Massachusetts and Rhode Island - Additional Appendices

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Blackstone River Watershed Reconnaissance Investigation

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APPENDIX E - ENVIRONMENTAL RESOURCES

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Section 1.0

Fisheries and Aquatic Resources

1.0 **Fisheries Resources**

1.1 **Resident Fisheries**

The existing historical and current information on resident fishery resources in the Blackstone River watershed in Rhode Island and Massachusetts is somewhat limited; however, a recent watershed fishery survey conducted by Rhode Island and additional site-specific fishery surveys conducted by Massachusetts, respectively, have provided a current basin wide evaluation of the status of the respective fisheries.

Historical Overview

Information regarding the status of the Blackstone River fisheries during the 1960s is contained within "The Proceedings of the Conference on Pollution of Interstate Waters of the Blackstone and Ten Mile Rivers and their Tributaries, Massachusetts and Rhode Island" (McKenthum 1965). The study reported that "the Blackstone River once supported a notable run of American Shad that was destroyed at an early date by the construction of dams. Presently, all fishery pursuits are severely limited by pollution. The main stem is practically uninhabitable for fish. A few fish mostly carp and suckers, are taken from the river. When pollution is abated, the Blackstone will be repopulated naturally by warm water species of fish. At present, because of pollution, there are no plans to develop a fishery. Trout, which are stocked in Lake Quinsigamond during the spring of each year provide sport fishing for about 30 days after the fish are released. Fisherville Pond near Fisherville, Massachusetts, is also reported to provide fishing."

Massachusetts Studies

A comprehensive fisheries survey of the Blackstone River Watershed was conducted by the Massachusetts Division of Fisheries and Wildlife (MADFW) in 1973 (Bergin 1974). Thirty-two sampling stations including five on the Blackstone River mainstem were surveyed by Massachusetts.

The objective of the 1973 Massachusetts study was to survey streams throughout the Blackstone River where coldwater fish carrying capabilities are unknown or questionable. Twenty-three (23) species of fish were collected throughout the watershed. The most common species collected during the investigation were, in rank order, white sucker, carp and brown trout. Approximately 13% of the first through third order streams supported populations of native brook and brown trout, with some individuals ranging to approximately 8 inches (20 cm). Streams which historically contained trout were found to lack coldwater species due to the destruction of trout habitat by poor land and water management practices such as ditching, channelization and dumping of toxic effluents. Native trout were found primarily in the undeveloped forested sections of the watershed. Consequently the majority of stream angling was based upon annual stocking of hatchery trout in a strictly put-and-take situation in streams that are highly accessible and easily fished.

A fisheries survey of the Blackstone River was also conducted in May 1981 in a cooperative effort by the Massachusetts DEQE and Division of Fisheries and Wildlife (MADFW) as part of the previously described "Sediment Control Plan for the Blackstone River" study (McGinn 1981). Ten sites were sampled along the length of the river. A wide variety of game fish (e.g. yellow perch, bluegill, and largemouth bass) were collected in the upper reaches, however, the diversity began to decline at the third downstream sampling site along the Middle River. Only two pollution tolerant species, white sucker and bullhead, were collected. This area was heavily industrialized and loss of habitat was attributed to intensive urban development. Fish populations remain depressed throughout the next several sampling sites as the River passed through Worcester, Grafton and Northbridge; all of which had a number of significant discharges to the River. Improvement was noted in the lower stretches of the Massachusetts portion of the River in Uxbridge, Millville and Blackstone which supported populations of yellow perch, bluegill, pumpkinseed, chain pickerel and largemouth bass among other species.

The Massachusetts Department of Environmental Protection (MADEP), Division of Water Pollution Control (MADWPC) Technical Services Branch, as part of a June 1985 biomonitoring survey of the Blackstone River and selected tributaries, conducted a fish toxics screening investigation (Johnson et al. 1992). This screening was part of the MADFW Fish Toxics Monitoring Program administered jointly by the MADFW and MADWPC. The objective of the program was to develop a statewide database of contaminants in freshwater fish and identify those bodies of water that may pose a threat to human health and aquatic life as a consequence of elevated contaminants. The white sucker and yellow and brown bullhead were targeted species due to their bottom feeding habits. Other fish sampled included golden shiner, common shiner, chain pickerel, pumpkinseed, bluegill, black crappie and largemouth bass. Metals concentrations in fish flesh were found to be fairly uniform at all stations sampled, and were comparable to tissue levels found in fish from other rivers in the state. However, results of the benthic macroinvertebrate community investigation revealed benthic macroinvertebrates that indicated some of the worst water quality to be found in Massachusetts inland streams (Johnson et al. 1992).

Two additional fishery surveys were conducted in Massachusetts in 1988 by MADFW. The first, which was conducted at a reach of the Middle River in Worcester on July 8th, yielded only three species, white sucker, bluegill and yellow bullhead. The second more extensive survey, conducted in September at three sites between Millville and Blackstone, yielded a wide variety of gamefish including largemouth bass, chain pickerel and one brown trout. Fishing pressure was observed to be heavy in the Rolling

Mill Dam area and locals reported good largemouth bass fishing and an occasional trout and northern pike.

A study monitoring bioaccumulation in fish was conducted by the MADEP from June 1985 through June 1990 in order to investigate the potential for increase uptake of metals following resuspension of contaminated sediments in the vicinity of the Riverdale Impoundment (Maietta 1990). Sediments were disturbed during the replacement of flashboards for mill hydropower generation in 1984. The replacement of the flashboards resulted in the reflooding of a large area of exposed sediments which were documented to be contaminated with high concentrations of heavy metals (McGinn 1981). PCBs/percent lipids and arsenic were added to the list of parameters in 1990 as a result of concerns voiced by the State of Rhode Island regarding contributions of toxics from the Blackstone River to Narragansett Bay. Species analyzed included carp, white sucker, largemouth bass, yellow perch and brown bullhead.

Results indicated that resuspension of sediments did not result in increasing bioaccumulation of heavy metals in white sucker or brown bullhead (Maietta 1990). Levels of chromium were slightly elevated in yellow perch and brown bullhead. Mercury was below the current USFDA Action Level of 1.0 mg/kg methyl mercury in all samples analyzed. PCBs, while not above the current USFDA Action Level of 2.0 mg/kg, were well above detectable levels and appear to be cause for concern from a risk assessment perspective since there was no data from other stations on the Blackstone River. The author recommended that additional fish toxics work was needed to confirm or deny his conclusion that PCBs in concentrations may pose a potential health risk to fisherman who consume their catch.

To further investigate the status of the fisheries resources, the Corps conducted a fish community survey in Fisherville Pond, on October 15-16, 1996, as part of this Reconnaissance Investigation to supplement a prior gill net survey conducted by MADFW in July 1992 (complete survey report provided in Section 4.1.2). There were two main objectives of the Corps survey. The first was to provide current fisheries data to qualitatively assess the status and subsequent needs of the existing fishery. The second was to determine the appropriate representative fish receptors (assessment endpoints) for the Fisherville Pond Preliminary Baseline Ecological and Human Health Risk Characterization (McLaren/Hart 1997; see Appendix I). The preliminary ecological baseline risk assessment on Fisherville Pond water quality and sediment was conducted to determine if existing contaminant concentrations pose a significant risk to the fish community. Results of the site specific fishery survey and corresponding assessment for Fisherville Pond, which is considered representative (i.e. typical) of other impoundments in the basin, can be applied to the existing resident fisheries on a basin wide basis.

The combined results of the two limited surveys indicate that the fish community of Fisherville Pond, dominated by warm water species, is similar to that reported for other impoundments and ponds within the Blackstone River watershed in Massachusetts and Rhode Island. Two of the species collected, rainbow trout and brook trout, are coldwater species and were considered stocked holdovers from the Quinsigamond River (Table 1 in Section 4.1.2). The top six species (based on abundance), representing over 94% of the total (517 individuals), were (in rank order) white sucker (47.2%), bluegill (18.4%), golden shiner (11.4%), yellow perch (8.7%), largemouth bass (4.6%), and carp (3.9%) (Table 4 in Section 4.1.2). Many of the species collected are considered to be valuable as food or sport fish.

Fisherville Pond supports a moderately diverse and abundant warm water fish community. The dominance of the fish population by more pollution tolerant species (e.g. white sucker, golden shiner and carp) indicates that the Fisherville Pond System (i.e. Fisherville Pond, Blackstone River and Quinsigamond River complex) is somewhat degraded by a combination of water and/or sediment quality and less than stable pool height. However, the presence in good numbers of less tolerant species (e.g. largemouth bass, yellow perch, and bluegill) demonstrates strong potential for the development of a more balanced fish community concurrent with improving habitat conditions.

Since moderate numbers of fish were collected in Fisherville Pond, it is evident that the existing surface water and sediment quality do not cause significant acute effects to fish that are readily observable (e.g. fish kills). Apparently, the contaminant concentrations in the water and/or sediment have not adversely impacted reproduction and recruitment of fish, since juveniles (young-of-the-year) as well as adults of two species (i.e. bluegill, largemouth bass) were collected during the fall 1996 survey. However, the potential level of significance of any direct adverse impacts to any of the species present can not be definitively determined by existing data.

Based upon a review of the limited survey data and analyses, it is apparent that we do not know enough about the fish population of the Fisherville Pond System to predict effects of existing water and/or sediment quality and water level management to the fish community. Accordingly, the Central District Aquatic Biologist recommended (see review comment letter provided at the end of Section 4.1.2) that the Massachusetts Division of Fisheries & Wildlife, with Corps assistance, design and conduct more intensive surveys and analyses of selected species (e.g. age and growth studies) including a survey of the Blackstone and Quinsigamond Rivers immediately above the Fisherville Pond impoundment during the late summer or early fall time period.

As part of the Blackstone River Watershed Resource Assessment and Management Plan (MADEP and UESPA 1995) for development of a TMDL for the Blackstone River, fishery resource areas in Massachusetts were identified and described in order that any recommendations made under a TMDL allocation consider potential impacts to these resource areas. Stocked trout waters were identified in this report as priority areas for protection. Waters stocked with trout are required to be of high quality and indicate areas that should be focused on for protection, and for determination of possible impact if development projects occur nearby. Stocked trout waters in the Massachusetts portion of the Blackstone River Basin are described in the following section.

However, more important than protecting waters stocked with hatchery trout, is protecting waters that support wild populations of trout (i.e. naturally reproducing). Numerous waters in the upper portion of the basin are identified by MADFW as "exceptional wild trout waters" (e.g. Ironstone (Bacon) Brook in Uxbridge) and are consequently not stocked. Several streams, which were formerly stocked (e.g. Cold Spring Brook in Sutton), are no longer stocked since the existing wild trout populations are large enough to maintain an excellent fishery. Other streams that contain wild trout populations are also stocked to supplement existing populations (e.g. Mill River in Mendon and Blackstone).

In addition, the following fisheries issues were also noted in MADEP and USEPA (1995). The Mill River, Peters Brook, and Abbott Run have populations of the American brook lamprey (species of concern). Also, several tributaries to the mainstem Blackstone River have rare species or species with special habitat needs. The Mumford River has good potential for spawning habitat for northern pike. The lower portion of Cold Spring Brook in Sutton has good trout habitat, and other streams especially those in the western portion of the basin, may also provide good trout habitat.

<u>Massachusetts Trout Stocked Waters</u>

Eleven brooks, streams, and/or rivers and six lakes and/or ponds in the Blackstone River basin are presently stocked by MADFW (1997). Table 1 lists the basin waters stocked with trout including those waters in the Rhode Island portion.

Rhode Island Studies

A comprehensive fisheries survey of the Blackstone River watershed was conducted by the Rhode Island Division of Fish and Wildlife (RIDFW) in 1975 (Demain and Guthrie 1979). In summary, nineteen (19) species of fish, representing seven (7) families, were collected from twenty-one (21) sampling stations during the Blackstone River watershed survey including three on the mainstem Blackstone River. The RIDFW also conducted a survey of ponds in the watershed in the late 1970s (Guthrie and Stolgitis 1977).

The purpose of the 1975 Rhode Island survey was to provide information on the fish populations of the Blackstone River and its tributaries. The study indicated that the water quality of the mainstem Blackstone River was unsuitable for most game fish and panfish species and consequently supported populations of fish undesirable for sport fishing. White suckers dominated the Blackstone River catch; the only other species collected in rank order were brown bullhead, bluegill and fallfish. The Branch River, which is the largest tributary, showed some improvement over the Blackstone, with warm water gamefish and panfish (e.g. largemouth bass, yellow perch, and chain pickerel) appearing in the samples.

The survey was conducted in July and August in order to determine if adverse conditions such as high water temperatures and low flow rates, factors which are detrimental to fish life, were present. The majority of the tributaries sampled showed conditions suitable for warm water fish species, however, few tributaries demonstrated conditions suitable for native brook trout which require coldwater habitat and high dissolved oxygen levels.

A baseline fisheries survey was conducted in Rhode Island in 1987 in the vicinity of the proposed primary water supply withdrawal intake structure for the Ocean State Power combined cycle power generating plant in Woonsocket (Ecology and Environment 1987). Four sites in a 1.5 mile reach, two upstream and two downstream of the proposed intake, were sampled by a variety of methods in the Blackstone River. Ten species of fish were collected during the May and July 1987 survey. In contrast the RIDFW 1975 survey reported only three species of fish in the Woonsocket vicinity (Demaine and Guthrie 1979). The most abundant species collected in both surveys was the white sucker. The results of this survey indicate that since the 1975 survey the fishery resources of the Blackstone River in the vicinity of Woonsocket have improved. Overall, there was greater species richness, and the species present included several that have recreational value as sport fish (i.e. largemouth bass, bluegill, pumpkinseed, yellow perch, and chain pickerel). Although different sampling methods were used during the two surveys, making direct comparisons of the overall abundance of fish populations difficult, it appears that in addition to an increase in species richness, the overall abundance of fish populations has increased (Ecology and Environment 1987). In addition, the presence of large numbers of juveniles of some species during the survey (e.g. largemouth bass) indicates that the Blackstone River provides a suitable spawning habitat for these species.

In 1994 and 1995, the Rhode Island Division of Fish and Wildlife conducted comprehensive fishery investigations (stream and pond surveys) on the Blackstone River, and adjacent Woonasqsuatucket and Moshassuck River watersheds (Libby 1996). In summary, a total of thirty-one species of fish, representing 12 families, were collected from 54 stations during the

Blackstone River watershed survey as indicated in Table 2 (Table 1 in Libby 1996).

Bluegill and yellow perch were the most abundant species of fish collected from the pond stations (Table 3 in Libby 1996). Collectively, they represented approximately 65 percent of the catch-per-unit-effort (CPUE). Largemouth bass, bluegill, pumpkinseed, and yellow perch were the most widely distributed species, occurring in at least eight of the nine ponds sampled. Six of the nine ponds sampled in the present survey coincided with ponds surveyed earlier by Guthrie and Stolgitis (1977). Differences were observed between the two surveys in the composition of the catch. For example, among the game species, smallmouth bass were found in Wallum Lake by Guthrie and Stolgitis but were not found there in the present survey. In addition, northern pike were caught in Echo Lake in the present survey but were not caught there in the earlier survey.

