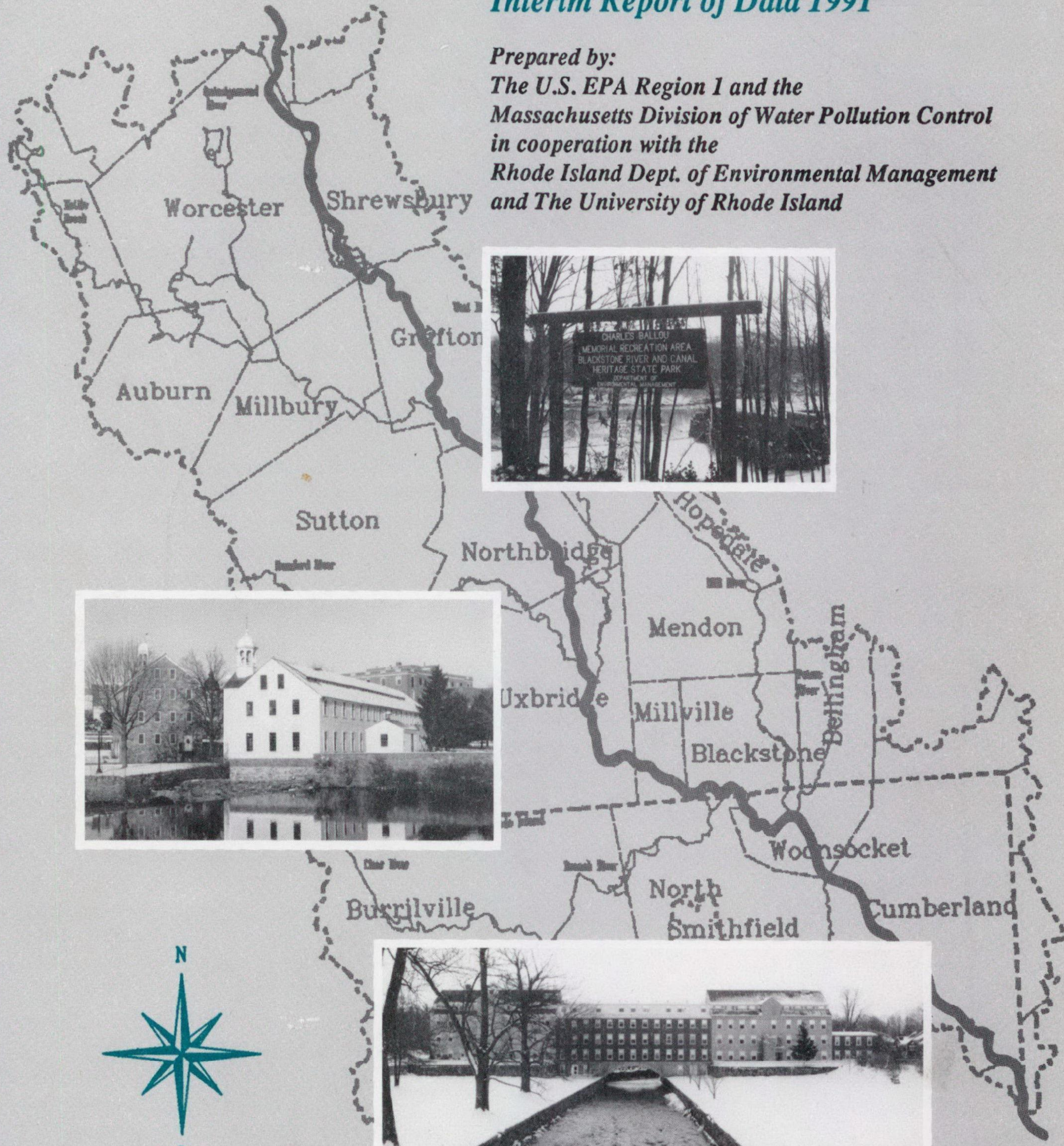
Blackstone River Initiative

Phase 1: Dry Weather Assessment Interim Report of Data 1991

Prepared by:
The U.S. EPA Region 1 and the
Massachusetts Division of Water Pollution Control
in cooperation with the
Rhode Island Dept. of Environmental Management
and The University of Rhode Island



Forward

The Blackstone River is an extremely valuable aquatic resource located in south central New England in the states of Massachusetts and Rhode Island. The river basin has experienced a long history of pollution dating back to the industrial revolution. Numerous water quality studies have been conducted over the years by Massachusetts and Rhode Island for a variety of flow and weather conditions. While much has been learned from these studies, they were developed independently by Massachusetts and Rhode Island for their respective river segments. This has constrained the integration and use of the data for a comprehensive and up-to-date analysis of the extent and nature of pollution and contamination within the watershed.

The Blackstone River Initiative was organized by EPA at the request of the commissioners of the Massachusetts Department of Environmental Protection and Rhode Island Department of Environmental Management to:

- make informed decisions on the future course of pollution controls and abatements
- address public interest in water quality issues
- address concerns of the Narragansett Bay Project
- assess development of site specific criteria for metals
- assess toxicity based NPDES controls and related issues
- determine dry and wet weather loadings to the river.

This report established a comprehensive data base for dry weather conditions for the entire Blackstone River and its major tributaries. A second phase of the initiative which is in progress includes wet weather studies.

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The principal contributors to this document are Elaine Hartman, and Gerald Szal, Massachusetts Department of Environmental Protection, Division of Water Pollution Control; Celeste Barr, Jack Paar, and Peter Nolan, Environmental Services Division, EPA Region I; and David Pincumbe, Water Management Division, EPA Region I. Peter Nolan was responsible for overall technical coordination for the Blackstone Initiative, David Pincumbe was responsible for contract management, Elaine Hartman/Paul Hogan and Diane Switzer were responsible for field logistics for MADEP and EPA respectively. Gerald Potamis, Water Management Division, EPA Region I served as the chairperson for the Blackstone Initiative work group. Other participants and contributors to the initiative include: Alan Cooperman, Massachusetts DEP; Christopher Deacutis, Rhode Island DEM; William Beckwith, EPA Region I; and Richard Zingarelli, Narrangansett Bay Project. The University of Rhode Island (URI) Department of Civil Engineering conducted the water quality chemical analysis under cooperative agreement with EPA. Raymond Wright of URI provided consultation and invaluable technical advice.

The US Geological Survey conducted river flow measurements and provided access to river gauge data. Deborah Cohen of Management Technologies Inc. (EPA contractor) provided GIS support and produced all maps.

Catherine Lei, EPA Region I, provided computer assistance for the development of charts and graphs. The Environmental Monitoring and Support Laboratory (EPA Newtown, Ohio) provided contract and QA support for the macroinvertebrate community identifications.

The final production of this report was coordinated by The New England Interstate Water Pollution Control Commission.

The cooperation of the following industrial and municipal facilities along the river is gratefully acknowledged: Massachusetts—Douglas POTW, Grafton POTW, Millbury POTW, Northbridge POTW, Upper Blackstone WPAD, Upton POTW, Uxbridge POTW, City of Worcester CSO facility, Guilford Industries, New England Plating, and Worcester Finishing and Spinning. Rhode Island—Woonsocket POTW, GTE, and Okinite.

Upper Blackstone and Woonsocket provided laboratory and storage space during the course of the initiative.

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1991 BLACKSTONE RIVER SURVEY
Phase 1: Dry Weather Assessment

BLACKSTONE RIVER INITIATIVE

The Blackstone River is located in south-central Massachusetts and flows from Worcester, Massachusetts to the Seekonk River in Pawtucket, Rhode Island. The river has a total length of 48 miles, a drainage area of 540 square miles, and is an important natural, recreational, and cultural resource to both the Commonwealth of Massachusetts and the State of Rhode Island. The Blackstone River is also the second largest source of fresh water to Narragansett Bay, a productive and diverse estuary important for fishing, shellfishing, tourism, and recreation. In 1986, the United States Congress established the Blackstone River Valley National Heritage Corridor along portions of the river in both Massachusetts and Rhode Island. The Blackstone River has had a long history of pollution problems associated with both industrial and municipal discharges and is considered a major source of pollutants to Narragansett Bay. Problems with water withdrawals and the regulation of river flows by the hydropower industry have also been identified.

In recognition of the importance of the Blackstone River both to the quantity and quality of water in Narragansett Bay, the Blackstone River Initiative was organized. The major component of this multi-phased initiative is a basin-wide assessment of the river, selected tributaries, and discharges which is being conducted by the U.S. Environmental Protection Agency-Region I and the Massachusetts Division of Water Pollution Control, in cooperation with the Rhode Island Department of Environmental Management and the University of Rhode Island (URI). The assessment is composed of two phases. Phase I, conducted during 1991 and the focus of this Interim Dry Weather Report of Data, documents dry weather conditions in the river and tributaries. Components of the survey include monitoring the chemistry and toxicity of effluent discharges, river water, and sediments, and evaluating the biological communities. Phase II will document and evaluate the river, tributaries, and discharges during a total of three storm events. Two storms were sampled during the fall of 1992. A third storm is scheduled for sampling during the spring of 1993.

Previous Studies

The Massachusetts portion of the Blackstone River has been extensively studied over the last 30 years by the Massachusetts Department of Environmental Protection's Division of Water Pollution Control. Approximately 30 reports have been produced on the water quality in the river and tributaries, the wastewater discharge quality, sediment analyses, wasteload allocations for dischargers, biological analyses, and management plans. Several studies on the Rhode Island portion have also been conducted by the State of Rhode Island, as recently as 1985 and 1989. These studies include the fate and transport of metals from the state line to Slater's Mill Pond. In recent years, the Narragansett Bay Project (NBP) has also funded numerous projects involving the analyses of these and other historical data as well as the generation of new data relative to the water quality of Narragansett Bay and the tributaries which contribute to the Bay.

Conclusions from these data indicate that the Blackstone River is a major source of pollutants to Narragansett Bay. Specifically, the Blackstone has been identified as the largest dry weather source of suspended solids, cadmium, lead, and nitrogen, and the second largest dry weather source of copper, nickel, and chromium to Narragansett Bay. Nitrogen driven productivity has been identified as the major component of the dissolved oxygen depletion in Narragansett Bay. Water quality criteria violations have been documented throughout the river for cadmium, copper, lead, and zinc, and at various locations for dissolved oxygen. Dissolved oxygen violations could likely be more severe under critical low flow conditions.

Potential water quality problems associated with the operation of hydroelectric facilities and water withdrawals have been identified. In addition, the resuspension at high flow of contaminated sediments located in the impoundments behind many of the dams has been identified as a major concern. These sediments were shown to be heavily laden with metals, organic compounds, and hydrocarbons. An evaluation of previous studies by URI resulted in a recommendation to conduct a comprehensive water quality sampling effort of the entire Blackstone River since no continuous data set existed for the Blackstone River from Worcester, MA to the Slaters Mill Dam in Pawtucket, RI. The assessment portion of the Blackstone River Initiative was organized to address these water quality and sediment concerns.

Blackstone River Assessment Phase I (Dry Weather Study-1991)

Phase I of the Blackstone River assessment is composed of three sections: the water quality of the river, tributaries and discharges; the toxicity of the water, discharges, and the sediments; and, the composition and "health" of the macroinvertebrate communities in the basin. This interim data report is the first report on the project, for the work completed to date. The report is divided into three chapters. Each chapter details the methods and results of each section listed above.

Six appendices are also available which provide the following information: laboratory data and quality assurance/quality control: chemistry and toxicity of selected effluents; methods of biological analyses; taxonomic listing of species collected; and sediment oxygen demand studies.

During the 1991 dry weather survey, water quality samples were collected along the Blackstone River at 15 locations in Massachusetts and Rhode Island, plus six tributaries (Quinsigamond River, Mumford River, West River, Mill River, Branch River, and Peters River). Effluent data from 12 dischargers, including the two largest by volume (Upper Blackstone Water Pollution Abatement District and Woonsocket Wastewater Treatment Plant), were obtained. Both river water and effluent water were assessed for toxicity and chemical content. Sediment toxicity and sediment pore water toxicity tests were performed on samples collected from seven locations in ponded areas behind dams on the Blackstone and Mumford Rivers. The "health" of the biological community was also assessed through analysis of the benthic macroinvertebrate populations at eight stations on the Blackstone mainstem and in two tributaries. In addition, sediment oxygen demand studies were conducted at 10 locations on the Blackstone River from Singing Dam in Sutton, MA to Albion Dam in Cumberland, RI.

Aerial photographs of the entire river were obtained to update information on land uses and wetland and aquatic resources. Geographical Positioning System (GPS), which uses satellite electronic telemetry, was used to fix the location of outfalls, dams, and other areas and features of importance. The Geographical Information System (GIS) was used to develop maps and to determine river mile locations of important features.

The Blackstone River Assessment Phase I-Dry Weather Study provides for the first time, an intensive interstate sampling and analytical program for the entire Blackstone River. It includes the first comprehensive toxicological analyses of ambient waters, effluents, and sediments, as well as the first analysis of the "health" of the benthic biological community for the length of the river.

Blackstone River Assessment Phase II (Wet Weather Study-1992 to 1993)

Phase II of the Blackstone River study consists of a comprehensive monitoring program for the entire river under wet weather conditions. The program includes monitoring approximately 20 stations for 3 separate storm events. Two storm events were completed in the fall of 1992 and the third is scheduled for the spring of 1993. For each storm, monitoring is conducted prior to the storm, during the storm, and after the storm until the river returns to pre-storm conditions.

These data, coupled with stream flow data, will enable the calculation of mass loadings for each storm for conventional and toxic pollutants and will enable an estimate of dry weather versus wet weather loadings. The major point sources (including CSO facilities) are monitored during each storm event to further divide the wet weather component into point sources and non-point sources. An attempt will also be made to determine that portion of the wet weather non-point source pollutant load component that is the result of resuspension of river sediments and that portion that is the result of new runoff.

The individual storm event data will be used to identify areas of concern relative to pollutant loadings from wet weather runoff. This information along with available information on land uses will enable the regulatory agencies to target the implementation of Best Management Practices and other abatement actions to reduce loadings to the river during wet weather.

Annual wet weather pollutant loadings for individual reaches of the river will be estimated based on the individual storm event data by using historical rainfall data. As in the individual storm events, the wet weather component of the total annual pollutant loads will be further separated into point sources and non-point sources depending on the availability of long term information from the major point sources. Also, as in the individual storm event data, an attempt will be made to determine that portion of the annual wet weather pollutant loads that is the result of resuspension of river sediments and that portion that is the result of new runoff. Projections of annual wet weather pollutant loadings of metals and nitrogen are of particular concern relative to the restoration of the Blackstone River, and to Narragansett Bay.

Summary

The data from the dry and wet weather studies will provide the baisis for a comprehensive evaluation of all the important water quality measures as well as some cause and effect relationships relative to point source and non-point source discharges. The dry-weather data will be used to develop mathematical models of the dissolved oxygen dynamics and the fate of metals in the Blackstone River. The models will be able to predict water quality under critical conditions, i.e., low receiving water flow and maximum permitted pollutant loads. The completed models can then be used to develop wasteload allocations for regulating the discharges to the Blackstone River to ensure that water quality standards for the river are met under critical conditions. The models will also be able to predict annual dry weather loadings of pollutants to Narragansett Bay. Of particular concern relative to Narragansett Bay is the pollutant loadings of metals and nitrogen. Data from the wet weather portion of the project will be used to estimate annual wet weather loads to the Blackstone River and Narragansett Bay to provide a comparison of wet versus dry weather loading. The information will also be used to prioritize restoration measures for the Blackstone River and Narragansett Bay, and to assist in targeting Best Management Practices for selected areas.

EXECUTIVE SUMMARY

1991 BLACKSTONE RIVER SURVEY

DRY WEATHER STUDY INTERIM DATA REPORT

Executive Summary
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1991 BLACKSTONE RIVER SURVEY
Executive Summary

This interim data report details the results of the first phase of a two phase project and is a comprehensive basin-wide assessment of the Blackstone River and selected tributaries during dry weather conditions. In recognition of the importance of the Blackstone River both to the quantity and quality of water in Narragansett Bay, the U.S. Environmental Protection Agency-Region I and the Massachusetts Division of Water Pollution Control, in cooperation with the Rhode Island Department of Environmental Management and the University of Rhode Island, have initiated a multi-year, interagency, and interstate project to assess the Blackstone River and selected tributaries. The dry weather portion of the project was conducted during 1991. The second phase, to be conducted during 1992-1993, encompasses a stormwater evaluation of the basin. Subsequent reports will detail the results of Phase II as well as an integrated analyses and assessment of the overall conditions in the Blackstone River basin. The information generated will be used to issue permits, identify present and potential problem areas, and recommend solutions.

Basin Information:

The Blackstone River flows from the city of Worcester, Massachusetts to the tidal waters of the Seekonk River in Pawtucket, Rhode Island. The total length of the river is approximately 48 miles with a drainage area of about 540 square miles. Roughly 70% of the drainage area is located in Massachusetts, the remaining 30% is located in Rhode Island (Figure 1). The river is an important natural, recreational, and cultural resource to both the State of Rhode Island and the Commonwealth of Massachusetts. In 1986, the United States Congress established the Blackstone River Valley National Heritage Corridor along portions of the river in both Massachusetts and Rhode Island. The Blackstone River is the second largest source of fresh water to Narragansett Bay, a productive and diverse estuary important for fishing, shellfishing, tourism, and recreation.

The river begins in the city of Worcester at the confluence of the Middle River and Mill Brook. Mill Brook originates at Salisbury Pond in Worcester and flows through an underground conduit until converging with the Middle River. The Blackstone flows through numerous impoundments of various sizes along the 48-mile length of the river. Fourteen significant dams are present on the mainstem (Table 1 and Figure 2) and several of these dams are used for hydropower generation. Six major tributaries to the Blackstone contribute approximately 33% of the total flow in the river during low flow, and 60% of the total flow during higher flow conditions. These tributaries include the Quinsigamond River, Mumford River, West River, Branch River, Mill River, and Peters River. Of these, the Mumford River and the Branch River contribute the majority of the total tributary flows to the main stem during low flow (9% and 15% respectively).

The Blackstone has a long history of pollution. First, textiles, later on, steel and wire and the metal finishing industry used the river for power and manufacturing and to discharge their waste. Since the early 1970's to the present, with the implementation of the federal permitting program, many dischargers have greatly improved their waste treatment technology and the river has shown substantial improvement. However, a number of problems do remain. The goals for the Massachusetts and Rhode Island portions of the river are to support a healthy and diverse aquatic community, to provide suitable wildlife habitat, and to provide primary and secondary contact recreation opportunities.

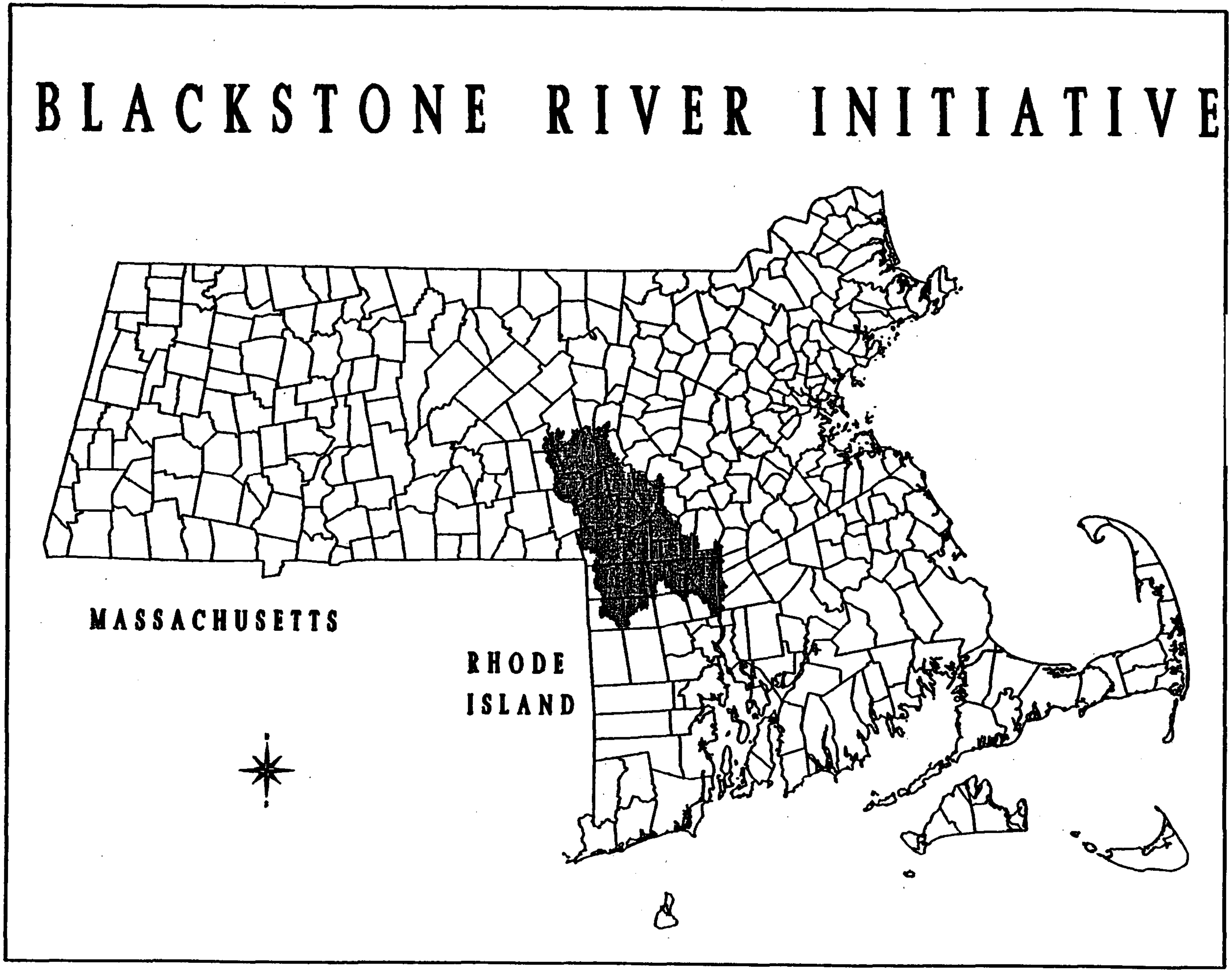
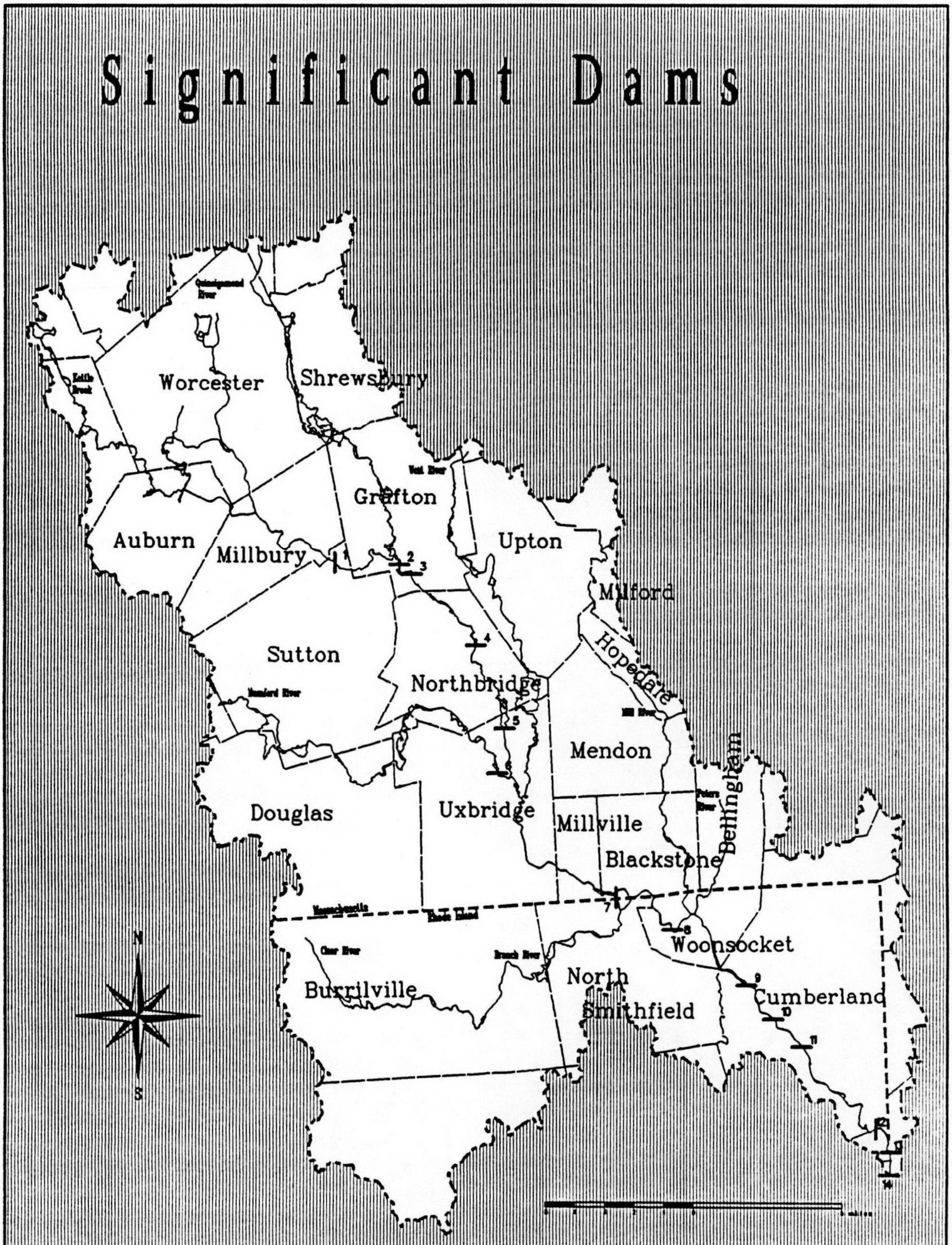


Figure 1
Blackstone River Survey 1991

Table 1
Blackstone River Survey 1991

SIGNIFICANT DAM LOCATIONS				
MAP NO.	NAME	TOWN	KM	MI
1	Singing Dam	Sutton	64.2	39.8
2	Fisherville Dam	Grafton	58.8	36.5
3	Farnumsville Dam	Grafton	57.4	35.6
4	Riverdale Dam	Northbridge	51.5	31.9
5	Rice City Pond Dam	Uxbridge	44.9	27.8
6	Uxbridge Dam (Mumford River)	Uxbridge	41.2:1.0	25.5:0.6
7	Tupperware Dam	Blackstone	28.8	17.8
8	Thundermist Dam	Woonsocket	23.0	14.3
9	Manville Dam	Cumberland	15.9	9.9
10	Albion Dam	Cumberland	13.3	8.2
11	Ashton Dam	Cumberland	11.0	6.8
12	Central Falls Dam	Cumberland	3.2	2.0
13	Pawtucket Dam	Pawtucket	1.3	0.8
14	Slaters Mill Dam	Pawtucket	0.0	0.0

Figure 2
Blackstone River Survey 1991



Phase I-Dry Weather Study: Objectives and Overview

The objectives of the Phase I-Dry Weather Project are to document dry weather conditions in the river and tributaries. Components of the survey include monitoring the chemistry and toxicity of effluent discharges, river water, and sediments, and evaluating the biological communities. The data from these surveys can be divided into those collected during the low flow months of July and August and those collected during the higher flow month of October. This report is divided into three chapters that detail sampling and results. These chapters are: ambient water quality and wastewater discharge data; toxicity of river water, discharges, and sediments; and the composition and health of the macroinvertebrate community.

During the 1991 dry weather survey, water quality samples were collected along the Blackstone River at 15 locations in Massachusetts and Rhode Island (Table 2 and Figure 3), plus six tributaries (Quinsigamond River, Mumford River, West River, Mill River, Branch River, and Peters River). Effluent data from 12 dischargers, including the two largest by rate of flow (Upper Blackstone Water Pollution Abatement District and Woonsocket Wastewater Treatment Plant) were obtained. Both river water and effluent water were assessed for toxicity and chemical content. Sediment toxicity and sediment pore water toxicity tests were performed on samples collected from seven locations in ponded areas behind dams on the Blackstone and Mumford Rivers (Table 3 and Figure 4). The health of the biological community was also assessed through the benthic macroinvertebrate populations at eight stations in the Blackstone mainstem and in two tributaries (Table 4 and Figure 4). Sediment oxygen demand studies were also conducted at 10 locations on the mainstem.

Aerial photographs for the entire river were obtained to update information on land uses and wetland and aquatic resources. Geographical Positioning System (GPS), which uses satellite electronic telemetry, was used to fix the location of outfalls, dams and other areas and features of importance. The Geographical Information System (GIS) was used to develop maps for the report and to determine river mile locations of various points of interest.

There are 37 permitted discharges to the Blackstone River and major tributaries. Twenty-one of these are in Massachusetts and 16 are in Rhode Island. Out of the 37 dischargers, 18 were identified for further consideration and review as part of the study (Figures 5 and 6 and Tables 5 and 6). Out of these dischargers, 12 were chosen for conducting whole effluent toxicity analyses with associated chemical analyses. Some whole effluent toxicity data was already available for most of the 6 discharges not selected. The Upper Blackstone Water Pollution Abatement District (UBWPAD) and the Woonsocket Wastewater Treatment Plant are the only two facilities for which comprehensive sampling was conducted during the study. The locations of the significant discharges relative to the various sampling stations are indicated in Figures 3 and 4.

Chapter 1 - Ambient Water Quality and Wastewater Discharge Data

Dissolved oxygen concentrations and percent saturation values met water quality standards at all mainstem (surface water) stations under low flow conditions with one exception (Station BLK 01 at Millbury St. during August at 4.9 mg/l). However, a number of values very near the quality standard of 5 mg/l for Class B waters were measured at several stations due to diurnal variations resulting from photosynthetic activity, especially in the impoundments. Rice City Pond had a low value of 5.6 mg/l during the night and a high value of 10.3 mg/l during the day in August. The highest value (12 mg/l) was seen at Riverdale St. Values above 10 mg/l were also recorded at McCracken Rd., Singing Dam, and the Fisherville Impoundment. For the tributaries, only the Mumford River showed early morning values in August below the 5 mg/l standard (4.4 mg/l and 4.7 mg/l). The Peters River showed dissolved oxygen

Table 2
Blackstone River Survey 1991

WATER QUALITY STATION LOCATIONS

STATION	DESCRIPTION	TOWN	KM	MI
BLK1	Millbury St.	Worcester	73.7	45.7
BLK2	McCraken Rd.	Millbury	70.7	43.9
BLK3	Riverlin St.	Millbury	66.6	41.3
BLK4	Blackstone St. (Singing Dam)	Sutton	64.2	39.8
BLK5:QR	Millbury St.	Grafton	59.2:3.4	36.7:2.1
BLK6	Route 122A	Grafton (Fisherville)	58.6	36.3
BLK7	Riverdale St.	Northbridge (Riverdale)	51.5	31.9
BLK8	Hartford St. (Rice City Pond)	Uxbridge	44.9	27.8
BLK9:MR	Mendon St. (Rt. 16)	Uxbridge	41.2:1.0	25.5:0.6
BLK10:WR	Hecla St. (Off Rt. 16)	Uxbridge (Centerville)	39.1:1.0	24.2:0.6
BLK11	Route 122 Bridge	Uxbridge	37.4	23.2
BLK12	Route 122 (First RR bridge south of Millville Center)	Millville	30.8	19.1
BLK13	Bridge St.	Blackstone	26.7	16.6
BLK14:BR	Route 146A	Forestdale	28.01:1.3	17.4:0.8
BLK15:MI	Privilege St.	Woonsocket	21.4:1.2	13.3:0.7
BLK16:PR	Route 114 (Diamond Hill Rd.)	Woonsocket	21.2:1.8	13.1:1.1
BLK17	Route 122 (upstream POTW)	Woonsocket	20.6	12.8
BLK18	Manville Hill Rd. (Main St.)	Cumberland	15.9	9.9
BLK19	School St./Albion Rd.	Cumberland (Albion)	13.1	8.1
BLK20	Whipple Bridge, Lonsdale Ave./Mendon Rd.	Cumberland (Lonsdale)	5.9	3.7
BLK21	Exchange St. (Old Slater Mill)	Pawtucket	0.3	0.2

Figure 3
Blackstone River Survey 1991

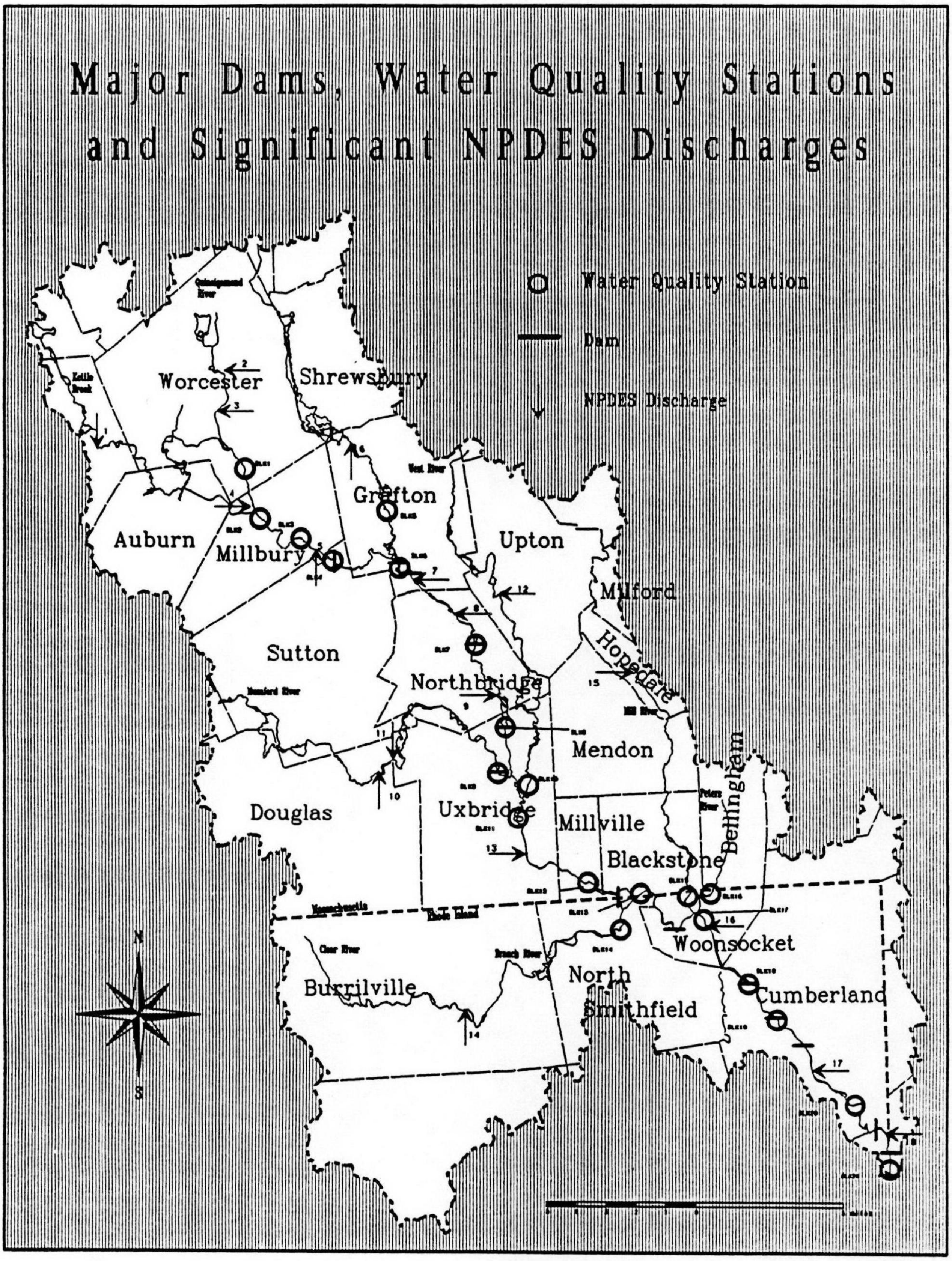


Table 3
Blackstone River Survey 1991

SEDIMENT SAMPLING STATION LOCATIONS				
STATION	DESCRIPTION	TOWN	KM	MI
SED1	Upstream Singing Dam	Sutton	63.9	39.6
SED2	Upstream Fisherville Dam	Grafton	59.1	36.6
SED3	Sutton Street (formerly Rockdale Pond)	Northbridge	54.2	33.6
SED4	Rice City Pond	Uxbridge	44.5	27.6
SED5	Upstream Blackstone Dam (Tupperware Dam)	Blackstone	28.9	17.9
SED6	Upstream Dam at Manville Hill Road	Manville	16.1	9.9
SED7	Upstream Slater Mill Dam	Pawtucket,RI	0.1	0.1
MSED1: MR	Mumford River (Gilboa Pond)	East Douglas	41.2:13.7	25.5:8.5
MSED2: MR	Mumford River (Grays Pond) off Manchaug Street	East Douglas	41.2:18.3	25.5:11.3

Figure 4
Blackstone River Survey 1991

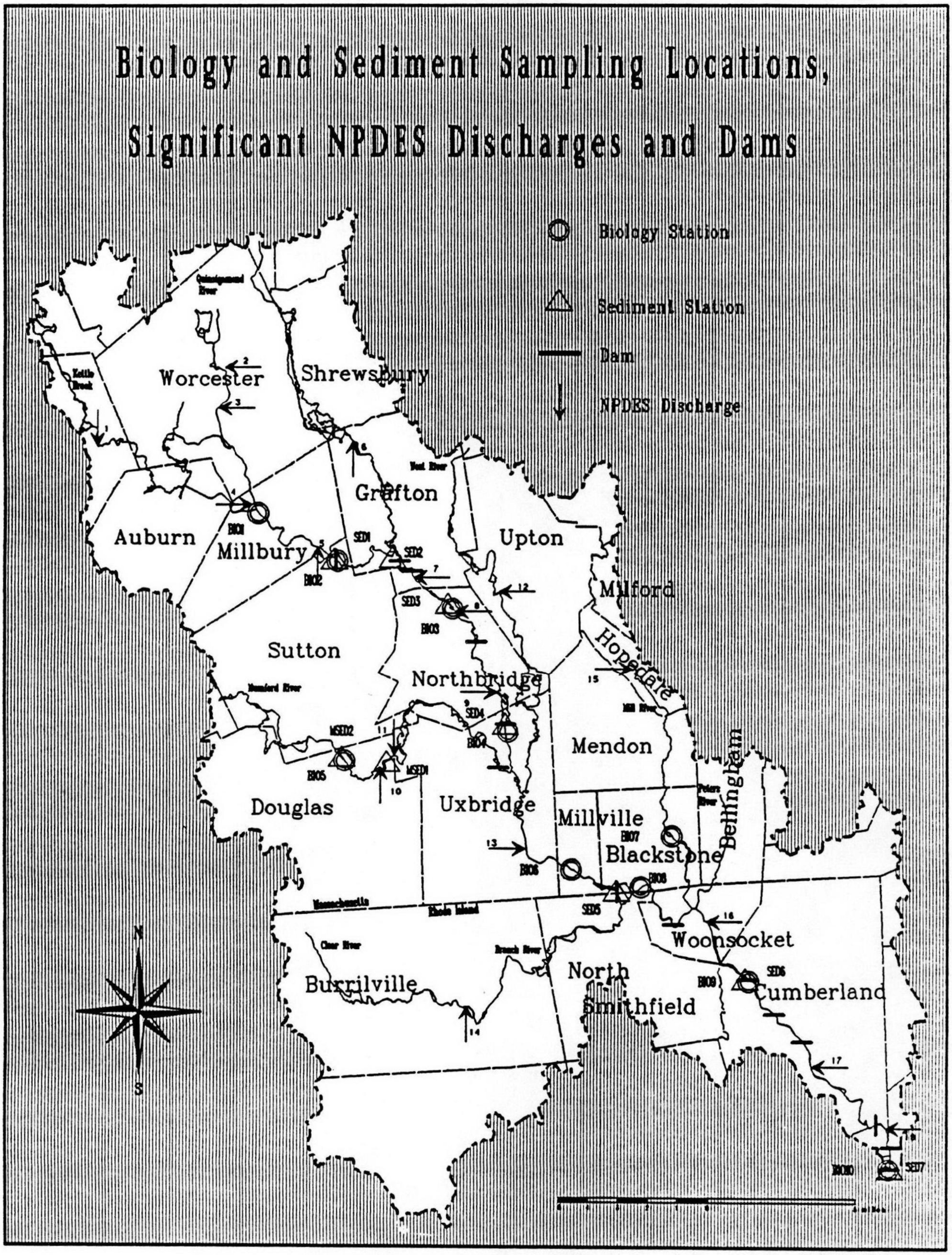


Table 4
Blackstone River Survey 1991

BENTHIC MACROINVERTEBRATE SAMPLING STATION LOCATIONS				
STATION	DESCRIPTION	TOWN	KM	MI
BIO1	Blackstone River in a riffle/run area located approximately 160 yards upstream of McCracken Road Bridge.	Millbury	71.0	44.0
BIO2	Blackstone River in a riffle/run area located approximately 70 yards downstream from Singing Dam.	Sutton	64.1	39.7
BIO3	Blackstone River in a deep riffle area located behind the Coz Chemical Company, upstream from the Sutton Street Bridge.	Northbridge	54.2	33.6
BIO4	Blackstone River in a run/pool/riffle area located behind an island downstream from the outlet of Rice City Pond, Hartford Avenue.	Uxbridge	44.2	27.4
BIO5	Mumford River in a riffle/run area located approximately 5 yards downstream from an unnamed bridge off of Manchaug Street at the outlet of Grays Pond.	East Douglas	41.2:18.0	25.5:11.1
BIO6	Blackstone River in a run/riffle area located approximately 90 yards upstream of Central Street Bridge.	Millville	31.9	19.8
BIO7	Mill River in a riffle/run/riffle area located approximately 70 yards upstream of Summer Street Bridge.	Blackstone	21.4:4.8	13.3:3.0
BIO8	Blackstone River in a riffle area located approximately 40 yards downstream from the Bridge Street Dam on First Avenue.	Blackstone	26.6	16.5
BIO9	Blackstone River in a run/riffle area located approximately 180 yards downstream from the Manville Hill Road Bridge.	Lincoln, RI	15.8	9.8
BIO10	Blackstone River in a run/riffle area located approximately 40 yards downstream from the Slater Mill Dam.	Pawtucket, RI	0.0	0.0

Table 5
Blackstone River Survey 1991

PERMITTED DISCHARGERS TO BLACKSTONE RIVER WATERSHED		
FACILITY NAME	**PERMIT NUMBER**	**RECEIVING WATER**
NORTON COMPANY	MA0000817	WEASEL BROOK
NEW ENGLAND PLATING	MA0005088	MILL BROOK
WYMAN GORDON - WORCESTER	MA001112	BLACKSTONE R.
MCCAULEY NAZARETH HOME	MA0025585	KETTLE BROOK
WORCESTER SPINNING & FINISHING	MA0004171	KETTLE BROOK
SIGNAL RESCO (WHEELABRATOR) MILLBURY	MA0029271	BROAD MEADOW BROOK
UPPER BLACKSTONE	MA0102369	BLACKSTONE R.
MILLBURY	MA0100650	BLACKSTONE R.
LEWOTT CHEMICALS	MA0028592	BLACKSTONE R.
WYMAN GORDON - N.GRAFTON	MA0004341	QUINSIGAMOND R.
WYMAN GORDON - MILLBURY	MA0001121	BONNY BROOK
GRAFTON	MA0101311	BLACKSTONE R.
COZ INDUSTRIES	MA0032549	BLACKSTONE R.
NORTHBRIDGE	MA0100722	BLACKSTONE R.
DOUGLAS	MA0101095	MUMFORD R.
GUILFORD INDUSTRIES	MA0001538	MUMFORD R.
UPTON	MA0100196	WEST R.
UXBRIDGE	MA0102440	BLACKSTONE R.
ZAMBARANO MEMORIAL HOSPITAL	RI0000129	CLEAR R.
BURRILLVILLE	RI0100455	CLEAR R.

Table 5 (cont.)

Blackstone River Survey 1991

FACILITY NAME	PERMIT NUMBER	RECEIVING WATER
TUREX, INC.	RI0000116	BRANCH R.
GLAS-KRAFT, INC.	RI0000906	BRANCH R.
PHILLIPS COMPONENTS	RI0000019	BRANCH R.
LIQUID CARBONIC CORP.	RI0021415	BRANCH R.
TUPPERWARE	RI0000566	BRANCH R.
BLACKSTONE-SMITHFIELD	RI0000485	BLACKSTONE R.
HOPEDALE	MA0102202	MILL R.
ACS INDUSTRIES	RI0021393	BLACKSTONE R.
WOONSOCKET WWTP	RI0100111	BLACKSTONE R.
WOONSOCKET WTP	RI0001627	BLACKSTONE R.
A.T. CROSS CO.	RI0000124	CROOK FALL BROOK
PACIFIC ANCHOR	RI0020451	BLACKSTONE R.
OKONITE	RI0020141	BLACKSTONE R.
PAWTUCKET WTP	RI0001589	ABBOTT RUN BROOK
ATTCUM PROPERTIES	MA0022381	BLACKSTONE R.
GTE PRODUCTS	RI0001180	BLACKSTONE R.
CUMBERLAND ENGINEERING	MA0000311	BLACKSTONE R.

Table 6

SIGNIFICANT NPDES DISCHARGES						
MAP NO.	NAME	NPDES PERMIT NO.	RECEIVING WATER	TOWN	KM	MI
1	Worcester Spinning & Finishing	MA0004171	Kettle Brook	Leicester	77.9:17.1	48.9:10.6
2	New England Plating	MA0005088	Blackstone R.	Worcester		
3	Wyman Gordon	MA0001112	Blackstone R.	Worcester		
4	UBWPAD	MA0102369	Blackstone R.	Millbury	71.4	44.4
5	Millbury WWTP	MA0100650	Blackstone R.	Millbury	65.5	40.7
6	Wyman Gordon	MA0004341	Quinsigamond R.	Grafton	59.2:10.3	36.7:6.4
7	Grafton WWTP	MA0101311	Blackstone R.	Grafton	57.0	35.4
8	COZ Chemical	MA0032549	Blackstone R.	Northbridge	53.9	33.5
9	Northbridge WWTP	MA0100722	Blackstone R.	Northbridge	47.0	29.2
10	Douglas WWTP	MA0101095	Mumford R.	Douglas	41.2:14.6	25.5:9.1
11	Guilford Industries	MA0001538	Mumford R.	Douglas	41.2:13.2	25.5:8.2
12	Upton WWTP	MA0100196	West R.	Upton	39.1:14.9	24.2:9.3
13	Uxbridge WWTP	MA0102440	Blackstone R.	Uxbridge	35.14	21.84
14	Burriville WWTP	RI0100455	Clear River	Burrilville	17.8	11.1
15	Hopedale WWTP	MA0102202	Mill R.	Hopedale	21.4:16.8	13.3:10.4
16	Woonsocket WWTP	RI0100111	Blackstone R.	Woonsocket	20.14	12.52
17	Okonite Industries	RI0020141	Blackstone R.	Ashton	9.43	5.86
18	GTE	RI0001180	Blackstone R.	Central Falls	2.78	1.73

Figure 5
Blackstone River Survey 1991

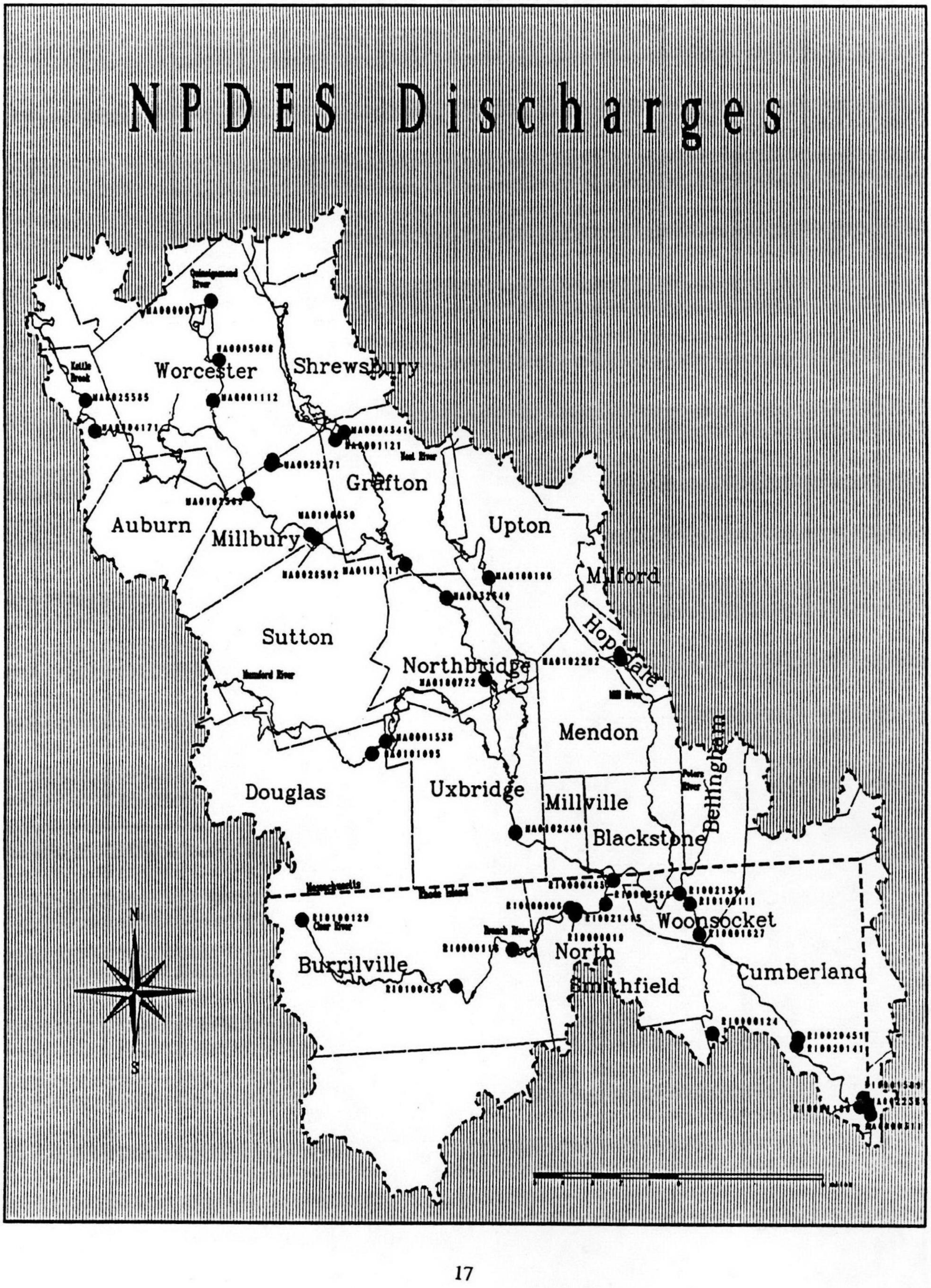
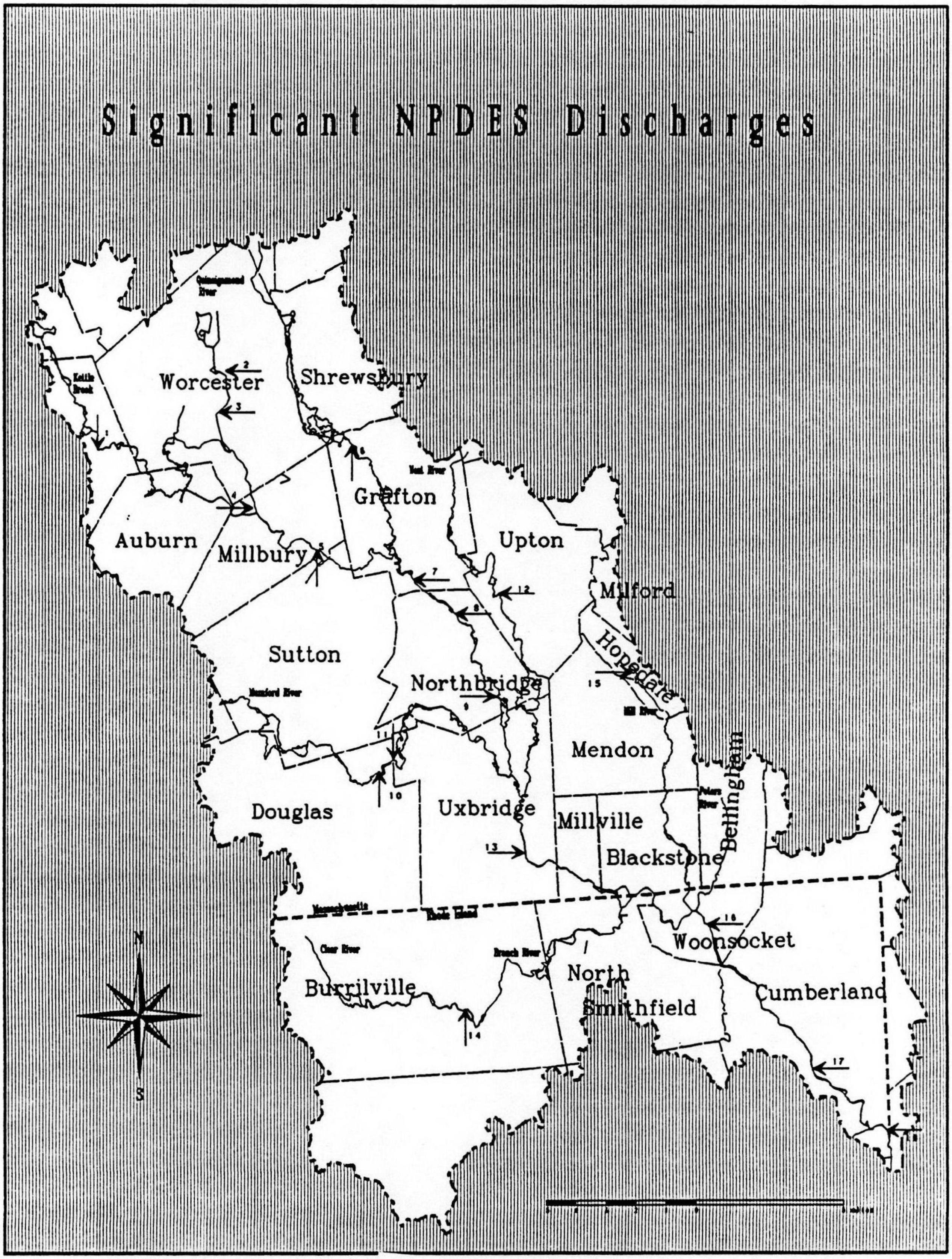


Figure 6
Blackstone River Survey 1991



violations with two values of 4.9 mg/l concentrations in July during the daytime. All values in October were above 7 mg/l in the mainstem and in the tributaries because of higher flows and cooler temperatures.

Of note is the fact that dissolved oxygen sags which might have occurred in impoundments below the UBWPAD and the Woonsocket WWTP discharges would have been missed because of access restrictions on sampling locations. Sampling stations in the vicinity of these impoundments were located immediately downstream of dams where any drops in dissolved oxygen. would have recovered because of reaeration over the dam. Mathematical modeling will be used to predict dissolved oxygen levels in the impoundments below the two major dischargers.

Large diurnal swings in pH outside of the water quality standards range were recorded at a number of stations with the largest ranges in the impoundments. Violations of pH are likely related to the excessive high levels of primary productivity as indicated by high chlorophyll a concentrations which are the result of elevated levels of phosphorus instream.

The data indicated that the river has marginal bacterial contamination at a number of locations along the mainstem, but is not grossly polluted. Also of note, was that the impact from the chlorinated effluent of the UBWPAD was seen in the water column downstream from the plant discharge at which point the bacterial levels were reduced to zero. High levels of fecal coliform bacteria (above the water quality standard of 400 organisms per 100 ml maximum for Massachusetts and 500 organisms per 100 ml maximum for Rhode Island) were seen at several locations along the mainstem and in one tributary. These stations included Millbury St. with the highest levels (1800-3500 colonies per 100 ml), Riverlin St. (20-1060 colonies per 100 ml), Singing Dam (300-2300 colonies per 100 ml), Fisherville Impoundment (120-900 colonies per 100 ml) and Slaters Mill Dam (140-560 colonies per 100 ml). Levels above the water quality standards of 200 colonies per 100 ml for geometric means were recorded at Millbury St., Riverlin St., Singing Dam, Fisherville, Hamlet Ave. in Woonsocket, and Lonsdale Ave. in Pawtucket. For the tributaries, only the Branch River (160-460 colonies per 100 ml) and Peters River (260-1060 colonies per 100 ml) exceeded both the maximum and the geometric mean standards.

Metals data from water chemistry sampling indicated that some metals exceeded water quality criteria at some locations. When compared to an upstream station at the low flow conditions of July and August a large increase was seen in the concentration and loading of metals (cadmium, copper, chromium, and nickel) below the Upper Blackstone Water Pollution Abatement District. Downstream of Rice City Pond, and to a lesser extent at stations below the Woonsocket treatment plant, there were also increases in metals loading. In general, the metals levels decreased substantially downstream of the UBWPAD, as the Blackstone River slowed through a series of impoundments. The process was reversed as the water flowed through Rice City Pond at which point the metals levels again peaked at the outlet, possibly indicating reintroduction of metals from river sediments. The metals levels continued to decrease to the Rhode Island border at which point the ambient water concentrations were again in the same range as amounts found in the river above the UBWPAD during low flow periods. Lead levels followed a different trend. Increased levels were seen in the Fisherville area and just above the state line. The metals levels tested during the higher flow conditions in October showed different trends. The quantity of metals in the river water were significantly higher than the low flow periods reflecting increased input, resuspension, and transport downstream.

Available nitrogen (ammonia and nitrate/nitrite) concentrations in the river increased substantially downstream of the Woonsocket Treatment Plant, from approximately 0.1 mg/l to 0.8 mg/l for ammonia and from 1 mg/l to over 2 mg/l for nitrate in August. Ammonia levels increased only slightly below the UBWPAD, while nitrate levels increased substantially, from about 0.7 mg/l to between 3 and 4 mg/l. The difference between the two facilities in terms of the form of nitrogen which is discharged reflect the type of treatment. The UBWPAD converts the ammonia to nitrate prior to discharge. Ammonia can result in instream toxicity to aquatic organisms and contributes to the depletion of dissolved oxygen in the river. Both ammonia and nitrate contribute to eutrophication in Narragansett Bay which has been identified as a major component of the dissolved oxygen sag in the upper Bay. Both facilities contribute large amounts of nitrogen to the river and subsequently to Narragansett Bay. The UBWPAD has a stringent discharge limit for ammonia and is in compliance with this limit; but no limit for nitrate is in the permit. The Woonsocket permit contains no discharge limit for ammonia or nitrate. Both facilities also discharge high levels of phosphorus to the river. Neither facility has a discharge limit for phosphorus.

The two largest dischargers to the river were each discharging considerably less than permitted flow levels during the surveys. During the two low flow surveys the oxygen demanding load discharged from Woonsocket was less than 1/2 of the permitted load while the oxygen demanding load discharged from UBWPAD was less than 1/6 of the permitted load.

Although on a concentration basis for metals there is no appreciable difference between the two discharges, except for nickel, the UBWPAD discharges substantially higher metal loads. In the Woonsocket effluent, nickel increases greatly between the pre-chlorination and post-chlorination samples.

The UBWPAD provides advanced treatment. The Woonsocket treatment plant provides standard secondary treatment prior to discharge. UBWPAD is producing a high quality effluent in terms of conventional pollutants but the discharge flow is large and the stream flow to which the plant discharges is very low.

Although the river flow was low during two of the three surveys, the study does not reflect critical conditions, i.e. maximum permitted pollutant loads and critical river flow and temperature. Mathematical modeling will be used to predict pollutant concentrations in the river during critical conditions.

Chapter 2 -Toxicity Testing

Effluent toxicity for the 12 discharges to the Blackstone Basin that were tested ranged from extremely toxic to essentially non-toxic depending on the source and type of discharge.

The surface water toxicity testing conducted during the 1991 survey on two freshwater species (one fish and one cladoceran) showed minimal toxicity in the water column based upon survival of the test fish at all stations. However fish growth was reduced in four out of 60 test samples (20 stations tested 3 times each). These included Fisherville-MA, Cumberland-RI (twice), and Pawtucket-RI. The results of the freshwater cladoceran tests indicated two occurrences (Mendon St. in Uxbridge and Rte. 122 in Uxbridge) of reduced survival and reproduction out of 60 test samples.

The sediment toxicity tests indicated that the Blackstone River sediments in many areas are very toxic. The whole sediment toxicity tests used two benthic organisms, midgefly larvae and amphipods. Both organisms showed significant impacts due to exposure to river sediments, depending on location and sample date. The amphipods overall were more sensitive than the midge larvae. Acute toxicity testing on sediment pore water produced significant mortality on minnows and daphnids at four locations; Singing Dam, Fisherville Pond, Rockdale Pond at Sutton St., and Tupperware Dam in Blackstone.

Chapter 3 - Macroinvertebrates

The macroinvertebrate taxa lists and the metrics derived from them all suggested the same general trend: the invertebrate community sampled at the most upstream station (located about one half mile downstream of the UBWPAD and downstream of the city of Worcester) was fairly degraded. The quality of the invertebrate assemblage improved dramatically between the first and second station (located about four miles downstream in Sutton). Between the second station and fourth station (located in Uxbridge) the community assemblages do not change as substantially, but do exhibit minor improvements. Between the BIO4 station and BIO6 station (in Millville), invertebrate community assemblages exhibit extensive improvements compared to upstream stations. Between BIO6 and BIO8 (located near the state line) the improvements are even more substantial. Across the state line and downstream of the city of Woonsocket, RI, the quality of the community assemblage degenerates. Metric values from samples collected from BIO9 (located in Lincoln, RI) all indicate a negative change in the quality of the benthic community as compared to those for BIO8; these regress even further at the second Rhode Island station, BIO10 (located in Pawtucket, RI). However, data on macroinvertebrate populations collected in 1991, compared with data collected in 1985, showed improvements at most stations. It should be noted that, due to the lack of an appropriate clean water reference station a detailed evaluation is limited to a comparison of the river stations to one another and not to a reference station with a healthy macroinvertebrate community.

Summary

In general, the study has shown so far that the sediments and the two treatment plants are major sources of pollutants contributing to levels above water quality standards, with significant transport of these materials downstream when the flows in the river increase. Ambient toxicity testing did not show the impact one would predict based on water quality criteria. Only 5% of the total ambient chronic tests performed showed potential for water column toxicity. Sediments on the other hand demonstrated greater potential toxicity. Effluent toxicity for the major dischargers to the Blackstone Basin ranged from extremely toxic to essentially non-toxic depending on the source and type of discharge.

The dry weather phase of the Blackstone River assessment provides, for the first time, an intensive interstate sampling and analytical program on the entire river. This up to date and comprehensive analysis of the extent and nature of water quality problems in the Blackstone River was deemed necessary so that environmental regulatory agencies could make informed decisions on the course of cleanup and required pollution controls. This program included the first comprehensive, toxicological analyses of ambient waters, effluent, and sediments for the Massachusetts and Rhode Island segments. Also included is the first analysis of the health of the benthic biological community for the length of the river. This data set will be used to conduct mathematical modelling for waste load allocations for metals, dissolved oxygen, and phosphorous as well as for modeling of nitrogen loads to Narragansett Bay. The data set will also be used for evaluating the appropriateness of water quality criteria.

The data will be combined with the information collected under the Phase II-Wet Weather Study to provide information both on the sources of pollution during both low flow conditions and wet weather and the ranking of the importance of these sources on a watershed-wide basis to assist in future permitting and abatement efforts.

A detailed discussion of the methods and results of the ambient water quality and wastewater discharge analysis, the toxicological analysis, and the benthic macroinvertebrate analysis can be found in the following chapters. The raw data as well as numerous data summaries are also included. The locations of water quality sampling stations, sediment sampling stations, and benthic macroinvertebrate sampling stations can be found in Tables 2, 3, and 4 respectively.

CHAPTER 1

1991 BLACKSTONE RIVER DRY WEATHER SURVEY

AMBIENT WATER QUALITY AND WASTEWATER DISCHARGE DATA

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Chapter 1
List of Tables and Figures

1991 BLACKSTONE RIVER SURVEY
Ambient Water Quality and Wastewater Discharge Data

In 1991, the Massachusetts Division of Water Pollution Control (DWPC), the U.S. Environmental Protection Agency, the University of Rhode Island, and the Rhode Island Department of Environmental Management sampled 21 water quality stations in the Blackstone River Basin. The stations (see Table 1-1 and Figure 1-1) included 15 on the mainstem (ten in Massachusetts and five in Rhode Island) and six tributaries (Quinsigamond River, Mumford River, West River, Branch River, Mill River and Peters River). Three two-day surveys were conducted on July 10 and 11, August 14 and 15, and October 2 and 3. In addition, effluent samples were collected at the two major dischargers, the Upper Blackstone Water Pollution Abatement District and the Woonsocket Treatment Plant, over a period of five days prior to the ambient river sampling. Additional effluent sampling was conducted on different dates at these two facilities and at ten (10) additional industrial and municipal facilities in the basin as part of the toxicity testing component of the project.

Methods

For the instream sampling, four sets of discrete grab samples were collected once every six hours, over the first 24-hour period for each of the three surveys. The samples were analyzed for five-day biochemical oxygen demand (BOD_5), total suspended solids, total volatile solids, chloride, total Kjeldahl-nitrogen, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, total and dissolved metals (cadmium, chromium, copper, lead, and nickel) and calcium and magnesium. Nitrogen and phosphorus levels are reported as mg/l of N and mg/l of P, respectively. Fecal coliform samples were collected during the 0400 run on the first day of each survey. In addition, surface grab samples for dissolved oxygen were collected every six hours over the 48-hour period. Temperature, pH, and conductivity readings were taken in the field concurrently with the D.O. samples. Additional surface dissolved oxygen values were taken on some dates for some stations downstream of dams. The stations were identified using the BLK code number with the designation of ".1" at the end. For example, BLK08 denotes sampling above the dam and BLK08.1 was the station below the dam. Samples were also collected for chlorophyll a analyses, on the 0400 and 1600 river runs, on the first day of each survey period.

Samples were collected using teflon buckets, and pre-cleaned plastic bottles provided by the University of Rhode Island. Samples were stored in iced coolers for transport.

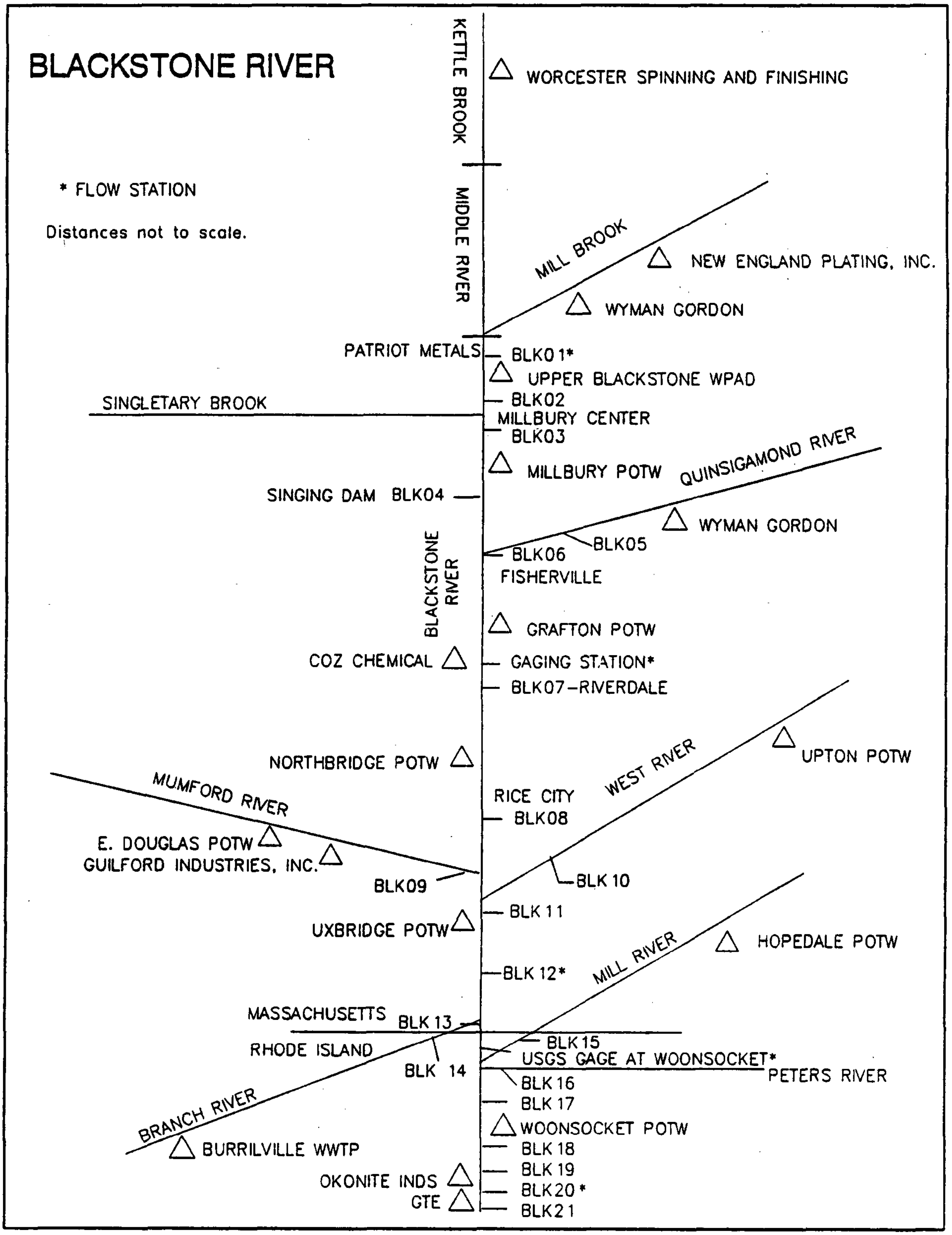
All samples were transported at the end of each survey run to the laboratory conducting the analyses, where samples were analyzed using methods approved by the EPA. Chemical, nutrient, metal, and chlorophyll analyses were conducted by the University of Rhode Island. Fecal coliform analyses were performed by the Massachusetts DEP Lawrence Experiment Station. Dissolved oxygen determinations were performed by the DWPC and EPA field personnel at the DWPC field office in Westborough, Massachusetts for the Massachusetts samples, and in Woonsocket, Rhode Island for the Rhode Island samples. A modified Winkler titration was used for the oxygen determinations. Backup field dissolved oxygen readings were also taken using a Yellow Springs meter. Instances in which it was necessary to use these meter readings in place of the Winkler method results are indicated in the tables. Meter readings were only substituted if water samples could not be taken, as the meter readings tended to be higher in some stretches of the river indicating interference probably as a result of chlorine. Temperature readings were taken in the field using a hand held thermometer. An Orion Research Model 211 digital field pH meter, calibrated prior to each survey run, was used for pH measurements.

