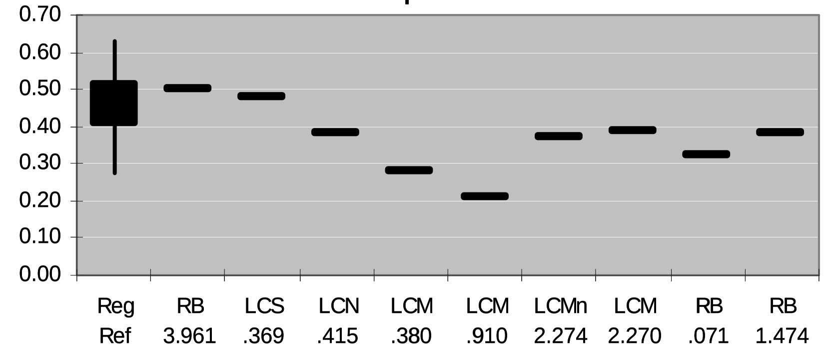
06 Hilsenhoff Biotic Index (HBI)



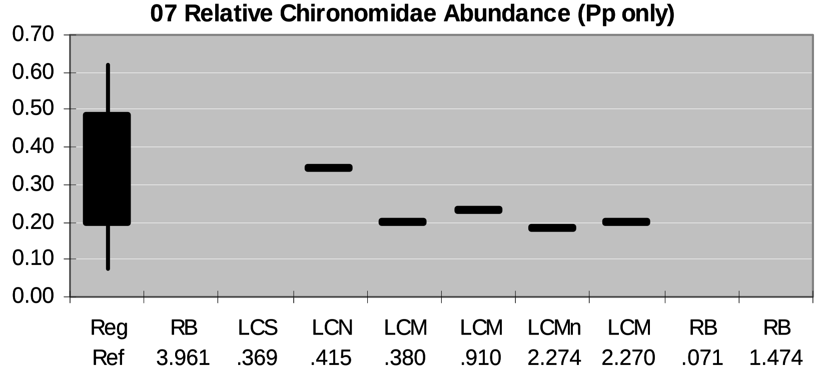
07 Relative Chironomidae Abundance



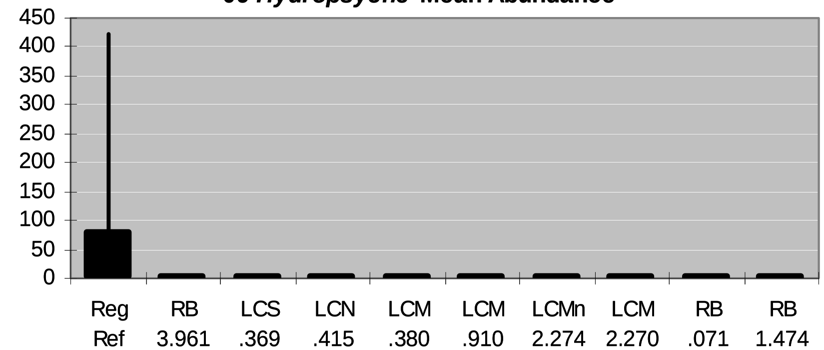
08 Relative Diptera Richness



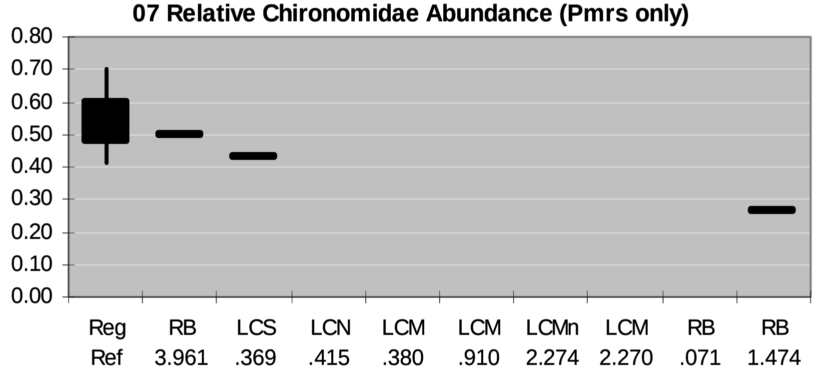
07 Relative Chironomidae Abundance (Pp only)



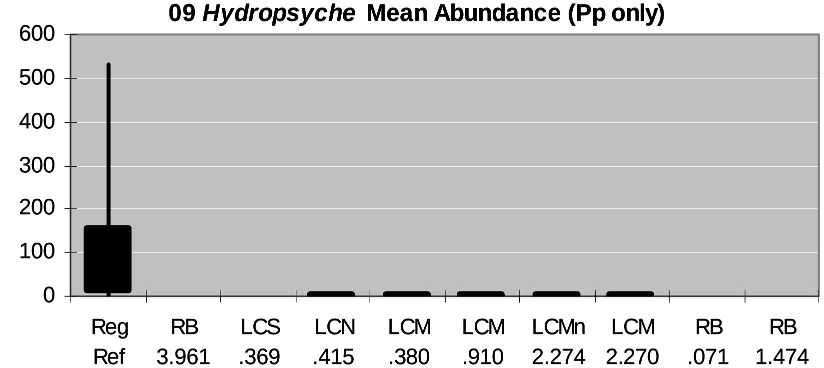
09 *Hydropsyche* Mean Abundance

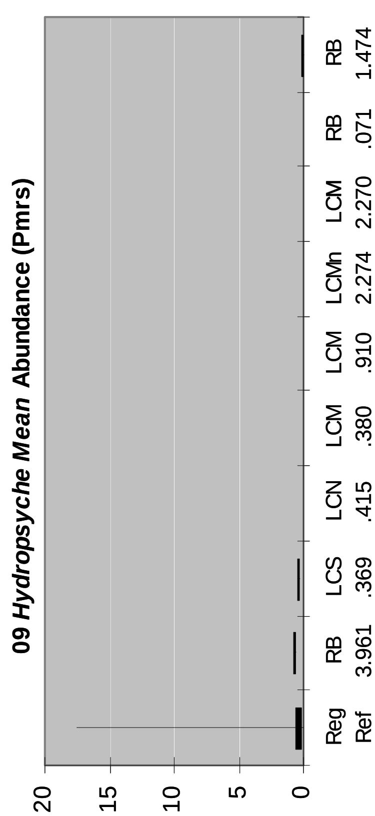


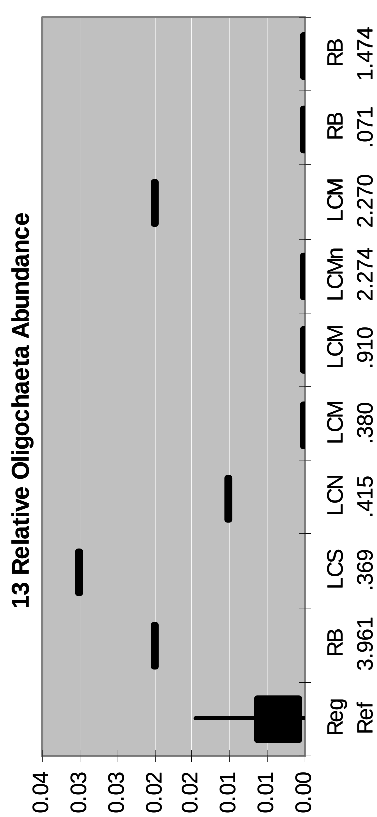
07 Relative Chironomidae Abundance (Pmrs only)

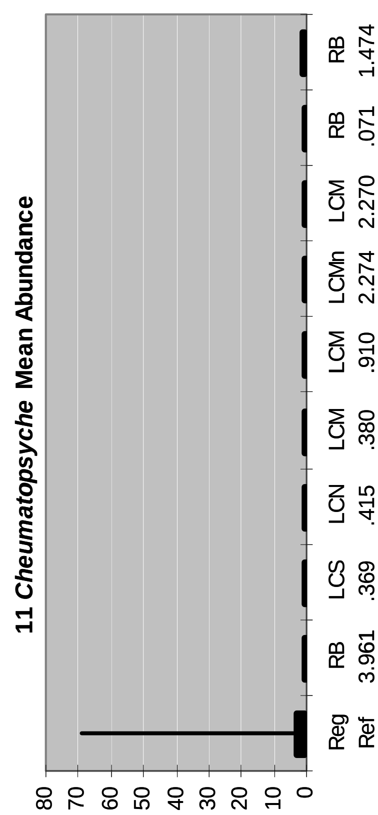


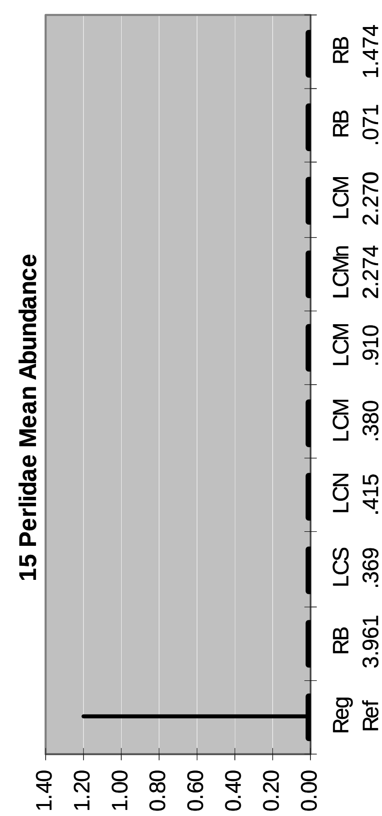
09 *Hydropsyche* Mean Abundance (Pp only)

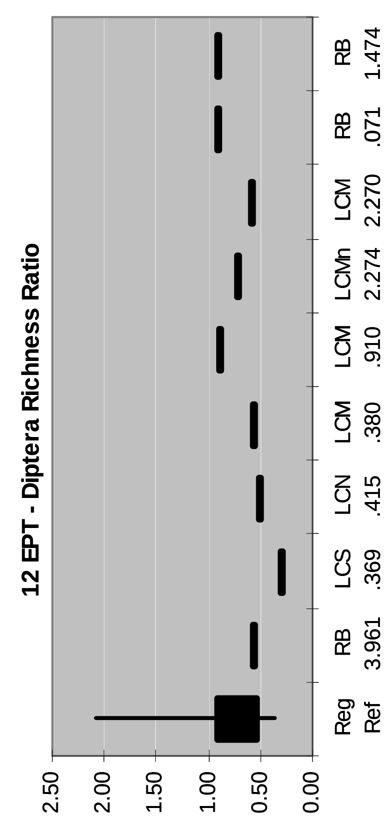


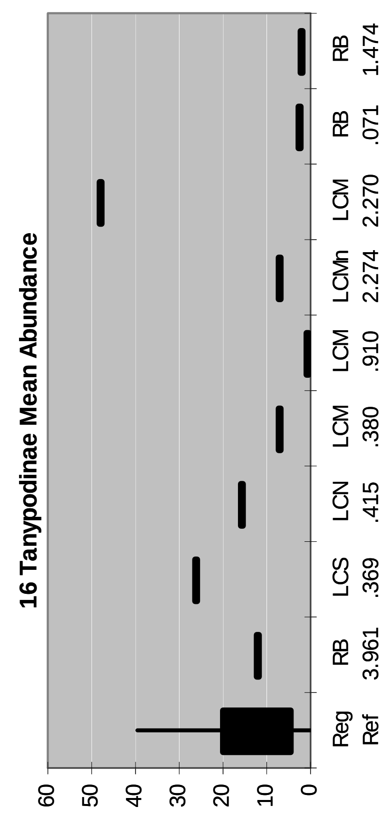

09 *Hydropsyche Mean* Abundance (Pmrs)
20
15
10
5
0
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

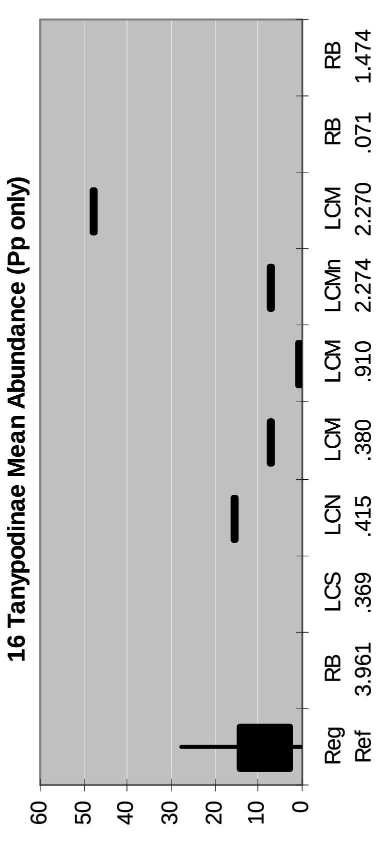

13 Relative Oligochaeta Abundance
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

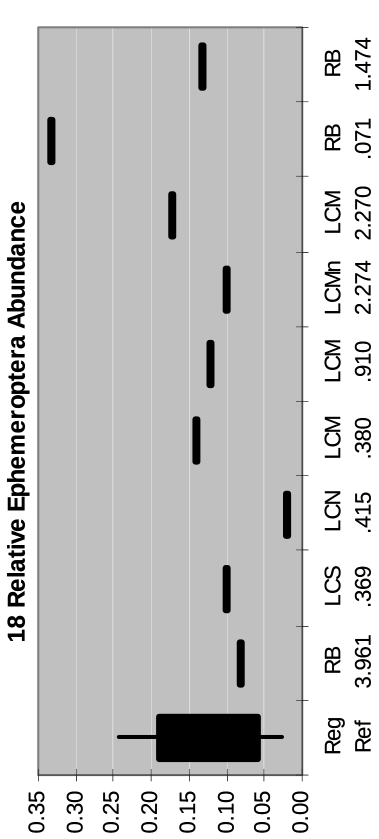

11 *Cheumatopsyche* Mean Abundance
80
70
60
50
40
30
20
10
0
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

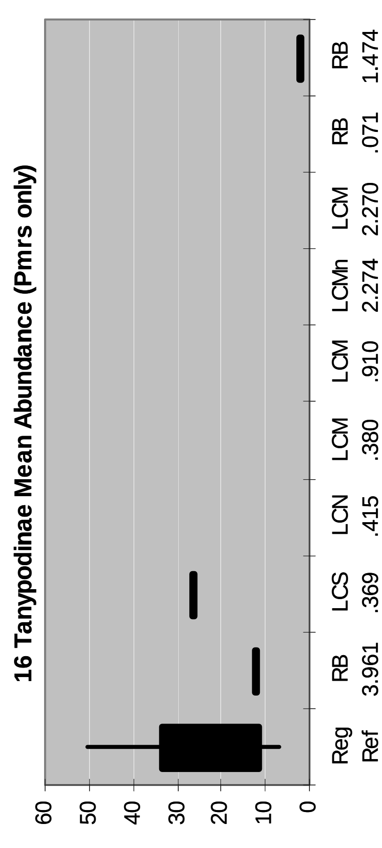

15 Perlidae Mean Abundance
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

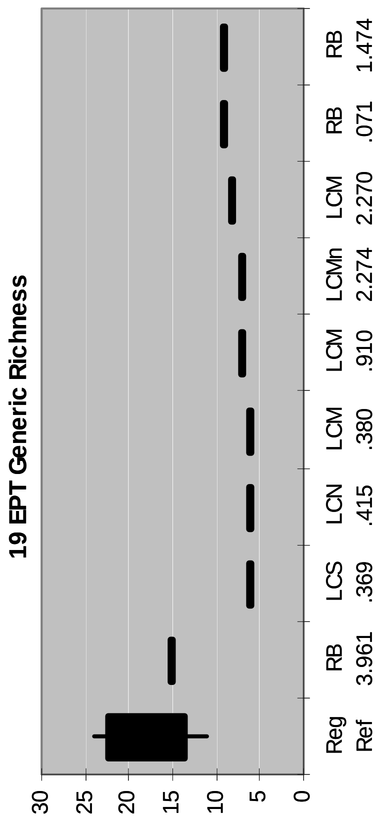

12 EPT - Diptera Richness Ratio
2.50
2.00
1.50
1.00
0.50
0.00
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

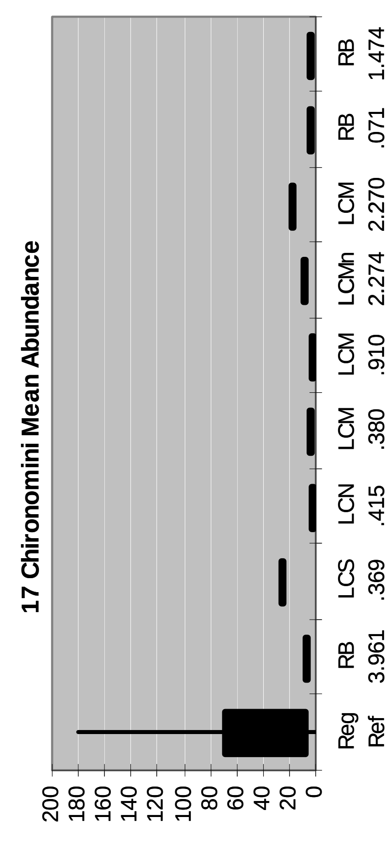

16 Tanypodinae Mean Abundance
60
50
40
30
20
10
0
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

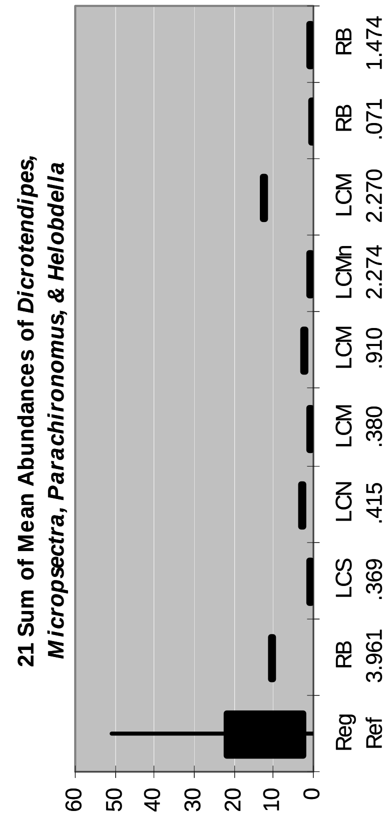

16 Tanypodinae Mean Abundance (Pp only)
0 10 20 30 40 50 60
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474


18 Relative Ephemeroptera Abundance
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

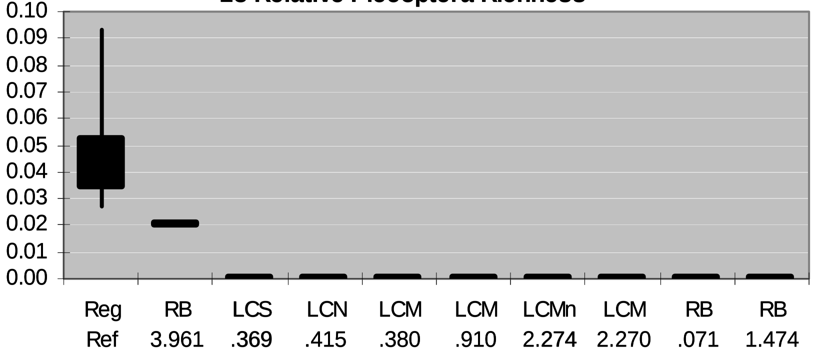

16 Tanypodinae Mean Abundance (Pmrs only)
0 10 20 30 40 50 60
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474


19 EPT Generic Richness
0 5 10 15 20 25 30
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

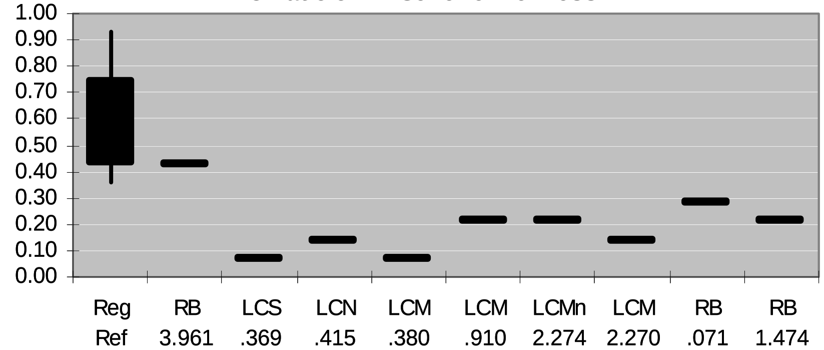

17 Chironomini Mean Abundance
0 20 40 60 80 100 120 140 160 180 200
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474


21 Sum of Mean Abundances of Dicrotendipes, Micropsectra, Parachironomus, & Helobdella
0 10 20 30 40 50 60
Reg Ref
RB 3.961
LCS .369
LCN .415
LCM .380
LCM .910
LCMn 2.274
LCM 2.270
RB .071
RB 1.474