The brook trout, comprising almost 25 percent of the total CPUE, was the most abundant species collected from stream stations (Table 4 in Libby 1996). Wild brook trout were from 13 of the 45 stations sampled. Brook, brown, and/or rainbow trout, that had been stocked by the Division for its put-and-take fishery, were collected in Wallum Lake, Mill Pond/Clear River, or Brandy Brook. Pumpkinseed, fallfish, and the tessellated darter were also very abundant at many of the stream stations. Collectively, they represented nearly 40% of the total CPUE.

Four stream stations in the present survey (Libby 1996) coincided with stations used in the 1970s by Demaine and Guthrie (1979). Differences were observed between the two surveys in the composition of catch (Table 4 in Libby 1996). For example, at Clear River (Stream Station No. 1.4.6), largemouth bass and brown bullhead were found in 1975 but absent in 1994-95, while brook trout, chain pickerel, and swamp darter were found in 1994-95 but absent in 1975. The largemouth bass was the most widely distributed species in the Blackstone River watershed in Rhode Island, occurring at 26 of the 54 stations sampled (Figures 4-34 in Libby 1996). Some species, such as the alewife (landlocked), bridal shiner, brown trout, creek chubsucker, longnose dace, and smallmouth bass, were only found at a single station. The blueback herring that were collected in the Blackstone River from Station 1.1.2 (Broad Street, Cumberland) represented the progeny of adults that were stocked earlier in the year to determine the potential for restoring river herring to the Blackstone River.

The range in conductivities, water temperatures, pHs, and oxygen concentrations measured at each station in the Blackstone River watershed during the 1994-95 sampling period are presented below (Libby 1996):

Parameter	Range	Mean	SD
Conductivity (uS)	34-392	115.8	79.7
Water Temperature (C)	10-28	18.8	4.1
pH	4.15-7.9	6.33	0.7
Oxygen (mg/l)	3.7-11.0	8.01	1.63

Rhode Island Trout Stocked Waters

As a result of improving water quality (primarily decreasing ambient water temperatures and increasing dissolved oxygen levels) in the mainstem Blackstone River, the RIDFW initiated annual trout stocking, a cold water habitat species, in the lower Blackstone River beginning in 1994. A total of 2,285 adult brown trout were stocked in 1994 below the dams at Valley Falls, Martin Street Bridge, Ashton Meadows, and Albion. The improved water quality and observed aquatic productivity indicated some potential for a quality fishery. The primary limiting factor appears to be the relatively high water temperatures reached during the summer months; however, an evaluation of trout "holdover" survival has not been conducted. Public opinion of the program has been favorable with RIDFW receiving positive comments throughout the fishing season. During prolific caddis "hatches", many people were observed fishing with fair success. The fish caught appeared to be in good condition. Following this initial success, the following number and species of trout have been stocked in subsequent years: 2,400 in 1995 (300 brown, 1400 rainbow, and 700 brook trout); 3,400 in 1996 (1200 brown, and 2200 rainbow trout); and 2,600 to date in 1997 (1300 brown, and 1300 rainbow trout).

In addition the Blackstone River, seven brooks, streams, and/or rivers and six lakes and/or ponds in the Blackstone River basin are presently stocked by RIDFW (1997). Table 1 lists the basin waters stocked with trout including those waters in the Massachusetts portion.

Basin Summary

The Blackstone River and its major tributaries are on the continued rebound today from severe historical environmental degradation. Based on a review of the existing fishery survey data, the mainstem Blackstone and major tributaries presently supports an improving recreational warm water fishery throughout the basin and a put and take stocked trout fishery in selected portions (e.g. lower Blackstone River). Wild brook and brown trout fisheries exist only in the upper reaches of the basin where suitable coldwater fish habitat and high dissolved oxygen levels persist.

Previous studies show that this has not always been the case. Data collected during the 1970s suggested that water quality parameters were indicative of polluted conditions, and biological studies showed a corresponding reduction in abundance and diversity of aquatic organisms. Prior to the enactment of the Federal Water Pollution Control Act Amendments of 1972, the Blackstone River and its tributaries received numerous untreated wastewater effluents resulting in degraded water and sediment quality. Studies in the 1980s and into the 1990s suggested the beginning of river biota recovery resulting from improved water quality in response to the addition and upgrading of sewage treatment plants (i.e. improvements in wastewater treatment facilities), although toxicants in sediment and in fish tissue continue to pose concerns. The recovery of the basin was also facilitated by the enactment and promulgation of environmental protection acts and implementation of regulations (e.g. wetland protection act/regulations) which include the protection of riparian (riverfront) areas in order to preserve the natural integrity of rivers and adjacent land for the important values these areas provide. Natural riverfront areas are critical to maintaining a thriving fisheries. Maintaining vegetation along rivers promotes fish cover, increases food and oxygen availability, decreases sedimentation, and provides spawning habitat. Maintenance of water temperatures and depths is critical to many important fish species. Where groundwater recharges surfaces water flows, loss of recharge from impervious surfaces within the riverfront area may aggravate low flow conditions and increase water temperatures. In some cases, summer stream flows are maintained almost exclusively from groundwater recharge. Small streams are most readily impacted by removal of trees and other vegetation.

The earlier surveys indicated that the fishery resources present in the mainstem Blackstone River and major tributaries were generally typical of warm water habitats, however, they included only species capable of surviving in poor quality waters resulting in resident fish populations that were undesirable for sport fishing. The more recent surveys, including those of the macroinvertebrate communities (see Section 1.4), reflect improvements in water quality. While the current basin fishery is still characteristic of warm water habitats, there is a greater number of recreational game species present including yellow perch, white perch, largemouth bass, smallmouth bass, black crappie, chain pickerel, and northern pike, all typical of better water quality conditions, and all providing improved recreational fishing opportunities.

In summary, the dominance of the current fish population by more pollution tolerant species (e.g. white sucker, golden shiner and carp) indicates that the Blackstone River System is somewhat degraded by a combination of water and/or sediment quality. However, the presence in good numbers of less tolerant species (e.g. largemouth bass, yellow perch, and bluegill) demonstrates strong potential for the development of a more balanced fish community concurrent with improving habitat conditions.

In addition, the reintroduction of anadromous fishes to their previous spawning grounds (see Section 1.2) will also have a positive effect on the ecology of those freshwater systems (Loesch 1987). In freshwater areas where herring have been restored, studies show that resident fish populations were enhanced. The juvenile herring produced in the spawning run serve as a food supply for bass and other resident species. All life stages of anadromous herrings are important forage for many freshwater and marine fishes; in addition, birds, amphibians, reptiles, and mammals have also been documented as predators. The mortality of anadromous alewives provides an important source of nutrients for headwater ponds.

TABLE 1

BLACKSTONE RIVER BASIN

Massachusetts and Rhode Island Trout Stocked Waters (1997)

Massachusetts Division of Fisheries & Wildlife

Rhode Island Division of Fish and Wildlife

Massachusetts

Brooks/Streams/Rivers	Town/City
Big Bummit Brook	Shrewsbury, Grafton
Center Brook	Upton
Emerson Brook	Uxbridge
Fox Stream	Blackstone
Mill River	Mendon, Blackstone
Miscoe Brook	Grafton
Muddy Brook	Mendon
Mumford River	Douglas
Peters River	Bellingham
Quinsigamond River	Grafton
Warren Brook	Upton
West River	Grafton, Northbridge, Upton, Uxbridge

Lakes/Ponds	Town/City
Coes Pond	Worcester
Jordan Pond	Shrewsbury
Lake Quinsigamond	Worcester, Shrewsbury
Pratt Pond	Upton
Singletary Lake	Millbury, Sutton
Wallum Lake	Douglas

Rhode Island

Brooks/Streams/Rivers	Town/City
Abbotts Run Brook	Cumberland
Blackstone River	Cumberland, Lincoln
Brandy Brook	Glocester
Chepachet River	Glocester, Burrillville
Clear River	Burrillville
Round Top Brook	Burrillville
Silvy's Brook	Cumberland

Lakes/Ponds	Town/City
Cass Pond	Woonsocket
Lapham Pond	Burrillville
Memorial Park Pond	Lincoln
Round Top Ponds	Burrillville
Silvy's Pond	Cumberland
Spring Grove Pond	Glocester
Sylvester's Pond	Woonsocket
Tarklin Pond	Burrillville
Upper Rochambeau Pond	Lincoln
Wallum Lake	Burrillville

Table 2. - Species of fish collected during the Blackstone River watershed survey of streams and ponds in Rhode Island.

Common Name	Scientific name
Petromyzontidae	
American brook lamprey	*Lampetra appendix*
Anguillidae	
American eel	*Anguilla rostrata*
Clupeidae	
Alewife	*Alosa psuedoharengus*
Cyprinidae	
Common carp	*Cyprinus carpio*
Common shiner	*Luxilus cornutus*
Golden shiner	*Notemigonus crysoleucas*
Blacknose dace	*Rhinichthys atratulus*
Longnose dace	*Rhinichthys cataractae*
Fallfish	*Semotilus corporalis*
Bridle shiner	*Notropis bifrenatus*
Catostomidae	
White sucker	*Catostomus commersoni*
Creek chubsucker	*Erimyzon oblongus*
Ictaluridae	
Brown bullhead	*Ameiurus nebulosus*
Yellow bullhead	*Ameiurus natalis*
Esocidae	
Redfin pickerel	*Esox americanus*
Chain pickerel	*Esox niger*
Northern pike	*Esox lucius*

Table 2. - Continued.

Common Name	Family	*Scientific name*
	Salmonidae	
Rainbow trout		*Oncorhynchus mykiss*
Brown trout		*Salmo trutta*
Brook trout		*Salvelinus fontinalis*
	Cyprinodontidae	
Banded killifish		*Fundulus diaphanus*
	Percichthyidae	
White perch		*Morone americana*
	Centrachidae	
Banded sunfish		*Enneacanthus obesus*
Pumpkinseed		*Lepomis gibbosus*
Bluegill		*Lepomis macrochirus*
Smallmouth bass		*Micropterus dolomieu*
Largemouth bass		*Micropterus salmoides*
Black crappie		*Pomoxis nigromaculatus*
	Percidae	
Swamp darter		*Etheostoma fusiforme*
Tessellated darter		*Etheostoma olmstedi*
Yellow perch		*Perca flavescens*

1.2 **Anadromous Fisheries**

Background and Overview

The Blackstone River is the second largest tributary to Narragansett Bay, draining approximately 475 square miles in south central Massachusetts and northern Rhode Island. Historically it supported spawning runs of anadromous species of fish. Each spring adult American shad, river herring (alewife and blueback herring), and Atlantic salmon would ascend the river to spawn (Borden 1993). Unfortunately, the extensive construction of dams for water power in the late 1700's and 1800's prevented these migratory fish from returning to the river basin's historical spawning and nursery areas and consequently these fish runs were eliminated in the Blackstone River Basin. The first dam on the Blackstone was constructed in 1793 to generate power for Slater's Mill despite protests of upstream farmers and fishermen (BRVNHCC 1993). The effect of the dam was to destroy the anadromous fishery migration.

Atlantic salmon once constituted a large portion of the commercial catch in Narragansett Bay (Desbonnet and Lee 1991). However, the bay fishery was very short-lived, completely collapsing by 1869. The collapse can be attributed to the salmon's loss of access to suitable spawning grounds in upper reaches of Bay tributaries. All tributaries to the Providence and Seekonk rivers including the Blackstone were dammed by the early 1800s to provide water power for the region's burgeoning industrial needs (Goode 1887; cited in Desbonnet and Lee 1991). The Blackstone River becomes the tidal Seekonk River immediately downstream of the Main Street Dam in Pawtucket, the first dam on the Blackstone River. This closing of the tributaries would have severely resticted, if not completely eliminated, access of salmon to their historical spawning beds in the upper tributaries upon which they were reared. Although the fishery was not studied to any great extent before it collapsed, and reference to damming as a cause for the fishery collapse is anecdotal, the adverse effect of river dams on salmonids is well documented for Atlantic salmon stocks. With no recruitment occurring in Narragansett Bay for Atlantic salmon populations, local extinction of the area's salmon was rapid and complete.

Alewives, another anadromous fish species, commanded an extensive fishery in Narragansett Bay from the mid-1800s to the turn of the century (Desbonnet and Lee 1991). But by the early 1900s this commercial fishery was declining rapidly, and it was essentially abandoned by 1930. This species, like the salmon, travels up the estuary to spawn, but it is not as reliant as salmon upon gaining access to the upper reaches of tributaries to successfully reproduce. Although damming of tributaries in Narragansett Bay may have negatively influenced alewife stocks, the fishery's failure is generally attributed to overfishing (Goode 1887; cited in Desbonnet and Lee 1991). During the spring alewife runs, fish traps were placed throughout Narragansett Bay, particularly in the East and West passages and the mouth of Sakonnet Bay. These fish traps were often placed so densely that it was virtually impossible for any alewives to reach the upper bay without becoming lodged in one (Goode 1887; cited in Desbonnet and Lee 1991). Alewives have not been fished on a commercial basis in Narragansett Bay waters since the fishery's collapse (Desbonnet and Lee 1991). Since the late 1950s, however, alewives have begun to return to Narragansett Bay in increasing numbers, and have often been noted in the Providence and Seekonk rivers. Spawning now occurs in some of the lower and coastal tributaries of the bay which remained accessible, and the species appears to be re-populating itself as a springtime visitor to Narragansett Bay waters.

It is apparent that the collapse of Narragansett Bay fisheries for anadromous species is not directly attributable to water quality degradation in the estuary and tributaries (Desbonnet and Lee 1991). Overfishing took a rapid toll on the populations of these fishes as they moved through the bay to spawn, and loss of access to historic spawning areas via the construction of dams, at least for salmon, prevented the rapidly depleted adult stocks from replacing themselves. In the case of the alewife fishery, water quality degradation in the Providence and Seekonk rivers may have caused a loss of suitable spawning habitat, but extraordinary fishing pressure apparently was the main cause of the extinction of the commercial fishery in Narragansett Bay (Desbonnet and Lee 1991). American shad and river herring were not mentioned as anadromous fish species that contributed to the Narragansett Bay commercial catch in Desbonnet and Lee's 1991 report entitled "Historical Trends: Water Quality and Fisheries, Narragansett Bay."

Recent improvement in water quality along with advancements in fishway technology indicate that restoring populations of American shad and river herring to the lower reaches of the Blackstone River system is feasible (Borden 1993). Restoration of Atlantic salmon would be extremely difficult since historic salmon spawning and nursery habitat areas located in the upper tributaries of the Blackstone River are inaccessible due to numerous dams on the mainstem river and tributaries. In addition, most of the tributary headwaters are impounded, resulting in feeder streams too warm for salmon survival (Demaine and Guthrie 1979). Accordingly, Atlantic salmon are not considered as a viable restoration target species for the Blackstone River based upon the analyses and proposed actions in the "Final Environmental Impact Statement (FEIS) 1989-2012: Atlantic Salmon Restoration in New England" issued by the USFWS in 1989. The Blackstone River was not included among the 28 major rivers in New England that contained significant Atlantic salmon populations in pre-colonial times (MacCrimmon and Gots 1979, Kendall 1935; cited in USFWS 1989) and consequently is not one of the rivers targeted for restoration in the FEIS. Consequently, the primary restoration goal is to establish self-sustaining runs of American shad and river herring. The secondary goal is to provide access to all potential spawning and nursery habitats for anadromous, semi-anadromous, catadromous, and residential fish species in order to maximize the biotic potential of the basin fisheries.