Table 1-1
1991 Blackstone River Survey

LOCATION OF MONITORING STATIONS				
RIVER MILE	STATION NUMBER	RIVER	LOCATION	TOWN
Massachusetts				
45.7	BLK 01	Blackstone River	Millbury Street	Worcester
43.9	BLK 02	Blackstone River	McCracken Road	Millbury
41.3	BLK 03	Blackstone River	Riverlin Street	Millbury
39.8	BLK 04	Blackstone River	Blackstone Street (Singing Dam)	Sutton
36.7:2.1	BLK 05	Quinsigamond River	Millbury Street	Grafton
36.3	BLK 06	Blackstone River	Route 122A (Fisherville)	Grafton
31.9	BLK 07 (above dam)	Blackstone River	Riverdale Street	Northbridge
	BLK 07.1 (below dam)	Blackstone River	Riverdale Street	Northbridge
27.8	BLK 08 (above dam)	Blackstone River (Rice City Pond)	Hartford Road	Uxbridge
	BLK 08.1 (below dam)	Blackstone River	Hartford Road	Uxbridge
25.5:0.6	BLK 09 (above dam)	Mumford River (Route 16)	Mendon Street	Uxbridge
	BLK 09.1 (below dam)	Mumford River (Route 16)	Mendon Street	Uxbridge
24.2:0.6	BLK 10	West River	Hecla Street	Uxbridge
23.2	BLK 11	Blackstone River	Route 122	Uxbridge
19.1	BLK 12	Blackstone River	RR Bridge & 122	Millville
16.6	BLK 13	Blackstone River	Bridge Street	Blackstone
Rhode Island				
17.4:0.8	BLK 14	Branch River	Rte. 16A	Forestdale
13.3:0.7	BLK 15	Mill River	Privilege Street	Woonsocket
13.1:1.1	BLK 16	Peters River	Rte. 114/Diamond Hill Road	Woonsocket
12.8	BLK 17	Blackstone River	Rte. 122 (Upstream of WPOTW)	Woonsocket
9.9	BLK 18	Blackstone River	Manville Hill Road	Cumberland
8.1	BLK 19	Blackstone River	School St./Albion Rd. - Albion Bridge	Cumberland/ Albion
3.7	BLK 20	Blackstone River	Whipple Bridge on Lonsdale Ave.	Cumberland/ Lonsdale
0.2	BLK 21	Blackstone River	Exchange Street	Pawtucket

Figure 1-1
Blackstone River 1991

Schematic of Sampling Stations, Flow Stations, and Wastewater Dischargers



Instream flow measurements were taken in conjunction with the water quality sampling at four stations (Worcester, Northbridge, and Millville, Massachusetts, and Lonsdale, Rhode Island). Flow readings were also obtained from the U.S. Geological Survey (USGS) gages located at Northbridge, Massachusetts, Woonsocket, Lonsdale and Manville Dam, Rhode Island, the West River below the West Hill Dam in Uxbridge, Massachusetts, and on the Quinsigamond River. The instream flow measurements were collected by the USGS and the Massachusetts DEP by taking velocity readings and integrating over the cross-sectional area of the river. The velocity readings were taken either instream or from a bridge using the cable method. The flow data were entered into the Massachusetts Stream 7B Wasteload Allocation Model to develop flow profiles at each of the sampling locations for each of the surveys. The model, which had previously been developed for the Massachusetts segment only, was extrapolated to include the Rhode Island portion of the river for the hydraulic relationships only. The flows obtained through the Stream 7B model are preliminary and will be finalized once the Qual2EU model is developed by the University of Rhode Island for both the Massachusetts and Rhode Island segments of the river.

Effluent analyses were conducted on 24-hour composite samples collected daily for five days prior to the water quality surveys. The effluents were collected at the Upper Blackstone Water Pollution Abatement District Wastewater Treatment Plant in Massachusetts and the Woonsocket Wastewater Treatment Plant in Rhode Island. Samples were collected during the following periods: July 5-10 for Survey 1, August 9-14 for Survey 2, September 20-24, and September 30-October 2, 1991 for Survey 3. The September 20-24 sampling was terminated due to the onset of heavy rains. Some of these samples were analyzed. All wastewater treatment plant data for the Upper Blackstone and Woonsocket facilities appear in Tables 1-(27-46) both as concentrations and as pounds per day (#/day). Wastewater samples were handled and analyzed for the same parameters and by the same procedures as the instream samples.

Effluent samples were also collected from 12 dischargers in the Blackstone River basin as part of the toxicity testing at these facilities. Three (3) facilities were tested in Rhode Island: Okonite Industries, GTE, and the Woonsocket WWTP. In Massachusetts, the nine facilities tested were: Upper Blackstone WPAD in Millbury, MA, Uxbridge WWTP, Northbridge WWTP, Millbury WWTP, Guilford Industries in Douglas, MA, Douglas WWTP, Grafton WWTP, New England Plating in Worcester, MA, and Worcester Spinning and Finishing in Leicester, MA. Samples were not collected concurrently with the river surveys conducted during this study. Instead, the facilities were sampled once each during the summer of 1991, either during June or during August, except for the UBWPAD and the Woonsocket Wastewater Treatment Plant which were sampled twice. As part of this testing, the samples were analyzed by a laboratory under contract to the EPA, for aluminum, cadmium, calcium, chromium, copper, lead, magnesium, nickel, zinc, ammonia, total solids, total suspended solids, total organic carbon, and alkalinity. The data from this segment of the project appear in Appendix A.

Results and Discusssion

All laboratory data analyzed by the University of Rhode Island (URI) appear in Appendix B. Appendix C lists the quality assurance/quality control information. The field data for dissolved oxygen, pH, and temperature, and the bacterial data analyzed by the DEP Lawrence Experiment Station appear in Tables 1-(3-12).

The data analyzed by URI are organized by parameter and then by station. Because there were four data points for each instream parameter for each survey date, these data were averaged to produce one value for each day. In the calculation of daily mean concentrations, a decision was made for values reported on the laboratory sheets as 'less than the limit of detection,' to set these values equal to the limit of detection. The limits of detection used were specified by the University of Rhode Island, where the analyses were conducted. These limits are listed in Appendix B.

Graphs were produced for all instream parameters showing daily mean concentrations versus river mile for the surveys conducted in July, August, and October, from the upstream reaches in Worcester, Massachusetts to the Slater's Mill Dam in Rhode Island. Mean values were also calculated for the combined July and August survey dates since the flows for these two surveys were very similar. The concentrations measured for each parameter were then extrapolated, where appropriate, to pounds per day using flows calculated for each river station. Flows were calculated from instream measurements and formulas contained in the Massachusetts Stream 7B Wasteload Allocation Model for the Blackstone River. The flows, mean daily concentrations, and loadings appear in the accompanying tables. Graphs of loadings for each parameter at each station are also provided. (It should be noted that the graphs for dissolved oxygen, pH and some additional parameters should not be used to interpolate values between stations. The graphs were produced as the best method for visualizing comparisons between stations for the entire river length. Values may change dramatically between stations.)

Graphs were also produced for each of the six tributaries showing daily average concentrations, and loadings for each parameter at each tributary. Tables listing the data points for the graphs are attached. Flows for the tributaries were also derived either from the Stream 7B model or provided by the USGS from continuously recording gages on selected tributaries.

Identification of survey data in the tables and graphs is as follows. For the instream sampling, July 10 and 11 is Survey 1, August 14 and 15 is Survey 2, and October 2 and 3 is Survey 3. The wastewater discharge data are similar except for the additional 5 days of sampling conducted at the end of September. This survey period (September 20-24) is identified by date in the tables since it does not correspond to any of the instream sampling.

Hardness values were calculated by applying the formula contained in the *Standard Methods for the Examination of Water and Wastewater* (16th Edition) to the calcium and magnesium values measured instream. Tables and graphs of these hardness values are included together with a table showing ambient metal criteria for the Blackstone River and tributaries based upon the hardness levels.

In general, the flows measured instream for July and August were very low and although not at 7Q10 were close to 7Q2. 7Q10 is defined as the lowest flow over 7 consecutive days during any 10 consecutive year period. 7Q2 is defined as the lowest flow over 7 consecutive days during any 2 consecutive years. 7Q10 and 7Q2 in the Blackstone River at Northbridge, MA have been calculated by the United States Geological Service as 45 cfs, and 72 cfs, respectively. Flows during July/August at Northbridge developed through the Stream 7B model were 77.9 cfs. 7Q10 and 7Q2 flows in the Blackstone River at Woonsocket, RI have been calculated by the USGS as 101 cfs and 134 cfs. Flows calculated at Woonsocket through the Stream 7B model were 148.6 cfs. All field flow information and graphs of the river flow versus river mile appear as Table 1-47.

Flows for the month of October were four to five times higher than the first two surveys, and reflected the recent rains at the end of September which postponed the third survey. As a comparison, the flows during the October survey were approximately 50% higher than mean October flows. The two distinct river flows provide a unique comparison of river and effluent dynamics between base flow conditions and high flows for parameter concentrations and overall loadings, and show resuspension and transport dynamics during higher flows. In a review of all data, it should be noted that the study was not at critical conditions (maximum loading and low flow). Although the flow was low it was not at 7Q10, and the treatment plants were not discharging at capacity.

Dissolved Oxygen and pH

Dissolved oxygen, temperature, and pH data for the river and tributaries appear in Tables 1–(3-11) and are depicted graphically in Figures 1–(2-31).

Dissolved oxygen concentrations and percent saturation values met water quality standards at all mainstem stations under low flow conditions with one exception (Station BLK01 at Millbury St. during August at 4.9 mg/l). However, a number of values very near the Massachusetts and Rhode Island water quality standard of 5 mg/l for Class B waters were measured at several stations. In August, Rice City Pond had a low value of 5.6 mg/l during the night and a high value of 10.3 mg/l during the day showing the impact of biological activity in the impoundment. The highest value (12 mg/l) was seen at Riverdale St. Values above 10 mg/l were also recorded at McCracken Rd., Singing Dam, and at Fisherville. For the tributaries, only the Mumford River showed early morning values in August below the 5 mg/l standard (4.4 mg/l and 4.7 mg/l) and the Peters River exhibited two values of 4.9 mg/l in July. All values in October were above 7 mg/l in the mainstem and in the tributaries due to higher flows, cooler temperatures, and decreased biological activity.

The Massachusetts and Rhode Island water quality standards for percent saturation for dissolved oxygen differ. Massachusetts uses a value of 60% while Rhode Island uses a value of 75%. If the Massachusetts standard is used for the Massachusetts river segment no violations exist. If the Rhode Island standard is used for the Rhode Island portion station BLK20 falls below the water quality standard, for the July 10 and 11, and August 14 and 15 surveys.

It should be noted that any dissolved oxygen sag that might have occurred below the Woonsocket WWTP or the UBWPAD discharge would have been missed due to access restrictions on the location of the sampling stations. The first two water quality sampling stations below the discharge were located immediately downstream of dams where any D.O. sag would have recovered due to reaeration over the dam. The next sampling station (BLK20) is more than 6 miles below the discharge. Also, all dissolved oxygen samples were taken from surface waters. Therefore, in deeper impoundments any variability in dissolved oxygen values between surface and bottom waters would have been missed. Also, with regard to any dissolved oxygen sag, it must be remembered that although river flow was low, the study was not at critical conditions (i.e. maximum load and low flow of 7Q10).

A comparison of dissolved oxygen values with data collected in 1988 by the MDWPC for the upper and middle reaches of the Blackstone River show some improvement over the last few years. However, comparisons are difficult because during the 1991 survey, the flows and the ultimate oxygen demanding load from the UBWPAD were higher. The 1988 survey flows were slightly less than twice the 1991 flows. The 1988 data indicate D.O. violations in June at Millbury St., Worcester (<4 mg/l) and Hartford St., Uxbridge (<3 mg/l), and in August at Singleton St., Woonsocket (<4 mg/l) and Hartford St., Uxbridge (<5 mg/l).

Large diurnal swings in pH with some values outside of the Massachusetts water quality standards range of 6.5-8.3 standard units for Class B waters were recorded at a number of stations on the mainstem with the largest ranges in the impoundments. In most instances, pH measurements in the tributaries were within the water quality standards range. The most notable exceptions for the tributaries occurred on the August 14 survey during which time pH measurements were lower than 6.5 standard units. The pH standard used for Rhode Island was 6.5-8.0. Massachusetts standards also state that values will vary by not more than 0.5 units outside of the background range.

Bacteria

Fecal coliform data appear in Table 1–12. Bacteria data for the river are graphed as colonies per 100 ml versus river mile in Figure 1–32. Tributary levels are compared in Figure 1–33.

High levels of fecal coliform bacteria above water quality standards (400 colonies per 100 ml for the Massachusetts standard and 500 colonies per 100 ml for the Rhode Island standard) were seen at several locations along the mainstem and in one tributary. These stations included Millbury St. with the highest levels (1800-3500 colonies per 100 ml), Riverlin St. (20-1060 colonies per 100 ml), Singing Dam (300-2300 colonies per 100 ml), Fisherville (120-900 colonies per 100 ml) and Slaters Mill Dam (140-560 colonies per 100 ml). Levels above the water quality standards for geometric means (200 colonies per 100 ml for the Massachusetts and Rhode Island standards) were recorded at Millbury St., Riverlin St., Singing Dam, Fisherville, Hamlet Ave. in Woonsocket, and Lonsdale Ave. in Pawtucket. For the tributaries, only the Branch River (160-460 colonies per 100 ml) and Peters River (260-1060 colonies per 100 ml) exceeded both the 400 colonies per 100 ml water quality standard for 10 percent of the samples, and the 200 colonies per 100 ml standard for a geometric mean. Of note is the abrupt change in fecal coliform levels between the Millbury St. station (1800-3500 colonies per 100 ml) and the McCracken Rd. station (0-20 colonies 100 ml) showing the impact of the introduction of chlorinated wastewater from the UBWPAD.

Metals

Data tables listing mean daily concentrations, mean daily loadings, and flows, for the river and the tributaries are listed in Tables 1–(14-20). Graphs which display the values versus river miles, for the mainstem, and values compared among tributaries, appear as Figures 1–(36-55). Graphs of the loadings versus the river mile appear as Figures 1–(73-87). Hardness data appear in Table 1–13. Graphs of the hardness versus river mile appear in Figure 1–34. A comparison of hardness data among tributaries appears in Figure 1–35. Water quality criteria at different hardness levels is presented in Table 1–2.

The metals data were evaluated using a number of different approaches. First, the values were compared to water quality criteria to identify river reaches which exceeded federal and state standards. Secondly, a station by station comparison was made of the instream concentration by graphing river mile versus concentration. This provides a method for identifying areas which may contribute to instream levels or areas which act as temporary sinks or storage for materials. Thirdly, the concentrations of each parameter were extrapolated where appropriate to instream loadings. This provided an idea of the total quantity or loading instream at each station, and the amount either being transported downstream or the amount being deposited. The loadings allowed for a comparison of the July/August low flow survey information with the October higher flow survey.

In the comparison of metals data to water quality criteria, average daily values were compared to the water quality criteria rather than the discrete data collected at each six hour interval during the survey. This procedure moderates the effect of outlying data points. Use of this method precluded a judgement on whether to discard each data point that initially appeared high or low. Also, the data were graphed comparing the average value for the July survey, the average value for the August survey, and the average value for the October survey to the water quality criteria. On the same graph, the average value for the low flow period (July and August combined) was also presented. This allowed for two comparisons on the same graph: (1) the average value for each survey for July, August, or October to water quality criteria, and (2) a comparison of conditions during the low flow period (July and August) to conditions instream during higher flows.

During the low flow period of July/August, the graphs for concentrations of each metal are similar to the graphs for loadings for each metal. The metals data from the instream sampling showed a distinct pattern for cadmium, chromium, copper and nickel. In general, during the low flow conditions of July and August, cadmium, copper, and nickel concentrations and loadings were low at the first station and then increased substantially below the UBWPAD. The levels (concentrations and loadings) tended to decrease rapidly downstream as the metals appeared to precipitate out into the sediments in the impoundments. The process was reversed as the water flowed through the very shallow Rice City Pond at which point the metals concentrations again increased for cadmium, chromium, and copper, indicating reintroduction of metals from river sediments. This resuspension of solids can be seen by a comparison of the total and dissolved metals graphs, and the total suspended solids graphs. These graphs show a larger increase in total metals than dissolved metals, with the largest increase seen in chromium. The metals levels continued to decrease to the Rhode Island border at which point the levels were again similar to the background amounts found in the river above the UBWPAD during low flow periods. Chromium followed a similar pattern except that levels were highest at the most upstream station in Worcester. Lead graphs showed no distinct trends. Highest levels were seen in the Fisherville, Riverdale, and Rice City Pond areas and just above the state line. In Rhode Island, concentrations of all metals also increased slightly below the Woonsocket treatment plant but to a much smaller extent than seen in the Massachusetts segment.

During the October survey, the concentrations of metals were in most cases lower than, or the same as, the concentrations measured in the river during the lower flow surveys of July and August. The total quantities of materials instream were actually much larger but were masked by dilution from the prior heavy rains. A clearer comparison of the dynamics in the river is seen through a comparison of the loading graphs presented for each metal (Figures 1-(73-87)). These graphs adjusted for the difference in flows between the surveys. Two graphs are presented on each page. The upper graph shows the pounds per day for the July/August survey versus the river miles for a particular parameter. The lower graph shows the pounds/day for the October survey versus the river miles for the same parameter.

While the July/August loading graphs mimic the July/August concentration graphs, the October loading graphs are very different from the October concentration graphs and show different trends. The quantity of metals in the river water during October were significantly higher than during the low flow periods reflecting increased input, resuspension from sediments, and transport downstream. The same increase was seen in October as in July/August between station BLK01 and BLK02 with the introduction of metals from the UBWPAD, and also to a much smaller extent below the Woonsocket WWTP, but these increases which characterized the river during low flow periods were dwarfed by the much larger increases seen through the reintroduction of metals from the impoundments. This increase and transport is displayed for all five metals. The large increase began at Rice City Pond and continued to increase throughout the Massachusetts portion. At the state line, the levels again decreased. This could be due to settling taking place. Three tributaries enter at this point (the Branch, Mill, and Peters Rivers) but the introduction of this water should not affect the loadings other than to increase them. Only cadmium, chromium, and copper were reduced in loadings at the state line. The lead graph which displayed no distinct trends during the low flow period, followed the same trends in October as the other four metals. That is, an increase was seen beginning in the impoundments and increasing downstream. Lead levels remained low in the upper reaches of the river, then reached the highest peak for the entire river length downstream of the Woonsocket treatment plant (45 pounds/day compared to the 3 pounds/day in the upper reaches). Nickel levels dipped slightly at the state line and then continued to increase throughout the Rhode Island portion.

A comparison of metals levels with water quality criteria indicated that cadmium, chromium, copper, and lead levels exceeded ambient criteria at some locations. However, in an evaluation of the extent of metals concentrations above water quality criteria, it must be noted that water quality standards for metals are based upon water hardness. A hardness level of 50 mg/l was selected upon which to calculate the metals criteria for the mainstem stations. This level may not be protective for the central and lower stretches of the river which exhibit a lower hardness level due to the introduction of less buffered water from the tributaries. A table of acute and chronic water quality criteria is presented showing levels at 60 mg/l, 50 mg/l, 40 mg/l and 30 mg/l of hardness as a comparison for the mainstem stations (Table 1–2). A graph showing hardness levels versus river miles is also included (Figure 1–34). For the tributaries, water quality criteria are given for 30 mg/l for the Peters River, and 40 mg/l for the Quinsigamond River. Hardness values for the three remaining tributaries are as follows: 10 mg/l hardness for the Branch River, 15 mg/l hardness for the Mumford River and the West River, 20 mg/l for the Mill River. However, according to new regulations promulgated by the USEPA on December 22, 1992 in the Federal Register, any waters with a hardness value less than 25 mg/l, must use 25 mg/l in the calculation, as the formulas cannot be extrapolated below this value. A graph of the tributaries versus the hardness is presented (Figure 1–35).

Nickel levels remained below acute and chronic water quality criteria at all times, at all stations, on both the mainstem and in the tributaries. However, a seven-fold increase in nickel levels was measured below UBWPAD as compared with upstream levels.

Chromium levels instream were compared with Cr+6 chronic water quality standards since there are no water quality standards for total chromium. Only two locations on the mainstem (above UBWPAD and in Rice City Pond) exceeded chronic criteria. Chromium concentrations never exceeded acute criteria in the mainstem nor acute or chronic criteria in the tributaries. Of note, compared to the patterns for other metals, were the elevated levels of chromium found in the river as it flowed through the city of Worcester above the UBWPAD. (Chromium(+6) water quality criteria are not based upon instream hardness levels.)

Cadmium levels in the mainstem exceeded chronic water quality criteria at all Massachusetts stations except for the most upstream station sampled, and also exceeded chronic criteria levels at the first station sampled below the Woonsocket treatment plant. Cadmium acute water quality criteria were exceeded at the first three stations below UBWPAD. Cadmium levels in the tributaries exceeded chronic criteria on one survey in the West River and on one survey on the Peters River. Acute criteria were not exceeded in the tributaries.

Copper levels exceeded acute and chronic water quality criteria at all Massachusetts stations with the highest levels found below UBWPAD and Rice City Pond. Copper levels were slightly elevated above chronic criteria in all Rhode Island stations, but acute criteria were only exceeded at the first two sampled. In the tributaries, copper levels exceeded acute and chronic criteria in the Mumford River, the West River, the Branch River and the Peters River. Chronic criteria were exceeded in the Mill River.

Lead levels in the mainstem exceeded chronic criteria at all stations, and exceeded acute criteria at two stations, Fisherville and Riverdale. For the tributaries, acute criteria lead levels were exceeded on the Mill River. Chronic criteria for lead were exceeded on all the tributaries for all sample dates.

Nutrients, Chlorophyll, and BOD

Ammonia, nitrate, TKN, phosphorus, chlorophyll a, and BOD daily average values, and loadings appear in Tables 1–(21-25) with the chloride and solids data. The data were graphed as concentration versus river mile as follows. Ammonia and nitrate are in Figures 1–(62-65) for concentrations, and Figures 1–(88-90) for loadings. BOD levels are in Figure 66, and loadings are in Figures 1– 91 and 1–92. Phosphorus and chlorophyll appear in Figures 1–(56-61) and Figures 1–(95-97).

Chlorophyll levels indicated abundant growth, during the months of July and August, in the impoundments where river flows slowed and the river widened and became more shallow. Also of note were the high levels at stations 11, 12, 18, 19 and 20. Growth was highest in the Riverdale and Rice City Pond impoundments, at which points advanced eutrophication was evident. Lower growth was evident in the upper reaches where velocities were higher. The highest levels were measured at the first two Rhode Island stations below the Woonsocket treatment plant with values between 20 and 25 µg/l. Overall, planktonic growth was abundant in July, moderate in August, and low during the cooler, higher flow period of October. These growth levels likely accounted for the large diurnal swings in pH and dissolved oxygen seen in July and the moderate diurnal ranges in August. The lowest fluctuations were seen in October. In general, highest pH values were measured during the late afternoon and lower values were measured in the early morning.

Dissolved phosphorus levels were very high in the upper reaches with values exceeding above 1 mg/l downstream from the UBWPAD. The values remained high at the next few stations, and then dropped to lower levels in the impoundments where the biological community removed this available phosphorus to produce organic matter. Levels of phosphorus in these segments were 0.2-0.5 mg/l, while chlorophyll levels rose from <0.3 µg/l to around 20 µg/l. The increased growth in the impoundments was evidenced in the high levels of chlorophyll produced by the planktonic community. (Total phosphorus was not measured during this survey.) Peaks in ortho-P were evident at McCracken Road where levels were 100 times the values measured at the nearest upstream station, and below Woonsocket WWTP where values were more than five times those recorded at the next upstream station during August.

Total Kjeldahl nitrogen levels were not graphed due to the low levels recorded. Most values were below the limit of detection of 1 mg/l.

Ammonia concentrations in the river appeared to be more impacted by the Woonsocket treatment plant than the UBWPAD during low flows. Levels increased substantially downstream of the Woonsocket treatment plant to over 1 mg/l, and increased to a lesser extent downstream of the UBWPAD to about 0.6 mg/l. Ammonia concentrations appeared high (>0.5 mg/l) in the first station sampled and continued to increase slightly up to Singing Dam, and reflected the input from the Millbury treatment plant. The concentrations of ammonia below the Woonsocket treatment plant appeared to be much higher in the low flow months than in the higher flow months, in contrast to the UBWPAD where concentrations were about the same during the low and high flow surveys. Ammonia loadings below the Woonsocket treatment plant reached 850 pounds/day as compared with less than 400 pounds/day below UBWPAD during the July/August survey. In October, the ammonia loadings below Woonsocket were near 800 pounds/day while below the UBWPAD the levels were just under 300 pounds/day.

In contrast, nitrate appeared to be much more evident below the UBWPAD reaching near 4 mg/l at McCracken Rd. and between 4 and 5 mg/l at the next two downstream stations as nitrification occurred (during which ammonia was converted to nitrate). During the October survey, nitrate concentrations below UBWPAD were much lower than during July and August. These lower nitrate levels were seen for the entire river length in Massachusetts and Rhode Island. A review of the graphs of pounds/day for ammonia and nitrate in the Rhode Island section (Figures 1–(88-90)) showed the impact of the Woonsocket treatment plant on the ammonia levels and the subsequent increase in nitrate levels throughout the lower portion of the river to Slater's Mill Dam as nitrification occurs. During July and August, nitrate levels reached over 2000 pounds/day at the last station as compared with about 900 pounds/day above Woonsocket. The dynamics of nitrate loading during October in the lower stretches of the river are not as clear. A large increase is seen at river miles 19.1 and 16.6 (with values ranging near 3700 pounds/day), with another large increase at Slaters Mill Dam (from 1400 to 3700 pounds/day). The upper stretches of the river remain fairly low with values around 300 pounds/day.

Biochemical oxygen demand was low to moderate throughout the river length with increases seen again in Rice City Pond, and downstream through the next two river stations, and then again at the two stations below Woonsocket. The highest value recorded was 3 mg/l and occurred below Woonsocket. The values for BOD showed improvement in the Massachusetts portion, if compared to the 1988 MDWPC survey, during which times levels reached as high as 8 mg/l in one section of the river. BOD loading graphs for the July/August and the October surveys (Figures 1–91 and 1–92) indicated the same trends (i.e. relatively lower levels in the upstream portions, then increased production and resuspension of organic material as the water passed through Riverdale and Rice City Pond with continuing increases downstream for the entire length).

Solids and Chloride

Total suspended solids, total volatile solids, and chloride mean daily values and loadings appear in Tables 1–22 and 1–26. Graphs of the data versus river mile are presented in Figures 1–(67-72) for concentrations, and Figures 1–93 and 1–94 for loadings.

Total suspended solids and total volatile solids concentrations also exhibited a pattern similar to the total chlorophyll levels with the highest values measured in Rice City Pond (between 10-12 mg/l and over 4 mg/l, respectively). Organic matter made up less of a percentage of the solids component at Rice City Pond (even with the tremendous spike seen in TSS and TVS levels at this station) than at the station below the UBWPAD, showing the contribution of resuspended sediments from this shallow impoundment to the water column. The TSS and TVS graphs for loadings showed the increases in solids input from the impoundments during low flows again being dwarfed by the very large increases during higher flows, with transport downstream rather than settling taking place. At some locations, the increase in October of TSS and TVS was 4-5 times the amount seen during the lower flow survey.

Chloride concentrations were very high during the July and August surveys, from the most upstream river station (over 120 mg/l) downstream to Rice City Pond, showing the impact to the river from the city of Worcester and the input of the treatment plants. Another peak was measured just over the state line in Rhode Island where values reached to 90 mg/l. During the October survey, chloride concentrations were lower, showing the effects of dilution.

Effluents

Wastewater treatment plant data for the Upper Blackstone Water Pollution Abatement District and the Woonsocket Treatment Plant appear in Tables 1–(27-46).

The two largest dischargers to the river were each discharging considerably less than permitted flow levels during the surveys. During the two low flow surveys the oxygen demanding load discharged from Woonsocket was less than 1/2 of the permitted load while the oxygen demanding load discharged from UBWPAD was less than 1/6 of the permitted load. Both facilities discharge high levels of phosphorus and nitrogen to the river. The nitrogen discharged from UBWPAD is mostly in the form of nitrate while the nitrogen discharged from Woonsocket includes high levels of ammonia. Ammonia can result in toxicity to aquatic organisms and also contributes to the depletion of dissolved oxygen in the river. Both ammonia and nitrate contribute to eutrophication in Narragansett Bay which has been identified as a major component of the dissolved oxygen sag in the upper Bay. Neither facility has a discharge limit for phosphorus or for nitrate. The UBWPAD has a stringent discharge limit for ammonia with which it is in compliance. The Woonsocket permit contains no discharge limit for ammonia. Although on a concentration basis for metals there was no appreciable difference between the two discharges except for nickel, the UBWPAD discharged higher metal loads, except under some conditions for nickel. In the Woonsocket effluent, nickel increases greatly between the pre-chlorination and post-chlorination samples. The UBWPAD provides advanced treatment due to the large volume of flow that is discharged to a relatively low stream flow. Woonsocket provides standard secondary treatment prior to discharging.

Summary

1. Although the river was not at critical conditions (i.e. low streamflow of 7Q10 and maximum effluent discharge), flows were close to 7Q2, and the surveys encompassed both high and low flow periods thereby allowing for a comparison of river dynamics under baseline and high flow conditions. During the 1991 study, the UBWPAD and the Woonsocket Wastewater Treatment Plant were discharging within the NPDES permit effluent guidelines.

2. In general, the instream water quality data demonstrate that the sediments and the two treatment plants are major sources of metals and nutrients. These sources contribute to metals levels above water quality standards. The treatment plants and inputs from Rice City Pond appear to be the dominant features during low flow conditions. During higher flows, runoff and resuspension of metals and significant transport of these materials downstream appear to be the dominant characteristics.

3. Blackstone River water column metal concentrations were very high in some segments for some metals. Total metal concentrations were compared with water quality criteria. Copper levels exceeded acute and chronic water quality criteria at all Massachusetts stations. Chronic levels were exceeded in Rhode Island at all stations, but acute criteria were exceeded only at the first two. Chromium levels only exceeded chronic criteria at two stations. There appeared to be a chromium source above the first Massachusetts station. Cadmium levels exceeded chronic criteria at all Massachusetts stations except the first one, and exceeded criteria below Woonsocket. Lead levels exceeded chronic criteria at all stations and acute criteria at Fisherville and Riverdale. Nickel levels remained below acute and chronic water quality criteria levels at all times in the Blackstone River and tributaries.

4. Comparison with 1988 data shows some improvement in dissolved oxygen concentrations instream, although comparisons are difficult between the two data sets since 1988 flows were higher and the ultimate oxygen demanding loads were higher. However, large diurnal swings in D.O. and pH are evident throughout, with the worst exhibited in the impoundments. These result from a combination of decomposition of deposited organic matter and increased algal productivity due to increased nutrients. Even with these large diurnal swings, few exceedences for D.O. outside of water quality standards were evident in either the mainstem or the tributaries. Many more values outside water quality standards were seen for pH than D.O.

5. Elevated fecal coliform counts in the water above the UBWPAD result from sources in the city of Worcester. Further downstream, unknown sources have resulted in high bacterial levels in Singing Dam, Riverlin, Fisherville, and Slaters Mill Dam areas. Chlorinated wastewater and instream residual chlorine from the UBWPAD have reduced bacteria levels in the river at the next downstream station to near zero.

6. Biologically available phosphorus levels are very high below the UBWPAD, but do not exhibit an impact on the river in the upper reaches until the flow begins to slow in the impoundments. Uptake of phosphours at this point is very rapid and indicated by the increase in the planktonic community chlorophyll levels. High ortho-phosphorus levels were recorded from the Woonsocket treatment plant to Slater's Mill Dam.

7. Discharge from the Woonsocket treatment plant appears to be a dominant factor in instream ammonia levels downstream. Discharge from the UBWPAD raised nitrate levels instream. The difference between the two plants of whether ammonia was discharged or nitrate was discharged reflected different types of wastewater treatment. The UPWPAD processes convert the ammonia to nitrate prior to discharge. Nitrate creates less of an oxygen demand in the river water. Ammonia levels also appeared elevated below the Millbury plant.

8. The UBWPAD discharge met permit limits during this study. However, the flow in the river to which the plant discharges is very low in these upper reaches, offering little dilution. Therefore, the characteristics of the effluent determine the characteristics of the river at this point. During the July/August low flow surveys, the UBWPAD was 74% of the river flow. During the higher flow survey in October, the UBWPAD was 45% of the total river flow.

9. The Woonsocket treatment plant is a determining factor in the characteristics of the Rhode Island portion of the river. The flow to which the plant discharges is large. During the July/August surveys, the Woonsocket Treatment Plant is 6% of the total river flow. During October, the Woonsocket plant is 2 % of the total river flow. The river is transporting high levels of nutrients and metals at this point from upstream sources, especially during high flow situations. However, these upstream sources alone do not account for the magnitude of the increase measured below the Woonsocket treatment plant.

10. The Blackstone River impoundments, except for Rice City Pond, act as settling basins for solids, nutrients, and metals from point and non-point sources during low flow periods. Rice City Pond acts as a source even during low flows. These impoundments then become significant sources of these constituents, with resuspension of deposited material during higher flows.

WATER QUALITY CRITERIA
(μg/l)

		HARDNESS				
		60 mg/l	50 mg/l	40 mg/l	30 mg/l	25 mg/l
CADMIUM	Chronic	0.76	0.66	0.55	0.44	0.38
	Acute	2.2	1.88	1.4	1.0	0.82
CHROMIUM (+6)	Chronic	11	11	11	11	11
	Acute	16	16	16	16	16
CHROMIUM (+3)	Chronic	136	117	98	77	67
	Acute	1143	984	820	648	558
COPPER	Chronic	7.6	6.5	5.4	4.2	3.6
	Acute	11	9.2	7.5	5.7	4.8
LEAD	Chronic	1.7	1.3	0.99	0.69	0.54
	Acute	43	34	25	18	14
NICKEL	Chronic	102	88	73	57	49
	Acute	921	789	653	512	439

Table 1-3
Blackstone River Survey 1991

DISSOLVED OXYGEN (mg/l)									
STATION	RIVER MILE	JULY 10				JULY 11			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	6.4	7.7	7.8	6.4	6.4	7.1	8.3	6.5
BLK02	43.9	6.3	7.2	7.2	6.4	6.8	7.2	8.2	6.7
BLK03	41.3	7.5	7.9	8.0	7.4	7.3	7.9	7.9	7.5
BLK04	39.8	8.1	8.1	8.0	7.9	8.0	8.0	7.8	8.0
BLK06	36.3	7.1	8.4	8.5	7.3	7.1	8.1	8.7	7.4
BLK07	31.9	7.3	7.6	10.0	9.2	7.9	10.5	12.7	8.8
BLK07.1							8.3	8.5	
BLK08	27.8	6.1	9.8	13.0	6.9	6.0	10.2	12.9	7.9
BLK08.1							9.4	10.5	
BLK11	23.2	6.6	9.6	9.5	6.4	6.9	9.6	10.2	7.4
BLK12	19.1	6.9	11.2	11.5	8.2	7.0	12.0	11.8	8.4
BLK13	16.6	8.2	10.7	11.0	9.3	9.1	12.0	12.2	9.9
BLK17	12.8	7.5	9.5	8.9	7.1	7.3	9.4	8.8	7.0
BLK18	9.9	8.0	8.0	7.9	8.0	8.1	8.0	8.0	7.7
BLK19	8.1	7.6	8.1	8.0	7.3	7.2	7.9	7.8	7.3
BLK20	3.7	5.6	8.1	9.1	6.4	5.3	8.5	10.2	6.4
BLK21	0.2	7.0	8.9	9.0	7.2	7.3	8.7	9.2	6.8
TRIBUTARIES									
BLK05	36.7,2.1	6.0	6.8	7.0	5.5	5.7	6.5	6.8	5.4
BLK09	25.5,0.6	5.4	7.1	8.0	8.6	5.5	6.1	10.0	8.8
BLK09.1		7.6	7.8	10.0	7.8	7.5	7.7	8.0	8.2
BLK10	24.2,0.6	6.3	6.9	7.0	6.0	6.3	6.5	7.5	6.2
BLK14	17.4,0.8	7.2	7.7	7.8	6.9	7.0	8.0	7.9	7.1
BLK15	13.3,0.7	6.8	8.1	7.9	6.7	7.8	8.1	7.9	6.6
BLK16	13.1,1.1	5.1	4.9	6.2	4.9	5.2	5.3	6.7	5.4

Table 1-4
Blackstone River Survey 1991

DISSOLVED OXYGEN (mg/l)

Note: Meter readings were used for Stations 2, 3, 4, 5, 6, 7, 8 and 9.1 on August 14 at 1000 hr.

STATION	RIVER MILE	AUGUST 14				AUGUST 15			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	6.2	7.2	7.2	5.9	6.0	6.9	7.0	4.9
BLK02	43.9	6.2	10.2	7.5	6.3	6.0	7.2	7.4	6.4
BLK03	41.3	7.1	10.1	7.7	7.1	7.0	7.8	7.9	7.4
BLK04	39.8	7.8	10.2	7.8	7.4	7.2	7.7	8.0	7.7
BLK06	36.3	7.2	10.0	8.1	7.0	6.8	7.9	8.3	7.4
BLK07	31.9	7.4	9.3	12.0	8.8	7.9	7.0	7.9	8.0
BLK07.1									
BLK08	27.8	6.2	10.0	10.3	6.2	5.6	7.9	9.4	6.3
BLK08.1			9.9				7.9	8.9	
BLK11	23.2	6.4	8.8	7.7	6.8	6.4	7.8	8.5	6.9
BLK12	19.1	6.3	9.3	9.3	6.9	6.2	7.5	9.7	7.7
BLK13	16.6	7.3	8.9	8.8	8.0	7.4	8.5	9.0	8.1
BLK17	12.8	7.4	8.7	8.5	7.1	8.0	8.1	8.8	7.1
BLK18	9.9	7.7	7.4	7.8	7.8	7.6	7.5	7.4	7.5
BLK19	8.1	7.7	8.0	7.7	7.4	7.1	7.6	7.5	7.2
BLK20	3.7	6.2	9.1	9.0	6.5	5.5	6.5	8.3	6.4
BLK21	0.2	7.3	9.2	8.8	7.3	7.1	7.5	8.6	7.2
TRIBUTARIES									
BLK05	36.7,2.1	6.3	10.2	6.9	5.9	5.8	7.1	6.9	5.9
BLK09	25.5,0.6	4.7	9.6	9.0	5.6	4.4	5.7	8.2	6.8
BLK09.1		7.3	8.7	7.7	7.2	7.2	7.2	7.5	7.6
BLK10	24.2,0.6	6.0	6.2	5.8	5.8	5.6	5.8	5.9	5.9
BLK14	17.4,0.8	6.9	7.5	7.8	6.6	6.8	7.2	7.7	6.8
BLK15	13.3,0.7	6.6	8.3	7.3	6.4	6.4	7.5	7.8	6.8
BLK16	13.1,1.1	6.4	6.1	6.4	5.6	5.6	5.8	5.8	5.1

Table 1–5
Blackstone River Survey 1991

DISSOLVED OXYGEN (mg/l)

STATION	RIVER MILE	OCTOBER 2				OCTOBER 3			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	9.2	8.6	8.5	8.1	8.4	8.7	8.5	8.2
BLK02	43.9	8.0	7.9	7.9	7.7	7.6	8.1	7.7	7.6
BLK03	41.3	8.6	9.0	8.5	8.1	8.5	8.1	8.5	8.3
BLK04	39.8	9.1	9.2	8.8	8.8	8.8	9.0	8.8	8.9
BLK06	36.3	8.8	9.0	8.7	8.6	8.5	8.3	8.7	8.3
BLK07	31.9	8.4	8.1	8.8	8.1	7.6	8.3	8.1	8.0
BLK07.1		9.1	9.0	8.9		8.7	8.7	8.6	
BLK08	27.8	8.2	8.7	8.3	7.9	7.6	8.0	8.0	7.1
BLK08.1		8.5	8.9	8.5		8.0	8.4	8.4	
BLK11	23.2	8.7	9.0	8.6	8.4	8.2	9.0	8.4	8.3
BLK12	19.1	8.8	9.2	8.5	8.4	8.1	8.5	8.4	8.3
BLK13	16.6	8.7	8.7	8.8	8.5	8.0	8.7	8.3	8.3
BLK17	12.8	9.4	9.4	9.0	8.7	9.1	9.0	9.1	8.9
BLK18	9.9	9.6	9.5	9.4	9.3	9.3	9.2	9.1	9.2
BLK19	8.1	9.6	9.7	9.1	9.2	9.3	9.2	9.3	9.3
BLK20	3.7	9.2	9.6	9.1	8.9	9.0	9.0	8.8	8.8
BLK21	0.2	9.6	9.6	9.4	9.2	9.5	9.1	9.0	8.9
TRIBUTARIES									
BLK05	36.7,2.1	9.2	9.4	9.4	8.9	9.1	9.3	8.8	8.6
BLK09	25.5,0.6	8.6	10.1	9.0	7.9	8.1	8.9	9.1	8.3
BLK09.1		9.3	9.4	8.9	8.7	8.9	9.2	9.1	9.0
BLK10	24.2,0.6	9.2	9.4	8.9	8.8	8.6	9.1	8.4	8.5
BLK14	17.4,0.8	9.3	9.4	9.1	9.2	8.9	9.2	9.2	9.2
BLK15	13.3,0.7	9.3	9.4	9.2	9.0	9.2	9.4	9.1	9.1
BLK16	13.1,1.1	7.8	7.7	7.7	7.5	7.1	7.2	7.0	7.3

Table 1-6
Blackstone River Survey 1991

TEMPERATURE DATA (°C)

STATION	RIVER MILE	JULY 10				JULY 11			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	18.3	20.0	22.8	20.0	20.0	20.8	23.0	20.0
BLK02	43.9	19.7	21.6	22.8	20.0	19.4	21.6	23.0	21.0
BLK03	41.3	19.4	21.0	23.9	20.0	18.9	21.0	20.0	21.0
BLK04	39.8	19.4	20.0	23.9	21.0	19.4	20.8	23.0	22.2
BLK06	36.3	20.6	21.8	23.9	20.0	20.0	22.5	23.0	21.0
BLK07	31.9	22.8	23.9	24.4	21.0	21.6	23.6	25.0	23.3
BLK07.1							23.3	24.0	
BLK08	27.8	20.6	23.3	26.6	20.0	20.0	23.6	27.0	22.8
BLK08.1							23.9	27.0	
BLK11	23.2	21.0	23.9	23.3	20.0	20.6	23.9	23.0	22.2
BLK12	19.1	20.6	23.3	23.9	19.5	20.0	22.8	22.0	22.2
BLK13	16.6	21.0	23.9	23.9	19.5	20.6	23.3	23.0	22.8
BLK17	12.8	21.0	23.0	25.0	22.7	22.0	23.2	25.2	22.8
BLK18	9.9	22.0	23.5	25.0	22.9	22.0	23.0	25.0	23.5
BLK19	8.1	22.0	23.8	25.0	23.7	23.0	24.0	25.0	23.1
BLK20	3.7	20.8	23.0	25.0	23.0	22.0	23.5	25.0	23.0
BLK21	0.2	22.1	23.7	25.0	22.5	22.3	24.0	25.3	21.6
TRIBUTARIES									
BLK05	36.7,2.1	20.6	22.5	25.0	21.0	20.3	22.8	25.0	22.2
BLK09	25.5,0.6	21.0	22.8	25.0	20.0	20.6	23.3	25.0	22.8
BLK09.1		21.0	23.3	25.0	20.0	20.6	23.3	25.0	22.8
BLK10	24.2,0.6	18.9	22.8	23.0	19.0	18.9	22.0	23.0	21.0
BLK14	17.4,0.8	21.8	22.2	25.0	23.2	22.1	23.0	26.5	22.1
BLK15	13.3,0.7	20.6	23.2	25.0	22.8	21.5	24.0	26.2	22.5
BLK16	13.1,1.1	19.0	19.2	25.0	22.0	20.0	20.0	23.5	21.5

Table 1–7
Blackstone River Survey 1991

TEMPERATURE DATA (°C)									
STATION	RIVER MILE	AUGUST 14				AUGUST 15			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	22.9	22.7	26.5	24.0	23.5	23.4	24.4	22.5
BLK02	43.9	22.4	23.9	24.1	24.0	23.0	23.6	24.3	24.0
BLK03	41.3	22.3	23.5	26.0	24.0	24.0	24.0	24.6	24.0
BLK04	39.8	22.4	23.8	26.3	24.0	23.5	24.0	24.0	24.0
BLK06	36.3	22.8	25.3	26.0	25.0	24.0	25.0	24.5	24.0
BLK07	31.9	24.2	29.0	28.4	25.0	25.0	25.0	25.0	24.5
BLK07.1									
BLK08	27.8	22.8	27.1	25.8	25.0	24.5	25.0	25.0	24.0
BLK08.1			30.0				24.0	24.3	
BLK11	23.2	23.4	31.0	25.0	25.0	24.5	25.0	24.6	24.5
BLK12	19.1	22.8	28.0	25.4	25.0	24.0	24.0	24.5	24.0
BLK13	16.6	23.5	28.6	25.3	25.0	24.0	25.0	25.0	25.0
BLK17	12.8	22.9	24.1	25.8	23.9	23.5	23.3	24.9	23.4
BLK18	9.9	24.0	24.9	26.4	24.2	24.3	24.0	24.8	23.9
BLK19	8.1	23.8	24.9	25.7	24.3	23.8	23.8	24.6	24.1
BLK20	3.7	23.9	24.9	25.6	24.2	23.0	23.4	24.8	24.1
BLK21	0.2	24.0	25.1	25.3	24.2	23.8	24.0	24.8	23.5
TRIBUTARIES									
BLK05	36.7,2.1	23.6	24.6	26.5	24.0	24.0	24.0	24.8	24.0
BLK09	25.5,0.6	25.8	27.2	26.6	26.0	25.0	25.0	25.5	26.0
BLK09.1		24.0	26.5	26.6	26.0	25.0	25.0	25.3	24.5
BLK10	24.2,0.6	21.8	26.5	24.8	23.0	24.0	24.0	24.6	24.5
BLK14	17.4,0.8	23.2	24.2	27.3	24.9	24.5	24.0	25.8	24.3
BLK15	13.3,0.7	23.8	25.5	28.3	24.2	24.0	23.8	25.3	23.5
BLK16	13.1,1.1	20.5	20.8	23.8	22.5	21.2	20.5	22.1	21.1

Table 1–8
Blackstone River Survey 1991

TEMPERATURE DATA (°C)

STATION	RIVER MILE	OCTOBER 2				OCTOBER 3			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	15.0	16.0	18.0	18.0	16.0	16.0	17.0	16.0
BLK02	43.9	16.0	17.0	19.0	18.0	17.0	17.0	19.0	18.0
BLK03	41.3	16.0	18.0	19.0	18.0	17.0	17.0	18.5	18.0
BLK04	39.8	16.0	18.0	19.0	18.0	17.0	18.0	19.0	18.0
BLK06	36.3	15.0	19.0	18.0	17.0	16.0	16.0	17.0	17.0
BLK07	31.9	15.0	18.0	18.0	18.0	16.5	17.0	18.0	17.0
BLK07.1		15.0	16.0	18.0		16.5	17.0	17.0	
BLK08	27.8	15.0	18.0	17.0	18.0	16.0	17.0	17.0	18.0
BLK08.1		15.0	18.0	17.0		16.0	17.0	17.5	
BLK11	19.1	14.5	16.5	17.0	17.0	16.0	17.0	16.5	16.0
BLK12	16.6	14.5	17.0	17.0	17.0	15.5	16.0	16.0	16.0
BLK13	12.8	14.3	17.0	17.0	17.0	16.0	16.0	18.0	16.0
BLK17	9.9	15.7	17.0	17.3	17.3	17.0	18.4	18.5	17.5
BLK18	8.1	15.5	17.8	17.6	17.0	17.0	18.2	18.5	17.7
BLK19	3.7	15.1	19.2	17.0	17.1	16.7	18.0	18.2	17.6
BLK20	0.2	15.3	17.8	16.8	16.7	16.9	17.9	18.0	17.4
BLK21	13.0	16.0	19.4	17.2	16.8	16.8	17.9	18.3	17.7
TRIBUTARIES									
BLK05	36.7,2.1	14.0	16.0	16.0	16.0	16.0	16.0	17.0	17.0
BLK09	25.5,0.6	14.5	18.0	17.0	16.0	15.5	16.0	17.0	17.0
BLK09.1		14.5	18.0	18.0	16.0	15.5	16.0	17.0	16.0
BLK10	24.2,0.6	13.0	17.0	16.0	15.0	15.0	16.0	16.0	15.0
BLK14	17.4,0.8	16.0	17.1		17.3	16.8	18.0	18.3	17.1
BLK15	13.3,0.7	15.7	17.3	17.3	16.4	16.4	17.5	18.0	17.0
BLK16	13.1,1.1	14.9	16.1	17.4	16.8	16.5	17.7	17.5	16.3

Table 1–9
Blackstone River Survey 1991

pH MEASUREMENTS (standard units)									
STATION	RIVER MILE	JULY 10				JULY 11			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	7.0	7.2	7.2	7.0	7.0	7.1	7.2	7.1
BLK02	43.9	6.9	7.0	6.8	6.7	6.8	6.9	6.8	6.8
BLK03	41.3	6.9	7.4	7.3	7.1	7.2	7.3	7.5	7.2
BLK04	39.8	7.2	7.4	7.5	7.4	7.3	7.3	7.7	7.4
BLK06	36.3	7.2	7.6	8.4	7.3	7.2	7.4	7.9	7.4
BLK07	31.9	7.2	7.4	8.0	7.8	7.3	7.8	9.1	7.5
BLK07.1							7.6	8.2	
BLK08	27.8	7.1	8.1	8.6	7.2	7.1	7.9	9.4	7.4
BLK08.1							8.2	9.2	
BLK11	23.2	7.2	8.8	7.6	7.5	6.8	8.1	8.6	7.5
BLK12	19.1	7.2	8.7	8.0	7.2	6.8	9.1	9.3	8.1
BLK13	16.6	7.4	8.6	8.0	8.4	7.4	9.2	9.4	8.9
BLK17	12.8	6.8	8.7	9.3	8.3	7.8	9.1	9.4	8.7
BLK18	9.9	7.2	7.9	8.2	7.8	7.3	7.9	8.1	7.6
BLK19	8.1	7.3	7.6	8.6	7.7	7.4	7.8	8.0	7.5
BLK20	3.7	7.0	7.0	7.5	7.3	7.0	7.6	8.3	7.2
BLK21	0.2	7.1	7.1	8.0	7.3	7.2	7.7	8.7	7.3
TRIBUTARIES									
BLK05	36.7,2.1	7.1	7.5	7.2	7.2	7.1	7.2	7.2	7.2
BLK09	25.5,0.6	6.9	7.1	7.5	7.5	6.3	7.0	8.0	7.5
BLK09.1		7.0	7.5	7.1	7.6	6.5	7.1	7.7	7.4
BLK10	24.2,0.6	6.8	7.2	6.3	6.9	6.3	6.9	7.0	6.9
BLK14	17.4,0.8	6.5	6.7	6.7	6.9	7.0	7.4	7.5	6.8
BLK15	13.3,0.7	6.8	6.5	7.3	7.2	7.0	7.4	7.6	7.3
BLK16	13.1,1.1	6.8	6.5	6.6	6.9	6.6	7.0	6.9	6.9

Table 1-10
Blackstone River Survey 1991

pH MEASUREMENTS (standard units)

* Meter Not Working

STATION	RIVER MILE	AUGUST 14				AUGUST 15			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	7.1	7.0	7.2	7.2	6.5	6.2	7.0	7.0
BLK02	43.9	6.9	6.9	6.8	7.0	7.0	6.4	6.8	6.9
BLK03	41.3	7.2	7.3	7.5	7.2	7.0	6.6	7.3	6.8
BLK04	39.8	7.4	7.3	7.3	7.6	7.0	6.6	7.1	6.7
BLK06	36.3	7.2	7.5	7.3	7.5	7.5	6.2	6.5	6.9
BLK07	31.9	7.2	8.0	9.1	*	6.5	6.2	6.5	7.0
BLK07.1									
BLK08	27.8	7.1	7.7	8.4	*	7.0	5.8	6.6	7.0
BLK08.1			7.6				5.9		
BLK11	23.2	7.1	7.6	7.4	*	6.5	5.2	5.9	6.5
BLK12	19.1	7.1	8.0	8.0	*	6.5	5.2	6.5	6.4
BLK13	16.6	7.2	8.0	8.0	*	6.5	5.5	6.2	6.9
BLK17	12.8	7.4	7.8	8.7	7.4	7.3	7.6	8.4	7.3
BLK18	9.9	7.2	7.2	7.5	7.3	7.2	7.2	7.2	7.2
BLK19	8.1	7.3	7.5	7.6	7.3	7.2	7.3	7.3	7.3
BLK20	3.7	7.2	7.5	7.6	7.1	6.9	7.0	7.3	7.0
BLK21	0.2	7.3	7.9	8.3	7.4	7.3	7.3	7.7	7.2
TRIBUTARIES									
BLK05	36.7,2.1	7.2	7.3	7.1	7.3	7.0	6.2	7.3	6.7
BLK09	25.5,0.6	6.7	7.3	7.8	*	7.0	5.7	6.1	6.4
BLK09.1		7.0	7.4	7.5	*	7.0	5.5	6.0	6.4
BLK10	24.2,0.6	6.8	6.9	6.9	*	6.5	6.6	5.4	6.4
BLK14	17.4,0.8	7.0	7.2	7.3	7.1	7.0	7.1	7.3	7.1
BLK15	13.3,0.7	7.2	7.4	7.7	7.1	7.0	7.2	7.6	7.2
BLK16	13.1,1.1	6.8	6.8	6.7	6.7	6.7	6.7	6.7	6.7

Table 1–11
Blackstone River Survey 1991

pH MEASUREMENTS (standard units)

STATION	RIVER MILE	OCTOBER 2				OCTOBER 3			
		400	1000	1600	2200	400	1000	1600	2200
BLK01	45.7	7.1	7.4	7.3	7.1	7.0	7.1	6.7	7.1
BLK02	43.9	7.0	7.1	6.6	6.9	6.9	7.0	6.6	7.1
BLK03	41.3	7.3	7.4	7.1	7.2	7.2	7.3	6.9	7.3
BLK04	39.8	7.4	7.5	7.2	7.4	7.4	7.5	7.2	7.2
BLK06	36.3	7.2	7.3	7.1	7.3	7.3	7.3	7.1	7.2
BLK07	31.9	7.2	7.1	7.0	7.2	7.2	7.2	7.2	6.2
BLK07.1		7.2	7.4	7.1		7.4	7.4	7.3	
BLK08	27.8	7.2	7.1	6.8	7.1	7.2	7.2	7.2	6.2
BLK08.1		7.3	7.1	6.9		7.2	7.2	7.3	
BLK11	23.2	7.1	7.2	6.6	7.0	7.1	7.1	6.9	7.2
BLK12	19.1	7.4	7.2	6.7	7.1	7.1	7.2	7.0	7.5
BLK13	16.6	7.2	7.2	6.7	7.0	7.1	7.1	6.9	7.4
BLK17	12.8	7.1	7.2	7.2	7.2	7.1	7.2	7.2	7.1
BLK18	9.9	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.1
BLK19	8.1	7.2	7.3	7.3	7.3	7.3	7.3	7.2	7.3
BLK20	3.7	7.1	7.2	7.2	7.1	7.1	7.1	7.1	7.1
BLK21	0.2	7.1	7.3	7.2	7.2	7.2	7.2	7.2	7.1
TRIBUTARIES									
BLK05	36.7,2.1	7.3	7.4	7.1	7.3	7.4	7.4	7.0	7.2
BLK09	25.5,0.6	6.9	7.1	6.8	6.8	7.2	7.0	6.7	6.7
BLK09.1		7.2	7.2	6.8	8.7	7.2	7.1	6.6	6.7
BLK10	24.2,0.6	6.8	6.9	6.4	6.6	6.8	6.7	6.5	7.0
BLK14	17.4,0.8	6.8	6.8	6.9	6.8	6.8	6.9	6.9	6.8
BLK15	13.3,0.7	7.1	7.1	7.1	7.0	7.0	7.3	7.1	7.0
BLK16	13.1,1.1	6.7	6.8	6.7	6.7	6.7	6.8	6.7	6.7

FECAL COLIFORMS/100ml

STATION	RIVER MILE	JULY 10	AUGUST 14	OCTOBER 2
BLK01	45.7	1800	4180	3500
BLK02	43.9	20	0	20
BLK03	41.3	580	1060	20
BLK04	39.8	2300	760	300
BLK06	36.3	900	320	120
BLK07	31.9	100	80	320
BLK08	27.8	120	320	160
BLK11	23.2	80	80	140
BLK12	19.1	80	20	120
BLK13	16.6	100	80	40
BLK17	12.8	400	150	360
BLK18	9.9	20	60	240
BLK19	8.1	120	60	140
BLK20	3.7	200	20	60
BLK21	0.2	560	140	140
TRIBUTARIES				
BLK05	36.7,2.1	40	40	40
BLK09	25.5,0.6	300	120	20
BLK10	24.2,0.6	80	80	80
BLK14	17.4,0.8	160	220	460
BLK15	13.3,0.7	20	80	120
BLK16	13.1,1.1	380	1060	260

Table 1–13 Blackstone River Survey 1991

AVERAGE VALUES FOR CALCIUM, MAGNESIUM, & HARDNESS (mg/l)

		JULY 10 & 11			AUGUST 14 & 15			OCTOBER 2 & 3			JULY & AUGUST		
STATION	RIVER MILE	Ca	Mg	HARDNESS	Ca	Mg	HARDNESS	Ca	Mg	HARDNESS	Ca	Mg	HARDNESS
BLK01	45.7	23.2	3.9	74.0	21.7	2.8	65.4	14.4	2.9	48.0	22.4	3.3	69.1
BLK02	43.9	19.2	3.6	62.6	17.1	3.0	55.2	16.1	3.4	53.9	18.1	3.3	58.9
BLK03	41.3	17.0	3.4	56.6	17.0	3.1	55.2	15.4	3.5	52.9	17.0	3.3	55.9
BLK04	39.8	19.4	3.4	62.6	16.7	3.1	54.3	14.8	3.0	49.3	18.1	3.2	58.5
BLK06	36.3	17.5	3.2	56.9	15.7	3.0	51.3	14.1	2.9	46.9	16.6	3.1	54.1
BLK07	31.9	15.9	3.2	52.6	14.9	2.6	48.0	13.3	2.8	44.6	15.4	2.9	50.3
BLK08	27.8	15.3	3.1	51.1	13.4	2.5	43.8	12.8	3.2	45.1	14.4	2.8	47.5
BLK11	23.2	12.9	2.7	43.2	11.0	2.0	35.6	9.6	2.5	34.1	12.0	2.3	39.4
BLK12	19.1	12.8	2.6	42.4	10.8	1.9	34.5	9.4	2.3	32.9	11.8	2.2	38.5
BLK13	16.6	11.5	2.3	38.2	9.3	1.7	30.2	9.3	2.1	31.6	10.4	2.0	34.2
BLK17	12.8	11.5	2.3	38.1	9.0	1.8	29.6	8.0	1.8	27.6	10.2	2.0	33.8
BLK18	9.9	11.8	2.3	38.9	10.0	1.9	32.7	7.5	2.4	28.7	10.9	2.1	35.8
BLK19	8.1	11.7	2.4	39.0	10.8	2.1	35.4	8.2	2.1	29.0	11.2	2.2	37.2
BLK20	3.7	11.9	2.5	39.8	11.8	2.2	38.7	8.6	1.9	29.4	11.9	2.3	39.3
BLK21	0.2	12.3	2.5	41.0	11.5	2.2	37.6	8.2	2.5	30.7	11.9	2.3	39.3
TRIBUTARIES													
BLK05	36.7,2.1	15.0	2.8	49.2	13.3	2.7	44.2	11.7	2.5	39.6	14.1	2.8	46.7
BLK09	25.5,0.6	5.3	1.2	18.2	5.0	1.1	16.8	3.4	1.3	13.8	5.1	1.1	17.5
BLK10	24.2,0.6	6.1	1.3	20.7	5.4	1.2	18.4	4.2	1.8	18.0	5.7	1.3	19.6
BLK14	17.4,0.8	3.9	1.1	14.2	5.0	1.0	16.9	2.5	0.9	10.0	4.5	1.1	15.5
BLK15	13.3,0.7	6.8	1.6	23.3	6.2	1.4	21.2	5.0	1.9	20.2	6.5	1.5	22.3
BLK16	13.1,1.1	9.9	2.2	33.9	8.3	1.9	28.4	7.5	2.6	29.4	9.1	2.1	31.1

Table 1-14
Blackstone River Survey 1991

TOTAL METALS, ug/l
COPPER, CADMIUM, LEAD, NICKEL, CHROMIUM
DAILY AVERAGE VALUES FOR JULY 10 AND AUGUST 14

		COPPER		CADMIUM		LEAD		NICKEL		CHROMIUM	
STATION	RIVER MILE	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14
BLK01	45.7	9.3	9.8	0.36	0.33	4.4	21.1	5.2	7.7	3.8	11.2
BLK02	43.9	36.5	25.1	3.62	4.16	3.0	8.5	28.3	41.9	4.9	6.4
BLK03	41.3	31.8	26.1	2.59	3.51	2.7	10.2	23.3	37.0	3.3	4.9
BLK04	39.8	27.2	24.8	2.03	2.90	5.2	6.9	17.0	33.8	3.4	4.0
BLK06	36.3	22.2	24.6	1.10	1.86	48.1	13.6	10.9	24.8	3.6	3.9
BLK07	31.9	21.6	17.9	0.87	0.98	100.5	15.8	8.8	19.7	4.9	4.1
BLK08	27.8	34.4	27.0	1.42	1.81	19.5	25.5	10.4	18.3	14.9	10.6
BLK11	23.2	22.5	16.3	1.16	1.00	27.6	14.3	7.0	11.5	8.1	5.5
BLK12	19.1	10.9	12.4	0.53	1.50	8.4	11.2	6.0	11.2	2.3	3.2
BLK13	16.6	10.3	10.3	0.68	0.71	14.2	16.0	6.2	8.3	3.0	2.8
BLK17	12.8	9.9	9.5	0.52	0.48	4.2	6.4	7.1	7.0	1.3	1.9
BLK18	9.9	8.9	9.9	0.56	1.01	3.8	5.7	4.9	9.0	1.9	4.4
BLK19	8.1	7.6	8.0	0.41	0.60	2.3	5.9	4.5	9.4	1.2	2.1
BLK20	3.7	7.3	7.8	0.31	0.45	1.7	3.0	4.5	10.0	1.1	2.2
BLK21	0.2	7.6	7.9	0.33	0.43	3.6	3.5	4.5	10.6	1.2	1.5
TRIBUTARIES											
BLK05	36.7,2.1	2.4	2.4	0.17	0.12	1.9	5.3	0.7	1.5	0.2	0.9
BLK09	25.5,0.6	7.3	1.9	0.13	0.16	3.8	3.3	1.1	0.8	0.9	1.5
BLK10	24.2,0.6	13.9	2.7	0.70	0.18	9.7	3.5	3.2	0.6	1.2	1.0
BLK14	17.4,0.8	5.8	3.3	0.10	0.26	7.0	2.6	1.2	0.8	0.5	1.0
BLK15	13.3,0.7	3.8	3.7	0.08	0.18	1.2	14.0	1.0	0.7	0.3	0.5
BLK16	13.1,1.1	16.8	2.5	0.45	0.15	8.5	4.2	4.1	0.3	0.9	0.6

DISSOLVED METALS, ug/l
COPPER, CADMIUM, LEAD, NICKEL, CHROMIUM
DAILY AVERAGE VALUES FOR JULY 10 AND AUGUST 14

		COPPER		CADMIUM		LEAD		NICKEL		CHROMIUM	
STATION	RIVER MILE	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14
BLK01	45.7	3.1	6.7	0.06	0.25	1.1	3.9	3.5	7.1	1.2	6.2
BLK02	43.9	29.4	21.9	3.07	3.77	1.2	5.8	25.3	40.0	2.9	5.6
BLK03	41.3	22.9	21.5	2.02	3.11	1.0	7.1	20.2	33.0	2.3	3.5
BLK04	39.8	19.9	21.1	1.26	2.43	0.7	4.0	14.6	30.0	2.1	2.7
BLK06	36.3	15.2	19.3	0.67	1.68	26.3	9.0	8.9	24.0	1.4	2.0
BLK07	31.9	12.9	11.5	0.48	0.80	4.3	10.7	7.1	18.5	1.4	1.7
BLK08	27.8	8.3	14.9	0.18	1.26	2.5	14.5	6.2	17.1	1.4	2.7
BLK11	23.2	6.9	7.8	0.29	0.66	3.0	8.7	5.4	9.9	1.1	1.6
BLK12	19.1	6.3	8.3	0.21	0.73	3.1	6.7	4.5	9.3	1.1	1.2
BLK13	16.6	4.8	5.8	0.15	0.55	1.4	12.9	4.4	7.2	0.7	1.2
BLK17	12.8	4.1	4.3	0.19	0.27	0.9	1.7	3.9	4.7	0.6	0.8
BLK18	9.9	6.4	8.2	0.27	0.75	0.7	3.2	4.0	7.4	1.1	2.5
BLK19	8.1	4.8	5.4	0.16	0.57	0.4	3.2	4.2	8.9	0.8	1.0
BLK20	3.7	3.9	4.9	0.14	0.30	1.0	1.3	3.6	8.9	0.4	0.8
BLK21	0.2	4.0	4.5	0.09	0.28	0.7	1.5	2.9	7.8	0.7	0.8
TRIBUTARIES											
BLK05	36.7,2.1	1.1	0.8	0.12	0.10	0.7	2.9	0.6	0.7	0.4	0.3
BLK09	25.5,0.6	0.2	0.5	0.05	0.12	0.7	2.2	0.2	0.3	0.4	0.6
BLK10	24.2,0.6	0.5	1.7	0.05	0.13	1.2	2.9	0.2	0.5	0.2	0.6
BLK14	17.4,0.8	1.2	1.8	0.05	0.15	5.9	1.1	0.8	0.7	0.3	0.6
BLK15	13.3,0.7	1.4	0.6	0.06	0.04	0.8	0.5	0.7	0.4	0.2	0.2
BLK16	13.1,1.1	5.5	1.9	0.18	0.13	3.0	2.1	1.5	0.3	0.2	0.3

Table 1–15
Blackstone River Survey 1991

Table 1–16
Blackstone River Survey 1991

TOTAL & DISSOLVED CADMIUM CONCENTRATIONS AND LOADINGS

		AVG FLOW	AVERAGE JULY 10 & AUGUST 14				FLOW	OCTOBER 2			
		JULY10 & AUG14	(ug/l)		(pounds/day)		OCT 2	(ug/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	TOTAL	DISS.	TOTAL	DISS.	(cfs)	TOTAL	DISS.	TOTAL	DISS.
BLK01	45.7	13.8	0.34	0.15	0.03	0.01	69.1	0.29	0.16	0.11	0.06
BLK02	43.9	58.4	3.89	3.42	1.22	1.08	133.3	1.97	1.65	1.41	1.18
BLK03	41.3	61.5	3.05	2.57	1.01	0.85	145.5	2.61	2.06	2.04	1.61
BLK04	39.8	63.8	2.46	1.84	0.85	0.63	153.6	1.77	1.12	1.47	0.93
BLK06	36.3	75.2	1.48	1.18	0.60	0.48	228.2	1.69	0.71	2.08	0.87
BLK07	31.9	77.9	0.92	0.64	0.39	0.27	236.0	1.17	0.84	1.49	1.07
BLK08	27.8	80.3	1.62	0.72	0.70	0.31	243.1	1.45	0.96	1.90	1.25
BLK11	23.2	106.3	1.08	0.48	0.62	0.27	484.3	1.29	0.71	3.36	1.86
BLK12	19.1	108.1	1.01	0.47	0.59	0.27	500.0	1.17	0.63	3.15	1.70
BLK13	16.6	137.3	0.69	0.35	0.51	0.26	607.8	1.12	0.58	3.67	1.88
BLK17	12.8	148.6	0.50	0.23	0.40	0.18	655.0	0.69	0.49	2.42	1.72
BLK18	9.9	179.5	0.79	0.51	0.76	0.49	679.7	0.71	0.32	2.60	1.18
BLK19	8.1	180.3	0.50	0.37	0.49	0.35	682.8	0.55	0.34	2.01	1.23
BLK20	3.7	182.4	0.38	0.22	0.37	0.22	691.6	0.50	0.35	1.87	1.30
BLK21	0.2	189.6	0.38	0.19	0.38	0.19	721.8	0.49	0.25	1.89	0.98
TRIBUTARIES											
BLK05	36.7,2.1	7.9	0.14	0.11	0.006	0.005	60.5	0.06	0.05	0.020	0.016
BLK09	25.5,0.6	17.5	0.14	0.09	0.013	0.008	141.5	0.11	0.05	0.084	0.038
BLK10	24.2,0.6	7.8	0.44	0.09	0.018	0.004	93.1	0.10	0.07	0.050	0.035
BLK14	17.4,0.8	28.3	0.18	0.10	0.027	0.015	104	0.08	0.06	0.045	0.034
BLK15	13.3,0.7	7.0	0.13	0.05	0.005	0.002	29.2	0.05	0.02	0.008	0.003
BLK16	13.1,1.1	2.5	0.30	0.15	0.004	0.002	10.4	0.08	0.07	0.004	0.004