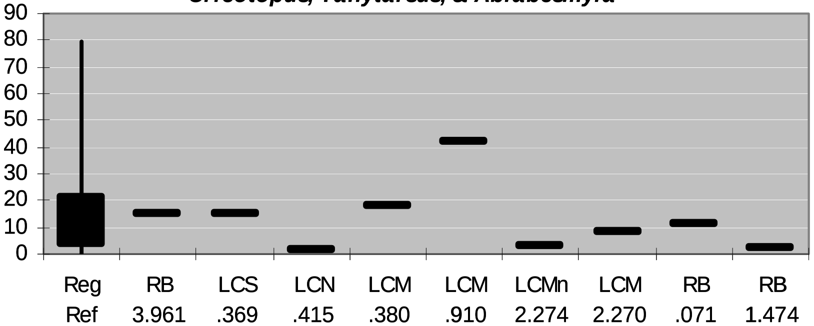
23 Relative Plecoptera Richness



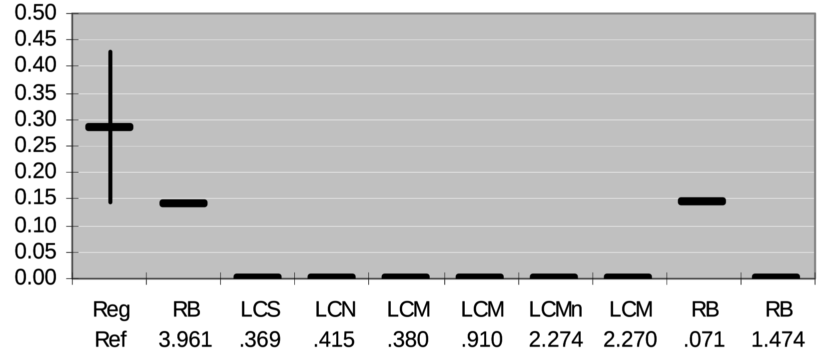
28 Ratio of EP Generic Richness



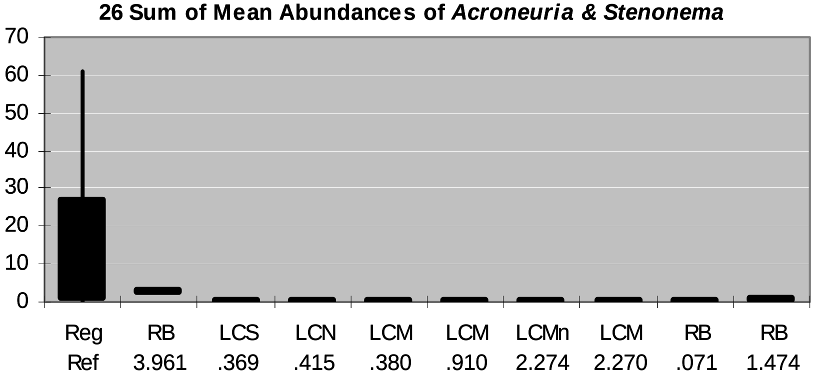
25 Sum of Mean Abundances *Cheumatopsyche, Cricotopus, Tanytarsus, & Ablabesmyia*



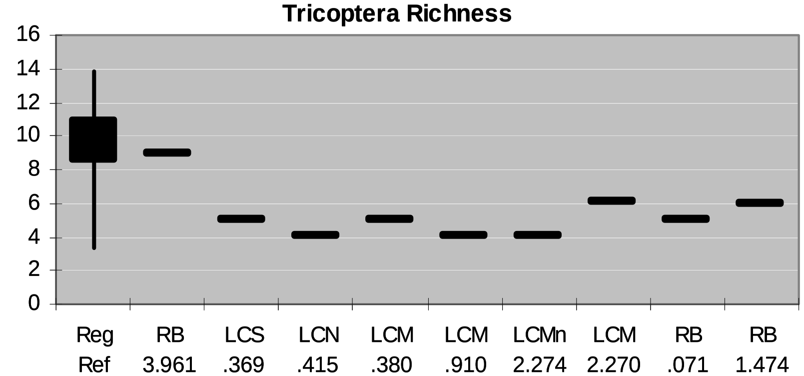
30 Ratio of Class A Indicator Taxa



26 Sum of Mean Abundances of *Acroneuria & Stenonema*



Tricoptera Richness



APPENDIX F
CAUSAL DESCRIPTIONS, BASIC INTERACTIONS, AND SOURCES

This appendix characterizes the candidate causes listed for this case study, potential interactions among causes, and sources (or anthropogenic activities) from a *general* perspective. The main text of this report discusses *specific* connections among candidate causes, including probable causal interactions occurring at the impaired study sites. This appendix frequently refers to the conceptual model figures (CM Figures 1 – 10), which precede the appendices.

Candidate cause descriptions

Candidate cause #1 – Increased autochthony (CM Figure 2)

Autochthony, or the production of organic matter within the stream itself, increases when conditions are favorable for primary producer growth. If nutrients, light, and other resources required by primary producers are abundant and physical conditions such as water velocity favor the establishment and accumulation of algae and macrophytes, then plant biomass or production is likely to increase (Mosisch et al., 2001; Biggs, 2000). Conditions favoring autochthonous production (e.g., riparian devegetation) are often simultaneously associated with reduced allochthonous inputs, or inputs of terrestrially-derived organic matter such as leaf litter and wood (Gregory et al., 1991). This shift in the dominance of autochthonous versus allochthonous organic matter may translate into a change in the basal food resources supporting stream communities.

The abundance of EPT taxa requiring allochthonous coarse particulate organic matter (e.g., shredding stoneflies and caddisflies) may decrease if basal food resources are altered as described above (Wallace et al., 1997). Some EPT taxa feed on algae and associated fine particulate organic matter; therefore, loss of shredding EPT taxa may be offset by increases in scraping or filtering EPT taxa (Feminella and Hawkins, 1995). To more fully understand food resource effects, taxa should be considered either individually or according to functional feeding groups. Non-insect taxa feeding on algae and associated fine particles (e.g., snails) may also increase. Abundance of primary producers often increases in response to elevated nutrients. Thus, HBI, which was designed to reflect organic pollution, is likely to increase with increases in autochthony. Brook trout abundance may decrease due to increased autochthony indirectly through decreases in preferred prey.

Anthropogenic activities contributing to increased autochthony for this case study include instream impoundment, lawn care and landscaping, and riparian devegetation.

Candidate cause #2 – Decreased dissolved oxygen (CM Figure 3)

Four primary pathways most likely contribute to decreased water column and/or interstitial dissolved oxygen concentrations in Long Creek: increases in water temperature, decreases in water turbulence leading to decreased aeration, changes in the balance between primary producer photosynthesis and respiration, and increases in heterotrophic respiration. Increases in water temperature result in decreased dissolved oxygen concentrations because the solubility of oxygen decreases with increasing water temperature. In addition, organism metabolism (and thus oxygen consumption) increases with increasing water temperature (Allan, 1995). Water turbulence increases aeration, which helps to incorporate atmospheric oxygen into the water column. Thus, factors reducing turbulent flow tend to reduce dissolved oxygen; these factors may include decreased large woody debris (Mutz, 2000) and decreased water velocity (Genkai-Kato et al., 2005). Increases in sediment deposition can cover and clog interstitial spaces, reducing the flow of oxygenated water into hyporheic areas (Argent and Flebbe, 1999). Increases in plant biomass and/or productivity, brought about by changing abiotic conditions (e.g., increased light and nutrients or decreased water velocity), may affect dissolved oxygen concentrations positively or negatively. Although stimulation of primary producers may lead to increased dissolved oxygen through increased photosynthesis, it also may increase dissolved oxygen consumption through increased plant respiration; this is especially true under low light conditions (i.e., on cloudy days or at night) when photosynthesis is limited (Allan, 1995). Dead plant matter also enters the organic matter pool, leading to increased heterotrophic respiration.

Reductions in dissolved oxygen concentration can asphyxiate organisms, ultimately resulting in decreases in sensitive taxa, such as mayflies (Connolly et al., 2004), stoneflies, and salmonids (Barwick et al., 2004), and increases in tolerant non-insect taxa such as oligochaetes and pulmonate snails (Peckarsky et al., 1990).

Anthropogenic activities contributing to decreased dissolved oxygen for this case study include channel alteration, instream impoundment, lawn care and landscaping, and riparian devegetation.

Candidate cause #3 – Altered flow regime (CM Figure 4)

For the purposes of this case study, altered flow regime refers to several potential hydrologic modifications, including changes in water velocity, decreases in base discharge (or baseflow), and increases in storm discharge (or stormflow). Increased and decreased water velocity can affect aquatic biota. Increases in stream discharge and water velocity may increase shear force within the channel, dislodging biota from the stream bottom. Decreases in water velocity may convert lotic environments to more lentic habitats. Decreases in baseflow may result in decreased aquatic habitat availability in terms of wetted channel width or depth and decreased habitat quality in terms of flow heterogeneity. Baseflow reductions, coupled with increased stormflows, result in increased rates and/or magnitudes of flow fluctuations within stream channels (i.e., increased flashiness). Peak discharges may be higher, occur more rapidly and frequently, and return to base discharge levels more quickly, and base discharge levels may be lower than before the flow regime was altered.

Some EPT taxa prefer running water habitats and are found on substrate surfaces in riffles. These epibenthic taxa may be more easily scoured than taxa that can burrow into sediments (e.g., oligochaetes), especially on unstable substrates (Holomuzki and Biggs, 2000). Conversion of higher water velocity areas into lower flow areas may eliminate lotic habitat. Brook trout may be impaired by decreased water velocity, as juvenile and adult salmonids require certain velocities for optimal foraging and growth (Baker and Coon, 1997).

Anthropogenic activities contributing to altered flow regime for this case study include channel alteration, impervious surfaces, instream impoundment, riparian devegetation, and watershed devegetation.

Candidate cause #4 – Decreased large woody debris (CM Figure 5)

Large woody debris provides habitat for aquatic insects and fish and creates turbulence which allows atmospheric oxygen to diffuse into the water column. Large woody debris provides stable substrate for aquatic organisms, which is especially important in low gradient systems with relatively unstable bottom sediments (Benke and Wallace, 2003; Smock et al., 1989; Benke et al., 1984). Large woody debris also can retain macroinvertebrate food resources (e.g., leaves). Some EPT taxa, particularly clingers, require stable substrates for attachment (Merritt and Cummins, 1996). In sandy-bottomed streams, large woody debris is often the only stable substrate available and may be heavily colonized by epibenthic taxa (Benke et al., 1984). Benke and Wallace (2003; a synthesis manuscript describing the significance of wood for invertebrate communities in streams and rivers) provide diverse examples of macroinvertebrate use of large woody debris: some filtering caddisflies create habitat by gouging into woody debris; filtering invertebrates may use woody debris for net building; some caddisflies use pieces of woody debris to construct their cases; and some invertebrates use wood surfaces to climb out of the water as part of the emergence process. Debris dams may provide cover and create deep water habitats for fish (Neumann and Wildman, 2002; Flebbe, 1999), and decreases in large woody debris have been correlated with reduced trout numbers (Flebbe, 1999).

Anthropogenic activities contributing to decreased large woody debris for this case study include channel alteration and riparian devegetation.

Candidate cause #5 – Increased sediment (CM Figures 6 & 7)

Increased erosion of sediments from terrestrial environments or from stream channels and banks leads to increased input of fine (< 2 mm diameter) sediment particles to stream environments. Once in the stream, this sediment can either remain suspended in the water column or become deposited on the channel bottom, depending on whether flow conditions are sufficient for mobilization. Both suspended and deposited sediment can affect aquatic biota through direct and indirect pathways, as documented in numerous reviews (e.g., Wood and Armitage, 1997; Waters, 1995). High suspended sediment concentrations may decrease the ability of visual feeders, such as brook trout, to detect prey (Sweka and Hartman, 2001a), leading to increased foraging energy expenditure (Sweka and Hartman, 2001b). Suspended sediment may reduce light penetration, which can negatively impact primary producers; in addition, low light levels may stimulate downstream drift of invertebrates (Pearson and Franklin, 1968). As sediment is deposited and streambeds become increasingly embedded, interstitial spaces are eliminated. This can reduce interstitial flow, thereby creating hypoxic conditions (see dissolved oxygen discussion above), and eliminating benthic and hyporheic habitat for aquatic invertebrates and embryonic and larval fish. Several studies have shown negative effects of sediment on EPT taxa (e.g., McClelland and Brusven, 1980) and brook trout (e.g., Argent and Flebbe, 1999; Alexander and Hansen, 1986). In contrast, certain non-insect taxa such as oligochaetes are tolerant of sedimentation (Zweig and Rabeni, 2001). Sediment deposition also may lead to increased water temperatures as pool habitats fill with sediment and deeper, cooler water refuges are eliminated. As fine sediments deposit, bed particle size and stability tend to decrease. This reduction can lead to increased dislodgement of biota, especially during storms, and this loss of biota may be exacerbated by the loss of interstitial refugia associated with increased sedimentation (Borchardt and Statzner, 1990). Shifting substrates and layers of fine deposited sediment may also bury organisms.

Anthropogenic activities contributing to increased sediment for this case study include channel alteration, impervious surfaces, instream deposits, instream impoundment, winter road sanding, salting, and plowing, riparian devegetation, and watershed devegetation.

Candidate cause #6 – Increased temperature (CM Figure 8)

Stream water temperatures can increase through three major pathways: increased warming of water within the stream channel, decreased input of cold water, and/or increased input of warm water. When more light reaches the water surface as a result of riparian devegetation, heat energy transfer to the water column increases; decreases in water velocity may exacerbate this situation by increasing retention time and thus heat transfer to a given volume of water. Slower moving water also may allow increased water loss through evaporation and/or evapotranspiration. Decreases in baseflow reduce the volume of water that must be heated to raise water temperature, making it easier to warm the system. In addition, baseflow is often determined by groundwater inputs; because these inputs tend to be colder than surface waters during summer months, reductions in baseflow originating from subsurface water sources may translate into warmer summer water temperatures. Finally, increased inputs of heated surface runoff (e.g., from impervious surfaces) can raise stream water temperatures (Paul and Meyer, 2001).

Increases in stream temperature may lead to thermal stress for biotic assemblages, resulting in increases in warm-water tolerant taxa and decreases in taxa preferring colder waters, such as stoneflies and brook trout (Lessard and Hayes, 2003). Brook trout may be especially susceptible to warmer temperatures, as they prefer water temperatures below 20°C (Picard et al., 2003; Galli and Dubose, 1990).

Anthropogenic activities contributing to increased temperature for this case study include channel alteration, detention basins, impervious surfaces, instream impoundments, riparian devegetation, and watershed devegetation.

Candidate cause #7 – Increased toxic substances (CM Figure 9)

Several types of toxic substances could cause the biological impairment observed in Long Creek, including metals, pesticides, organic contaminants, sodium chloride and/or ammonia. Increases in ionic strength may play a role, either directly (e.g., through osmoregulatory effects) or through effects on metal toxicity (Bäckström et al., 2004). Toxic inputs to Long Creek may be traced back to point and nonpoint sources (e.g., industrial effluent discharges and surface runoff from impervious surfaces, respectively). Adverse effects may include long-term chronic exposures to baseflow concentrations or more episodic acute exposures to stormflow concentrations. Stormflow concentrations may be more difficult to quantify given event frequency and variability. This candidate cause is especially complex, as organisms are likely to be exposed to multiple toxic substances simultaneously.

Some EPT taxa are considered relatively intolerant of toxic substances, while some non-insect taxa (e.g., oligochaetes) are relatively pollution-tolerant. For example, Ephemeroptera richness has been found to be a sensitive indicator of both elevated metal concentrations and elevated conductivity (Yuan and Norton, 2003).

Anthropogenic activities contributing to increased toxic substances for this case study include impervious surfaces, industrial processes, landfill leachate, lawn care and landscaping, and winter road sanding, salting, and plowing.

Basic causal interactions

Candidate causes do not act independently. Each candidate cause influences, and is influenced by, other candidate causes (CM Figure 10). In this section, we examine potential linkages among the seven candidate causes described above.

Increased temperature relates directly to decreased dissolved oxygen concentrations, as oxygen solubility decreases at warmer water temperatures while metabolic activity—and thus oxygen consumption—increases (Allan, 1995). This increase in metabolic activity can also result in greater biological uptake of toxic substances. In addition, warmer temperatures result in decreased dissociation of ammonium hydroxide, which is highly toxic to many aquatic organisms, especially fish (Wetzel, 2001). A three-way interaction occurs as decreased dissolved oxygen levels in warm water change the redox potential of toxic substances, thereby influencing the biological availability of toxics such as heavy metals (Dodds, 2002).

Increased autochthony can be linked to decreases in dissolved oxygen through the balance between photosynthesis and respiration in living plant tissue and the oxygen demand incurred from microbial respiration of decaying autochthonous plant material. Increased autochthony may also be linked to increased sediment and altered flow regimes at localized spatial scales; for example, algal mats and macrophytes can affect flow patterns by damping water velocities (Green, 2005), which can lead to increased sediment deposition and retention. This linkage goes both ways, however, as increased sediment and altered flow regime can influence primary producers. Increased sediment may attenuate light levels (thereby decreasing photosynthesis) and/or scour algae from stream bottoms. Additionally, increased water velocities and/or discharges frequently associated with altered flow regimes can cause increased scouring of algal mats.

Decreases in large woody debris can be linked to altered flow regime, increased sediment, increased temperature, decreased dissolved oxygen, and increased autochthony. Large woody debris can decrease water velocity in some areas of the channel, resulting in greater flow heterogeneity and potentially mitigating negative impacts from peak discharges. Conversely, altered flow regime may lead to diminished large woody debris accumulation, as snag habitats may be washed out by higher and more frequent storm discharges. Large woody debris accumulations often result in the creation of pools within the stream channel. Deep water habitats can serve as cool water refuges in summer months, and the loss of such refuges can exacerbate the influence of increased water temperatures, especially for coldwater fish species. Large woody debris projecting above the stream bed generates turbulence, which can increase aeration of the water column and dissolved oxygen concentrations. Increased autochthony may be indirectly affected by decreased large woody debris, as retention of allochthonous resources tends to decrease in the absence of debris dams.

Altered flow regime and increased sediment are often coupled, as flow regime may determine the extent to which fine sediments are suspended in the water column or deposited on the channel bottom. At high flows, more sediments and sediments of larger size are suspended and scoured from the stream bed; while at low flows, deposition may increase. Changes in flow regime can influence transport of toxic substances to and within the stream channel. For example, decreases in baseflow may result in decreased dilution of toxic effluents. Alteration of flow regime may result in decreased turbulence, leading to decreased dissolved oxygen concentrations.

Increased sediment may be associated with increased toxic substances and/or increased autochthony, as both pollutants and nutrients (especially phosphorus) can adsorb to sediment particles (House, 2003; Laws, 1993). Adsorption may limit bioavailability of toxic substances and nutrients to water column taxa but may also result in higher exposures for sediment-dwelling taxa (Laws, 1993). Decreases in water depth associated with increased sediment deposition may result in warmer stream temperatures. Sediment clogging of interstitial spaces may reduce interstitial flow and contribute to hypoxic conditions in hyporheic areas (Greig et al., 2005).

Sources or anthropogenic activities

<u>Channel alteration</u>

Stream channel geomorphologic changes often occur in conjunction with factors affecting stream discharge and sediment supply (e.g., watershed infiltration rates, riparian devegetation, and watershed devegetation). Direct alteration of channel configuration can be a source of stress to aquatic systems. In this case study, human-induced channel alteration primarily takes the form of road culverts, floodplain fill, and stream relocation. Culverts and similar instream structures may create unfavorable and/or artificial instream transitions whereby piped, often confined, stream sections with low roughness lead to and from less altered sections of stream channel. As a result, high velocity flows exiting culverts may scour out pools. A culvert may also act as a check dam or grade control structure, creating pond-like conditions upstream. Upstream and downstream pond-like conditions may lead to increased water temperature. Culverts sized for maximum stormflows physically separate the channel from the original local floodplain. Culverts may also act as a physical barrier by way of elevated velocities or direct impediment of, for example, migrating fish. Artificial floodplain fill (e.g., carting in fill material for urban development on the floodplain) may restrict overbank flows, increase channel velocity, increase erosion (especially when inappropriate fill material is used or fill material is inadequately compacted), decrease floodplain habitat and wetted stream area, and lead to channel incision (i.e., narrowing and deepening of the stream channel). Water velocities in narrow, simplified channels may be increased (Sweeney et al., 2004), and high-energy stormflow may remain within incised channels, potentially causing increased erosion and reduced bank stability (Paul and Meyer, 2001). Large woody debris may also wash out of a simplified channel system more quickly. Stream relocation may increase erosion as banks are left unprotected and unsupported by vegetation. The physical act of relocating a stream (grading, construction, etc.) often increases sediment loading. After a stream is relocated, and often confined, the stream may attempt to meander, seeking more stable locations, causing additional sediment loading.