The main restoration concern of the Rhode Island Division of Fish and Wildlife (RIDFW) is to provide fish passage facilities at the lower four dams (i.e. Phase 1 of the comprehensive Strategic Anadromous Fish Restoration Plan) to open sufficient spawning and nursery habitat for self-sustaining populations of shad and river herring. The second major concern of the RIDFW is sufficient flows during critical life-cycle periods during August and the spring upstream migration. Other concerns include but are not limited to seasonal river flows, water releases/flow regulation, water withdrawals, flow duration curves, and water and sediment quality, although contaminated sediments may have little bearing on the success of anadromous fish restoration on the Blackstone since healthy populations of anadromous species exist in river systems with comparable sediment contamination (O'Brien 1993).

However, the restoration of anadromous fish to the Blackstone River is an enormous undertaking and consequently a multi-state, multi-agency (federal, state, local and private) approach is required, combining all existing technical and financial resources for anadromous fish restoration.

Consequently, the goal of restoring target species of anadromous fish to the Blackstone River will be conducted in a phased approach focusing first on short term actions (i.e. implementation of Phase I objectives by providing upstream and downstream fish passage at the lower four dams) and identifying long term activities in Phase II during development of the Blackstone River Basin Strategic Anadromous Fish Restoration Plan. The phased approach for restoring anadromous fish is discussed later in this section.

<u>Life History and Environmental Requirement Summaries of Targeted Anadromous Fish Species for Restoration to the Blackstone River</u>

Detailed life history information/species profiles on the targeted species are available in numerous documents in the literature for American shad (e.g. Weiss-Glanz et al. 1986; etc;) and river herring (e.g. Fay et al. 1983; Gray 1992; etc;). The following briefly summarizes their respective life histories and environmental requirements.

American shad:

The American shad, <u>Alosa sapidissima</u>, is an anadromous member of the family Clupeidae (herrings). Along the Atlantic coast, its range extends from southern Labrador to northern Florida. American shad undertake extensive seasonal migrations along the Atlantic coast. Shad migrate into rivers for spawning beginning in April in southern rivers and continuing until July in the northernmost rivers. Following their postspawning downstream migration, adult shad migrate north along the coast to Canada where they feed during the summer. A southward migration occurs along the continental shelf where the fish winter prior to spring spawning migrations to their natal (river of origin) rivers. Although shad weighing more than 10 pounds are occasionally captured, adult males typically weigh between 1 and 1/2 to 6 pounds, and females between 3 and 1/2 to 8 pounds. Shad may grow to 30 inches in length, but fish 20 to 24 inches long are the largest usually caught.

American shad have a range of life history patterns depending on their river of origin. In southern rivers, shad return to spawn by age 4, and spawn 300,000 to 400,000 eggs; they usually spawn only once, however. With increasing latitude, the mean age at first spawning increases to 5, and the number of eggs per spawning decreases to 125,000 to 250,000 eggs; the number of spawnings per life time, however, increases. In Rhode Island waters, American shad juveniles leave their nursery areas in late fall, mature in the ocean, and return to the tributaries to spawn in the spring after two to five years. Spawning sites are the same from year to year. Shad spawn at night, usually in shallow water with moderate currents in the main stem of rivers.

The critical life stages of American shad are the eggs, larvae, and early juveniles (Klauda et al. 1991). Water temperatures > 13 C, pH > 6.0, and dissolved oxygen > 5.0 mg/L are important requirements for shad eggs. Larvae require water temperatures of 15.5-26.1 C, pH > 6.7, dissolved oxygen > 5.0 mg/L and suspended solids < 100 mg/L. Requirements of juvenile shad are similar to those of larvae.

River Herring:

River herring is a term applied collectively to alewife, Alosa pseudoharengus, and blueback herring, Alosa aestivalis, because of similarities in appearance, time of spawning, methods of capture, and uses of the commercial catch. Both species are also members of the family Clupeidae (herrings). The coastal range of the blueback herring is from Nova Scotia to Florida; the coastal range of the alewife is farther north, from Labrador to South Carolina. In coastal rivers where the ranges overlap, the fisheries for the two species are mixed. Both species are anadromous and undertake upriver spawning migrations during spring. Few individuals of either species exceed 12 inches in length or about 2/3 of a pound in weight. Alewives may live as long as 10 years and reach a length of 14 inches. Blueback herring live for about 7 or 8 years and reach a maximum length of about 13 inches.

Alewives spawn in the spring when water temperatures are between 16 C and 19 C; blueback herring spawn later in the spring, when water temperatures are about 5 C warmer. Fecundity (reproductive potential) and age at maturity for both species are similar. Between 60,000 and 300,000 eggs are produced per female; and maturity is reached at ages 3 to 5, primarily at age 4. In Rhode Island waters, river herring juveniles leave their nursery areas in fall, mature in the Atlantic Ocean, and return after two to five years to the tributaries for spring spawning.

Despite their similarities, there are important life history differences (Loesch 1987). Alewives select lentic (still water) areas for spawning. Blueback herring spawn in lotic (moving water) sites in the sympatric distribution (i.e. when they occupy the same range as alewife), but use primarily lentic sites in their allopatric (occurring in different areas) range. The differential selection of spawning sites by blueback herring reduces competition with alewives for spawning grounds in sympatry. River herring return to natal streams for spawning, but they also readily colonize new streams or ponds and reoccupy streams from which they have been extirpated.

The critical life stages of alewife (AW) and blueback herring (BH), like the American shad, are the eggs, larvae, and early juveniles (Klauda et al. 1991). Water temperatures > 11 C (AW) and 14 C (BH), pH > 5.0 (AW) and > 5.7 (BH) and dissolved oxygen (DO) > 5.0 mg/L (AW and BH) are important habitat requirements for eggs. Larvae require water temperatures at least 8 C (AW) and 14 C (BH), pH > 5.5 (AW) and > 6.2 (BH), DO > 5.0 mg/L, and suspended solids < 500 mg/L.

Habitat Issues:

In addition to the blockage of shad and herring spawning migrations by dams, acid deposition and subsequent stream acidification may be a major problem in the decline and/or restoration of many anadromous fish. Laboratory studies have shown that river herring eggs and larvae suffer high mortalities below pH 6.5 and total dissolved aluminum levels greater than 0.34 mg/L. As reported in the Chesapeake Bay Program (1989), there is a high incidence of low pH and high dissolved aluminum events in many Eastern shore streams following heavy spring rains.

Removal of Fish Blockages

Where feasible, migratory fish (anadromous, semi-anadromous and catadromous) and residential fish passage would be restored through the removal and/or modification of upstream and downstream fish blockages. Passage may be restored by the removal or modification of obstructions such as small dams and utility crossings, the addition of fish ladders, fish locks, and fish lifts, and the retrofit of structures such as culverts and the removal or notching of existing weirs.

Barriers, both upstream and downstream, to fish migration exist on nearly every tributary of the Blackstone River system.

The most well known are the hydropower dams, but fish migration can be blocked by a structure only one foot high, such as a road culvert. A wide variety of small to mid-sized dams are found in the Blackstone River watershed. These dams include hydroelectric, historic mill and flood control dams, as well as wildlife or recreational impoundments. At one time there were approximately 45 dams on the mainstem Blackstone River, however, most of these have washed out during floods. Currently, there are 17 dams on the river, all of which are between 7 and 25 feet high, with the exception of the 40 feet high Thundermist Dam in Woonsocket.

The structures which act as upstream and/or downstream barriers to fish migration are diverse, ranging from hydropower dams to small road culverts. No one solution can address all situations. The following lists the diversity of potential solutions to address these problems.

<u>Potential Solutions for Removing Barriers to Migratory Fish Passage</u>

Fish passage technology has improved greatly in recent years. Several New England states have active and successful programs providing passage for migratory fish. For example, in Massachusetts, nearly 130 fishways maintain migrations on approximately one hundred tributaries. On the Connecticut River, migratory fishes have been restored to 174 miles of historic habitat as a result of fishway operations at 3 dams.

<u>Breaches</u>:

The simplest solution for fish passage is to remove part or all of an obstruction. Breaching is a practical alternative when the barrier is no longer in use or the benefits of passage favor a modification to the structure. A breach solves both upstream and downstream fish passage needs. However, other issues (e.g. contaminated sediments) may be critical in determining whether this solution is practical. The complete removal of a dam is discussed in further detail in Section 5.5.1.4 Dam Removal.

<u>Fish Ladders</u>:

A common solution is to install a fish passage facility, or fishway, to allow fish to pass over or around an obstruction during its upstream migration. On smaller blockages, a "fish ladder" can be used. This is an inclined water channel structure with a series of baffles or weirs which interrupt and slow the flow of water. The fish swim up the ladder just as they would natural rapids.

<u>Locks</u>:

Fish locks pass fish around dams by raising the water level in a chamber, which the fish have already entered, until the water surface rises above the barrier. Locks are useful for certain fish, such as striped bass and sturgeon, which generally will not use fish ladders.

Lifts:

For larger dams, where fish ladders may not be practical, a mechanized device known as a "fish lift or elevator" is often used. Fish are attracted by flow into a confined space and elevated in a volume of water over the dam. In some cases, fish will be transported in special tank trucks around several dams until all are fitted with passage facilities.

Retrofit:

Some structures such as culverts and gauging stations on smaller tributaries can be redesigned to provide the gradient and flow necessary for fish passage. Culverts can be buried below the streambed and gauging stations can be notched or modified to allow fish passage.

Downstream Fish Passage Considerations:

Upstream fish passage facilities allow adult anadromous fish to reach their spawning grounds but often do not provide for the safe return (e.g. minimizing the passage of fish through the hydroelectric turbines) of the adults and young to the marine environment. The lack of downstream fish passage facilities or inadequate facilities could have a significant negative impact on fish populations. Therefore, downstream fish passage facilities are also required at all dams on the Blackstone including the non-hydro dams but particularly at hydroelectric facilities to minimize entrainment of downstream-migrating fish in turbines.

A variety of downstream fish passage screening devices have been employed to prevent fish from becoming entrained in the turbine intake flows at hydroelectric facilities (USDOE 1991). The simplest, spill flows over the dam spillway, can transport fish over the hydropower dam rather than through the turbines. Typically, this is accomplished by placing a downstream migrant notch in the non-overflow section usually adjacent to the upstream fishway exit channel and providing for a plunge pool for the fish to safely fall into (see Attachment 1 of Appendix Z for details). Increased spillage at non-hydropower dams may be used to flush fish over a dam via a notch or through a bypass. At the other end of the scale, more sophisticated physical screening devices (e.g. angled bar racks) and light- or sound-based guidance measures are being studied to bypass downstream migrating fish with a minimal loss of water that could otherwise be used for power generation. There is presently no single downstream fish passage protection system or device which is biologically effective, practical to install and operate, and widely accepted to regulatory agencies (USDOE 1991) (see subsequent section on "Potential Impacts and Environmental Mitigation at Hydroelectric Projects" for more details).

Fish Passage Facilities at Lower Four Dams (Phase I) and Long Term Specific Steps to Restoring Anadromous Fisheries (Phase II/Long Term)

Primary Goal: establish self-sustaining runs of anadromous fish (American shad and river herring)

Secondary Goal: provides access to all potential spawning and nursery habitats for anadromous, semi-anadromous, catadromous and residential fish species for maximum biotic potential.

To achieve these goals, the following primary objectives were established:

1. To provide for migratory fish passage (upstream and downstream) at dams, and to remove stream blockages wherever feasible to allow access to the river's historical spawning and nursery habitat areas; and

2. Prior to and/or in conjunction with providing fish passage, reintroduce migratory fishes to habitat above present blockages. The young fish (juveniles) will become "imprinted" on the upstream habitat and will return to spawn there when fish passage is provided and/or the stream blockage is removed. Mature returning adult fish can be obtained from other river systems and/or trapped below blockages as they return to the Blackstone and transported and stocked upstream to spawn, or young hatchery-produced fish (fry and/or juveniles) or fish from other streams can be stocked above the blockages.

Phase I - Anadromous Fish Passage at Lower Four Dams

Description:

The objective of restoring anadromous fisheries to the Blackstone River can be achieved by either removing dams, or by providing upstream and downstream migratory fish passage facilities at dams, and by reintroducing migratory fishes to the river's historical spawning and nursery habitat areas. The feasibility and cost-effectiveness of removing dams should be evaluated as part of the selection of a comprehensive plan. Restoration efforts should be conducted in a phased approach, with Phase 1 involving the establishment of fish passage at the lower four dams in order that the target species (i.e. American shad and river herring) be able to reach the significant Valley Falls Pond/Marsh spawning and nursery habitat. Non-targeted fish species (e.g. rainbow smelt, sea-run brown trout, striped bass and sturgeon) are also expected to use these facilities. Below the Valley Falls Dam there is only limited spawning and nursery habitat. Future phases of the restoration efforts should also be based upon habitat areas.

These four projects are listed by Federal Energy Regulatory Commission (FERC) file numbers in upstream order as follows:

NAME	FERC #	TYPE
Main Street	3689	Exemption - 7/21/81
Slater Mill	No Hydro	
Elizabeth Webbing Co.	3037	Licensed - 7/13/81
Valley Falls	3063	Licensed - 8/28/91

In the exemption and/or license conditions for all three hydroprojects, there are statements or articles that require the licensee to provide the necessary fish passage facilities at the respective project. There are likewise articles or conditions that cover minimum flows to be passed down the diverted reach.

Conceptual Fish Passage Designs/Cost Estimates for the Lowermost Four Barriers on the Blackstone River in Rhode Island

The USFWS Engineering Field Office in January 1994, at the request of the State of Rhode Island, performed preliminary designs of potential upstream and downstream fish passage facilities for the lower four dams on the Blackstone River in Rhode Island (see COE 1994 Section 22-Study, Appendix C). The USFWS used low flow tailwater depths obtained by the Corps in 1993 downstream of the four dams and other available information. A written description of what a typical fishway, that is proposed for upstream and downstream fish passage on the Blackstone in Rhode Island, would look like and how it functions was also provided in the aforementioned Appendix C. The fishways were designed (sized) for passing American shad and river herring; therefore, they will also readily pass Atlantic salmon which possess greater swimming abilities. Preliminary "ballpark" cost estimates for upstream and downstream fish passage at the first four dams were also provided in the 1994 Blackstone River Restoration Study.

At the request of the Corps in December 1996, the USFWS Engineering Office was tasked to develop conceptual design plans and construction estimates for both upstream and downstream fish passage at each of the lowermost four dams. The conceptual construction estimate for fishways to pass American shad and river herring upstream and downstream from the four dams at the four locations was $2,205,000 as summarized below:

Preliminary Upstream/Downstream Fishway Cost Estimates

Dam (Vertical Lift)	Upstream	Downstream	1997 $
Main Street (20 ft)	600,000	50,000	650,000
Slater Mill (6.5 ft)	175,000	not needed	175,000
Eliz. Webbing (11.25 ft)	275,000	150,000	425,000
Valley Falls (8.75 ft)	225,000	100,000	325,000
Direct Cost Total =			1,575,000
Contingencies and Engineering & Administration =			630,000
Total Conceptual Construction Estimate =			$2,205,000

The annual Operation and Maintenance Cost for each project is estimated to be between $5,000 to $15,000.