Table 1–17
Blackstone River Survey 1991

TOTAL & DISSOLVED CHROMIUM CONCENTRATIONS AND LOADINGS

		AVG FLOW JULY10 & AUG14	AVERAGE JULY 10 & AUG 14 (ug/l)		AVERAGE JULY 10 & AUG 14 (pounds/day)		FLOW OCT 2	OCTOBER 2 (ug/l)		OCTOBER 2 (pounds/day)	
STATION	RIVER MILE	(cfs)	TOTAL	DISS.	TOTAL	DISS.	(cfs)	TOTAL	DISS.	TOTAL	DISS.
BLK01	45.7	13.8	7.5	3.7	0.56	0.28	69.1	3.9	1.6	1.4	0.6
BLK02	43.9	58.4	5.6	4.2	1.77	1.33	133.3	3.2	1.6	2.3	1.1
BLK03	41.3	61.5	4.1	2.9	1.36	0.96	145.5	3.2	1.4	2.5	1.1
BLK04	39.8	63.8	3.7	2.4	1.27	0.83	153.6	2.6	1.0	2.2	0.8
BLK06	36.3	75.2	3.8	1.7	1.52	0.68	228.2	2.3	0.6	2.9	0.8
BLK07	31.9	77.9	4.5	1.5	1.87	0.64	236.0	3.1	1.2	4.0	1.5
BLK08	27.8	80.3	12.8	2.1	5.53	0.89	243.1	4.1	1.1	5.3	1.5
BLK11	23.2	106.3	6.8	1.4	3.90	0.79	484.3	4.9	1.5	12.8	3.9
BLK12	19.1	108.1	2.7	1.1	1.60	0.66	500.0	4.7	1.1	12.7	3.0
BLK13	16.6	137.3	2.9	0.9	2.12	0.69	607.8	6.4	1.0	21.0	3.1
BLK17	12.8	148.6	1.6	0.7	1.29	0.55	655.0	3.2	1.0	11.2	3.4
BLK18	9.9	179.5	3.1	1.8	3.04	1.72	679.7	3.1	0.7	11.4	2.7
BLK19	8.1	180.3	1.6	0.9	1.57	0.85	682.8	2.6	0.7	9.6	2.6
BLK20	3.7	182.4	1.6	0.6	1.59	0.59	691.6	2.6	0.8	9.5	2.9
BLK21	0.2	189.6	1.3	0.7	1.37	0.73	721.8	2.4	1.0	9.3	3.9
TRIBUTARIES											
BLK05	36.7,2.1	7.9	0.6	0.3	0.024	0.014	60.5	0.2	0.2	0.07	0.07
BLK09	25.5,0.6	17.5	1.2	0.5	0.113	0.045	141.5	1.0	0.4	0.75	0.29
BLK10	24.2,0.6	7.8	1.1	0.4	0.046	0.017	93.1	0.4	0.3	0.19	0.15
BLK14	17.4,0.8	28.3	0.8	0.5	0.119	0.073	104	0.6	0.3	0.34	0.16
BLK15	13.3,0.7	7.0	0.4	0.2	0.015	0.008	29.2	0.3	0.2	0.04	0.03
BLK16	13.1,1.1	2.5	0.7	0.3	0.010	0.003	10.4	0.3	0.2	0.02	0.01

Table 1–18
Blackstone River Survey 1991

TOTAL & DISSOLVED COPPER CONCENTRATIONS AND LOADINGS

		AVG FLOW	AVERAGE JULY 10 & AUGUST 14				FLOW	OCTOBER 2			
		JULY10 & AUG14	(ug/l)		(pounds/day)		OCT 2	(ug/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	TOTAL	DISS.	TOTAL	DISS.	(cfs)	TOTAL	DISS.	TOTAL	DISS.
BLK01	45.7	13.8	9.6	4.9	0.7	0.4	69.1	9.0	5.4	3.4	2.0
BLK02	43.9	58.4	30.8	25.7	9.7	8.1	133.3	15.3	12.8	11.0	9.2
BLK03	41.3	61.5	28.9	22.2	9.6	7.4	145.5	16.1	11.9	12.6	9.3
BLK04	39.8	63.8	26.0	20.5	8.9	7.1	153.6	14.7	11.8	12.1	9.8
BLK06	36.3	75.2	23.4	17.3	9.5	7.0	228.2	13.8	9.3	16.9	11.4
BLK07	31.9	77.9	19.8	12.2	8.3	5.1	236.0	14.7	10.4	18.7	13.2
BLK08	27.8	80.3	30.7	11.6	13.3	5.0	243.1	17.1	10.7	22.4	14.0
BLK11	23.2	106.3	19.4	7.4	11.1	4.2	484.3	17.6	7.8	46.0	20.4
BLK12	19.1	108.1	11.7	7.3	6.8	4.2	500.0	13.9	7.4	37.5	20.0
BLK13	16.6	137.3	10.3	5.3	7.6	3.9	607.8	14.5	6.5	47.5	21.2
BLK17	12.8	148.6	9.7	4.2	7.8	3.4	655.0	8.4	4.4	29.7	15.5
BLK18	9.9	179.5	9.4	7.3	9.1	7.1	679.7	9.9	9.0	36.1	32.9
BLK19	8.1	180.3	7.8	5.1	7.6	4.9	682.8	8.5	6.4	31.3	23.4
BLK20	3.7	182.4	7.5	4.4	7.4	4.3	691.6	7.9	5.4	29.5	19.9
BLK21	0.2	189.6	7.8	4.2	7.9	4.3	721.8	8.7	5.2	33.7	20.3
TRIBUTARIES											
BLK05	36.7,2.1	7.9	2.4	1.0	0.10	0.04	60.5	1.7	1.4	0.6	0.5
BLK09	25.5,0.6	17.5	4.6	0.3	0.43	0.03	141.5	3.9	1.7	2.9	1.3
BLK10	24.2,0.6	7.8	8.3	1.1	0.35	0.05	93.1	3.7	1.6	1.9	0.8
BLK14	17.4,0.8	28.3	4.5	1.5	0.69	0.23	104	3.6	2.9	2.0	1.6
BLK15	13.3,0.7	7.0	3.7	1.0	0.14	0.04	29.2	3.5	1.6	0.6	0.2
BLK16	13.1,1.1	2.5	9.6	3.7	0.13	0.05	10.4	2.7	2.0	0.2	0.1

Table 1–19
Blackstone River Survey 1991

TOTAL AND DISSOLVED LEAD CONCENTRATIONS AND LOADINGS

		AVG FLOW	AVERAGE JULY 10 & AUGUST 14				FLOW	OCTOBER 2			
		JULY10 & AUG14	(ug/l)		(pounds/day)		OCT 2	(ug/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	TOTAL	DISS.	TOTAL	DISS.	(cfs)	TOTAL	DISS.	TOTAL	DISS.
BLK01	45.7	13.8	12.7	2.5	0.9	0.2	69.1	5.1	1.4	1.9	0.5
BLK02	43.9	58.4	5.7	3.5	1.8	1.1	133.3	3.7	1.7	2.6	1.2
BLK03	41.3	61.5	6.4	4.0	2.1	1.3	145.5	5.0	0.9	3.9	0.7
BLK04	39.8	63.8	6.1	2.4	2.1	0.8	153.6	4.2	2.0	3.4	1.7
BLK06	36.3	75.2	30.8	17.6	12.5	7.1	228.2	14.0	4.3	17.2	5.3
BLK07	31.9	77.9	58.1	7.5	24.4	3.2	236.0	8.1	3.8	10.3	4.8
BLK08	27.8	80.3	22.5	8.5	9.7	3.7	243.1	9.9	3.7	13.0	4.8
BLK11	23.2	106.3	20.9	5.8	12.0	3.3	484.3	9.8	3.1	25.5	8.0
BLK12	19.1	108.1	9.8	4.9	5.7	2.9	500.0	9.2	4.0	24.7	10.8
BLK13	16.6	137.3	15.1	7.2	11.2	5.3	607.8	9.8	2.5	32.1	8.2
BLK17	12.8	148.6	5.3	1.3	4.2	1.0	655.0	9.3	3.5	32.7	12.4
BLK18	9.9	179.5	4.7	1.9	4.6	1.9	679.7	12.7	5.3	46.3	19.4
BLK19	8.1	180.3	4.1	1.8	4.0	1.7	682.8	4.4	1.6	16.0	5.7
BLK20	3.7	182.4	2.4	1.1	2.3	1.1	691.6	4.4	1.5	16.4	5.5
BLK21	0.2	189.6	3.5	1.1	3.6	1.1	721.8	3.9	1.6	15.3	6.1
TRIBUTARIES											
BLK05	36.7,2.1	7.9	3.6	1.8	0.15	0.08	60.5	1.4	0.7	0.44	0.23
BLK09	25.5,0.6	17.5	3.6	1.4	0.33	0.13	141.5	4.2	1.3	3.19	0.98
BLK10	24.2,0.6	7.8	6.6	2.1	0.28	0.09	93.1	3.3	1.5	1.65	0.74
BLK14	17.4,0.8	28.3	4.8	3.5	0.73	0.54	104	2.9	2.0	1.60	1.14
BLK15	13.3,0.7	7.0	7.6	0.6	0.29	0.02	29.2	2.0	1.1	0.31	0.17
BLK16	13.1,1.1	2.5	6.4	2.5	0.09	0.03	10.4	3.0	1.4	0.17	0.08

Table 1–20
Blackstone River Survey 1991

TOTAL AND DISSOLVED NICKEL CONCENTRATIONS AND LOADINGS

		AVG FLOW JULY10 & AUG14	AVERAGE JULY 10 & AUGUST 14				FLOW OCT 2	OCTOBER 2			
			(ug/l)		(pounds/day)			(ug/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	TOTAL	DISS.	TOTAL	DISS.	(cfs)	TOTAL	DISS.	TOTAL	DISS.
BLK01	45.7	13.8	6.4	5.3	0.5	0.4	69.1	4.4	3.5	1.6	1.3
BLK02	43.9	58.4	35.1	32.7	11.0	10.3	133.3	11.8	10.4	8.5	7.5
BLK03	41.3	61.5	30.1	26.6	10.0	8.8	145.5	11.3	10.1	8.9	7.9
BLK04	39.8	63.8	25.4	22.3	8.7	7.7	153.6	10.8	9.3	8.9	7.7
BLK06	36.3	75.2	17.9	16.4	7.2	6.7	228.2	8.7	6.9	10.7	8.5
BLK07	31.9	77.9	14.2	12.8	6.0	5.4	236.0	8.5	7.6	10.8	9.7
BLK08	27.8	80.3	14.3	11.6	6.2	5.0	243.1	8.1	6.9	10.6	9.1
BLK11	23.2	106.3	9.2	7.6	5.3	4.4	484.3	7.7	5.4	20.2	14.2
BLK12	19.1	108.1	8.6	6.9	5.0	4.0	500.0	6.7	5.2	18.0	14.0
BLK13	16.6	137.3	7.2	5.8	5.3	4.3	607.8	6.7	4.9	21.9	16.0
BLK17	12.8	148.6	7.0	4.3	5.6	3.5	655.0	6.9	6.0	24.3	21.3
BLK18	9.9	179.5	7.0	5.7	6.7	5.5	679.7	6.3	5.2	23.2	18.9
BLK19	8.1	180.3	7.0	6.5	6.8	6.4	682.8	5.7	5.2	21.1	19.2
BLK20	3.7	182.4	7.2	6.2	7.1	6.1	691.6	6.2	6.2	23.2	23.2
BLK21	0.2	189.6	7.6	5.4	7.7	5.5	721.8	6.3	5.4	24.3	20.8
TRIBUTARIES											
BLK05	36.7,2.1	7.9	1.1	0.6	0.05	0.03	60.5	0.9	1.0	0.28	0.31
BLK09	25.5,0.6	17.5	1.0	0.3	0.09	0.02	141.5	2.0	0.6	1.51	0.42
BLK10	24.2,0.6	7.8	1.9	0.3	0.08	0.01	93.1	0.8	0.4	0.39	0.20
BLK14	17.4,0.8	28.3	1.0	0.7	0.15	0.11	104	2.4	1.9	1.35	1.08
BLK15	13.3,0.7	7.0	0.8	0.5	0.03	0.02	29.2	2.8	1.9	0.45	0.30
BLK16	13.1,1.1	2.5	2.2	0.9	0.03	0.01	10.4	2.3	1.6	0.13	0.09

Table 1–21 Blackstone River Survey 1991

AMMONIA, NITRATE, TKN & BOD (mg/l)
DAILY AVERAGE VALUES FOR JULY 10 AND AUGUST 14

		NH3		NO3		TKN		BOD	
STATION	RIVER MILE	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14
BLK01	45.7	0.20	0.52	0.65	0.75	0.8	1.1	0.9	1.8
BLK02	43.9	0.36	0.60	3.01	3.87	1.2	1.2	1.5	2.1
BLK03	41.3	0.20	0.62	3.93	4.18	1.1	1.2	0.9	2.0
BLK04	39.8	0.32	0.72	4.38	3.96	0.9	1.2	1.0	1.7
BLK06	36.3	0.13	0.63	2.48	3.43	0.9	1.1	1.0	1.8
BLK07	31.9	0.13	0.49	3.23	3.46	0.9	1.0	1.8	1.9
BLK08	27.8	0.11	0.31	2.64	3.45	0.9	1.0	2.2	2.3
BLK11	23.2	0.06	0.29	1.91	1.52	0.8	1.0	2.5	1.7
BLK12	19.1	0.05	0.28	1.68	2.46	0.9	1.0	2.8	1.7
BLK13	16.6	0.06	0.27	1.57	1.28	0.8	1.0	2.1	1.7
BLK17	12.8	0.06	0.12	1.06	0.89	0.8	1.0	2.3	1.9
BLK18	9.9	1.16	0.77	1.32	2.19	1.5	1.1	2.7	2.3
BLK19	8.1	0.85	0.67	1.49	1.73	1.4	1.0	3.0	2.6
BLK20	3.7	0.48	0.33	1.76	2.01	0.8	1.0	1.6	2.1
BLK21	0.2	0.31	0.41	1.87	1.86	0.8	1.0	1.8	2.3
TRIBUTARIES									
BLK05	36.7,2.1	0.06	0.23	1.12	0.10	1.0	1.0	1.0	1.3
BLK09	25.5,0.6	0.05	0.22	0.91	0.68	1.0	1.0	1.0	1.3
BLK10	24.2,0.6	0.05	0.25	0.11	0.32	1.0	1.0	1.0	1.3
BLK14	17.4,0.8	0.10	0.28	0.19	0.52	1.0	1.0	1.1	1.5
BLK15	13.3,0.7	0.05	0.25	0.32	0.39	1.0	1.0	1.3	1.9
BLK16	13.1,1.1	0.27	0.21	0.78	0.71	1.0	1.0	1.2	1.3

Table 1–22
Blackstone River Survey 1991

PHOSPHORUS, CHLORIDE, TSS, & TVS (mg/l) & CHLOROPHYLL (ug/l)
DAILY AVERAGE VALUES FOR JULY 10 AND AUGUST 14

		PHOSPHORUS		CHLOROPHYLL		CHLORIDE		TSS		TVS	
STATION	RIVER MILE	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14	JULY 10	AUG 14
BLK01	45.7	0.02	0.03	1.9	2.5	123	107	2.2	3.5	1.0	1.8
BLK02	43.9	0.79	1.10	2.0	1.0	106	101	3.9	3.1	2.4	2.0
BLK03	41.3	0.94	1.05	2.2	1.0	100	101	1.1	1.3	0.8	0.8
BLK04	39.8	0.81	0.97	1.5	1.0	99	97	1.5	2.0	0.7	1.3
BLK06	36.3	0.61	0.63	3.5	3.4	83	88	3.9	2.4	1.4	1.3
BLK07	31.9	0.56	0.28	14.1	7.2	77	98	6.1	6.4	2.8	3.2
BLK08	27.8	0.47	0.13	18.8	17.7	75	90	11.6	9.1	4.4	3.4
BLK11	23.2	0.23	0.05	15.9	6.0	68	58	10.5	4.4	4.3	2.3
BLK12	19.1	0.24	0.08	17.0	5.8	68	55	6.7	3.8	3.5	2.1
BLK13	16.6	0.26	0.05	19.2	10.5	58	47	7.2	4.8	3.5	3.0
BLK17	12.8	0.11	0.09	13.1	12.1	55	93	7.4	4.2	4.0	2.4
BLK18	9.9	0.17	0.54	22.3	7.6	73	58	5.8	4.0	2.8	2.5
BLK19	8.1	0.18	0.19	22.7	8.2	68	59	6.9	4.9	3.8	3.0
BLK20	3.7	0.15	0.18	8.4	9.3	56	64	3.9	4.9	2.1	2.3
BLK21	0.2	0.11	0.15	12.2	13.7	60	58	5.5	6.2	2.8	4.0
TRIBUTARIES											
BLK05	36.7,2.1	0.06	0.03	NS	1.5	68	71	0.8	1.3	0.7	0.8
BLK09	25.5,0.6	0.16	0.03	NS	1.5	20	18	1.7	1.5	0.9	1.0
BLK10	24.2,0.6	0.05	0.04	NS	1.5	43	44	1.9	1.5	1.0	0.7
BLK14	17.4,0.8	0.06	0.04	NS	2.4	22	28	1.4	3.1	0.8	2.1
BLK15	13.3,0.7	0.04	0.04	NS	4.6	23	27	2.7	4.8	1.1	3.4
BLK16	13.1,1.1	0.03	0.03	3.6	2.6	37	36	5.3	5.0	2.0	2.4

NS=no sample

Table 1–23
Blackstone River Survey 1991

AMMONIA & NITRATE CONCENTRATIONS AND LOADINGS

		AVG FLOW	AVERAGE JULY 10 & AUG 14				FLOW	OCTOBER 2			
		JULY10 & AUG14	(mg/l)		(pounds/day)		OCT 2	(mg/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	NH3	NO3	NH3	NO3	(cfs)	NH3	NO3	NH3	NO3
BLK01	45.7	13.8	0.36	0.70	26	52	69.1	0.15	1.18	54	440
BLK02	43.9	58.4	0.48	3.44	150	1082	133.3	0.39	1.93	278	1388
BLK03	41.3	61.5	0.41	4.05	135	1343	145.5	0.28	1.64	216	1282
BLK04	39.8	63.8	0.52	4.17	179	1434	153.6	0.29	1.53	240	1267
BLK06	36.3	75.2	0.38	2.89	154	1172	228.2	0.23	1.14	277	1405
BLK07	31.9	77.9	0.31	3.34	129	1403	236.0	0.21	1.16	267	1479
BLK08	27.8	80.3	0.21	2.70	90	1168	243.1	0.15	0.67	200	881
BLK11	23.2	106.3	0.18	1.71	100	980	484.3	0.09	0.95	228	2467
BLK12	19.1	108.1	0.16	2.07	95	1205	500.0	0.10	1.46	276	3921
BLK13	16.6	137.3	0.16	1.42	121	1053	607.8	0.10	1.20	319	3915
BLK17	12.8	148.6	0.09	0.98	73	782	655.0	0.24	0.76	830	2683
BLK18	9.9	179.5	0.97	1.76	936	1699	679.7	0.22	0.78	788	2858
BLK19	8.1	180.3	0.76	1.61	739	1567	682.8	0.21	0.67	782	2475
BLK20	3.7	182.4	0.40	1.89	397	1856	691.6	0.14	0.34	531	1258
BLK21	0.2	189.6	0.36	1.87	367	1906	721.8	0.19	0.86	720	3326
TRIBUTARIES											
BLK05	36.7,2.1	7.9	0.15	0.61	6	26	60.5	0.02	0.06	7	18
BLK09	25.5,0.6	17.5	0.14	0.79	13	75	141.5	0.02	0.10	17	74
BLK10	24.2,0.6	7.8	0.15	0.21	6	9	93.1	0.02	0.03	10	15
BLK14	17.4,0.8	28.3	0.19	0.36	28	54	104.0	0.04	0.19	21	105
BLK15	13.3,0.7	7.0	0.15	0.35	6	13	10.4	0.07	0.27	4	15
BLK16	13.1,1.1	2.5	0.24	0.75	3	10	29.2	0.05	0.52	8	82

Table 1–24
Blackstone River Survey 1991

TKN & ORTHO-P CONCENTRATIONS AND LOADINGS

		AVG FLOW	AVERAGE JULY 10 & AUG 14				FLOW	OCTOBER 2			
		JULY10 & AUG14	(mg/l)		(pounds/day)		OCT 2	(mg/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	TKN	ORTHO-P	TKN	ORTHO-P	(cfs)	TKN	ORTHO-P	TKN	ORTHO-P
BLK01	45.7	13.8	0.9	0.02	69	2	69.1	1.0	0.12	372	45
BLK02	43.9	58.4	1.2	0.94	362	297	133.3	1.0	0.54	740	384
BLK03	41.3	61.5	1.1	0.99	369	329	145.5	1.0	0.50	784	388
BLK04	39.8	63.8	1.1	0.89	366	306	153.6	1.0	0.43	828	354
BLK06	36.3	75.2	1.0	0.62	397	250	228.2	1.0	0.26	1230	317
BLK07	31.9	77.9	1.0	0.42	403	177	236.0	1.0	0.21	1272	267
BLK08	27.8	80.3	0.9	0.30	407	128	243.1	1.0	0.20	1310	259
BLK11	23.2	106.3	0.9	0.14	529	79	484.3	1.0	0.13	2610	326
BLK12	19.1	108.1	1.0	0.16	558	92	500.0	1.0	0.17	2695	451
BLK13	16.6	137.3	0.9	0.15	676	112	607.8	1.0	0.12	3276	393
BLK17	12.8	148.6	0.9	0.10	714	79	655.0	1.0	0.08	3530	274
BLK18	9.9	179.5	1.3	0.36	1246	346	679.7	1.0	0.10	3664	366
BLK19	8.1	180.3	1.2	0.18	1189	179	682.8	1.0	0.09	3680	331
BLK20	3.7	182.4	0.9	0.16	887	161	691.6	1.0	0.10	3728	363
BLK21	0.2	189.6	0.9	0.13	933	129	721.8	1.0	0.08	3891	311
TRIBUTARIES											
BLK05	36.7,2.1	7.9	1.0	0.05	43	2	60.5	1.0	0.02	326	7
BLK09	25.5,0.6	17.5	1.0	0.09	94	9	141.5	1.0	0.04	763	31
BLK10	24.2,0.6	7.8	1.0	0.04	42	2	93.1	1.0	0.02	502	10
BLK14	17.4,0.8	28.3	1.0	0.05	153	8	104.0	1.0	0.02	561	13
BLK15	13.3,0.7	7.0	1.0	0.04	38	1	10.4	1.0	0.02	56	1
BLK16	13.1,1.1	2.5	1.0	0.03	13	0	29.2	1.0	0.03	157	4

Table 1-25
Blackstone River Survey 1991

BOD & CHLOROPHYLL CONCENTRATIONS AND BOD LOADINGS

		AVG FLOW	AVERAGE JULY 10 & AUG 14			FLOW	OCTOBER 2		
		JULY10 & AUG14	(mg/l)	(ug/l)	(#/day)	OCT 2	(mg/l)	(ug/l)	(#/day)
STATION	RIVER MILE	(cfs)	BOD	CHLORO	BOD	(cfs)	BOD	CHLORO	BOD
BLK01	45.7	13.8	1.3	2.2	99	69.1	1.4	1.9	512
BLK02	43.9	58.4	1.8	1.5	555	133.3	1.2	2.0	880
BLK03	41.3	61.5	1.5	1.6	485	145.5	1.5	1.0	1176
BLK04	39.8	63.8	1.4	1.3	469	153.6	1.6	1.1	1304
BLK06	36.3	75.2	1.4	3.4	562	228.2	1.4	2.6	1691
BLK07	31.9	77.9	1.9	10.7	782	236.0	1.4	2.1	1717
BLK08	27.8	80.3	2.3	18.3	979	243.1	1.3	2.4	1671
BLK11	23.2	106.3	2.0	10.9	1132	484.3	1.1	1.5	2806
BLK12	19.1	108.1	2.3	11.4	1318	500.0	1.0	1.5	2762
BLK13	16.6	137.3	1.9	14.9	1388	607.8	1.1	2.4	3522
BLK17	12.8	148.6	2.1	18.6	1662	655.0	1.1	3.0	3707
BLK18	9.9	179.5	2.5	14.9	2395	679.7	1.1	2.0	3847
BLK19	8.1	180.3	2.8	15.4	2745	682.8	1.2	1.6	4416
BLK20	3.7	182.4	1.9	8.9	1831	691.6	1.2	2.4	4473
BLK21	0.2	189.6	2.1	12.9	2095	721.8	2.4	3.1	9240
TRIBUTARIES									
BLK05	36.7,2.1	7.9	1.1	1.5	48	60.5	1.1	3.8	342
BLK09	25.5,0.6	17.5	1.2	1.5	110	141.5	1.1	1.5	839
BLK10	24.2,0.6	7.8	1.2	1.5	48	93.1	1.0	2.2	514
BLK14	17.4,0.8	28.3	1.3	2.4	200	104.0	1.1	3.0	617
BLK15	13.3,0.7	7.0	1.6	4.6	21	10.4	1.1	5.0	59
BLK16	13.1,1.1	2.5	1.3	3.1	48	29.2	1.1	1.0	169

Table 1–26
Blackstone River Survey 1991

TSS AND TVS

		AVG FLOW	AVERAGE JULY 10 & AUG 14				FLOW	OCTOBER 2			
		JULY10 & AUG14	(mg/l)		(pounds/day)		OCT 2	(mg/l)		(pounds/day)	
STATION	RIVER MILE	(cfs)	TSS	TVS	TSS	TVS	(cfs)	TSS	TVS	TSS	TVS
BLK01	45.7	13.8	2.8	1.4	210	103	69.1	3.5	1.4	1285	531
BLK02	43.9	58.4	3.5	2.2	1094	677	133.3	4.0	2.7	2838	1940
BLK03	41.3	61.5	1.2	0.8	389	265	145.5	4.5	2.6	3529	2039
BLK04	39.8	63.8	1.7	1.0	593	327	153.6	3.4	1.9	2773	1573
BLK06	36.3	75.2	3.1	1.3	1267	542	228.2	6.3	3.0	7687	3690
BLK07	31.9	77.9	6.2	3.0	2603	1249	236.0	4.6	1.9	5788	2417
BLK08	27.8	80.3	10.4	3.9	4480	1677	243.1	6.0	2.5	7862	3276
BLK11	23.2	106.3	7.4	3.3	4254	1862	484.3	5.2	2.0	13443	5090
BLK12	19.1	108.1	5.2	2.8	3044	1617	500.0	3.8	1.6	10106	4177
BLK13	16.6	137.3	6.0	3.3	4422	2405	607.8	4.2	1.8	13596	5897
BLK17	12.8	148.6	5.8	3.2	4626	2563	655.0	3.8	1.8	13416	6355
BLK18	9.9	179.5	4.9	2.6	4717	2540	679.7	3.7	2.1	13555	7510
BLK19	8.1	180.3	5.9	3.4	5734	3280	682.8	3.3	1.9	12145	6993
BLK20	3.7	182.4	4.4	2.2	4277	2138	691.6	2.7	1.4	10189	5343
BLK21	0.2	189.6	5.9	3.4	5978	3424	721.8	2.8	1.4	10893	5252
TRIBUTARIES											
BLK05	36.7,2.1	7.9	1.1	0.8	46	32	60.5	0.9	0.7	277	228
BLK09	25.5,0.6	17.5	1.6	1.0	149	92	141.5	1.3	0.9	972	705
BLK10	24.2,0.6	7.8	1.7	0.8	69	35	93.1	1.5	1.1	728	527
BLK14	17.4,0.8	28.3	2.3	1.4	343	219	104.0	2.2	1.4	1205	757
BLK15	13.3,0.7	7.0	3.8	2.2	141	84	10.4	2.7	1.6	417	252
BLK16	13.1,1.1	2.5	5.2	2.2	69	30	29.2	2.3	1.3	126	70

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

METALS INFORMATION

CADMIUM (TOTAL) ug/l

	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	4.5	1.2		4.6	2.1	
2	4.0	4.9		4.4	6.8	
3	3.6	4.5	3.0	4.0	4.5	3.2
4	4.5	4.9	3.0	4.1	4.5	2.4
5	5.5	5.0	3.4	4.2	5.2	2.5
Ave	4.4	4.1	3.1	4.3	4.6	2.7
#/Day	0.9	1.1	1.1	0.9	1.3	0.9

CADMIUM (DISSOLVED) ug/l

	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	4.0	1.9		3.5	1.9	
2	1.9	4.3		2.8	4.7	
3	3.0	4.3	3.0	3.2	3.5	2.5
4	3.8	4.7	2.8	3.1	3.7	1.7
5	5.8	4.2	2.6	3.8	4.9	2.1
Ave	3.7	3.9	2.8	3.3	3.7	2.1
#/Day	0.8	1.1	1.0	0.7	1.0	0.7

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT METALS INFORMATION						
CHROMIUM (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	5.1	3.7		3.9	5.7	
2	3.3	3.6		6.6	5.1	
3	4.8	52.8	1.2	6.0	3.6	2.1
4	6.9	3.0	1.2	7.2	6.9	1.5
5	4.5	3.3	1.8	7.5	4.5	2.7
Ave	4.9	13.3	1.4	6.2	5.2	2.1
#/Day	1.0	3.6	0.5	1.3	1.4	0.7
CHROMIUM (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	4.0	3.5		1.6	4.0	
2	0.7	2.8		3.4	2.5	
3	2.2	3.7	0.7	2.2	1.3	0.7
4	5.8	2.2	0.7	2.8	1.3	ND
5	4.3	2.5	1.3	5.5	3.1	1.3
Ave	3.4	2.9	0.9	3.1	2.4	1.0
#/Day	0.7	0.8	0.3	0.6	0.7	0.3

Note: NS=no sample taken, ND=less than the limit of detection

Table 1-29
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT METALS INFORMATION						
COPPER (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	36.3	28.2		45.6	44.7	
2	36.6	43.5		43.5	33.0	
3	40.2	18.6	21.0	59.4	24.6	21.6
4	42.6	20.1	30.9	45.0	27.6	25.5
5	43.8	12.6	29.4	61.1	26.4	41.4
Ave	39.9	24.6	27.1	50.9	31.3	29.5
#/Day	8.3	6.7	9.3	10.5	8.5	10.2
COPPER (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	28.3	26.5		33.1	46.0	
2	33.1	25.0		26.8	15.4	
3	35.2	19.1	14.5	31.9	11.5	14.8
4	35.5	13.9	25.2	32.5	19.3	21.4
5	36.1	3.9	19.9	43.3	147.0	32.1
Ave	33.6	17.7	19.9	33.5	47.8	22.8
#/Day	7.0	4.8	6.8	6.9	13.0	7.8

Note: NS=no sample taken, ND=less than the limit of detection

Table 1-30
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

METALS INFORMATION

LEAD (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	6.9	6.1		5.4	8.6	
2	7.4	4.8		5.9	3.9	
3	5.7	5.1	1.5	6.2	4.6	2.1
4	6.5	3.2	1.8	6.8	4.4	1.8
5	6.6	3.8	1.8	6.9	3.2	2.4
Ave	6.6	4.6	1.7	6.2	4.9	2.1
#/Day	1.4	1.3	0.6	1.3	1.3	0.7

LEAD (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	3.7	5.9		3.3	8.1	
2	4.6	2.3		4.5	1.9	
3	3.7	3.6	0.4	4.2	3.2	0.3
4	4.1	1.4	1.0	3.9	1.6	2.4
5	3.1	1.9	0.7	4.2	1.5	0.9
Ave	3.8	3.0	0.7	4.0	3.3	1.2
#/Day	0.8	0.8	0.2	0.8	0.9	0.4

Table 1-31
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

METALS INFORMATION

NICKEL (TOTAL) ug/l

	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	22.2	122.0		27.6	163.0	
2	18.6	79.5		24.0	94.8	
3	15.6	67.5	18.0	21.8	76.8	17.1
4	14.7	58.2	20.4	21.0	66.0	23.2
5	32.1	44.7	27.3	23.7	52.2	25.8
Ave	20.6	74.4	21.9	23.6	90.6	22.0
#/Day	4.3	20.2	7.5	4.9	24.6	7.6

NICKEL (DISSOLVED) ug/l

	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	22.2	120.0		24.0	150.0	
2	13.2	75.3		16.5	87.0	
3	15.6	65.7	15.3	17.4	69.8	15.9
4	15.0	55.8	21.0	14.7	60.0	19.8
5	33.3	39.9	24.0	20.4	49.5	21.6
Ave	19.9	71.3	20.1	18.6	83.3	19.1
#/Day	4.1	19.4	6.9	3.9	22.7	6.6

Table 1-32
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

Note: NS=no sample taken, ND=less than the limit of detection

BIOCHEMICAL OXYGEN DEMAND (BOD) mg/l								
	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	3.0	2.0	6.7		5.0	3.8	2.9	
2	1.8	3.5	3.7		3.3	4.6	1.7	
3	1.0	2.3	3.4	5.2	2.0	5.7	3.2	4.5
4	3.0	1.9	2.9	5.5	2.8	3.9	1.9	3.2
5	5.0	ND	3.5	3.2	5.0	NS	2.5	4.7
AVERAGE	2.8	2.4	4.0	4.6	3.6	4.5	2.4	4.1
#/DAY	570.9	659.7	1667.8	1517.3	748.7	1224.2	1007.3	1353.6

TOTAL KJELDAHL NITROGEN (TKN) mg/l								
	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-22	SURVEY 3	SURVEY 1	SURVEY 2	9/20-22	SURVEY 3
1	2.0	1.4	ND		2.5	2.3	ND	
2	2.2	1.1	ND		2.2	1.8	ND	
3	2.9	1.1	ND	ND	1.6	1.4	ND	ND
4	1.0	1.3		ND	1.1	1.4		ND
5	1.0	1.3		ND	1.5	1.3		1.2
AVERAGE	1.8	1.2			1.8	1.6		1.2
#/DAY	376.4	337.3			368.2	446.1		393.0

Table 1-33
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

Note: NS=no sample taken, ND=less than the limit of detection

NITRATE (NO_3) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	6.3	7.2			6.8	6.0		
2	5.7	3.4			5.7	26.3		
3	NS	26.8		13.0	6.4	30.9		13.4
4	6.4	12.3		7.7	7.1	8.8		9.8
5	6.3	23.6		10.4	6.4	31.6		11.8
AVERAGE	6.2	14.7		10.4	6.5	20.7		11.7
#/DAY	1277.2	3988.3		4279.7	1340.3	5636.9		4816.4

AMMONIA (NH_3) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	0.8	0.2	0.5		1.1	0.2	0.8	
2	1.0	0.3	0.4		0.6	0.6	0.2	
3	0.2	0.2	0.2	0.3	0.1	0.1	0.2	0.2
4	0.5	0.3	1.0	0.4	0.2	0.1	0.4	0.1
5	0.2	0.3	0.4	0.2	0.2	NS	0.4	0.2
AVERAGE	0.5	0.3	0.5	0.3	0.5	0.3	0.4	0.2
#/DAY	111.7	70.7	206.4	98.3	103.4	68.0	165.1	54.6

Table 1-34
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

Note: NS=no sample taken, ND=less than the limit of detection

ORTHO-PHOSPHATE (PO_4) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	2.3	2.0			2.5	2.1		
2	2.0	2.9			2.0	3.0		
3	NS	2.1		3.1	2.4	1.9		3.3
4	2.5	2.1		2.5	3.0	2.2		2.4
5	1.4	2.9		2.6	1.6	2.6		3.4
AVERAGE	2.1	2.4		2.7	2.3	2.4		3.0
#/DAY	424.0	652.9		1128.4	475.7	642.0		1252.3

CALCIUM (Ca) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	13.0	12.3			13.0	11.8		
2	13.0	12.8			13.0	13.1		
3	12.0	13.2		13.3	13.0	13.6		12.7
4	12.5	11.9		12.7	12.0	11.9		12.4
5	13.0	13.2		13.4	13.0	13.2		13.1
AVERAGE	12.7	12.7		13.1	12.8	12.7		12.7
#/DAY	2626.8	3449.6		5421.8	2647.5	3460.5		5256.7

Table 1–35
Blackstone River Survey 1991

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

Note: NS=no sample taken, ND=less than the limit of detection

MAGNESIUM (Mg) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	3.2	3.3			3.2	3.4		
2	3.1	3.1			3.2	3.2		
3	3.0	3.2		3.4	3.0	3.2		3.5
4	3.0	3.1		3.1	3.0	3.3		3.4
5	3.1	3.2		3.2	3.1	3.3		3.5
AVERAGE	3.1	3.2		3.2	3.1	3.3		3.5
#/DAY	637.0	865.1		1334.8	641.2	892.3		1431.1

CHLORIDE (Cl) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	92	74	65		92	89	73	
2	92	50	73		96	62	92	
3	78	69	95	120	92	68	111	123
4	85	103	96	115	88	98	101	125
5	85	105	102	130	88	132	111	141
AVERAGE	86	80	86	122	91	90	98	130
#/DAY	17870.3	21818.5	35586.0	39843.9	18863.1	24430.2	40292.2	42463.8

UPPER BLACKSTONE POLLUTION ABATEMENT DISTRICT

Note: NS=no sample taken, ND=less than the limit of detection

TOTAL SUSPENDED SOLIDS (TSS) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	2.4	1.4	4.4		8.6	6.0	8.0	
2	1.8	4.4	5.2		4.8	2.4	2.8	
3	2.4	1.8	3.6	2.0	5.0	2.4	5.8	2.8
4	2.0	0.6	4.6	1.2	NS	2.2	NS	3.6
5	1.8	3.2	7.6	2.4	NS	20.4	4.6	3.0
AVERAGE	2.1	2.3	5.1	1.9	6.1	6.7	5.3	3.1
#/DAY	430.2	620.3	2097.2	611.3	1268.6	1817.3	2188.0	1026.1

VOLATILE SUSPENDED SOLIDS (VSS) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	2.0	0.8	3.2		7.0	4.4	6.8	
2	0.8	3.2	2.8		4.0	1.6	2.4	
3	2.2	1.0	3.0	1.6	3.8	2.0	4.6	1.8
4	1.6	ND	4.0	0.8	NS	1.2	NS	3.2
5	1.0	2.6	6.0	1.8	NS	18.4	3.8	2.2
AVERAGE	1.5	1.9	3.8	1.4	4.9	5.5	4.4	2.4
#/DAY	314.4	516.9	1516.8	458.5	1020.4	1501.7	1816.5	786.0

Table 1-36
Blackstone River Survey 1991

WOONSOCKET WASTEWATER TREATMENT PLANT METALS INFORMATION						
CADMIUM (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	3.1	4.8		3.2	4.8	
2	2.1	3.5		2.7	4.8	
3	2.4	3.8	0.9	2.6	3.3	ND
4	2.4	4.5	1.5	3.0	5.2	1.1
5	2.4	11.6	1.9	2.7	5.9	1.7
Ave	2.5	5.6	1.4	2.8	4.8	1.4
#/Day	0.1	0.3	0.1	0.1	0.2	0.1
CADMIUM (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	2.2	4.3		2.2	4.5	
2	1.7	3.0		3.1	3.5	
3	1.4	1.6	0.3	1.6	2.9	0.3
4	1.5	3.7	0.6	1.9	2.5	0.8
5	1.9	6.5	0.7	1.9	4.4	0.7
Ave	1.7	3.8	0.5	2.1	3.6	0.6
#/Day	0.1	0.2	0.03	0.1	0.2	0.03

WOONSOCKET WASTEWATER TREATMENT PLANT METALS INFORMATION						
CHROMIUM (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	3.9	9.0		4.2	14.7	
2	9.0	9.1		5.4	9.0	
3			0.9	3.6	5.7	ND
4	5.1	5.1	2.7	3.9	0.9	2.1
5	7.2	6.0	2.7	3.9	4.8	3.3
Ave	6.3	7.3	2.1	4.2	7.0	2.7
#/Day	0.3	0.3	0.1	0.2	0.3	0.2
CHROMIUM (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	5.1	7.2		3.1	9.1	
2	5.1	6.0		1.3	5.5	
3	2.7	2.7	0.4	0.4	3.1	ND
4	2.4	4.6	1.9	1.6	2.2	1.0
5	4.6	4.9	1.9	3.7	3.1	1.9
Ave	4.0	5.1	1.4	2.0	4.6	1.5
#/Day	0.2	0.2	0.1	0.1	0.2	0.1

NOTE: NS=no sample taken, ND=less than the limit of detection

WOONSOCKET WASTEWATER TREATMENT PLANT METALS INFORMATION						
COPPER (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	41.1	24.6		38.4	33.0	
2	33.3	41.4		46.2	43.5	
3	54.1	36.9	28.2	36.9	39.0	7.5
4	44.1	37.8	24.6	39.0	147.0	9.0
5	32.1	54.0	21.6	44.4	39.9	20.0
Ave	40.9	38.9	24.8	41.0	60.5	12.2
#/Day	1.8	1.8	1.4	1.8	2.8	0.7
COPPER (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	27.1	13.0		25.6	30.1	
2	25.0	28.0		32.2	35.5	
3	31.0	12.7	5.9	22.0	31.5	3.4
4	36.5	32.8	13.0	18.4	29.5	10.9
5	22.5	51.1	12.1	30.1	29.1	9.4
Ave	28.4	27.5	10.3	25.7	31.1	7.9
#/Day	1.3	1.3	0.6	1.2	1.4	0.5

NOTE: NS=no sample taken, ND=less than the limit of detection

WOONSOCKET WASTEWATER TREATMENT PLANT

METALS INFORMATION

LEAD (TOTAL) ug/l

	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	5.2	12.3		3.9	10.8	
2	3.6	10.1		5.1	8.7	
3	5.1	6.9	7.2	3.9	9.6	3.0
4	5.7	9.6	5.1	6.3	21.0	3.9
5	3.9	18.9	6.9	4.2	12.3	6.0
Ave	4.7	11.6	6.4	4.7	12.5	4.3
#/Day	0.2	0.5	0.4	0.2	0.6	0.3

LEAD (DISSOLVED) ug/l

	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	2.4	4.7		1.6	5.2	
2	1.6	5.5		1.6	5.2	
3	1.6	ND	1.9	0.7	2.5	1.0
4	1.6	7.9	2.2	1.6	4.3	2.8
5	1.9	14.5	1.0	1.3	6.7	2.2
Ave	1.8	8.2	1.7	1.4	4.8	2.0
#/Day	0.1	0.4	0.1	0.1	0.2	0.1

NOTE: NS=no sample taken, ND=less than the limit of detection

WOONSOCKET WASTEWATER TREATMENT PLANT METALS INFORMATION						
NICKEL (TOTAL) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	10.5	9.3		205	168	
2	10.8	98.7		223	196	
3	18.0	7.1	18.9	256	222	16
4	9.0	9.9	17.1	263	255	69
5	13.8	11.4	10.4	121	210	79
Ave	12.4	27.3	15.5	213.6	210.2	54.7
#/Day	0.6	1.3	0.9	9.6	9.7	3.1
NICKEL (DISSOLVED) ug/l						
	PRECHLORINATION			POSTCHLORINATION		
DAY	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 1	SURVEY 2	SURVEY 3
1	6.8	14.4		192	164	
2	16.8	8.1		207	160	
3	8.6	6.9	16.8	223	205	10
4	5.7	6.9	8.4	238	207	71
5	8.4	9.3	9.9	120	187	11
Ave	9.3	9.1	11.7	196.0	184.6	30.7
#/Day	0.4	0.4	0.7	8.8	8.5	1.8

NOTE: NS=no sample taken, ND=less than the limit of detection

Table 1-42
Blackstone River Survey 1991

WOONSOCKET WASTEWATER TREATMENT PLANT

NOTE: NS=no sample taken, ND=less than the limit of detection

BIOCHEMICAL OXYGEN DEMAND (BOD) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	3.1	9.2	13.4		4.2	8.4	11.9	
2	5.0	7.2	10.2		7.5	7.5	8.7	
3	6.9	19.1	18.6	20.8	3.7	14.4	7.7	14.0
4	6.5	10.2	25.5	22.0	NS	12.2	13.5	20.0
5	9.9	10.5	21.9	22.0	7.6	6.2	18.5	16.0
AVERAGE	6.3	11.2	17.9	21.6	5.8	9.7	12.1	16.7
#/DAY	281	517	1025	1348	257	448	690	1040

TOTAL KJELDAHL NITROGEN (TKN) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-22	SURVEY 3	SURVEY 1	SURVEY 2	9/20-22	SURVEY 3
1	32.1	18.6	9.3		25.6	13.7	6.4	
2	27.2	15.4	8.7		13.4	17.1	7.5	
3	38.8	19.5	7.7	15.1	42.0	18.8	7.5	11.5
4	NS	15.6		13.1	NS	17.2		13.5
5	24.3	17.6		11.1	42.0	17.8		13.7
AVERAGE	30.6	17.3	8.6	13.1	30.8	16.9	7.1	12.9
#/DAY	1368	798	490	818	1375	779	408	805

Table 1–43
Blackstone River Survey 1991

WOONSOCKET WASTEWATER TREATMENT PLANT

NOTE: NS=no sample taken, ND=less than the limit of detection

NITRATE (NO_3) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	0.4	1.7			0.9	3.8		
2	0.4	3.7			0.9	2.0		
3	0.4	29.7		1.6	0.9	38.8		1.4
4	0.3	33.2		2.1	NS	9.9		2.7
5	0.3	39.6		3.8	1.0	58.5		4.7
AVERAGE	0.4	21.6		2.5	0.9	22.6		2.9
#/DAY	16	993		143	41	1040		168

AMMONIA (NH_3) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	26.6	15.2	6.5		28.6	12.9	7.7	
2	1.0	15.0	10.8		27.7	9.5	9.9	
3	28.2	13.5	13.0	12.1	27.8	12.0	15.8	13.2
4	21.5	12.0	13.0	10.5	28.4	16.8	13.8	13.5
5	21.4	13.2	6.1	8.9	NS	14.3	8.4	10.5
AVERAGE	19.7	13.8	9.9	10.5	28.1	13.1	11.1	12.4
#/DAY	882	634	565	655	1257	603	636	774

Table 1-44
Blackstone River Survey 1991

WOONSOCKET WASTEWATER TREATMENT PLANT

NOTE: NS=no sample taken, ND=less than the limit of detection

ORTHO-PHOSPHATE (PO_4) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	3.6	3.5			3.9	3.7		
2	2.6	3.6			3.0	3.7		
3	3.5	4.7		4.2	3.5	4.5		4.1
4	3.1	4.6		4.6	NS	ND		4.2
5	1.3	4.7		3.9	3.1	4.9		3.7
AVERAGE	2.8	4.2		4.2	3.4	4.2		4.0
#/DAY	126	194		242	151	193		229

CALCIUM (Ca) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	11.0	12.7			11.0	11.8		
2	13.0	13.8			12.0	13.4		
3	12.0	12.0		13.6	13.0	13.1		12.9
4	13.0	14.3		14.3	11.0	13.8		14.1
5	13.0	13.7		13.8	12.0	12.9		13.4
AVERAGE	12.4	13.3		13.9	11.8	13.0		13.5
#/DAY	554	612		795	527	598		770

Table 1-45
Blackstone River Survey 1991

WOONSOCKET WASTEWATER TREATMENT PLANT

NOTE: NS=no sample taken, ND=less than the limit of detection

MAGNESIUM (Mg) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2		SURVEY 3	SURVEY 1	SURVEY 2		SURVEY 3
1	4.2	3.8			4.0	3.8		
2	4.3	3.7			4.3	3.6		
3	4.1	3.8		4.0	4.3	3.9		3.9
4	3.9	3.9		3.9	4.7	3.8		4.1
5	3.5	3.8		4.6	3.4	3.7		4.8
AVERAGE	4.0	3.8		4.2	4.1	3.8		4.3
#/DAY	179	175		238	185	173		244

CHLORIDE (Cl) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	125	225	258		154	290	310	
2	105	200	212		114	283	260	
3	85	145	202	330	100	200	232	335
4	247	160	240	328	NS	175	273	210
5	335	263	410	159	142	205	440	191
AVERAGE	179.4	198.6	264.4	272.3	127.5	230.6	303.0	245.3
#/DAY	8020	9143	15127	16997	5700	10616	17335	15311

Table 1-46
Blackstone River Survey 1991

WOONSOCKET WASTEWATER TREATMENT PLANT

NOTE: NS=no sample taken, ND=less than the limit of detection

TOTAL SUSPENDED SOLIDS (TSS) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	7.2	16.4	8.0		6.0	14.6	16.9	
2	10.4	14.6	8.4		8.2	16.6	16.0	
3	5.0	8.8	22.2	28.6	7.6	8.4	15.0	13.2
4	11.4	7.6	33.2	28.8	NS	8.8	20.4	23.6
5	8.8	29.4	28.4	38.2	7.0	22.8	24.4	26.4
AVERAGE	8.6	15.4	20.0	31.9	7.2	14.2	18.5	21.1
#/DAY	383	707	1147	1989	322	656	1061	1315

VOLATILE SUSPENDED SOLIDS (VSS) mg/l

	PRECHLORINATION				POSTCHLORINATION			
DAY	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3	SURVEY 1	SURVEY 2	9/20-24	SURVEY 3
1	7.8	10.8	6.4		4.8	10.8	14.0	
2	8.0	10.4	7.0		6.2	12.2	12.9	
3	3.2	6.4	16.8	20.8	7.2	5.2	13.3	9.6
4	8.8	5.6	25.6	21.6	NS	4.8	17.6	17.6
5	6.4	19.2	23.6	27.7	5.2	15.2	19.2	20.0
AVERAGE	6.8	10.5	15.9	23.4	5.9	9.6	15.4	15.7
#/DAY	306	482	909	1458	262	444	881	982

Table 1– 47
Blackstone River Survey 1991

Blacksone River Field Flow Data (cfs)					
	July 10	August 14	October 2	7Q2	7Q10
US STEEL	13.5	14	69.1		
NORTHBRIDGE	77.4	84.5	236	72	45
MILLVILLE	98.7	117.8	483		
WOONSOCKET	142	157	676	134	101
	132 (7/11)	146 (8/15)	595 (10/3)		
LONSDALE AVE.	189.3	199.7	760		