Detention basins

For the purposes of this case study, the term "detention basins" refers to all water containment features, natural or engineered, offset from the original stream channel, regardless of outflow characteristics (that is, temporary or longer retention times). Detention basins are often designed to mitigate the impacts of peak stormflows, thereby altering flow regimes. Detention basins with extended retention times (commonly referred to as retention basins) may allow the opportunity for water temperatures to rise. Furthermore, basins designed for indefinite retention may withhold water from groundwater and subsurface flows, potentially altering baseflow dynamics.

Impervious surfaces

Impervious surfaces (e.g., roads, parking lots, sidewalks, roofs, and compacted soils) impact watershed hydrology by altering runoff spatially and temporally (see Center for Watershed Protection, 2003 and Paul and Meyer, 2001 for reviews of impervious surface effects on aquatic systems). Impervious surfaces prevent precipitation from infiltrating soils, thereby increasing storm runoff volume and peak discharge. Impervious surfaces generally have higher thermal conductivity than surrounding areas and can elevate the temperature of surface runoff. Impervious surface runoff may contain higher concentrations of substances associated with vehicle use and related human activities (e.g., metals and polycyclic aromatic hydrocarbons), as these chemicals generally accumulate on impervious surfaces. Reduced infiltration resulting from increased impervious surface can lead to decreased groundwater recharge and decreased stream flow dependent on sub-surface inputs.

Industrial processes

Waste products from industrial processes may contain a variety of toxic substances including heavy metals and organic compounds. Waste material may reach surface water through direct discharge or non-point sources, such as impervious surface runoff.

Instream deposits

Sediment sources within the stream channel comprise potential instream sediment deposits. Instream sources can also serve as a source of downstream sediment deposition, often in association with impervious surface area and urbanization (Trimble, 1997).

Instream impoundment

Instream impoundments generally decrease flow velocity, increase water residence time, and potentially transform lotic environments into lentic ecosystems. Impoundments may create low-lying saturated areas with altered vegetation, thereby decreasing the number of trees and associated canopy shade. Impoundment may increase water temperature and evaporation and evapotranspiration rates.

Landfill leachate

Toxic compounds associated with waste deposited in landfills can be mobilized when surface or subsurface water percolates through landfill areas. Leachate can enter aquatic systems downstream of landfills, leading to contamination and biological impairment (Noaksson et al., 2003; Dickman and Rygiel, 1998).

Lawn care and landscaping

This activity refers to the care of golf courses, residential lawns, and similar vegetated/manicured areas demanding fertilizers, pesticides, and/or irrigation for continued upkeep. Fertilizer may reach streams through surface runoff or subsurface movement, and may introduce additional nutrients (e.g., phosphorus and nitrogen) to stream channels (Groffman et al., 2004; King et al., 2001; Barth, 1995). Pesticides enter surface water through similar pathways (Phillips et al., 2002; Crawford, 2001; Schueler, 1995). Irrigation may impact baseflow characteristics by increasing low flows between storms.

Riparian devegetation

Removal of vegetation such as trees, bushes, and grasses from streamside areas impacts riparian ecosystems in several ways. Riparian devegetation reduces canopy cover over the stream channel, potentially increasing the amount of light reaching the stream and thus light levels and water temperatures (Ebersole et al., 2003; Poole and Berman, 2001). Allochthonous organic matter inputs to stream channels decrease (Angradi et al., 2004; Scarsbrook et al., 2001) as availability of leaf litter and large woody debris decrease due to removal of streamside vegetation. Riparian vegetation and its associated root network protect stream banks from collapse and erosion. Stream bank vegetation often absorbs the forces of erosive flows, further stabilizing banks.

Watershed devegetation

Watershed devegetation refers to the removal of trees, bushes, and other plants from areas within the watershed not immediately adjacent to the stream channel. Watershed vegetation removal may result in several changes that affect aquatic systems. Devegetated soils are prone to compaction (see impervious surfaces above), leading to reduced infiltration and increased surface runoff during subsequent storms. Reduced vegetation can translate into less vegetative uptake of water, further increasing surface and subsurface runoff. Devegetated land surfaces absorb more heat, resulting in elevated surface runoff temperatures during storm events (Center for Watershed Protection, 2003).

Winter sanding, salting, and plowing

Winter maintenance activities include sanding, salting, deicing, and snow plowing and disposal for areas such as roads, parking lots, and airport runways. Road sanding can result in direct inputs of sand into stream systems when applied sand is washed from roads with surface runoff. Road salting may similarly lead to direct inputs of sodium and calcium chloride and toxic substances associated with deicing chemicals or salt/abrasive mixtures (Anderson et al., 2000). Snow plowed from impervious areas may include sand, salt, and other potentially toxic substances associated with impervious surfaces; subsequent disposal of plowed snow by direct dumping into streams or disposal in areas near stream banks may increase the potential for surface water contamination.

APPENDIX G
MEASURED VARIABLES

Measured Variable	Source		Applicable Sites	Description & Comments
	Citation	Location		
aquatic vegetation	MEDEP, 2002a	Table 3.6.3	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	dominant aquatic vegetation estimated visually as a percent of the reach in the vicinity of the site; observations made by MEDEP from 9/22/1999 to 9/26/1999
baseflow discharge	MEDEP, 2002a	Figure 3.5.10	LCN .415 RB 3.961	baseflow discharge was measured by MEDEP on 8/19/2000 & 9/18/2000, then divided by watershed area (cfs/ac); surrogate site LCN .585 was used to represent LCN .415
baseflow thalweg velocity	MEDEP, 2002a	Table 3.6.1	LCMn 2.274 RB 3.961	thalweg baseflow velocities taken at 2m intervals for 200m stretch of the reach in the vicinity of the site; MEDEP estimated velocity by observing floating organic debris during low flow or baseflow conditions 8/5/1999 - 8/6/1999
canopy shade	MEDEP, 2002a	Table 3.6.4	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	canopy shade was quantified as an average percent based on three visual estimates of riparian zone condition--taken upstream, downstream, & mid-stream--in the vicinity of biological monitoring rockbag sample locations; observations made by MEDEP from 9/22/1999 to 9/26/1999
chlorophyll *a*	MEDEP, 2002a	Figure 3.2.1	LCN .415 LCMn 2.274 RB 3.961	chlorophyll *a* measurements taken at surrogate sites LCN .585, LCMn 2.714, & RB 2.790; these apply to sites LCN .415, LCMn 2.274, & RB 3.961, respectively; surrogate sites represent open-canopy sections of the streams; MEDEP collected data in June & July, 2000
large woody debris count	MEDEP, 2002a	Table 3.6.9	LCM 2.270 LCMn 2.274 RB 3.961	woody debris pieces, categorized as above 5 cm and 10 cm in diameter, were counted for stream sites; surrogate site RB 3.500 was used to represent RB 3.961; MEDEP collected data between 11/19/2002 & 12/6/2002
muck mud	MEDEP, 2002a	Table 3.6.4	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	muck mud (defined as black, very fine organic, FPOM) was quantified as a percent of the total organic substrate components at the site based on visual estimation; observations made by MEDEP from 9/22/1999 to 9/26/1999
Pfankuch rating	MEDEP, 2002a	Table 3.7.2	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	surrogate site LCN .404 was used to represent LCN .415; MEDEP collected data between 10/19/2000 & 11/3/2000
percent impervious surface	MEDEP, 2002a	Table 3.1.2	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	MEDEP estimated percent impervious surface using USGS topographic maps (circa 1970's & 1980's) and 1995 aerial photographs

Measured Variable	Source		Applicable Sites	Description & Comments
	Citation	Location		
Rapid Bioassessment Protocol (RBP) scores	MEDEP, 2002a	Table 3.6.8	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	RBP scores taken by MEDEP on 10/11/1999 & 10/12/1999; numeric RBP scores converted to qualitative condition scores for use in analyses herein
sediment chemistry, 1993	South Portland Engineering Dept, 1994	Appendix C	NA	sediment samples tested for cadmium, copper, lead, nickel, & zinc; samples collected by MEDEP on 10/31/1993; sampled at Long Creek & Red Brook just U/S of Clark's Pond; surrogate site representation not established--i.e., this data was used to generalize differences between the two study watersheds
sediment chemistry, 2003	U.S. EPA, 2004a	laboratory report	LCN .415 LCMn 2.274 RB 3.961	sediment samples tested for antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, thallium, vanadium, & zinc; samples collected by MEDEP 10/10/2003 & analyzed by U.S. EPA 10/24/2003
sediment size	MEDEP, 2002a	Appendix G	LCN .415 LCMn 2.274 RB 3.961	pebble counts conducted by size; surrogate sites LCN .595 & LCM 2.896 were used to represent LCN .415 & LCM 2.270, respectively; MEDEP collected data throughout 2000
sediment toxicity, 2003	US EPA, 2004a	toxicity study	LCN .415 LCMn 2.274 RB 3.961	toxicity tests were conducted for stream site sediment samples (see above, U.S. EPA 2004a) on survival & growth of *C. tentans* (chironomid) & *H. azteca* (amphipod) 10/24/2003
stormflow event, 1994	South Portland Engineering Dept, 1994	report text & Appendix F	NA	precipitation & stream flow data for storm event on 8/18/1994, for locations on Long Creek & Red Brook just U/S of Clark's Pond; surrogate site representation not established--i.e., this data was used to generalize differences between the two study watersheds
stormflow event, 2001	MEDEP staff, 2005	received as spreadsheet	LCN .415 RB 3.961	storm hydrograph produced by MEDEP for 9/25/2001 event; surrogate site RB 1.694 was used to represent RB 3.961
temperature: weekly minimum, maximum, & mean	MEDEP staff, 2005	received as spreadsheet	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	weekly minimum, maximum, & mean from several weeks in August of 1999; RB 3.961 & LCN .415 include 3 simultaneous weeks of measurements ending 8/7/1999, 8/14/1999, & 8/21/1999; RB 3.961, LCM 2.270, & LCMn 2.274 include 1 week of simultaneous measurements ending 8/21/1999; all measurements made by MEDEP
water chemistry, 1992 (baseflow)	South Portland Engineering Dept, 1994	Appendix A	NA	baseflow sampling for lead, copper, & zinc conducted on 10/5/1992; sampled at Long Creek & Red Brook just U/S of Clark's Pond; surrogate site representation not established--i.e., this data was used to generalize differences between the two study watersheds

Measured Variable	Source		Applicable Sites	Description & Comments
	Citation	Location		
water chemistry, 1994 (stormflow)	South Portland Engineering Dept, 1994	Appendix E	NA	stormflow sampling for copper, lead, zinc, & TSS; samples during storm event on 8/18/1994; sampled at Long Creek & Red Brook just U/S of Clark's Pond; surrogate site representation not established--i.e., this data was used to generalize differences between the two study watersheds
water chemistry, 2000 & 2001 (stormflow)	MEDEP, 2002a	Appendix C, Tables 1a - 1c	LCN .415 RB 3.961	stormflow sampling for cadmium, copper, lead, nickel, zinc, total phosphorous, ortho-phosphorous, total Kjeldahl nitrogen, nitrate (NO2), nitrite (NO3), chloride, & TSS; three samples were taken by MEDEP during each of three storm events (nine total) on 3/28/2000, 10/18/2000, & 9/25/2001; surrogate sites LCN .585 & RB 1.694 used to represent LCN .415 & RB 3.961, respectively
water chemistry, 2000 (baseflow)	MEDEP, 2002a	Appendix C, Tables 2a - 2c	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	baseflow sampling for cadmium, copper, lead, nickel, zinc, total phosphorous, ortho-phosphorous, total Kjeldahl nitrogen, nitrate (NO2), nitrite (NO3), chloride, & TSS, conducted by MEDEP on three days: 8/6/2000, 8/23/2000, & 9/19/2000; surrogate site LCN .585 was used to represent LCN .415
water chemistry, PAHs, 2000 (stormflow)	U.S. EPA, 2000a	laboratory report	LCN .415 RB 3.961	stormflow sampling for polycyclic aromatic hydrocarbons (PAHs); samples collected by MEDEP 10/23/2003 & analyzed by U.S. EPA 10/28/2003. surrogate sites LCN .585 & RB 1.694 used to represent LCN .415 & RB 3.961, respectively
water chemistry, PAHs, 2001 (stormflow)	U.S. EPA, 2001	laboratory report	LCN .415 RB 3.961	stormflow sampling for polycyclic aromatic hydrocarbons (PAHs); samples collected by MEDEP 9/25/2001 & analyzed by U.S. EPA 10/19/2003. surrogate sites LCN .585 & RB 1.694 used to represent LCN .415 & RB 3.961, respectively
water chemistry, 2003 (low flow)	U.S. EPA, 2004a	laboratory report	LCN .415 LCMn 2.274 RB 3.961	low flow water samples tested for aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, silver, thallium, vanadium, & zinc; samples collected by MEDEP 10/10/2003 & analyzed by U.S. EPA 10/21/2003
water quality, 2000 (baseflow)	MEDEP, 2002a	Appendix C, Tables 3a & 3b	LCN .415 LCM 2.270 LCMn 2.274 RB 3.961	three early morning (5:00am - 7:00am) low flow, single point, water quality samples taken by MEDEP for dissolved oxygen, specific conductivity, & salinity on 6/15/2000, 9/1/2000, & 9/30/2000; measurements taken approximately 10 cm above stream bottom; note that the YSI model 85 field meter used to take measurements calculates salinity secondarily using measured conductivity; surrogate site LCN .585 was used to represent LCN .415

APPENDIX H
SCATTER PLOTS (S-R FROM THE FIELD)

Scatter plots were developed using data presented in the MEDEP (2002a) Long Creek and Red Brook final report. The project team developed plots for variables with at least five study sites. All water quality and chemistry data represent water column baseflow averages. The following table shows the variables plotted and the project team's interpretation—that is, whether the variables appear to correlate with any of three biological endpoints analyzed: EPT richness, percent non-insects, and/or HBI. Boxes were placed around scatter plots indicating a potential correlation, according to project team interpretation. A table of statistical correlation coefficients follows the scatter plot figures. Coefficients supplemented visual interpretation of the actual plots, when determining whether to list an endpoint correlation in the table immediately below.

	Scatter plot variable	**Correlation interpretation**
Figure H-1	Total Kjeldahl nitrogen	HBI
Figure H-2	Nitrate + nitrite	
Figure H-3	Total phosphorus	HBI
Figure H-4	Ortho phosphorus	HBI
Figure H-5	Aquatic vegetation (including diatoms)	
Figure H-6	Aquatic vegetation (macroalgae/phytes only)	
Figure H-7	Dissolved oxygen saturation	HBI
Figure H-8	Dissolved oxygen concentration	HBI
Figure H-9	Large woody debris with diameter $\geq$ 5 cm	EPT richness, HBI (low n)
Figure H-10	Large woody debris with diameter $\geq$ 10 cm	EPT richness, HBI (low n)
Figure H-11	D50 substrate particle size	
Figure H-12	Pfankuch bank stability	
Figure H-13	Temperature, weekly minimum	
Figure H-14	Temperature, weekly maximum	HBI
Figure H-15	Temperature, weekly mean	
Figure H-16	Canopy shade	
Figure H-17	Zinc	
Figure H-18	Chloride	EPT richness, % non-insects, HBI
Figure H-19	Specific conductivity	EPT richness, % non-insects, HBI
Figure H-20	Impervious surface area	EPT richness
Figure H-21	RBP epifaunal substrate / available cover	
Figure H-22	RBP pool substrate characterization	HBI
Figure H-23	RBP pool variability	
Figure H-24	RBP sediment deposition	
Figure H-25	RBP channel flow status	
Figure H-26	RBP channel alteration	
Figure H-27	RBP channel sinuosity	EPT richness
Figure H-28	RBP bank stability	
Figure H-29	RBP bank vegetative protection	
Figure H-30	RBP riparian vegetative zone width	

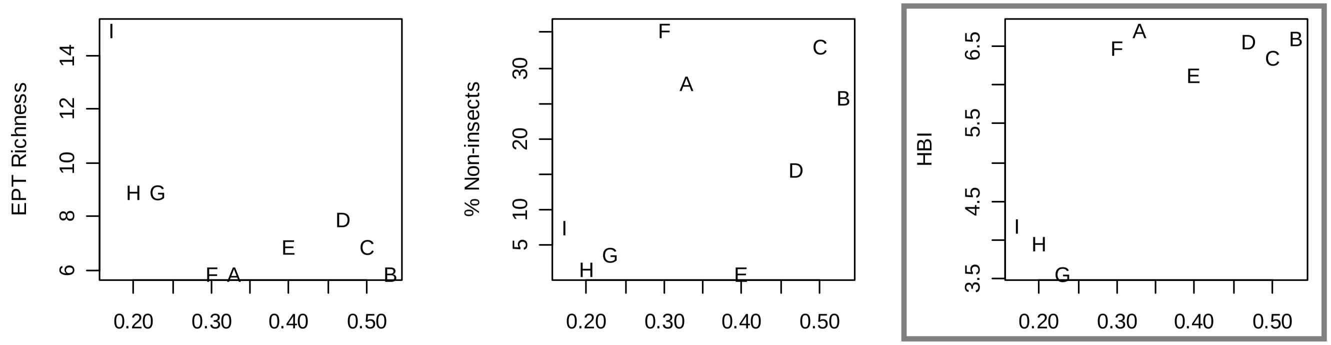


Figure H-1. Total Kjeldahl nitrogen, mg/L

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

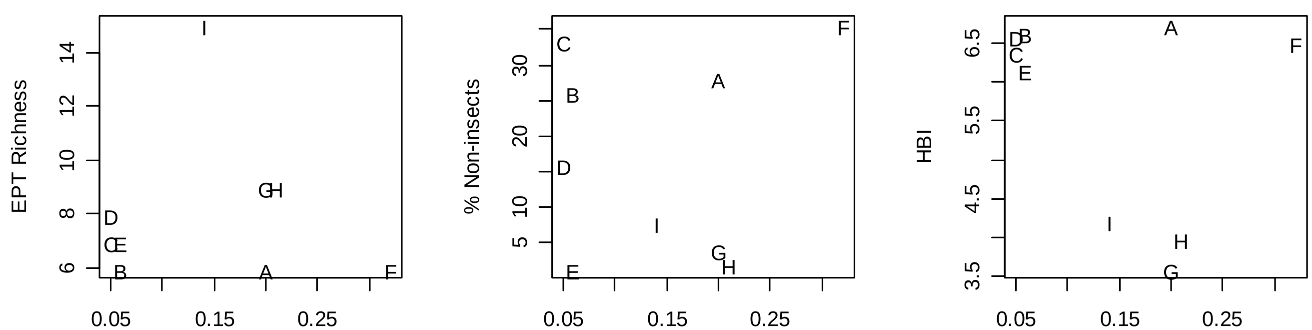


Figure H-2. Nitrate + nitrite, mg/L

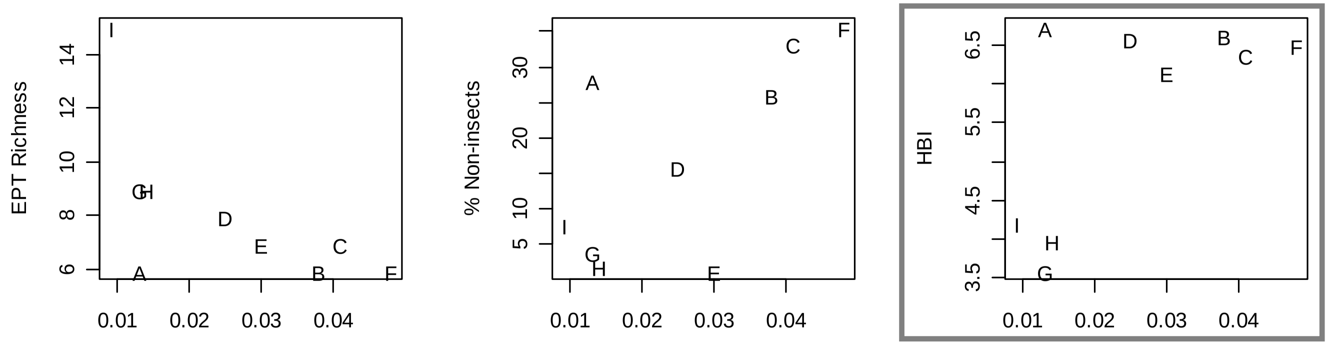


Figure H-3. Total phosphorus, mg/L

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

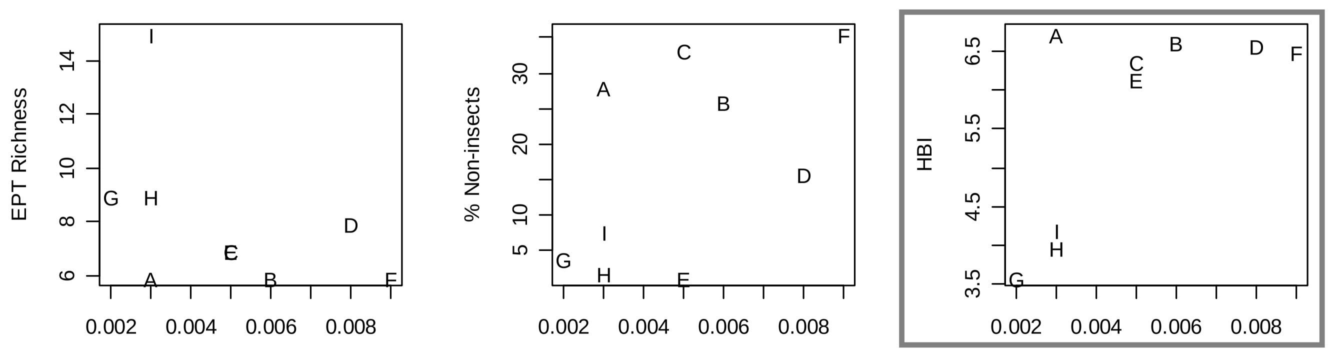


Figure H-4. Ortho phosphorus, mg/L

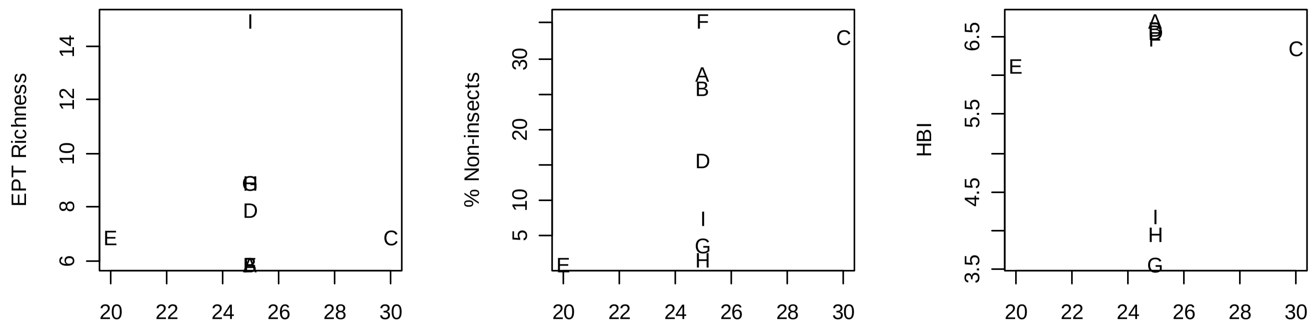


Figure H-5. Aquatic vegetation, % of local reach (including diatoms)