The detailed cost and design plans submitted by the USFWS, titled "Blackstone River Restoration Cost Estimate and Design Information for Fishways", are provided at the end of this section.

Phase II/Long Term Anadromous Fish Restoration Plans

Future Population Estimates Based on Potential Habitat Above Each Dam in Rhode Island

Potential habitat estimates in acreage for alewife and blueblack herring above each dam in Rhode Island were determined by RIDFW fisheries biologists through aerial photo-interpretation and the use of a planimeter (Erkan 1994). Given the habitat acreage, potential population sizes were predicted for alewife and blueback herring populations (combined) on the Blackstone River following the methodology described by Gibson (1984). These estimates are provided in tabular format at the end of this section. The predictions assume an unimpeded route to the respective spawning areas (i.e. 100% fish passage above dams/fish ladders). However, a 5-10% mortality due to energy expenditure in fish ladder passage at each dam is considered reasonable. The significance of habitat acreage becomes obvious when considering the potential net population increases upstream of Valley Falls and Manville dams as illustrated by the population estimates.

A potential population of approximately 110,000 river herring is predicted based upon potential habitat acreage if fish passage facilities are constructed and operated on the first four dams (i.e. Phase I). The predicted alewife/blueback herring population approaches 250,000 if fish passage facilities are constructed and operated at all ten dams on the Blackstone River in Rhode Island.

Currently the RIDFW has no method to estimate American shad populations albeit they are attempting to develop a model using CFS average flows on known shad runs (Erkan 1994).

Alternatively, RIDFW may use potential adult American shad production estimate methodology being developed by the Connecticut Marine Fisheries Division for their plan for the restoration of anadromous fish to the Thames River Basin (Gephard 1994) or those being used in anadromous fish restoration plans in other New England States. For example, Maine estimated potential shad populations in the Kennebec River based on the production of 2.3 shad per 100 square yards of water surface acreage (MEDMR 1986). Using this approach, potential populations of approximately 12,000 and 51,000 American shad could be produced if fish passage facilities are constructed and operated on the first four dams and all ten dams in Rhode Island, respectively.

Potential Impacts and Environmental Mitigation at Hydroelectric Projects

There are presently six hydropower dams under FERC jurisdiction on the Blackstone River including three of the first four dams in Rhode Island.

The purpose of environmental mitigation requirements at hydroelectric projects is to avoid or minimize the adverse effects of development and/or operation. Adverse impacts include but are not limited to upstream and downstream fish passage, instream flows, and water quality (specifically, dissolved oxygen (DO)). Hydropower mitigation usually involves costs, such as reduced profits to owners and/or developers and reduced energy production.

The restoration of anadromous fish to the Blackstone River will require facilities for upstream fish passage at dams. The costs of upstream fish passage mitigation are relatively easy to determine (USDOE 1991). In addition to the capital costs of constructing the fishway (ballpark cost estimates for the first four dams previously provided), there are operation and maintenance costs (e.g. for clearing debris from the fish ladder or fish lift/elevator and for electrical power to operate a fish lift/elevator), lost power generation resulting from flow releases needed to operate a fish ladder or fish lift/elevator (including attraction flows), and any monitoring and reporting costs.

A variety of screening devices are employed to prevent fish that are moving downstream from being drawn into turbine intakes (USDOE 1991). The simplest downstream passage technique is the use of spill flows similar to those used to increase DO concentrations or provide instream flows. Fish are naturally transported below the hydropower project in these nonpower water releases. Techniques that incorporate more sophisticated technology are under development, but are not widely used. For example, light- or sound-based guidance measures are being studied as ways to pass migrating fish downstream with a minimal loss for power generation.

A number of measures, some used in combination, are employed to reduce entrainment of downstream-migrating fish in turbines. The most common downstream fish passage device is the angled bar rack, in which the trash rack is set at an angle to the intake flow and the bars may be closely spaced (approximately 2 cm) (USDOE 1991). This device is commonly used in the Northeast. Other frequently used fish screens range from variations of conventional trash racks (e.g., use of closely spaced bars) to more novel designs employing cylindrical, wedge-wire intake screens. Intake screens usually have a maximum approach velocity requirement and a sluiceway or some other type of bypass is employed as well.

In addition to the capital costs of constructing a downstream fish passage facility (ballpark cost estimates for the first four dams previously provided), costs typically include those for cleaning closely spaced screens or maintaining traveling screens, lost power generation resulting from flow releases needed to operate sluiceways or other bypasses, and monitoring and reporting.

The potential strategies to mitigate for the aforementioned adverse environmental impacts of the lower four dams (i.e. primarily up- and downstream fish passage) will require additional detailed site-specific evaluation, study and design.

<u>Ongoing Studies and Investigations</u>

The Blackstone River Anadromous Fish Restoration Task Force, established by RIDEM's Division of Fish and Wildlife (RIDFW) in early 1993, conducted periodic meetings to discuss the issues associated with the restoration efforts through June 1994, prior to issuance of the final Blackstone River Restoration Study in November 1994. The primary mission of the task force is to consolidate and coordinate the individual efforts of various state, federal, and local organizations that are interested in the restoration and management of fish populations in the Blackstone River. The task force has open-ended membership and currently includes representation from a variety of interests including the Massachusetts Division of Fisheries and Wildlife. Since the primary objective to achieving the restoration goal is to remove the impediments to anadromous fish migrations by providing upstream and downstream fish passage, future meetings will need to involve the dam owners, especially the hydroelectric facility operators who will ultimately be required by FERC to pay for these facilities under the conditions imposed in their present license and/or exemptions.

In the spring of 1993, RIDFW released approximately 3,000 adult blueback herring just below Albion Dam, between Cumberland and Lincoln. These fish were obtained from the Charles River via a cooperative effort with the Massachusetts Division of Marine Fisheries and transported in a 1,000 gallon fiberglass tank equipped with aeration devices. Juvenile blueback herring, representing viable natural reproduction by the stocked adults, were recovered in August 1993 above the Valley Falls Dam (Erkan 1993). A school of juvenile bluebacks were observed immediately upstream of the Valley Falls Dam and nine were subsequently captured using their 16-foot electrofishing boat. The captured fish ranged in size from approximately 2 1/2 to 3 1/4 inches (60-82 millimeters), and appeared to be in excellent condition (health). These efforts indicate that the river has a high anadromous fish restoration potential.

Restore Anadromous Fish - Overall Strategy

The goal of restoring anadromous fisheries to the Blackstone River can be achieved by either removing dams, or by providing upstream and downstream migratory fish passage facilities at dams, and by reintroducing migratory fishes to the river's historical spawning and nursery habitat areas. The feasibility and cost-effectiveness of removing dams should be evaluated as part of the selection of a comprehensive plan. Restoration efforts should be conducted in a phased approach, with Phase 1 involving the establishment of fish passage at the lower four dams in order that the target species (i.e. American shad and river herring) be able to reach the significant Valley Falls Pond/Marsh spawning and nursery habitat. Non-targeted fish species (e.g. rainbow smelt, sea-run brown trout, striped bass and sturgeon) are also expected to use these facilities. Below the Valley Falls Dam there is only limited spawning and nursery habitat. Future phases of the restoration efforts should also be based upon habitat areas.

An active Strategic Anadromous Fish Restoration Plan (SAFRP) is required by the Federal Energy Regulatory Commission (FERC) before they will require hydropower facility owners to provide for fish passage facilities, even if the right of the Federal government to require these facilities is already stipulated in the FERC license and/or exemption, as it is for the three of the lower four dams (Phase I) under FERC jurisdiction. The purpose of the SAFRP is to demonstrate that restoration of the anadromous fishery resource is feasible and realistic. The states, Federal government, or other organizations will need to find programs and funds to implement fish passage facilities at non-FERC dams. Both Rhode Island's DFW and the MADFW support the goal of restoring anadromous fish to the Blackstone River.

Specific steps to restoring anadromous fisheries were developed during the Section 22 Study and are as presented below:

1. Form a task force to coordinate the individual efforts of various state, federal, and local organizations interested in the restoration of anadromous fish to the Blackstone River (see "Prior and Ongoing Programs" section of this report). The Rhode Island DFW has taken the lead. Dam owners/hydropower operators must be included in the task force. Involvement of the state of Massachusetts is important to this effort and will become

critical after Phase I of the restoration effort is completed.

2. Determine potential spawning, nursery habitat and forage areas. Some of this information has been developed for this report for the Rhode Island segments, but should be done also for Massachusetts segments in order to assess potential basinwide habitat.

3. Predict future populations of shad and herring based on estimated habitat acreage. Some of this information has been developed for this report for the Rhode Island segments. This should also be done for Massachusetts segments, so that the ultimate potential populations for the river can be determined.

4. Insure that river segments have sufficient flow at all times, particularly downstream of hydropower facilities. This may require extensive coordination with FERC.

5. Determine if all river segments have sufficient water quality for each life history stage of the anadromous fish.

6. Implement an active interim trap-and-truck stocking program for shad and herring to reintroduce the fish to the habitat above the dams. A trap-and-truck program is critical to facilitate the documentation of spawning viability and potential production estimates. In addition, the young fish (juveniles) will become "imprinted" on the habitat and will return to spawn there when fish passage is provided or dams are removed. RIDFW has performed limited trapping and trucking in the lower reaches of the Blackstone River. MADFW could potentially supply American shad from the Connecticut River at Holyoke for the trap-and-truck program.

7. Develop and implement a Blackstone River Basin Strategic Anadromous Fish Restoration Plan (SAFRP). The approved SAFRP should describe the task force's goals, document habitat areas and future populations, and document the viability of the fish as demonstrated in the interim trap-and-truck stocking program. The SAFRP should include an anadromous fish passage operational plan with sequential target dates for upstream and downstream passage for all dams based on "trigger numbers" for specific species returning to the base of each dam or passed at dams with fish passage facilities.

8. Obtain tailwater depths downstream of dams under average flow conditions. This step is necessary to perform preliminary fish passage designs. The Corps of Engineers installed staff gages and obtained tailwater depths at the lower four dams.

9. Perform preliminary fish passage designs. USFWS has performed conceptual design of fish passage facilities for the lower four dams. Preliminarily designs will need to be developed for all targeted dams further upriver based on the SAFRP.

10. Coordinate with the appropriate State Historic Preservation Office. This is necessary to identify their concerns, particularly at structures registered as Historic Structures, relative to the dam's appearance or historical integrity as a result of the proposed fish passage facilities/modifications. Although the Historic Preservation Offices are likely to support the goal of restoring historic anadromous fisheries, they are likely to have significant concerns at the dams.

11. Petition FERC to require fish passage facilities and any other appropriate project modifications at hydropower dams under their jurisdiction. This step should be performed by the states, in conjunction with the US Fish and Wildlife Service (USFWS). Recent legislation requires FERC to give equal consideration to both power generation and fish passage.

12. Determine the impact of the fish passage facilities on hydropower operations and the reciprocal impact of the operation of the turbines on fish passage. This step will require the cooperation of USFWS and the hydropower owners.

13. Perform final fish passage design and cost estimates. Approximate cost of Denil-type fishways, used by fish for upstream passage, are $15,000 to $20,000 for each vertical foot (difference between dam spillway and tailwater elevations). There are no rules-of-thumb for downstream fish passage costs as they are highly site-specific. Costs will likely be significantly impacted by any historic National Register status or canoe/boat portage that may be included.

14. Construct fish passage facilities at the lower four dams (Phase I).

15. Manage restored fish stocks to protect the newly-introduced fishes until a self-sustaining population has been established. This may include recreational or commercial harvest restrictions.

16. Establish a high level of involvement by the Massachusetts Division of Fisheries and Wildlife (MADFW) once Phase 1 is successfully completed. The MADFW has expressed an interest in extensive involvement at that time (personal communication, Mark Tisa, Ph.D., Assistant Director, Fisheries, 19 April 1994).

17. Re-introduce anadromous fish populations to stocking areas farther upstream (per the SAFRP) in order to document the viability of the fish in those areas.

18. Evaluate the effectiveness of the fish passage facilities to assure the cost effectiveness of future efforts.

19. Document progress in reaching the SAFRP production goals. An annual report should be prepared.

20. Review FERC permits to insure incorporation of fish passage

requirements in future licenses and/or exemptions.

21. Develop and implement a public support and involvement program to insure the long-term success of the anadromous fish restoration program.

22. Identify research needs/conduct needed studies on matters such as the evaluation of potential shad and river herring habitat in Massachusetts or the potential Atlantic salmon habitat in the Blackstone River watershed. Studies and associated costs should be identified early in the process to assure that the studies receive funding.

BLACKSTONE RIVER ANADROMOUS FISHERIES HABITAT ACREAGE AND POPULATION PREDICTIONS

DAM NUMBER AND NAME	HABITAT ACREAGE TO NEXT DAM	CUMULATIVE HABITAT ACREAGE	PREDICTED[1] ALEWIFE/BLUEBACK POPULATION SIZE	NET POPULATION INCREASE ABOVE EACH DAM
1) Main Street	1.18	1.18	3,719.9	3,719.9
2) Slater Mill	13.67	14.85	22,065.93	18,346.03
3) Webbing Mills	23.79	38.64	43,220.09	21,154.16
4) Valley Falls	109.08	147.72	110,946.69(139,995.21)[2]	67,726.60(96,775.12)[2]
5) Pratt (passable)	57.92	205.64	139,995.21	29,048.52
6) Ashton	35.28	240.92	156,478.67	16,483.46
7) Albion	39.69	280.61	177,230.20	20,751.33
8) Manville	103.65	384.26	217,265.13	40,034.93
9) Woonsocket Falls	42.92	427.18	234,055.04	16,789.91
10) Bridge Street	33.22	460.40	246,707.67	12,652.63

Population estimates adapted from Gibson, 1984. $P=3311.3(A^{.703})$, where A = total habitat acreage and P = total population size.

1-Method assumes 100 percent fish passage above dams/fish ladders.
A 5-10 percent mortality is considered reasonable.

2-The figure in parentheses is a prediction of potential population
size upstream of Valley Falls Dam and assumes fish passage through Pratt Dam.

Gibson, M. R. 1984. On the relationship between stock size and production area in anadromous alewives. RI Dept. Env. Mgmt., Div. Fish and Wildlife, Research Reference Document 84/2. 10 pp.