Figure 1– 2
Blackstone River 1991

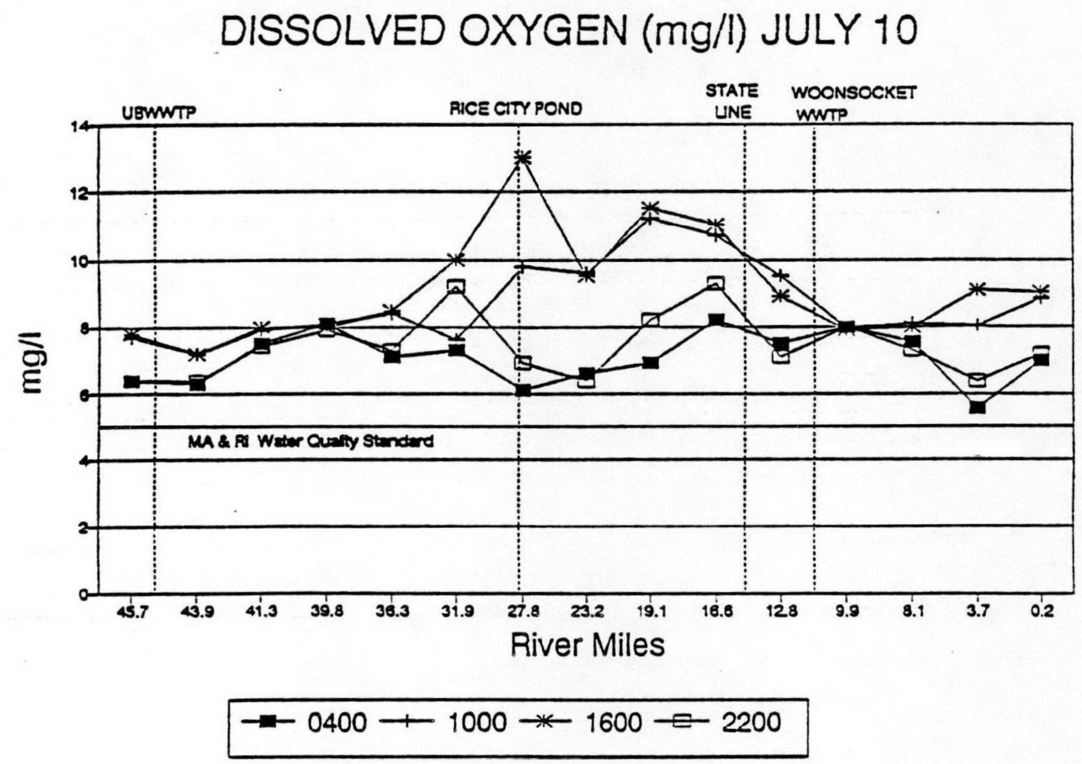


Figure 1–2A
Blackstone River 1991

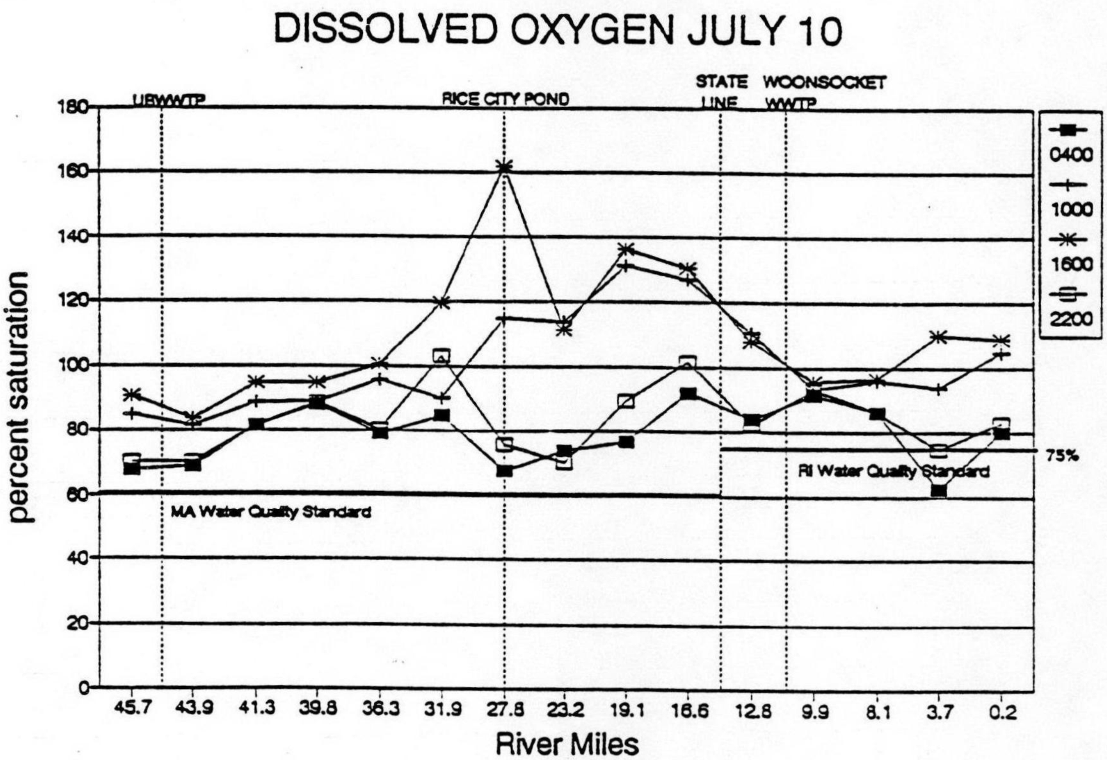


Figure 1–3
Blackstone River 1991

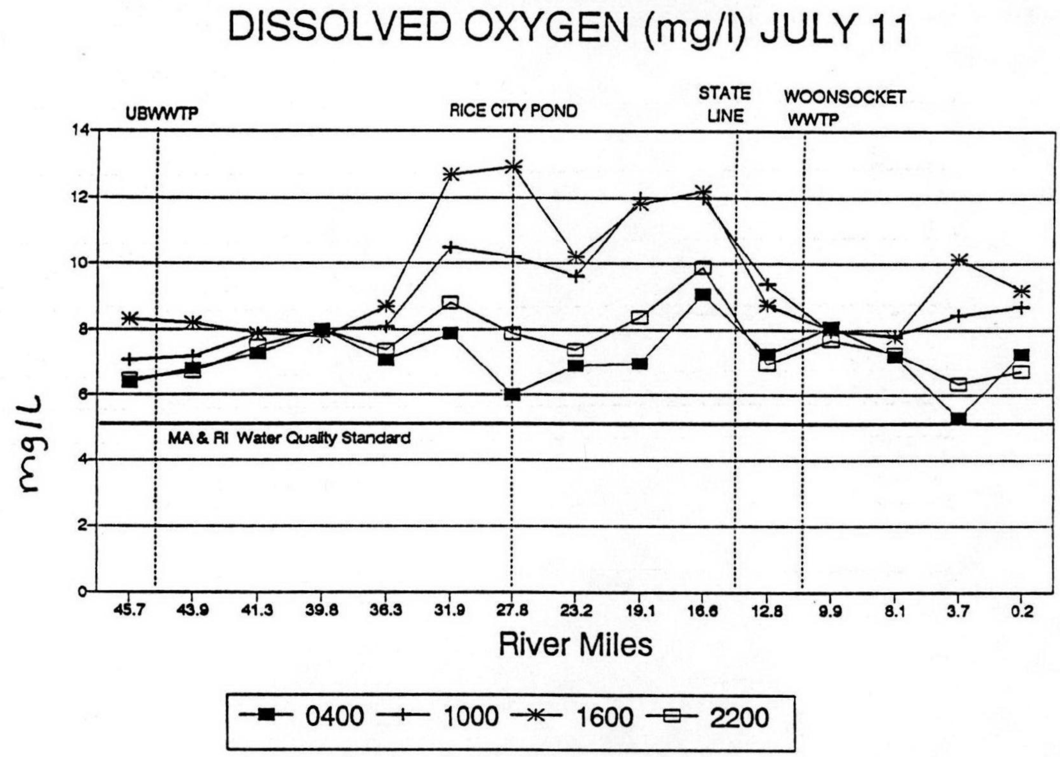


Figure 1– 3A
Blackstone River 1991

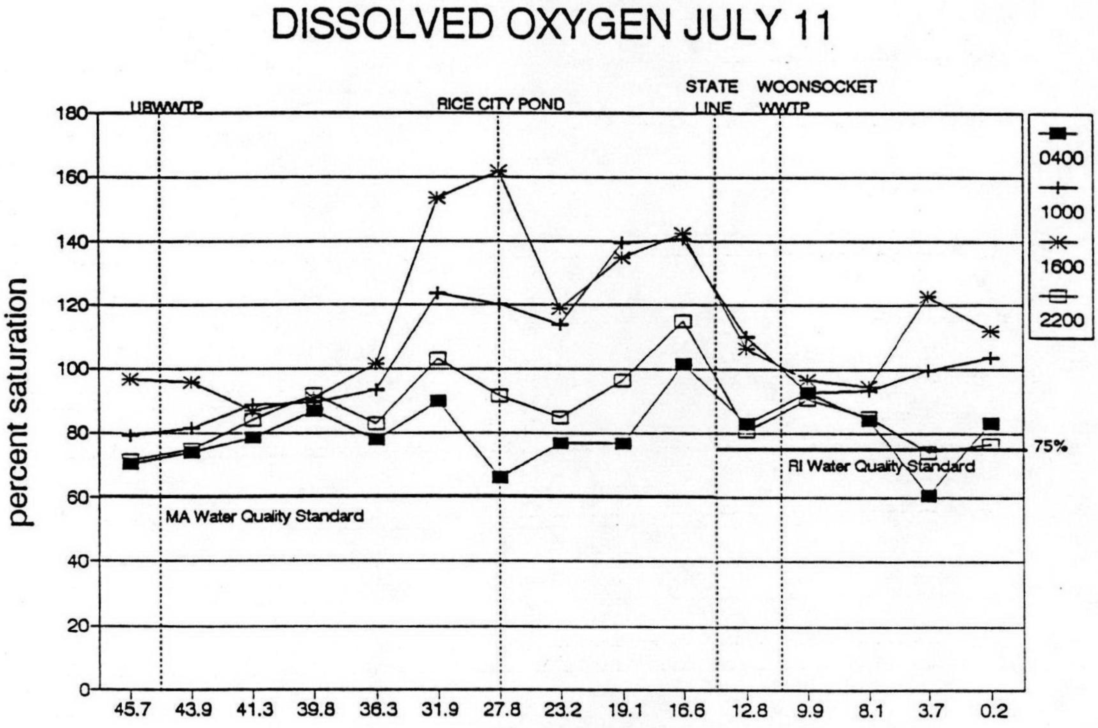


Figure 1-4
Blackstone River 1991

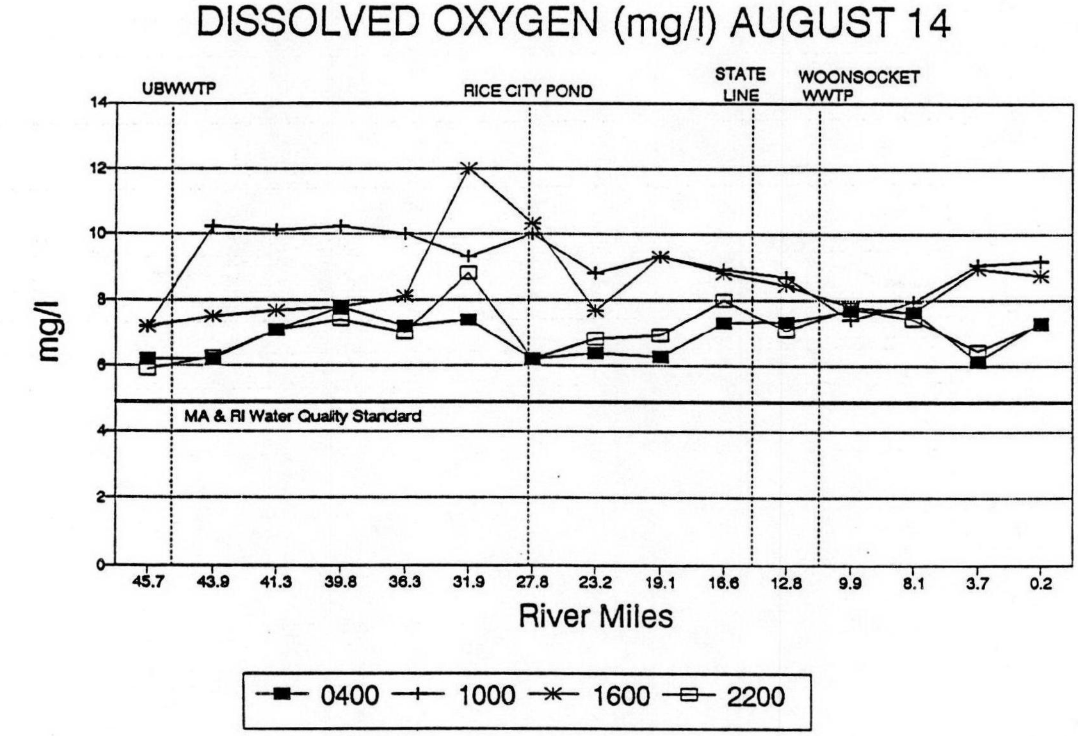


Figure 1- 4A
Blackstone River 1991

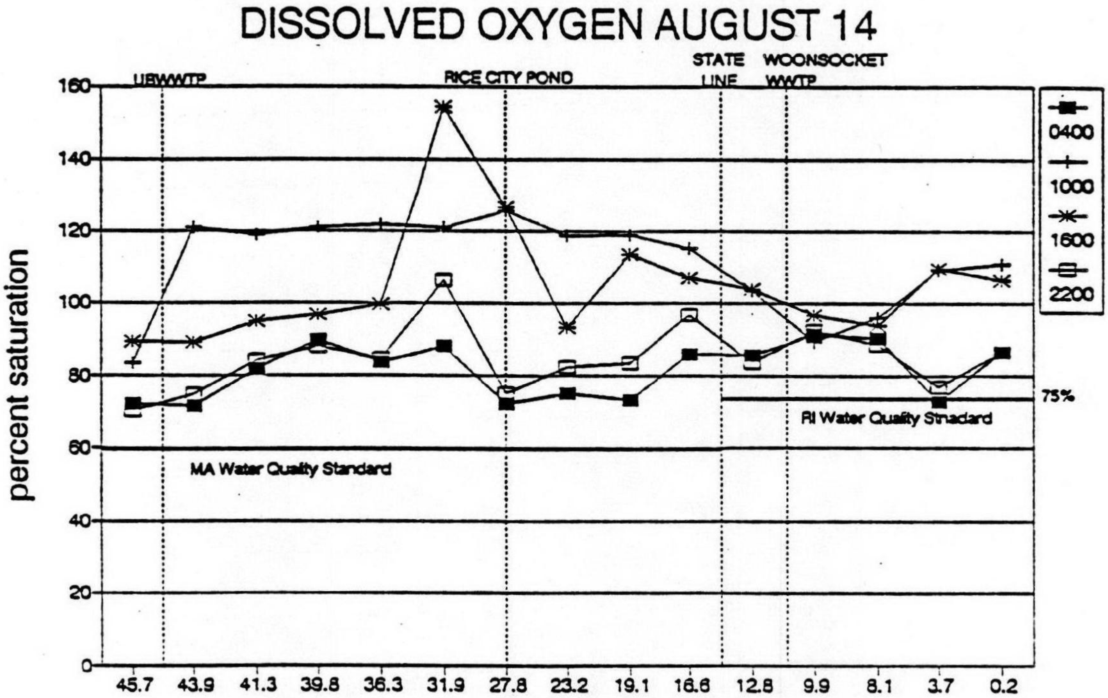


Figure 1–5
Blackstone River 1991

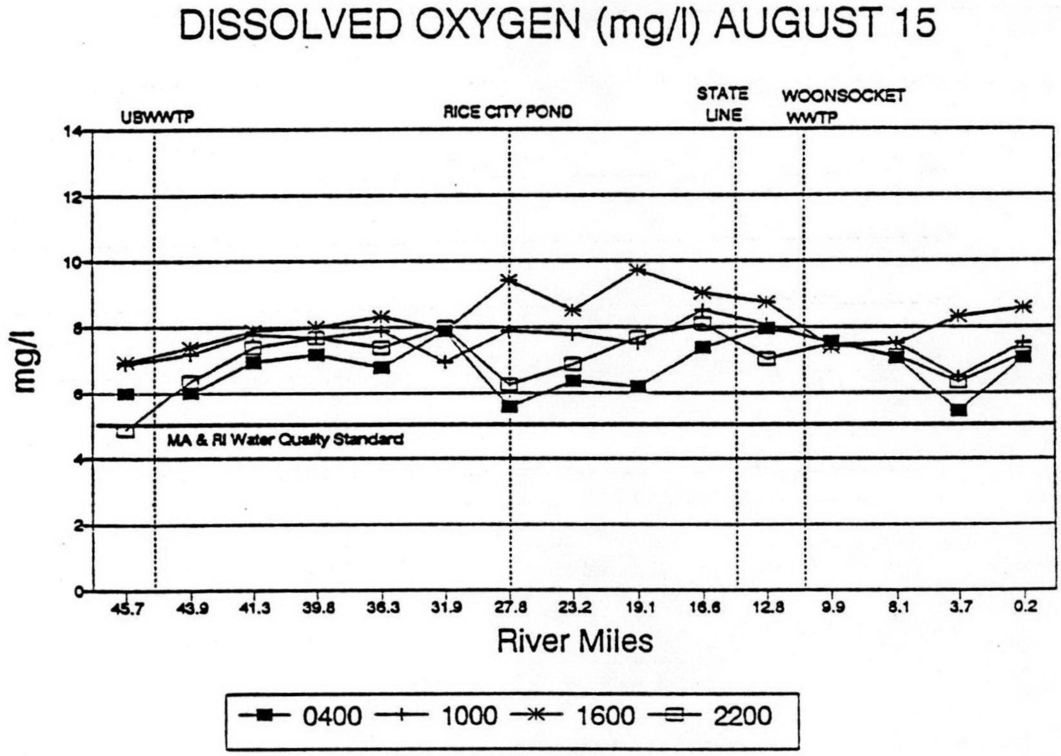


Figure 1–5A
Blackstone River 1991

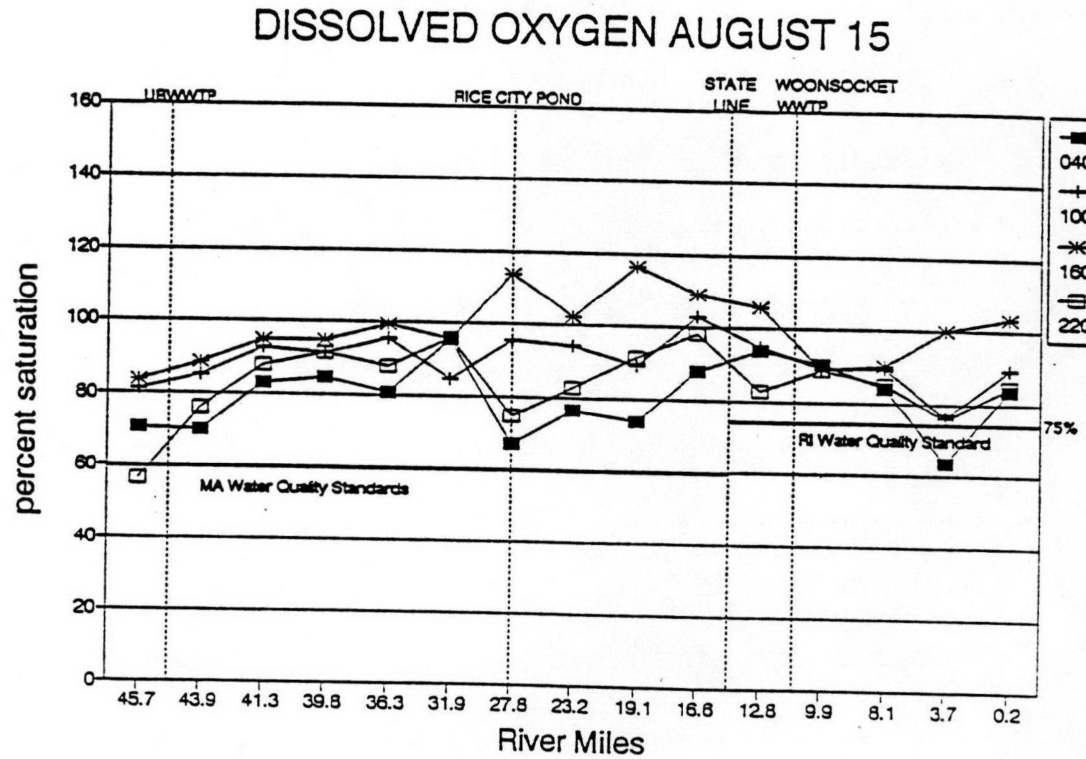


Figure 1–6
Blackstone River 1991

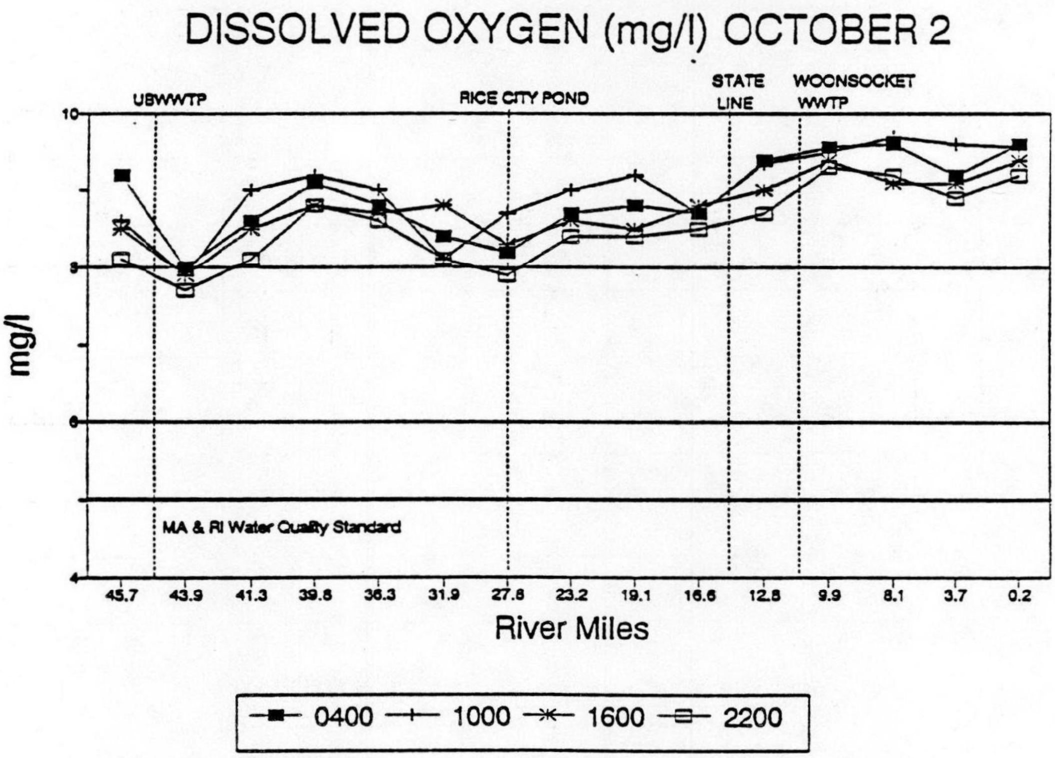


Figure 1–6A
Blackstone River 1991

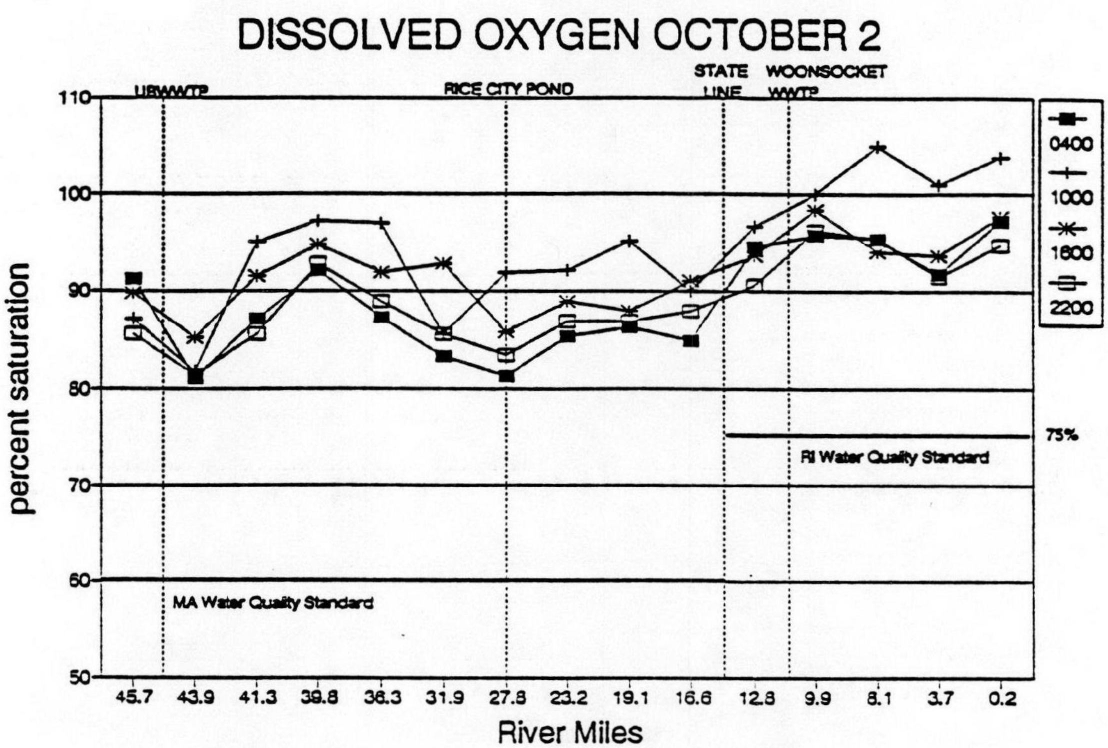


Figure 1–7
Blackstone River 1991

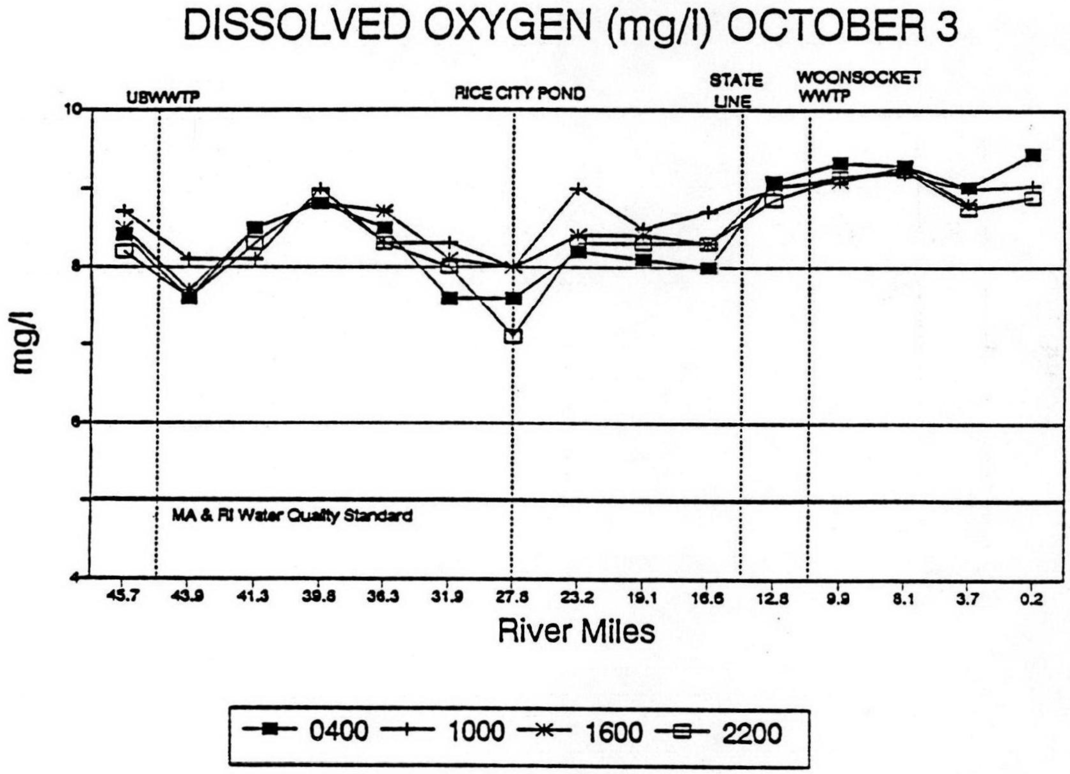


Figure 1–7A
Blackstone River 1991

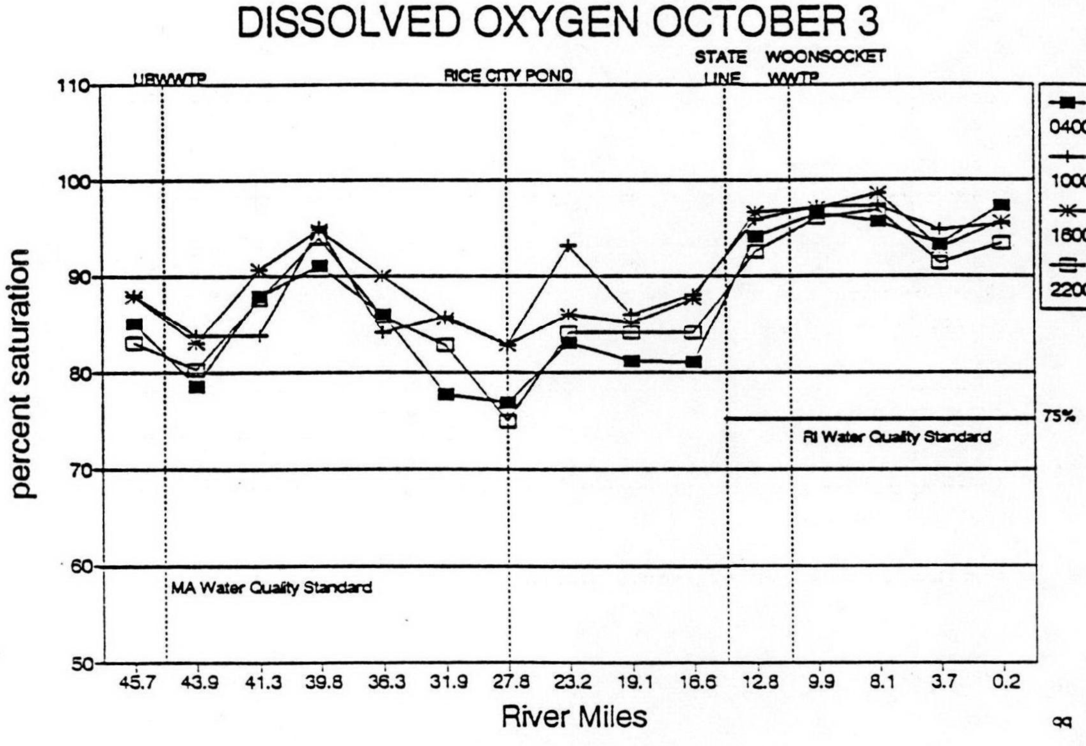


Figure 1–8
Blackstone Tributaries 1991

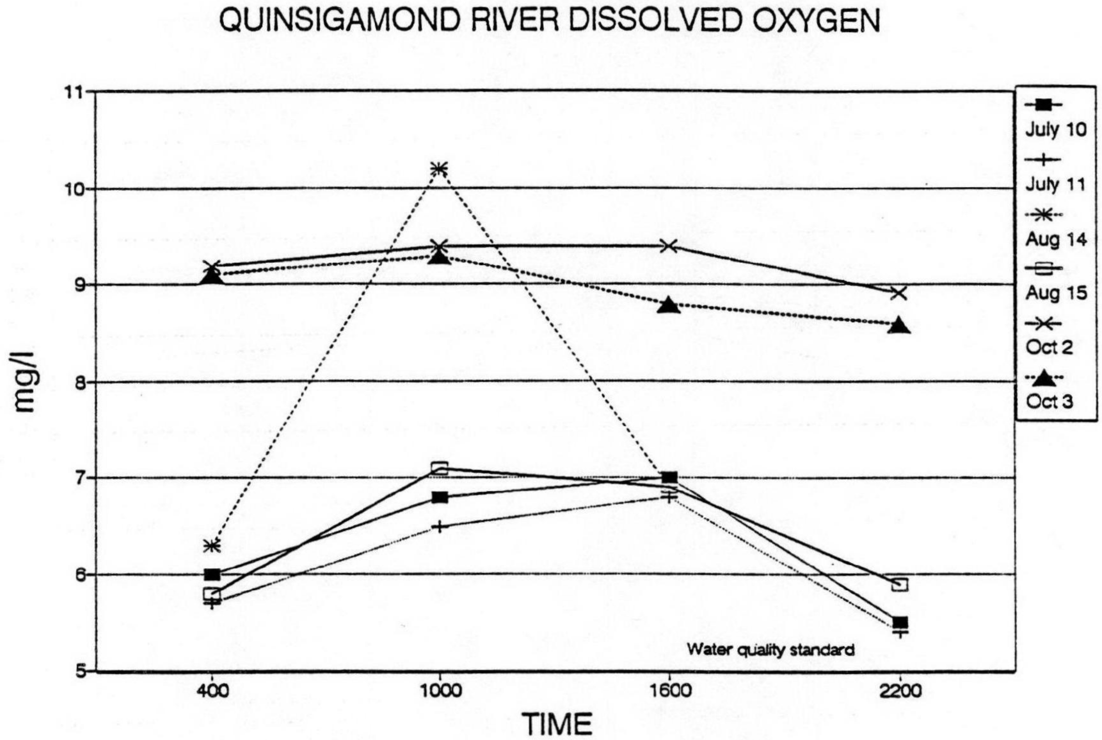


Figure 1– 9
Blackstone Tributaries 1991

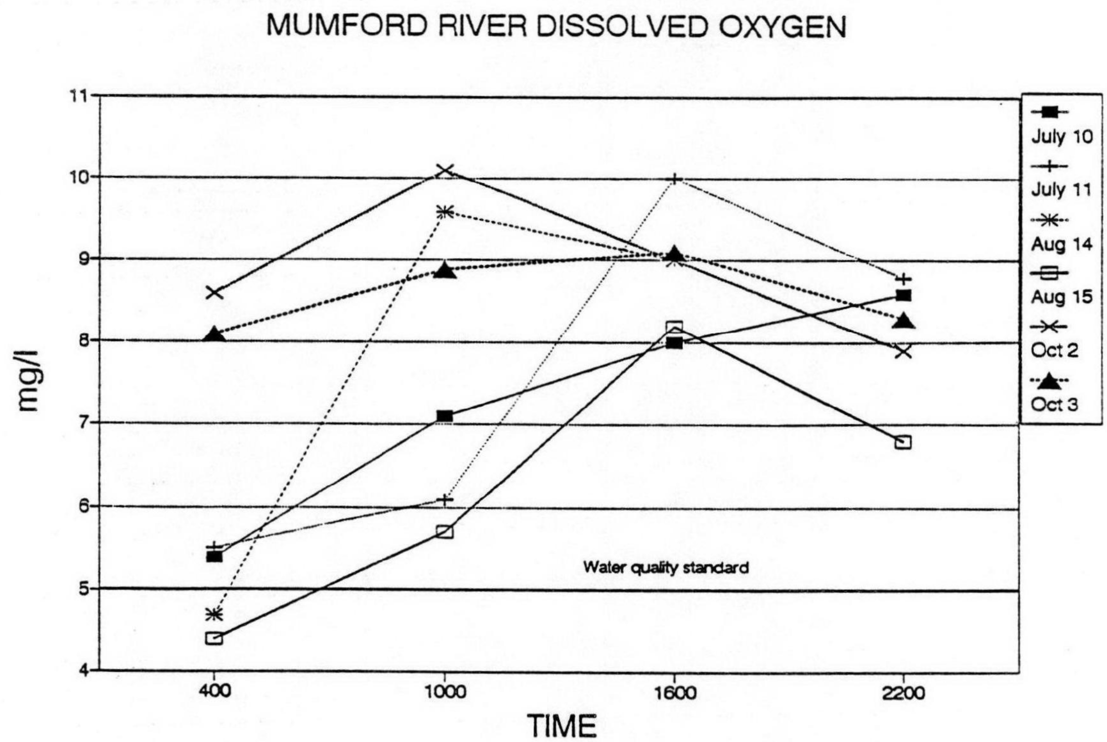


Figure 1–10
Blackstone Tributaries 1991

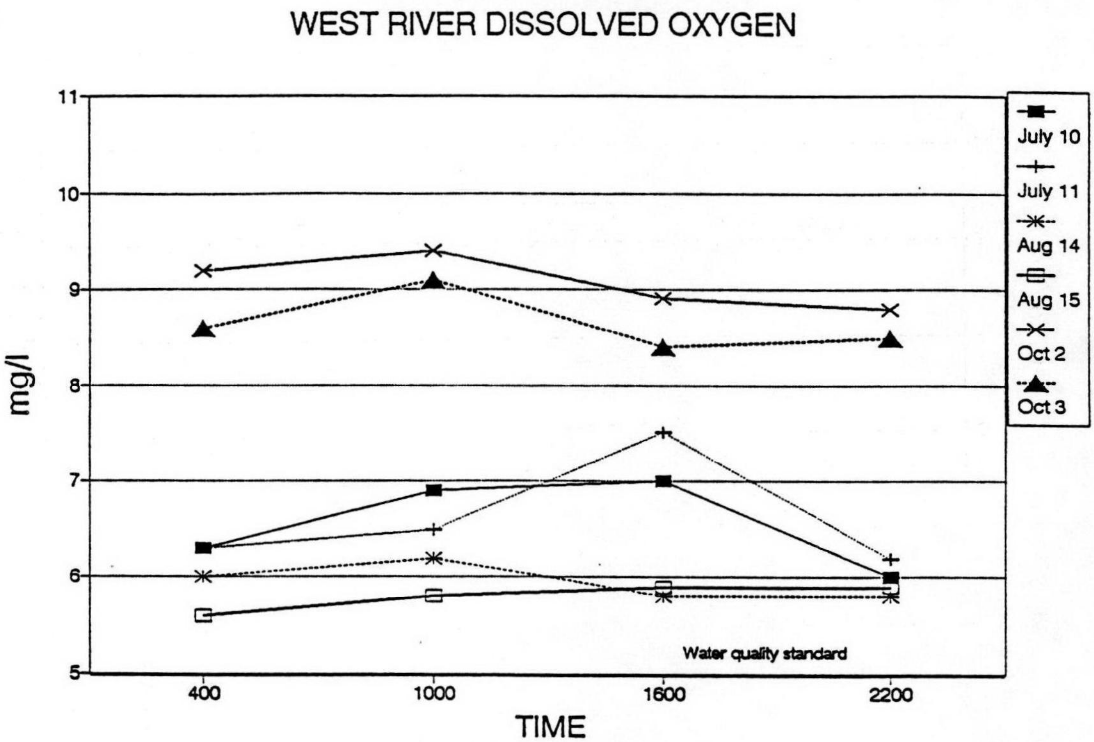


Figure 1–11
Blackstone Tributaries 1991

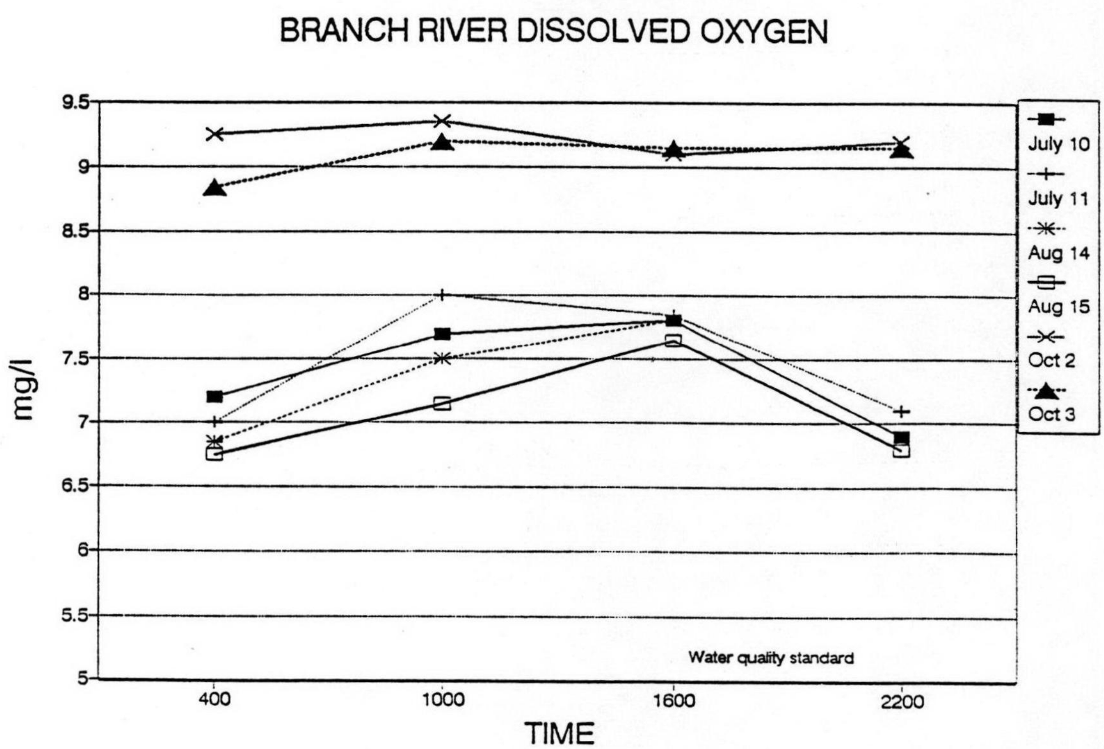


Figure 1– 12
Blackstone Tributaries 1991

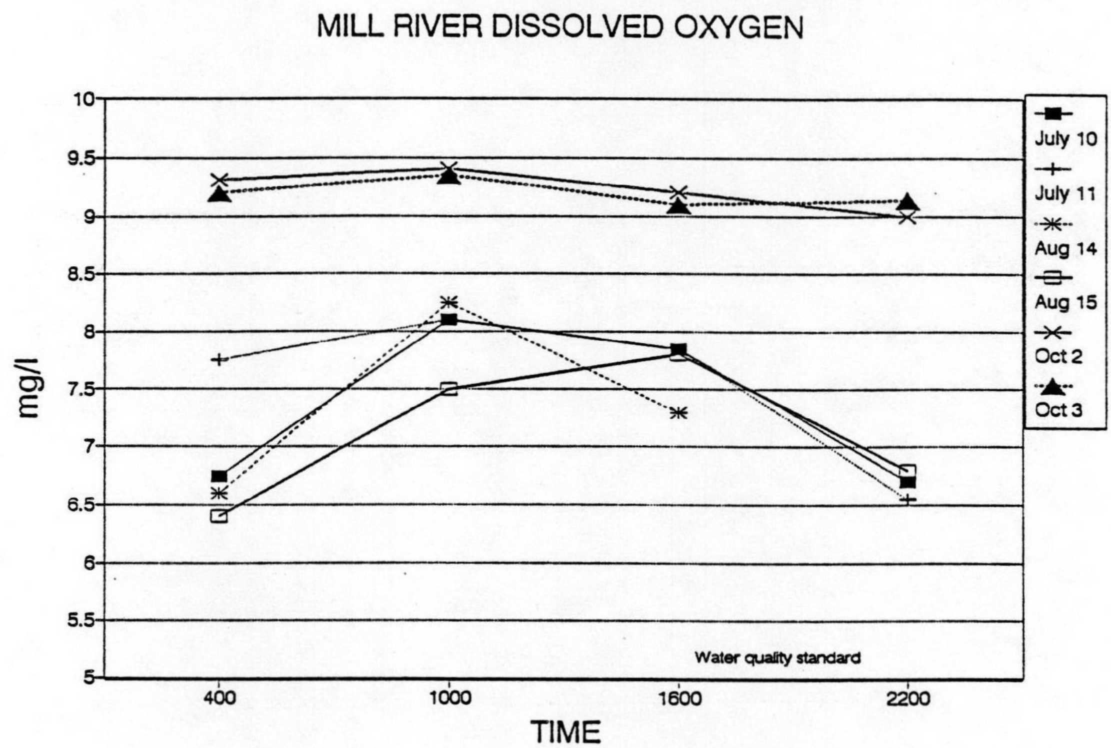


Figure 1– 13
Blackstone Tributaries 1991

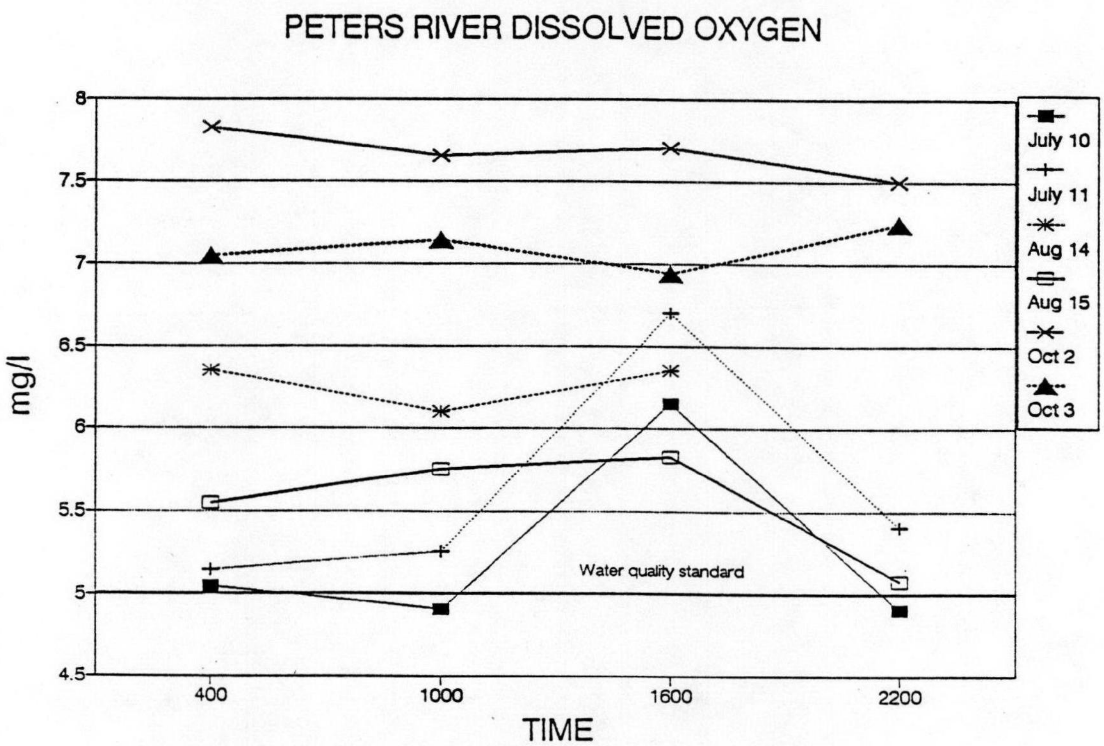


Figure 1-14
Blackstone River 1991

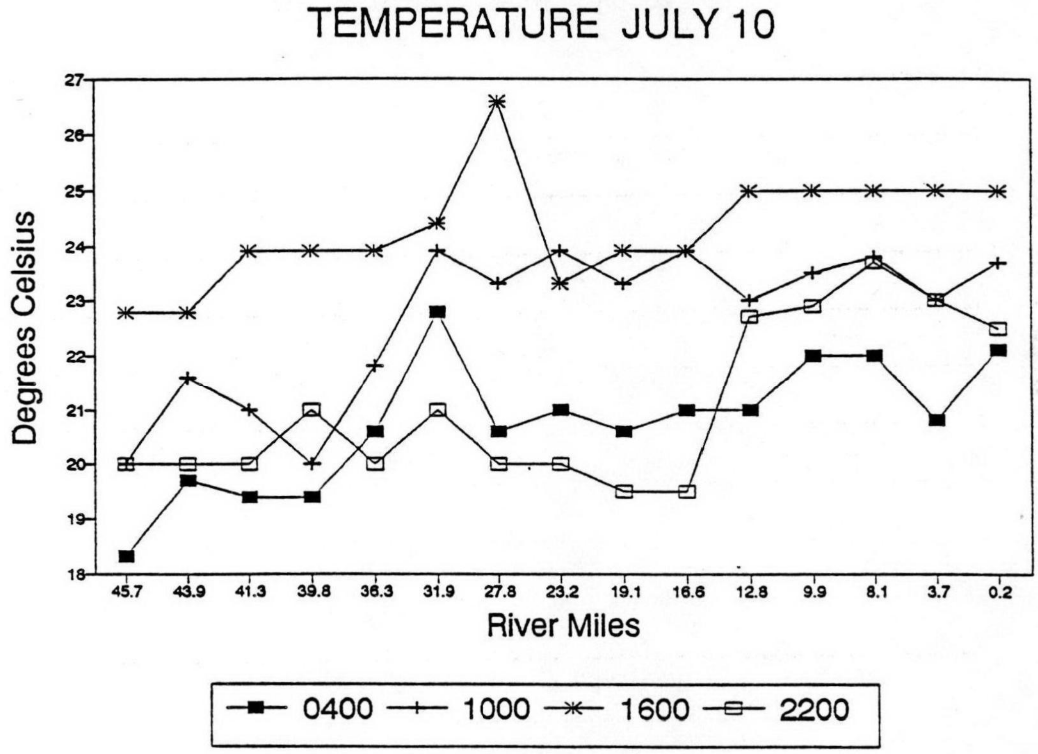


Figure 1-15
Blackstone River 1991

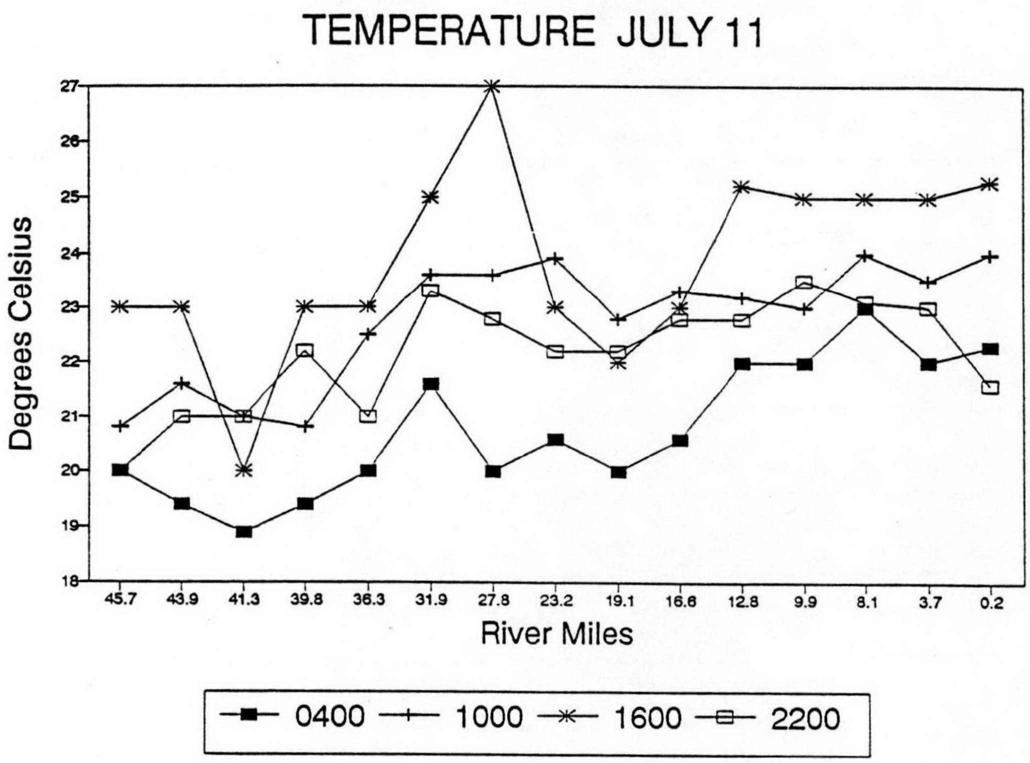


Figure 1-16
Blackstone River 1991

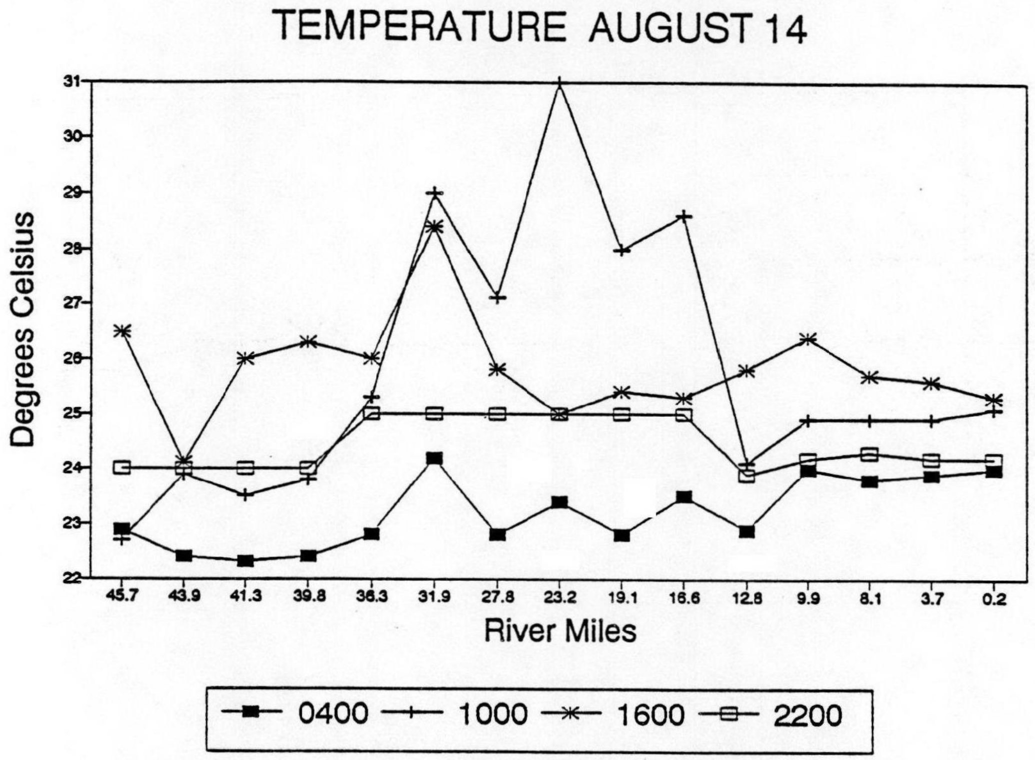


Figure 1-17
Blackstone River 1991

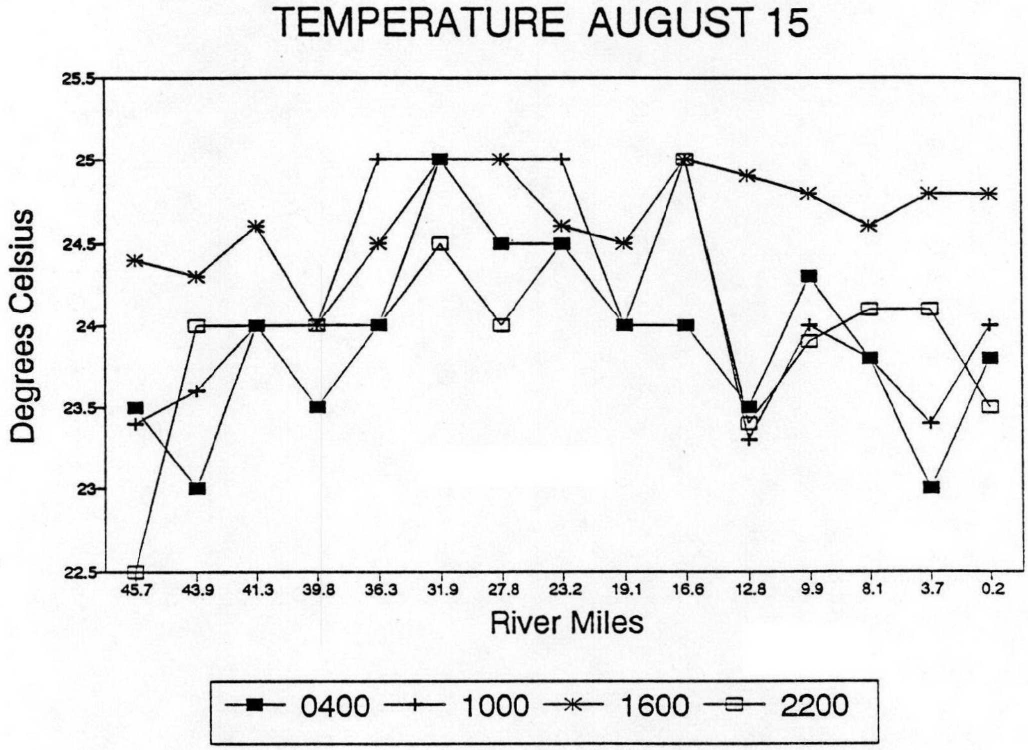


Figure 1–18
Blackstone River 1991

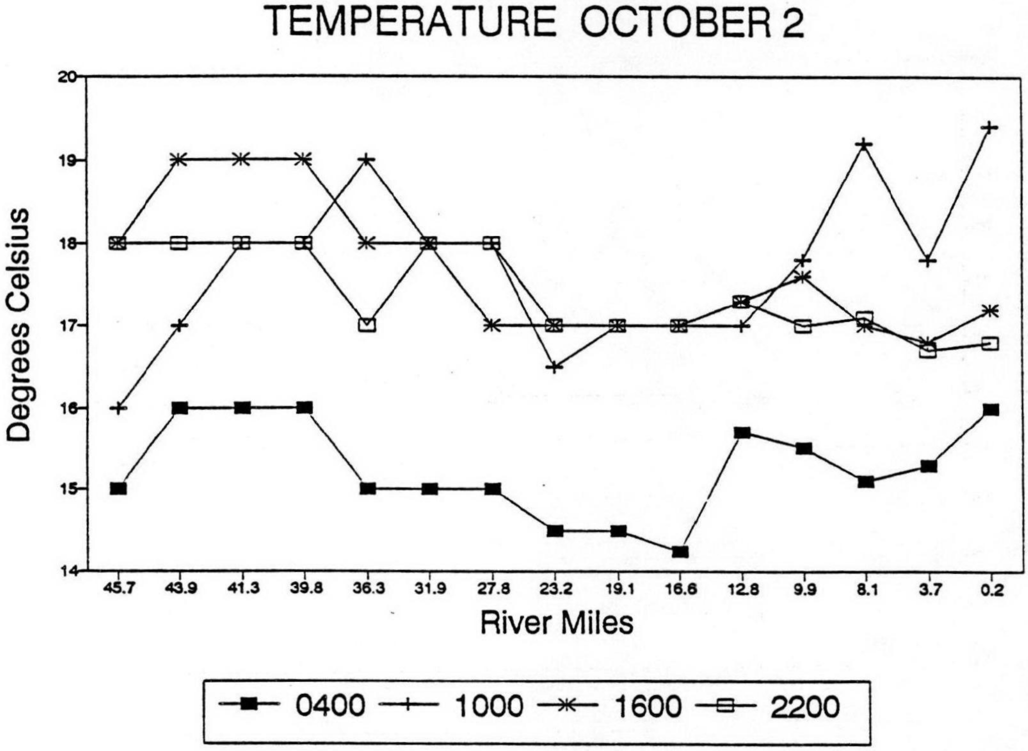


Figure 1–19
Blackstone River 1991

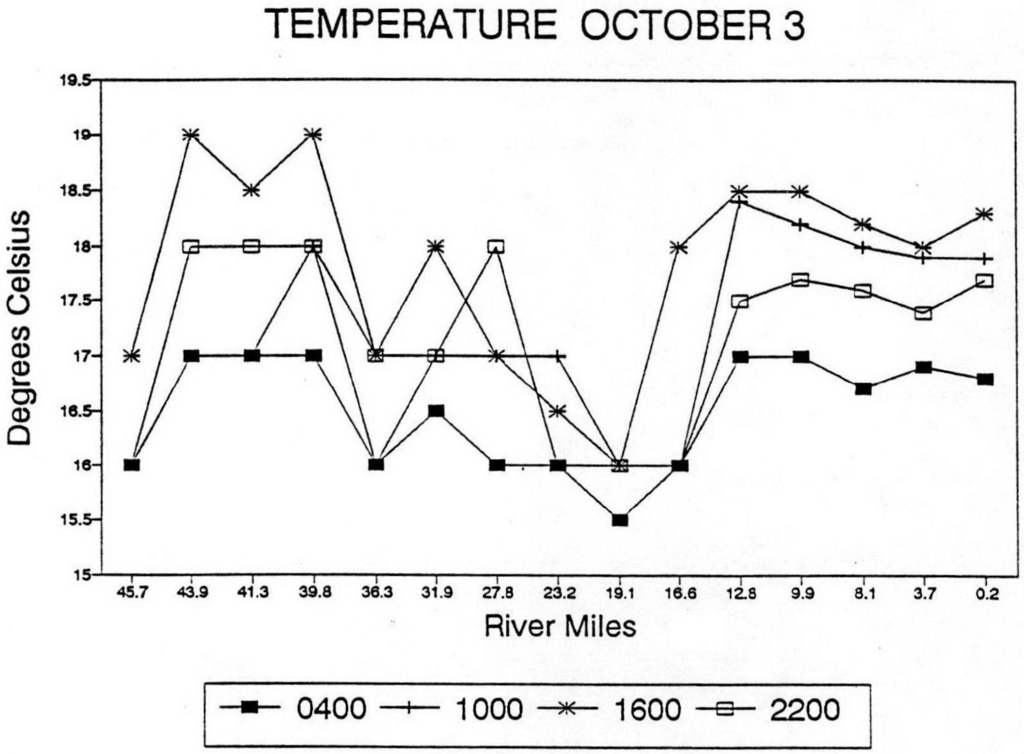


Figure 1- 20
Blackstone River 1991

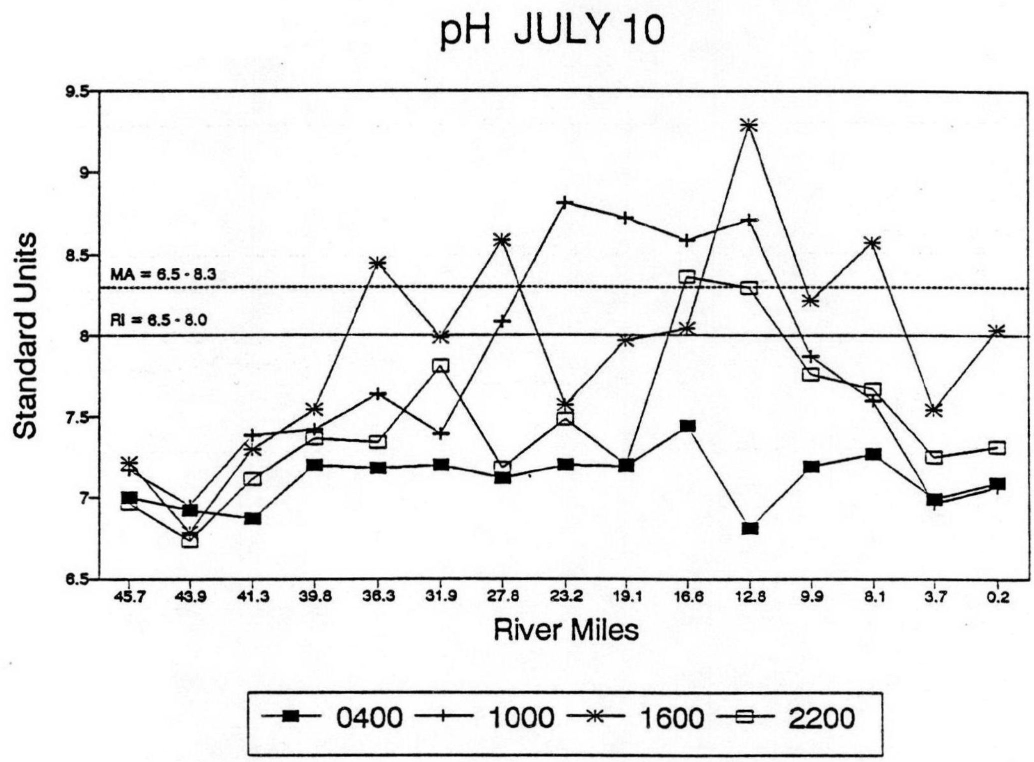


Figure 1- 21
Blackstone River1991

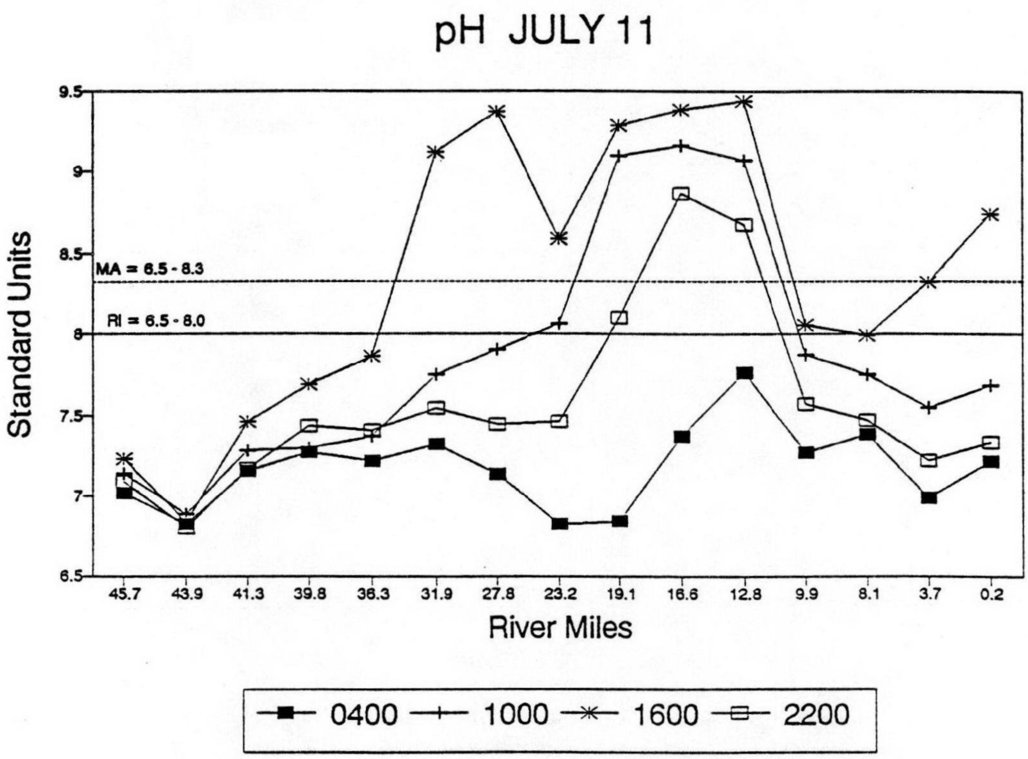


Figure 1–22
Blackstone River 1991

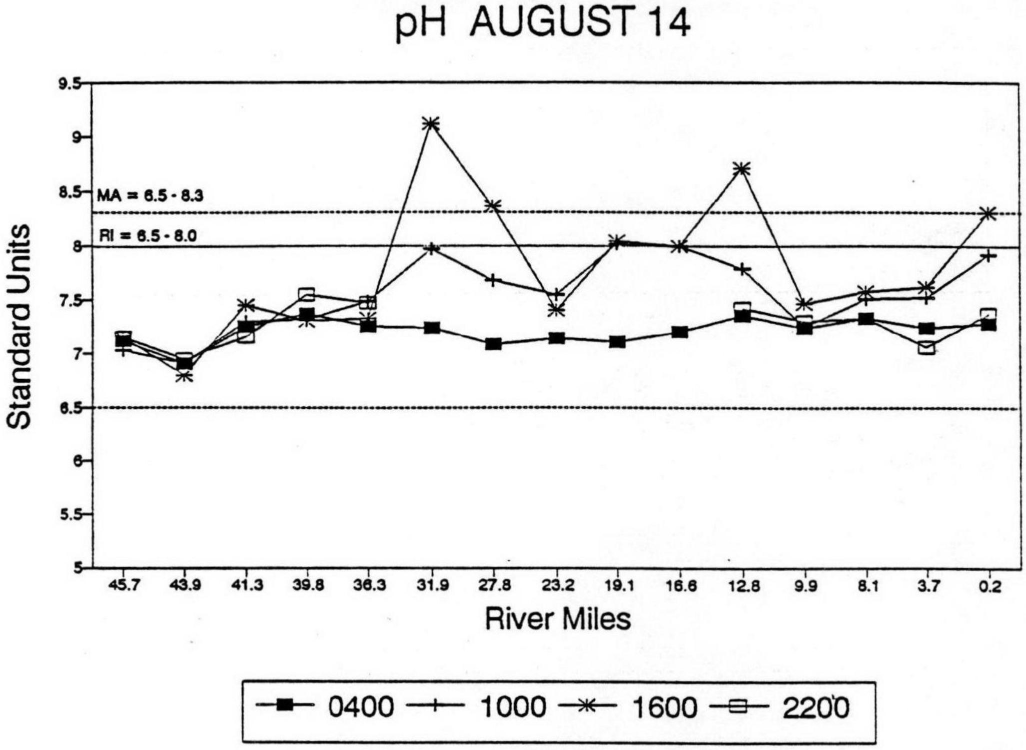


Figure 1–23
Blackstone River 1991

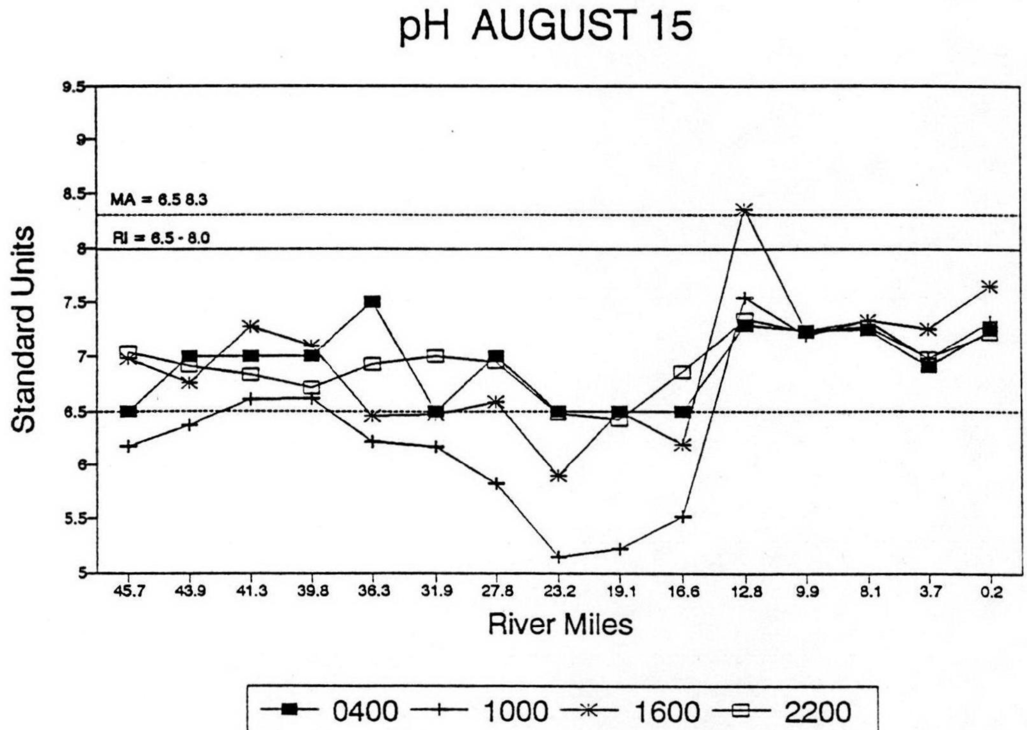


Figure 1–24
Blackstone River 1991

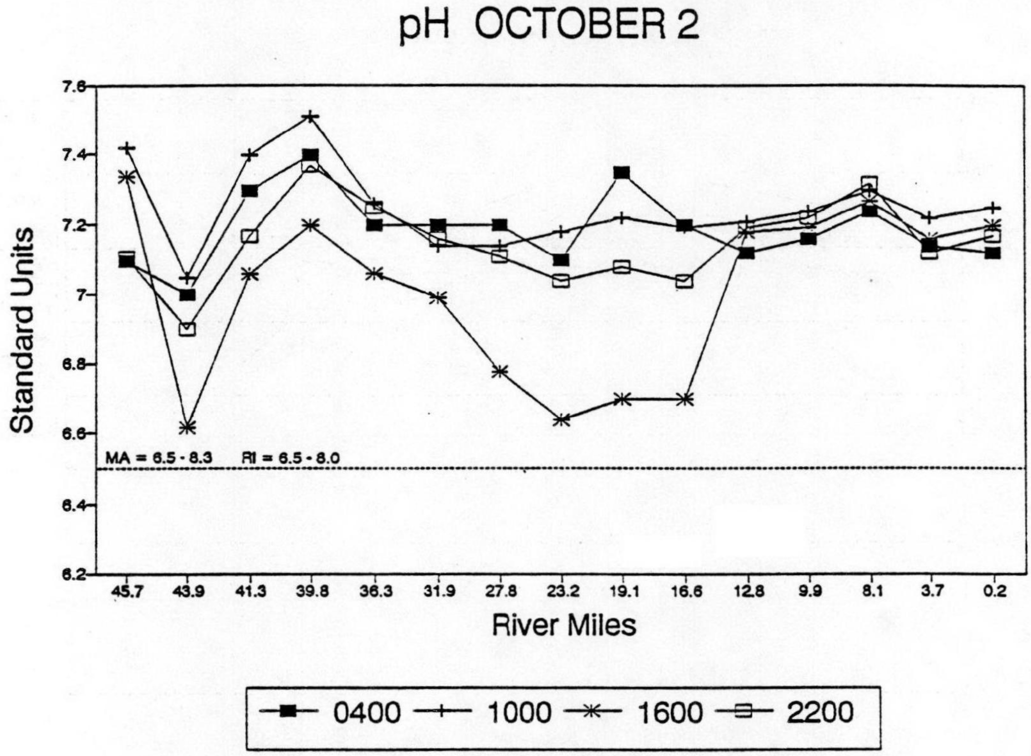


Figure 1–25
Blackstone River 1991

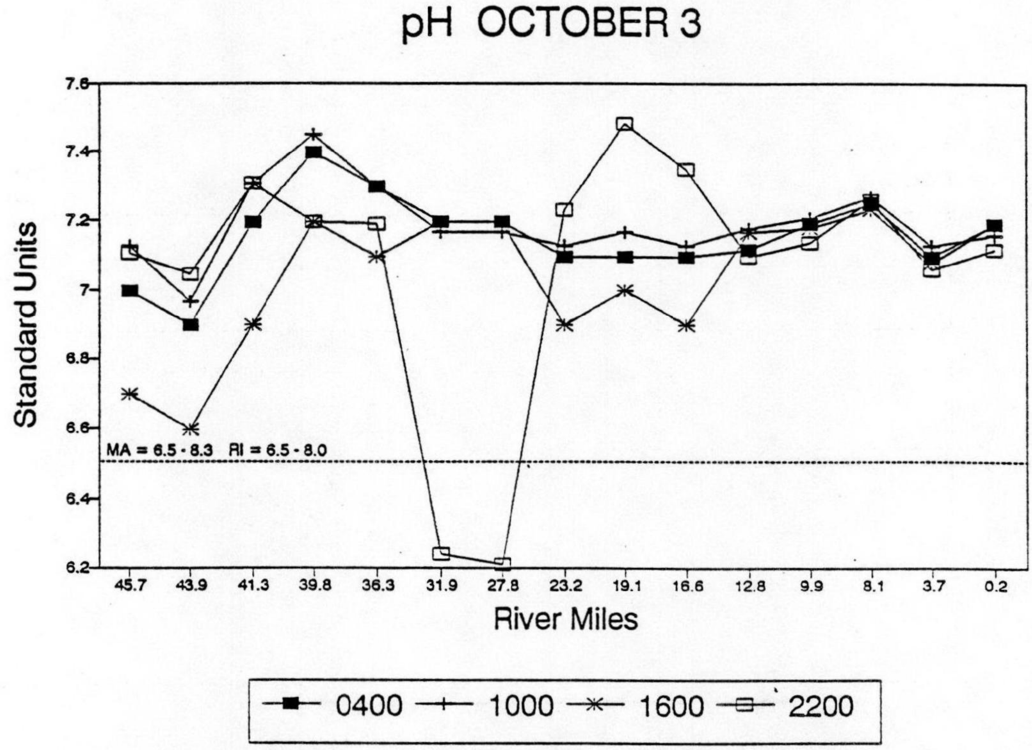


Figure 1- 26
Blackstone Tributaries 1991

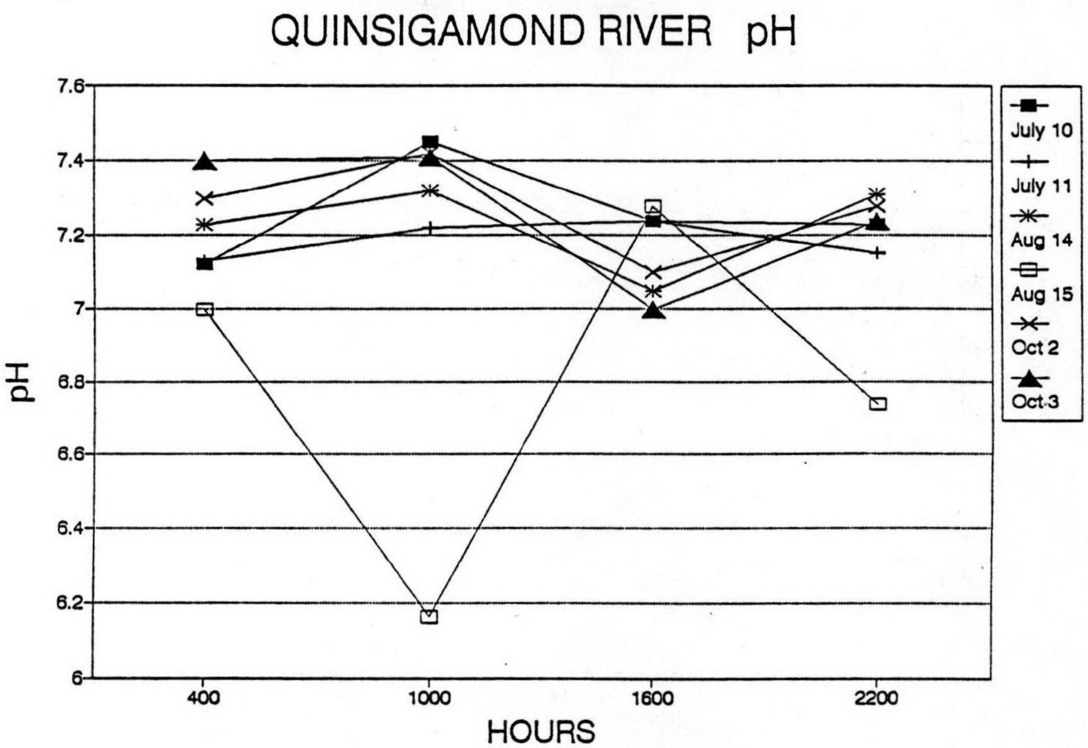


Figure 1- 27
Blackstone Tributaries 1991

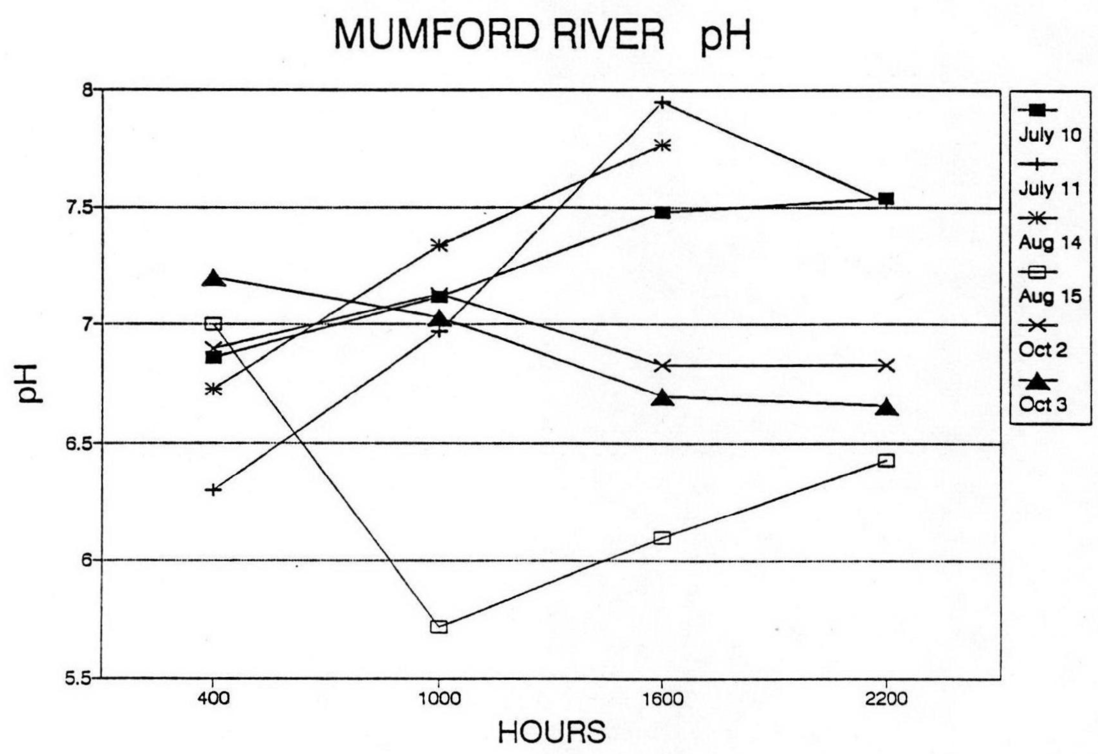


Figure 1–28
Blackstone Tributaries 1991

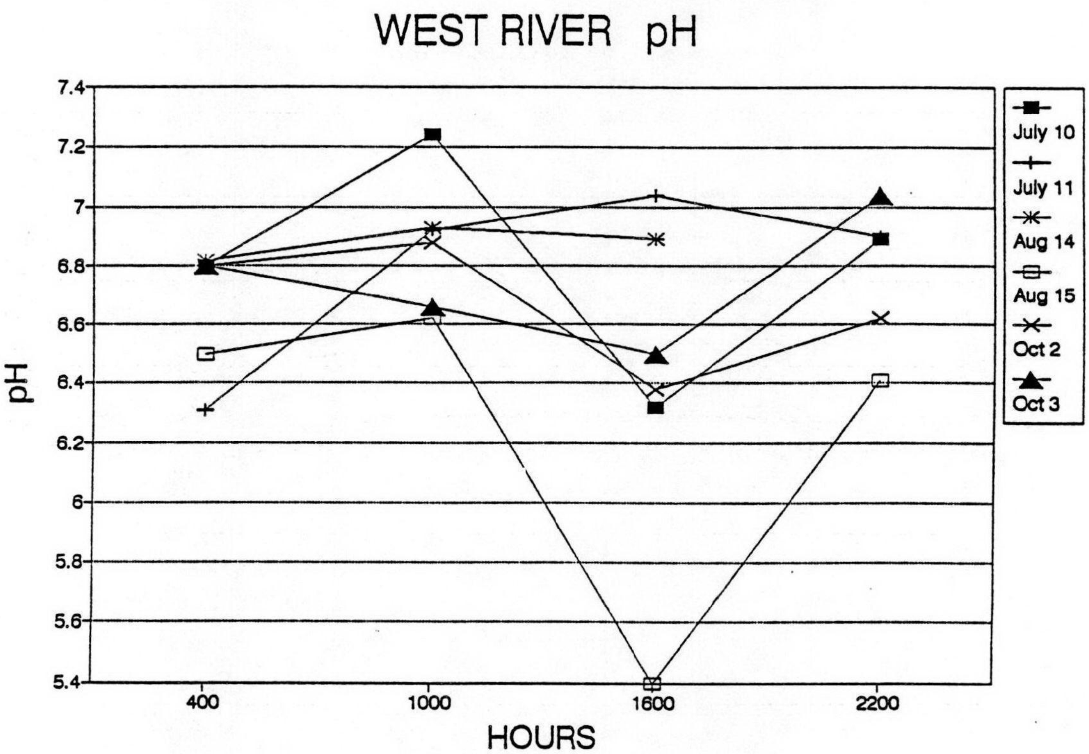


Figure 1–29
Blackstone Tributaries 1991

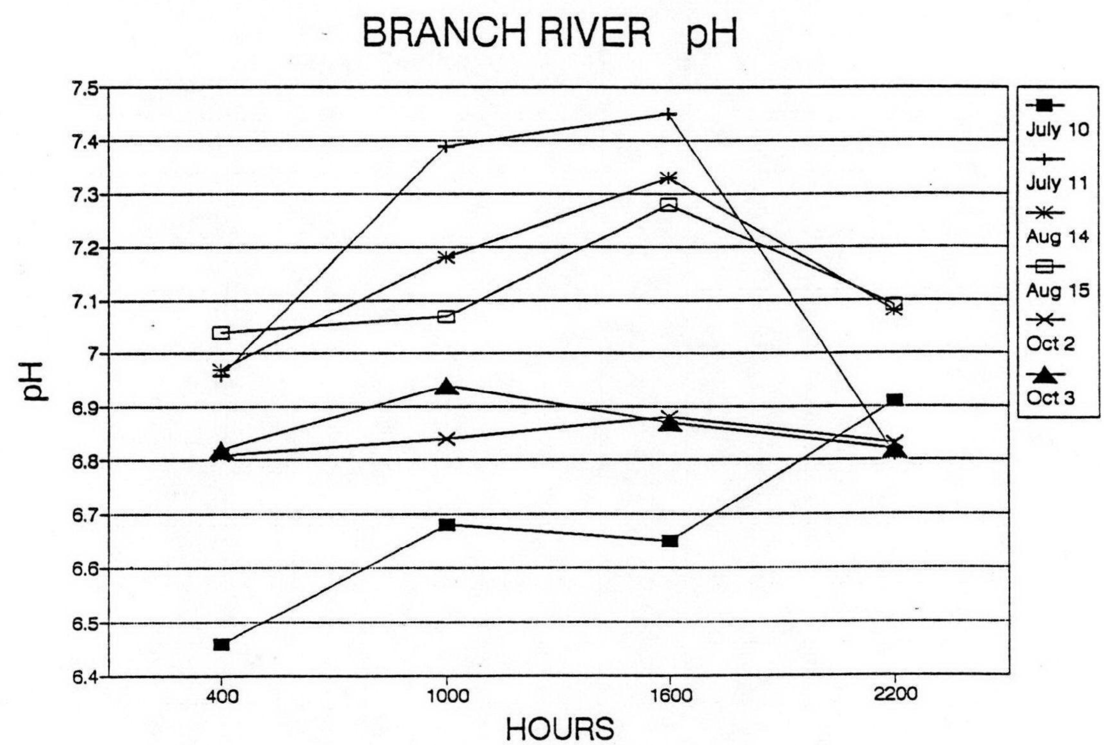


Figure 1–30
Blackstone Tributaries 1991

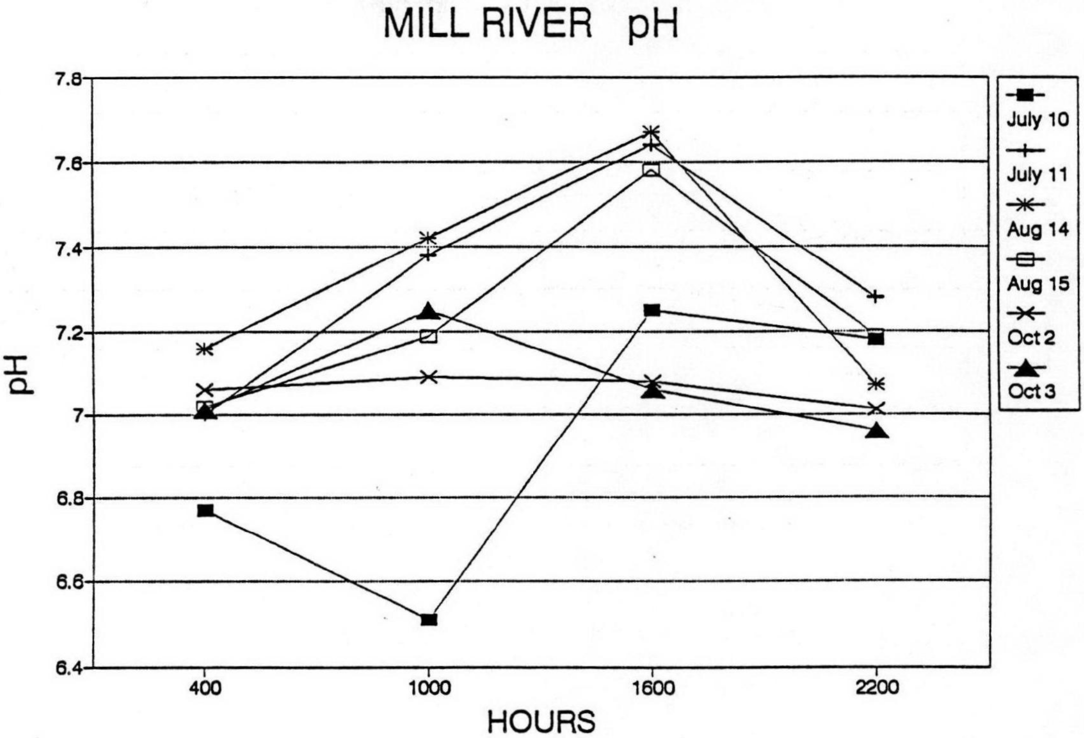


Figure 1–31
Blackstone Tributaries 1991

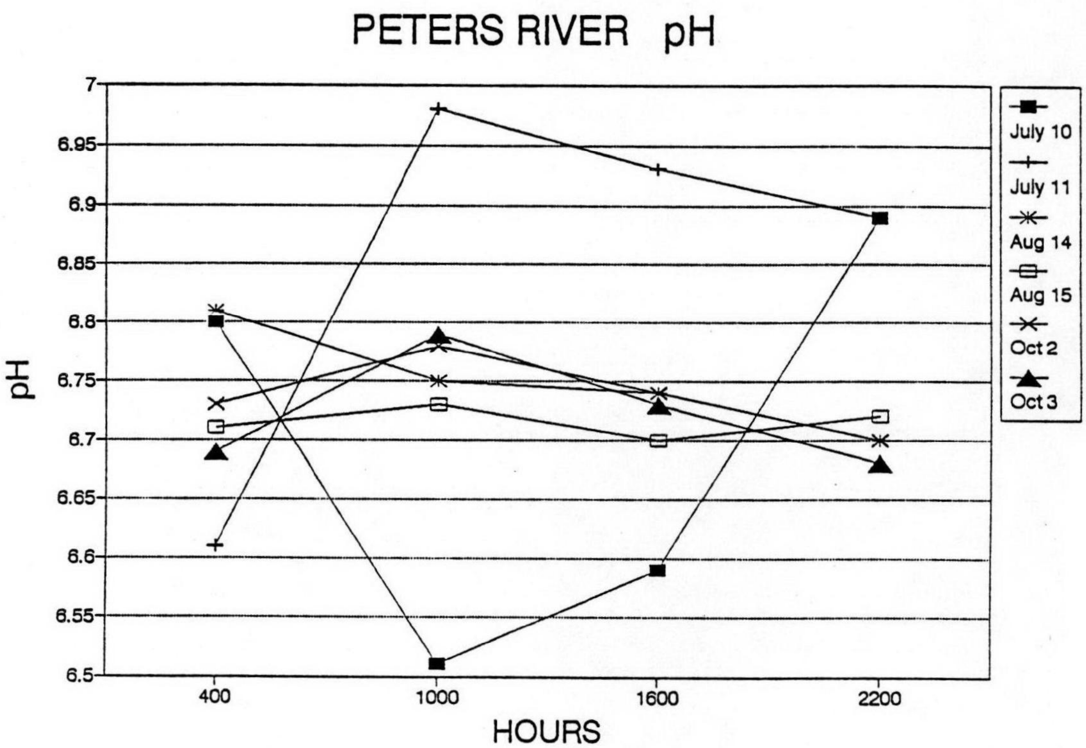


Figure 1– 32
Blackstone River 1991