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

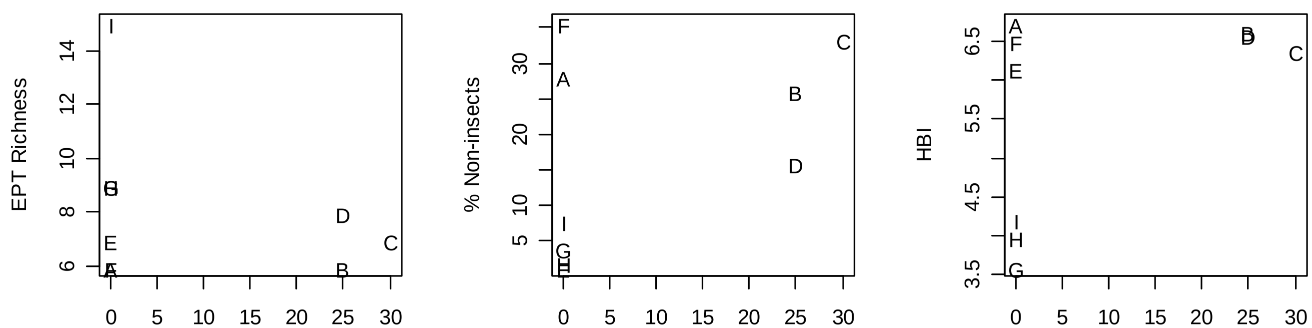


Figure H-6. Aquatic vegetation, % of local reach (macroalgae & macrophytes only)