United States Department of the Interior

FISH AND WILDLIFE SERVICE
300 Westgate Center Drive
Hadley, Massachusetts 01035-9589

In Reply Refer To:
FWS/Region-5/BA-EN

March 11, 1997

Mr. William Mullen
New England Division
U. S. Army Corps of Engineers
Planning Division
424 Trapelo Road
Waltham, Massachusetts 02254

Dear Mr. Mullen:

The purpose of this letter is to transmit to your office the enclosed cost estimates for both upstream and downstream fish passage at each of the lowermost 4 barriers on the Blackstone River in Rhode Island that are currently being investigated under your "General Investigation of Environmental Restoration of the Blackstone River Watershed". The conceptual plans for fish passage at each of these four projects have been forwarded under separate cover. These four projects are listed by Federal Energy Regulatory Commission (FERC) file numbers in upstream order as follows:

NAME	FERC #	TYPE
Main Street (Pawtucket 2)	3689	Exemption - 7/21/81
Slater Mill	No Hydro	
Elizabeth Webbing Co.	3037	Order Issuing License 7/13/81
Valley Falls	3063	Order Issuing License 8/28/81

These conceptual plans were initially requested by your office in a letter dated December 12, 1996. A cost estimate for Service engineering staff to complete the conceptual designs was provided by letter dated Jan 2, 1997. On January 9, 1997, we received a formal notice from your office to proceed. The conceptual construction estimate for fishways to pass American shad and river herring upstream and downstream from the dams at the 4 locations is $2,205,000.

If you need any additional information on these cost estimates or the conceptual plans for fish passage at these barriers, please contact Dick Quinn at our Engineering Field Office in Newton Corner, MA. His telephone number is (617) 244-0837.

Sincerely,

David Wesley

for Vincent F. Gasbarro
Regional Engineer

Enclosure

cc: M. Grader, USFWS, NEFO(ES)
G. Mannesto, USFWS, RIFO(ES)
J. O'Brien, RIF&W
L. Stolte, CNEAFC

BLACKSTONE RIVER RESTORATION COST ESTIMATE AND DESIGN INFORMATION FOR FISHWAYS

At each of the four dams, the Service has recommended that a Denil fishway (4' wide, 1 on 8 slope) be constructed for upstream passage of American shad and river herring. Under normal flow conditions, each fishway passes approximately 10 cfs (at a 30 inch depth of water passing down the fishway), and at high flows (a 4-foot depth of water passing down fishway), it will pass about 35 cfs. These relatively small volumes of flow are not adequate to assure fish passage up the diverted reaches created by the three hydroprojects. Additional flow must be passed at the dams immediately above each of the hydroprojects. The enclosed plans specify the additional flow requirements for each of the bypass reaches of the Blackstone River.

At each of the three hydroprojects where downstream passage facilities are required, the Service has recommended using a standard downstream migrant bypass facility in conjunction with a 1" clear spaced trash rack, overlay or punched plate overlay. The overlay needs to be in place only during the downstream migration period which is generally from late summer to early fall. The existing trash rack configurations and site conditions at each of the three projects preclude usage of an angled trash rack set at a 45° (horizontal) angle to the direction of flow. For these sites, an attraction and conveyance flow of 40 to 45 cfs is recommended to be passed down the bypass facility. In addition to applying the overlays in the headpond for downstream fish passage, tailrace barrier (diversion) screens are recommended at the Elizabeth Webbing and Valley Falls Hydroprojects to exclude the upstream migrating adult alosa.

There are no detailed topographic survey data at any of the project sites within the waterway. More detailed survey is required prior to completing final designs at each of the sites, particularly at the Main Street Dam. At that project, there are some very large ledge outcrops that appear to support the old 30' wide arch bridge portion of Main Street. In addition, a very large piece of ledge is in the river channel below the arch section of Main Street. Conceptual plans place the entrance channel to the fishway immediately downstream of this ledge outcrop in a position where the ledge will provide non-overflow protection. Additionally, the top of this ledge outcrop has to be surveyed to determine the exact course of the upper portion of the Denil fishway. The additional survey may result in some realignment of the fishway.

From a fish passage standpoint at the Slater Mill Dam, the preferred location for the fishway would be on the right abutment looking downstream. The proposed fishway would be located on left abutment for reasons of access and preservation of the Slater Mill Historical Complex.

The Service has not been able to confirm information regarding the hydroproject at Valley Falls Dam. The license conditions issued August 28, 1981 by the FERC for this project do not reflect what is presently on site. That license was for two 409 kilowatt turbines located in the basement of the south mill building (now a senior citizens housing unit). The present project has a new powerhouse with what appears to be two horizontal bulb units located between the two housing units. Attempts to contact the licensee and FERC have not yet produced needed information on capacity and site conditions. As soon at this information is received, Mr. Quinn from Service Engineering staff will forward copies to you and discuss what impact, if any, it will have on our proposed conceptual plans.

It should be reemphasized that in the license conditions for all three hydroprojects, there are statements or articles that require the licensee to provide the necessary fish passage facilities at the respective project. There are likewise articles or conditions that cover minimum flows to be passed down the diverted reach.

The estimated costs for each of the four projects are as follows:

		(1997 $)
Main Street Dam:		
Upstream Fishway -		
20' lift (difference in entrance & exit channels)		
Approx length of fishway walls - 270'		600,000
Downstream Fishway		
standard bypass - 4' wide		
30' punched plate overlay		
10' open flume		50,000
	TOTAL	650,000
Slater Mill Dam		
Upstream Fishway (no downstream fishway needed)		
6.5' lift		
approx length of fishway walls - 104'		175,000
	TOTAL	175,000
Elizabeth Webbing Company Dam		
Upstream Fishway		
11.25' lift		
approx length of fishway walls - 155'		275,000
Downstream Fishway		
Standard bypass - 4' wide		
140' of 30" ∅ smooth pipe		
40' of punched plate & rack		
Tailrace Screen		150,000
	TOTAL	425,000
Valley Falls Dam		
Upstream Fishway		
8.75' lift		
approx length of fishway walls - 130'		225,000
Downstream Fishway		
Standard bypass - 4' wide		
40' of 30" ∅ smooth pipe		
30' of punched plate		
Tailrace Screen		100,000
	TOTAL	325,000
	Direct Cost Total:	$1,575,000

This estimate does not include any Contingencies, Engineering & Design, Supervision & Administration, Construction Management, Permits, or any borings. Contingencies for this project are estimated to be 15 percent. Typical E&D & S&A are estimated to be about 25 percent for a project of this scale. At least several borings at each site would be required, with the exception of Main Street where several addition holes would likely be required. Each bore hole runs about $5,000. These costs reflect 1997 conditions.

Therefore, with the Contingencies and Engineering & Administration percentages applied, the total estimated construction cost for the 4 fishways would be $2,205,000.

The annual Operation and Maintenance Cost for each project is estimated to be between $5,000 to $15,000.

1.3 Contaminant Levels in Fish

Results of MADEP analysis of edible fillets of fish from the Blackstone River basin for selected metals, PCBs, and organochlorine pesticides is summarized in Table 1.3-1 and 1.3-2. These tables are adapted from Appendix D of the draft Blackstone River Initiative report. Details concerning sampling methods and laboratory analysis are provided in the draft report.

Cadmium was below detection levels in all samples. Arsenic, chromium, copper, and lead were below detection in most samples analyzed.. A sample from Waite Pond in Leicester (WPF93-6+7) had a mercury concentration which exceeded the United States Food and Drug Administrations' (USFDA) Action Level of 1.0 mg/kg. The average mercury concentration in Waite Pond was 0.817 mg/kg which is well above the Massachusetts Department of Public Health's (MDPH's) health based trigger level of 0.5 ppm. None of the fish from the Blackstone River had mercury concentrations in exceedance of the MDPH's "trigger level. Although chromium and lead were below method detection limits in most samples, high outliers (>1.2 mg/kg) were reported in nine samples for chromium and three samples for lead.

PCBs analysis resulted in the detection of PCB Arochlors 1254 and 1260 in many of the samples from the Blackstone River, however, PCBs were not present in samples from Waite Pond. Of the thirty-one fish analyzed from the Blackstone River, five samples had Total PCB concentrations which exceeded the USFDA's Action Level of 2.0 ppm. Four of these fish were common carp and one was a largemouth bass. Three additional fish had total PCB concentrations which were greater than 1 ppm. These concentrations were found in samples of white suckers.

PCBs while absent from Waite Pond and at fairly low concentrations in Fisherville Impoundment appear to be a problem further downstream on the Blackstone River. Concentrations increase dramatically between Fisherville Impoundment and Riverdale Impoundment, the next major impoundment downstream. While there is potentially a source somewhere between these two locations, it must be noted that the dam at Fisherville Impoundment was open and the Fisherville station was more like a stream station than a true impoundment.

In June of 1994, the MDPH issued advisories regarding the PCB contamination. The advisories were issued for Riverdale Pond, Rice City Pond, and the Blackstone River Impoundment above Blackstone Gorge (Tupperware). The first part of each advisory is consistent and reads: " 1. Children under 12, pregnant women and nursing mothers should refrain from consuming any fish ... in order to prevent exposure of developing fetuses, nursing infants and young children to PCBS." The second recommendation of the advisories is somewhat variable. The Riverdale Pond advisory goes on to recommend that "2. The general public should limit consumption of Riverdale Pond fish to two meals per month." The Rice City Pond advisory goes on to recommend that "2. The general public should refrain from consumption of Rice City Pond carp." and the Blackstone River Impoundment above the Blackstone Gorge recommends that "2. The general public should refrain from consumption of Blackstone River Impoundment above the Blackstone Gorge carp and white suckers."

Organochlorine pesticides were not detected in any samples. Pesticides analyzed for included Aldrin, BHC, Lindane, DDD, DDE, DDT, Dieldrin, Endosulfan, Endosulfan sulfate, Endrin, Endrin aldehyde, Heptachlor, Heptachlor epoxide, Methoxychlor, Toxaphene, Chlordane, Hexachlorocyclopentadiene, Hexachlorobenzene, and Trifurlin

TABLE 1.3-1: Results of Metal Analysis

Sample Code	Species Code	Sample Type	Metals Concentrations (mg/kg wet weight)						
			As	Cd	Cr	Cu	Hg	Pb	Se
Waite Pond									
WPF93-1	LMB	I	0.04	bdl[3]	1.2	0.6	0.810	bdl	0.26
WPF93-2	LMB	I	bdl	bdl	bdl	bdl	0.938	bdl	0.19
WPF93-3-5	LMB	C	0.10	bdl	1.2	bdl	0.948	bdl	0.21
WPF93-6+7	BB+YB	C	bdl	bdl	1.2	bdl	1.04	bdl	0.24
WPF93-8+9	WP	C	bdl	bdl	bdl	1.4	0.660	bdl	0.34
WPF93-10-12	YP	C	bdl	bdl	bdl	bdl	0.869	bdl	0.24
WPF93-13-17	B	C	bdl	bdl	bdl	0.6	0.457	bdl	0.28
Fisherville Pond (37.0)									
BRF93-60	C	I	bdl	bdl	bdl	0.8	0.102	bdl	0.42
BRF93-61	WS	I	bdl	bdl	bdl	bdl	0.178	bdl	0.22
BRF93-62-64	WS	C	0.06	bdl	bdl	bdl	0.179	bdl	0.40
BRF93-65	YB	I	bdl	bdl	bdl	0.8	0.291	2.2	0.16
BRF93-66	LMB	I	bdl	bdl	bdl	bdl	0.280	bdl	0.20
BRF93-67	LMB	I	bdl	bdl	bdl	bdl	0.302	bdl	0.11
BRF93-68+69	LMB	C	0.085	bdl	bdl	bdl	0.179	bdl	0.14
BRF93-70-74	YP	C	bdl	bdl	1.2	bdl	0.074	bdl	0.65
BRF93-75-79	B	C	bdl	bdl	bdl	bdl	0.173	bdl	0.27

Results of Metals Analysis (continued)

Riverdale Impoundment (32.0)

BRF93-100	C	I	bdl	bdl	bdl	bdl	0.081	bdl	0.38
BRF93-101-105	B	C	bdl	bdl	bdl	bdl	0.156	bdl	0.29
BRF93-106-110	YP	C	0.08	bdl	bdl	bdl	0.070	bdl	0.60
BRF93-111+112	BB	C	bdl	bdl	bdl	bdl	0.081	bdl	0.11
BRF93-113	LMB	I	bdl	bdl	bdl	bdl	0.155	bdl	0.30
BRF93-114+115	LMB	C	bdl	bdl	2.8	bdl	0.149	bdl	0.28
BRF93-116	WS	I	bdl	bdl	bdl	bdl	0.058	bdl	0.15
BRF93-117-119	WS	C	0.06	bdl	bdl	bdl	0.059	bdl	0.46

Rice City Pond (28.0)

BRF93-50	C	I	bdl	bdl	bdl	1.0	bdl	bdl	0.45
BRF93-51	C	I	0.06	bdl	bdl	bdl	0.042	bdl	0.46
BRF93-52	WS	I	bdl	bdl	bdl	bdl	0.094	bdl	0.31
BRF93-53	WS	I	0.07	bdl	1.4	bdl	0.118	bdl	0.36
BRF93-54-56	WS	C	0.08	bdl	bdl	bdl	0.086	bdl	0.42
BRF93-57	YB	I	bdl	bdl	bdl	0.8	0.160	bdl	0.23
BRF93-58	B	I	0.09	bdl	bdl	bdl	0.077	bdl	0.20

Tupperware Impoundment (18.2)

BRF93-1	C	I	bdl	bdl	bdl	1.0	0.068	bdl	0.35
BRF93-2	LMB	I	bdl	bdl	0.6	bdl	0.479	bdl	0.16
BRF93-3	LMB	I	bdl	bdl	bdl	bdl	0.487	1.8	0.15
BRF93-4-6	LMB	C	0.06	bdl	1.2	bdl	0.316	bdl	0.12

TABLE 1.3-2: Results of PCB, Organochlorine Pesticide, and % Lipids Analysis

Station (river mile)	Sample Code	Species Code	Sample Type	% Lipids	PCBs (mg/kg) 1254	PCBs (mg/kg) 1260
Waite Pond	WPF93-1	LMB	I	0.12	<MDL	<MDL
	WPF93-2	LMB	I	1.8	<MDL	<MDL
	WPF93-3-5	LMB	C	0.07	<MDL	<MDL
	WPF93-6+7	YB,BB	C	0.26	<MDL	<MDL
	WPF93-8+9	WP	C	0.51	<MDL	<MDL
	WPF93-10-12	YP	C	0.13	<MDL	<MDL
	WPF93-13-17	B	C	0.07	<MDL	<MDL
Fisherville Pond	BRF93-60	C	I	0.47	0.16	0.20
(37.0)	BRF93-61	WS	I	1.3	0.38	0.33
	BRF93-62-64	WS	C	0.84	0.20	0.19
	BRF93-65	YB	I	0.28	<MDL	0.14
	BRF93-66	LMB	I	0.14	<MDL	0.11
	BRF93-67	LMB	I	0.32	<MDL	<MDL
	BRF93-68+69	LMB	C	0.13	<MDL	<MDL
	BRF93-70-74	YP	C	0.15	<MDL	<MDL
	BRF93-75-79	B	C	0.12	<MDL	<MDL
Riverdale Impoundment	BRF93-100	C	I	1.6	1.1	1.5
(32.0)	BRF93-101-105	B	C	0.20	<MDL	<MDL
	BRF93-106-110	YP	C	0.21	<MDL	<MDL
	BRF93-111+112	BB	C	0.08	<MDL	0.18
	BRF93-113	LMB	I	0.40	1.4	1.4
	BRF93-114+115	LMB	C	0.27	0.39	0.48
	BRF93-116	WS	I	1.1	0.48	0.55
	BRF93-117-119	WS	C	0.70	0.44	0.50

Results of PCB, Organochlorine Pesticide, and % Lipids Analysis (continued)

Station (river mile)	Sample Code	Species Code	Sample Type	% Lipids	PCBs (mg/kg) 1254	1260
Rice City Pond (28.0)	BRF93-50	C	I	1.5	2.0	2.0
	BRF93-51	C	I	4.4	2.3	2.1
	BRF93-52	WS	I	0.50	0.57	0.21
	BRF93-53	WS	I	0.26	0.11	0.13
	BRF93-54-56	WS	C	1.1	0.56	0.47
Tupperware Impoundment (18.2)	BRF93-1	C	I	3.9	2.4	2.3
	BRF93-2	LMB	I	0.20	<MDL	0.31
	BRF93-3	LMB	I	0.13	<MDL	0.19
	BRF93-4-6	LMB	C	0.12	<MDL	0.15
	BRF93-7	CP	I	0.11	<MDL	<MDL
	BRF93-8-11	BB	C	0.60	<MDL	<MDL
	BRF93-12-16	B	C	0.21	<MDL	0.26
	BRF93-17-20	YP	C	0.12	<MDL	<MDL
	BRF93-21-23	WS	C	0.78	0.80	1.0

[1]The following organochlorine pesticides were below detection in all samples analyzed: Aldrin, BHC< Lindane, DDD, DDT, DDE, Dieldrin, Endosulfan, Endosulfan Sulfate, Endrin, Endrin aldehyde, Heptachlor, Heptachlor epoxide, Methoxychlor, Toxaphene, Chlordane, Hexachlorocyclopentadiene, Hexachlorobenzene, and Trifurlin.