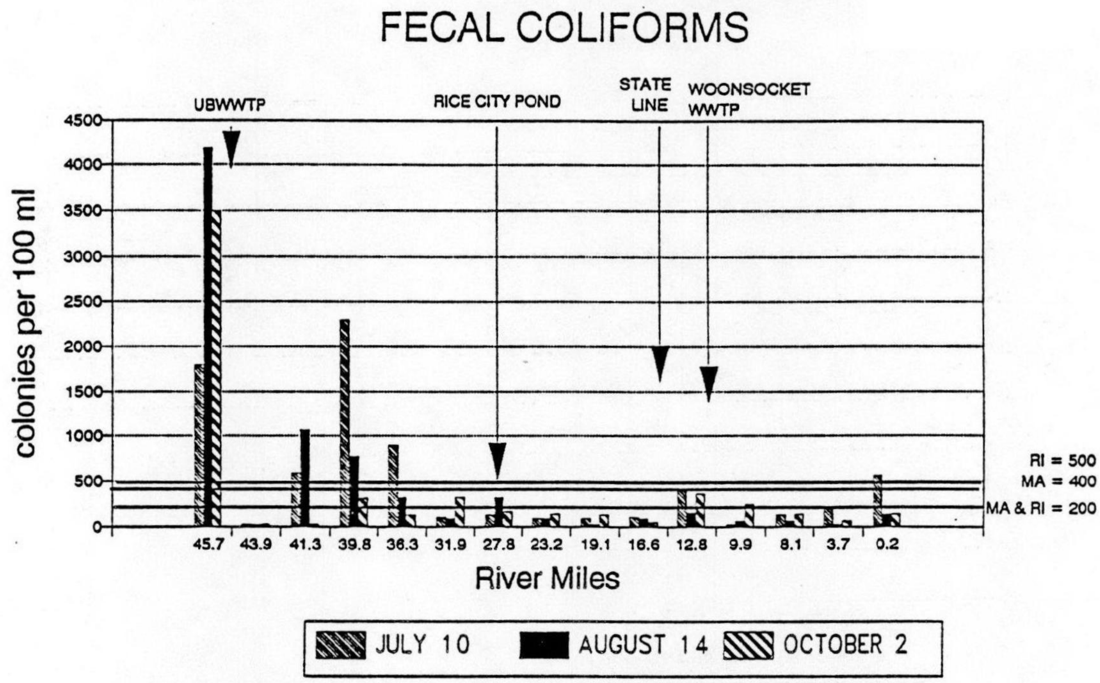


Figure 1– 33
Blackstone Tributaries 1991

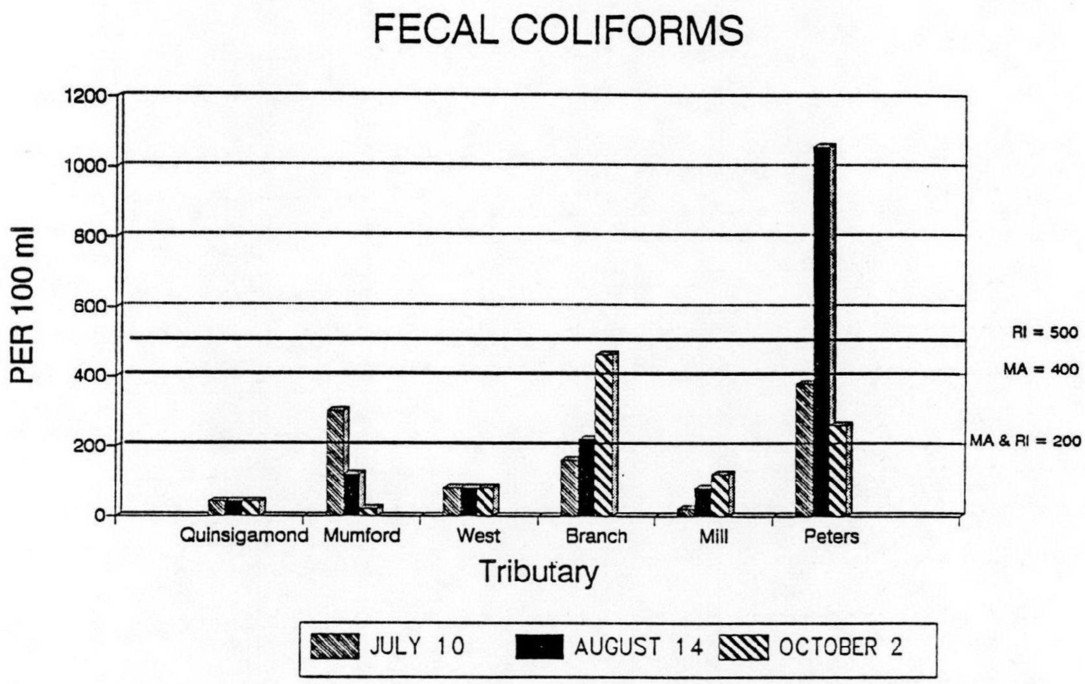


Figure 1–34
Blackstone River 1991

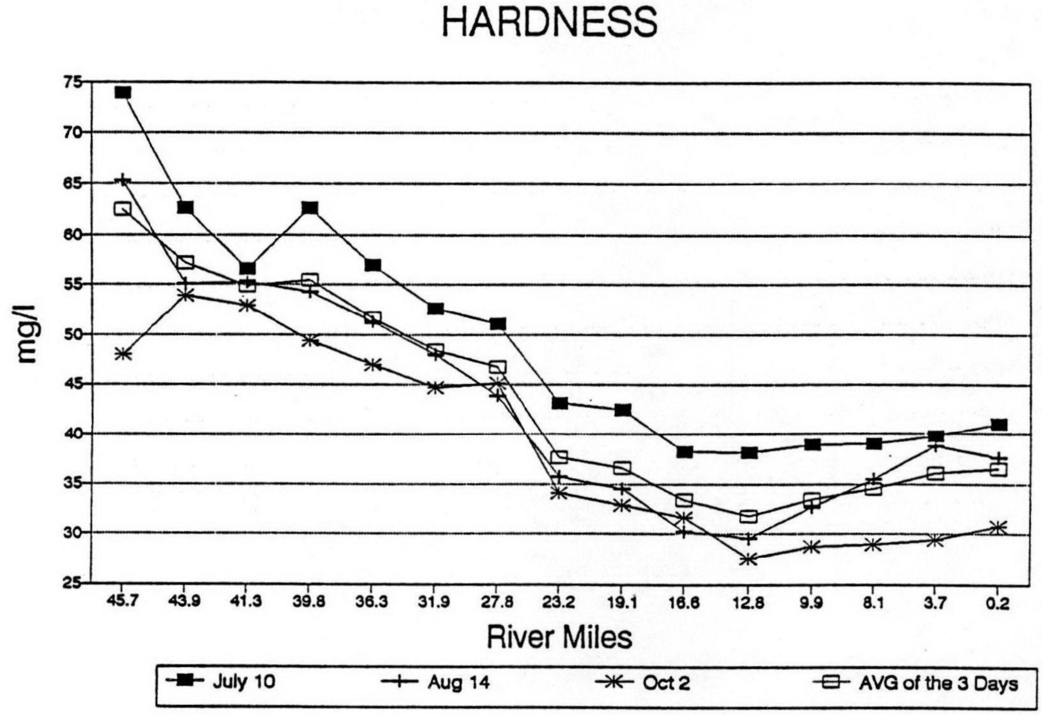


Figure 1–35
Blackstone Tributaries 1991

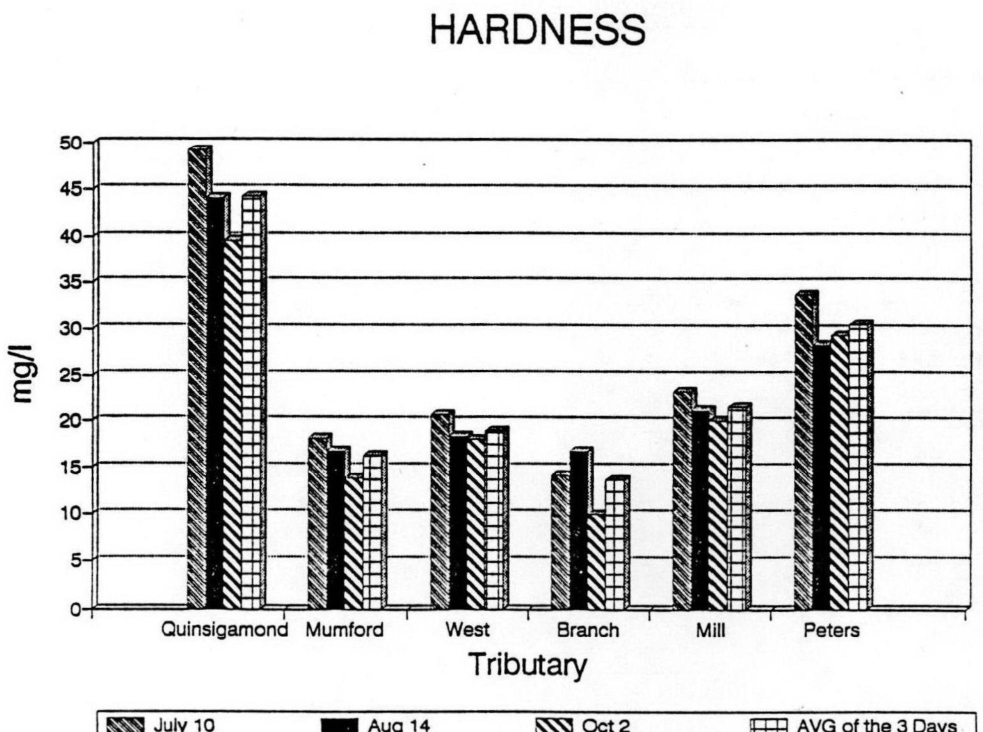


Figure 1–36
Blackstone River 1991

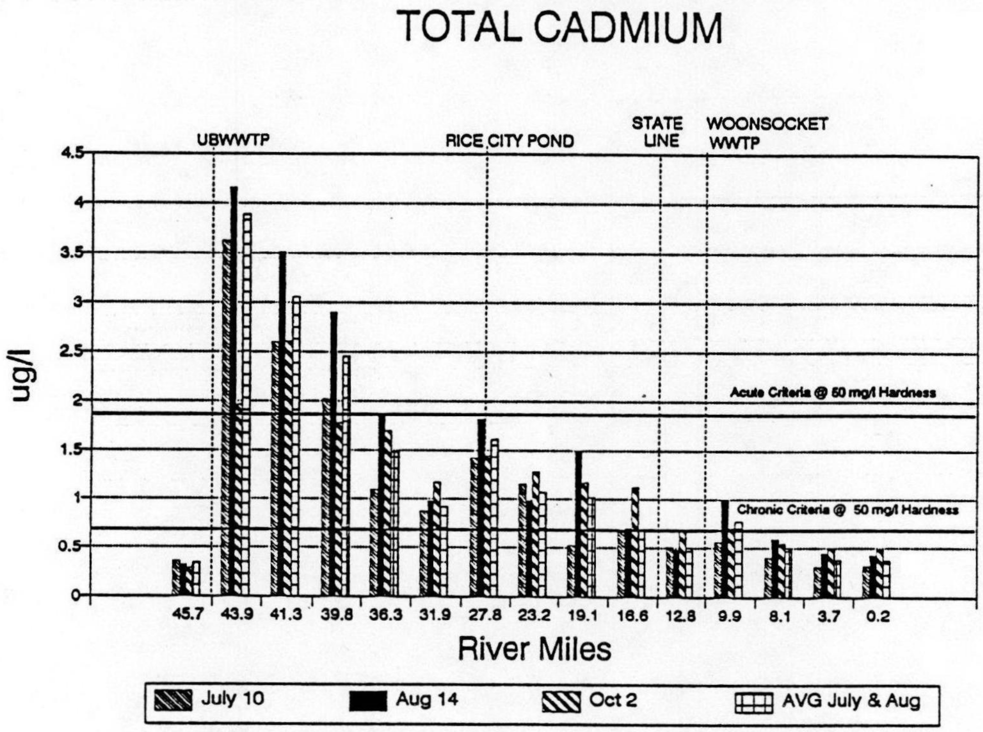


Figure 1–37
Blackstone River 1991

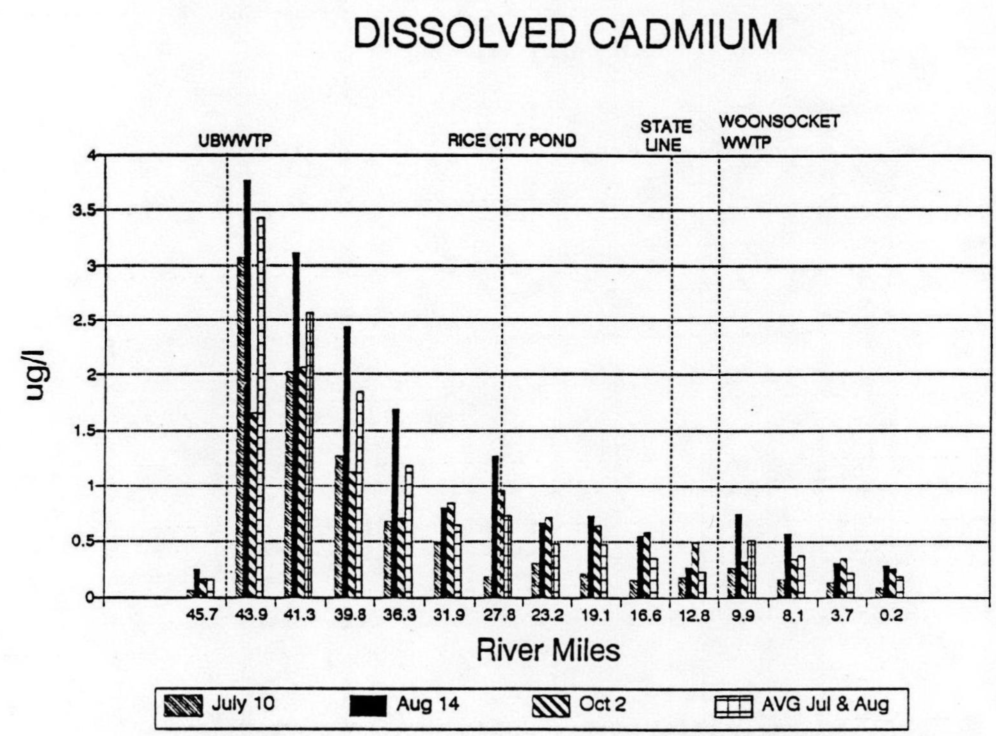


Figure 1–38
Blackstone River 1991

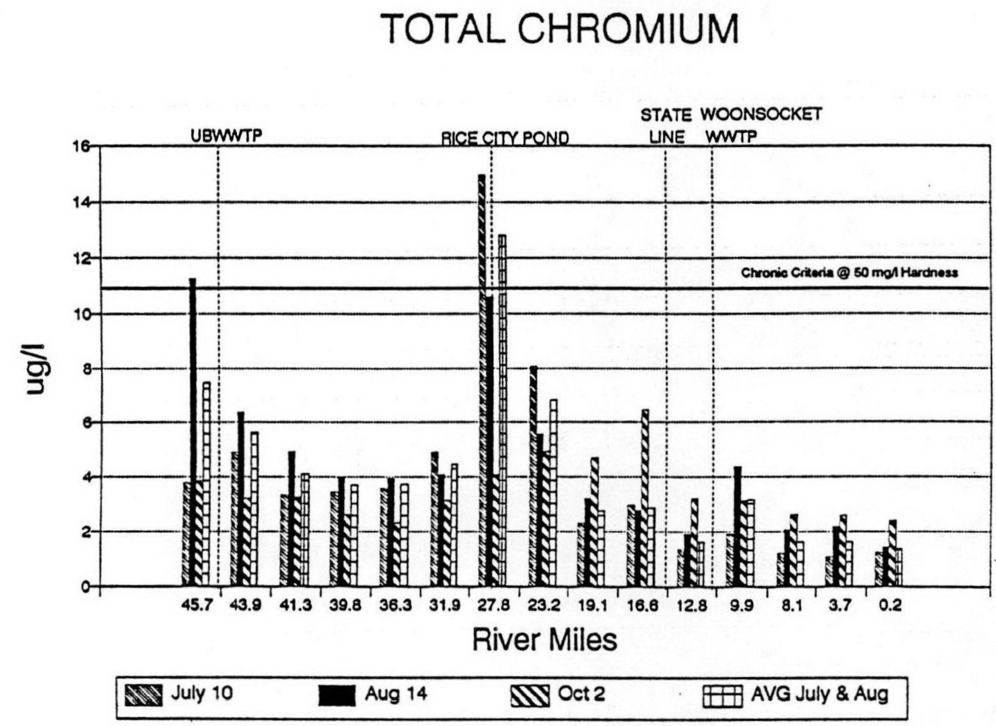


Figure 1–39
Blackstone River 1991

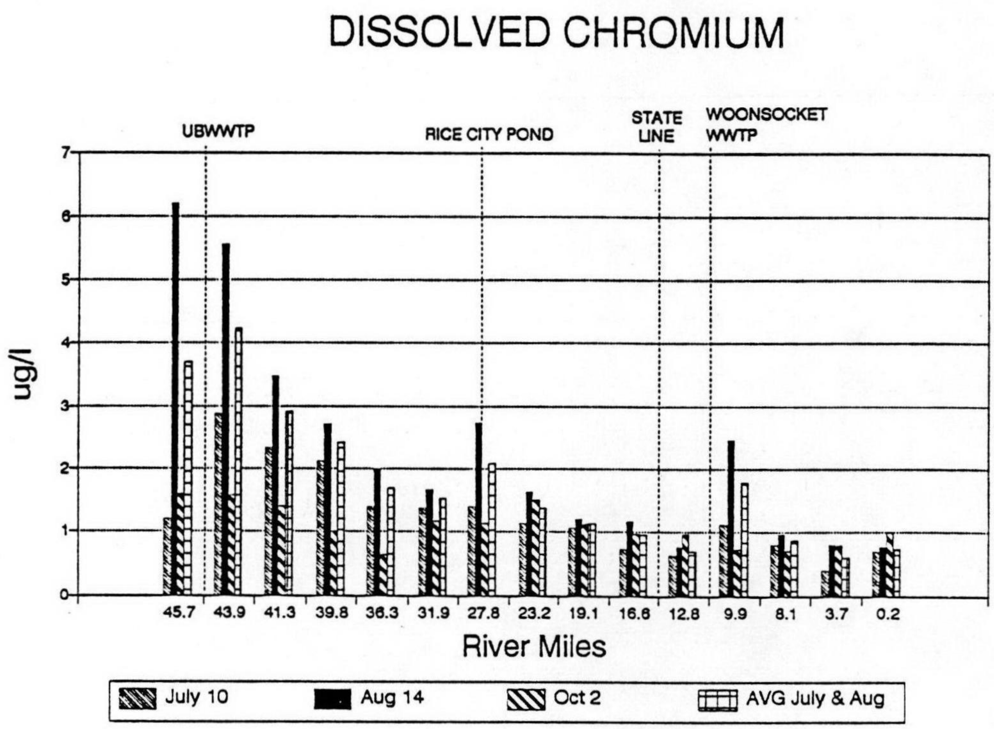


Figure 1– 40
Blackstone River 1991

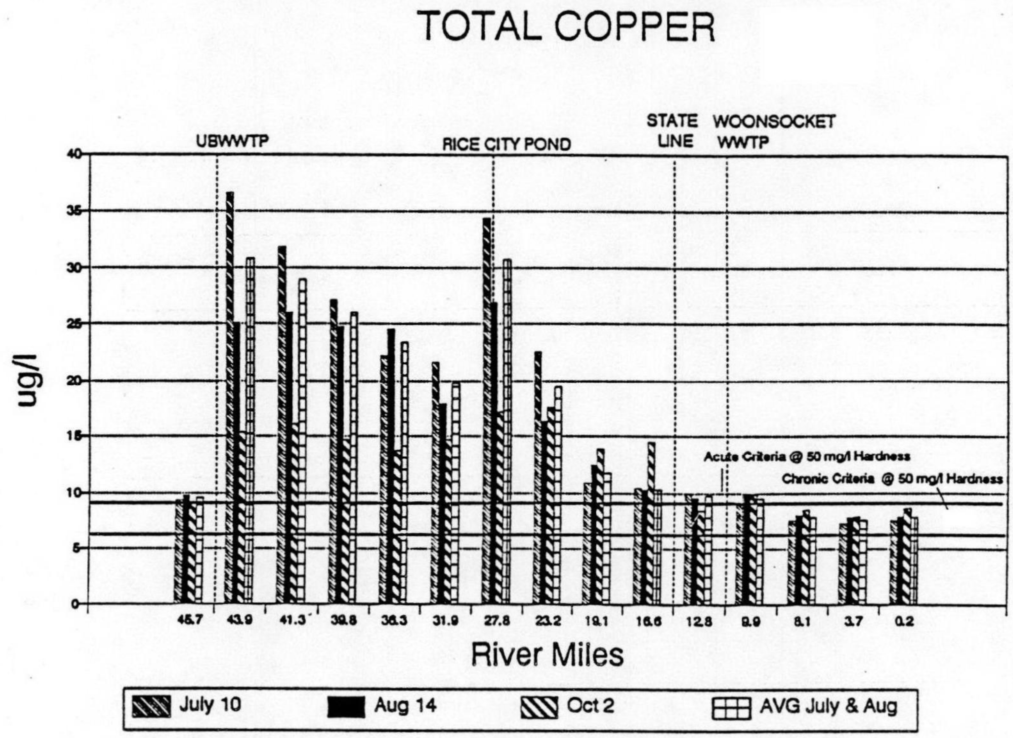


Figure 1– 41
Blackstone River 1991

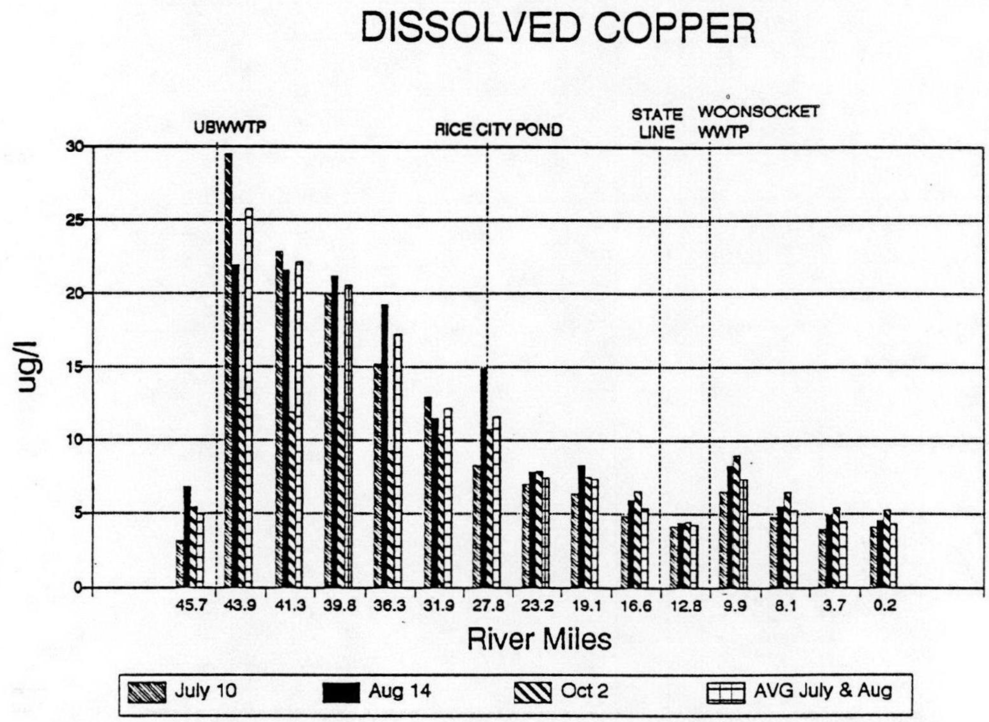


Figure 1–42
Blackstone River 1991

TOTAL LEAD

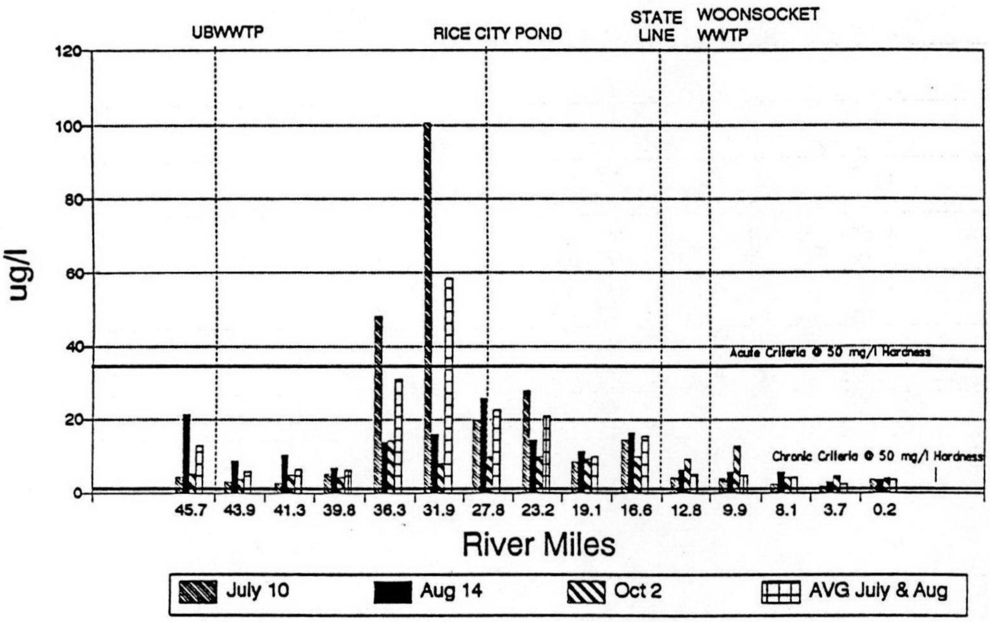


Figure 1–43
Blackstone River 1991

DISSOLVED LEAD

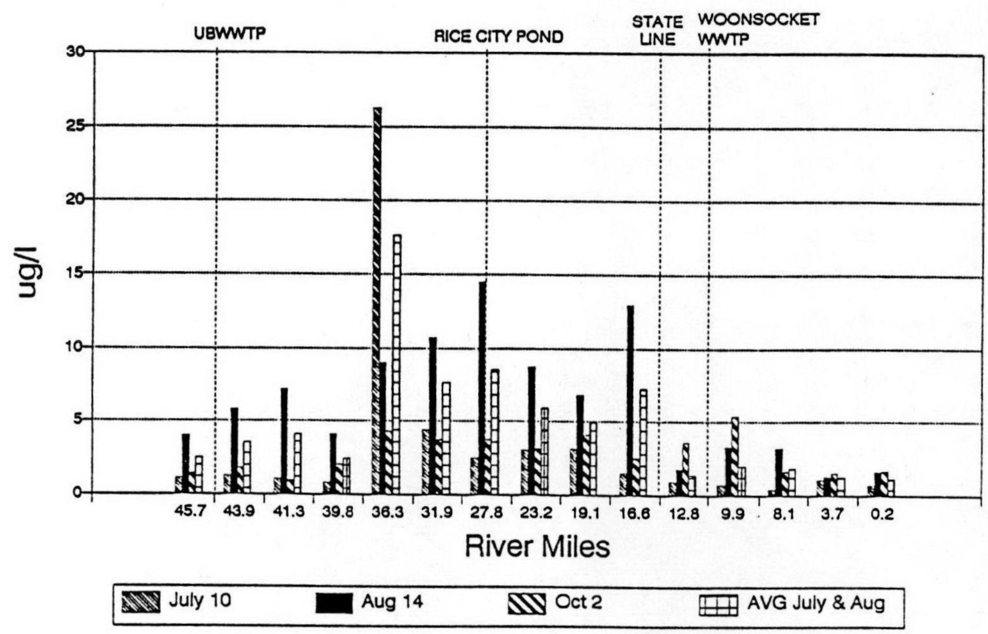


Figure 1– 44
Blackstone River 1991

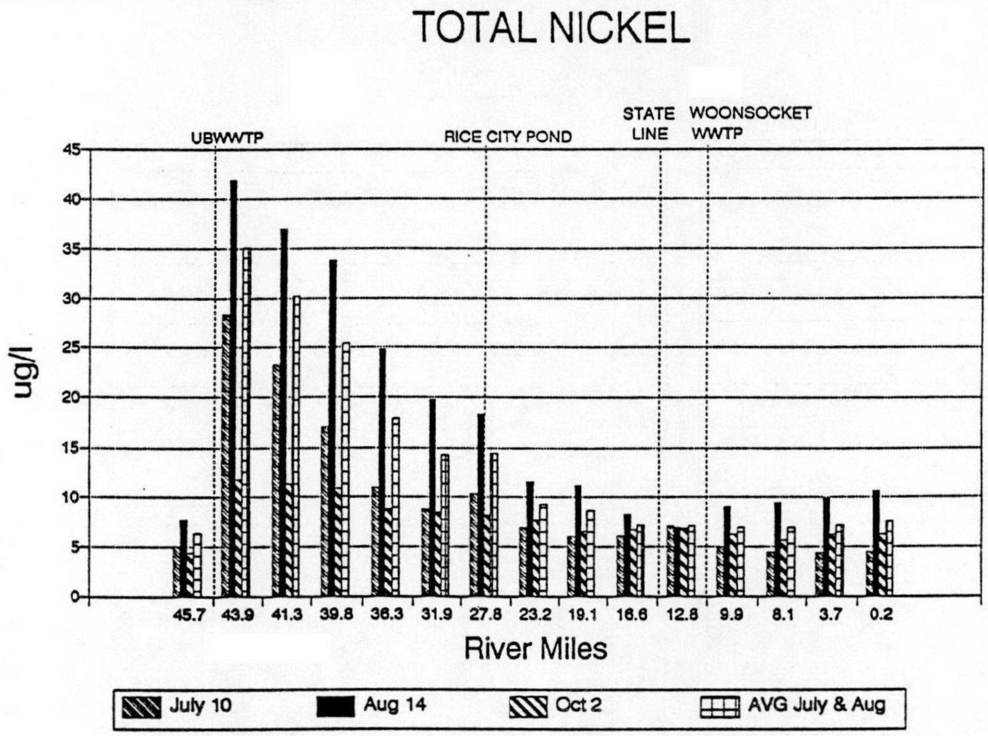


Figure 1– 45
Blackstone River 1991

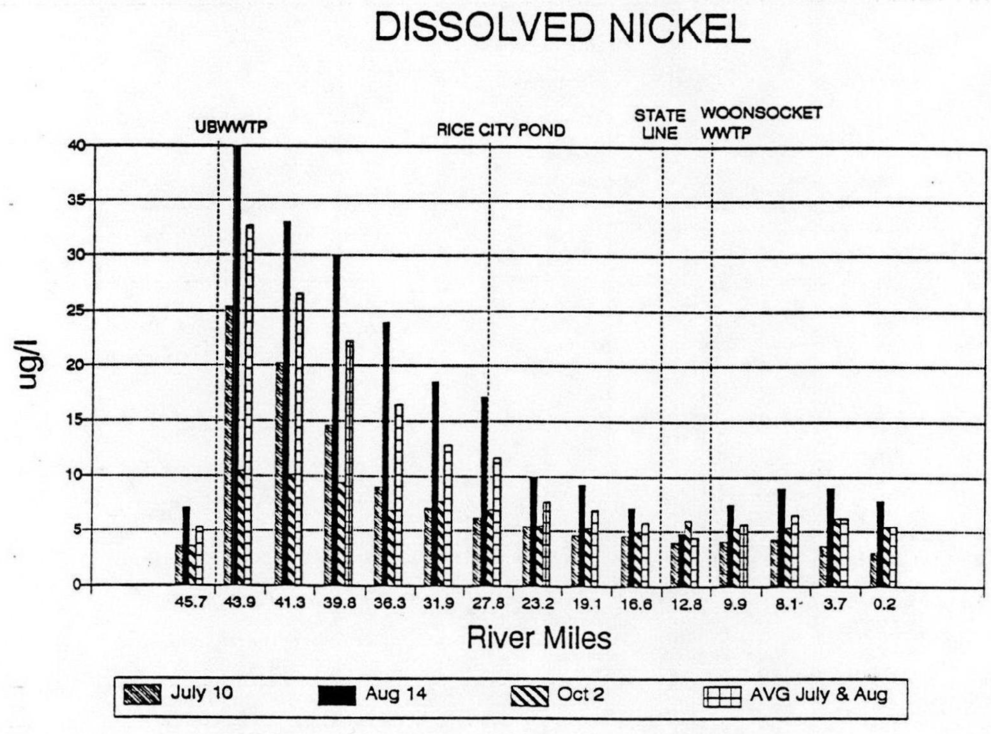
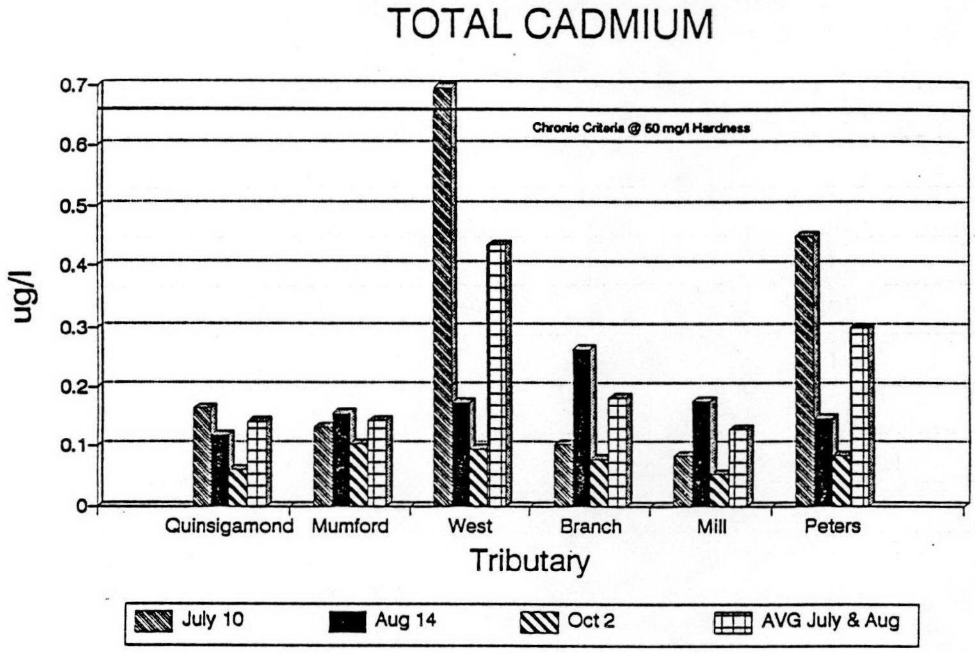


Figure 1-46
Blackstone Tributaries 1991



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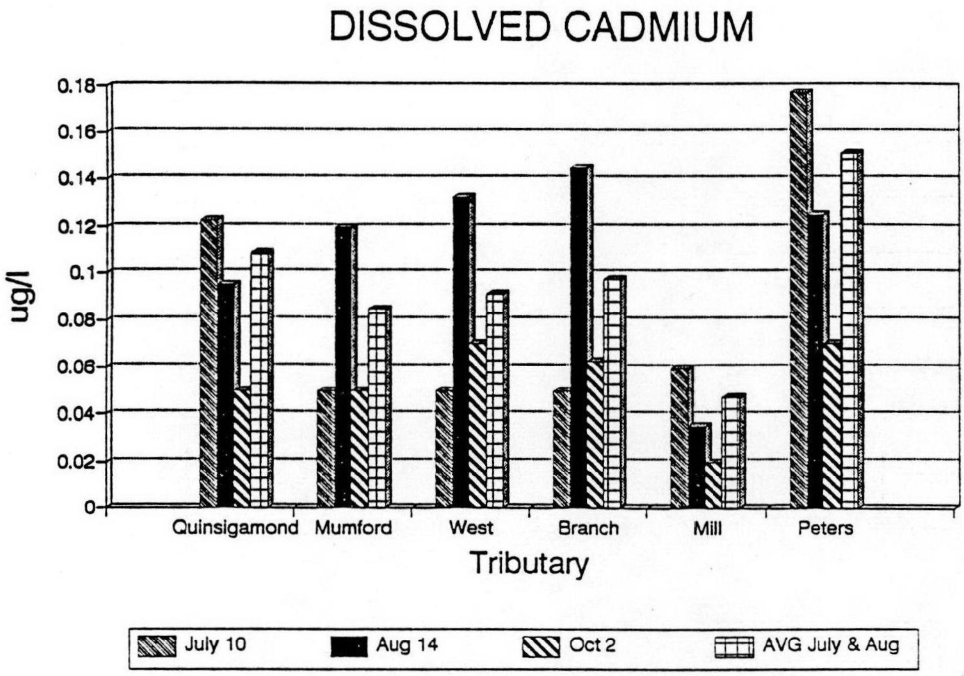
Blackstone Tributaries 1991



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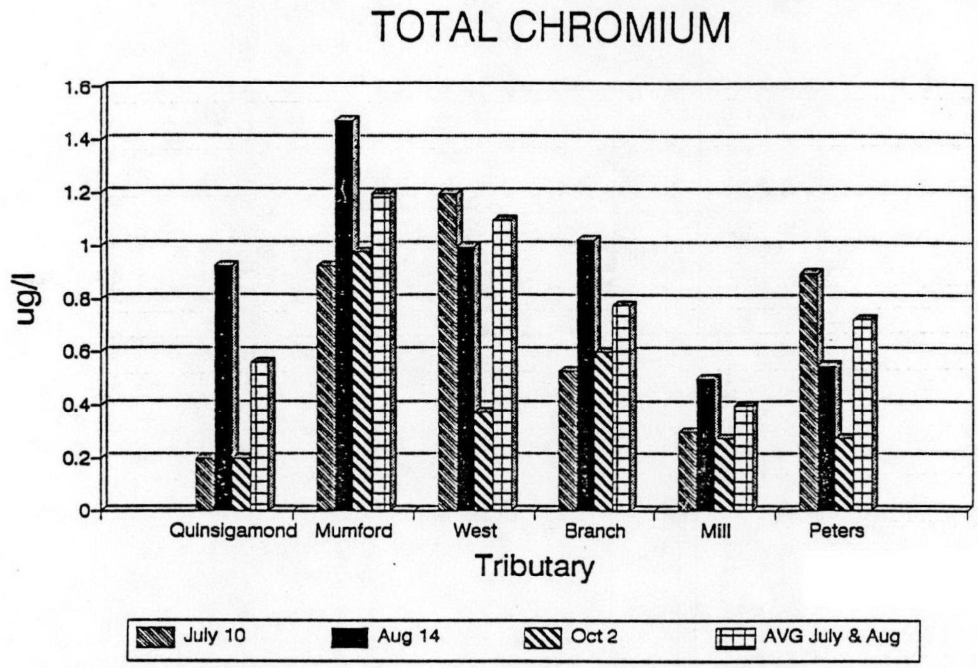
Blackstone Tributaries 1991



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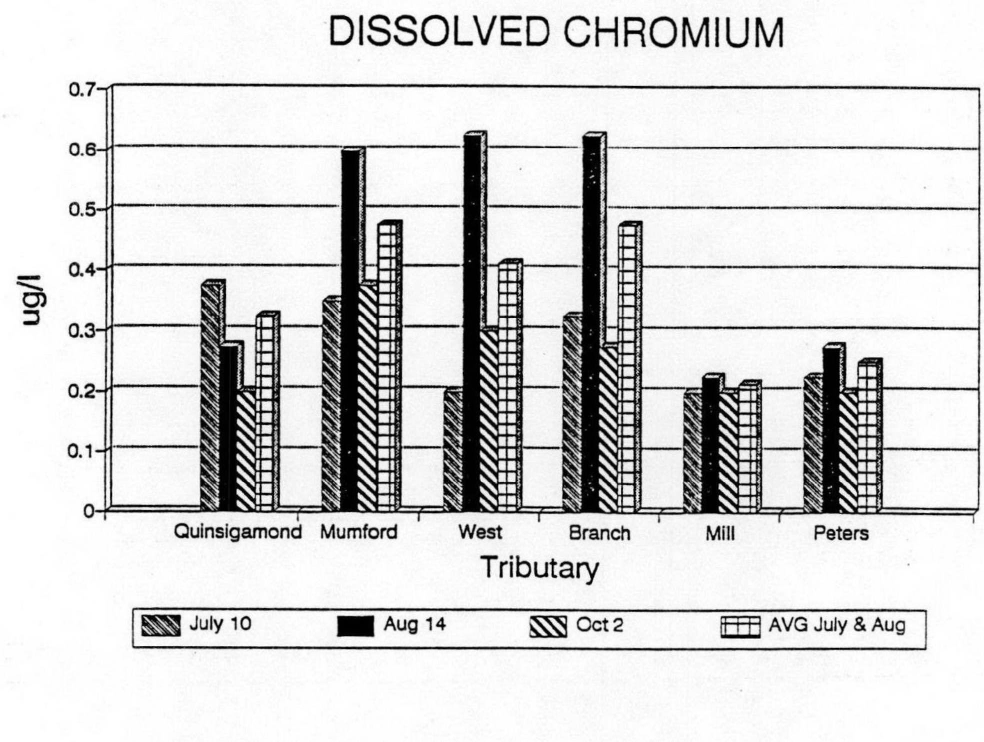
Blackstone Tributaries 1991



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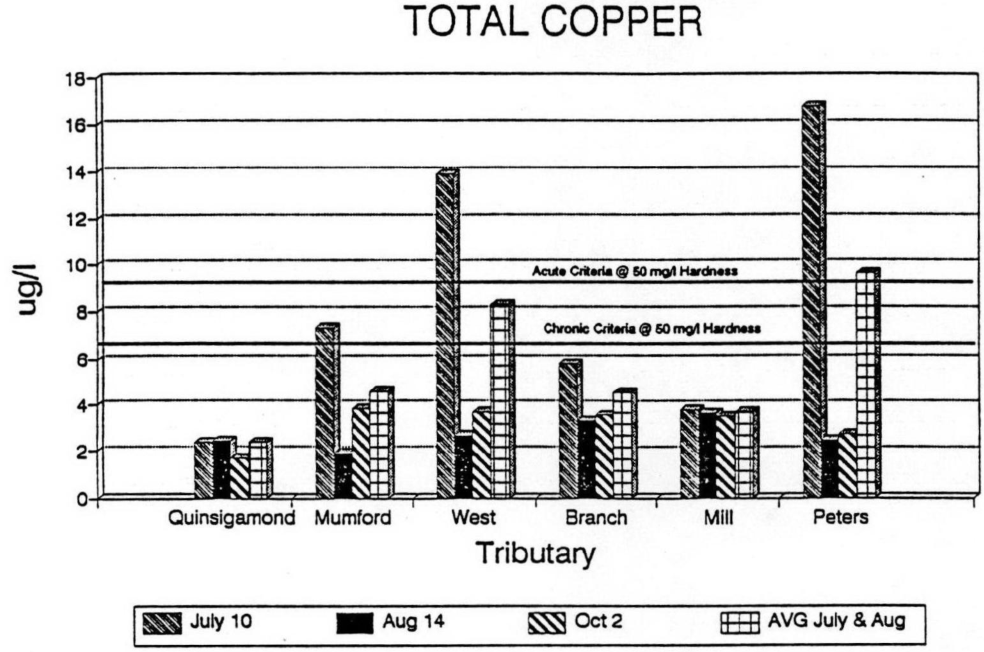
Blackstone Tributaries 1991



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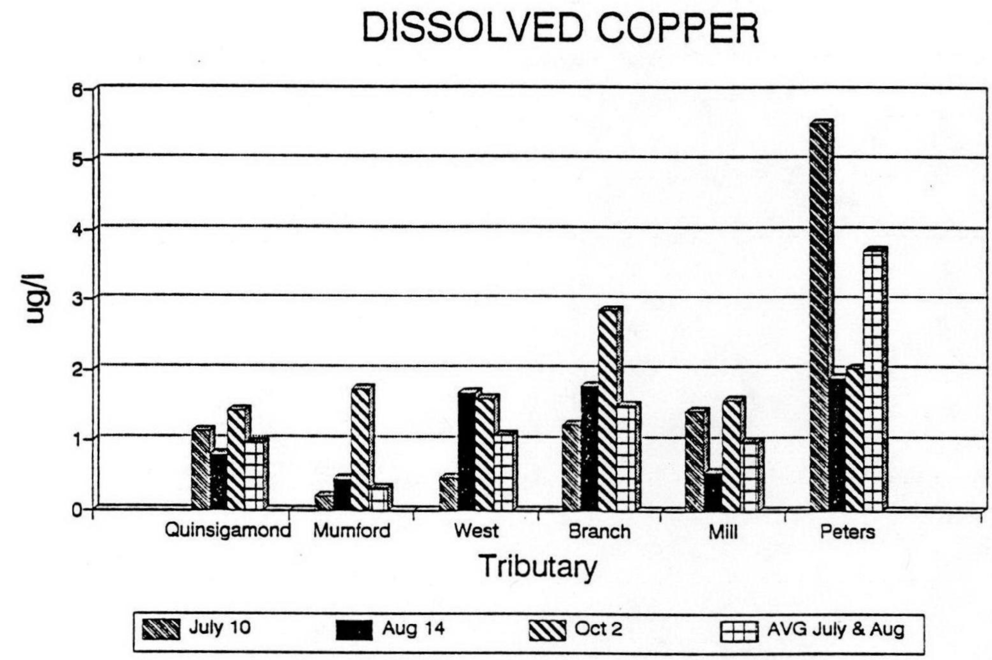
Blackstone Tributaries 1991



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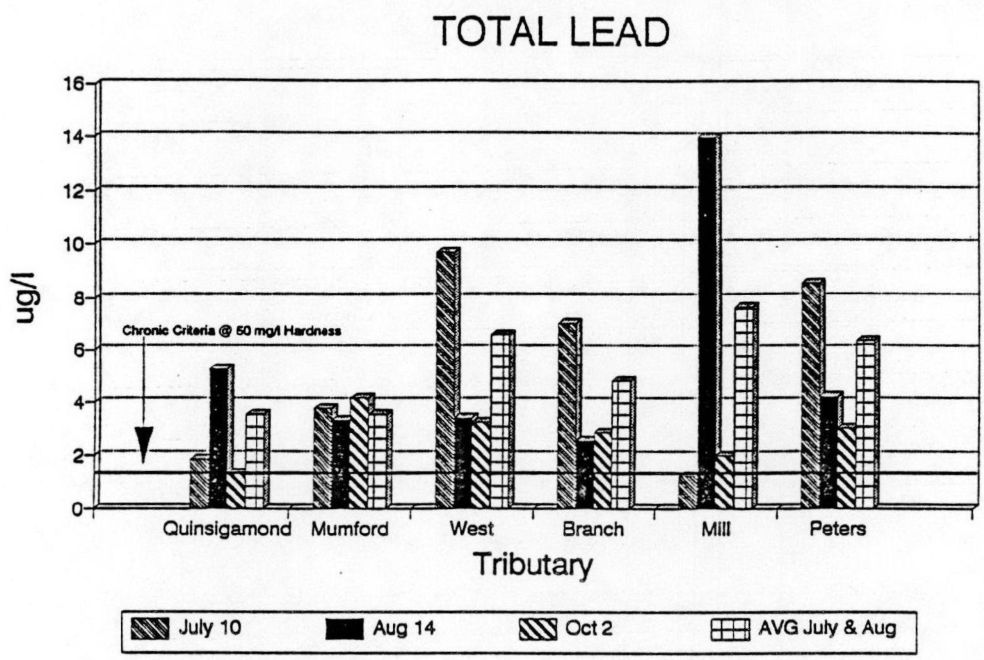
Blackstone Tributaries 1991



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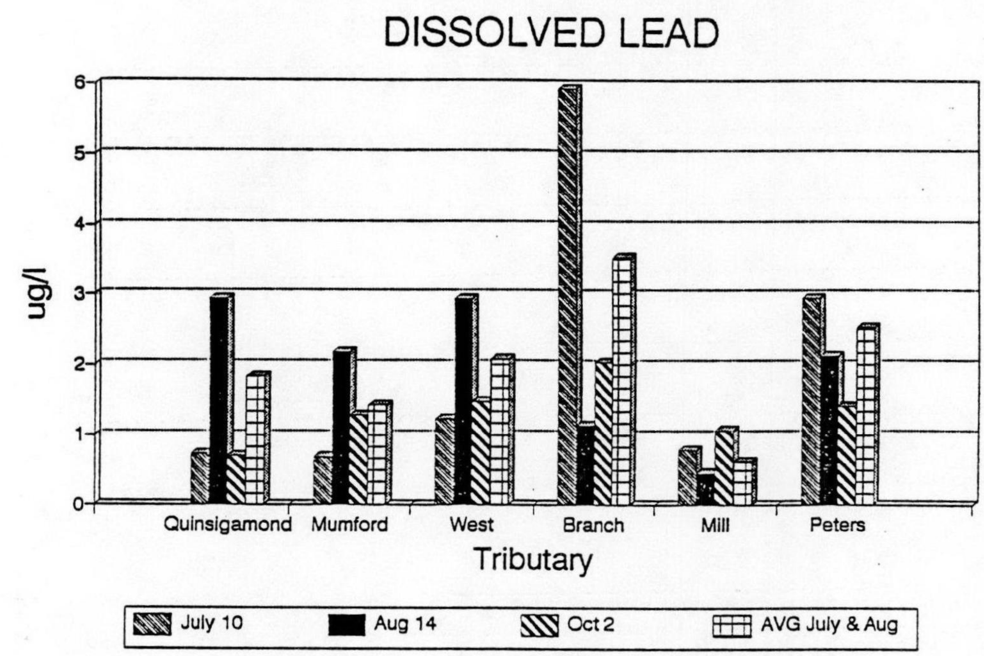
Blackstone Tributaries 1991



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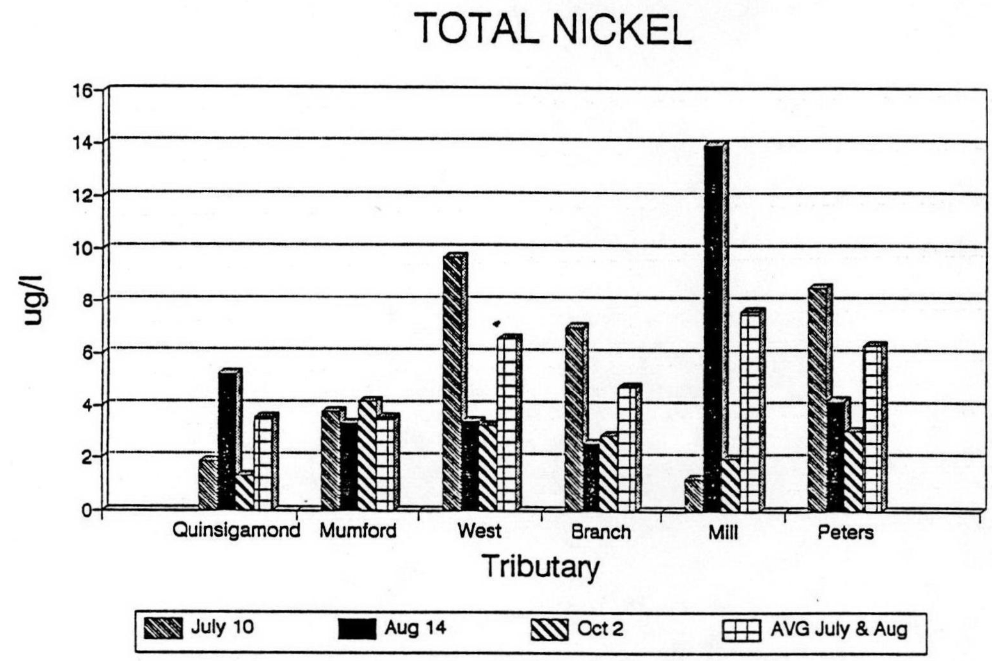

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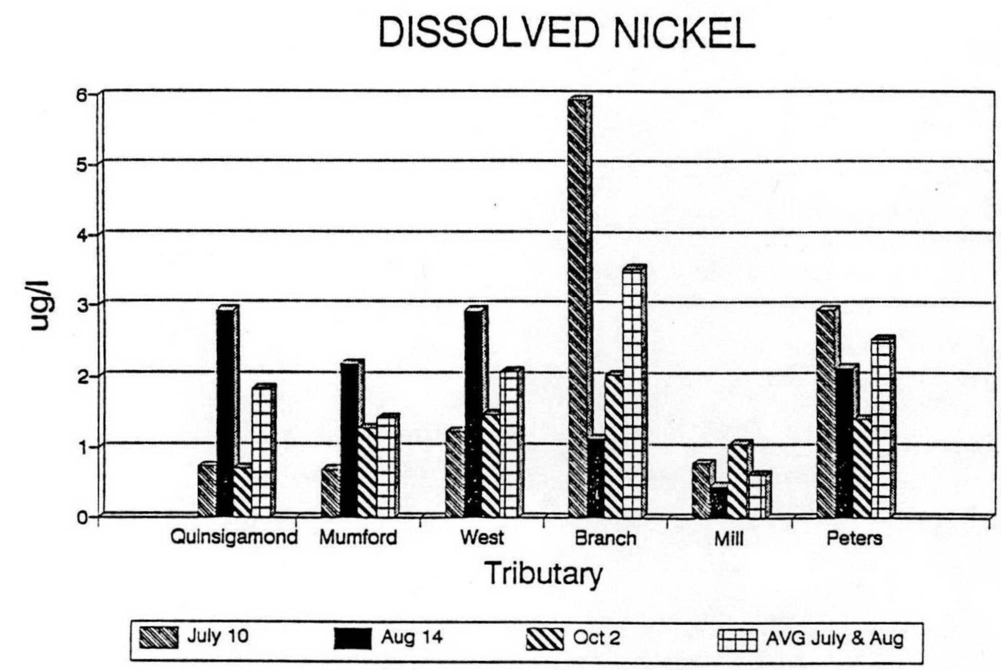

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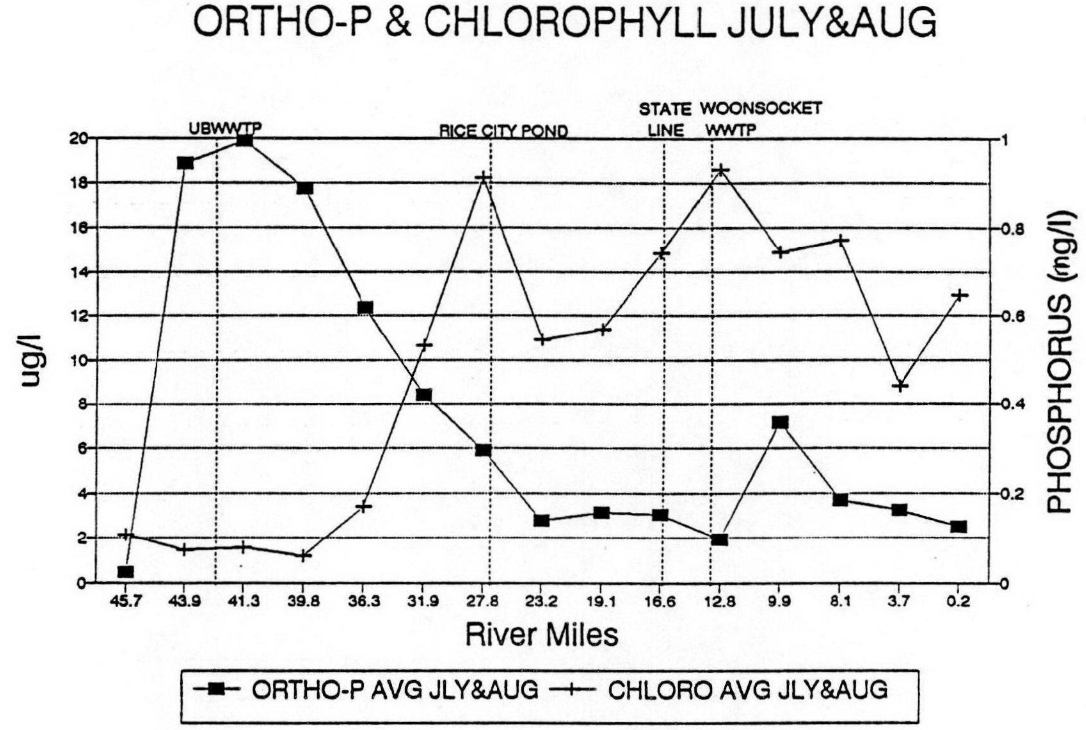
Blackstone River 1991



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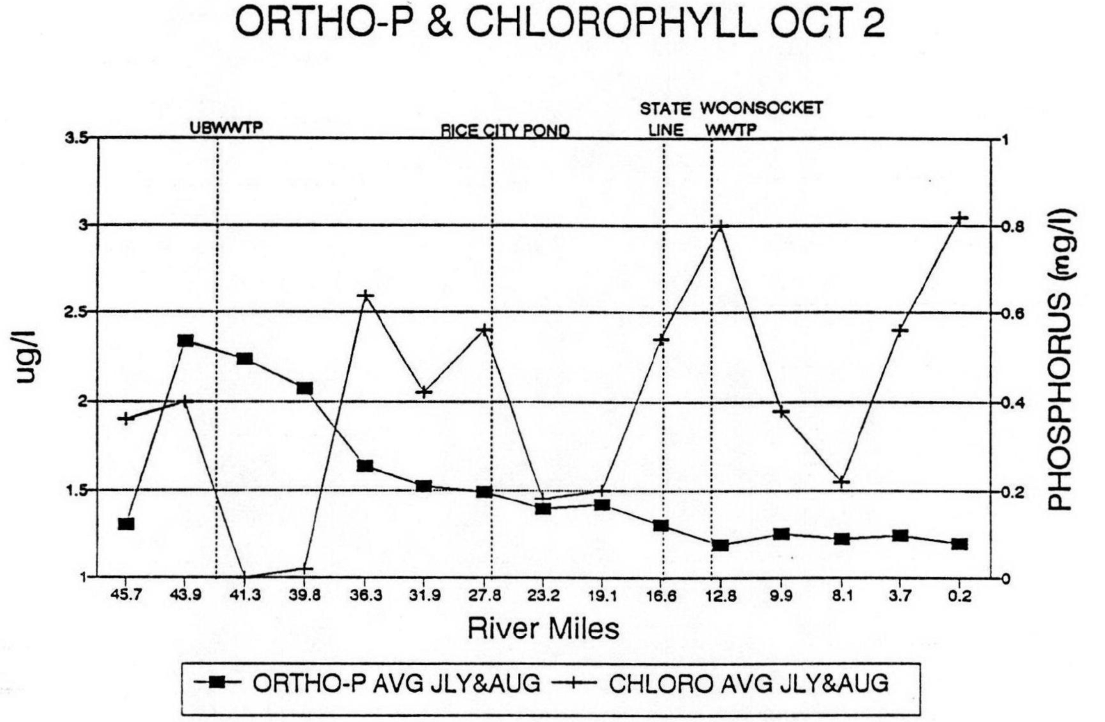
Blackstone River 1991



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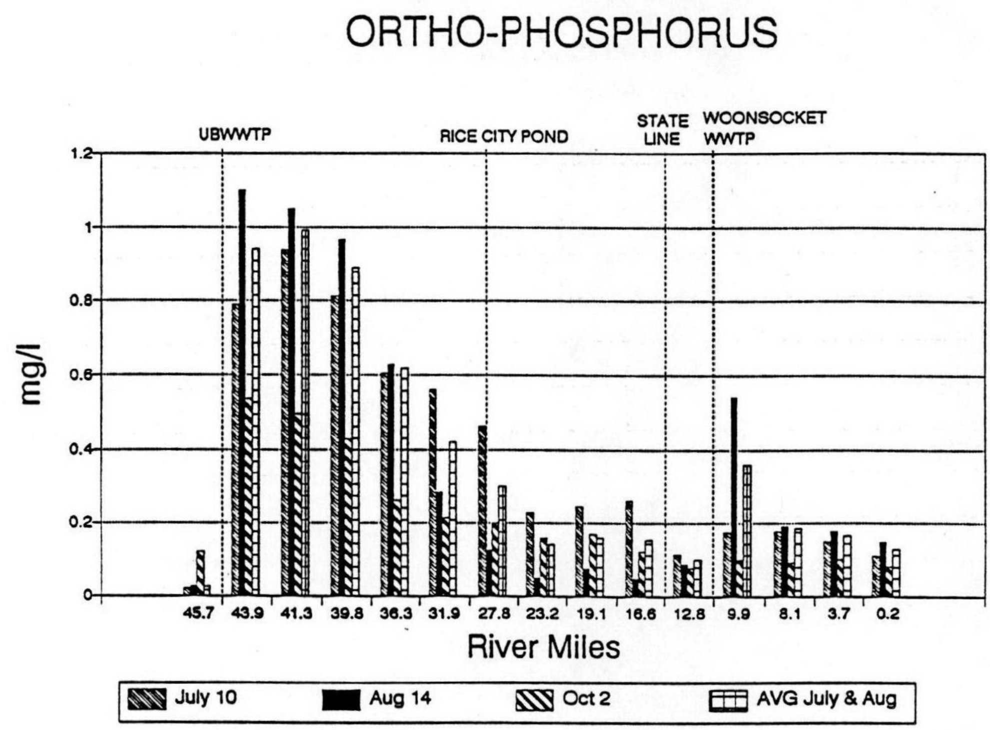
Blackstone River 1991



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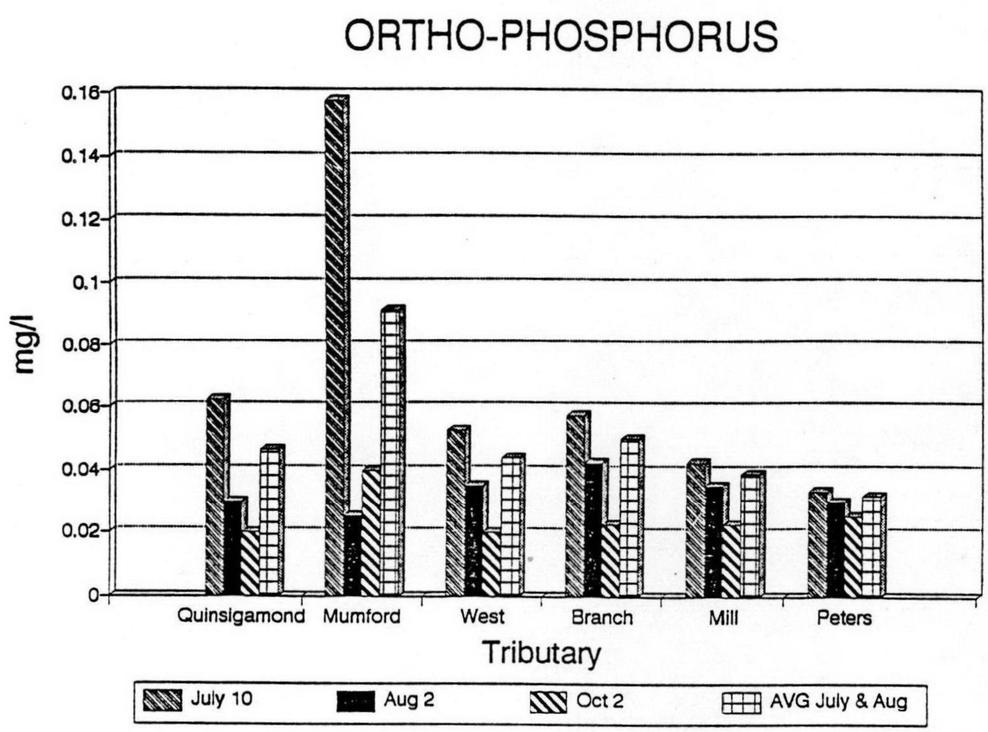
Blackstone Tributaries 1991



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Blackstone River 1991

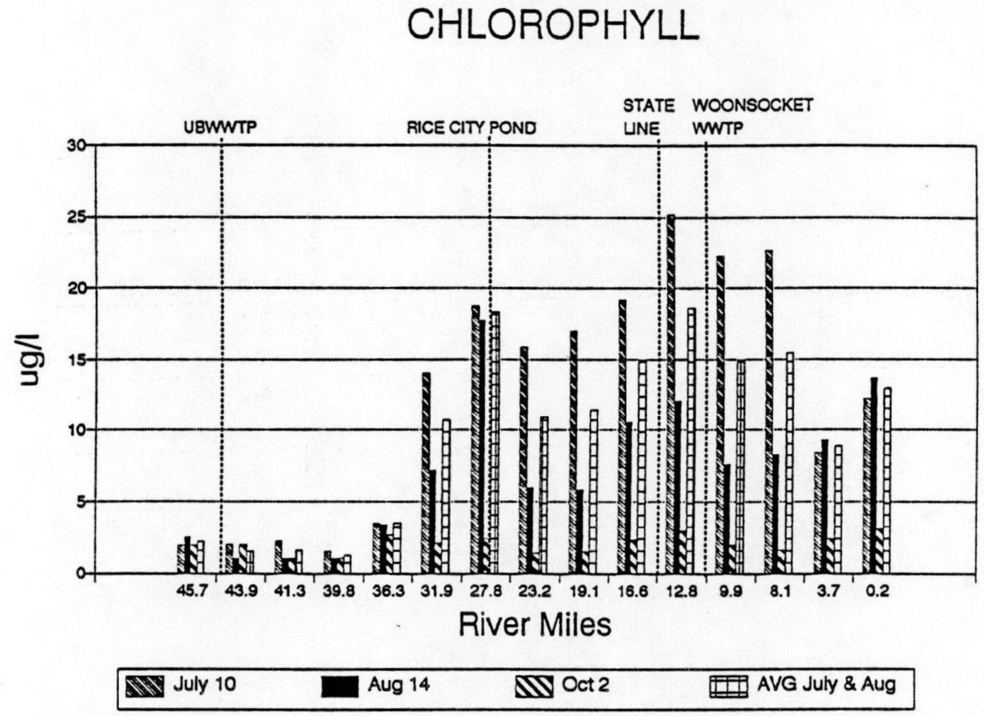
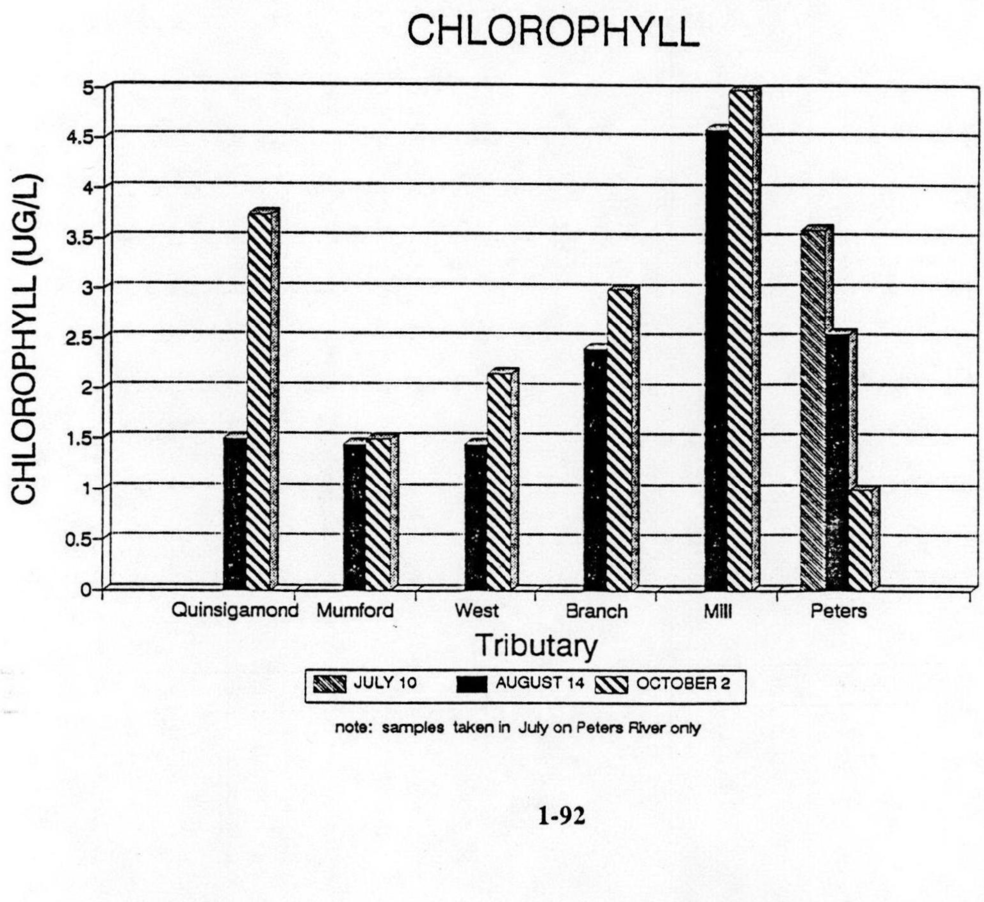
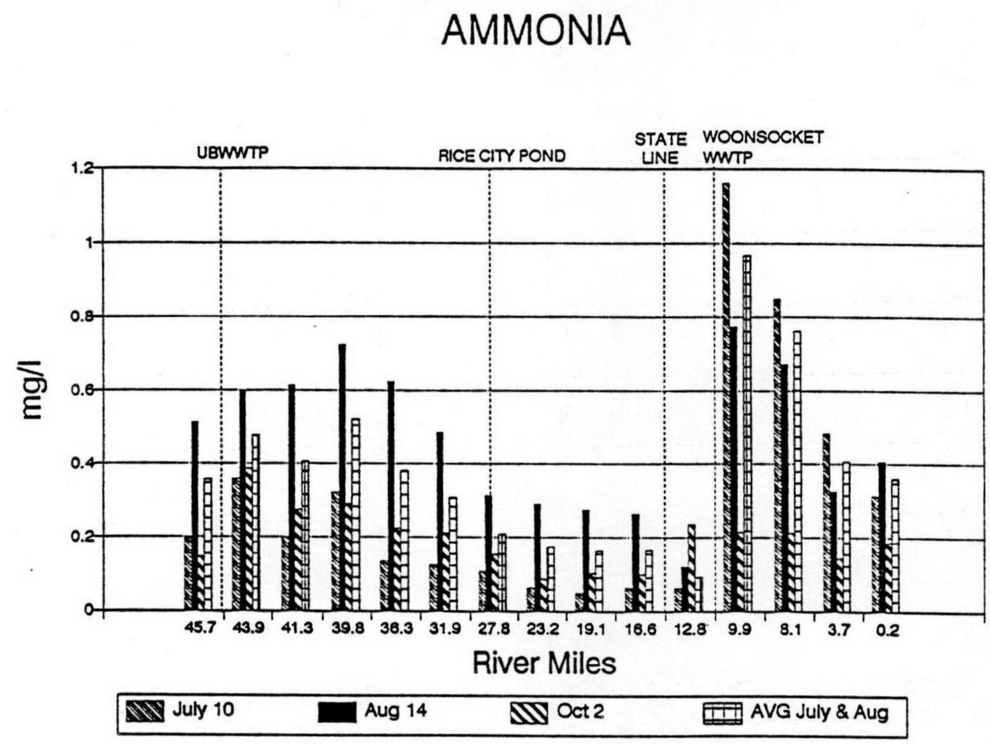