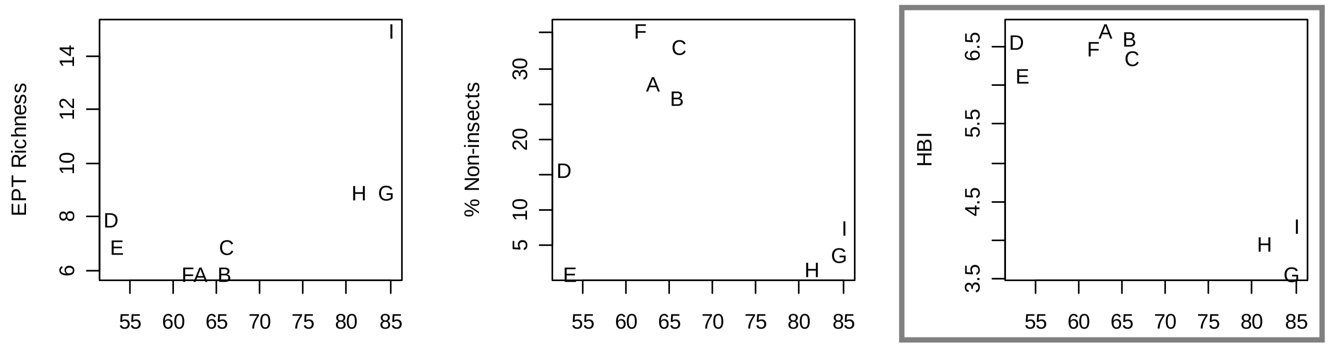


Figure H-7. Dissolved oxygen saturation, %

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

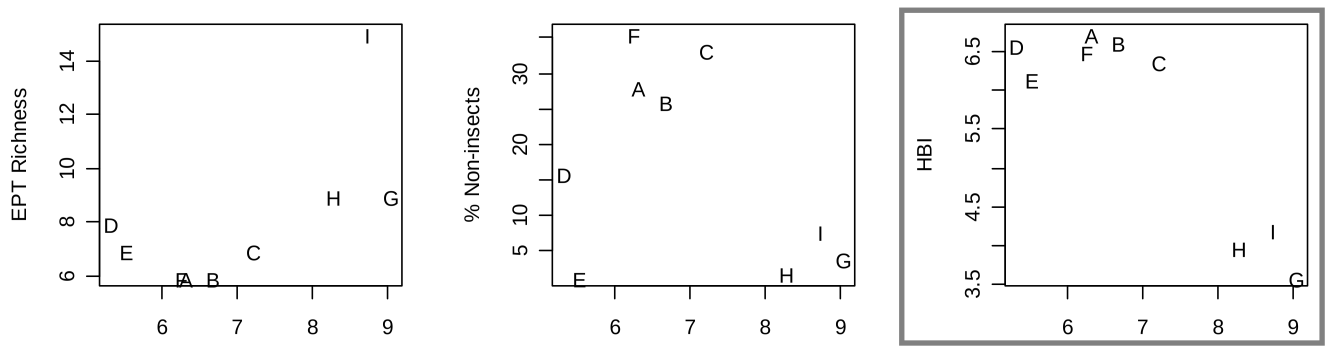


Figure H-8. Dissolved oxygen concentration, mg/L

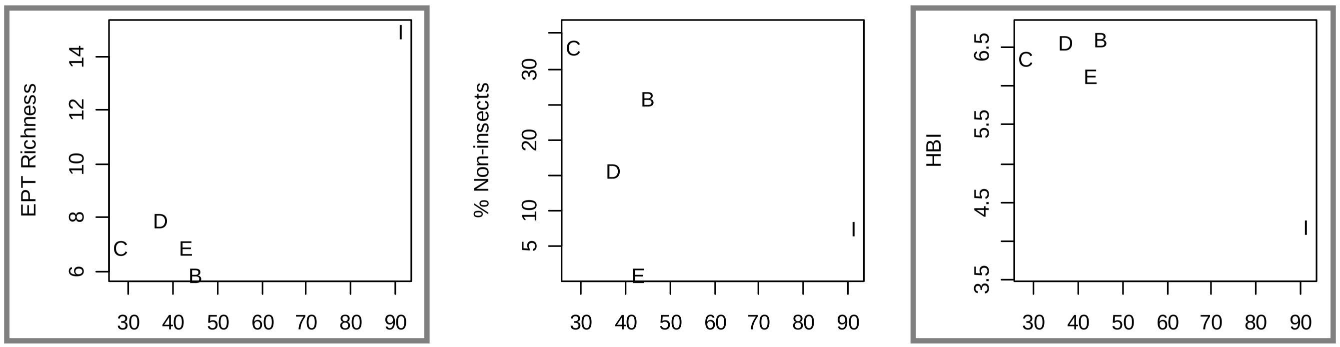


Figure H-9. Large woody debris, # of pieces with diameter ≥ 5 cm

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

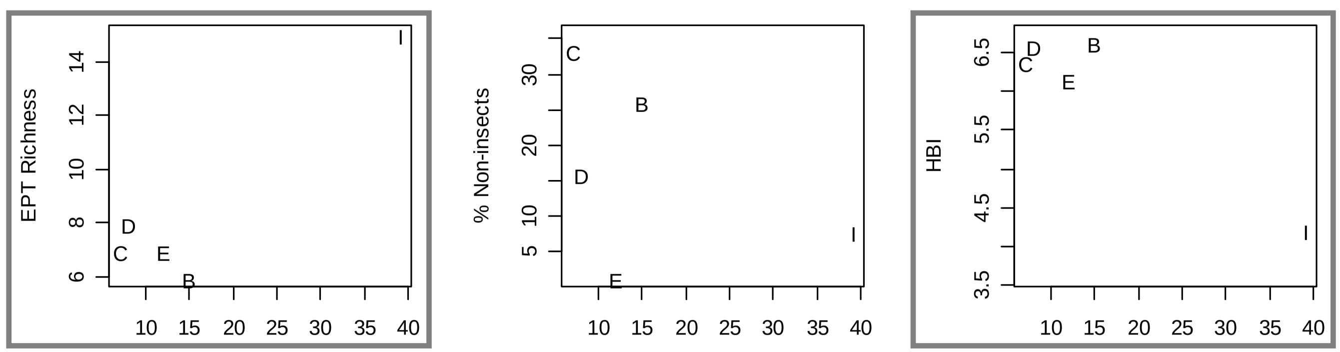


Figure H-10. Large woody debris, # of pieces with diameter ≥ 10 cm

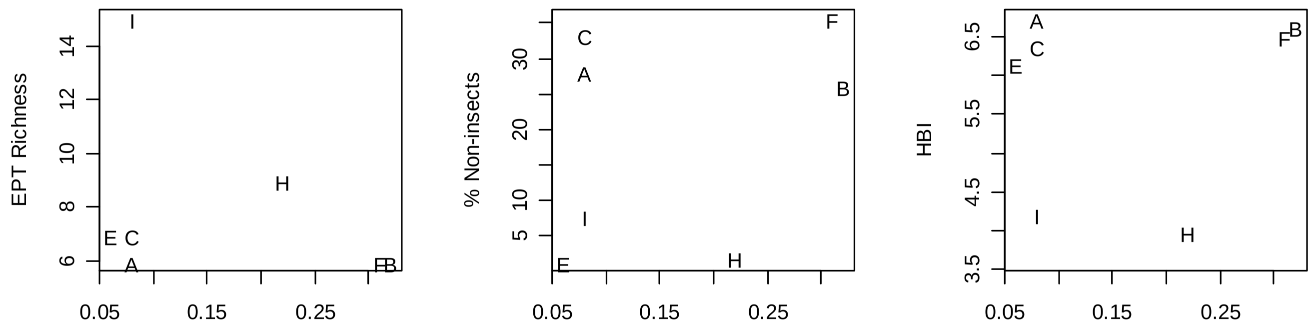


Figure H-11. D50 substrate particle size, mm

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

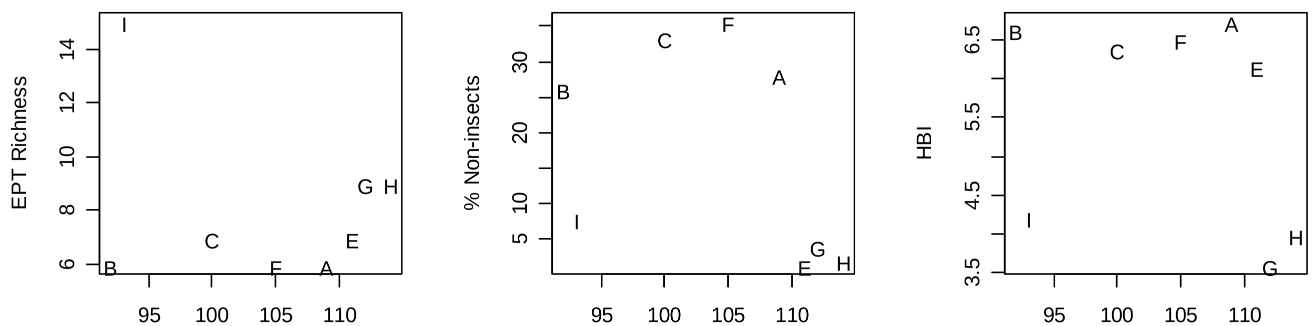


Figure H-12. Pfankuch bank stability score

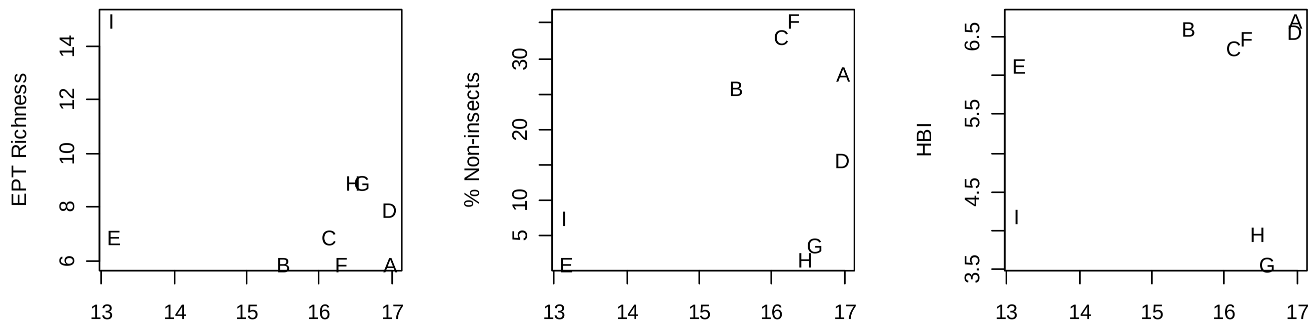


Figure H-13. Temperature, weekly minimum, C°

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

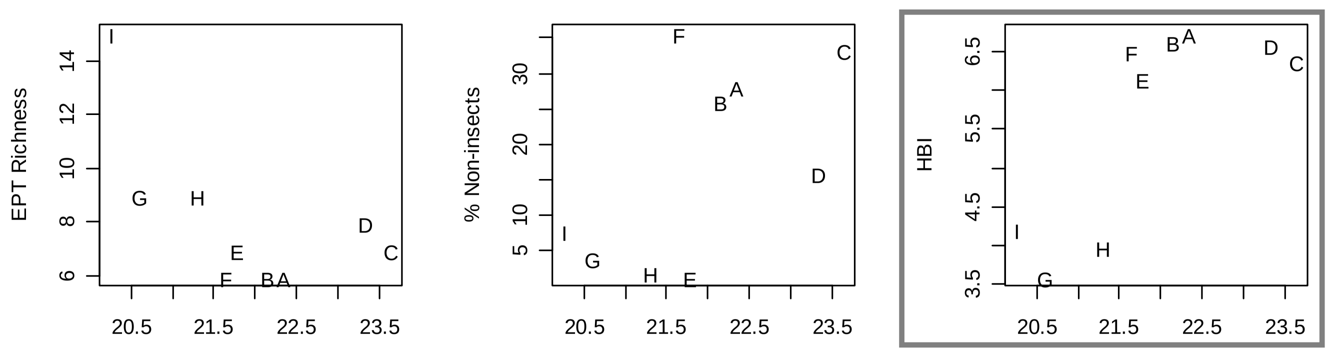


Figure H-14. Temperature, weekly maximum, C°

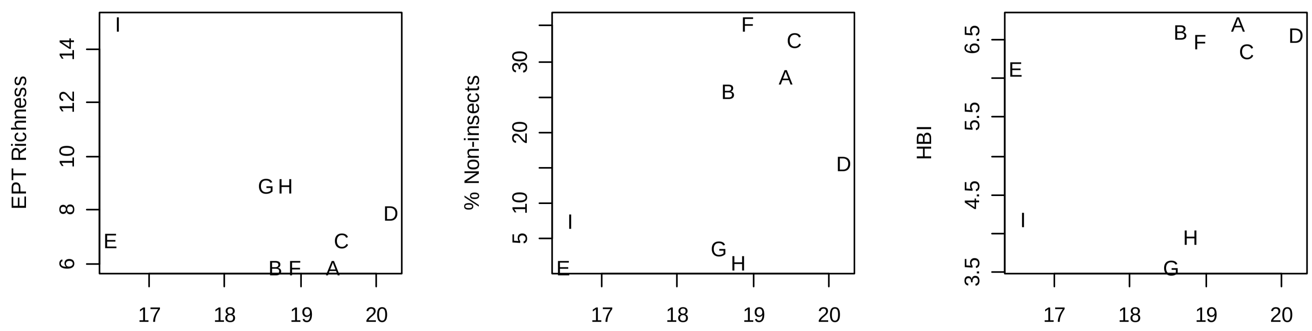


Figure H-15. Temperature, weekly mean, C°

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

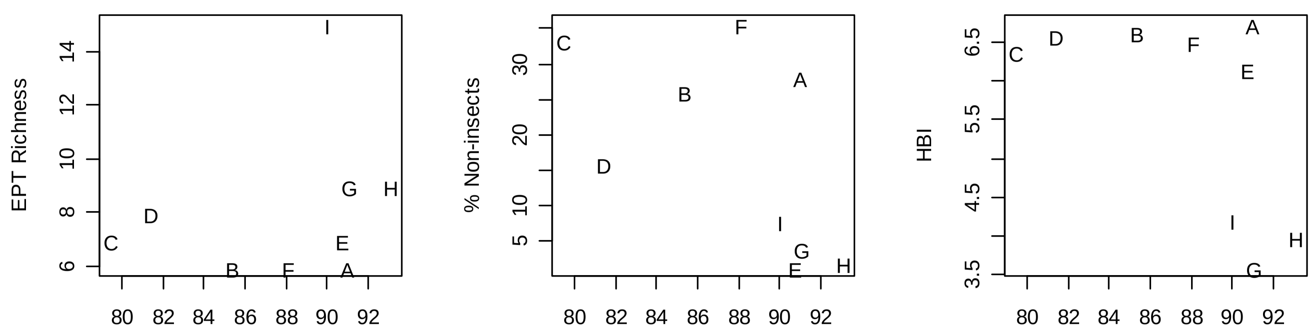


Figure H-16. Canopy shade, % cover

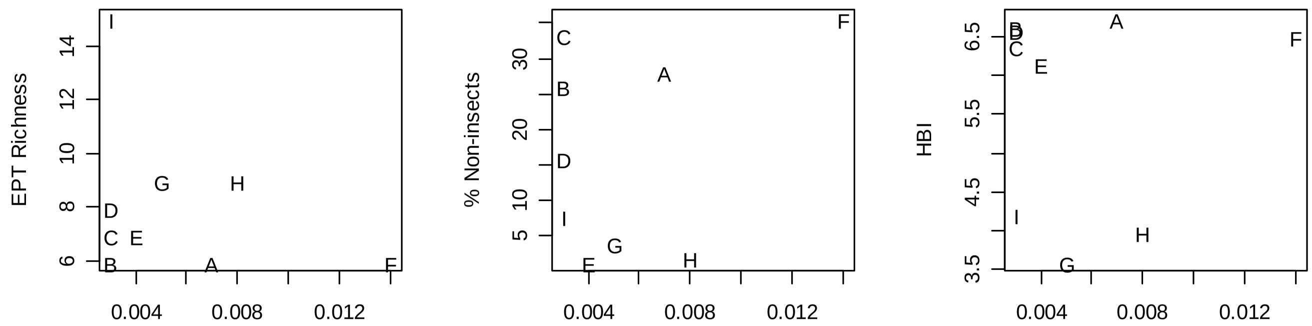


Figure H-17. Zinc, mg/L

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

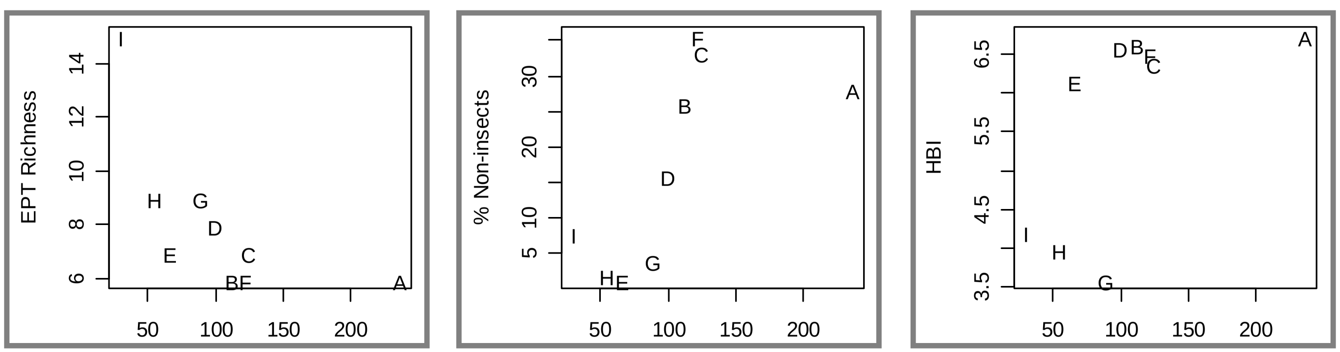


Figure H-18. Chloride, mg/L

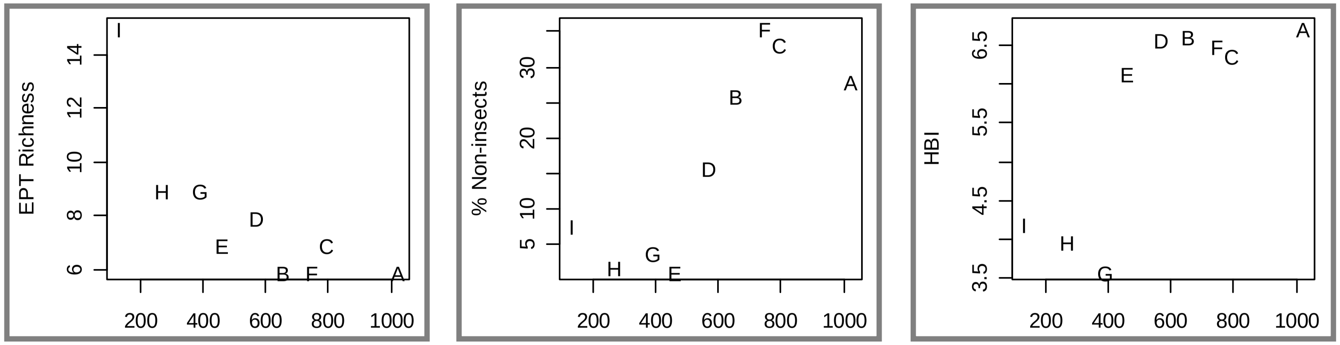


Figure H-19. Specific conductivity, µS/cm

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

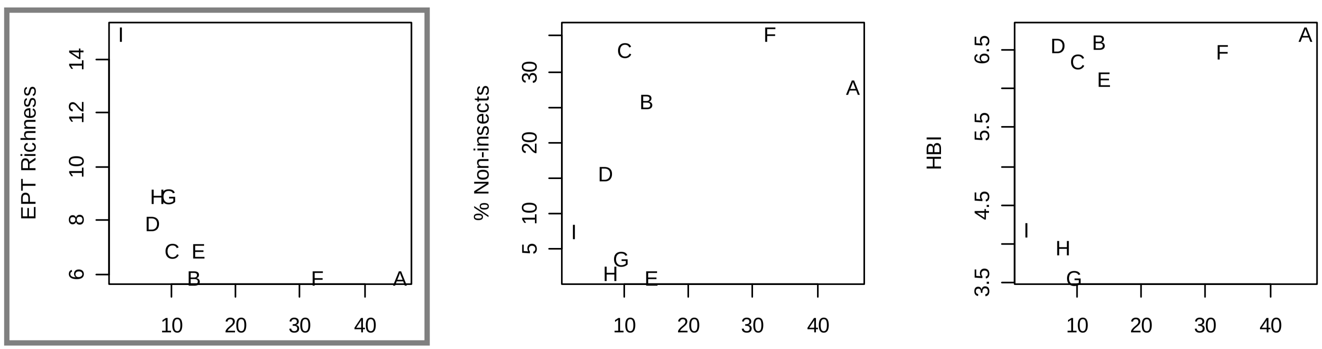


Figure H-20. Impervious surface area, %

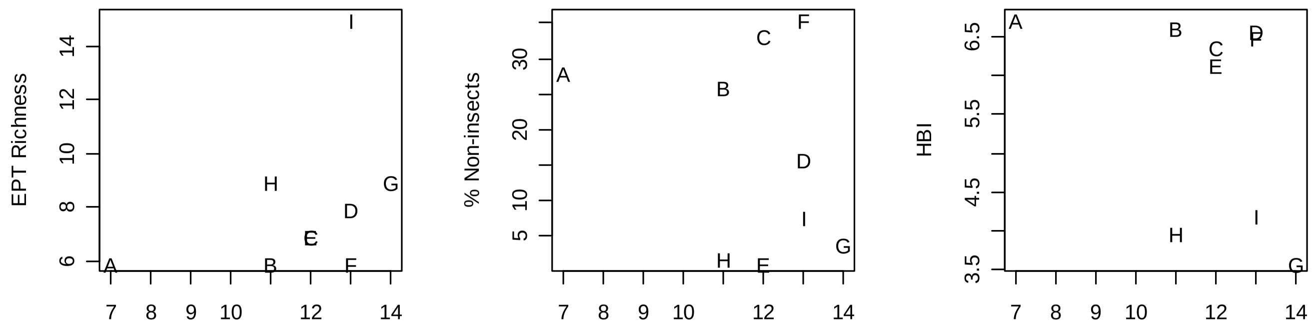


Figure H-21. RBP epifaunal substrate / available cover

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

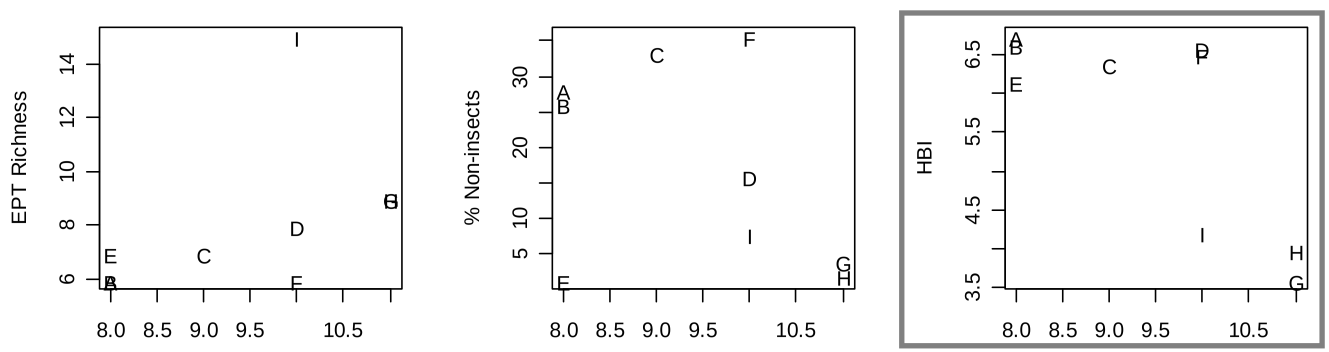


Figure H-22. RBP pool substrate characterization

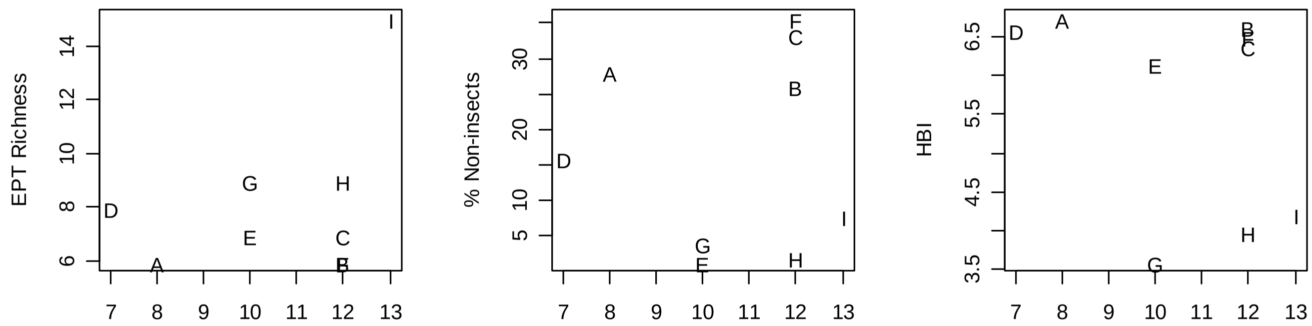


Figure H-23. RBP pool variability

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

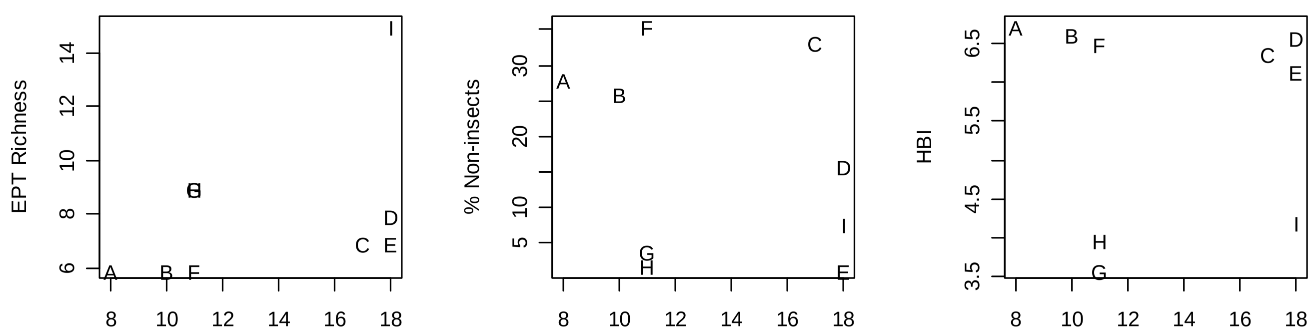


Figure H-24. RBP sediment deposition

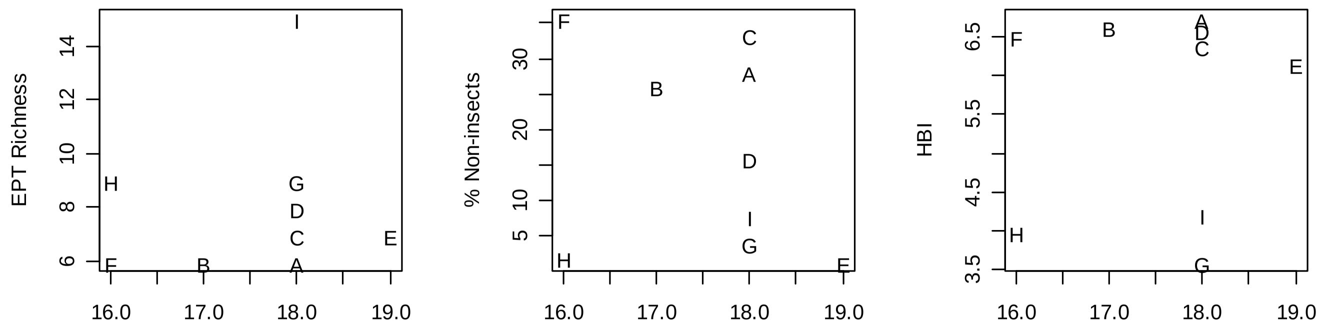


Figure H-25. RBP channel flow Status

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

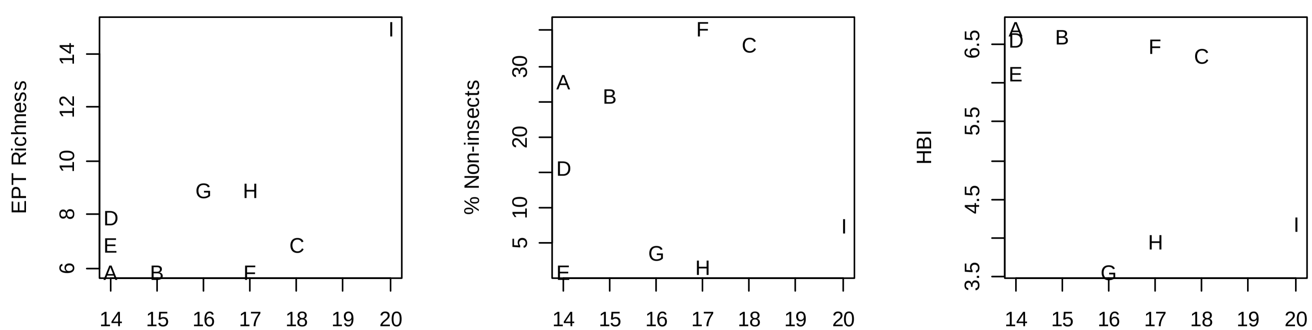


Figure H-26. RBP channel alteration

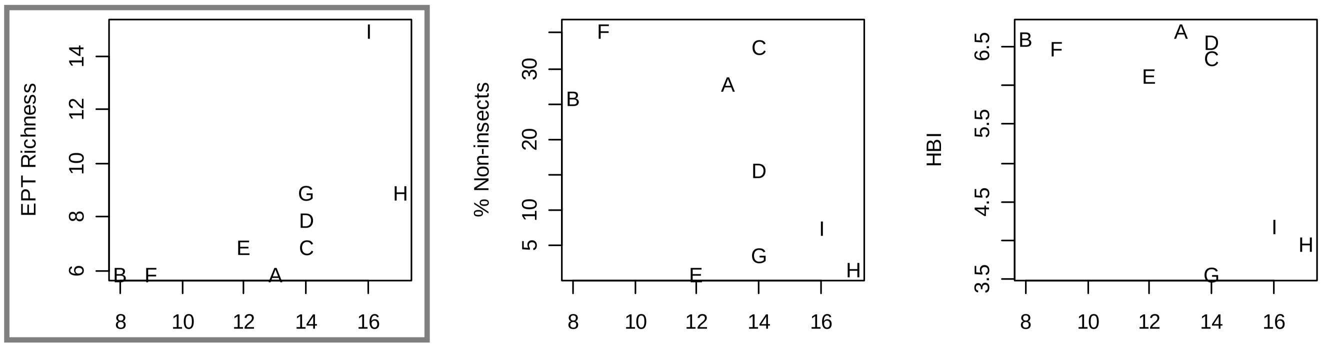


Figure H-27. RBP channel sinuosity

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

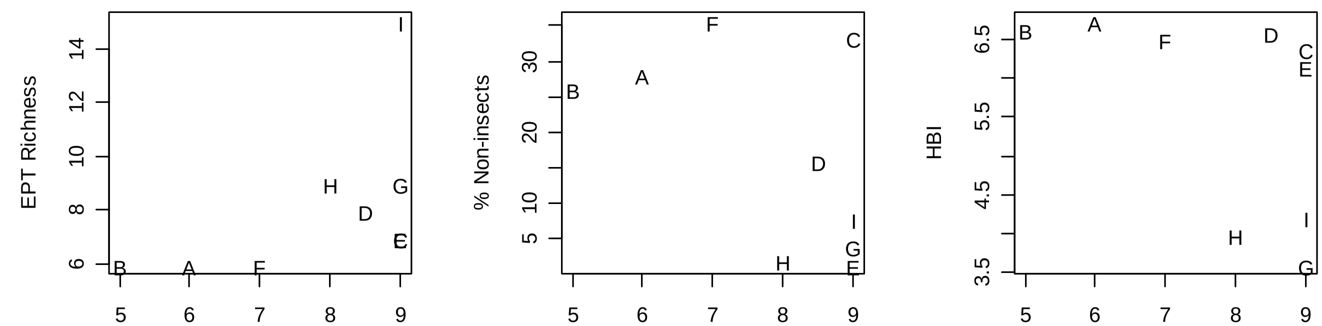


Figure H-28. RBP bank stability

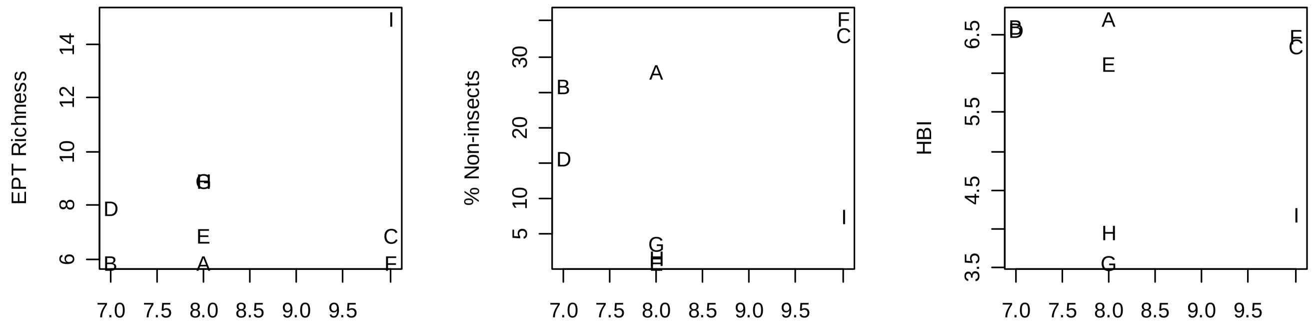


Figure H-29. RBP bank vegetative protection

Study Site Key

A	LCS .369	D	LCM 2.270	G	RB .071
B	LCM .380	E	LCMn 2.274	H	RB 1.474
C	LCM .910	F	LCN .415	I	RB 3.961

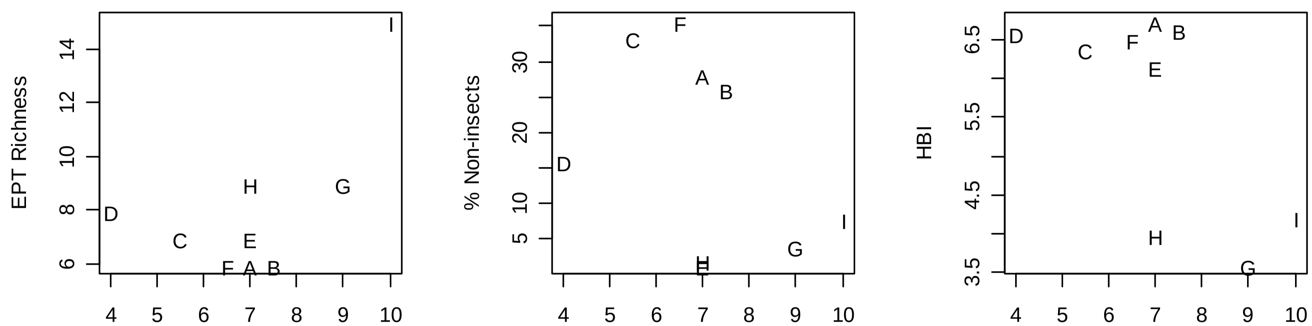


Figure H-30. RBP riparian vegetative zone width

Scatter plot statistical correlations

	EPT richness			Percent non-insects			HBI		
	Pearson's	Spearman's	Kendall's	Pearson's	Spearman's	Kendall's	Pearson's	Spearman's	Kendall's
Total Kjeldahl nitrogen	-0.637	-0.641	-0.509	0.504	0.367	0.222	0.798	0.650	0.444
Nitrate + nitrite	-0.011	-0.030	-0.063	0.124	0.017	-0.029	-0.290	-0.253	-0.203
Total phosphorus	-0.627	-0.640	-0.607	0.668	0.502	0.366	0.669	0.335	0.254
Ortho phosphorus	-0.451	-0.568	-0.445	0.542	0.502	0.354	0.691	0.570	0.471
Aquatic veg. (including diatoms)	0.000	0.000	0.000	0.574	0.639	0.559	0.042	0.091	0.043
Aquatic veg. (macroalgae/phytes only)	-0.291	-0.220	-0.201	0.457	0.408	0.373	0.504	0.398	0.298
Dissolved oxygen saturation	0.671	0.590	0.449	-0.398	-0.183	-0.111	-0.891	-0.617	-0.444
Dissolved oxygen concentration	0.646	0.564	0.389	-0.382	-0.200	-0.167	-0.889	-0.650	-0.500
LWD with diameter ≥ 5 cm	0.922	0.205	0.105	-0.517	-0.500	-0.400	-0.941	-0.300	-0.200
LWD with diameter ≥ 10 cm	0.915	0.205	0.105	-0.434	-0.500	-0.400	-0.947	-0.300	-0.200
D50 substrate particle size	-0.343	-0.427	-0.343	0.326	0.408	0.309	0.126	0.259	0.206
Pfankuch bank stability	-0.275	0.296	0.276	-0.407	-0.548	-0.357	-0.267	-0.548	-0.357
Temperature, weekly mean	-0.532	-0.316	-0.210	0.563	0.650	0.444	0.384	0.533	0.333
Temperature, weekly minimum	-0.514	-0.162	-0.150	0.418	0.200	0.222	0.164	0.267	0.222
Temperature, weekly maximum	-0.622	-0.573	-0.449	0.577	0.483	0.278	0.774	0.700	0.500
Canopy shade	0.251	0.325	0.210	-0.570	-0.600	-0.444	-0.565	-0.500	-0.333
Zinc	-0.317	-0.210	-0.164	0.315	0.026	0.000	0.053	-0.148	-0.122
Chloride	-0.658	-0.812	-0.688	0.677	0.817	0.611	0.616	0.733	0.500
Specific conductivity	-0.803	-0.864	-0.748	0.821	0.783	0.556	0.803	0.783	0.556
Impervious surface area	-0.600	-0.881	-0.748	0.572	0.417	0.278	0.527	0.533	0.389
RBP epifaunal substrate/avail. cover	0.391	0.487	0.419	-0.296	-0.077	-0.090	-0.397	-0.504	-0.389
RBP pool substrate characterization	0.481	0.702	0.600	-0.386	-0.251	-0.217	-0.746	-0.719	-0.588
RBP pool variability	0.348	0.215	0.167	0.045	0.114	0.093	-0.346	-0.332	-0.217
RBP sediment deposition	0.444	0.566	0.459	-0.284	-0.380	-0.304	0.006	-0.380	-0.304
RBP channel flow status	0.149	0.184	0.144	-0.278	-0.358	-0.300	0.103	-0.055	-0.033
RBP channel alteration	0.691	0.424	0.349	0.004	0.196	0.118	-0.513	-0.494	-0.354
RBP channel sinuosity	0.653	0.870	0.750	-0.578	-0.407	-0.319	-0.656	-0.627	-0.493
RBP bank stability	0.532	0.683	0.525	-0.542	-0.435	-0.304	-0.498	-0.705	-0.548
RBP bank vegetative protection	0.339	0.142	0.141	0.310	0.321	0.261	-0.126	-0.330	-0.196
RBP riparian vegetative zone width	0.610	0.365	0.250	-0.409	-0.424	-0.261	-0.670	-0.407	-0.319

Cells have been flagged (highlighted) with values greater or less than 0.7.