[2] C: carp; WS: white sucker; LMB: large mouth bass; CP: chain pickerel; BB: brown bullhead; YP: yellow perch
B: bluegill sunfish

[3]I = Individual
C = Composite

1.4 **Benthic Macroinvertebrates (Basin Overview)**

Bottom-dwelling ("benthic") species of invertebrates are known as "benthos" or "benthic macroinvertebrates" in an aquatic ecosystem. Benthic macroinvertebrates are those organisms that can be seen with the naked eye and are typically the subject of all benthos investigations. Benthic macroinvertebrates include organisms which inhabit the substrate surface or burrow within sediments for food or shelter (Odum 1971). The occurrence, density, and distribution of invertebrates is indicative of the overall water quality of aquatic ecosystems (Plafkin et al. 1989; APHA 1989). Furthermore, benthic macroinvertebrates function as strong indicators of extant environmental (local) conditions as many taxa have limited migration patterns and are excellent indicators of existing conditions due to relatively short life cycle of larval stages (Plafkin et al. 1989). Natural factors may also influence the type and abundance of benthic macroinvertebrates on a seasonal basis. Natural and/or factors such as streamflow fluctuations, water temperature, dissolved oxygen, anaerobic sediments, organic loading to the system, and chemical contamination are all important in structuring benthic communities. Macroinvertebrate communities are inherently variable, particularly seasonally, but also on shorter (e.g. monthly) and longer (e.g. annual) scales. In addition, macroinvertebrate communities are spatially variable, often occurring in "patches" of varying size. Consequently, the use of macroinvertebrates as an assessment tool must be approached cautiously, and that often the level of effort necessary (i.e. comprehensive surveys) to obtain meaningful information that incorporates natural and spatial variation is considerable.

Benthic macroinvertebrates feed primarily on aquatic vegetation (e.g. periphyton, submerged aquatic vegetation) and detritus (e.g. coarse particulate organic matter as leaf litter) and in turn become one of the lower trophic levels of the riparian/aquatic food chain. Benthic invertebrates are widely recognized for the important role they play in the aquatic food web. These creatures are eaten by larger invertebrates, crustaceans, finfish, wading birds, amphibians, turtles, and even some mammals. Therefore, a healthy benthos is essential to a healthy aquatic ecosystem. Benthos are most affected by toxic substances, water-borne sediments, and loss of microhabitat and vegetation. Different species comprising the benthos are affected by these factors to differing degrees. Therefore, the benthic quality of an aquatic ecosystem is a yardstick by which to measure/assess current water quality and habitat quality (e.g. substrate particle size) and the success of any effort to improve these parameters. They also influence nutrient and toxic dynamics through bioturbation and other processes (Diaz and Schaffner 1990).

Results of a comprehensive biomonitoring survey of the Blackstone River and selected tributaries undertaken by the Massachusetts Division of Water Pollution Control's Technical

Services Branch as part of a June 1985 water quality investigation revealed benthos that indicated some of the worst water quality to be found in Massachusetts inland streams (Johnson et al. 1992). However, data on benthic macroinvertebrate populations collected in 1991 during the comprehensive Blackstone River Initiative, compared with data collected in 1985, showed improvements at most stations (USEPA et al. 1991). Additional improvements in benthic macroinvertebrate populations are expected due to continued improvements in wastewater treatment facilities (e.g. the Upper Water Pollution Abatement District added dechlorination of its wastewater in the fall of 1993) and basin wide efforts to reduce non-point source pollution.

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Section 2.0

Wildlife

TABLE 2-1

Mammals Likely to Occur in the Blackstone River Basin

Common Name	Scientific Name	Status	Wet[1]
Insectivora			
Masked Shrew	*Sorex cinereus*	C/U	*
Water Shrew	*Sorex palustris*	U	*
N. Short-tailed Shrew	*Blarina brevicauda*	C	
Smoky Shrew	*Sorex fumeus*	LC/U	
Eastern Mole	*Scalopus aquaticus*	LC	
Hairy-tailed Mole	*Parascalops breweri*	LC	
Star-nosed Mole	*Condylura cristata*	C/U	*
Chiroptera			
Red Bat	*Lasiurus borealis*	U/R	
Hoary Bat	*Lasiurus cinereus*	R	
Keen Myotis	*Myotis keeni*	C/U	*
Little Brown Myotis	*Myotis lucifugus*	C	*
Silver-haired Bat	*Lasionycteris noctivagans*	U/R	*
Eastern Pipistrelle	*Pipistrellus subflavus*	U/R	*
Big Brown Bat	*Eptesicus fuscus*	C	*
Marsupialia			
Virginia Opossum	*Didelphis virginians*	C/U	*
Lagomorpha			
Snowshoe Hare	*Lepus americanus*	C	*
Eastern Cottontail	*Sylvilagus floridanus*	A	*
N.E. Cottontail	*Sylvilagus transitionalis*	U/R	*
Rodentia			
Beaver	*Castor canadensis*	C	*
Eastern Chipmunk	*Tamias striatus*	C	
White-footed Mouse	*Peromyscus lencopus*	C	
S. Bog Lemming	*Synaptomys cooperi*	U	*
House Mouse	*Mus musculus*	A	
Meadow Jumping Mouse	*Zapus hudsonius*	LC	*
Muskrat	*Ondatra zibethica*	C/U	*
Porcupine	*Erethizon dorsatum*	C/U	
Norway Rat	*Rattus norvegicus*	C	
Gray Squirrel	*Sciurus carolinensis*	C/A	
Red Squirrel	*Tamiasciurus hudsonicus*	C/U	
S. Flying Squirrel	*Glaucomys volans*	C/U	
S. Red-backed Vole	*Clethrionomys gapperi*	C	
Meadow Vole	*Microtus pennsylvanicus*	A	
Woodland Vole	*Microtus pinetorum*	C/U	
Woodchuck	*Marmota monax*	C	

TABLE 2-1

Continued.

Common Name	Scientific Name	Status	Wet[1]
Carnivora			
Long-tailed Weasel	*Mustela frenata*	C/U	
Ermine	*Mustela erminea*	C/U	
Fisher	*Martes pennanti*	C/U	
Mink	*Mustela vision*	C/U	*
River Otter	*Lotra canadensis*	U	*
Striped Skunk	*Mephitis mephitis*	C	
Coyote	*Canis latrans*	U/C	
Red Fox	*Vulpes vulpes*	C/U	
Gray Fox	*Urocyon cinereoargenteus*	C/U	
Racoon	*Procyon lotor*	C	*
Bobcat	*Felis rufus*	C/U	
Artiodactyla			
White-tailed Deer	*Odocoileus virginianus*	C	

Notes:

1. *: Strongly associated with wetland habitats.
2. Based on DeGraaf and Rudis (1986).
3. Legend:
   - A - abundant
   - C - common
   - U - uncommon
   - D - declining
   - R - rare
   - T - threatened
   - LA - locally abundant
   - LC - locally common

TABLE 2-2

Reptiles and Amphibians Known to Occur in the Blackstone River Basin

Common Name	Scientific Name	Status	Wet*
Salamanders and Newts			
Blue-spotted Salamander	*Ambystoma laterale*	T	*
Jefferson Salamander	*Ambystoma jeffersonianum*	LC/R	*
Marbled Salamander	*Ambystoma opacum*	U	*
Spotted Salamander	*Ambystoma maculatum*	C	*
Red-spotted Newt	*Notophthalmus v.viridescens*	C	*
N. Dusky Salamander	*Desmognathus f.fuscus*	C/A	*
Redback Salamander	*Plethodon cinereus*	A	
Four-toed Salamander	*Hemidactylium scutatum*	U/R	*
N. Spring Salamander	*Gyrinophilur piporphyriticus*	U/R	*
N. Two-lined Salamander	*Eurycea bibislineata*	C/A	*
Frogs and Toads			
Eastern American Toad	*Bufo a. americanus*	C	
Fowler's Toad	*Bufo woodhousii fowler*	U/LA	*
Gray Treefrog	*Hyla versicolor*	C	*
Northern Spring Peeper	*Hyla c. crucifer*	C/A	*
Bullfrog	*Rana cates beiano*	C	*
Green Frog	*Rana clamitans melanota*	C	*
Northern Leopard Frog	*Rana pipiens*	LC	*
Pickerel Frog	*Rana palustris*	LC	*
Wood Frog	*Rana sylvatica*	C	*
Turtles			
Common Snapping Turtle	*Chelydra s. serpentina*	C	*
Stinkpot	*Sternotherus odoratus*	C	*
Wood Turtle	*Clemmys insculpta*	C/D	*
Spotted Turtle	*Clemmys guttata*	U/R	*
Eastern Box Turtle	*Terrapene c. carolina*	LC	*
Painted Turtle	*Chrysemys p. picta*	C/A	*
Blandings Turtle	*Emydoidea blandingii*	S/LA	*
Snakes			
Northern Brown Snake	*Storeria d. dekayi*	C	
Northern Water Snake	*Nerodia s. sipedon*	C	*
Northern Redbelly Snake	*Storeria o. occipitomaculata*	LA	
Eastern Garter Snake	*Thamnophis s. sirtalis*	A	
Eastern Ribbon Snake	*Thamnophis s. sauritus*	C	*
Northern Ringeck Snake	*Diadophis punctatus edwards*	C	
Northern Black Racer	*Coluber c. constrictor*	LA	
E. Smooth Green Snake	*Opheodrys v. vernalis*	C	
Eastern Milk Snake	*Lampropeltis t. triangulum*	C	

Notes: see Table 2-1

TABLE 2-3

Breeding Birds Likely to Occur in the Blackstone River Basin.

Common Name	Scientific Name	Wetland*
Green-backed Heron	*Butorides striatus*	*
Great Blue Heron	*Ardea herodias*	*
American Bittern	*Botaurus leutiginosus*	*
Canada Goose	*Branta canadensis*	*
Mallard Duck	*Anas platyrhynchos*	*
American Black Duck	*Anas rubripes*	*
Wood Duck	*Aix sponsa*	*
Pied-billed Grebe	*Podilymbus podiceps*	*
Blue-winged Teal	*Anas discors*	*
Virgninia Rail	*Rallus limicola*	*
Sora Rail	*Porzana carolina*	*
Killdeer	*Charadrius vociferus*	
American Woodcock	*Scolopax minor*	
Spotted Sandpiper	*Actitis macularia*	
Solitary Sandpiper	*Tringa solitaria*	
Greater Yellowlegs	*Tringa melanoleeica*	
Broad-winged Hawk	*Buteo platypterus*	
Northern Harrier	*Circus cyaneus*	*
Red-tailed Hawk	*Buteo jamaicensis*	
American Kestrel	*Falco sparverius*	
Great-horned Owl	*Bubo virginianus*	
Wild Turkey	*Meleagris gallopavo*	
Ruffed Grouse	*Bonasa umbellus*	
Ring-necked Pheasant	*Phasianus colchicus*	
Wild Turkey	*Meleagris gallopavo*	
Ruby-throated Hummingbird	*Archilochus colubris*	
Belted Kingfisher	*Ceryle alcyon*	*
Northern Flicker	*Colaptes auratus*	
Downy Woodpecker	*Picoides pubescens*	
Hairy Woodpecker	*Picoides villosus*	
Eastern Kingbird	*Tyrannus tyrannus*	
Eastern Phoebe	*Sayornis phoebe*	
Great Crested Flycatcher	*Myiarchus crinitus*	
Least Flycatcher	*Empidonax minimus*	*
Cliff Swallow	*Hirundo purrhonota*	*
Barn Swallow	*Hirando rustica*	
Tree Swallow	*Tachycineta bicolor*	*
Blue Jay	*Cyanocitta cristata*	
American Crow	*Corvus brachyrhynchos*	
Black-capped Chickadee	*Parus atricapillus*	
Red-breasted Nuthatch	*Sitta canadensis*	
White-breasted Nuthatch	*Sitta carolinensis*	
Tufted Titmouse	*Parus bicolor*	*

TABLE 2-3

Continued.

Common Name	Scientific Name	Wetland*
House Wren	*Troglodyfes aedon*	
Marsh Wren	*Cistothorus palustris*	*
Golden-crowned Kinglet	*Regulus satrapa*	
Grey Catbird	*Dumetella carolinensis*	*
American Robin	*Turdus migratorius*	
Eastern Bluebird	*Sialis sialis*	
Northern Mockingbird	*Mimus polyglottus*	
Hermit Thrush	*Catharus guttatus*	
Wood Thrush	*Hylocichla mustelina*	
Veery	*Catharus fuscescens*	*
European Starling	*Sturnus volgaris*	
Red-eyed Vireo	*Vireo olivaceus*	*
Black-throated Blue Warbler	*Dendroica caerulescens*	*
Black-throated Green Warbler	*Dendroica virens*	
Chestnut-sided Warbler	*Dendroica penylvanica*	*
Magnolia Warbler	*Dendroica magnolia*	
Nashville Warbler	*Vermivora ruficapilla*	
Yellow Warbler	*Dendroica petechia*	*
Ovenbird	*Seiurus aurocapillus*	
Wood Thrush	*Hylocichla mustelina*	*
Common Yellowthroat	*Geothlypis trichas*	*
American Redstart	*Setophaga ruticilla*	*
Scarlet Tanager	*Piranga olivacea*	
Indigo Bunting	*Passerina cyanea*	*
Northern Carninal	*Cardinalis cardinalis*	*
Eastern Meadowlark	*Sturnella magna*	
Red-winged Blackbird	*Agelaius phoeniceus*	*
Common Grackle	*Quiscalus guiscula*	*
Brown-headed Cowbird	*Molothrus ater*	
Northern (Baltimore) Oriole	*Icterus galbula*	
Scarlet Tanager	*Piranga olivacea*	
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	
Purple Finch	*Carpodacus purpureus*	
Evening Grosbeak	*Coccothraustes vespertinus*	
American Goldfinch	*Carduelis tristis*	*
Rufous-sided Towhee	*Pipilo erythrophthalmus*	
American Tree Sparrow	*Spizella arborea*	
Chipping Sparrow	*Spizella passerina*	
Field Sparrow	*Spizella pusilla*	
House Sparrow	*Passer domesticus*	
Song Sparrow	*Melospiza melodia*	*
Swamp Sparrow	*Melospiza georgiana*	*
White-throated Sparrow	*Zonotrichia albicollis*	
Dark-eyed Junco	*Junco hyemalis*	
Mourning Dove	*Zenaida macroura*	

*: Species strongly associated with wetland habitat.