Figure 1– 61
Blackstone Tributaries 1991



note: samples taken in July on Peters River only

Figure 1– 62
Blackstone River 1991



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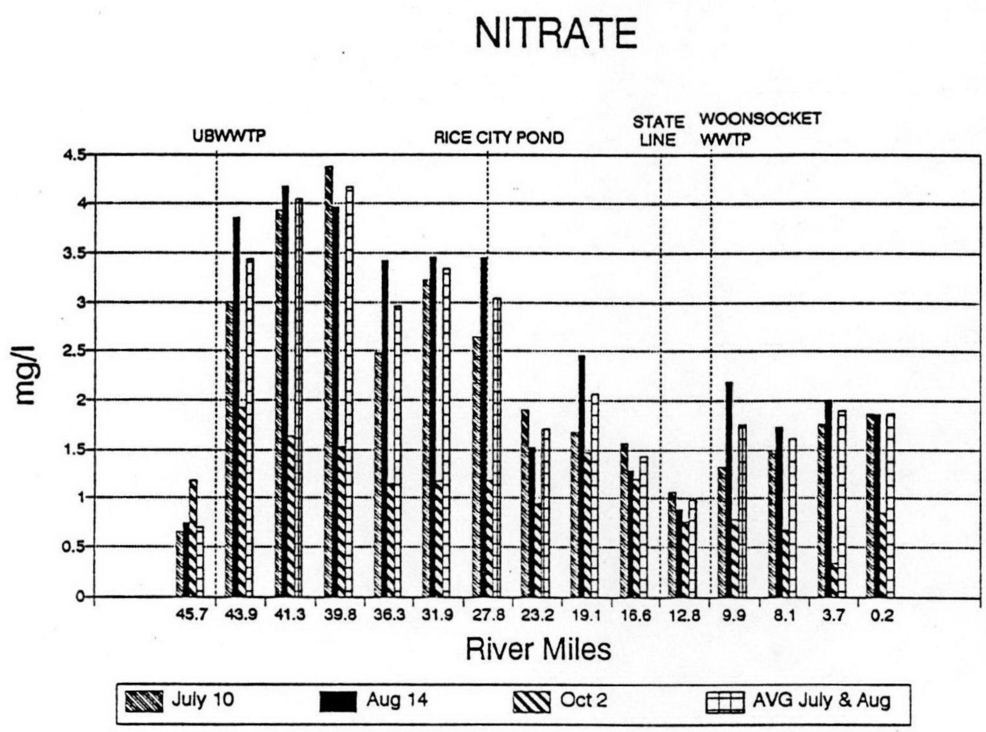
Blackstone River 1991



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Blackstone Tributaries 1991

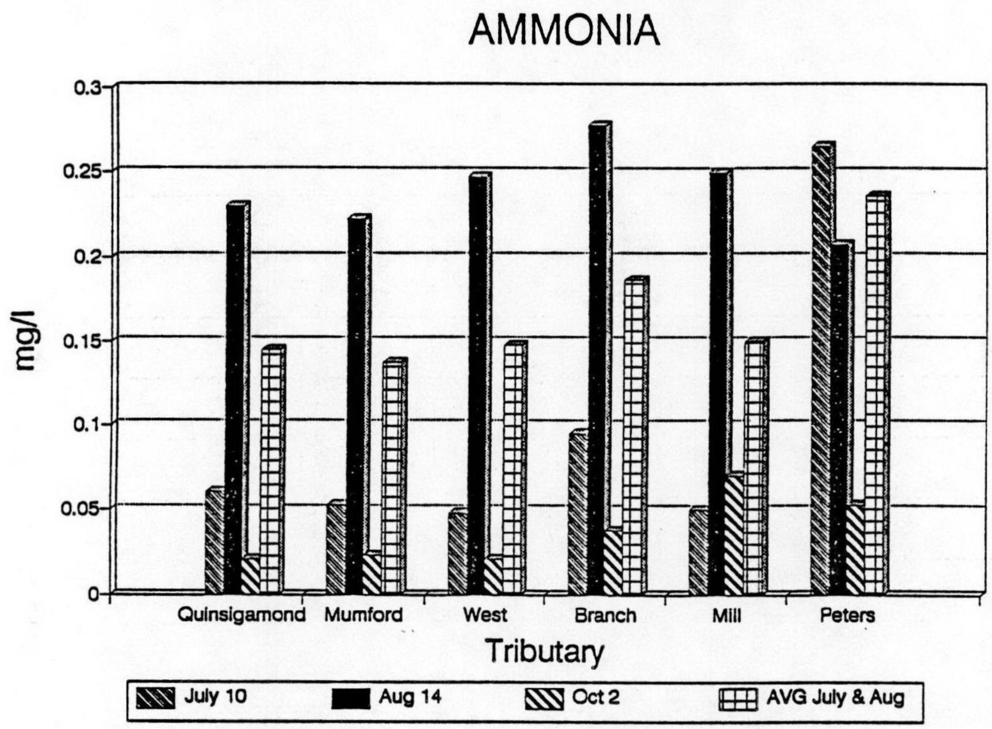
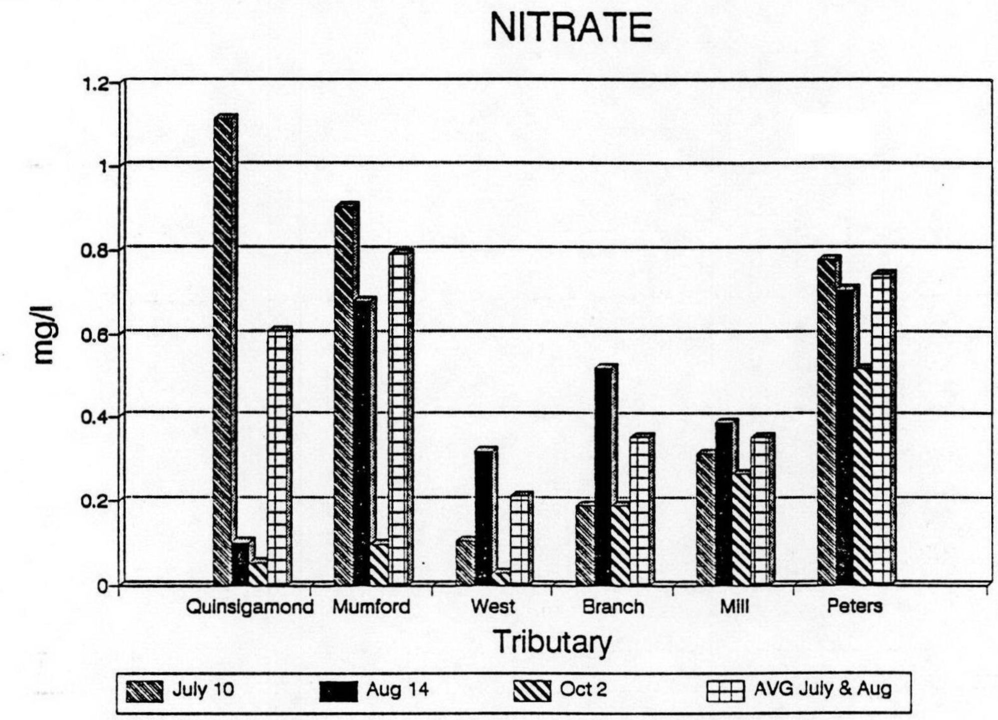


Figure 1– 65
Blackstone Tributaries 1991



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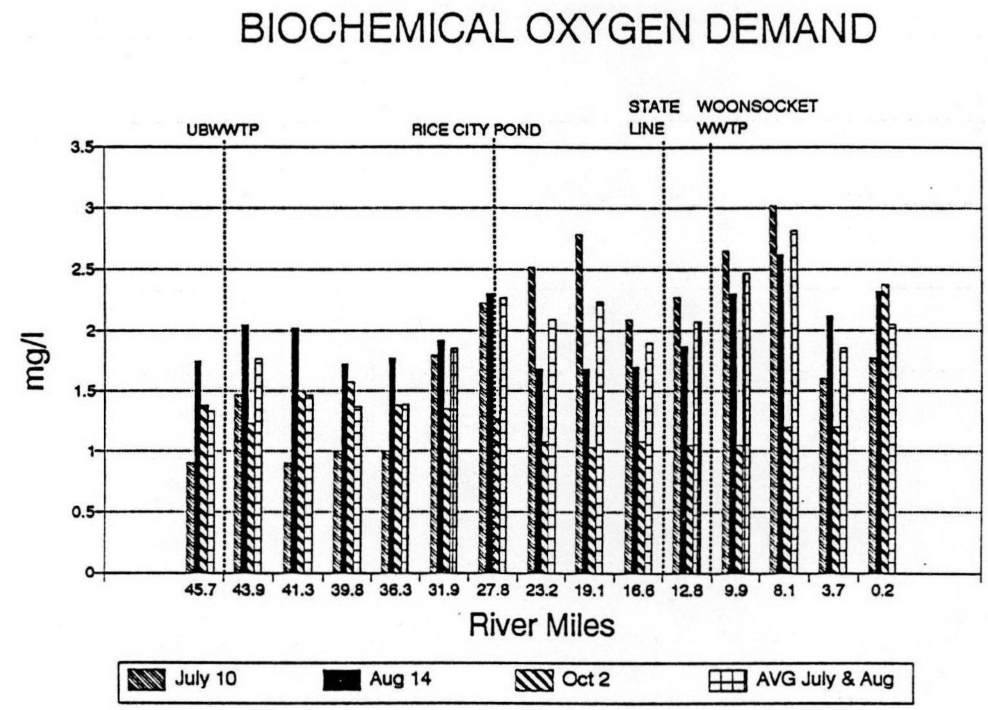
Blackstone River 1991



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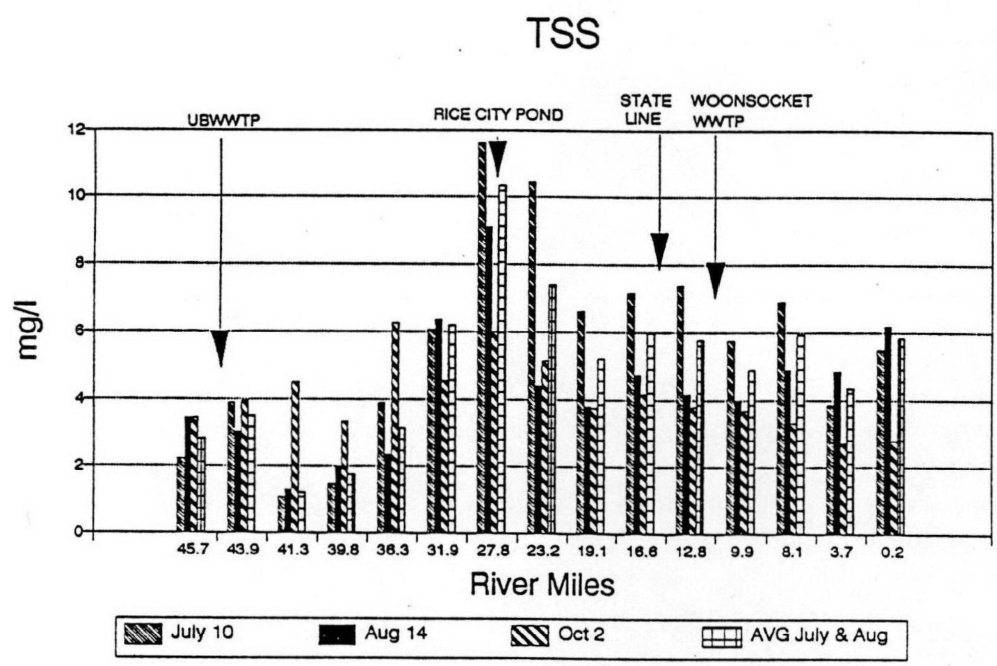
Blackstone River 1991



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Blackstone River 1991

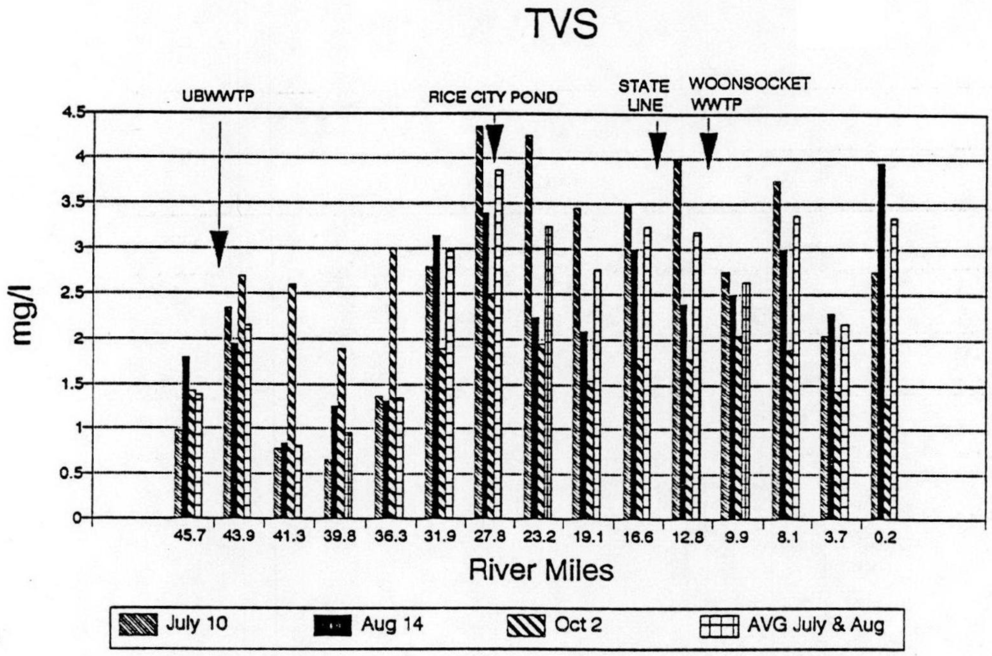
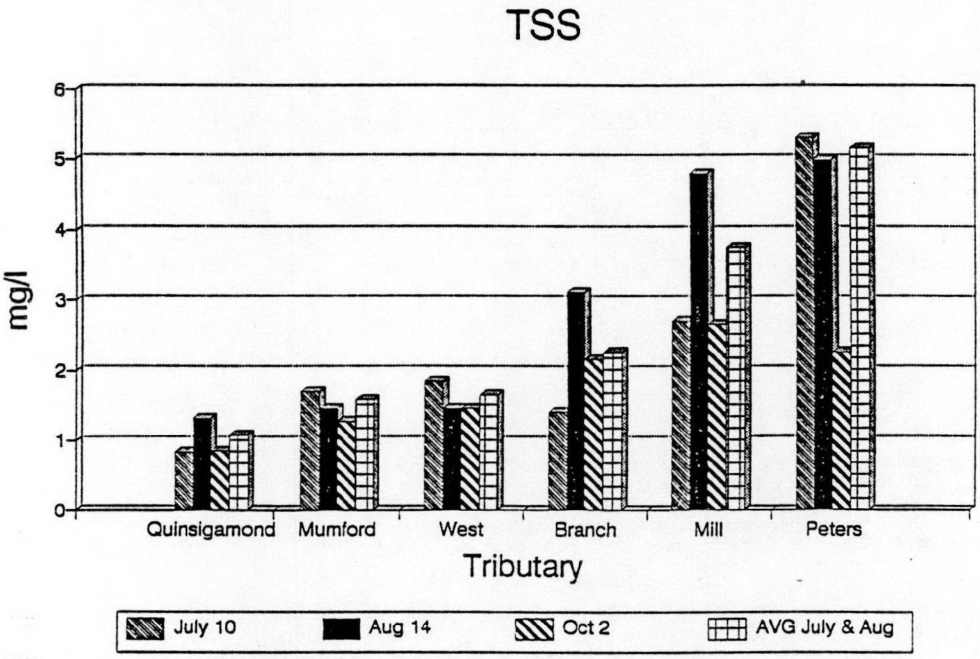


Figure 1– 69
Blackstone Tributaries 1991



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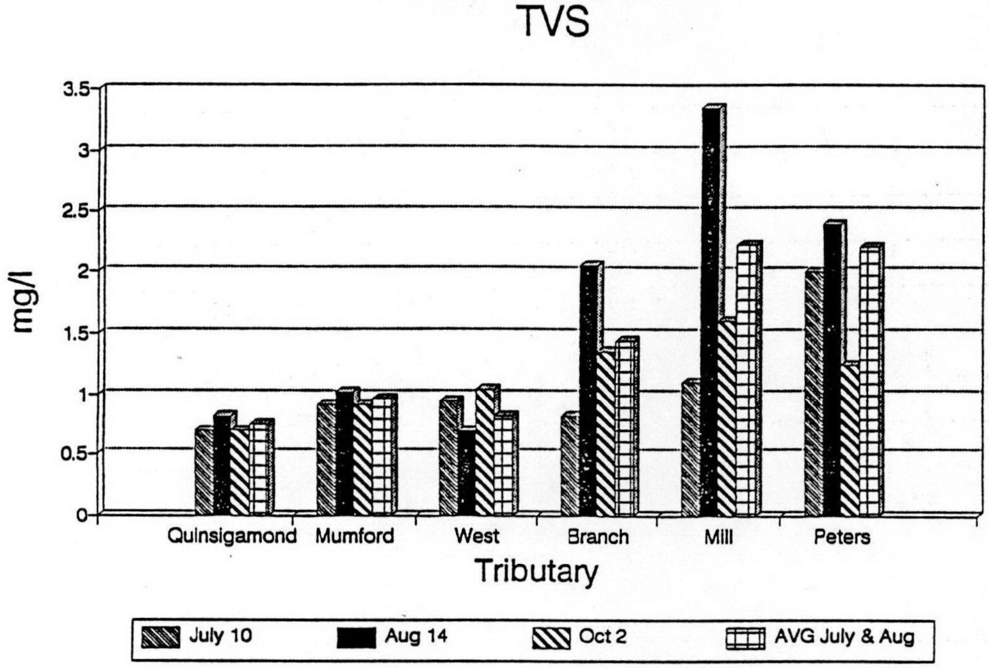
Blackstone Tributaries 1991



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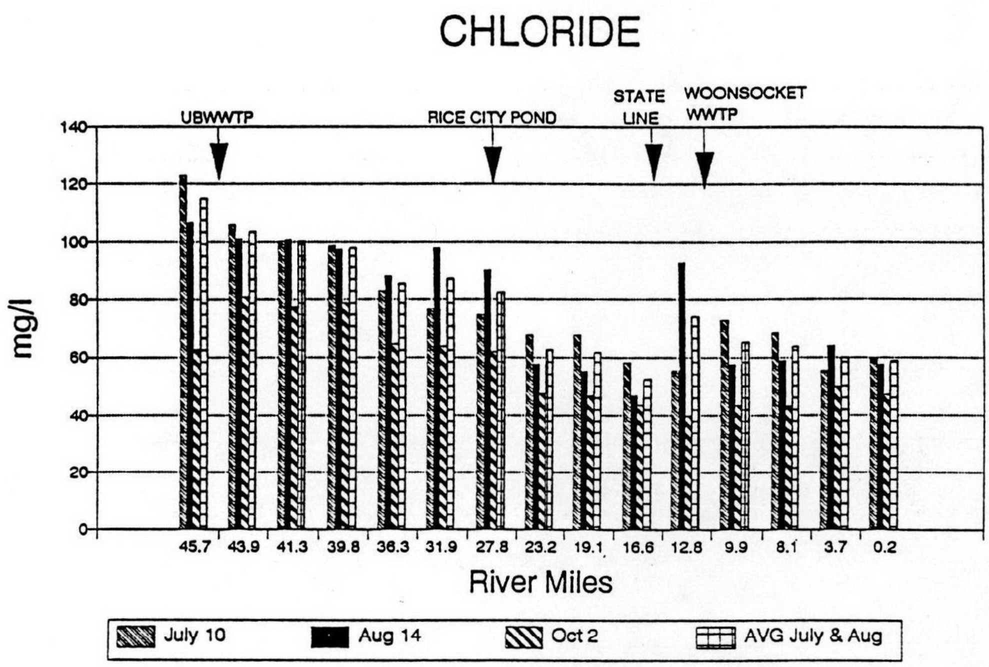
Blackstone River 1991



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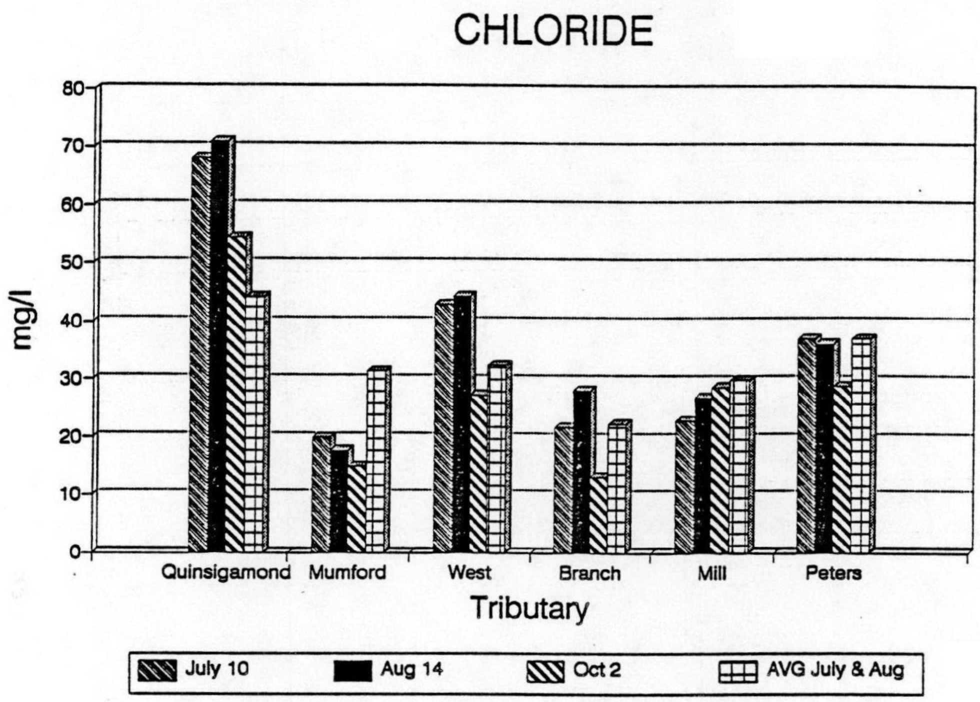
Blackstone Tributaries 1991



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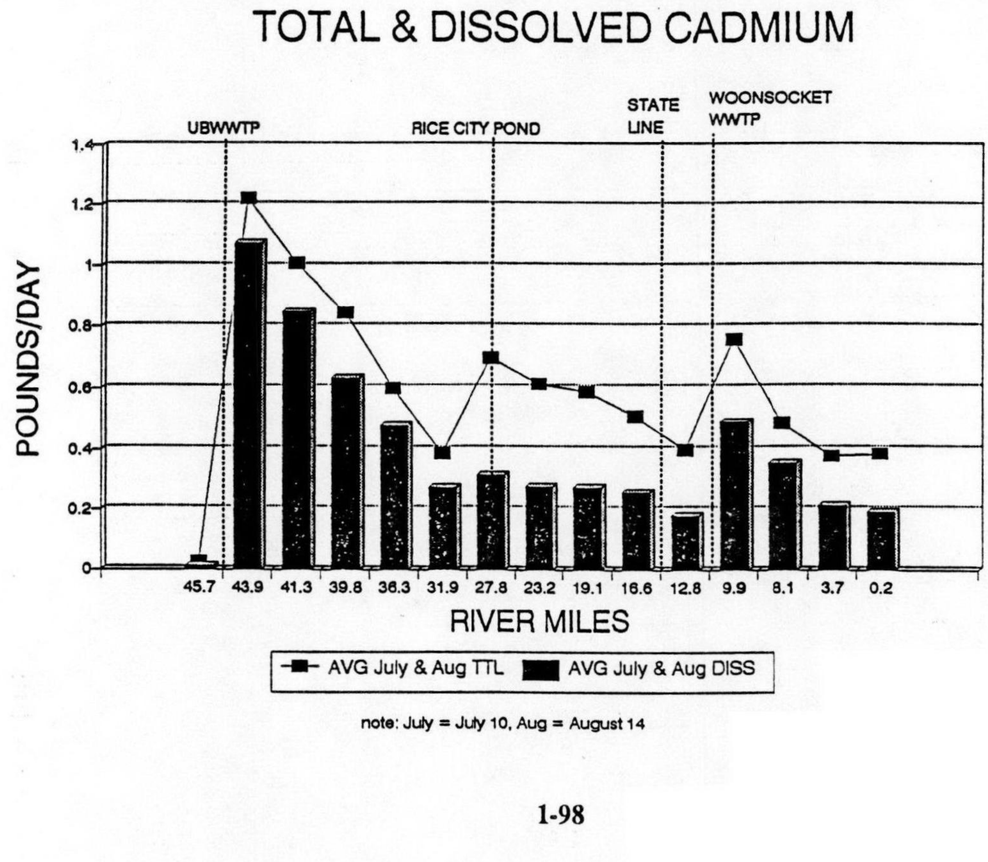
Blackstone River 1991



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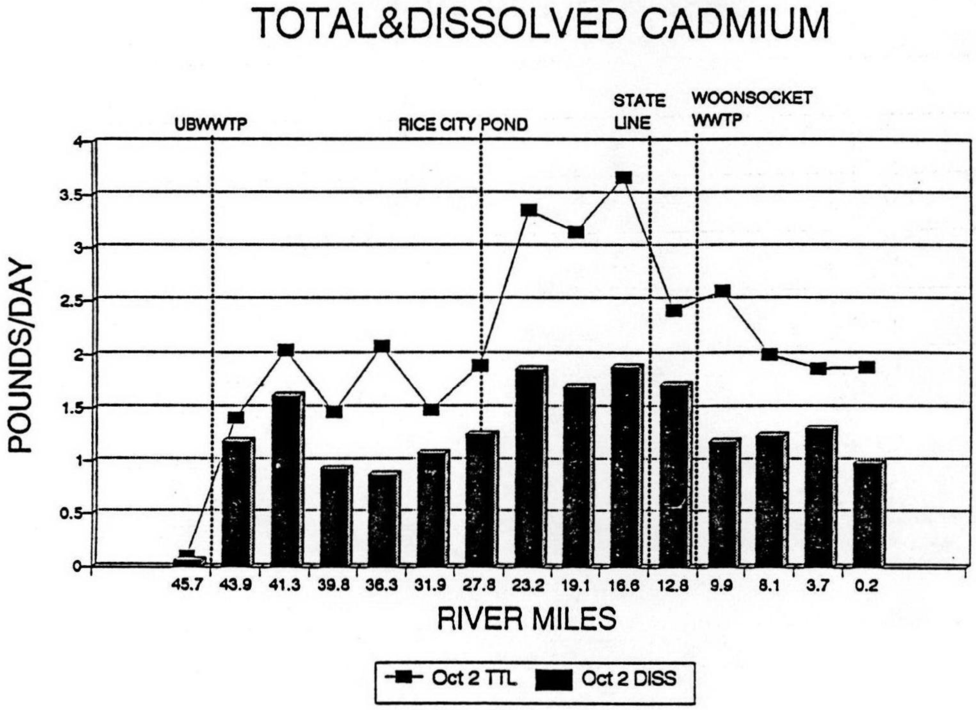
Blackstone River 1991



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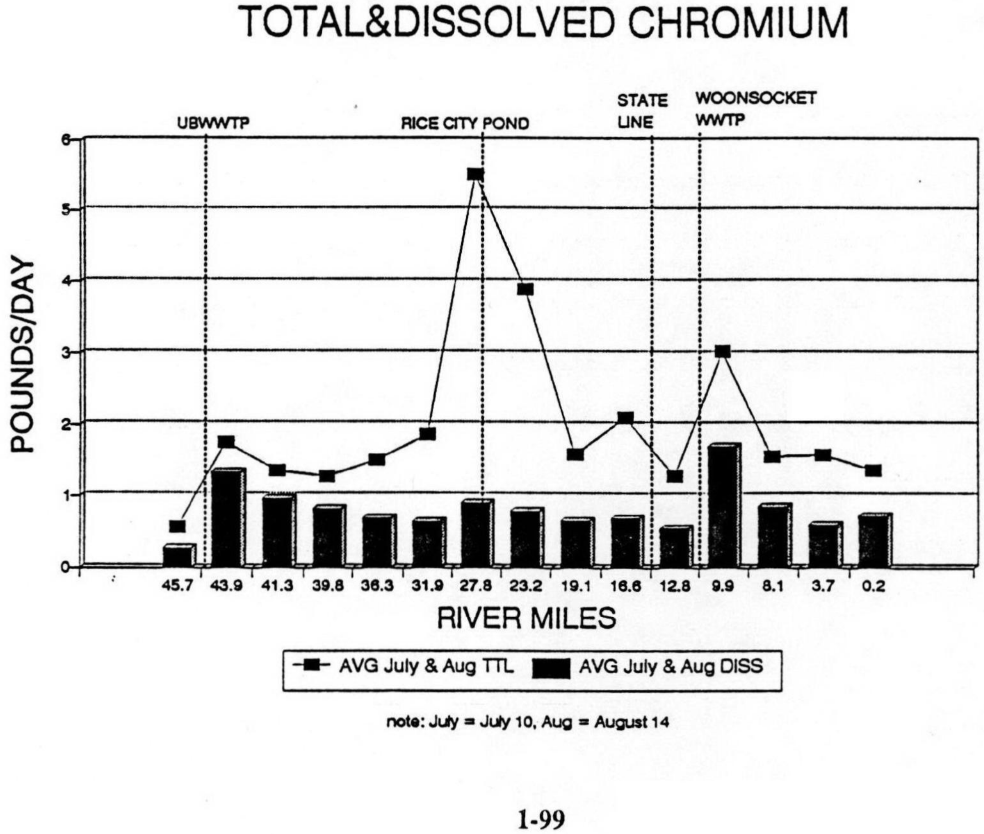
Blackstone River 1991



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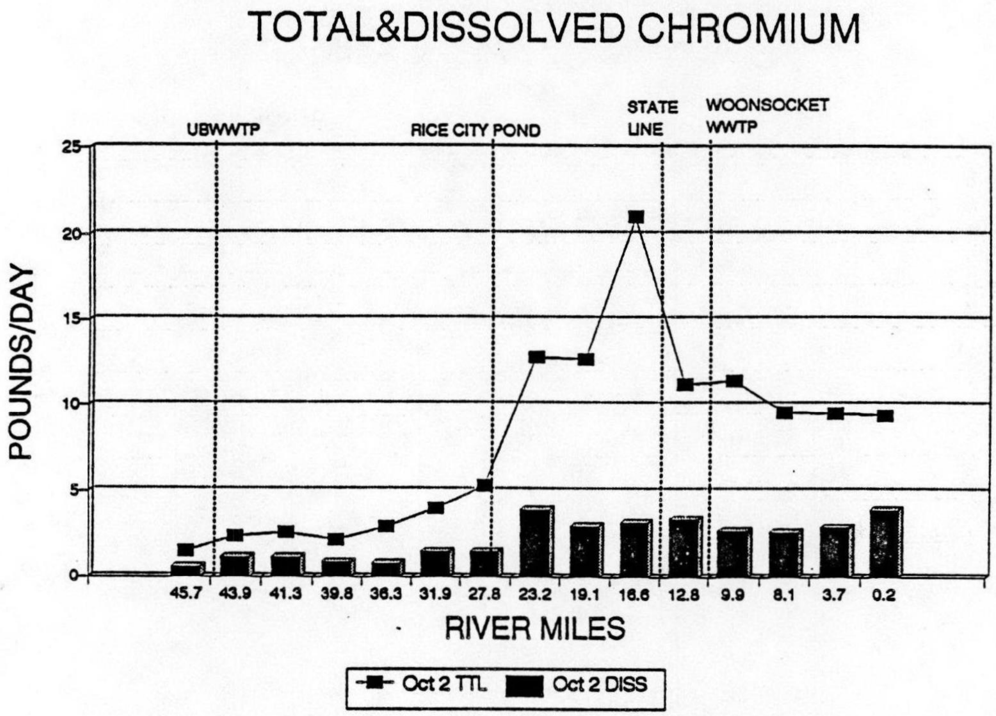
Blackstone River 1991



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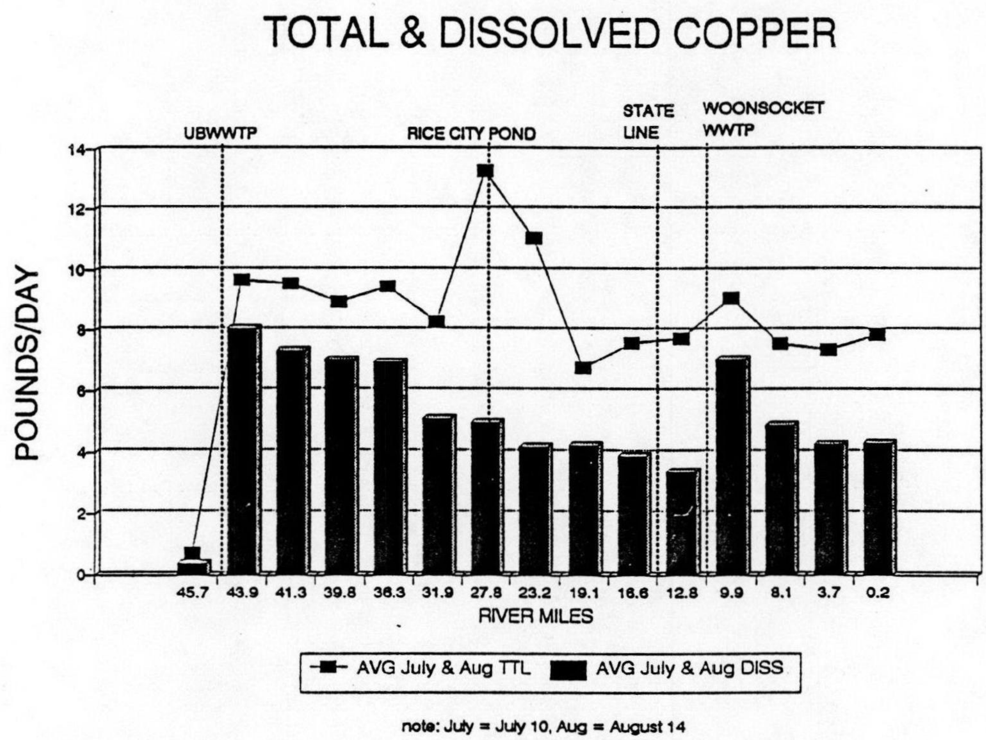
Blackstone River 1991



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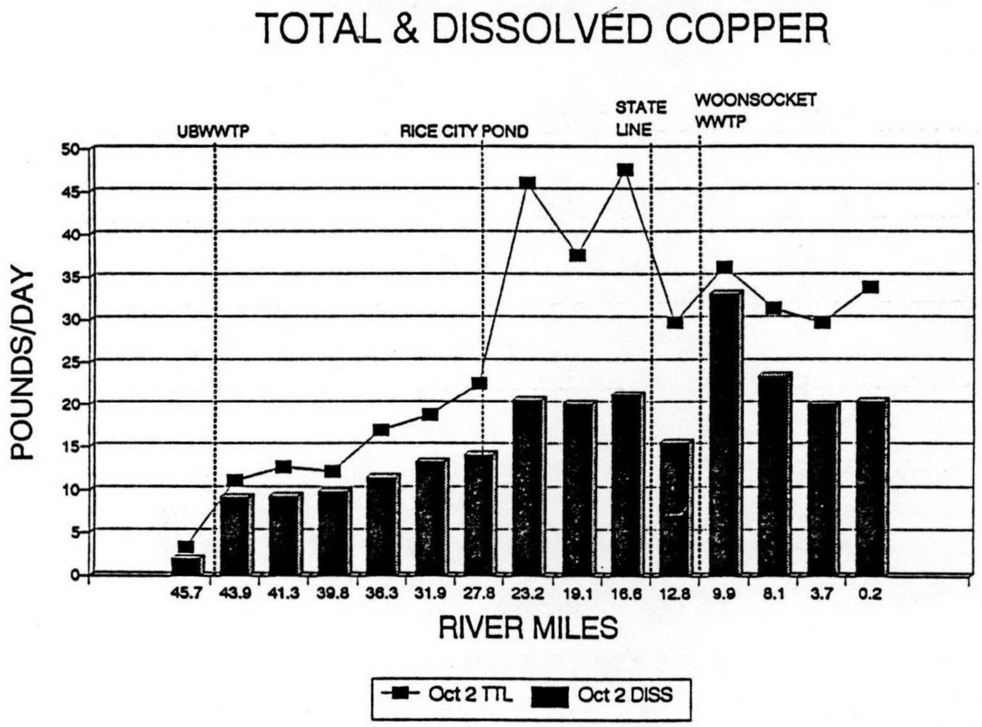
Blackstone River 1991



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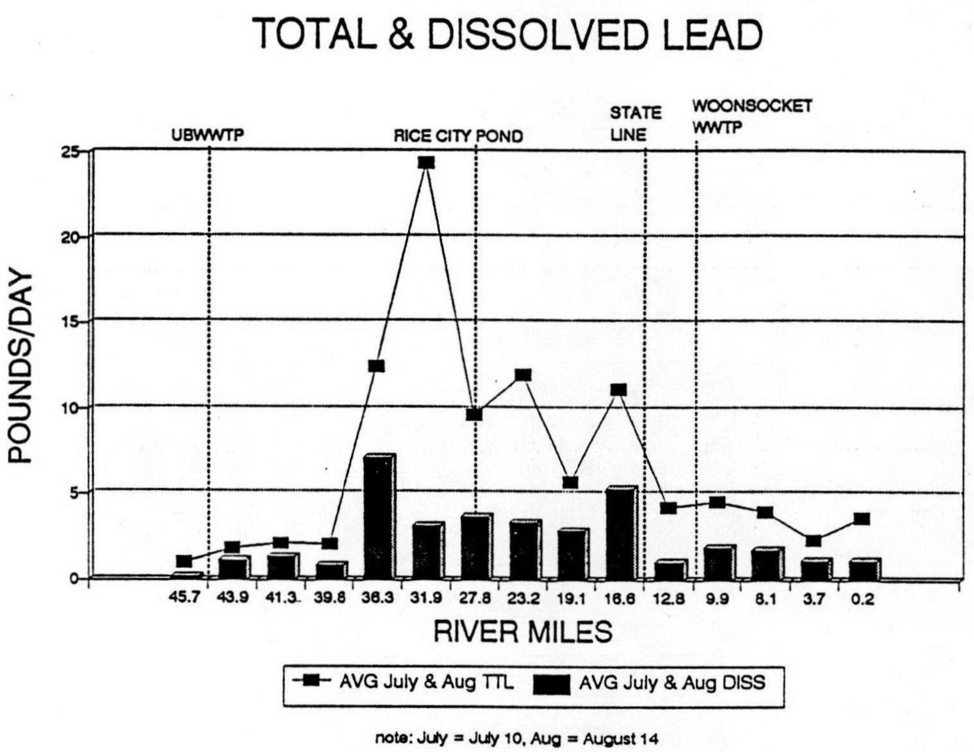
Blackstone River 1991



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Blackstone River 1991

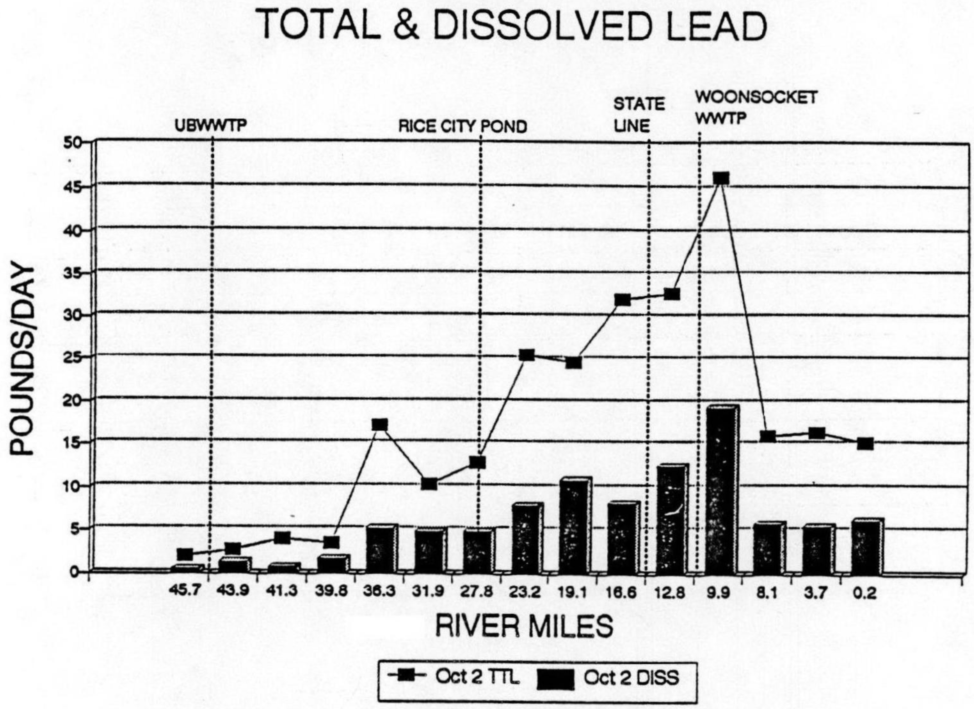


Figure 1– 81
Blackstone River 1991

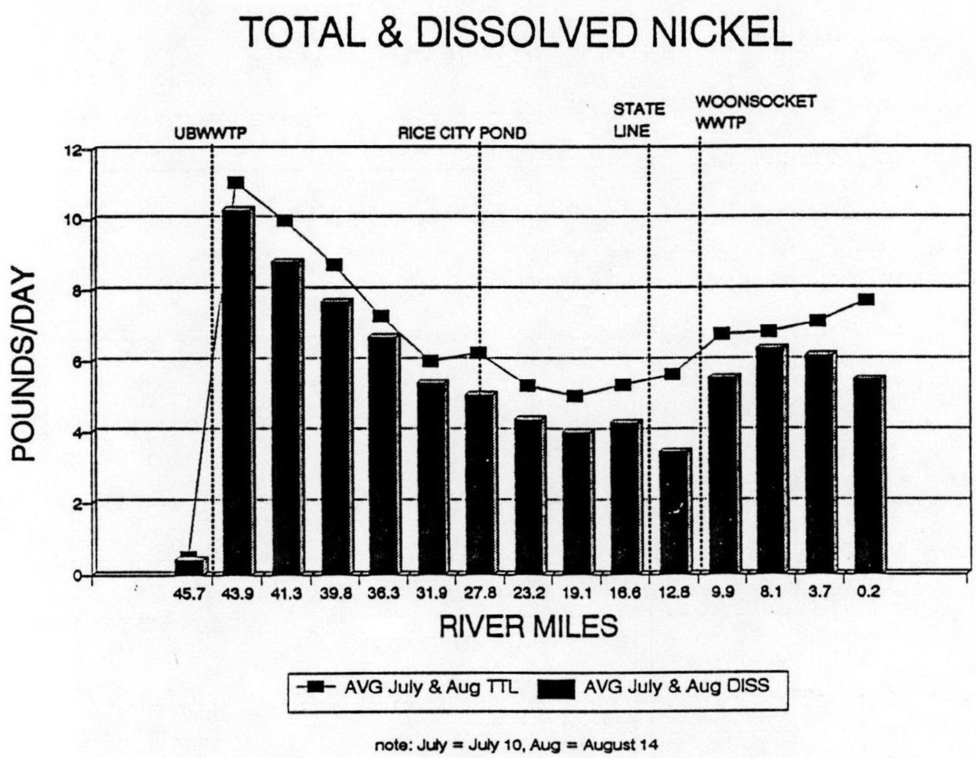


Figure 1– 82
Blackstone River 1991

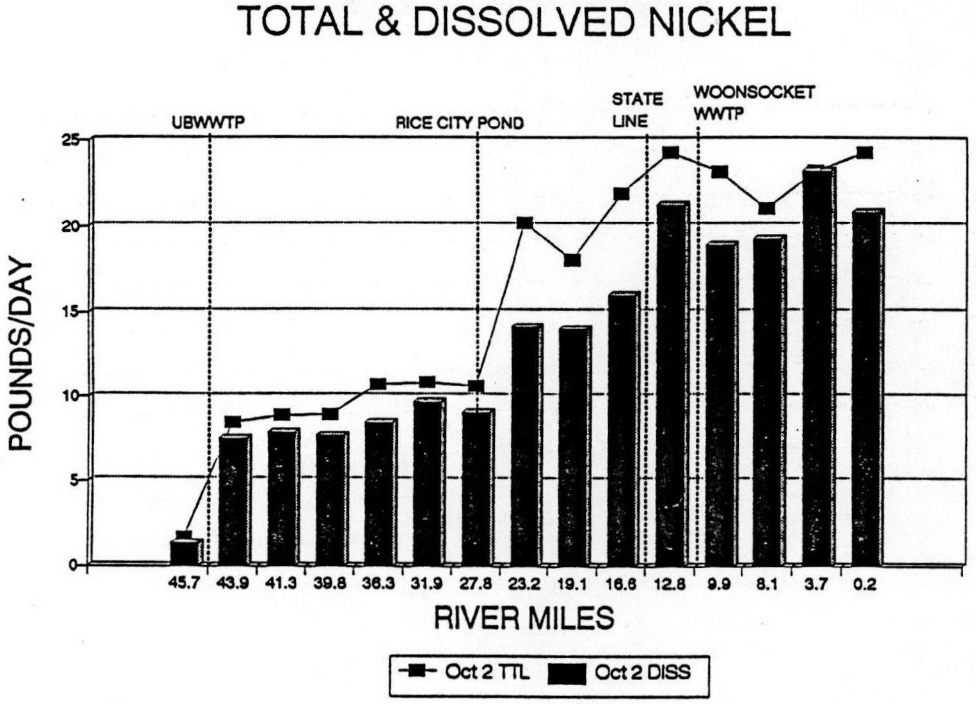
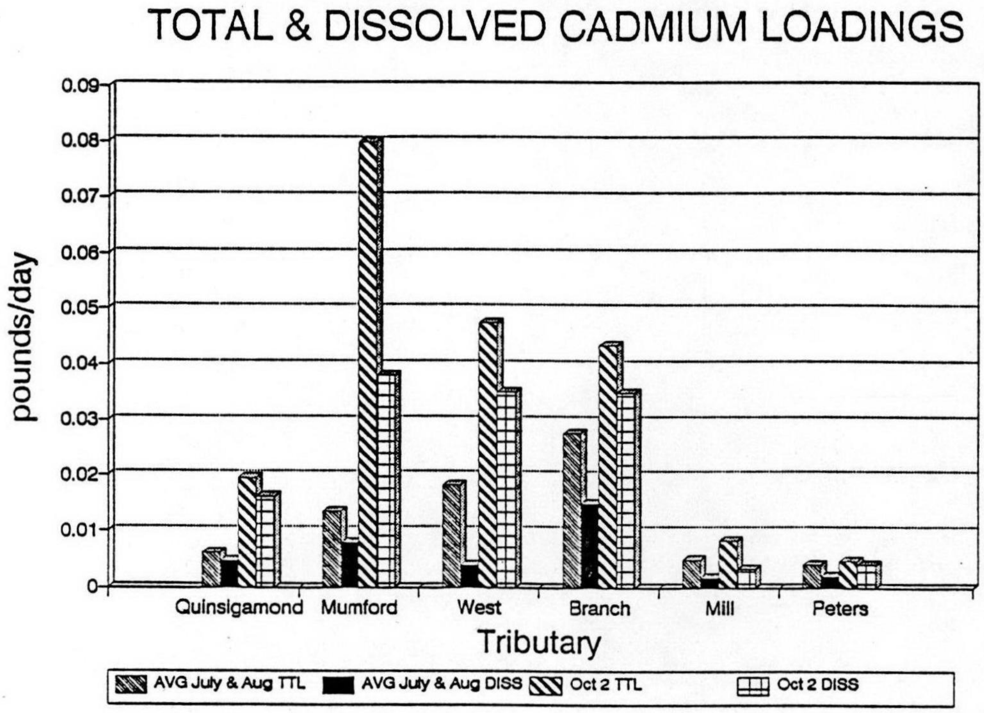


Figure 1–83
Blackstone Tributaries 1991



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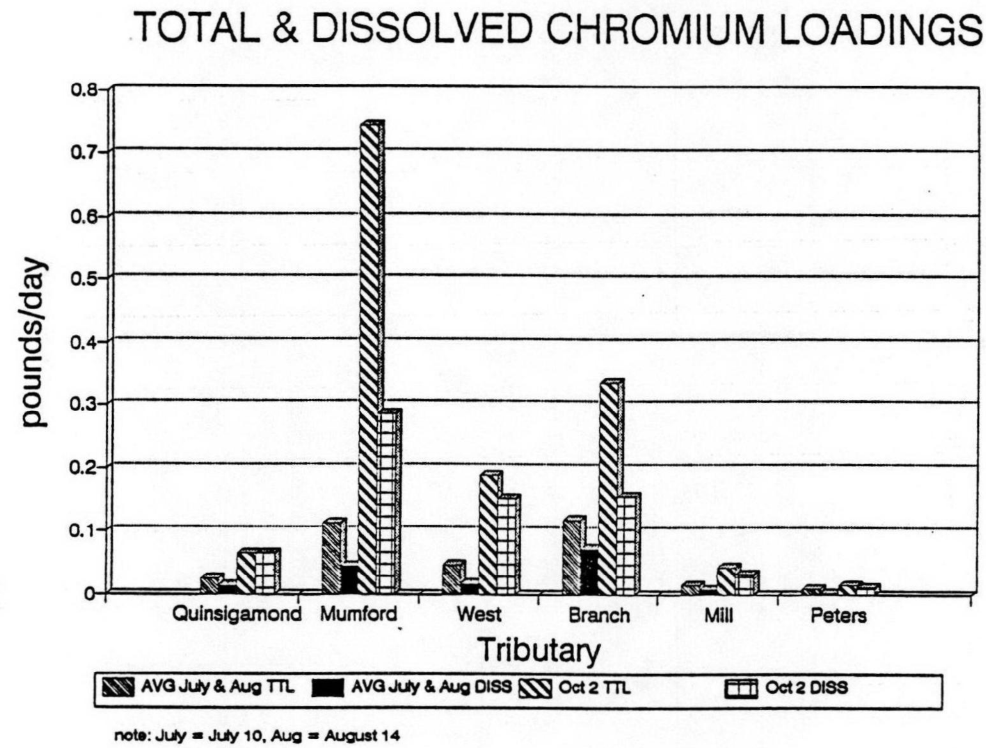
Blackstone Tributaries 1991



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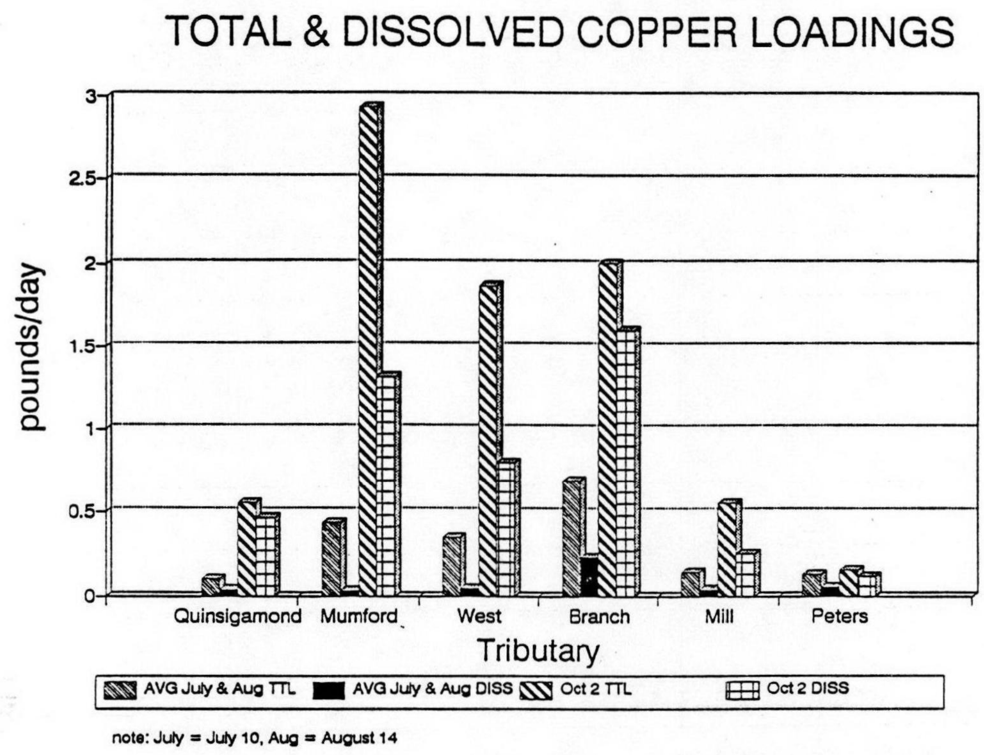
Blackstone Tributaries 1991



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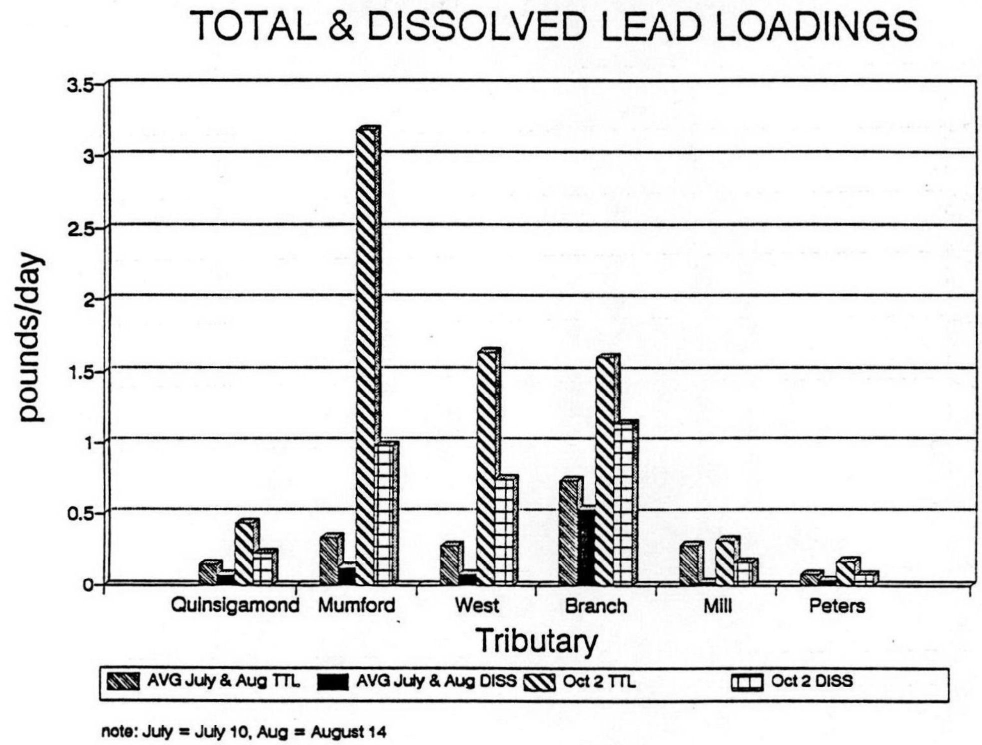

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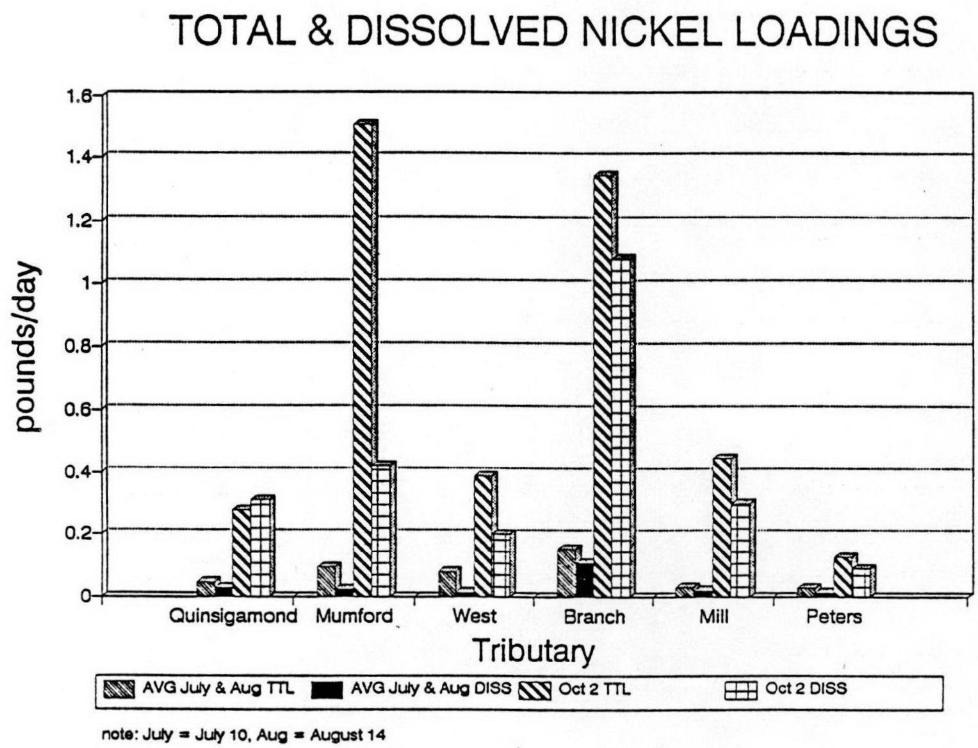
Blackstone Tributaries 1991



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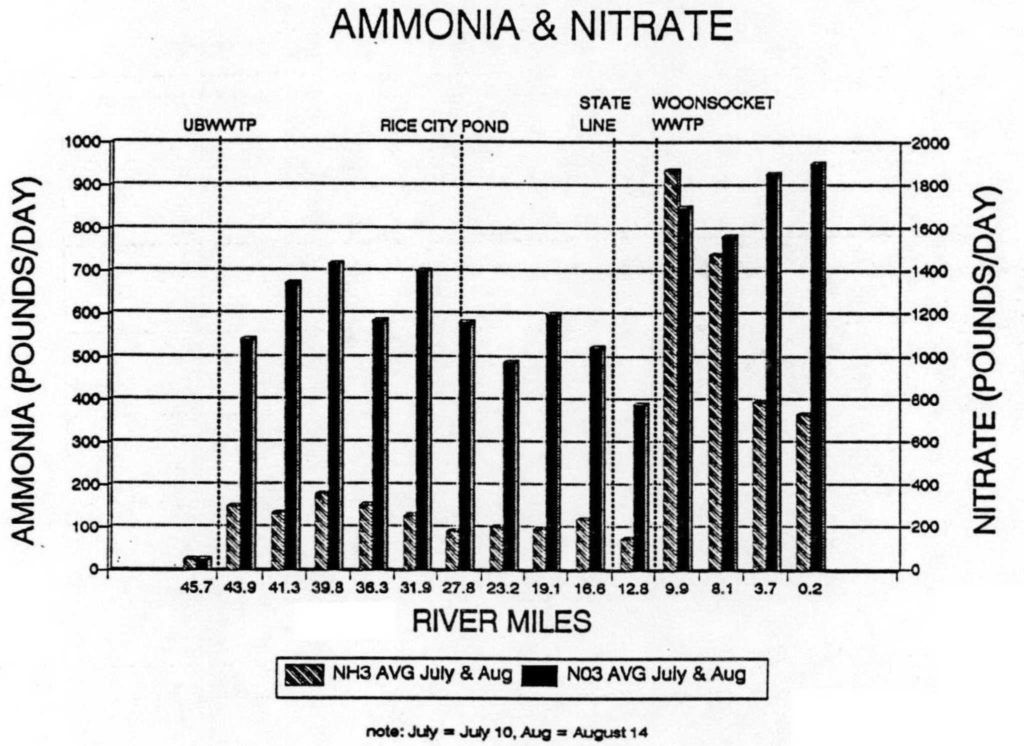
Blackstone River 1991



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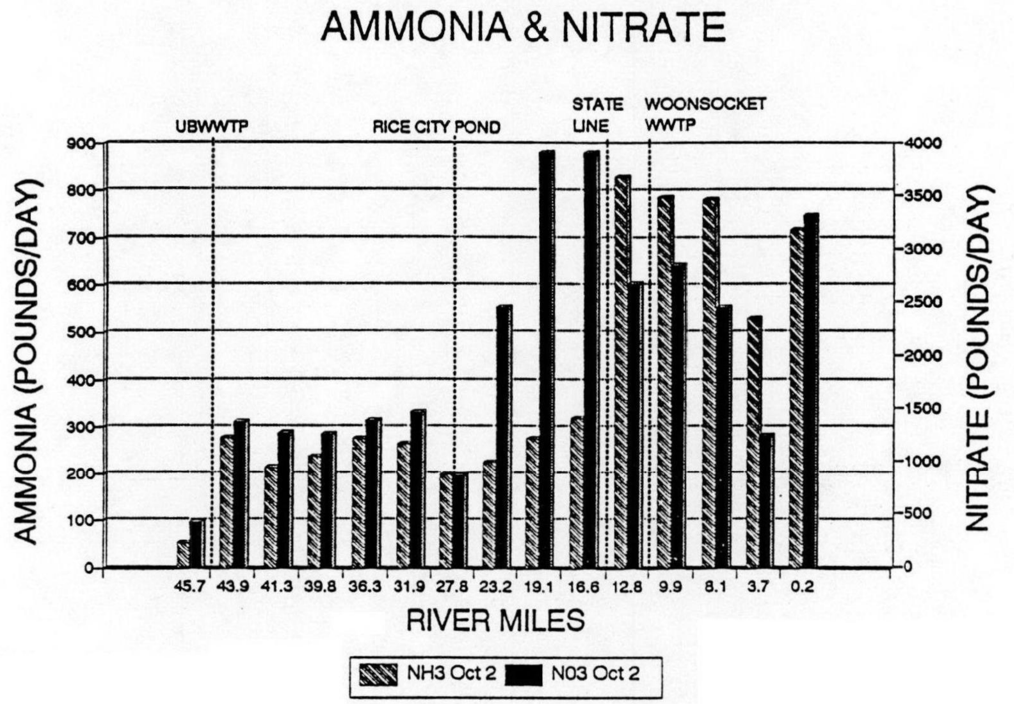
Blackstone River 1991



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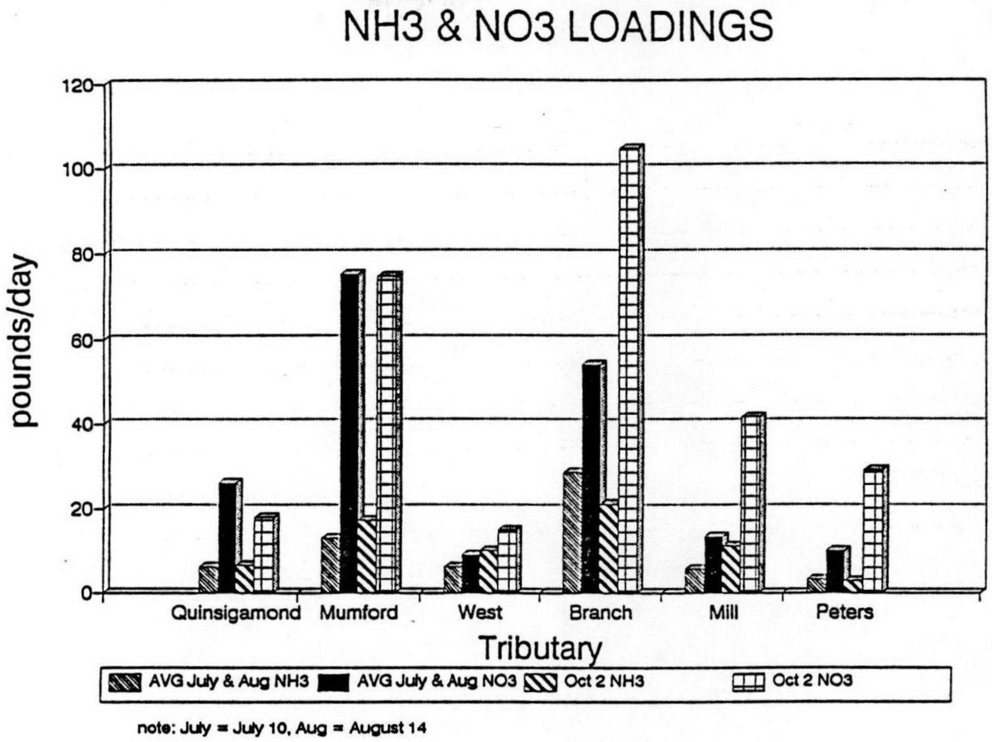
Blackstone Tributaries 1991



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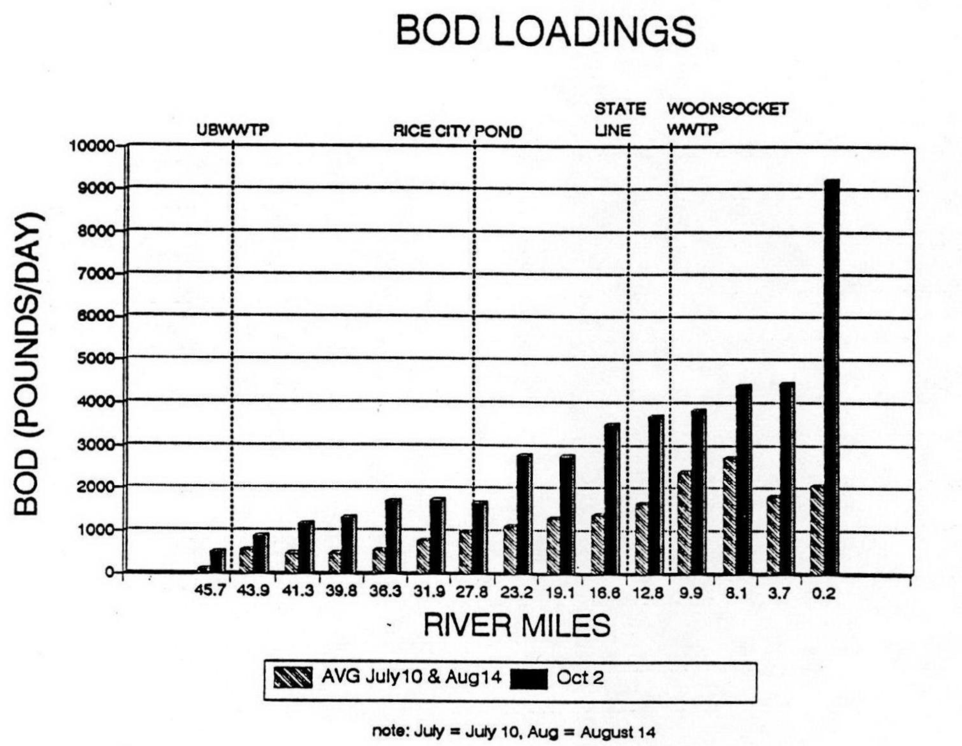
Blackstone River 1991



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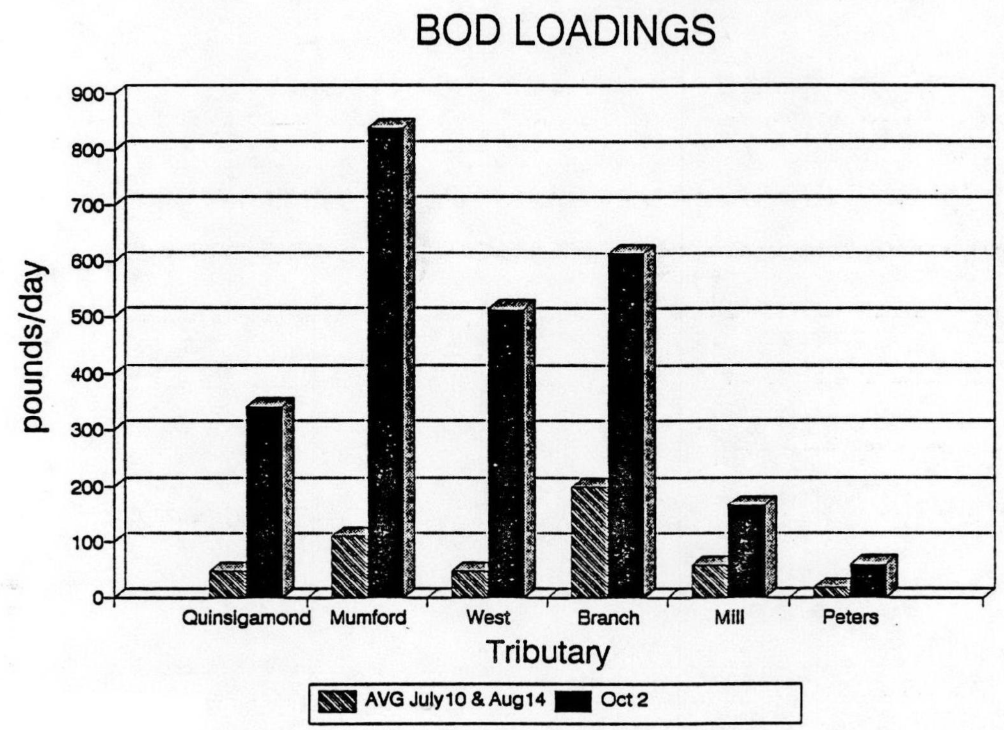
Blackstone Tributaries 1991



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Blackstone River 1991

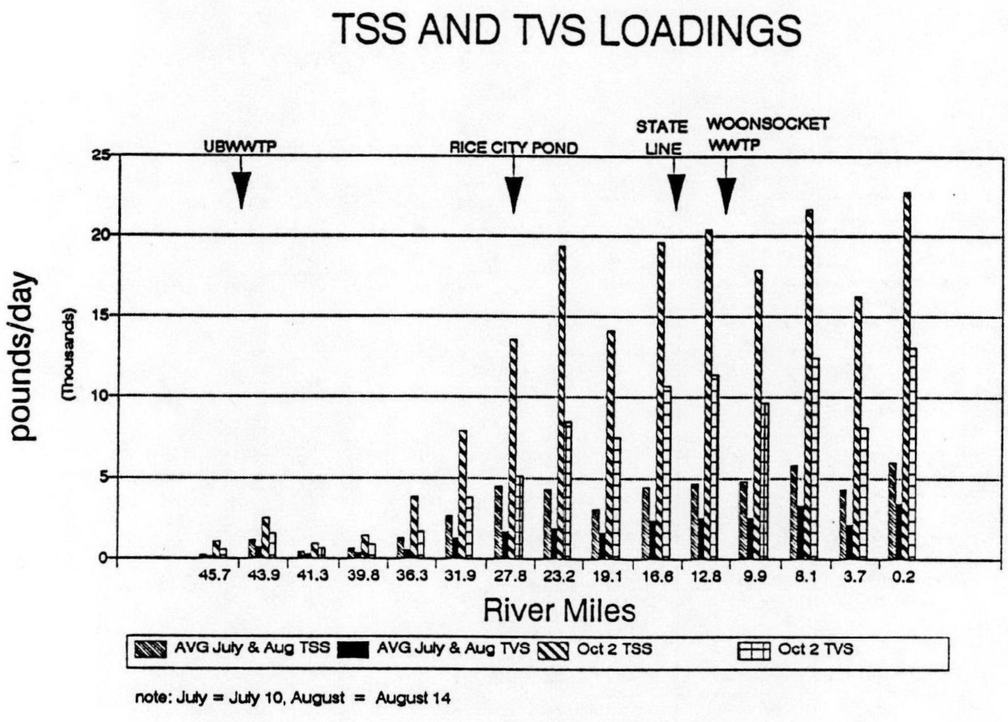

Figure 1–94
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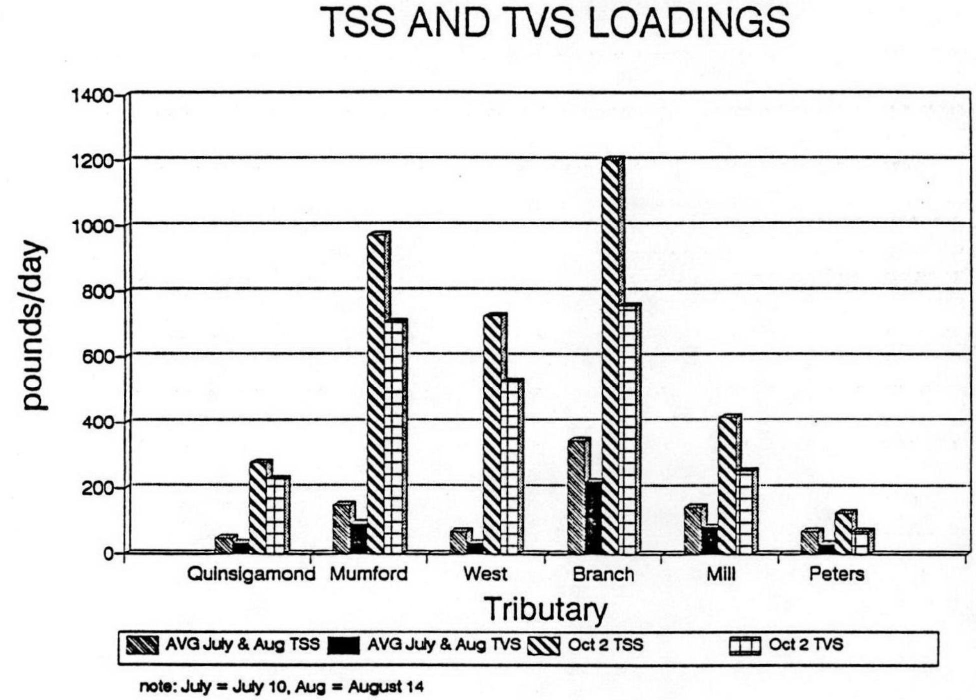
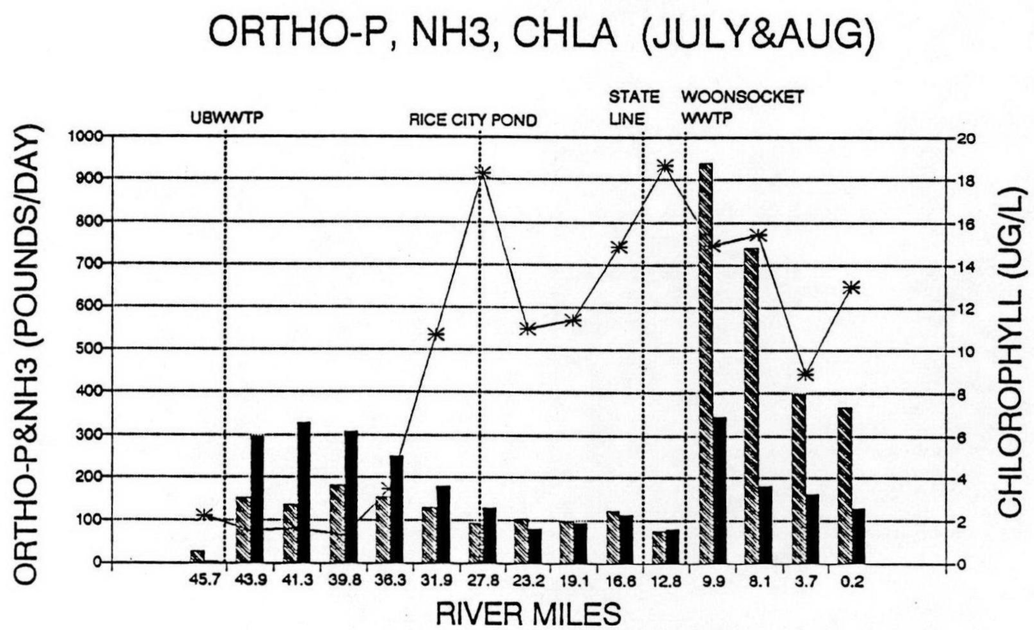


Figure 1–95
Blackstone River 1991



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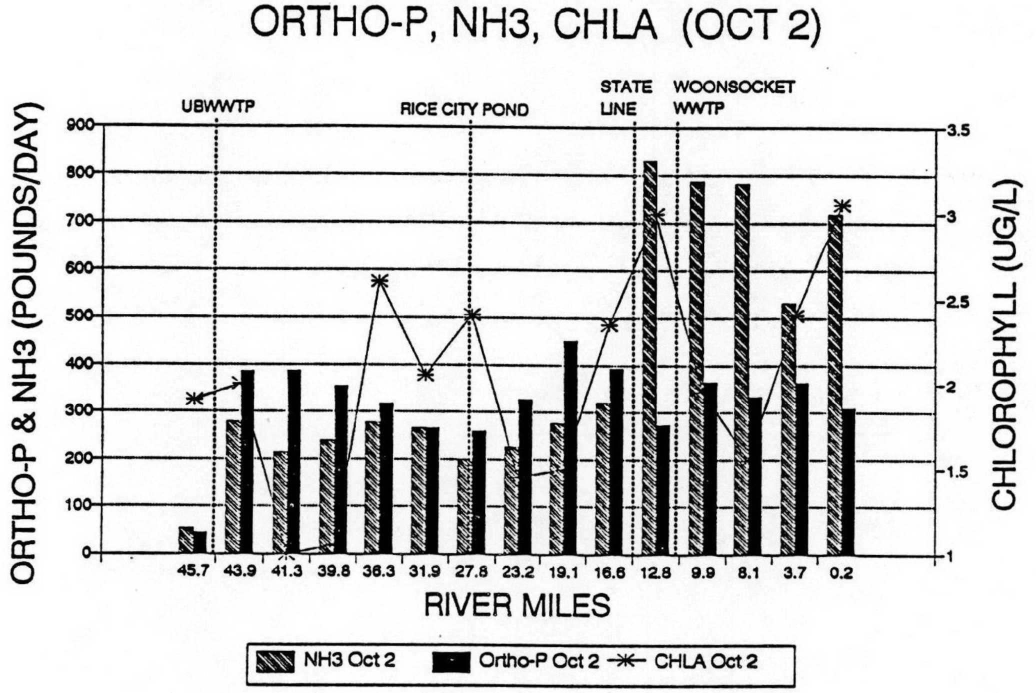
Blackstone River 1991



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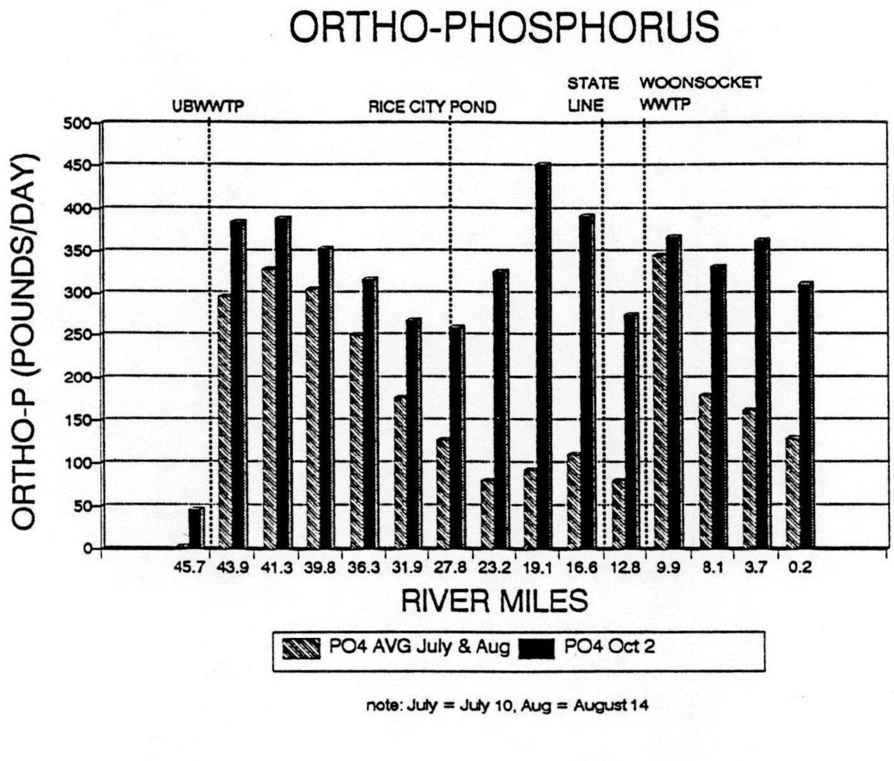
Blackstone River 1991



note: July = July 10, Aug = August 14

CHAPTER 2

1991 BLACKSTONE RIVER DRY WEATHER SURVEY

TOXICITY TESTING

by
Celeste Philbrick-Barr, John Paar III, and Peter M. Nolan
Environmental Services Division, EPA Region I

Chapter 2
List of Tables and Figures

1991 BLACKSTONE RIVER SURVEY
Chronic Toxicity Testing of Ambient Blackstone River Water

Introduction

As part of the Blackstone River Initiative, chronic toxicity testing was performed on water samples collected at 21 stations along the river during the summer and fall of 1991. There were three separate sampling surveys starting on: July 10, August 14, and October 2. Each sample consisted of a composite of four subsamples collected at six hour intervals.