APPENDIX I
SPECIES SENSITIVITY DISTRIBUTIONS (S-R from elsewhere)

Figure I-1. SSD – Baseflow – Invertebrate – Arsenic
Figure I-2. SSD – Baseflow – Chordate – Arsenic
Figure I-3. SSD – Stormflow – Invertebrate – Cadmium
Figure I-4. SSD – Stormflow – Chordate – Cadmium
Figure I-5. SSD – Baseflow – Invertebrate – Chromium
Figure I-6. SSD – Baseflow – Chordate – Chromium
Figure I-7. SSD – Stormflow – Invertebrate – Copper
Figure I-8. SSD – Stormflow – Chordate – Copper
Figure I-9. SSD – Baseflow – Invertebrate – Copper
Figure I-10. SSD – Baseflow – Chordate – Copper
Figure I-11. SSD – Stormflow – Invertebrate – Nickel
Figure I-12. SSD – Stormflow – Chordate – Nickel
Figure I-13. SSD – Baseflow – Invertebrate – Nickel
Figure I-14. SSD – Baseflow – Chordate – Nickel
Figure I-15. SSD – Stormflow – Invertebrate – Zinc
Figure I-16. SSD – Stormflow – Chordate – Zinc
Figure I-17. SSD – Baseflow – Invertebrate – Zinc
Figure I-18. SSD – Baseflow – Chordate – Zinc

Figure notes: CCC - criterion continuous concentration (chronic)
CMC - criteria maximum concentration (acute)
(CCC and CMC source: US EPA, 1986b)