Table 2-4

MADFW Waterfowl Banding Records for the Blackstone River Basin

Fisherville Pond

	Species Banded									
Year	MALL	ABDU	MXB	WODU	AGWT	BWTE	VIRA	SORA	COMO	AMCO
1967	23	12	9	2	2	1				
1968	55	31	5	12	5					
1969	12	4	4	3	1	1	1	9	1	1
1970	4	3	1	1		1		2	1	4
1971*	6	5	2	1				2	1	1
1972	36	4	5	8	8			1		
1973	no banding due to budget constraints									
1974	no banding due to budget constraints									
1975*	29	34	6	11	3	4	2	7	5	
1976	64	21	9	28	9	15	3	1		
1977*	10	8		3		1		1		
1978	27	3		26	4	1				
1979	22	2		21		1		2		
1980	36	1		14	3	2		1		
1981	86	15	4	29	6					
1982	area drained, no further banding done									

Lackey Pond

	Species Banded									
Year	MALL	ABDU	MXB	WODU	AGWT	BWTE	VIRA	SORA	COMO	AMCO
1976	9	12	5	3			2		3	
1977*	20	19		15						
1978	39	11	2	15						
1979	21	19	1	16						
1980	37	14		35						
1981	18	1		20						
1982	area drained, no banding done									
1983	45	17	4	53	1					
1984	6	4		6						
1985	55	31	1	75	9	4		2		
1986*	23	7		26	1					
1987	26	5	1	8			(bait trapping only)			
1988*	10	8	2	114	17					
1989	13	1	1	58	5	1		1		
1990	10	4		7	17	1	(low water)			
1991	dam leaking, water too low to airboat									
1992	dam leaking, water too low to airboat									
1993	dam leaking, water too low to airboat									

Table 2-4

Continued.

Rice City Pond

Year	MALL	ABDU	MXB	WODU	AGWT	BWTE	VIRA	SORA	COMO	AMCO
				Species Banded						
1975	28	35	1	15	4	18	1	2		
1977	3	1	2							
1978	1		1	13		1	(bait trapping only)			
1979	4	8	1	35		4	(bait trapping only)			
1980	1			8		4	(bait trapping only)			
1981				41			(bait trapping only)			
1982	54	13	5	17			(bait trapping only)			
1983	33	11		113		1	(bait trapping only)			
1984	38	12	1	23	1	2	(bait trap & airboat)			
1985	142	39	7	73	2	1	(bait trap & airboat)			
1986*	33	5	1	32				3 (bait & boat)		
1987	9			32			(bait trapping only)			
1988*				9						
1989	7		2	42	7			1		
1990	9	1		21				2		
1991	17			78	3			2		
1992	15		1	14	5					
1993				1				2		

* mechanical or equipment problems

MALL= mallard
ABDU= American black duck
MXB = mallard-black duck hybrid
WODU= wood duck
AGWT= American greenwinged teal
BWTE= bluewinged teal
VIRA= Virginia rail
SORA= sora rail
COMO= common moorhen
AMCO= American coot

Section 3.0

Rare and Protected Species

TABLE 3-1

Rare and Protected Species Known to Occur in the Blackstone River Basin - Massachusetts

Common Name	Scientific Name	Status	Wet*
Invertebrates			
Hessel's Hairstreak	*Mitoura hesseli*	SC	*
Northern Hairstreak	*Fixsenia favonius Ontario*	SC	*
Mystic Valley Amphipod	*Crangonyx aberrans*	SC	*
Smooth Branched Sponge	*Spongilla aspinosa*	SC	*
Reptiles and Amphibians			
Blue-spotted Salamander	*Ambystoma laterale*	SC	*
Marbled Salamander	*Ambystoma opacum*	T	*
Jefferson Salamander	*Ambystoma opacum*	SC	*
Spring Salamander	*Gyrinophilus porphyriticus*	SC	*
Wood Turtle	*Clemmys insculpta*	SC	*
Spotted Turtle	*Clemmys guttata*	SC	*
Eastern Box Turtle	*Terrapene c. carolina*	SC	
Fish			
American Brook Lamprey	*Lampetra appendix*	T	*
Birds			
Grasshopper Sparrow	*Ammodramus savannarum*	T	
Great Blue Heron	*Ardea herodias*	WL	*
Northern Harrier[2]	*Circus cyaneus*	T	*
Plants			
Climbing Fern	*Lygodium palmatum*	SC	*
Grass-leaved Ladies' Tresses	*Spiranthes vernalis*	SC	
Great Laurel	*Rhododendron maximum*	T	*
Large Whorled Pogonia	*Isotria vertcillata*	WL	
Pale Green Orchis	*Platanthera flava var. herbiola*	T	*
Papillose Nut-Sedge	*Scleria pauciflora*	E	
Philadelphia Panic Grass	*Panicum philadelphicum*	SC	*
Sclerolepis	*Sclerolepis uniflora*	E	*
Slender Cottongrass	*Eriophorum gracile*	T	*
Tall Nut-Sedge	*Scleria triglomerata*	E	*
Threadfoot	*Podostemum ceratophyllum*	SC	*
Tiny-Flowered Buttercup	*Ranunculus micranthus*	T	*

Notes:

1. E: endangered; T: threatened; SC: special concern; WL: watch list.

2. Noted at Fisherville Pond on two occassions during this study.

*: wetland dependent

Commonwealth of Massachusetts

Division of Fisheries & Wildlife

Wayne F. MacCallum, *Director*

7 April 1997

Michael Penko
U.S. Army Corps of Engineers
424 Trapelo Road
Waltham, MA 02254-9149

Re: Proposed Restoration Projects
Blackstone River Watershed
NHESP File: 97-1642

Dear Mr. Penko,

Thank you for contacting the Natural Heritage and Endangered Species Program for information regarding state-listed rare species in the vicinity of the above referenced site. I have reviewed the site and would like to offer the following comments.

The two sand and gravel pit areas indicated between the Providence and Worcester RR and Quaker Street in Upton fall just outside Estimated Habitat for the Spotted Turtle (Clemmys guttata) and Wood Turtle (Clemmys insculpta). The Rice City Pond site is located just north of Estimated Habitat for Spotted Turtle. The Spotted Turtle and the Wood Turtle are listed as species of Special Concern pursuant to the Massachusetts Endangered Species Act (MGL 131A) and its implementing regulations (321 CMR 10.00). Factsheets on both species are included for your information.

Also included is a list of species occurring within the Blackstone watershed and watershed map showing the Blackstone watershed. The numbers to the left of the scientific name column on the list correspond to the numbers on the watershed map.

This evaluation is based on the most recent information available in the Natural Heritage database, which is constantly being expanded and updated through ongoing research and inventory. Should your site plans change, or new rare species information become available, this evaluation may be reconsidered.

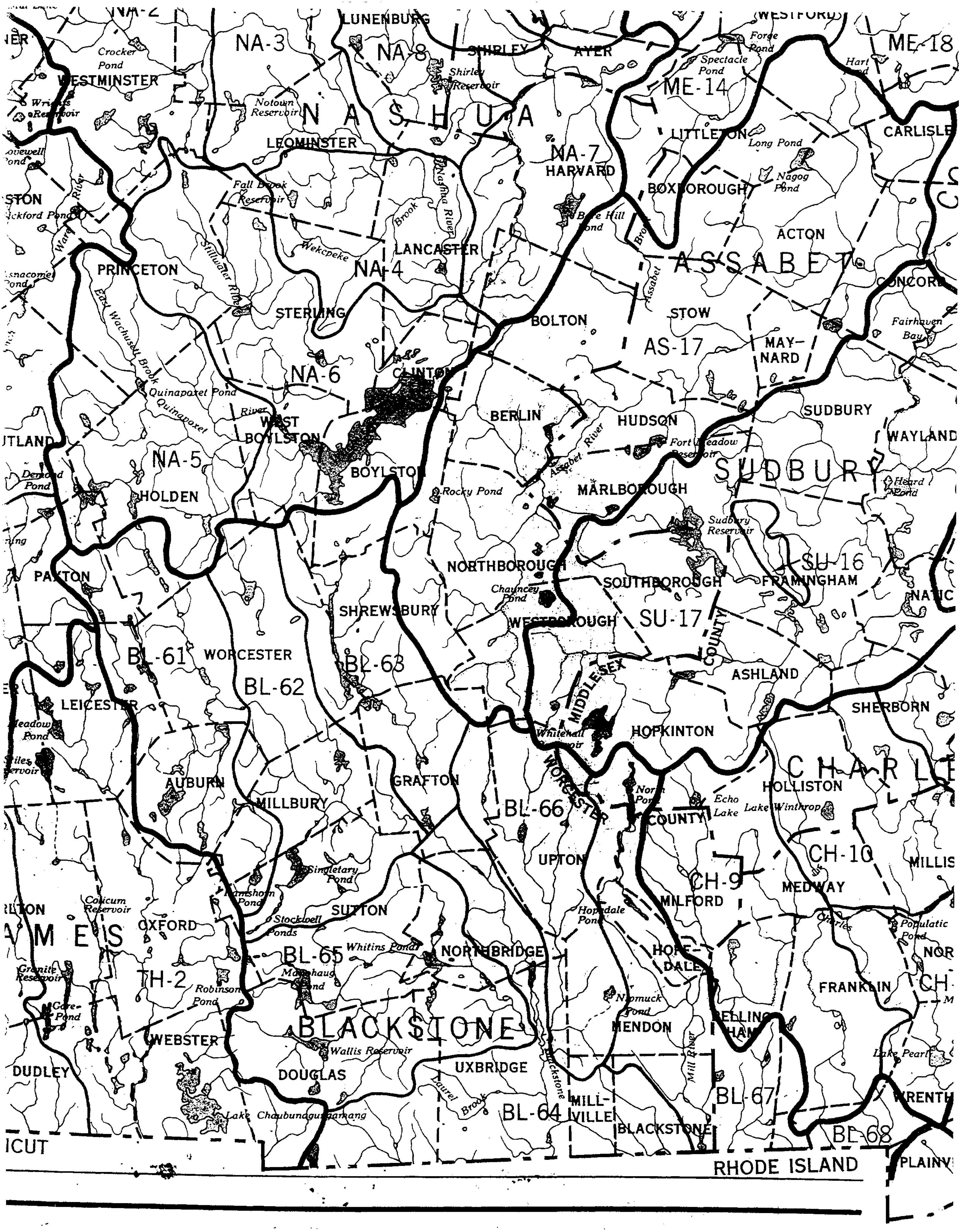
Please do not hesitate to call me at (508)792-7270 x.154 if you have any questions.

Sincerely,

Andrea Arnold

Andrea Arnold
Environmental Review Assistant

Natural Heritage & Endangered Species Program
Route 135, Westborough, MA 01581 **Tel:** (508) 792-7270 x 200 **Fax:** (508) 792-7275
An Agency of the Department of Fisheries, Wildlife & Environmental Law Enforcement
http://www.state.ma.us/dfwele


LUNENBURG
NA-3
NA-8
SHIRLEY
AYER
Forge Pond
Spectacle Pond
Crocker Pond
WESTMINSTER
Shirley Reservoir
ME-14
Notown Reservoir
NASHUA
LITTLETON
Long Pond
CARLISLE
LEOMINSTER
NA-7
HARVARD
Nagog Pond
BOXBOROUGH
Fall Brook Reservoir
Nashua River
Brook
Bare Hill Pond
ACTON
Wekepeke
LANCASTER
NA-4
ASSABET
PRINCETON
Stillwater River
Assabet
CONCORD
East Wachusett Brook
STERLING
BOLTON
STOW
Fairhaven Bay
AS-17
MAYNARD
NA-6
CLINTON
Quinapoxet Pond
Quinapoxet River
WEST BOYLSTON
BERLIN
HUDSON
SUDBURY
WAYLAND
Fort Meadow Reservoir
Assabet River
NA-5
BOYLSTON
SUDBURY
Heard Pond
Demond Pond
HOLDEN
Rocky Pond
MARLBOROUGH
Sudbury Reservoir
SU-16
NORTHBOROUGH
PAXTON
Chauncey Pond
SOUTHBOROUGH
FRAMINGHAM
SHREWSBURY
WESTBOROUGH
SU-17
COUNTY
BL-61
WORCESTER
BL-63
BL-62
MIDDLESEX
ASHLAND
LEICESTER
SHERBORN
Meadow Pond
Whitehall Reservoir
HOPKINTON
CHARLES
AUBURN
GRAFTON
HOLLISTON
WORCESTER
North Pond
Echo Lake
Lake Winthrop
MILLBURY
BL-66
COUNTY
CH-10
Singletary Pond
UPTON
CH-9
MEDWAY
Ramshorn Pond
MILFORD
Stockwell Ponds
SUTTON
OXFORD
Hopedale Pond
Charles
Populatic Pond
BL-65
Whitins Pond
NORTHBRIDGE
HOPEDALE
TH-2
Manchaug Pond
FRANKLIN
Robinson Pond
Nipmuck Pond
Gore Pond
BLACKSTONE
MENDON
WEBSTER
Wallis Reservoir
Mill River
Lake Pearl
DUDLEY
DOUGLAS
UXBRIDGE
Blackstone
Laurel Brook
BL-67
MILLVILLE
BL-64
BLACKSTONE
BL-68
RHODE ISLAND

Massachusetts Natural Heritage and Endangered Species Program
Division of Fisheries and Wildlife, Route 135, Westborough, MA 01581
Wetland species observed since 1980 in the Blackstone Watershed
May not include some data-sensitive species.