The tests utilized were the Fathead minnow, *(Pimephales promelas)* larval growth and survival test and the *Ceriodaphnia dubia* survival and reproduction test. The young of *P. promelas* and *C. dubia* were exposed for seven days to the samples with renewals occuring daily. The responses of the two organisms in the 21 samples were statistically compared to the responses of the organisms in laboratory control water.

Materials and Methods

The test procedures used follow those outlined in the EPA manual, *Short-Term Methods For Estimating The Chronic Toxicity Of Effluents and Receiving Waters To Freshwater Organisms*, 2nd Edition, (Methods 1000.0 and 1002.0), EPA/600/489/001.

All organisms were maintained at 25 degrees Celsius +/- 1 degree and 16:8 hour light/dark cycle. Survival was monitored every 24 hours and recorded on standard laboratory data sheets. Temperature, pH, conductivity, and dissolved oxygen were measured daily. Hardness was measured at the beginning of the test. Total residual chlorine (TRC) was measured at the beginning of the test only in samples collected at stations immediately downstream from wastewater treatment plants.

Data Analysis

Survival and mean dry weight data from the *P. promelas* test was analyzed using Kruskal-Wallis Anova by rank and Dunn's Multiple Comparison Test.

The survival data from the *Ceriodaphnia dubia* test was analyzed using Fisher's Exact Test, to determine whether a significant difference, relative to the control, existed for the river station samples. The reproduction data was analyzed using Shapiro-Wilks test for normality, Bartlett's test for homogeneity of variance and Dunnett's or Bonferroni's T-test to determine if significant differences existed between river samples and the control.

Results

Survival of fathead minnows was not affected in any of the stations tested. During Round I, there was reduced growth in the station 19 sample. During Round II, there was reduced fish growth in the station 6 sample. During Round III, there was reduced fish growth in the samples from station 19 and 21 (Table 2–1).

Ceriodaphnia survival was unaffected in any of the samples tested. Ceriodaphnia reproduction showed a statistically significant difference from the control only at station 9, during the October survey (Table 2–2).

BLACKSTONE RIVER AQUATIC TOXICITY TEST RESULTS
Fathead Minnow

Station #	% Survival I	II	III	Mean Wt. per fish (mg) I	II	III	Sig.* Effect
1	81	90	80	0.623	0.401	0.428	
2	100	100	90	0.647	0.428	0.461	
3	90	90	100	0.663	0.405	0.489	
4	97	70	100	0.6	0.394	0.495	
5	93	80	100	0.683	0.343	0.381	
6	83	100	90	0.673	0.329	0.533	*Round II
7	80	70	100	0.663	0.413	0.583	
8	90	80	100	0.547	0.496	0.613	
9	87	90	100	0.62	0.373	0.333	
10	97	100	100	0.623	0.505	0.793	
11	83	100	90	0.643	0.397	0.569	
12	100	90	90	0.613	0.42	0.455	
13	93	90	100	0.66	0.432	0.47	
14	87	100	80	0.69	0.45	0.48	
15	63	80	90	0.5	0.521	0.46	
16	97	100	100	0.59	0.429	0.447	
17	73	80	90	0.493	0.502	0.531	
18	83	100	100	0.537	0.447	0.547	
19	90	90	80	0.523	0.455	0.435	**Round I
20	87	87	90	0.553	0.452	0.491	
21	83	83	80	0.587	0.427	0.451	**Round I

Significantly different from control treatment as determined by Kruskal-Wallis test for * survival or ** growth. This test was because a lack of variance between values for each station precluded the use of other more common statistical tests.

BLACKSTONE RIVER AQUATIC TOXICITY TEST RESULTS
Ceriodaphnia dubia

Station #	% Survival I	II	III	Mean # Young I	II	III	Sig.*
1	100	90	80	31.8	24.3	22.1	
2	100	100	90	23.7	21.3	23.8	
3	100	90	100	24.7	24.6	21.4	
4	100	70	100	26.9	23.3	26.2	
5	100	80	100	23.3	15.6	22.0	
6	100	100	90	14.6+	28.4	25.0	
7	100	70	100	15.6+	18.8	26.3	
8	90	80	100	18.6+	25.2	24.6	
9	100	90	100	13.8+	14.4	8.5	**
10	100	100	100	10.7+	32.2	17.5	
11	100	100	90	22.3	29.3	23.6	
12	100	90	90	18.6	21.8	21.8	
13	100	90	100	15.3	27.7	21.9	
14	70	100	80	9.9	23.4	14.1	
15	100	80	90	12.0	21.2	21.6	
16	100	100	100	30.1	27.6	24.5	
17	100	80	90	36.4	20.1	21.3	
18	80	100	100	24.1	25.9	28.6	
19	100	90	80	37.8	28.2	26.8	
20	100	90	90	28.9	26.1	23.3	
21	100	90	80	30.1	24.6	27.3	

+This rack accidentally discarded on Day 6, so mean # of young on day 6 compared to mean # of control young on day 6.

Significantly different from control treatment as determined by *Fisher's Exact Test (for survival) or **Dunnett's Test (for reproduction).

Blackstone River Whole Sediment Toxicity Tests

Blackstone River sediments were analyzed twice in 1991 by the U.S. EPA Region I, ESD Biology Section. The first round (I) of tests was conducted on two separate occasions. Samples were collected from stations BSED 1 - 4, MSED 1 and LC on July 18, 1991 (Table 2–3). Testing began July 22, 1991. The remaining samples were collected from stations MSED 5 - 7, MSED 1, and LC September 3 and 4, 1991. Testing began September 3, 1991.

Samples for the second round (II) of tests were collected from stations BSED 1 - 7, MSED 2 and LC October 23 and 24, 1991. (After Round I was completed, a sample was collected at MSED2 because of suspected organic chemical contamination at the MSED1 location.) Testing began on October 30, 1991.

Table 2-3

Blackstone River Survey 1991 Sediment Station

Blackstone River Sediment Station		
Number	Name	
BSED1	Singing Dam	
BSED2	Fisherville Pond	
BSED3	Sutton St./Rockdale Pond	
BSED4	Rice City Pond	
BSED5	Tupperware Dam	
BSED6	Mannville Dam	
BSED7	Slater's Mill	
MSED1	Gilboa Pond, Mumford River	Reference
MSED2	Grey's Pond, Mumford River	Reference
LC	Lexington Pond Control	Reference
0	Lab Culture Water	Lab Control

Materials and Methods

Sediment Sample Collection and Preparation

Sediment samples were collected using a stainless steel petit ponar dredge from a boat or while wading, depending on the location. Collection included sediments from the upper four inches of aquatic substrate. Sediments were emptied from the dredge into a shallow plastic pan. Any surface water obtained with the sample was poured off and sediments were deposited in an airtight, five gallon pail. Approximately 18 liters of sediment were collected at each station. This volume would be used for whole sediment, pore water tests and chemical analyses. Samples were kept on ice in coolers and then stored in the ESD Biology Laboratory sample refrigerator which is maintained at 3°C.

Before the sediment samples were distributed to test chambers, they were homogenized. This was necessary since the samples were composites of multiple dredgings. A uniform distribution of sediment was obtained by stirring the sample for at least three minutes in the five gallon pail using a masonry mixing blade and a drill press with a H.P. motor.

Mixing and Sieving

Sieving is necessary to remove large stones, debris and predators. The sieve size used prior to toxicity testing is 500 microns. Sieving was performed on all samples tested including control and reference sediments.

Test Procedure

The day before the toxicity tests started (Day-1) each test sediment and the reference sediment (Lexington Pond) were mixed and an aliquot was added to the test chambers. The sediment in each chamber was smoothed using a spoon or spatula. Overlying water was added by pouring into a petri dish laid on top of the sediment. This reduces resuspension. To allow sediments to settle, no organisms were added to the test vessels for 12-24 hours. Water quality parameters were measured prior to the addition of the test organims.

The beakers were covered with watch glasses to prevent evaporation. Aeration was provided to each test chamber through a 1-ml. glass pipet which extended between the beaker spout and the watch glass cover to a depth not closer than 2 cm from the sediment surface. The air was bubbled into test chambers at a rate that does not cause turbulence or disturb the sediment surface. Water lost to evaporation was replaced as needed with temperature acclimated de-ionized water or overlying water. The tests were conducted for ten days.

The dissolved oxygen (D.O.) in each test chamber was measured in at least one test chamber in each treatment at the beginning and end of the test and at least weekly during the test and if the behavior of the organisms suggested D.O. might be low. A measured D.O. concentration should be >40% and <100% saturation. Conductivity, hardness, pH and alkalinity were measured every day.

The test chambers with sediment were set into an environmental chamber at the initiation of a test. The temperature of the chamber was 25^{o} C. Overlying water was partially replenished by pouring off 50% and adding new culture water. Additional information on test methods for the chironomid and amphipod tests appear in Appendix D.

Results

Chironomus tentans Test

The first *Chironomus tentans* test conducted on samples BSED 1-4 did not have adequate survival in either reference station sample. The minimum acceptable control survival is 80% and only 64% was achieved. There appeared to be no significant difference between survival at the BSED stations 1-4 (55-72%) and the reference station, LSED (64%). Dry weights were also measured but since the test was considered invalid, these are not analyzed.

The tests conducted on the samples from BSED 5-7 had greater than 80% survival in the MSED1 and MSED2 background reference samples. LSED, however, had a low survival rate of 57%. There was no significant difference between survival in samples 5-7 and MSED samples.

The second round of sediment tests included all stations BSED1-7. Significant mortality in samples from Singing dam(BSED 1) and Fisherville Pond(BSED 2) was recorded. The results of the Chironomus tentans tests are shown in Tables 2–(4-6).

Hyallela azteca

The first round of *Hyallela azteca* sediment toxicity tests exhibited adequate reference survival in the LSED and MSED samples. Significant mortality occurred in samples BSED1 and BSED4. The subsequent test conducted on BSED stations 5-7, did not meet minimum survival requirements in the reference station samples.

During the second round of testing, minimum survival was achieved in the LSED sample. No *H. azteca* were retrieved in sample BSED 2,3,4. Only one was retrieved in samples BSED 2 and 6, and two in MSED2. Every station tested showed a significant impact when compared against the LSED sample. The results of the *Hyallela azteca* tests are shown in Tables 2–(7-9).

INVERTEBRATE SEDIMENT TOXICITY TEST
Species: Chironomus tentans

July 22, 1991

Station		No. Live Animals at end of 14 days	Mean % Survival
BSED 1-A		14	
	B	15	
	C	16	
	D	10	
			68
BSED 2-A		16	
	B	17	
	C	15	
	D	10	
			72
BSED 3-A		12	
	B	9	
	C	8	
	D	15	
			55
BSED 4-A		13	
	B	15	
	C	9	
	D	14	
			64
LSED	A	14	
	B	16	
	C	7	
	D	14	
			64
MSED	A	12	
	B	9	
	C	8	
	D	9	
			48

All replicates contained 20 organisms.
Some organisms hatched out before test concluded, so exuviae were counted as "live".
Minimum survival of 80% not met by reference and background sediments, LSED and MSED.

INVERTEBRATE SEDIMENT TOXICITY TEST
<u>Species: Chironomus tentans</u>

September 10, 1991

Station	No. Live Animals at end of 14 days	Mean % Survival	Av. Weight
MSED 1			
A	10		
B	12		
C	16		
D	14		
		85	2.2 mg.
MSED2			
A	8		
B	17		
C	15		
D	15		
		89	1.9 mg.
LSED			
A	9		
B	2		
C	9		
D	14		
		57	3.5 mg.
BSD5			
A	12		
B	9		
C	13		
D	11		
		75	3.5 mg.
BSED6			
A	11		
B	16		
C	12		
D	9		
		80	2.4 mg.
BSED7			
A	16		
B	15		
C	8		
D	12		
		84	3.1 mg.

Total number of organisms per replicate is 15 except for MSED2-B, MSED1-C, and BSED6-B which contained 17, 16 and 16, respectively.

INVERTEBRATE SEDIMENT TOXICITY TEST
Species: *Chironomus tentans*

October 30, 1991

Station	No. Live Animals at end of 14 days	Mean % Survival
BSED 1-A	3	
B	2	
C	10	33
BSED 2-A	5	
B	3	
C	2	
		22
BSED 3-A	12	
B	16	
C	14	
		92
BSED 4-A	12	
B	15	
C	7	
		82
BSED 5-A	7	
B	14	
C	12	
		73
BSED 6-A	10	
B	9	
C	11	
		75
BSED 7-A	10	
B	5	
C	15	
		75
LSED A	15	
B	12	
C	16	
		96
MSED A	15	
B	11	
C	10	
		80

* All replicates contained 15 organisms except LSED-C which contained 16.

INVERTEBRATE SEDIMENT TOXICITY TEST
Species: Hyallela azteca

July 22, 1991

Station		No. Live Animals at end of 14 days	Mean % Survival
BSED 1-A		3	
	B	1	
	C	4	
	D	1	
			15
BSED 2-A		9	
	B	11	
	C	11	
	D	13	
			70
BSED 3-A		20*	
	B	13	
	C	12	
	D	12	
			86
BSED 4-A		1	
	B	0	
	C	3	
	D	0	
			7
LSED	A	13	
	B	18	
	C	16	
	D	21	
			85
MSED	A	14	
	B	11	
	C	14	
	D	12	
			85

*Station LSED and BSED 3-A contained 20 organisms per replicate. The rest contained 15 organisms per replicate.

INVERTEBRATE SEDIMENT TOXICITY TEST
Species: Hyallela azteca

September 22, 1991

Station	No. Live Animals at end of 14 days	Mean % Survival
MSED 1		
A	0	
B	0	
C	0	
D	0	
		0
MSED 2		
A	0	
B	0	
C	0	
D	0	
		0
LSED		
A	14	
B	10	
C	16	
D	17	
		23
BSED 5		
A	2	
B	5	
C	1	
D	3	
		18
BSED 7		
A	8	
B	9	
C	12	
D	6	
		58
BSED 6		
A	12	
B	2	
C	5	
D	1	
		33

Each replicate contained 15 organisms except for LSED C & D which contained 16 and 17, respectively.

INVERTEBRATE SEDIMENT TOXICITY TEST
Species: Hyallela azteca

October 30, 1991

Station		No. Live Animals at end of 14 days	Mean % Survival
BSED 1-A		0	
	B	0	
	C	1	
			1.7
BSED 2-A		0	
	B	0	
	C	0	
			0
BSED 3-A		0	
	B	0	
	C	0	
			0
BSED 4-A		0	
	B	0	
	C	0	
			0
BSED 5-A		4	
	B	1	
	C	1	
			13.4
BSED 6-A		1	
	B	0	
	C	0	
			1.6
BSED 7-A		2	
	B	9	
	C	4	
			25
LSED	A	16	
	B	16	
	C	18	
			84
MSED	A	1	
	B	1	
	C	0	
			4.5

* each replicate contained between 15-20 organisms. Percent survival calculated on exact total numbers of organisms per concentration.

Blackstone River Sediment Pore Water Analysis

Introduction

Pore water from seven Blackstone River sediment stations (see Table 2–3) were analyzed for toxicity using *Ceriodaphnia dubia* and the fathead minnow, *Pimephales promelas*. Forty-eight hour acute toxicity tests compared organism response in Blackstone River sediment pore water with lab culture water and control and reference pore water obtained from sediments in Gilboa Pond, Grey's Pond and Lexington Pond.

Blackstone River pore water toxicity was analyzed twice in 1991 by the U.S. EPA Region I, ESD Biology Section. The first round (I) of tests were conducted in two parts. Samples were collected from stations BSED1 - 4, MSED1 and LC, on July 18, 1991. Pore water was extracted by centrifugation July 23 and 24, 1991. Testing began July 24, 1991. The remaining samples were collected from stations BSED 5 - 7, MSED1 and LC on September 3 and 4, 1991. Pore water was extracted September 10 and 11 and testing began September 12, 1991.

Samples for the second round (II) of tests were collected from stations BSED1 - 7, M2 and LC on October 23 and 24, 1991. (After Round I was completed an additional sample was collected at MSED2 because of suspected organic chemical contamination at the MSED1 location.) Pore water was extracted from these samples November 5, 6, and 7 and testing began November 7, 1991.

Materials and Methods

Collection of Sediments

Composite sediment samples were collected either from a boat or by wading using a petite ponar dredge. Approximately 2 liters of sediments were emptied from the dredge into a shallow plastic pan, any surface water obtained with the sample was poured off and sediments were deposited in a airtight, five gallon pail. Approximately 18 liters were collected at each station, this volume would serve for whole sediment and pore water tests. Samples were kept on ice in coolers and then stored in the ESD Biology Laboratory sample refrigerator which is maintained at 3°C.

Pore Water Extraction

There are three widely accepted methods used to extract the interstitial water which fills the space between the solid portion of sediment. This liquid, know as pore water, can be extracted by vacuum filtration, mechanical compression through a filter or by centrifugation. Basically, centrifugation spins samples at extremely high speed which forces larger heavier particles to settle. Lighter particles, including water, remain above the settled particles and can be siphoned or poured off for collection. This force effectively squeezes the "water" out of the sediment. This later method has been shown to be one of the most efficient methods and was chosen for this study.

Before sediments could be centrifuged for pore water extraction they had to be homogenized. This was necessary since samples were composited by multiple dredgings. A uniform distribution of sediment was obtained by stirring the sample for at least three minutes in the five gallon pail using a masonry mixing blade and a drill press with a H.P. motor.

Once homogenized, 1000 mls of sediments were scooped into Nalgene centrifuge bottles. An IEC PR-7000 centrifuge was used with a number 966 rotor with six (6) 1000 ml capacity swinging buckets. To maintain balance care was taken to match, by weight or volume, the opposing samples in the centrifuge. Samples were centrifuged at 5200 r.p.m.s for 120 minutes at 3°C. This configuration of speed and rotor applied a force of 7406.53 x gravity (relative centrifugal force) to the sediments. Since some sediments were dryer than others additional sample needed centrifugation in order to yield the minimum amount of pore water (750 mls) to conduct the test. Centrifuged sediments were carefully removed from the centrifuge to prevent resuspension of particles. Pore water from each station was composited in 1 and 2 liter Erlenmeyer flasks and then, to prevent decomposition, stored in the sample refrigerator at 3°C.

Toxicity Testing

Just prior to test time the pore water temperature was raised to 25°C by immersing the flasks in a water bath. This was done prior to the introduction of the test organisms. Once the temperatures were raised the fathead minnow larvae, less than seven days old, and Ceriodaphnia neonates, less than 24 hours old, were randomly distributed and assigned to the various testing chambers. Fish were tested in 300 ml beakers containing approximately 200 mls of pore water. *C. dubia* were exposed in 30 ml glass test tubes containing approximately 15 mls of pore water.

Three replicates of ten fish each were exposed for 48 hours to each of the seven pore water stations, the reference, control and the culture water. For each pore water sample, thirty *Ceriodaphnia* were exposed (fifteen test tubes containing two each).

Results

Tables 2–10 and 2–11 list the survival for minnows and Ceriodaphnia respectively. The samples which significantly affected Ceriodaphnia survival were from stations 2,3, and 5. Minnow survival was affected in samples from stations 1,2,3,5 and 6.

Table 2-10
Blackstone River Sediment Pore Water

48 Hour Toxicity (% Survival) *Ceriodaphnia dubia*			
Round I			Round II Nov
STA	July	Sept	Nov
1	90	—	76
2	100	—	0
3	100	—	0
4	100	—	87
5	—	94	7
6	—	100	90
7	—	100	100
M1	94	94	—
M2	—	—	97
LC	100	100	97
0	100	16	100

Table 2-11
Blackstone River Sediment Pore Water

48 Hour Toxicity (% Survival) *Pimephales promelas*			
Round I			Round II Nov
STA	July	Sept	Nov
1	0	—	3
2	100	—	0
3	97	—	0
4	80	—	100
5	—	93	0
6	—	90	43
7	—	94	93
M1	—	100	—
M2	—	—	100
LC	100	100	100
0	100	100	97

Additional toxicity tests using fathead minnows were conducted in November on the pore water samples from the Fisherville Pond(BSED2) and Sutton St/Rockdale Pond(BSED3) because of the extreme toxicity exhibited during the Round II tests. LC50s were calculated by testing the following percent dilutions of the pore water: 100, 50, 25, 10, 5 and 1. Lab Control water was used as diluent. Table 2.–12 lists the results of this examination. The LC50s calculated for the station 2 and 3 samples were 32.6% and 10.6% pore water sample, respectively.

Table 2-12
Blackstone River Survey 1991

% Survival/ 48 Hours *Pimephales promelas*		
Dilut.	BSED 2	BSED 3
100	0	0
50	0	0
25	100	20
10	90	55
5	100	90
1	—	100
0	100	100
LC50	32.6%	10.6%

Effluent Toxicity Testing

Chronic toxicity tests were conducted on a total of fourteen municipal and industrial discharges to the Blackstone River or its tributaries. Most of these toxicity tests, employing *Ceriodaphnia dubia* and *Pimephales promelas*, were conducted during the of summer of 1991. These tests were performed by a contract laboratory for EPA. The samples were collected by EPA. Test methods followed those in the EPA *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms (1989).* Some earlier data collected in 1990 is included for the Upton wastewater treatment facility.

Seven day effective concentrations (EC50), No Observed Effect Concentrations (NOEC) and Lowest Observed Effect Concentrations (LOEC), and 48 hour lethal concentrations (LC50s) were calculated for each sample tested. Table 2–13 displays all these results. Effluent from the Upper Blackstone Water Pollution Abatement District; City of Woonsocket, Rhode Island; and from Upton, Massachussetts WWTP were tested on more than one occasion.

The LC50 of the Milbury, MA sample was >100% effluent for both the *Ceriodaphnia* and the *Pimephales* test. The LC50 for Douglas, MA WWTP was 62% and 66%, for *Ceriodaphnia* and *Pimephales*, respectively. The LC50 for New England Plating was 7.4% and 76% for *Ceriodaphnia* and *Pimephales*. The LC50s for Woonsocket were 29.5% and 60.4% for *Ceriodaphnia dubia* on the two testing occasions.

Table 2-13
Blackstone River Survey 1991

BLACKSTONE RIVER EFFLUENTS
Toxicity Test Results

Ceriodaphnia/Fathead

FACILITY	LC50 48 HR	EC50	NOEC	LOEC	PERMIT LC50
UBWPAD		>100% *	>100% *	>100% *	no limit
		>100% *	50/>100%	100%>100%	
Milbury	>100%*	82/>100%	50/>100%	100/>100%	100%
Grafton		>100% *	25/>100%	50/>100%	100%
Northbridge		>100% *	6.25/>100%	12.5/>100%	
Uxbridge		>100% *	>100%	>100%	100%
Douglas	62/66%	62/68%	25/50%	50/100%	
Upton +			25% *	50% *	
			100% *	100% *	100%
			12.5/50%	25/100%	
			12.5/100%	25/>100%	
Woonsocket	30/100%	66/63%	50% *	100% *	
RI	66/60.4%	29/>100%	25/>100%	50%/>100%	
Worcester Finishing	70/86%	35/65%	6.25/50%	12.5/100%	
NE Plating	7.4/76%	<6.25/>100%	<6.25/50%	6.25/100%	1/4 monitor
Guilfd Ind		>100% *	50/100%	100/>100%	12%
Okonite		>100% *	>100% *	>100% *	no permit
GTE 001A		18/17%	6.25/12.5%	12.5/25%	
GTE 001B		100/64%	50%	100%	monitor only

+indicates from earlier sampling effort
*indicates same result achieved with Ceriodaphnia and fathead minnow test

The *Pimephales promelas* LC50s for Woonsocket with these same effluent samples were >100% and 60.4% Only five of the fourteen dischargers tested have toxicity limits in their NPDES permits and none of these exceeded the toxicity limits of their permits.

DISSCUSSION OF BLACKSTONE RIVER SEDIMENT CHEMISTRY AND TOXICITY

Sediments were analysed for six metals, and 16 polynuclear aromatic hydrocarbons (PAHs). The values were compared against National Oceanic and Atmospheric Administration values compiled to indicate potential for biological effects from sediment bound contaminants (NOAA 1991). These two values named ER-L and ER-M represent contaminant concentrations in sediment that affect 10 and 50 percent, respectively, of the organisms tested or examined in selected studies. These values are identified as the Effects Range-Low and Effects Range-Median.

Another comparative point used in evaluating contaminant levels in the Blackstone River were the Region V EPA Great Lakes Sediment Classification Scheme (NOAA 1991).

Figures 2–(1-6) illustrate individual metal concentrations in sediment for each station sampled during round I of this study and the percent mortality for each sediment toxicity test. Figure 2–7 illustrates the same but for total metals at each station.

No chemical analyses were conducted on the sediments collected and tested in round II (November 1991) due to lack of funding.

Zinc concentrations exceeded the NOAA ER-M at Fisherville Dam, Sutton Street, Rice City Pond, Blackstone Dam, Manville Dam, and Gilboa Pond. The concentration of zinc was highest at Rice City Pond. According to the Great Lakes Sediment Classification scheme, all stations except Lexington and Grey's Pond would be considered highly polluted.

Nickel exceeded the ER-M only at Rice City Pond. Rice City Pond and Blackstone Dam would be considered highly polluted by the Great Lakes Classification scheme.

Lead concentrations greatly exceed the ER-M at Fisherville Pond and Rice City Pond. Concentrations slightly exceeded the ER-M for lead at Blackstone Dam, Manville Dam, Slater's Mil, and Gilboa Pond. Lead concentrations would classify all these sites as highly polluted according to the Great Lakes Classification scheme.

Copper concentrations exceeded the ER-M at Singing Dam, Fisherville Pond, and Rice City Pond. The copper concentrations at Blackstone Dam were close to the ER-M. All sites would be considered highly polluted except Grey's Pond and Lexington Pond.

Chromium concentrations exceed the ER-M at Fisherville Pond, Rice City Pond, and Gilboa Pond. Nearly all sites fall into the highly polluted range.

Cadmium concentrations at Rice City Pond alone exceeded the ER-M. The concentration at Blackstone Dam was close to the ER-M. This was the only site that would be classified highly polluted under the Great Lakes Sediment Classification scheme for cadmium.

Though metal concentrations at Rice City Pond and Fisherville Dam were the highest of all stations

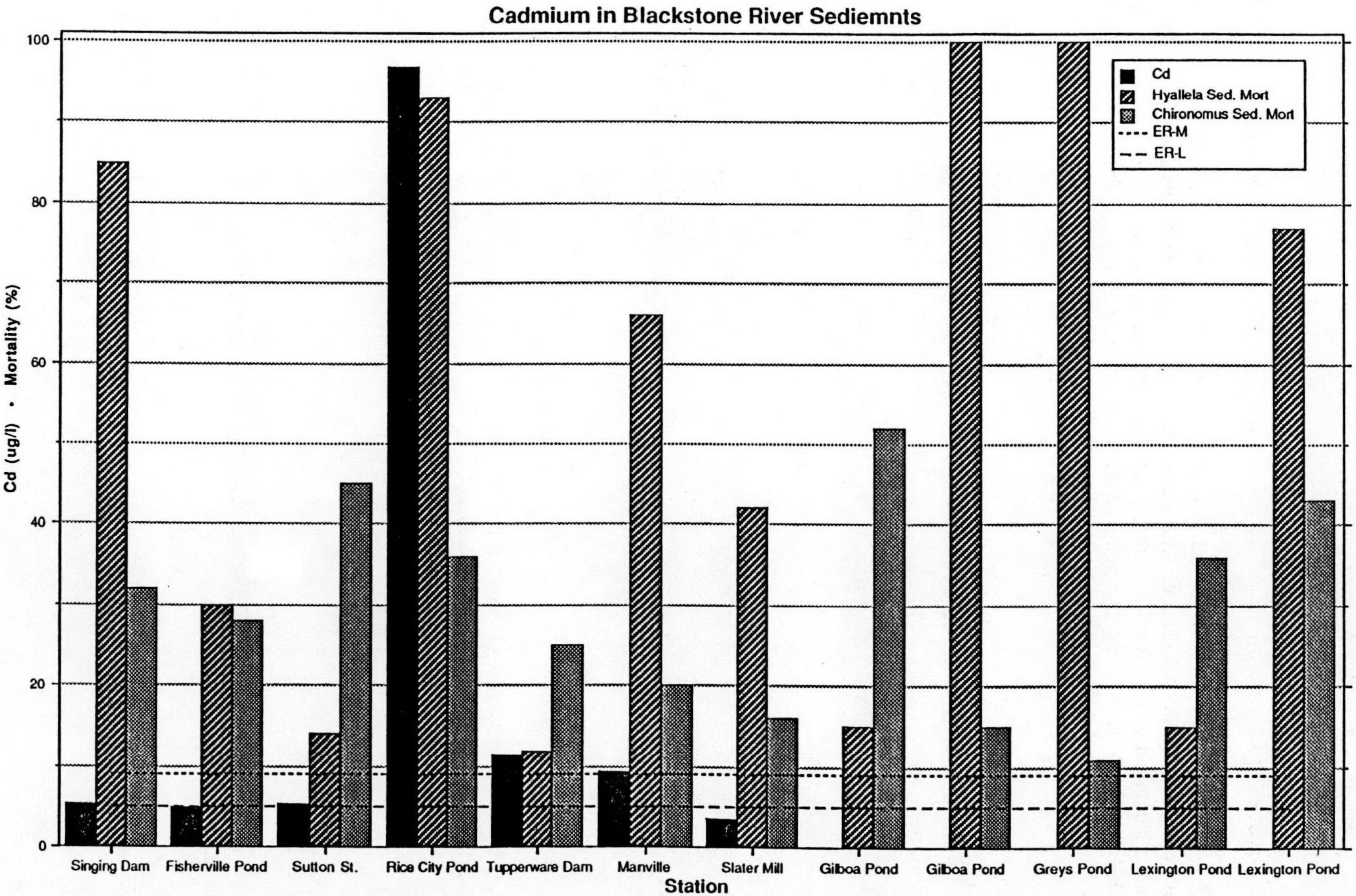


Figure 2–1
Blackstone River Survey 1991

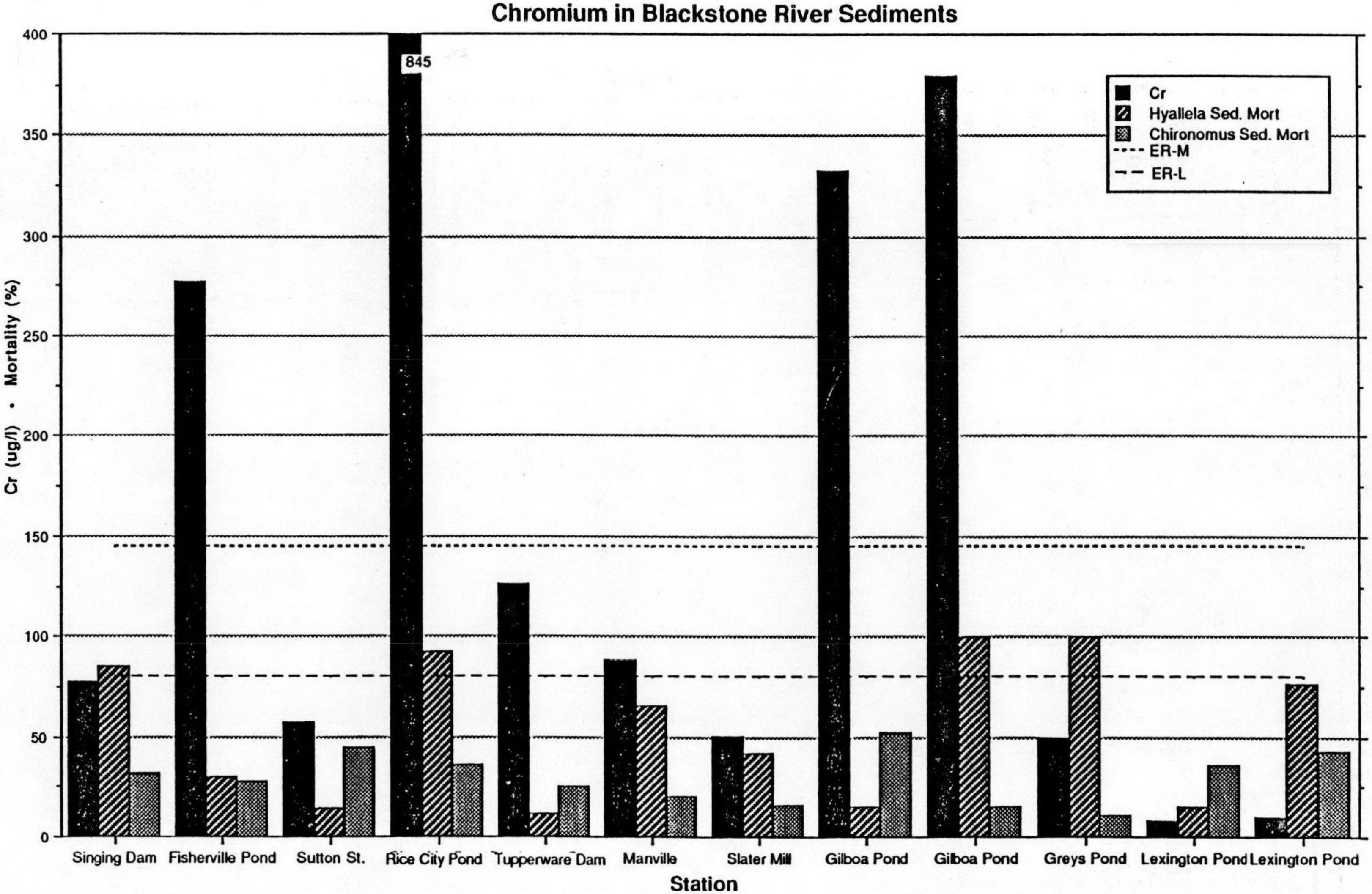


Figure 2–2
Blackstone River Survey 1991

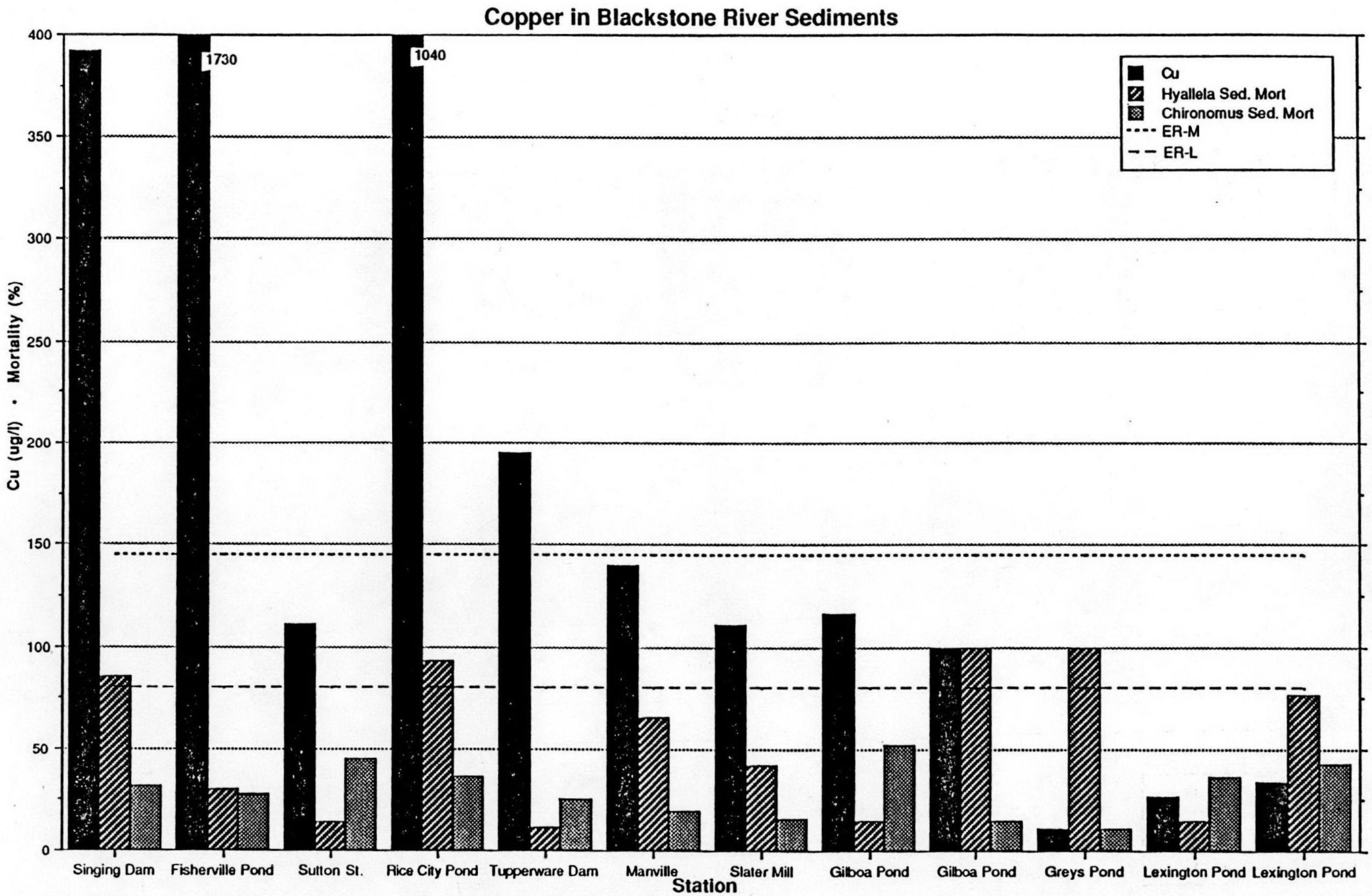


Figure 2–3
Bllackstone River Survey 1991

Nickel in Blackstone River Sediments

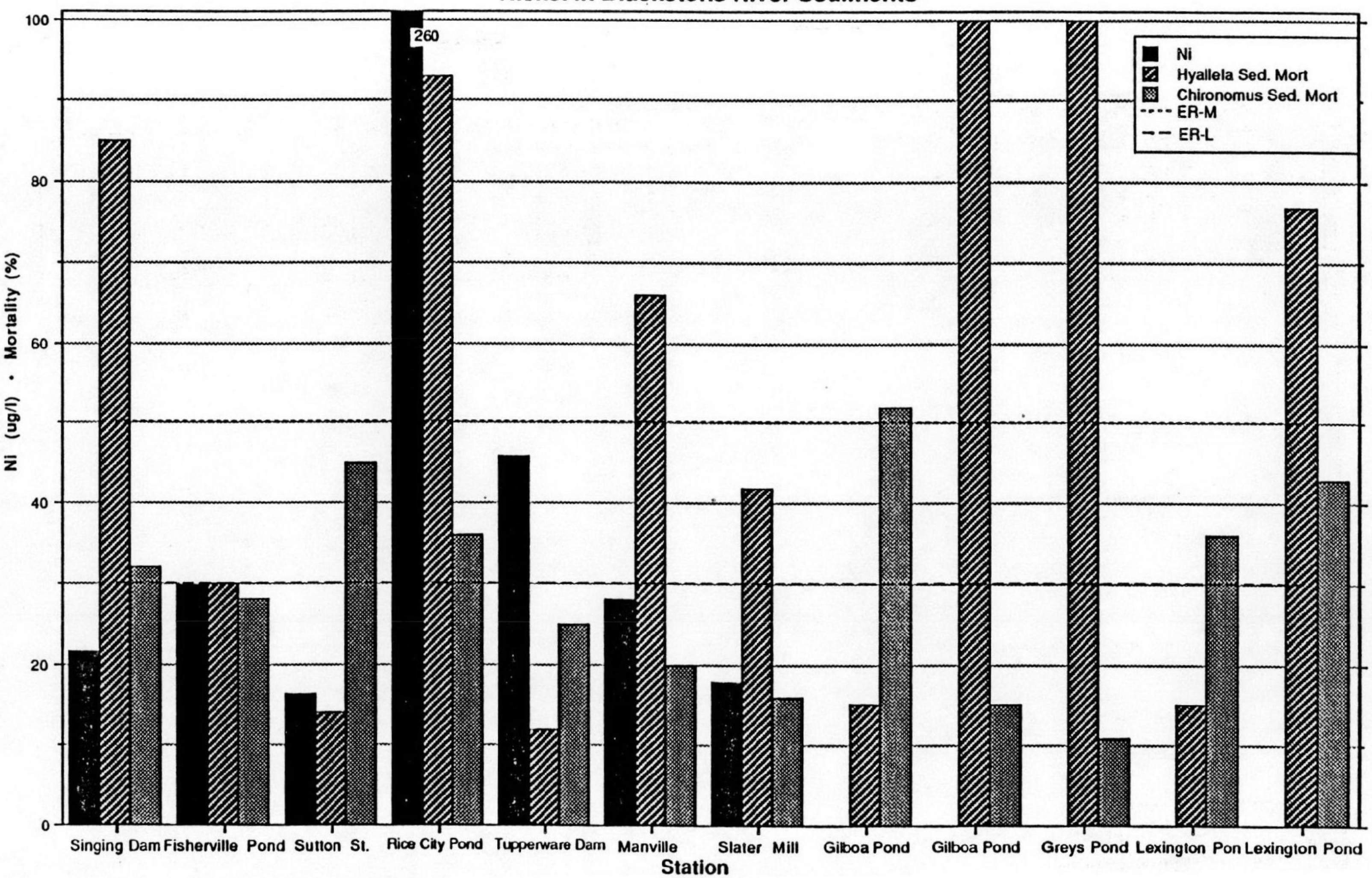


Figure 2-4
Blackstone River Survey 1991

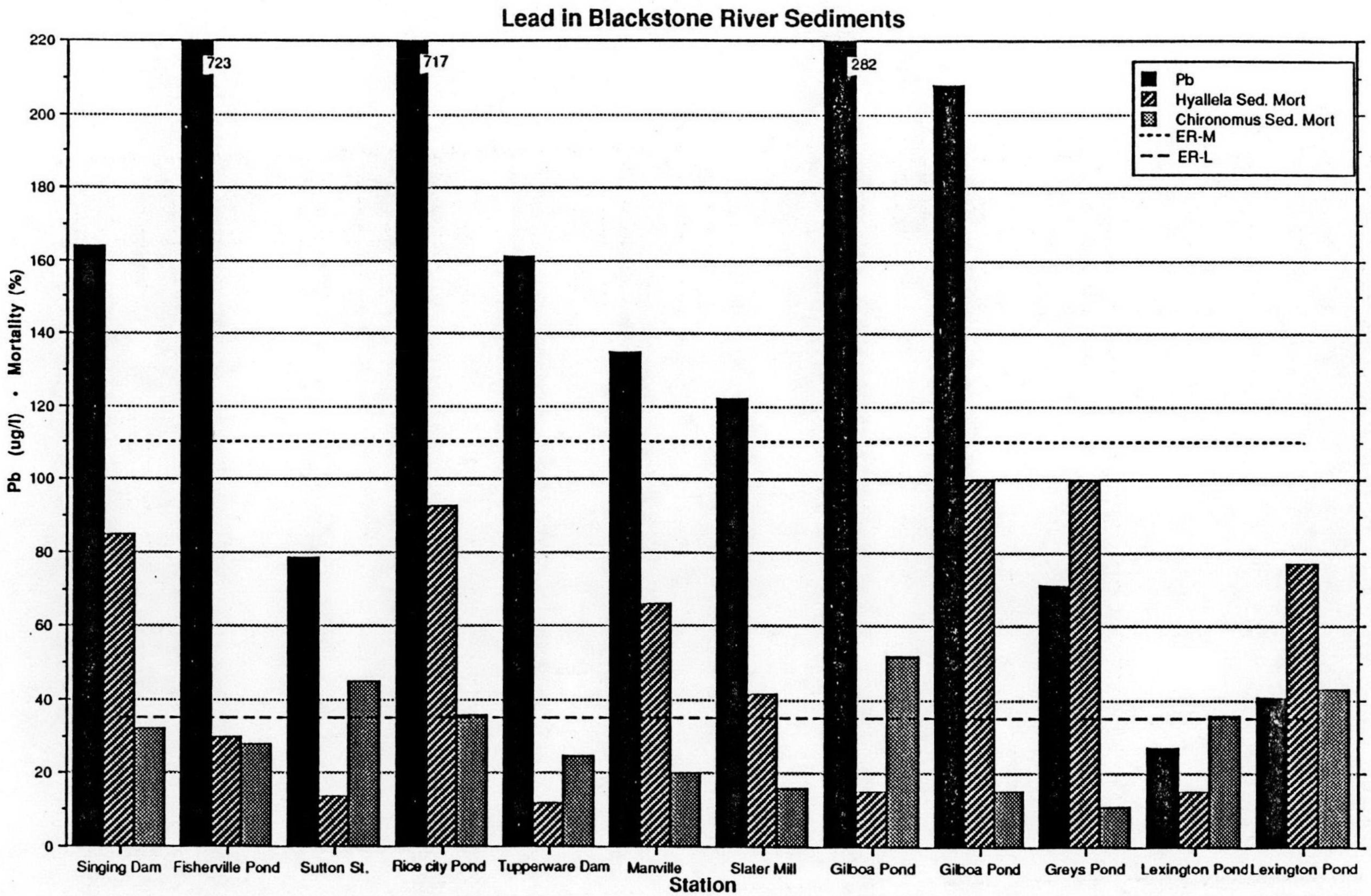


Figure 2–5
Blackstone River Survey 1991

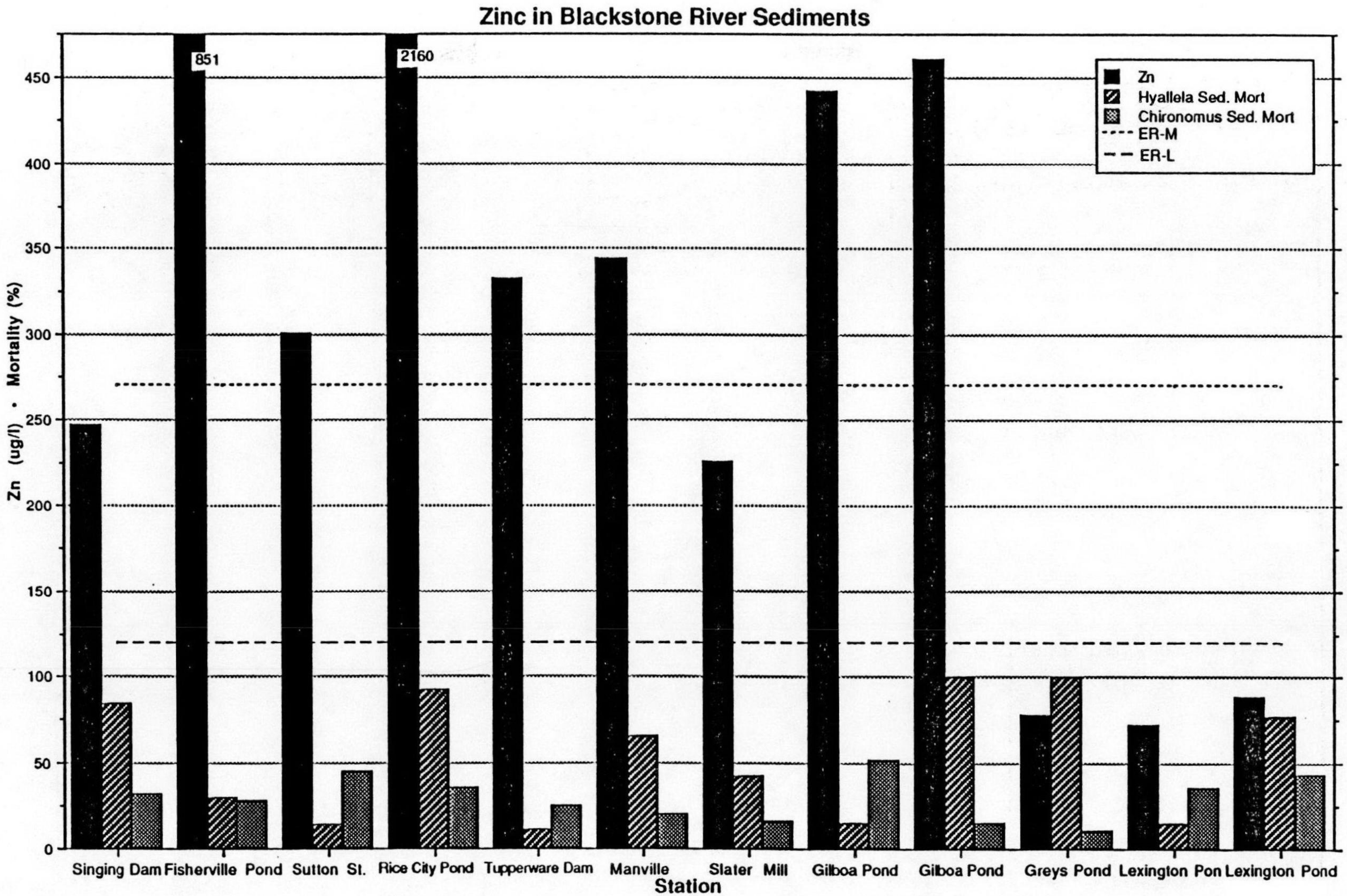


Figure 2–6
Blackstone River Survey 1991

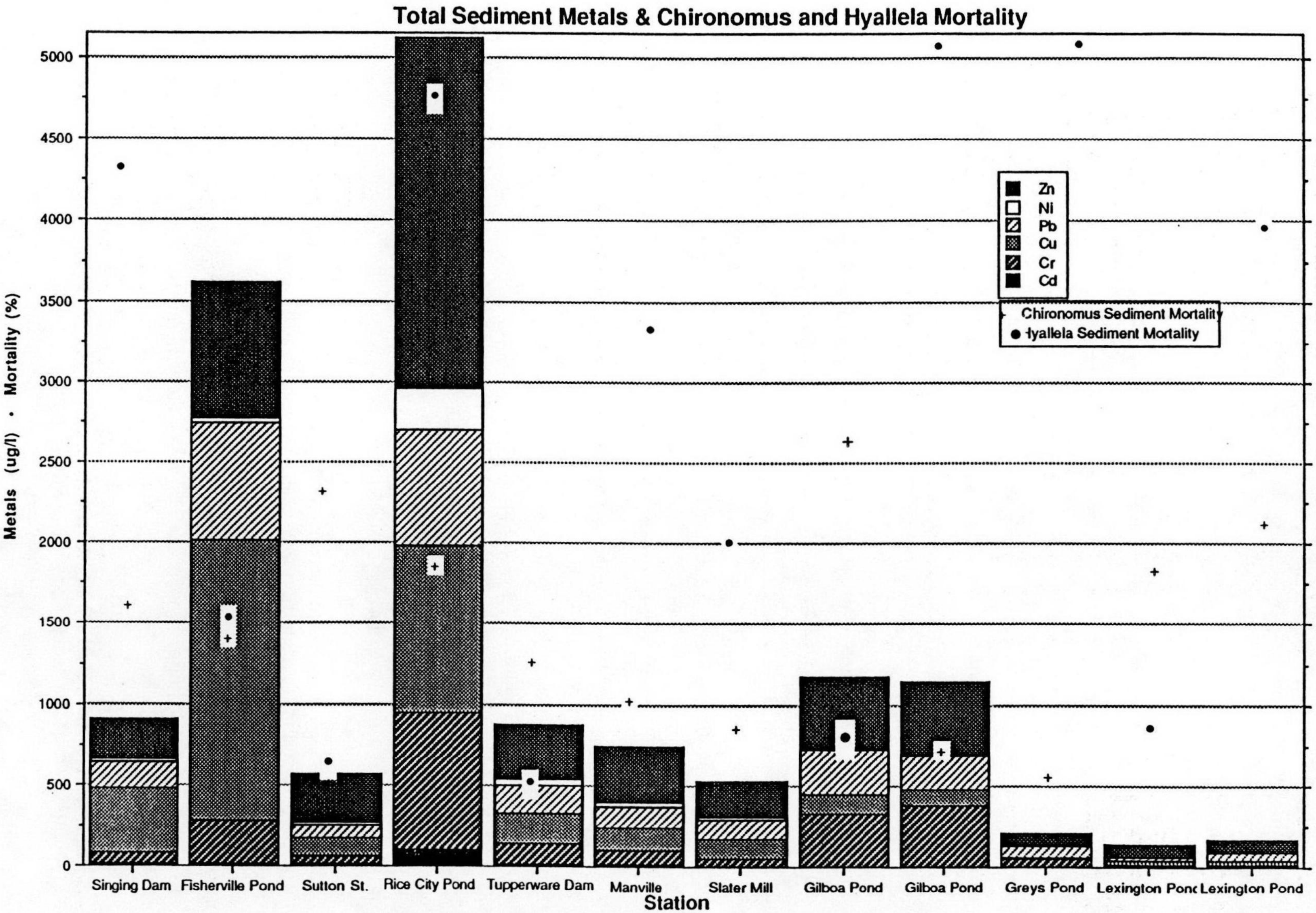


Figure 2–7
Blackstone River Survey 1991

analyzed, toxicity was only evidenced by the Hyallela azteca in the Rice City Pond sample. Chironomus tentans survived fairly well in this sediment (64 and 82% survival in rounds I and II). In Round I, when these metal concentrations were measured, survival of Hyallela and Chironomus were 70 and 72% in the Fisherville Dam sediment sample. Higher mortality of one or both species occurred in the samples from Singing Dam (BSED 1), Manville Dam (BSED5), Slater's Mill (BSED7), and Gilboa and Grey's Pond, the background samples

EPA Great Lakes Sediment Classification			
	nonpolluted	mod polluted	highly polluted
	(ppm dry weight)		
Cd			>75
Cr	<25 ppm dry wt	25-75	>75
Cu	<25	25-50	>50
Cu	<40	40-60	>60
Ni	<20	20-50	>50
Zn	<90	90-200	>200
Pb	<40	40-60	>60
Beyer, W.N. 1990. Evaluating Soil Contamination. U.S.Fish and Wildlife Service. Biological Report 90(2).			

Figure 2–8 illustrates the total concentration of Polynuclear Aromatic Hydrocarbons (PAHs) at each station as well as the ER-L and ER-M for total PAHs. Sediment samples from all stations contained PAHs higher than the ER-L but lower than the ER-M. The highest concentration of PAHs was in the first background station on the Mumford River at Gilboa Pond. This is followed by Singing Dam (BSED1), Fisherville Pond (BSED2), and Rice City Pond (BSED4). There is no strong correlation between PAH concentrations and the mortality evidenced in the whole sediment toxicity tests.

Dissussion of Pore Water Chemistry and Toxicity

Figures 2–(9-15) illustrate individual metal concentrations found in the pore water samples extracted from the sediment at each station. Percent mortality from the fathead minnow and Ceriodaphnia dubia acute toxicity tests are also illustrated.

The pore water from the Singing Dam sample exceeded acute EPA Ambient Water Quality Criteria (AWQC, EPA 1986) for chromium, copper, and cadmium. The criteria levels were adjusted for hardness. The fathead minnow acute toxicity test experienced 10% mortality in this sample.

Pore water from Fisherville Dam exceeded acute AWQC for lead, chromium, copper, and cadmium. No significant toxicity to either test specie occurred in this sample.

The pore water from Sutton Street exceeded only the acute AWQC for copper and no toxicity occurred in the same round of toxicity tests.