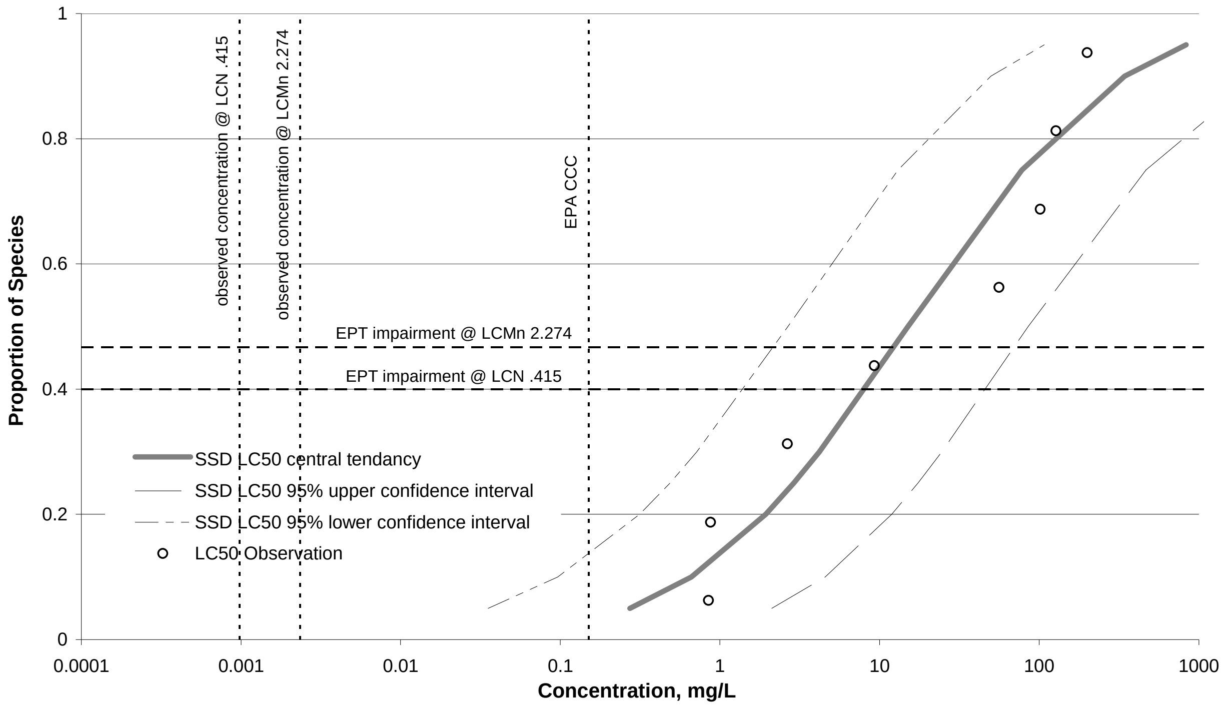


Figure I-1. **SSD – Baseflow – Invertebrate – Arsenic**

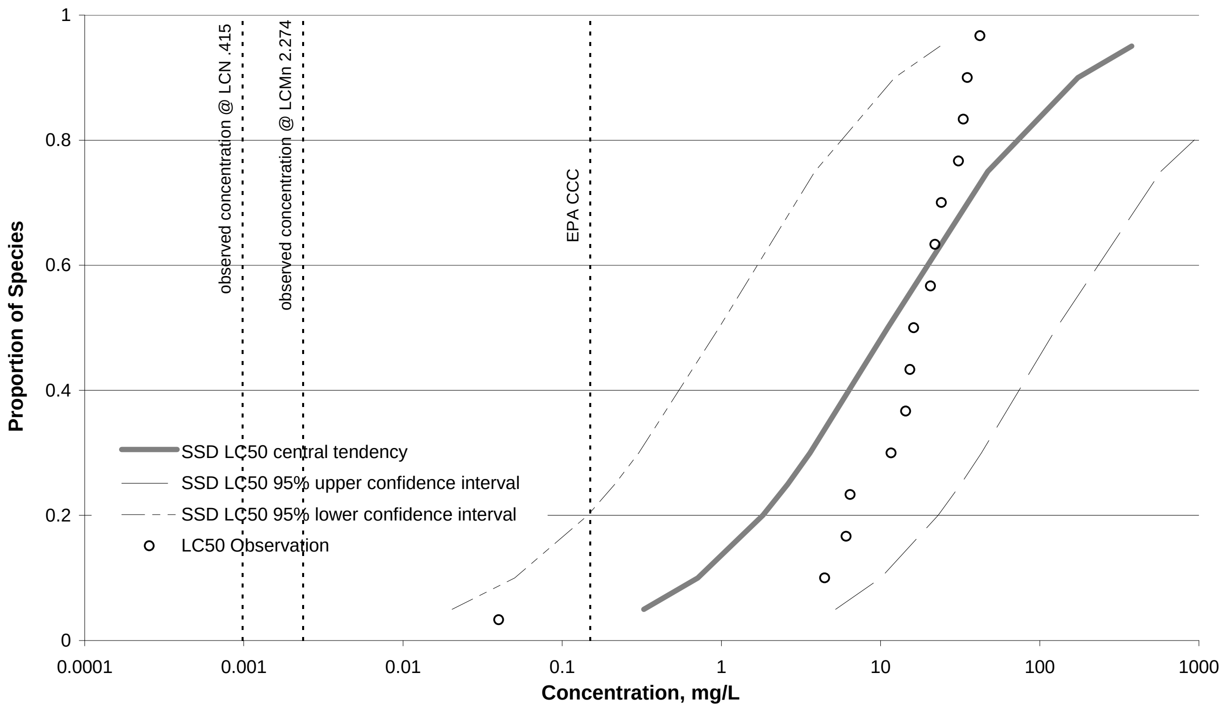


Figure I-2. **SSD – Baseflow – Chordate – Arsenic**

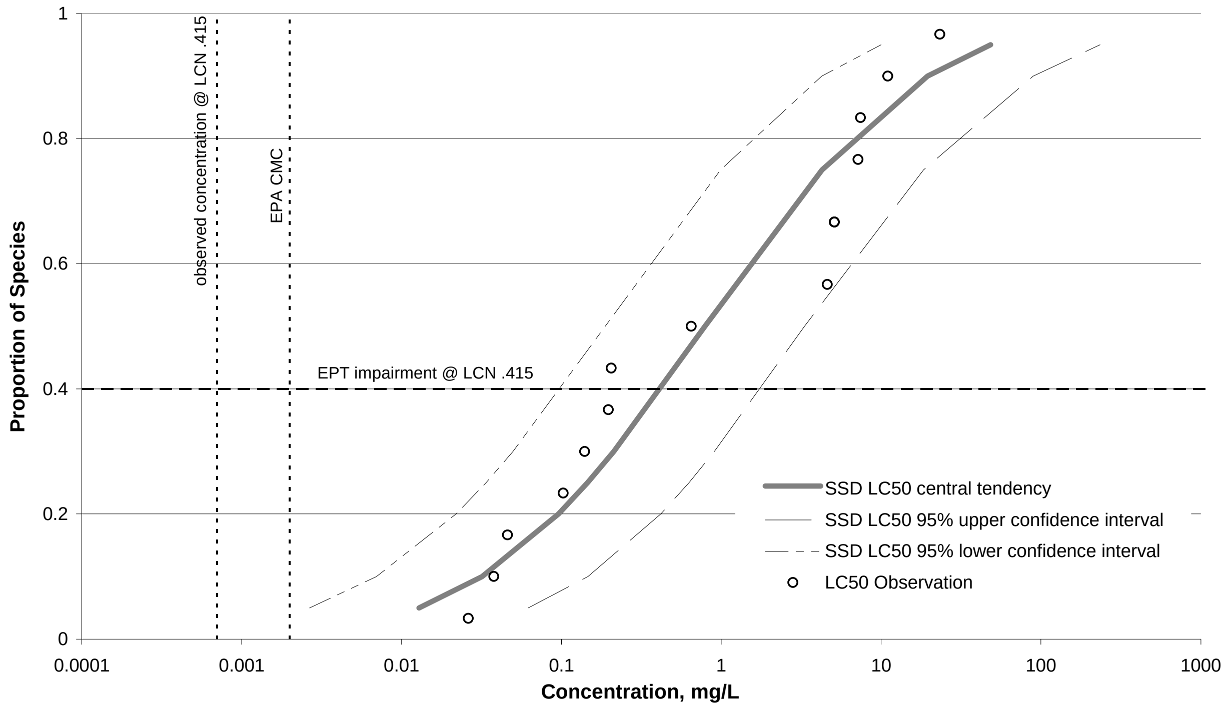


Figure I-3. SSD – Stormflow – Invertebrate – Cadmium

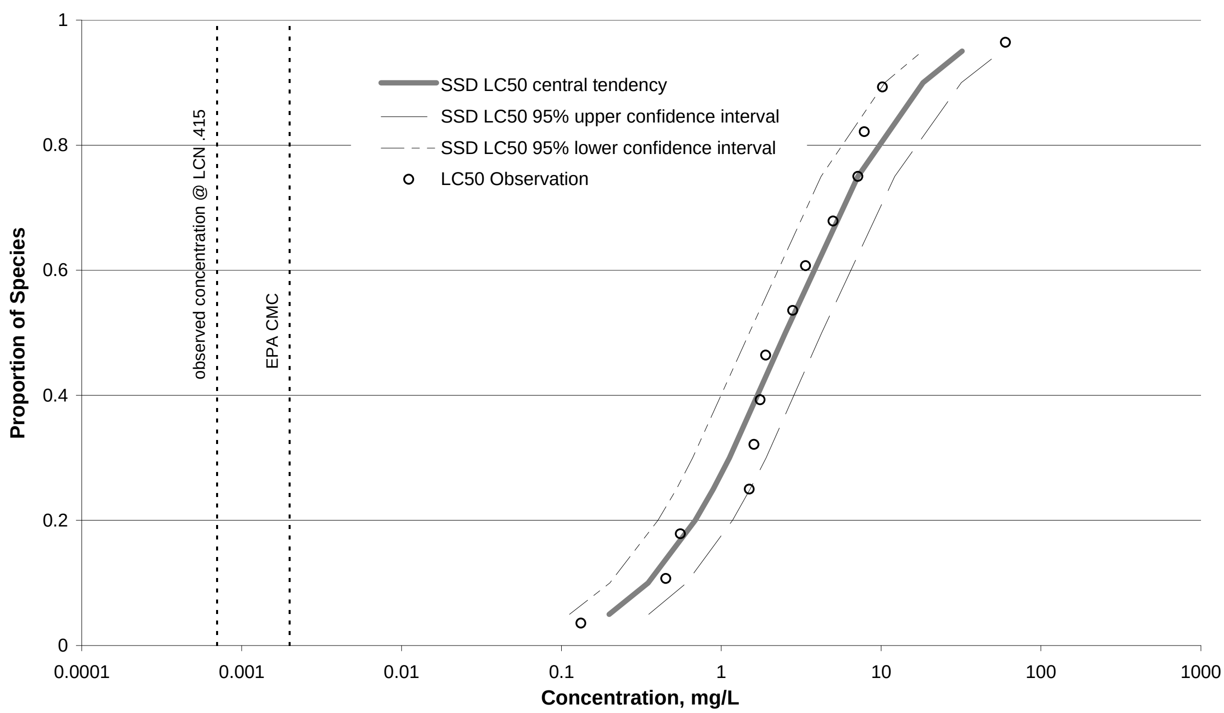


Figure I-4. SSD – Stormflow – Chordate – Cadmium

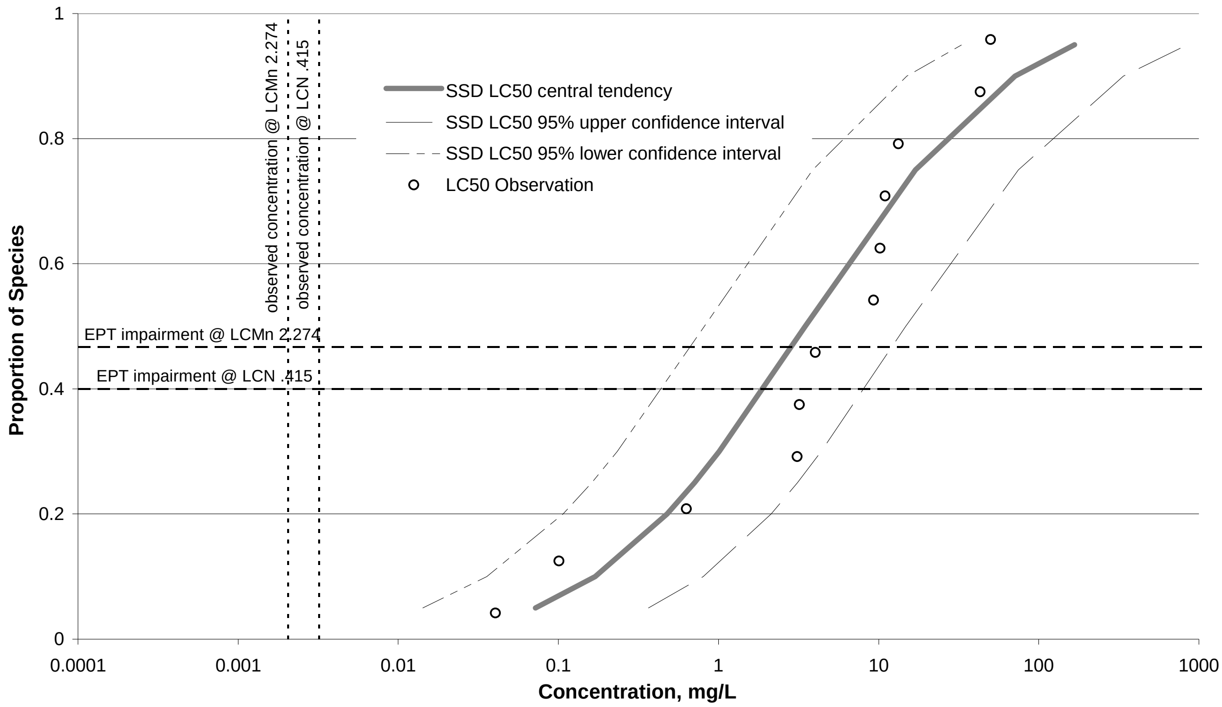


Figure I-5. SSD – Baseflow – Invertebrate – Chromium

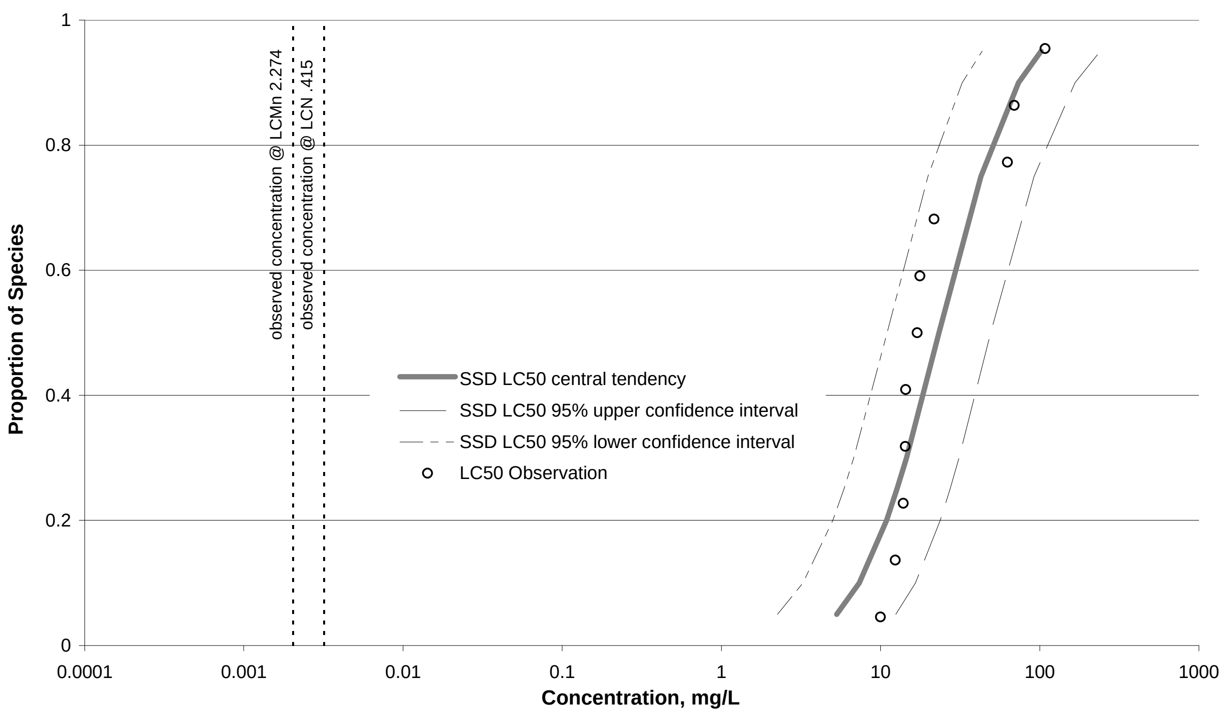


Figure I-6. SSD – Baseflow – Chordate – Chromium

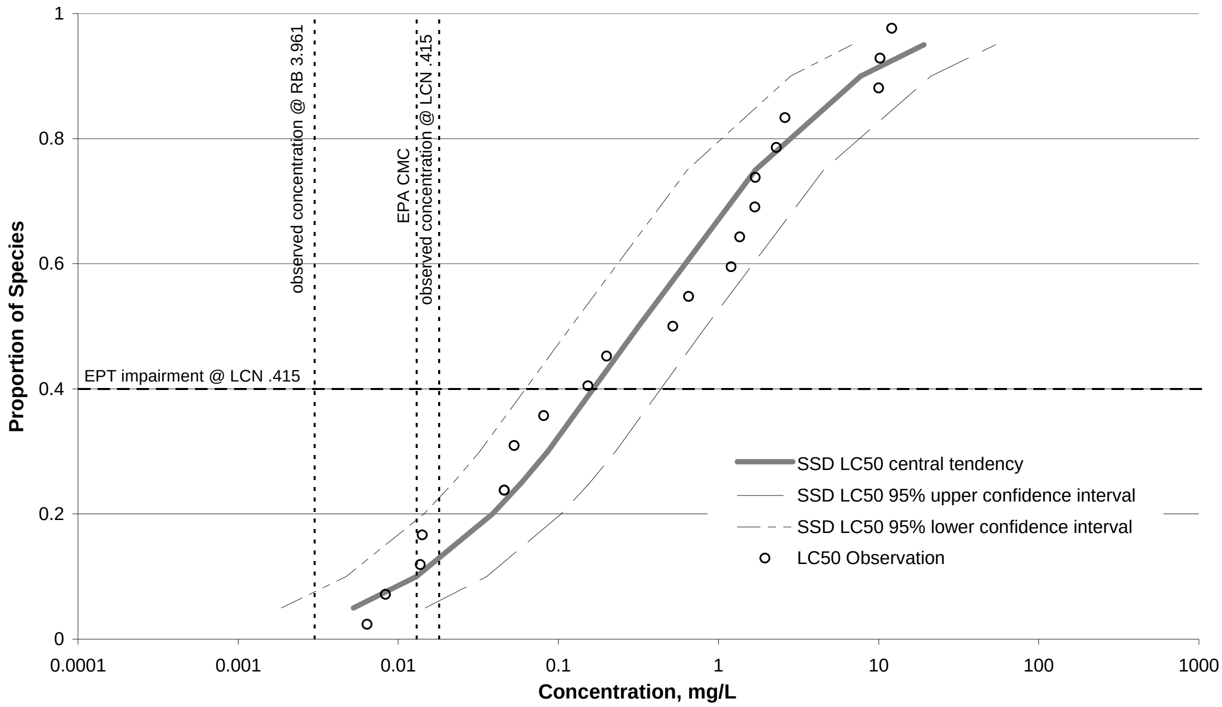


Figure I-7. **SSD – Stormflow – Invertebrate – Copper**

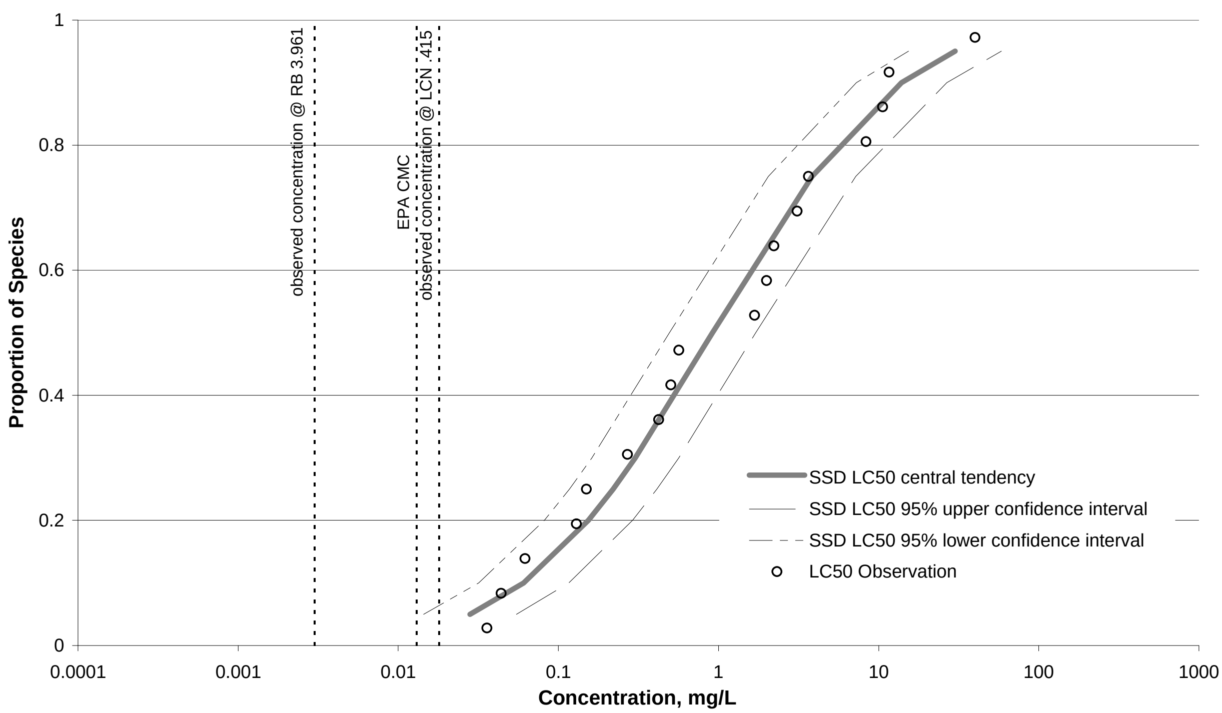


Figure I-8. **SSD – Stormflow – Chordate – Copper**

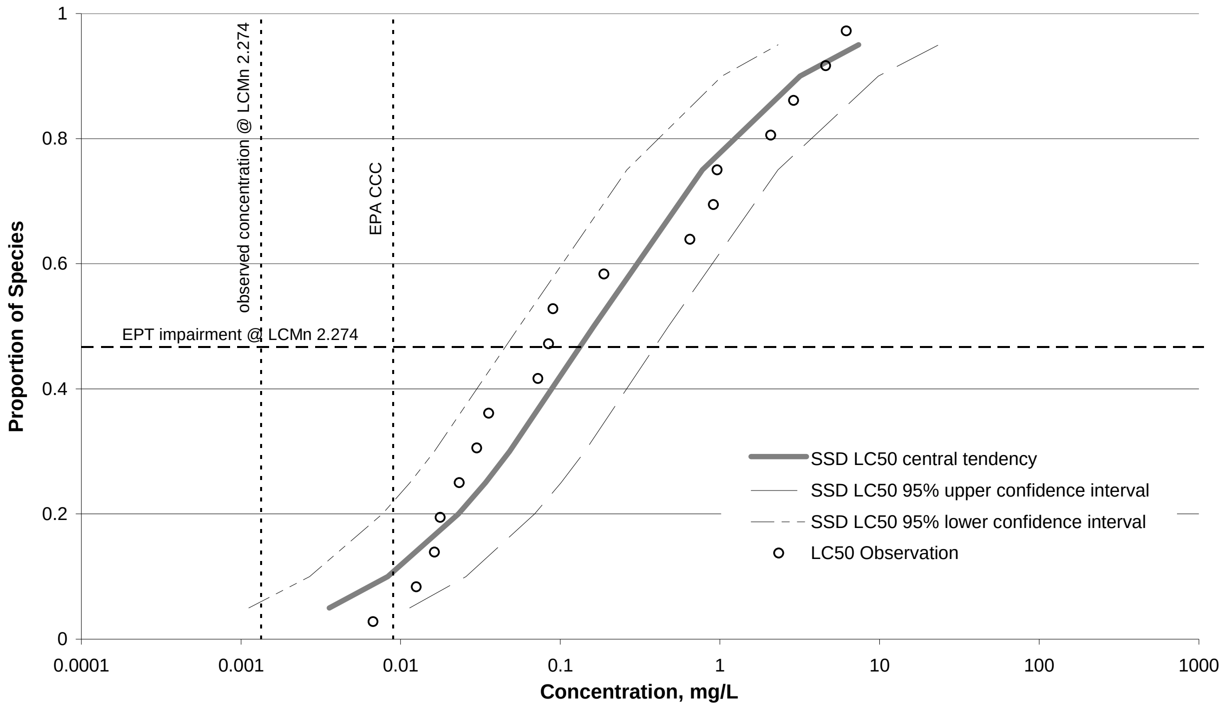


Figure I-9. SSD – Baseflow – Invertebrate – Copper

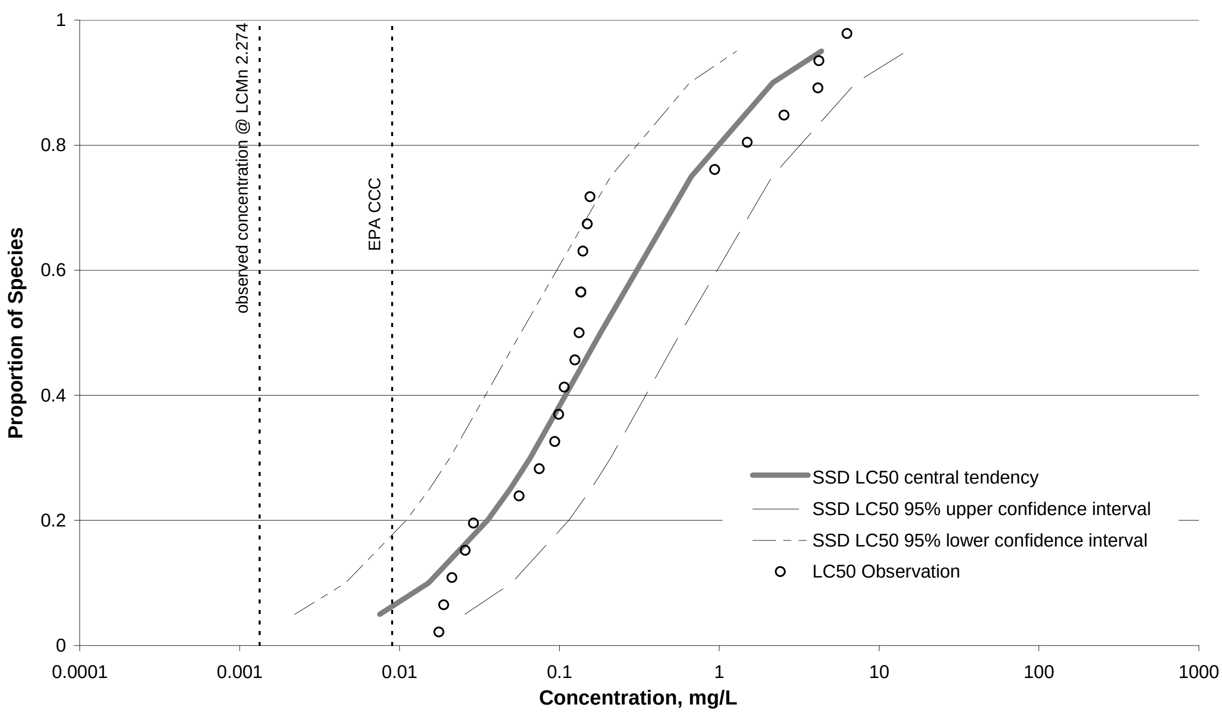


Figure I-10. SSD – Baseflow – Chordate – Copper

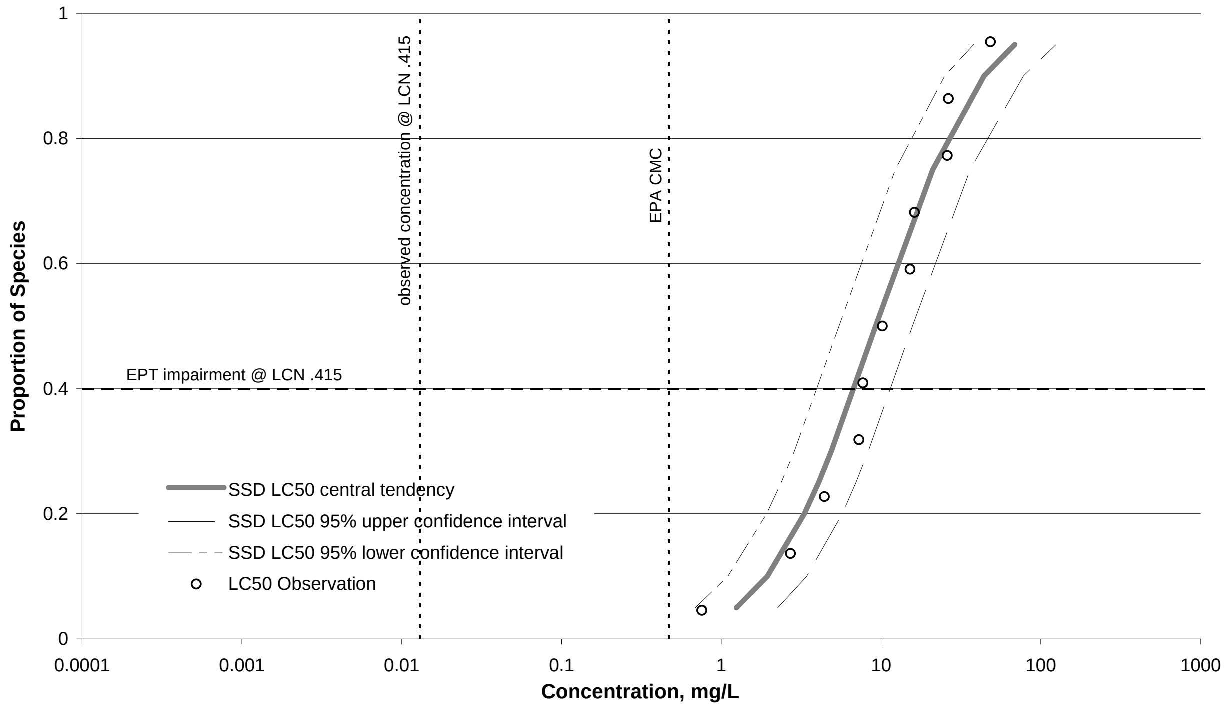


Figure I-11. SSD – Stormflow – Invertebrate – Nickel

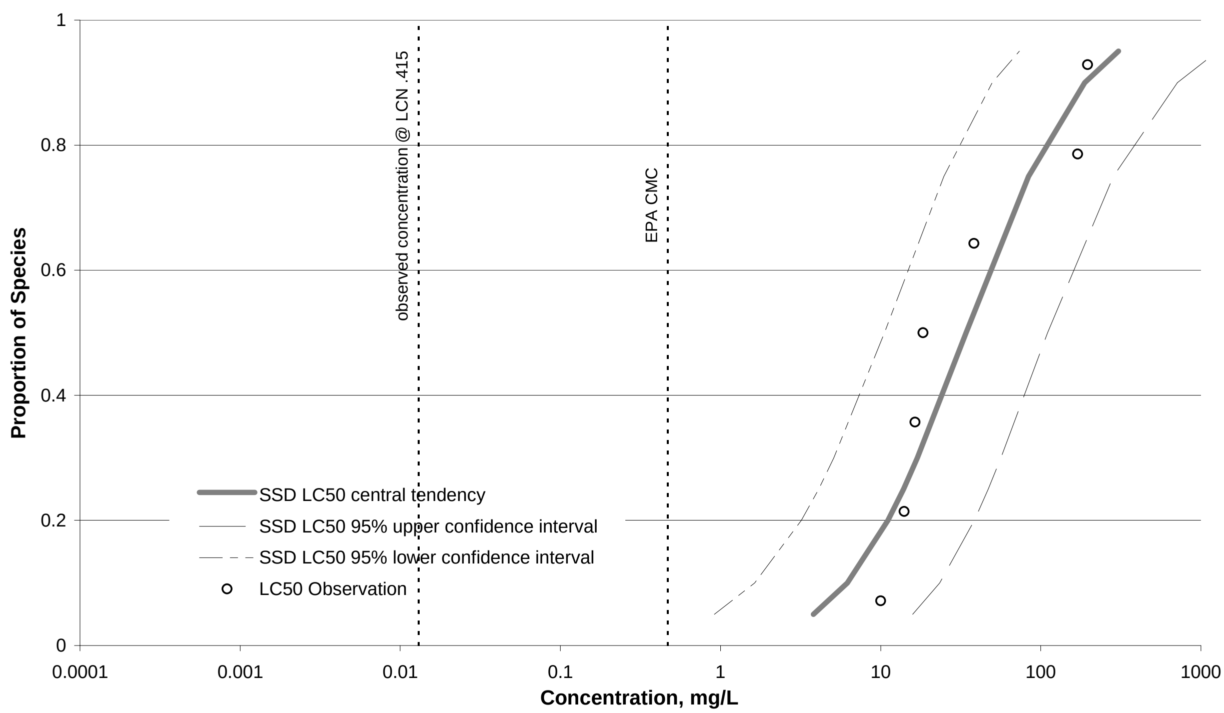


Figure I-12. SSD – Stormflow – Chordate – Nickel

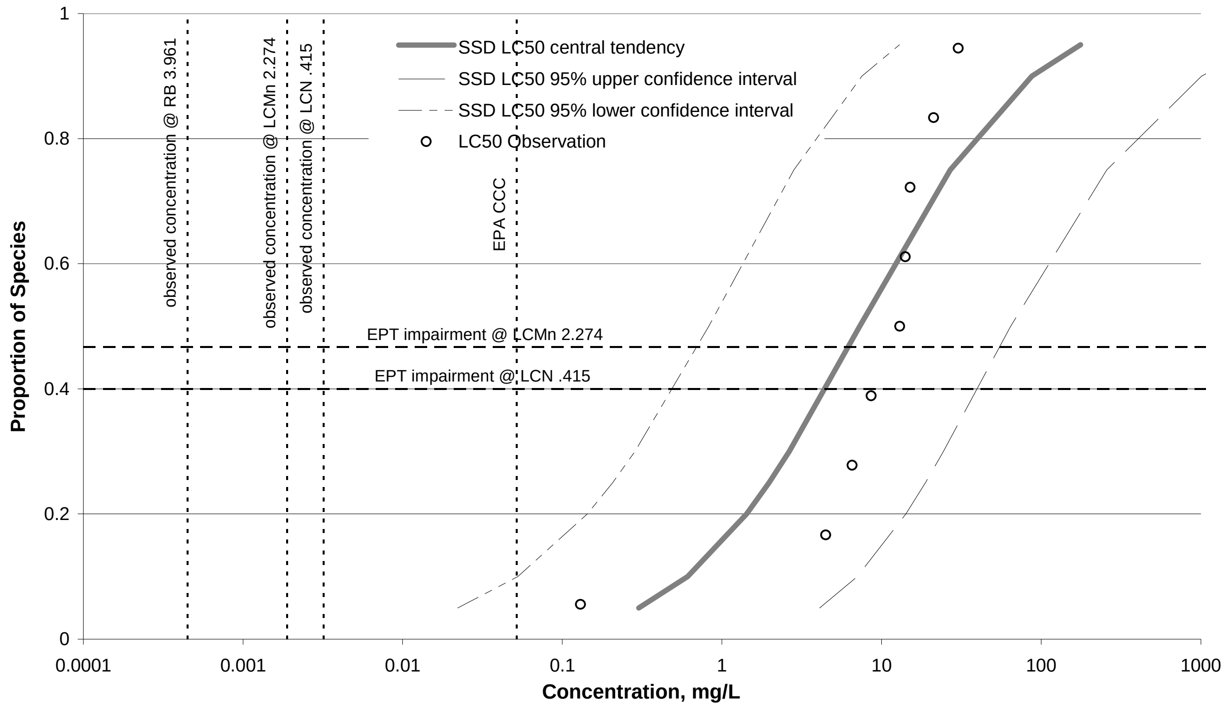


Figure I-13. SSD – Baseflow – Invertebrate – Nickel

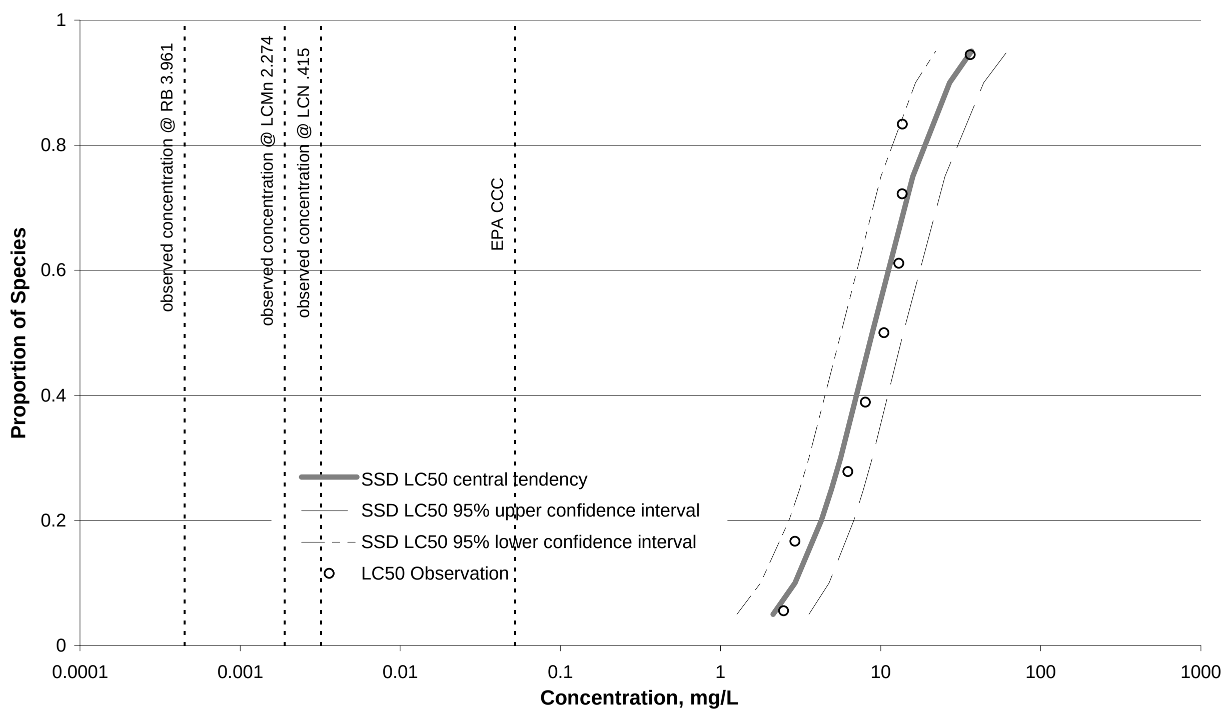


Figure I-14. SSD – Baseflow – Chordate – Nickel

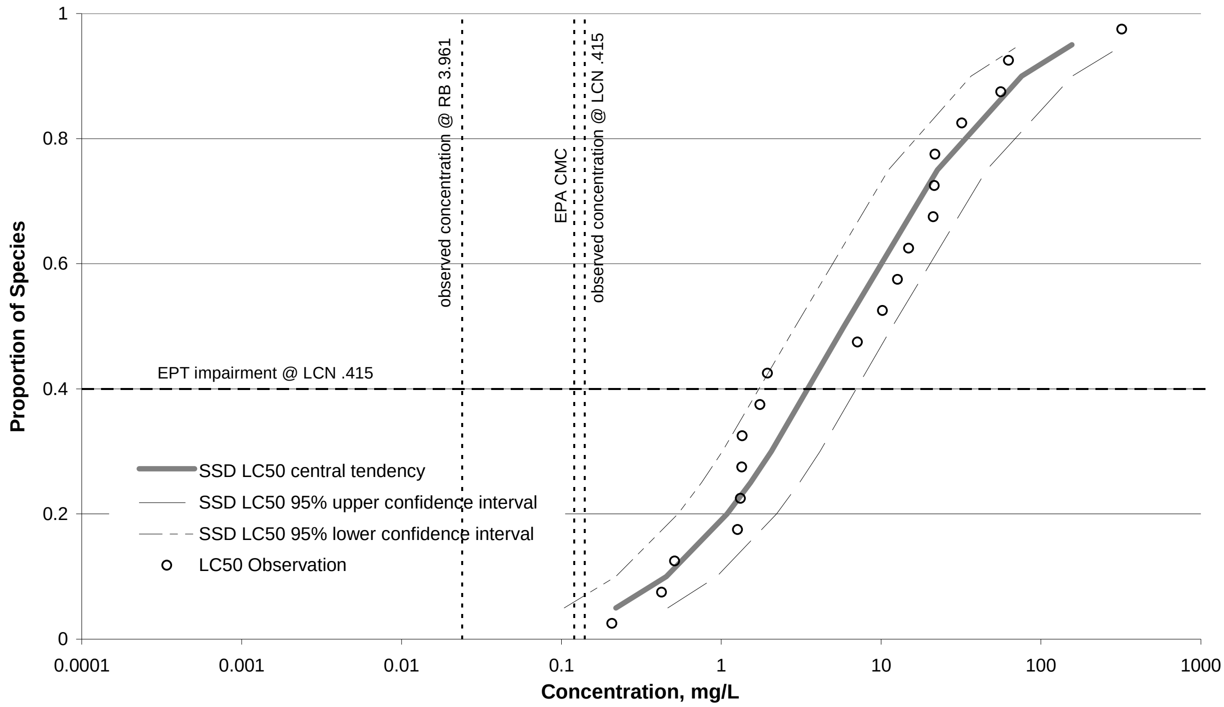


Figure I-15. SSD – Stormflow – Invertebrate – Zinc

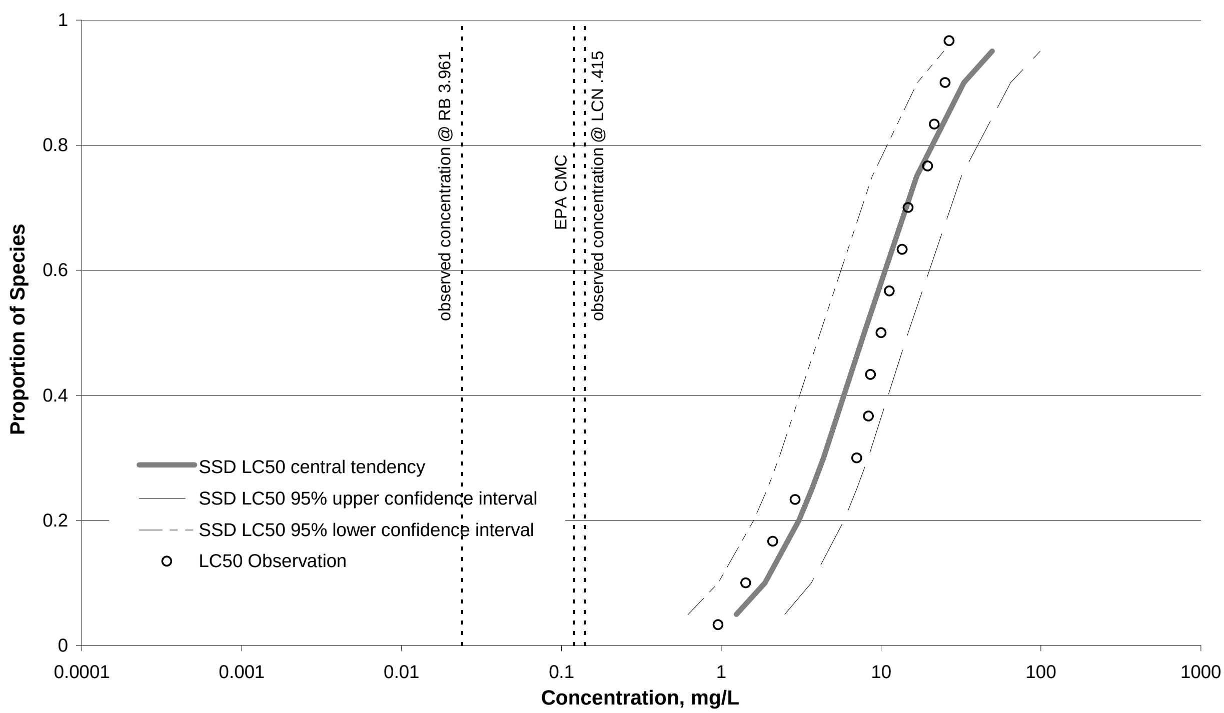


Figure I-16. SSD – Stormflow – Chordate – Zinc

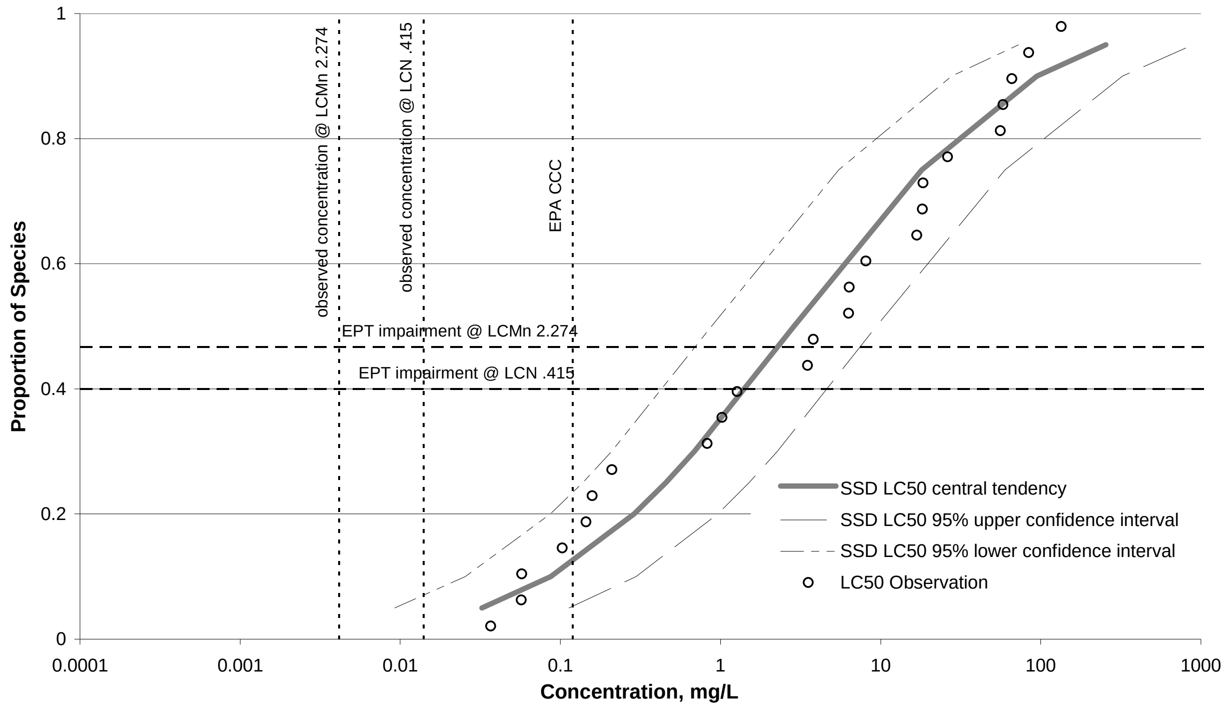


Figure I-17. SSD – Baseflow – Invertebrate – Zinc

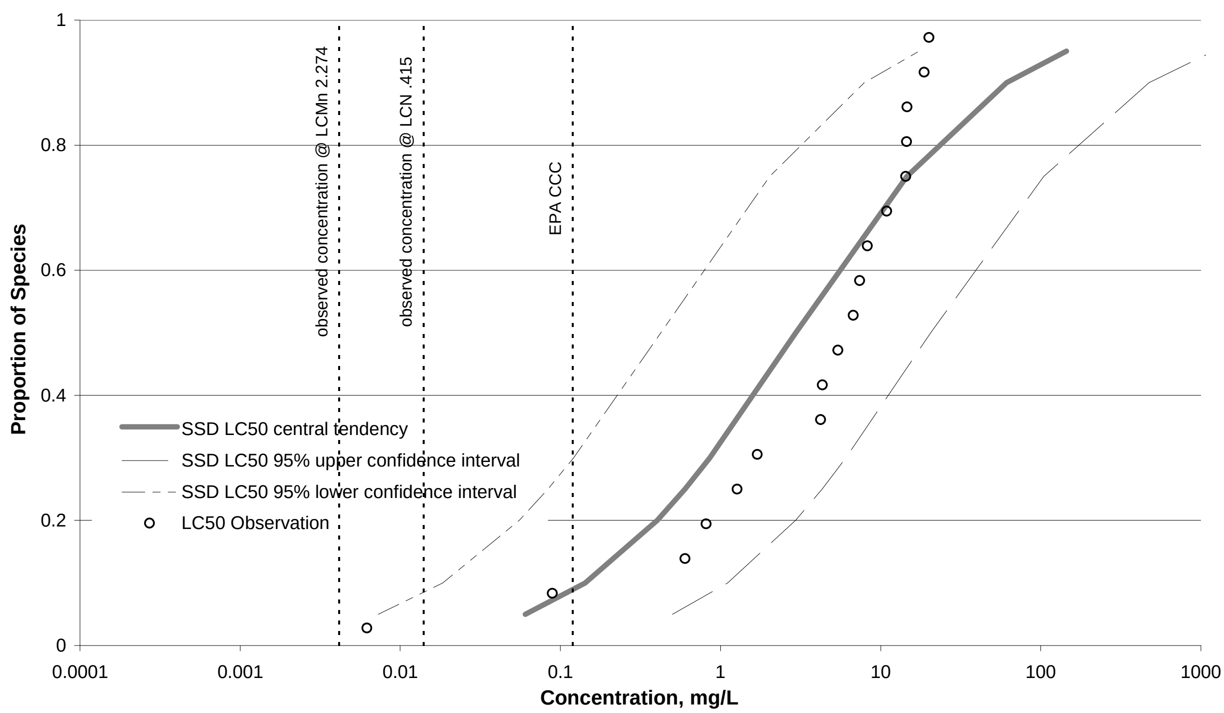
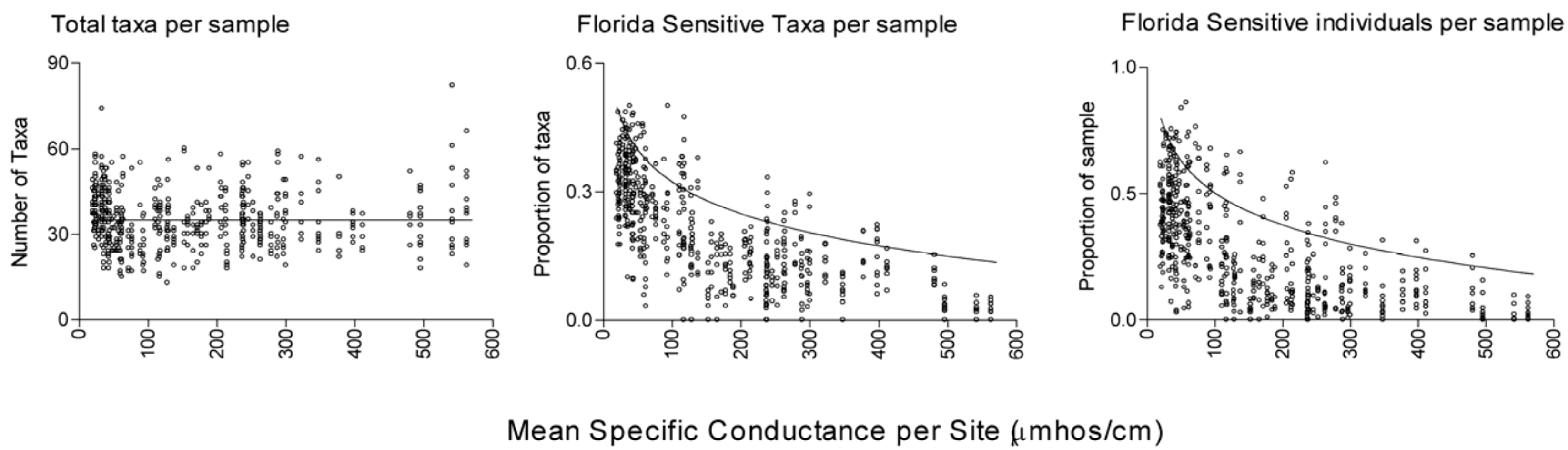


Figure I-18. SSD – Baseflow – Chordate – Zinc

APPENDIX J
SPECIFIC CONDUCTIVITY DATA FROM OTHER STATES



Data are (left to right) the total number of taxa per sample, the proportion of taxa that are Florida Sensitive Taxa, and the proportion of individuals identified that belong to Florida Sensitive Taxa. Slope of linear regression line for total taxa is non-significant, indicating that the number of taxa per sample is not significantly related to specific conductance at least disturbed sites. Center and right panels show the 90th quantile regression lines ($p<0.0001$ or smaller). There is a consistent, statistically significant negative relationship between the distribution and abudance of Florida Sensitive Taxa with respect to specific conductance at least disturbed sites. This contrasts with the lack of relationship between total taxa and specific conductance. Data from 86 least disturbed sites sampled 4 or more times (range 4-16 visits/site, 585 20-dipnet sweep samples, 1993-2003).

Figure J-1. Florida sensitive taxa at least disturbed sites versus specific conductivity
Source: Florida Department of Environmental Protection (2005).

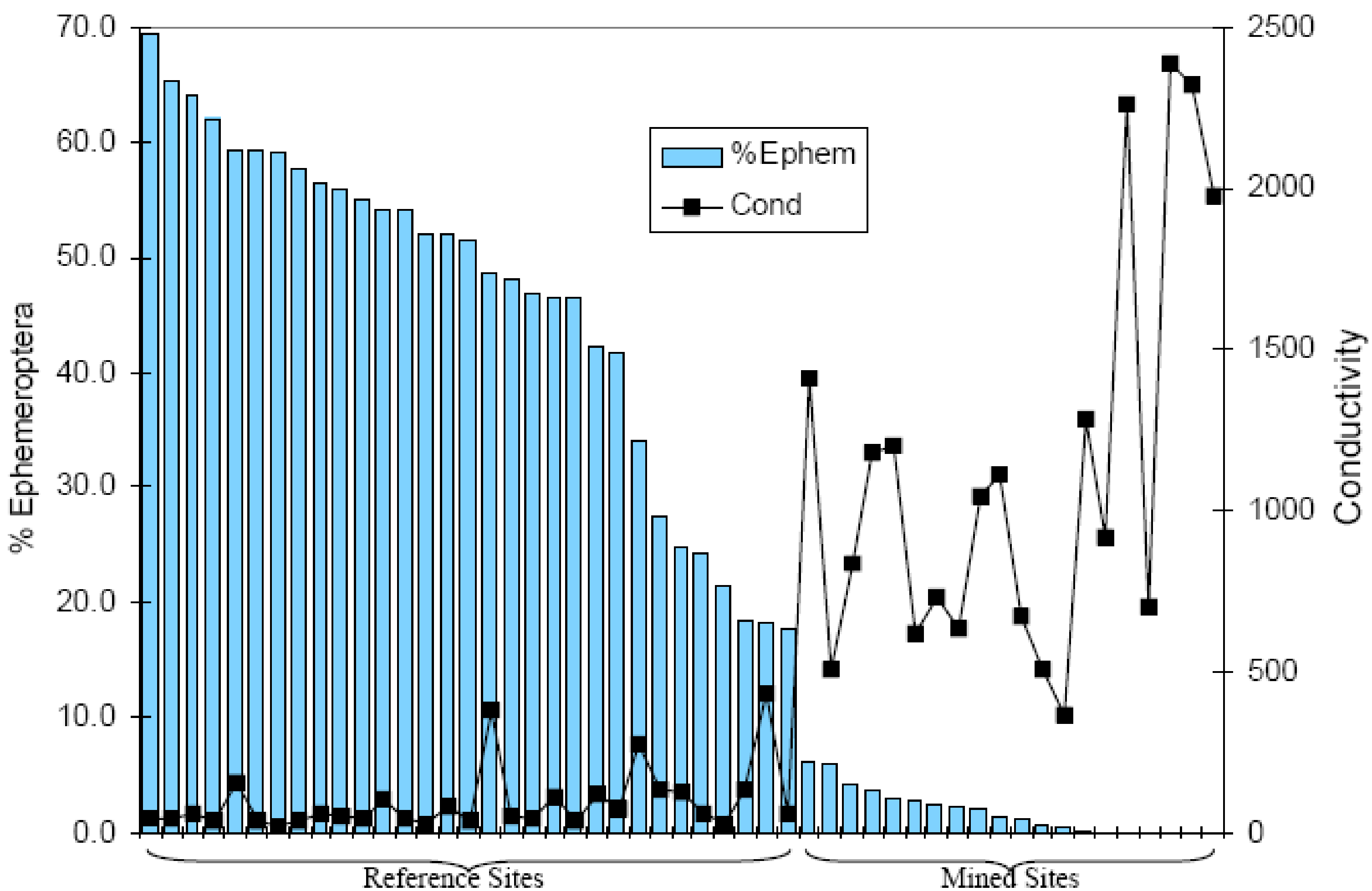


Figure J-2. Kentucky mined site Ephemeroptera (mayfly) abundance versus specific conductivity
Source: Pond (2004).

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