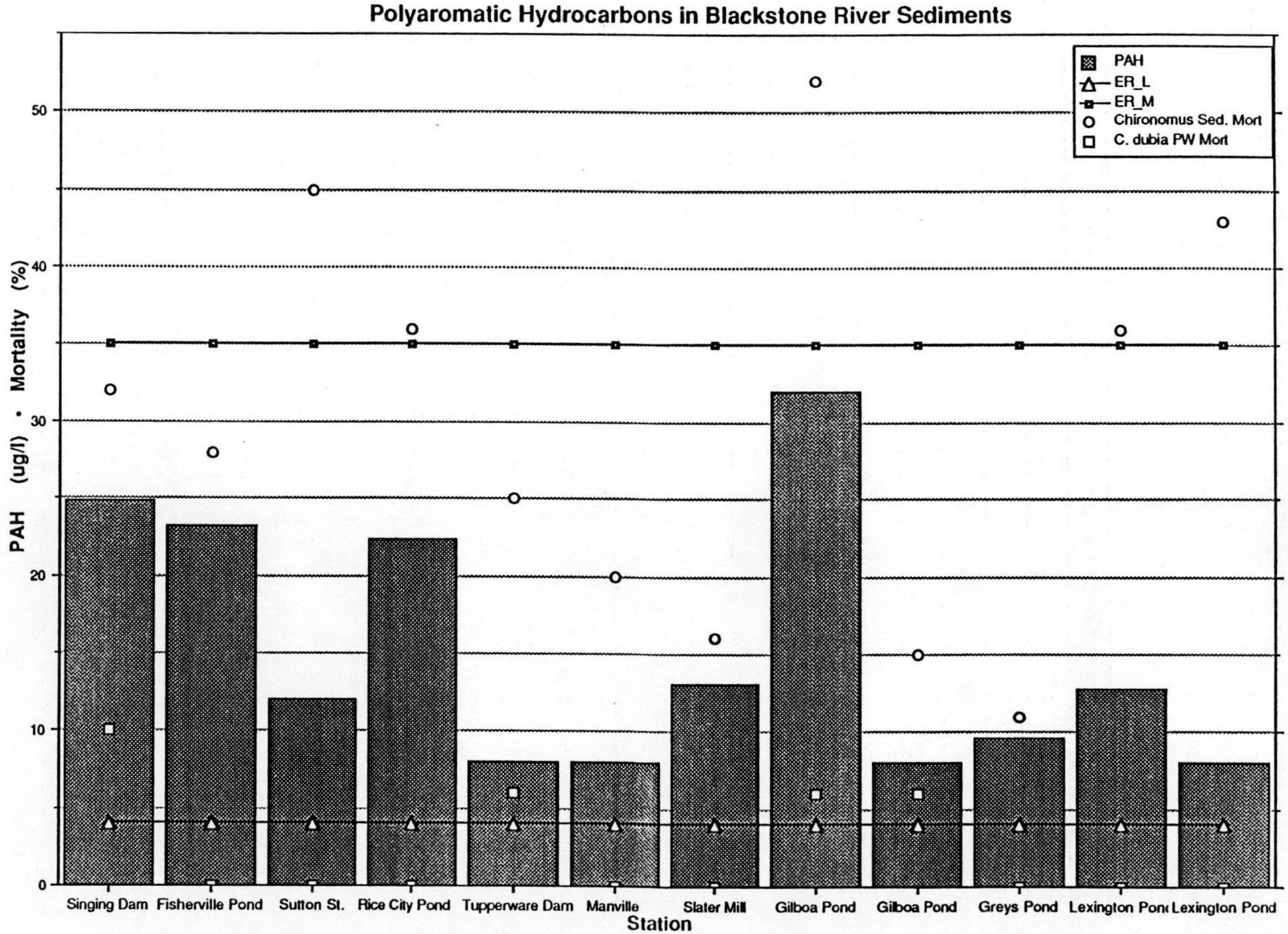


Figure 2–8
Blackstone River Survey 1991

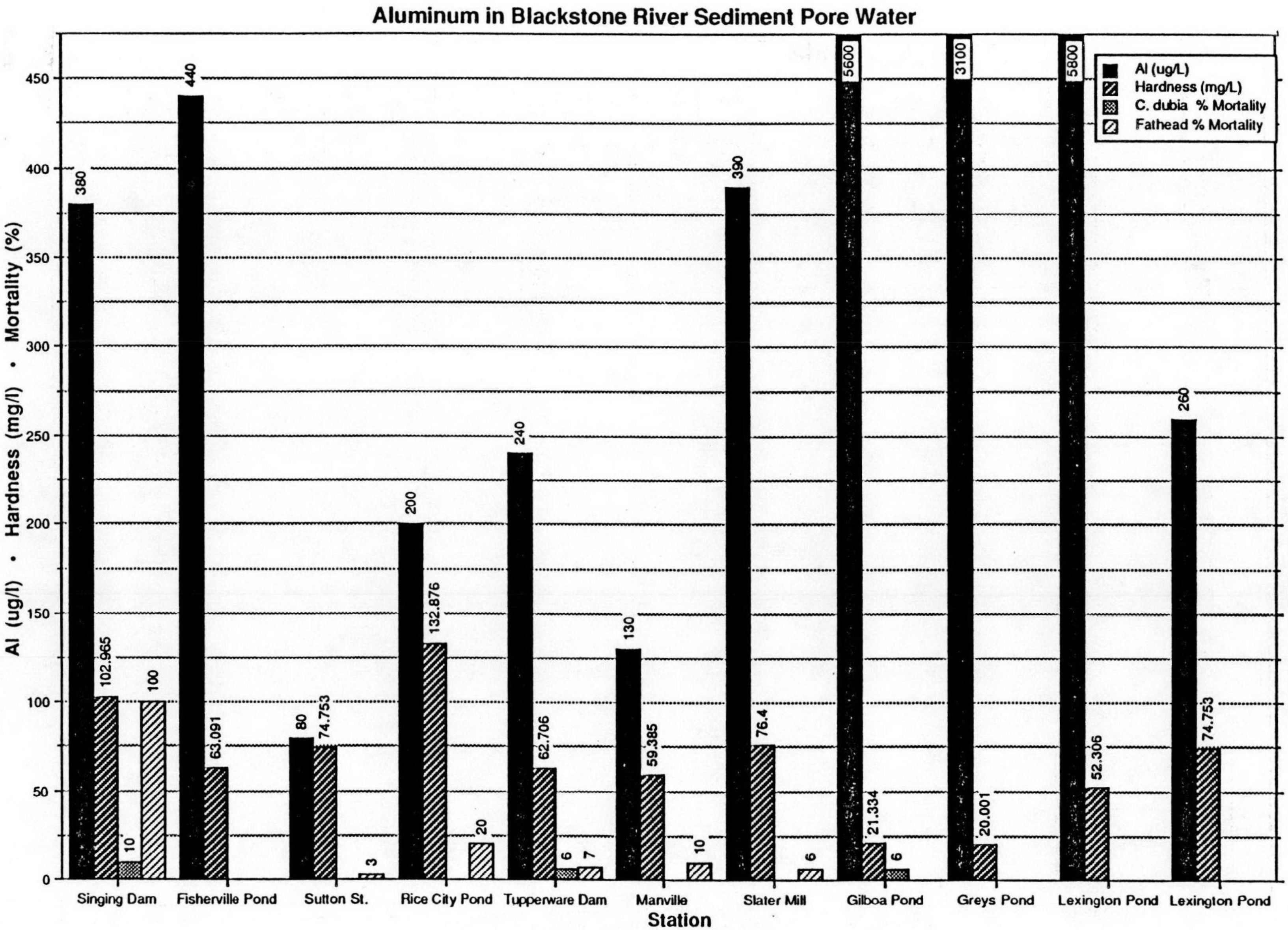
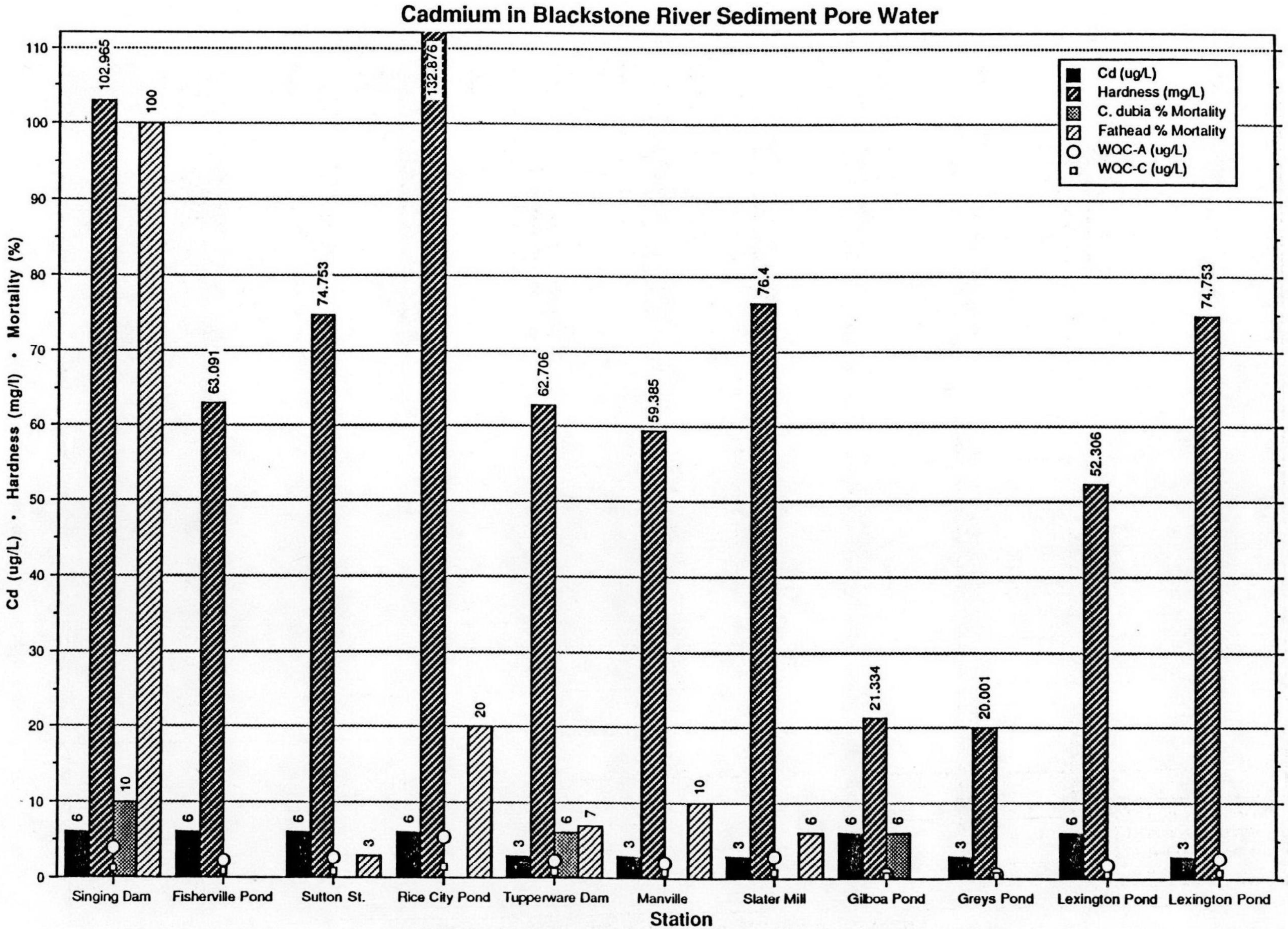


Figure 2-9
Blackstone River Survey 1991



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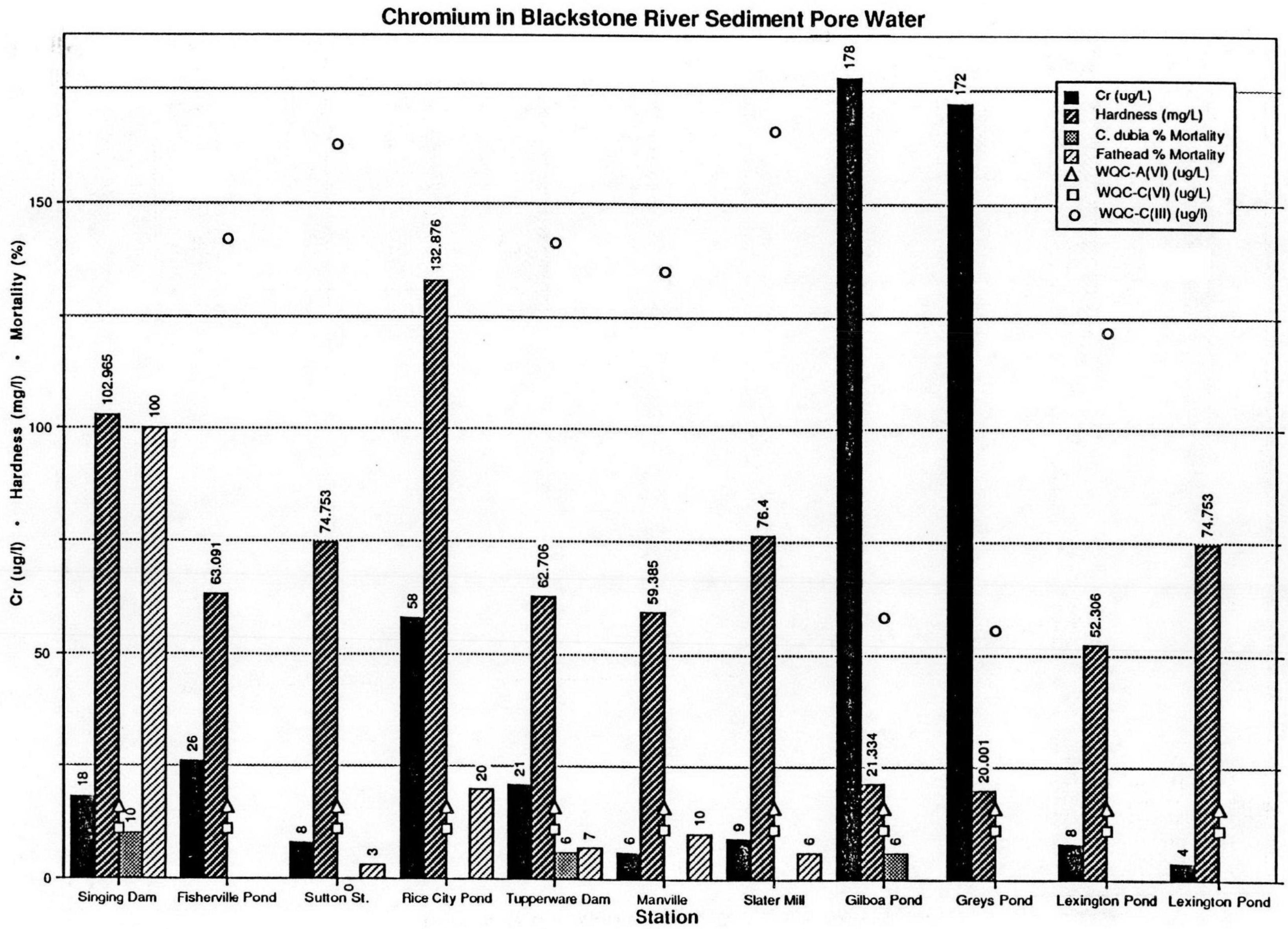
Blackstone River Survey 1991



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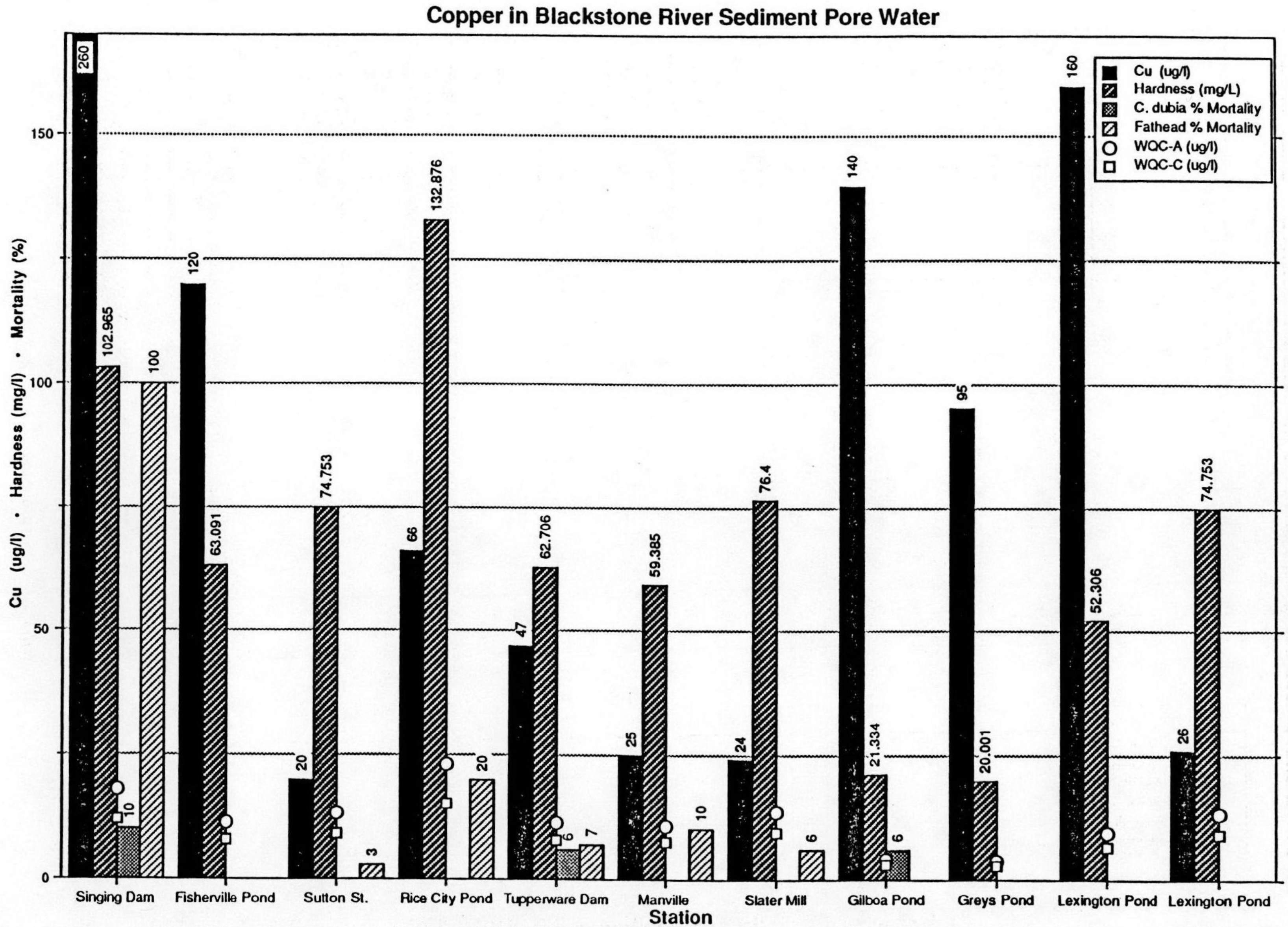
Blackstone River Survey 1991



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Blackstone River Survey 1991

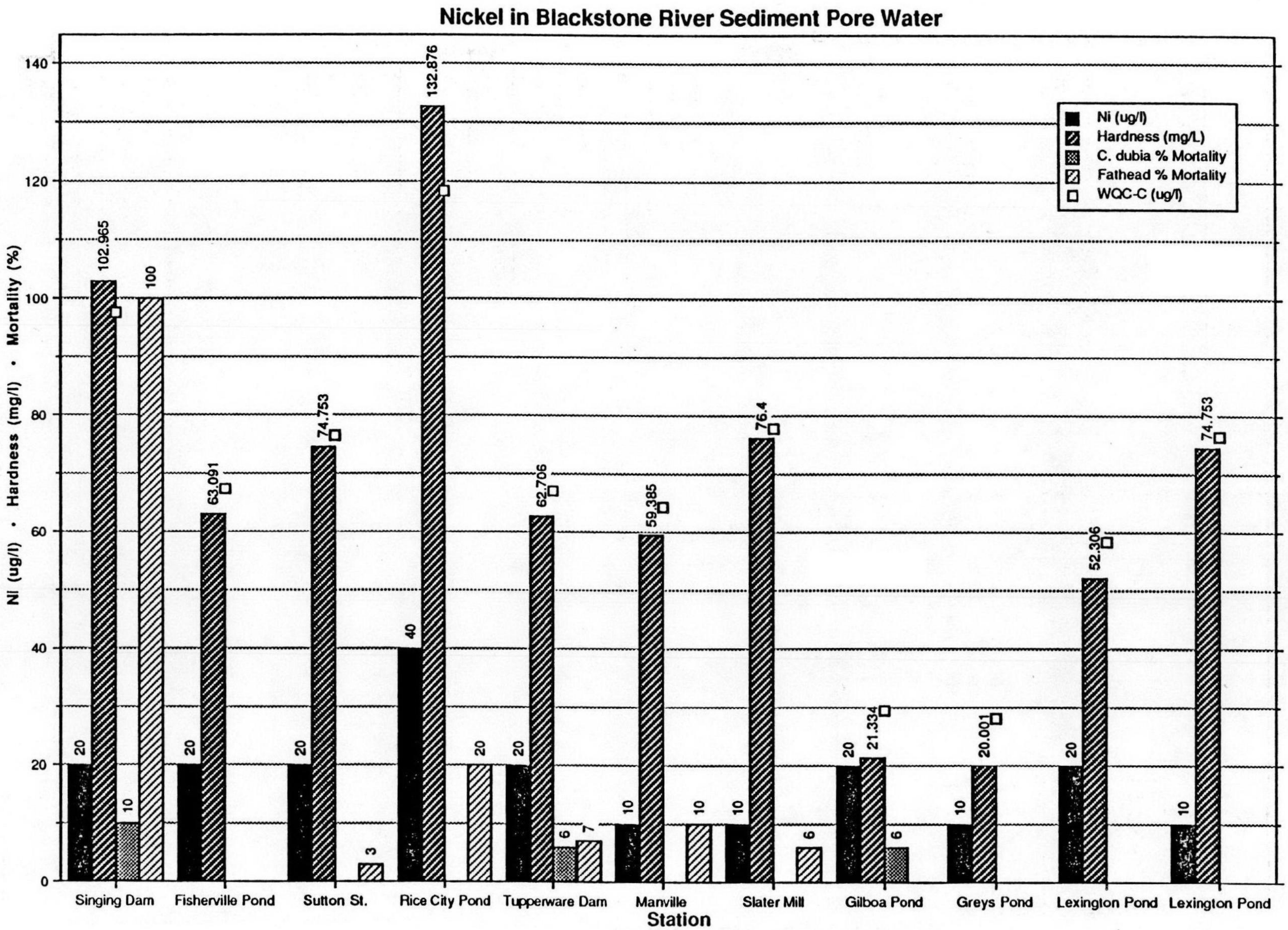

Figure 2-13
Blackstone River Survey 1991

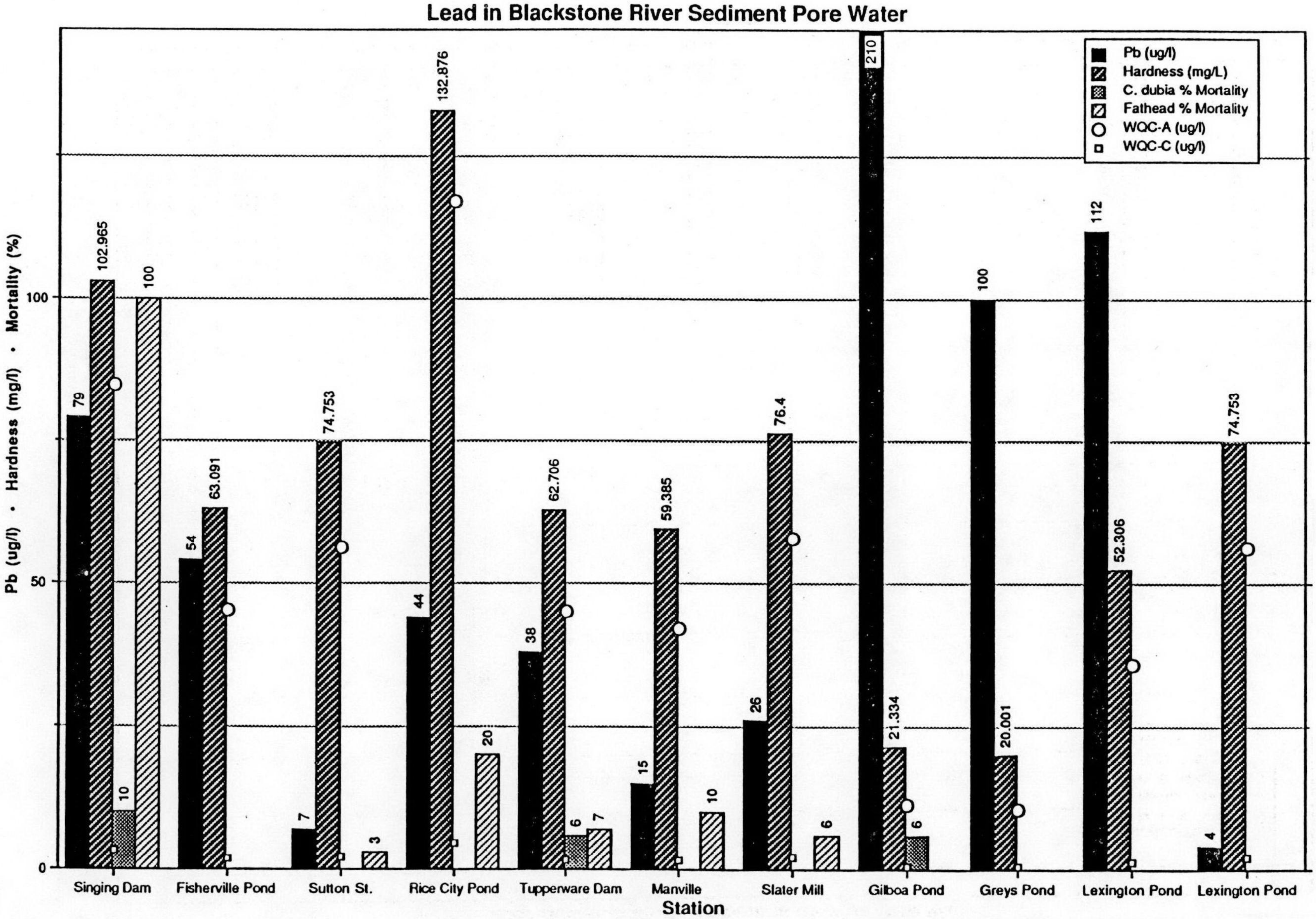

Figure 2–14
Blackstone River Survey 1991

Zinc in Blackstone River Sediment Pore Water

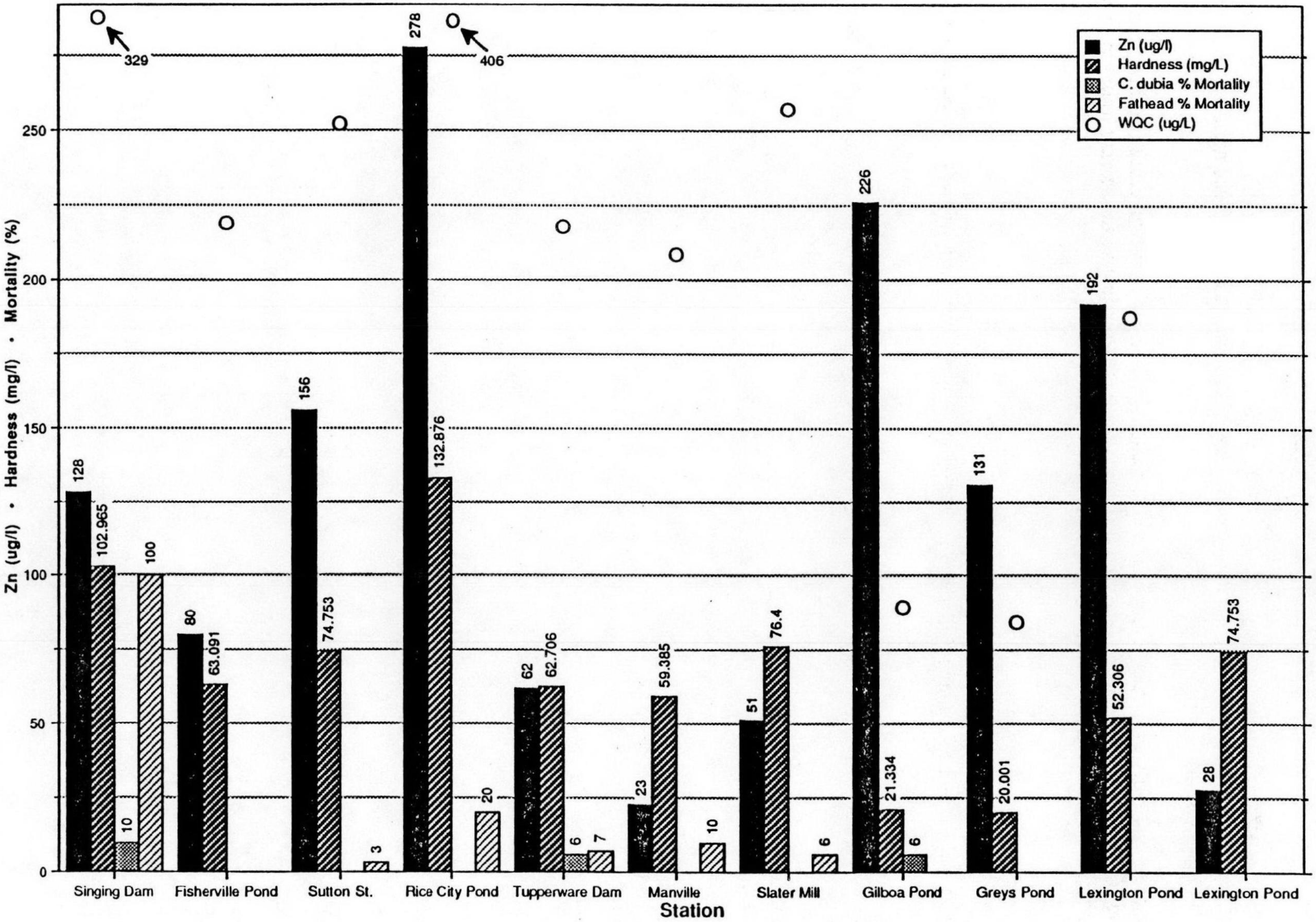

Figure 2–15
Blackstone River Survey 1991

The pore water sample from Rice City Pond exceeded acute AWQC for chromium, copper and cadmium. Only minor mortality occurred in the fathead minnow test (20%).

The pore water from the background stations of Gilboa and Grey's Pond and from Blackstone Dam, Manville Dam, and Slater's Mill exceeded acute AWQC for chromium and cadmium but no significant mortality occurred.

No chemical analysis of the pore water accompanied the second round of acute toxicity tests of pore water (due to lack of funding). Very significant mortality occurred during the second round in pore water samples from Fisherville Pond and Sutton Street.

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CHAPTER 3

1991 BLACKSTONE RIVER STUDY

BENTHIC MACROINVERTEBRATE COMMUNITY ANALYSES AT SELECT STATIONS

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Chapter 3
List of Tables and Figures

1991 BLACKSTONE RIVER SURVEY
Benthic Macroinvertebrate Community Analyses at Select Stations

Design Overview

Benthic macroinvertebrate communities were sampled at eight stations on the mainstem Blackstone River in Massachusetts and Rhode Island and at one station in each of two reference streams that are tributaries to the Blackstone River. Personnel from the Biology Sections of the U.S. Environmental Protection Agency (EPA), Environmental Services Division, Lexington, Massachusetts, and the Massachusetts Division of Water Pollution Control (DWPC) Office in North Grafton, Massachusetts collaborated on the field work for this study. Two techniques were used to collect benthic invertebrate samples: artificial substrate deployment and kick sampling. A number of metrics commonly used to evaluate various components of invertebrate community structure were employed to assess the samples. The quality of community assemblages sampled at Blackstone mainstem stations was evaluated through a comparison of metric values from one station to the next. In addition, metric values for the mainstem station samples were also compared to those for the samples collected from the two reference streams.

Methods and Station Locations

Rock Baskets: Rock baskets were deployed in riffle habitats in the Blackstone River and two of its tributaries, the Mumford River and the Mill River, in late July, 1991. They were recovered in late September of the same year. Station locations and specific dates of substrate deployments are listed in Tables 3–1 and 3–2. EPA station codes, river miles and DWPC station codes are assigned to each station. The latter are included to allow comparisons with past DWPC surveys (Johnson, et al., 1992; and Tennant, et al., 1974). Baskets were placed in stream sections where the water velocity at 5 cm from the bottom was 0.3 + or - 0.1 m/s. A low velocity flow meter (Swoffer model 2100) was used to measure current speed. Three rock baskets were deployed at each station and were anchored to the streambed with iron reinforcing bar and wire.

To remove rock baskets from the substrates, the investigators first placed a large plastic container downstream of each rock basket while it was being dislodged from the streambed in order to capture any organisms that might escape from the basket. Once the wire holding the basket in place was removed, the basket was lifted out of the stream in the plastic container and brought to the stream bank. Baskets were opened and each rock was gently rubbed (by hand) clean of organisms. Cleaned rocks were discarded and the remaining sample was rinsed in a Standard #30 mesh sieve-bucket. Samples were subsequently removed from the sieve and transferred to labelled glass jars filled with 95% ethanol.

Kick Nets: Kick net sampling was conducted on September 23 and 24, 1991, immediately prior to the removal of rock baskets from the substrates. Kick net sampling was confined to areas immediately downstream of the rock baskets. At each station, investigators disturbed one square meter of bottom substrates by foot while holding a d-frame net (30 mesh, Standard Sieve Series) downstream of the area being worked to capture invertebrates released from the stream substrates. Nets were picked clean of invertebrates and each kick net sample was transferred to a labelled jar filled with 95% ethanol.

Sample Processing: Samples generated from the rock basket and kick sampling were sent to Lotic, Inc., of Unity, Maine, where they were analyzed under an EPA contract. Personnel at Lotic spread the contents of each sample on a gridded pan and used a random number table to select a 100-organism subsample from each of the basket samples and three, 100-organism subsamples from each kick-net sample. These 100-organism subsamples (called samples in the remainder of the text) were identified to genus, and tabulated. Taxonomic lists generated for each station were sent to the DWPC office for analysis.

Data Analysis: A modification of the EPA Rapid Bioassessment Protocols (RBP) (Plafkin, et al., 1989) was used to evaluate the taxa lists from each site. RBP protocols call for quantitative comparisons between metric values derived from samples collected at a pristine (unimpacted by anthropogenic sources) reference station and those derived from samples collected at a test station. These comparisons yield an interpretation of pollution "impact" at the test station. It is important to select sites that have similar habitats in order to ensure that differences between stations are due to pollution rather than to habitat differences. Although the RBP document provides a method of assessing the habitat similarities between sites, the methods do not account for differences in stream order, or more exactly, drainage area. As the composition of invertebrate assemblages has been shown to change with increasing stream order (Allan, 1975; Cummins, 1979; and Minshall, et al., 1992) it may be inappropriate to make direct comparisons between metric values derived from samples collected at sites that differ greatly in drainage area.

There are no pristine streams in Central Massachusetts that drain as large an area as the Blackstone River does at most of the stations where studies were conducted. As a result, the drainage area size at each reference station was much smaller than that of the test stations on the mainstem Blackstone. The RBP protocols were not used as they are outlined since it was not possible to quantify any differences between reference and test stations that might be due to drainage area size. In consequence, invertebrate data are assessed in this report through a comparison of metrics and community assemblages from one station to the next and to reference stations to evaluate trends.

Six of the metrics recommended in the RBP document were used in evaluating invertebrate data collected in this study. These are briefly described below. Metric values were computed for each of the six 100-organism samples collected at each station.

Richness is the number of clearly different taxa from each sample. Since one most often finds a wider variety of organisms at clean sites than at polluted sites, this index is usually inversely correlated with pollution.

Biotic index values were calculated using tolerance values presented in Bode, et al. (1991). Each taxon is ascribed a value from zero to ten based on its history of occurrence in association with certain types of pollution. The index is computed as the number of organisms in the taxon multiplied by the pollution tolerance value for that taxon; the sum of these values over all taxa is divided by the number of individuals in the sample and represents the mean tolerance value for an organism in the sample. The Biotic index is most often positively correlated with organic pollution.

The Scraper/Collector-Filterer index is a ratio of the number of individuals in the scraper functional feeding group divided by the number of individuals classified as collector-filterers. The feeding group assignments listed in Bode, et al. (1991) were used for this index. The relative abundance of collector-filterers is often high in streams that are also high in concentrations of suspended organic materials. Scrapers are more often associated with waters that have a specific type of periphytic growth most often found in unimpacted streams. This index is usually inversely correlated with organic pollution.

The EPT/Chironomid Abundance index is a ratio of the number of individuals in the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders (mayfly, stonefly and caddisfly orders, respectively) divided by the number of individuals in the Chironomidae (the midges, a family of flies). Members of the three EPT orders are often associated with waters that are not prone to low levels of dissolved oxygen and other effects of organic pollution. One family of trichopterans, however, the Hydropsychidae, is often found in high numbers where the concentration of suspended organic matter is high. In contrast to most EPT taxa, certain species of chironomids are found in high numbers where oxygen concentrations dip to very low levels. Other species of chironomids have been found in high numbers in waters heavily contaminated with certain metals. This index is most often inversely correlated with pollution.

The Percent Contribution of Dominant Taxa index is most often positively correlated with water pollution. In general, organically enriched sites, or sites prone to other forms of pollution, are often dominated by one or two taxa that are tolerant of the pollutant(s). In contrast, streams in pristine areas often are inhabited by a wider variety of taxa with a more even distribution of individuals among different taxonomic groups.

The last index, EPT, is the number of distinctively different taxonomic groups from the EPT orders found in each sample. As mentioned, a wider variety of EPT taxa has been found in pristine waters than in areas subjected to anthropogenic disturbances.

Results and Discussion

The macroinvertebrate taxa lists (see Appendix E) and the metrics derived from them (Figures 3–(1-6)) all suggest the same general trend: the invertebrate community sampled at BIO1, the most upstream station on the Blackstone (located about half a mile downstream of the Upper Blackstone wastewater treatment plant and downstream of the city of Worcester), is fairly degraded. The quality of the invertebrate assemblage improves dramatically, however, between station BIO1 and BIO2 (located approximately four miles downstream in Sutton). Between stations BIO2 and BIO4 (located in Uxbridge) the community assemblages do not change as substantially, but still exhibit minor improvements. Between stations BIO4 and BIO6 (in Millville), invertebrate community assemblages exhibit extensive improvements compared to upstream stations. Between BIO6 and BIO8 (located in Blackstone, MA, near the Massachusetts-Rhode Island border) the improvements are even more substantial. Across the state line and downstream of the city of Woonsocket, Rhode Island, the quality of the community assemblage degenerates. Metric values from samples collected from BIO9 (located in Lincoln, RI) all indicate a negative change in the quality of the benthic community when compared to those for BIO8; these regress even further at the second Rhode Island station, BIO10 (in Pawtucket, RI).

The taxonomic composition of the sample from station BIO1 was heavily dominated by chironomids (see Figure 3–7): over 89% of the sample was made up of individuals from this one family of dipterans. Tubificid worms, also found at this site, were not found at any of the other stations in substantial numbers. These organisms are most often found in areas that are prone to heavy organic loading and oxygen stress. Although they were found in all kick samples collected at this station, none were found in the basket samples. One explanation for this is that the kick sampling exposes subsurface sediments. If these are poorly oxygenated, the likelihood of encountering tubificids or other organisms adapted to living in low oxygen environments is increased by using the kick sampling method when compared with the rock basket method. Rock baskets deployed in these studies were placed on top of the stream substrates and the flow rate of oxygenated water through these baskets was probably higher than through the natural substrates.

The Richness at station BIO1 is higher than that at some of the other mainstem stations. High Richness values are often a sign of a healthy community; however, the Biotic index for this station is also much higher than that for all other mainstem stations. The latter indicates that, on the average, the organisms in the BIO1 samples were much more tolerant of organic pollution than those from other stations. This is also reflected in the EPT index, the EPT/Chironomid index and the Scraper/Collector-Filterer index, all of which indicate a degraded condition at BIO1 compared to other stations farther downstream and compared to the two reference stations.

At station BIO2 and throughout the remainder of the mainstem stations, the invertebrate assemblages undergo a dramatic change from chironomid-dominated to hydropsychid caddisfly-dominated. The latter are commonly referred to as "net-spinning" caddisflies as they construct sizeable (up to approximately 3 cm long) nets from which they filter and collect organic food matter from the water column in the form of algae and fine suspended particulates.

It is likely that the large difference in the community assemblages between BIO1 and BIO2 is related to the toxic effects of chlorine from the Upper Blackstone wastewater treatment plant or other more upstream sources such as the Worcester CSO facility. Since there was no invertebrate station located upstream of BIO1, it is impossible to isolate the exact source of the impacts found at this station. In at least two other macroinvertebrate studies conducted by the Biology Section of DWPC (Johnson, et al., 1986; and Nuzzo and Kennedy, 1992), a similar change in community assemblages was documented downstream of chlorinated discharges. In each of these, hydropsychids were either eliminated or the percent composition of this group was drastically reduced. Midges and worms predominated at the stations closest to the chlorinated discharges in both of the past studies while hydropsychids and other groups began to appear farther downstream. Dissolved oxygen levels did not appear to be a factor in these studies, and neither did toxicity due to ammonia. Studies conducted by the DWPC (Nuzzo and Kennedy, 1992), and by DWPC in coordination with EPA (Szal, et al., 1991) have documented acute toxicity (mortality) of chlorine to fathead minnows *(Pimephales promelas)* in 24-hr *in situ* studies. In one of these studies, a zone of 100% mortality to deployed minnows extended as far as 1.5 miles downstream of the chlorinated discharge. As a result, it is not unreasonable to expect to see toxicity to the macroinvertebrate community at station BIO1 due to chlorine releases from nearby sources.

Richness at BIO2 is approximately the same as at BIO1. Tubificids have essentially disappeared from the sample. Chironomids, although much reduced in relative abundance, are still a major component of the community at this station. Two additional groups, the amphipods and isopods (both crustaceans) are important in the assemblage at this station, but not at any other. Both are considered collectors or gatherers of organic matter and the crustacean genera found at BIO2 are fairly tolerant of organic pollution and low oxygen conditions. The Biotic index exhibits its greatest improvement between stations BIO1 and BIO2 and remains approximately the same until station BIO8 where there is further improvement.

EPT organisms appear in substantial numbers at BIO2, but the EPT taxa at this site (genera Hydropsyche, Cheumatopsyche and Baetis) are only intermediate in their tolerance of organic pollution. Much more sensitive EPT taxa begin to appear in samples collected farther downstream. As EPT taxa are present at this station, this has a positive effect on both the EPT/Chironomid Abundance metric as well as the EPT index when compared with respective metric values from station BIO1.

The relative proportion of hydropsychids found in the benthic samples increases between stations BIO2 and BIO3 (located in Northbridge) and increases even further at station BIO4 (downstream of Rice City Pond in Uxbridge). Although we did not generate any quantitative information on invertebrate densities in this study, the high abundance of hydropsychids at stations BIO3 and BIO4 was noteworthy. They completely covered all exposed surfaces of the benthic substrates in riffle areas at these stations. The high numbers of hydropsychids were probably related at least in part to the number of impoundments and dams located along the Blackstone mainstem. Nutrients from upstream sites favor the production of phytoplankton in impounded areas; this in combination with the breakup of particulate organic matter as it passes over dams may have increased the concentration of organic matter in the size range most utilized by hydropsychids. Algae produced in impoundments may have represented an important component of the suspended particulates used as food by hydropsychids at BIO3 and BIO4. The decrease in relative abundance of hydropsychids at stations farther downstream may be a response to decreasing concentrations of organic matter or due to a change in form of the suspended organic particles (i.e., the latter may no longer be in the size range most utilized by hydropsychids).

Richness values decreased from station BIO2 to BIO3 and remained low at BIO4, probably as a result of the high densities of hydropsychids. EPT essentially remains the same through stations BIO2, BIO3 and BIO4, although mayfly densities (approximately 1.3% of the individuals collected) are higher at BIO4 than they are at BIO3 and BIO2 (only one ephemeropteran individual was found among the 600 individuals collected at each of the latter stations). The EPT/Chironomid Abundance index also improves from station BIO2 through station BIO4. This is a result of the increasing relative abundance of hydropsychid caddisflies.

Mayflies first become a significant component of the invertebrate assemblage at station BIO6 (located in Millville). Their prevalence increases slightly at the next station, BIO8, where they account for over 20% of the organisms collected. The change in relative abundance of mayflies from stations BIO2, BIO3 and BIO4 compared to stations BIO6 and BIO8 may be related, in part, to the organic component of the water column which no longer so strongly favors the Hydropsychidae. There are fewer impoundments and dams between BIO4 and BIO8 than there are between BIO1 and BIO4. A decrease in the turbidity of the water, due to both settling of particulates as well as to the filtering activity of hydropsychids at upstream sites, would also favor the growth of periphyton on substrates. This, in turn, would encourage the proliferation of the scraper functional feeding groups. The latter show a marked jump in relative abundance at stations BIO6 and BIO8. Data on periphyton productivity in riffle areas would be needed to evaluate this relationship.

Four of the six indices indicate improvements in the quality of the invertebrate assemblage from BIO6 to BIO8. Three of these show substantive improvements. Whereas richness increases only slightly from station BIO3 to BIO4, and then again slightly between stations BIO4 and BIO6, it increases by an additional 50% between BIO6 and BIO8. One component of this change in richness is the number of EPT taxa which increases approximately 60% between BIO4 and BIO6 and an additional 70% between BIO6 and BIO8. The overall evenness of the distribution of individuals among the different taxonomic groups increases from BIO6 to BIO8 (see Appendix E) and this is reflected in a decrease in the Percent Contribution of Dominant Taxa metric which averages below 40% at station BIO8. Values for this metric as well as for the EPT and Scrapers/Collector-Filterer metrics are more similar to those from the two reference streams than are values for these metrics from other stations. The Biotic index value for station BIO8, while still higher than the values for the two reference streams, averages lower than that for all the other mainstem stations. Without data from pristine streams in this ecoregion that are similar in drainage area to mainstem stations it is difficult to assess the degree of impairment, if any, still remaining at station BIO8.

The quality of the invertebrate community declines distinctly between stations BIO8 and the first Rhode Island station, BIO9. All six metrics undergo a negative change between the two stations. This trend continues between stations BIO9 and BIO10 (the most downstream station located in Pawtucket, RI) where there is further degradation of all six metrics. Major changes between stations BIO8 and the two Rhode Island stations include losses in sensitive EPT taxa, an increase in hydropsychids and an increase in the relative abundance of chironomids. The relative abundance of mayflies decreases from a mean of 24% in the BIO8 data set to a mean of 9% at BIO9 and is further reduced to a mean of 2% at BIO10. This is accompanied by an increase in the relative abundance of hydropsychids from 67% at BIO8 to 79% at BIO9 to 89% at BIO10. The increases in hydropsychids indicate either an increase in the suspended organic particulate concentrations in the water column in the Rhode Island segment of the river, or perhaps a negative change in dissolved oxygen concentrations which would preclude more sensitive taxa from colonizing these areas.

A comparison of the data from mainstem stations to the reference station data sets yields the same general trend as described above: the taxonomic composition of the community at BIO1 is least similar to the reference communities of all mainstem stations and the similarity between mainstem stations and reference stations increases until station BIO8 where the invertebrate community is most similar to the reference stations of all mainstem stations. This trend reverses in Rhode Island.

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Benthic Macroinvertebrate Sampling Station Locations

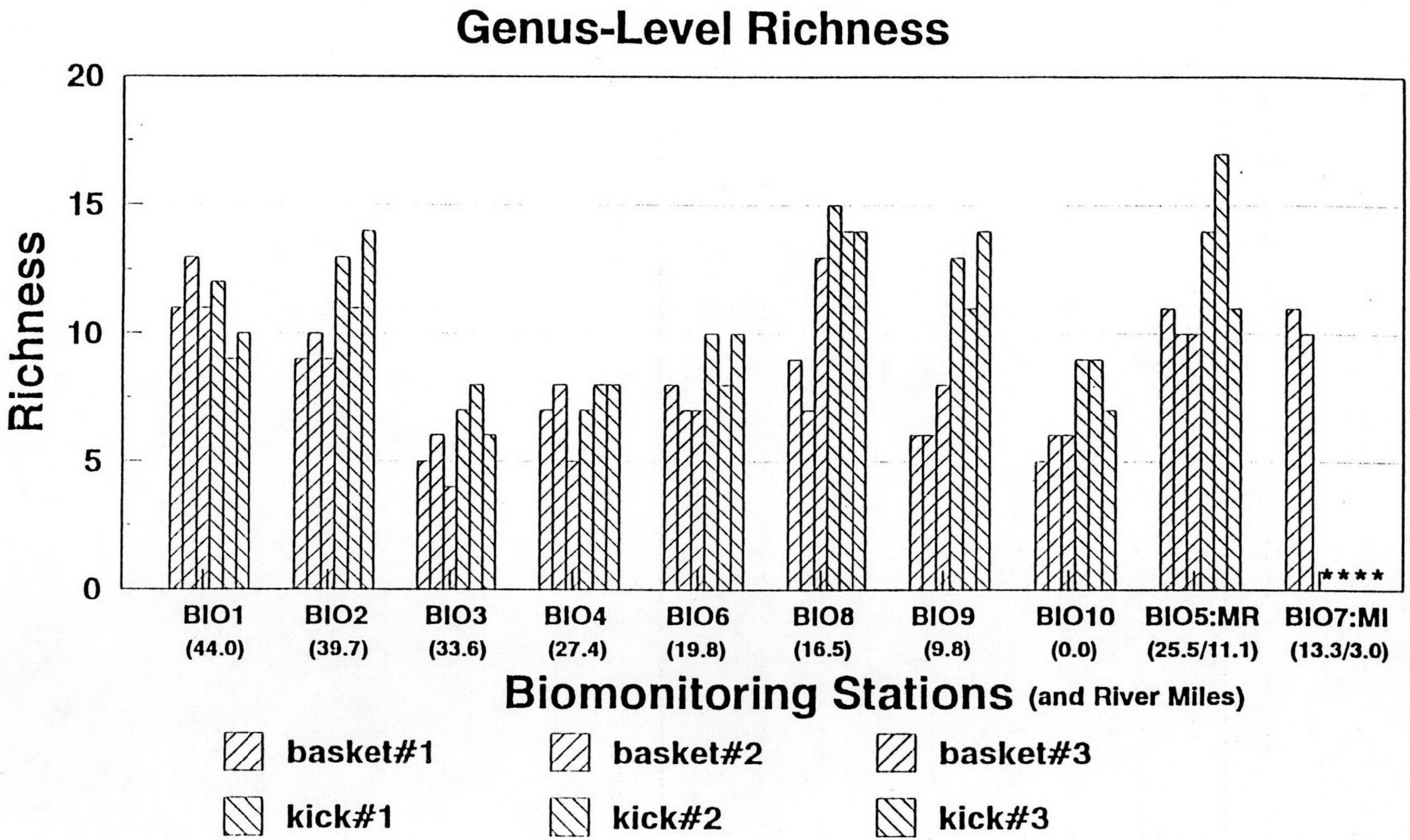
DWPC STATION ID	EPA STATION ID	RIVER MILE	DESCRIPTION	ARTIFICAL SUBSTRATES DEPLOYED	ARTIFICIAL SUBSTRATES COLLECTED
BS10	BIO1	44.0	Blackstone River in a riffle/run area located approximately 160 yds upstream of McCracken Road bridge, Millbury	30 July	23 Sept.
BS12	BIO2	39.7	Blackstone River in a riffle/run area located approximately 70 yds downstream from Singing Dam, Sutton	30 July	23 Sept.
BS14	BIO3	33.6	Blackstone River in a deep riffle area located behind the Coz Chemical Company, upstream from the Sutton Street Bridge, Northbridge	30 July	23 Sept.
BS16	BIO4	27.4	Blackstone River in a run/pool/riffle area located behind an island downstream from the outlet of Rice City Pond, Hartford Avenue, Uxbridge	30 July	23 Sept.
BS18	BIO6	19.8	Blackstone River in run/riffle area located approximately 90 yds upstream of Central Street Bridge, Millville	30 July	24 Sept.
BS19	BIO8	16.5	Blackstone River in a riffle area located approximately 40 yds downstream from the Bridge Street Dam, First Avenue, Blackstone	31 July	24 Sept.
BSRI1	BIO9	9.8	Blackstone River in a run/riffle area located approximately 180 yds downstream from the Manville Hill Road Bridge, Lincoln, RI	31 July	24 Sept.
BSRI2	BIO10	0.0	Blackstone River in a run/riffle area located approximately 40 yds downstream from Slater Mill Dam, Pawtucket, RI	31 July	24 Sept.
MF02	BIO5:MR	25.5/11.1	Mumford River in a riffle/run area located approximately 5 yds downstream from an unnamed bridge off of Manchaug Street at the outlet of Grays Pond, East Douglas	31 July	24 Sept.
ML05	BIO7:MI	13.3/3.0	Mill River in a riffle/run area located approximately 70 yds upstream of Summer Street Bridge, Blackstone	31 July	24 Sept.

Table 3–2
Blackstone River Survey 1991

Benthic Macroinvertebrate Sampling Station Bottom Types and Current Velocity[1] Measurements

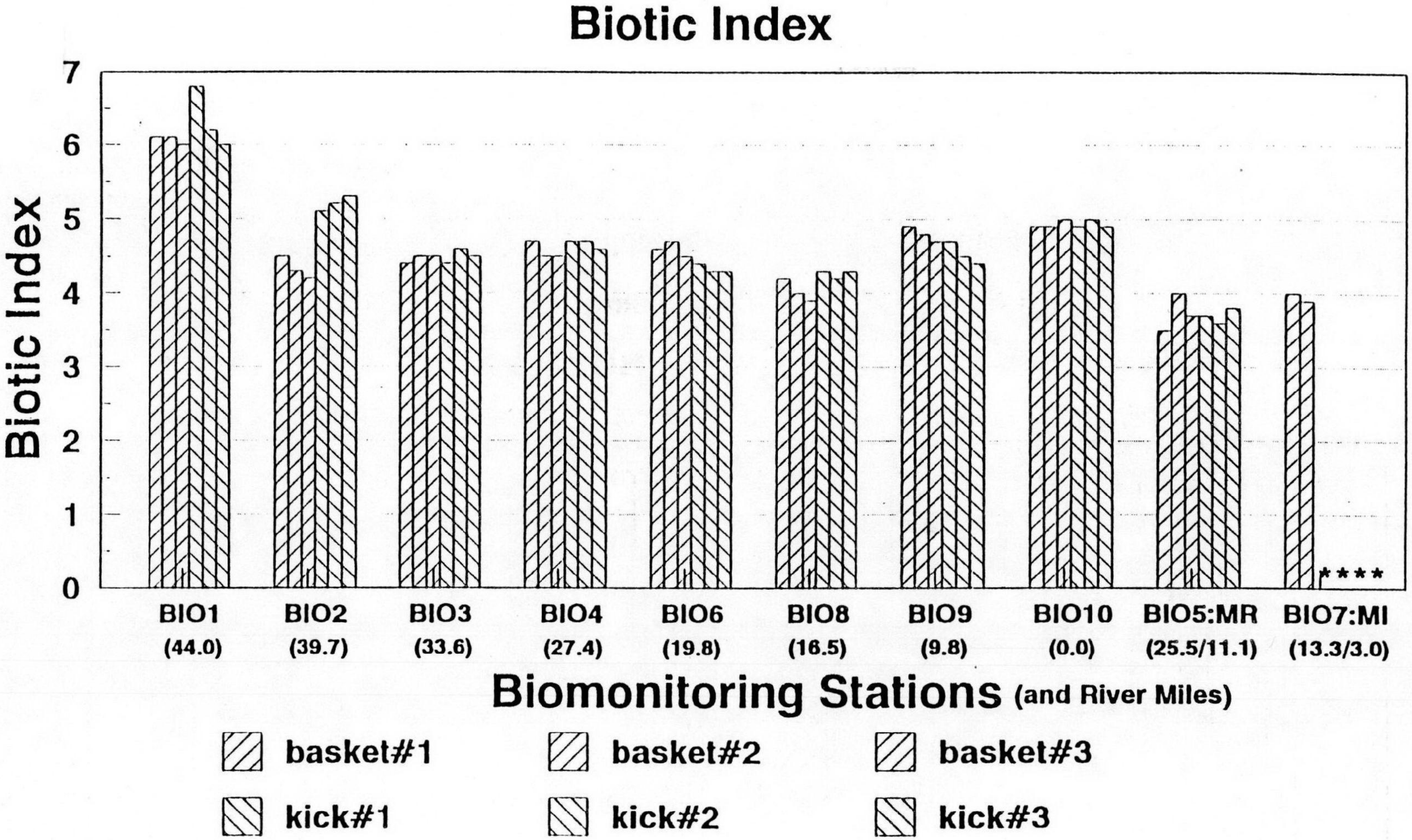
DWPC STATION ID	EPA STATION ID	RIVER MILE	BOTTOM TYPE	CURRENT VELOCITY		
BS10	BIO1	44.0	gravel	0.26	0.29	0.31
BS12	BIO2	39.7	cobble, gravel, boulder	0.37	0.38	0.21
BS14	BIO3	33.6	cobble, gravel	0.41	0.38	0.38
BS16	BIO4	27.4	coarse, gravel, sand cobble	0.40	0.32	0.25
BS18	BIO6	19.8	gravel, sand	0.20	0.33	0.44
BS19	BIO8	16.5	boulder	0.25	0.22	0.15
BSRI1	BIO9	9.8	boulder, cobble	0.19	0.21	0.39
BSRI2	BIO10	0.0	boulder, cobble, sand	0.32	0.39	0.40
MF02	BIO5:MR	25.5/11.1	cobble, gravel, sand	0.26	0.26	0.39
ML05	BIO7:MI	13.3/3.0	boulder	0.21	0.36	0.28

[1] Measurements reported as m/s over a 30 second integrated period at each rock basket.



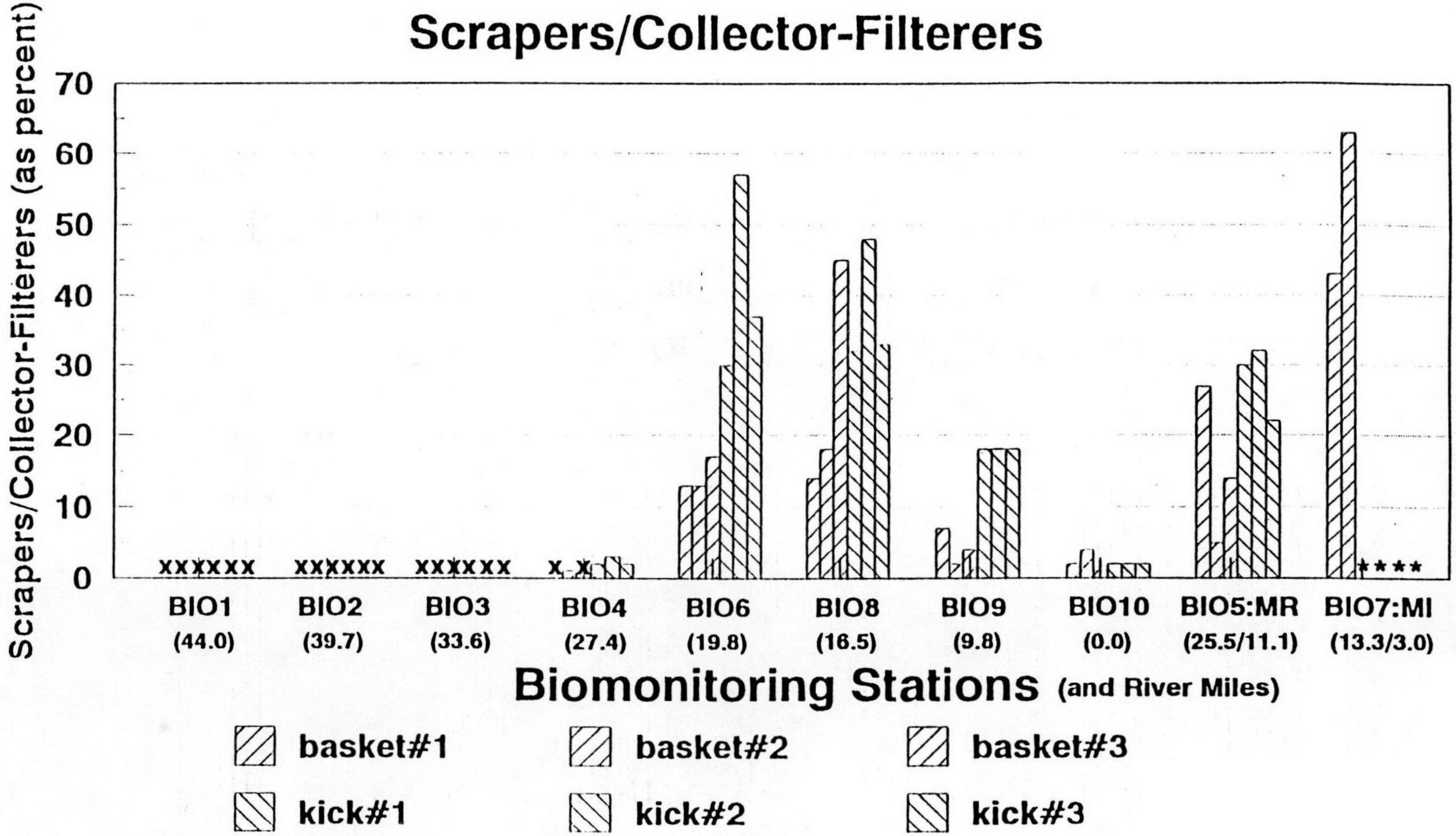
* denotes no data

Figure 3–1
1991 Blackstone River Macroinvertebrates



* denotes no data

Figure 3-2
Blackstone River Macroinvertebrates 1991

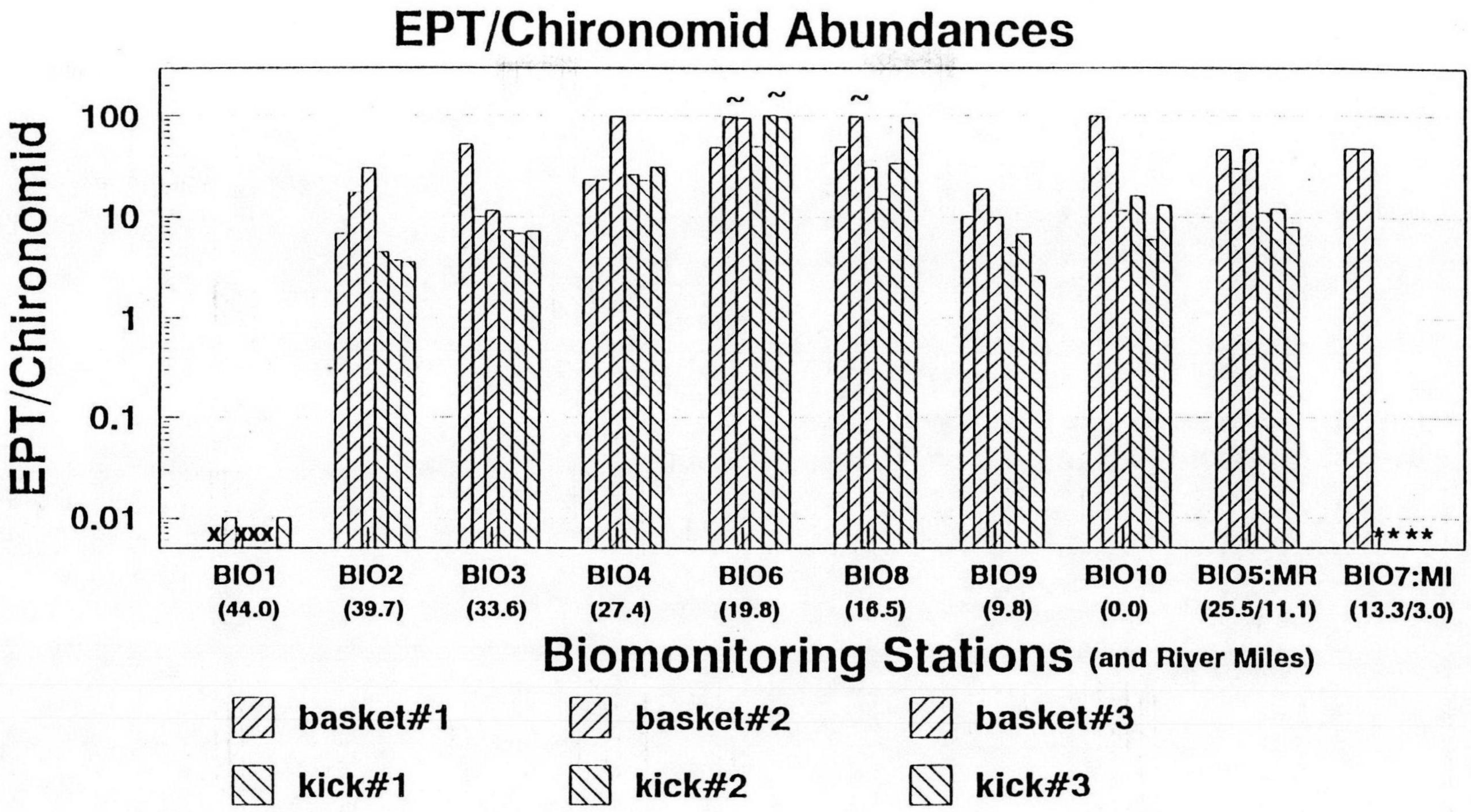


* denotes no data

x: No scrapers found in this sample

Figure 3-3

Blackstone River Macroinvertebrates 1991

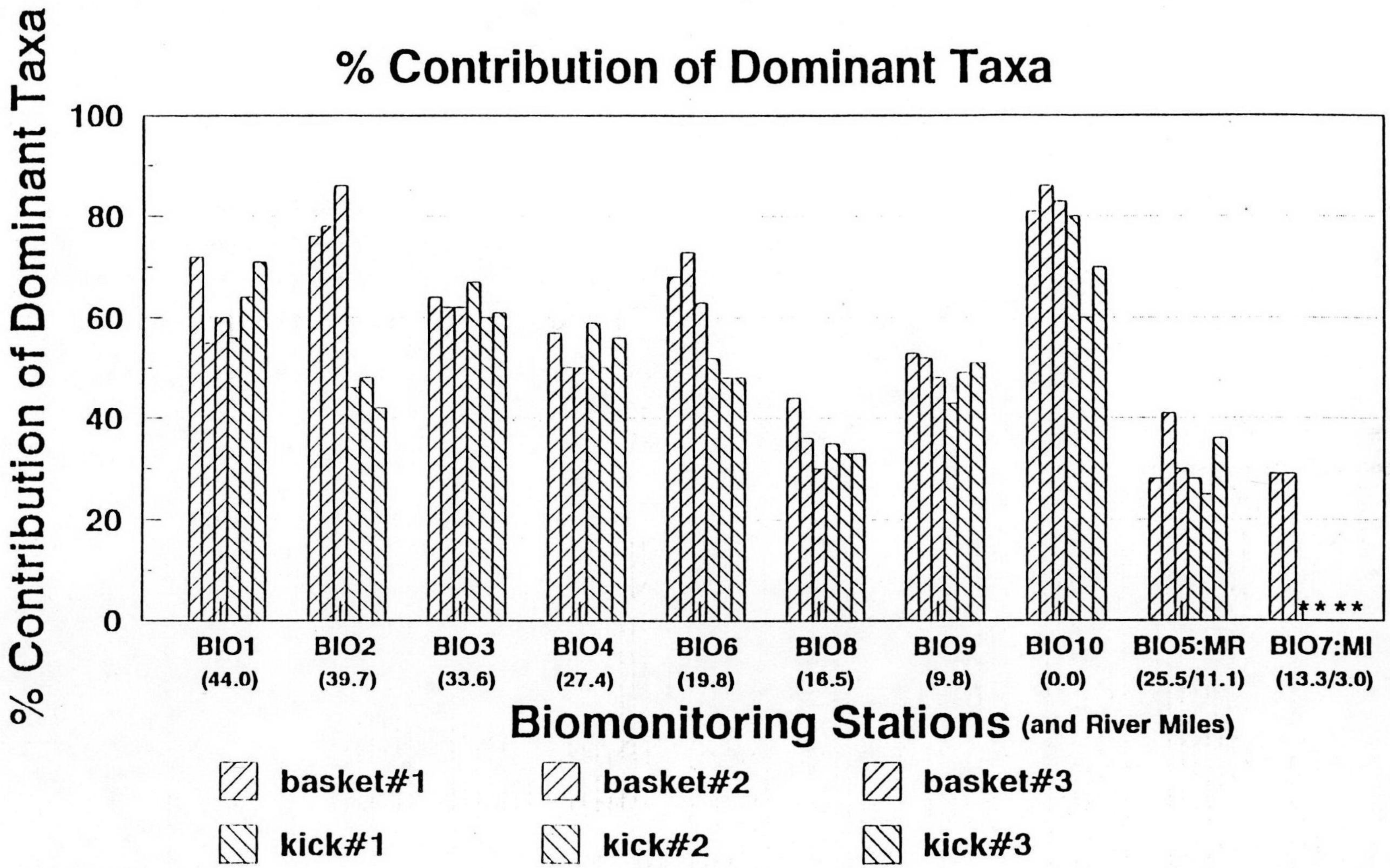


* denotes no data

~ denotes abundance of EPT since Chironomids = 0

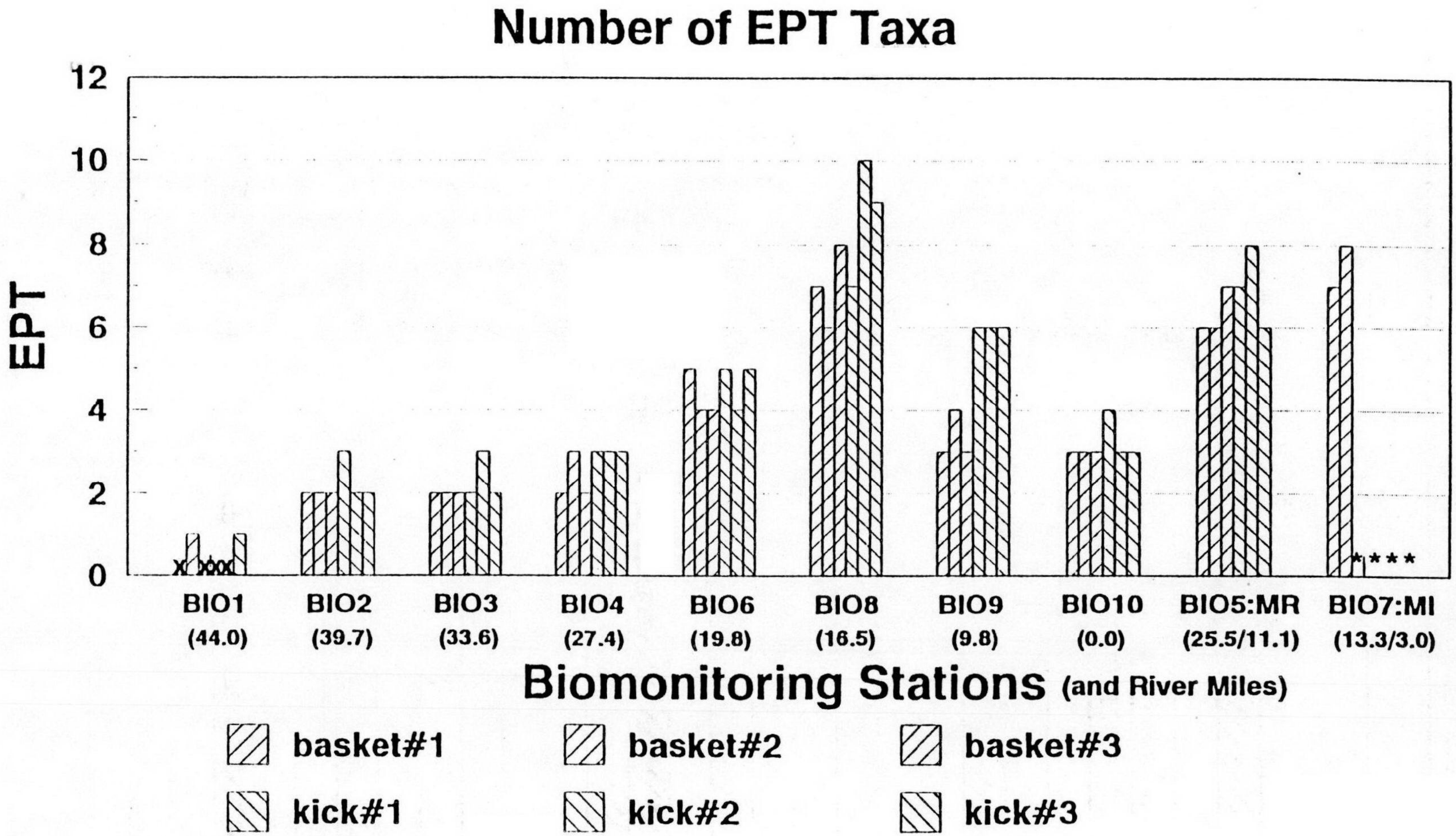
x: No EPT found in this sample

Figure 3-4
Blackstone River Macroinvertebrates 1991



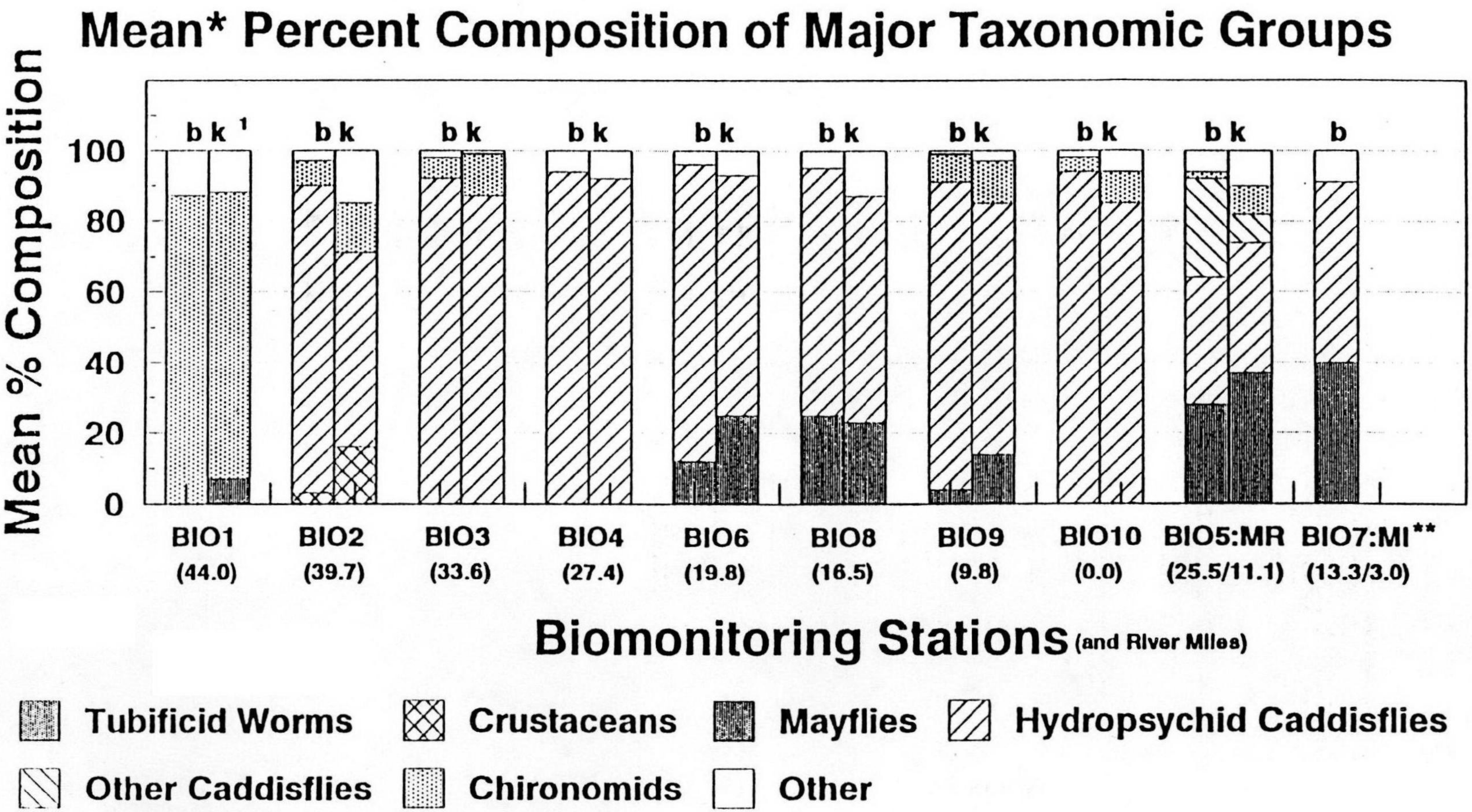
* denotes no data

Figure 3-5
Blackstone River Macroinvertebrates 1991



* denotes no data
x: No EPT found in this sample

Figure 3-6
Blackstone River Macroinvertebrates 1991



* Data are presented as a mean of three samples.

** Data presented are the mean of two samples. No kick samples were analyzed at this station.

[1] b represents basket data while k represents kick data.

Figure 3-7

Blackstone River Macroinvertebrates 1991