	Scientific Name	Common Name	DFW Rank	Fed Rank	Last Obs. Date
*** BL-61					
	AMBYSTOMA OPACUM	MARBLED SALAMANDER	T		1982-07-02
	AMBYSTOMA OPACUM	MARBLED SALAMANDER	T		1990-09-25
	AMMODRAMUS SAVANNARUM	GRASSHOPPER SPARROW	T		1993
	CERTIFIED VERNAL POOL		-		1991-09-25
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-08-05
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1990-06-16
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1991-04-13
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1991-05-18
	CLEMMYS INSCULPTA	WOOD TURTLE	SC		1990-09-22
	GYRINOPHILUS PORPHYRITICUS	SPRING SALAMANDER	SC		1994-05-29
	MITOURA HESSELI	HESSEL'S HAIRSTREAK	SC		1990-06-12
	RHODODENDRON MAXIMUM	GREAT LAUREL	T		1994-07-02
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1989-05
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1992-06-13
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1994-06-01
*** BL-62					
	CERTIFIED VERNAL POOL		-		1989-SPRG
	CERTIFIED VERNAL POOL		-		1989-SPRG
	CERTIFIED VERNAL POOL		-		1989-SPRG
	CERTIFIED VERNAL POOL		-		1989-SPRG
	CERTIFIED VERNAL POOL		-		1992-04
	CERTIFIED VERNAL POOL		-		1992-04
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1982-06-14
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1992-06-15
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1995-03-17
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1996
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1996-04
	CLEMMYS INSCULPTA	WOOD TURTLE	SC		1988-09-24
	FIXSENIA FAVONIUS ONTARIO	NORTHERN HAIRSTREAK	SC		1992-06-28
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1993-08
*** BL-63					
	AMBYSTOMA LATERALE	BLUE-SPOTTED SALAMANDER	SC		1992-03-10
	AMBYSTOMA LATERALE	BLUE-SPOTTED SALAMANDER	SC		1994-06-13
	AMBYSTOMA OPACUM	MARBLED SALAMANDER	T		1995-05-01
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1991-05-03
	CLEMMYS INSCULPTA	WOOD TURTLE	SC		1983-06-19
	CLEMMYS INSCULPTA	WOOD TURTLE	SC		1987-06-21
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1996-07-03

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Massachusetts Natural Heritage and Endangered Species Program
Division of Fisheries and Wildlife, Route 135, Westborough, MA 01581
Wetland species observed since 1980 in the Blackstone Watershed
May not include some data-sensitive species.

Scientific Name	Common Name	DFW Rank	Fed Rank	Last Obs. Date
*** BL-64				
AMBYSTOMA OPACUM	MARBLED SALAMANDER	T		1986-04-26
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1982
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-06
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-07-27
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-08
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-08-17
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1991-06-04
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1993-09-18
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1994-09-18
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1996-04-27
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1990-06-07
CRANGONYX ABERRANS	MYSTIC VALLEY AMPHIPOD	SC		1989-06-08
FIXSENIA FAVONIUS ONTARIO	NORTHERN HAIRSTREAK	SC		1987-07-05
FIXSENIA FAVONIUS ONTARIO	NORTHERN HAIRSTREAK	SC		1990-07-08
SCLERIA PAUCIFLORA VAR CAROLINIANA	PAPILLOSE NUT-SEDGE	E		1989-08-27
SCLERIA TRIGLOMERATA	TALL NUT-SEDGE	E		1986-07-05
SCLEROLEPIS UNIFLORA	SCLEROLEPIS	E		1981-09-24
SNE ACIDIC BASIN FEN	GRAMINOID FEN	-		1989
SNE ACIDIC SEEPAGE SWAMP, INLAND ATLANTIC WHITE CEDAR SWAMP		-		1989
SNE ACIDIC SEEPAGE SWAMP, INLAND ATLANTIC WHITE CEDAR SWAMP		-		1989
SNE BASIN SWAMP, COASTAL ATLANTIC WHITE CEDAR ASSOCIATION				1989
SPIRANTHES VERNALIS	GRASS-LEAVED LADIES'-TRESSES	SC		1993-08-26
SPONGILLA ASPINOSA	SMOOTH BRANCHED SPONGE	SC		1989-09-15
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1990-07-12
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1993-08-18
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1993-09-03
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1994-06-14
*** BL-65				
AMBYSTOMA OPACUM	MARBLED SALAMANDER	T		1995-04-28
CERTIFIED VERNAL POOL		-		1995-03-27
CERTIFIED VERNAL POOL		-		1995-03-27
CERTIFIED VERNAL POOL		-		1995-03-27
CERTIFIED VERNAL POOL		-		1995-04-28
CERTIFIED VERNAL POOL		-		1995-05
CERTIFIED VERNAL POOL		-		1996
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1992-04-30

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Scientific Name	Common Name	DFW Rank	Fed Rank	Last Obs. Date
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1993-06
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1993-06-08
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1995-06-21
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1992-04-30
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1992-11-22
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1994-10-31
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1996-08-12
ERIOPHORUM GRACILE	SLENDER COTTONGRASS	T		1988-07-21
GYRINOPHILUS PORPHYRITICUS	SPRING SALAMANDER	SC		1995-06-04
MITOURA HESSELI	HESSEL'S HAIRSTREAK	SC		1987-06-06
SNE ACIDIC BASIN FEN	GRAMINOID FEN	-		1988-07-21
SNE BASIN SWAMP, COASTAL ATLANTIC WHITE CEDAR ASSOCIATION				1988-01-
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1984-08-13
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1993-05-19
*** BL-66				
AMBYSTOMA JEFFERSONIANUM	JEFFERSON SALAMANDER	SC		1983-03-18
AMBYSTOMA OPACUM	MARBLED SALAMANDER	T		1989-09
ARDEA HERODIAS	GREAT BLUE HERON	- WL		1986
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1983-04-13
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1983-11-14
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-05
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1989-06
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1990-06-22
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1991-05-31
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1992-07-27
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1993-05-01
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1983-11-03
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1987-06-04
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1987-FALL
CLEMMYS INSCULPTA	WOOD TURTLE	SC		1992-10-06
LYGODIUM PALMATUM	CLIMBING FERN	SC		1995-09-18
PANICUM PHILADELPHICUM	PHILADELPHIA PANIC-GRASS	SC		1990-08-28
SNE LEVEL BOG	BOG, POOR FEN	-		1986
SNE LEVEL BOG	BOG, POOR FEN	-		1986-10-29
TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1990-09-13
*** BL-67				
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1988-04-20
CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1990-07-12

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	Scientific Name	Common Name	DFW Rank	Fed Rank	Last Obs. Date
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1992-07-21
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1993-05-07
	CLEMMYS GUTTATA	SPOTTED TURTLE	SC		1995-05-16
	CLEMMYS INSCULPTA	WOOD TURTLE	SC		1983
	CLEMMYS INSCULPTA	WOOD TURTLE	SC		1991-07-00
	LAMPETRA APPENDIX	AMERICAN BROOK LAMPREY	T		1980-08-13
	LAMPETRA APPENDIX	AMERICAN BROOK LAMPREY	T		1980-09-07
	LYGODIUM PALMATUM	CLIMBING FERN	SC		1995-06-28
	PANICUM PHILADELPHICUM	PHILADELPHIA PANIC-GRASS	SC		1986-09-03
	SNE ACIDIC BASIN FEN	GRAMINOID FEN	-		1986-07-10
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1990-06-28
	TERRAPENE CAROLINA	EASTERN BOX TURTLE	SC		1994-06-09
*** BL-68					
	ISOTRIA VERTICILLATA	LARGE WHORLED POGONIA	- WL		1983-06-12
	PLATANTHERA FLAVA VAR HERBIOLA	PALE GREEN ORCHIS	T		1984-09-30
	PODOSTEMUM CERATOPHYLLUM	THREADFOOT	SC		1984-09-30
	RANUNCULUS MICRANTHUS	TINY-FLOWERED BUTTERCUP	T		1983-05-23

123 Records Processed

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Section 4.0

Site Specific Information

4.1 Fisherville Pond

4.1.1 Vegetation

Fisherville Pond includes about 45 acres of shallow open water habitat and about 100 acres of emergent, wet meadow, scrub-shrub,and forested wetland (see Photographs 4-1 and 4-2 and Section 6.1 of Main Report). Most of the emergent and wet meadow wetland is present in two large areas located north and south of the Blackstone River near its confluence with the Quinsigamond River. Areas with standing water (emergent wetland) are vegetated primarily with emergents such as woolgrass, cattail, and some pickerelweed. Purple loosestrife, reed canary grass, *Phragmites*, sedges, *Bidens* sp., blue vervain, switchgrass, and other grasses are predominant in relatively dry interior (wet meadow) areas. Scattered shrubs and small trees such as black willow, heart- leaved willow, and grey birch also occur in wet meadow areas. Based on review of aerial photographs, much of the emergent and wet meadow vegetation developed from shallow open water habitat between 1938 and 1952.

About 9.1 acres of shallow open water/emergent habitat vegetated with cattail, pickerelweed, and other emergents was lost as a result of the 1982 drawdown. This include about 4.6 acres in the pool north of the dam and about 4.5 acres south of the power line (see plans in Section 6.1.1 of Main Report). Emergent vegetation has not become reestablished after return of normal water levels, presumably due to lack of suitable mudflat conditions to promote seed germination and seedling growth. The two areas, were the most important waterfowl habitat areas at Fisherville Pond prior to the drawdown.

Land around Fisherville Pond is a mix of undeveloped open land (old field), agricultural land, forested and shrub-shrub riparian habitat, power line corridor, and developed residential areas. Land east of pond and west of Providence Road is primarily undeveloped open land and agricultural land. The undeveloped land is vegetated with successional shrubs and herbaceous species characteristic of recently disturbed areas. Fill material (i.e. stumps and construction debris) has been dumped in some areas. An inactive, sparsely vegetated, gravel pit is present along the pond just south of the boat ramp. Wooded riparian habitat along the eastern side of the pond is generally limited to a narrow band of trees and shrubs located along the shoreline. Land west of the pond, between the power lines to the north and the Blackstone River/Canal to the south, is undeveloped and consists primarily of scrub-shrub wetland, upland shrubland, with some forested wetland and wet meadow. Common trees and shrub species present in riparian areas include red, white, and pin oak, red maple, black ash, silver maple, cottonwood, American beech, common catalpa, black, pussy, and heart-leaved willow, grey birch, buttonbush, silky dogwood, alder, sweet pepperbush, northern arrowwood, highbush blueberry, maleberry, and staghorn sumac.

4.1.2 Wildlife

Waterfowl resources at Fisherville Pond are discussed in Section 2.2.6 of the Main Report. Species noted during this study include Canada goose, mallard, and black duck. Other species noted at Fisherville during this study include northern harrier, red tailed hawk, great blue heron, northern cardinal, red winged blackbird, sora rail, northern leopard frog, painted turtle, muskrat, and river otter.

4.2 Lonsdale Drive-In

Paved areas at the drive-in are currently sparsely vegetated with grasses, shrubs, and small trees, and provide very little habitat value (see Photographs 4-3 and 4-4). Vegetation is best developed at lower area elevations near the river due to greater deposition of sediment in these areas. A narrow riparian zone along the river and a steep embankment between the drive-in and Route 122 is wooded.

The site is less than 1 mile upstream of the Lonsdale Marshes, a 200+ acre complex of open water and emergent marshes along the Blackstone River. The area is considered the most valuable wetland wildlife habitat in northern Rhode Island and is state-designated critical habitat for both resident and migratory birds and other wildlife. Open water and emergent habitat in the marshes provide nesting habitat for American black duck, mallard, green winged teal (rarely) and marsh-nesting birds such as least bittern and sora. The Lonsdale Marshes also provide important feeding and nesting habit for migrating waterfowl and habitat for resident wetland wildlife such as muskrat.

4.3 Former Rockdale Pond

Removal of the Rockdale dam reestablished about one 1 mile of free flowing riverine habitat and about 30 acres of riparian habitat located within the former impoundment. About 15 acres are severely degraded, including some areas which are largely devoid of vegetation more than 20 years after removal of the dam (see Photographs 4-5 and 4-6). Riparian habitat in the former impoundment is sparely vegetated with grasses, other herbaceous species, and scattered small tress and shrubs. The most highly degraded areas have very little (<10%) vegetative cover. Poor vegetative growth may be due to low ph (<5) low nutrient content, dry conditions, and high concentrations of metals in the soils. ORV traffic also damages vegetation in some areas. Embankments along the Blackstone River throughout much of the former impoundment are also poorly vegetated and subject to erosion.

4.4 Singing Dam Impoundment

Borings taken by McGinn suggest that much of the original impoundment is filled in with soft sediment. Open water is largely limited to a shallow (< 4" deep) 80 - 100 foot wide backwater channel which extends about 2000 feet upstream of the dam (see Section 6.4 of Main Report). The impoundment includes a large emergent marsh south of the channel and a large island located near the head of the impoundment. The channel along the southern side of the island is silted in and heavily vegetated. Land to the north of the impoundment is pasture or lightly wooded upland. Development near the impoundment includes a few homes, a factory, a state highway (Route 122A), and a power line crossing. A wastewater treatment plant operated by the Town of Millbury is located on the Blackstone River just upstream of the impoundment.

A study by the MADEP indicated that the impoundment is one of the most severely degraded lakes and ponds in the basin. No information is available about fisheries resources in the impoundment. Shallow water and poor water quality, however, is likely to severely limit development of warmwater fisheries according to MADFW fisheries biologist Lee McLaughlin (person. commun., 1997). Toxicity testing conducted by the Blackstone River Initiative indicated that benthic habitat quality is poor. Emergent marsh south of the channel provides good waterfowl habitat according to MADFW state waterfowl biologist H. Heusmann (person. commun., 1996). The imapct of sediment contamination on waterfowl has not been assessed. The area has an excellent mix of deep water marsh and open water habitat. The island and wooded areas along the southern side of the impoundment provide excellent riparian habitat.

4.5 Beaver Brook

Beaver Brook Park is a intensively developed recreational area with a variety of facilities including a baseball field, outdoor skating rink, and basketball courts. The Beaver Brook conduit passes through a grassy area along the western edge of the park. From the park downstream to May Street, the brook passes through a wooded area adjacent to large parking lot to the east and a residential neighborhood to the west. Land above the conduit is well vegetated with trees and shrubs. From May Street downstream to Maywood, the conduit passes through a residential area. Land along the conduit is vegetated with scattered trees and shrubs, forming a long linear greenway. Common tree species present include black locust, box elder and to a lesser extent oak, black and black cherry. Oriental knotweed and bramble are predominant in the understory. Trees range in size up to 12". Many of the larger trees are leaning and appear unstable due to the shallow substrate. Downstream of Maywood, the brook flows through a well vegetated, but very narrow, riparian corridor.

No information is available about fisheries resources in Beaver Brook downstream of Maywood Street. Shallow water depth, lack of instream cover, and poor water quality probably limit development of the fishery.

4.6 Riverdale Gravel Pit

The site currently includes a 7 acre deep water pond adjacent to the Blackstone River, about 15 acres of very poorly vegetated riparian habitat, several acres of emergent and scrub-shrub wetland, some early successional upland shrub habitat, and a small pond. The large pond is connected to the Blackstone during high flows by a small channel at its northern end. The site is isolated by undeveloped forested habitat to the north and south, and a steep ridge leading to Quaker Street to the east.

Much of the large pond near the Blackstone River is deeper than 5 ft. and emergent vegetation is limited to a very narrow fringe along the shoreline. A berm between the pond and river is wooded with red maple, alder, grey birch, and a tall sycamore. Riparian habitat immediately east and northeast of the pond is very poorly vegetated with scattered grasses, herbs, and a few shrubs (see Photograph). Well vegetated emergent and scrub shrub wetland interspersed with early successional wooded upland is predominant in the eastern third of the site.

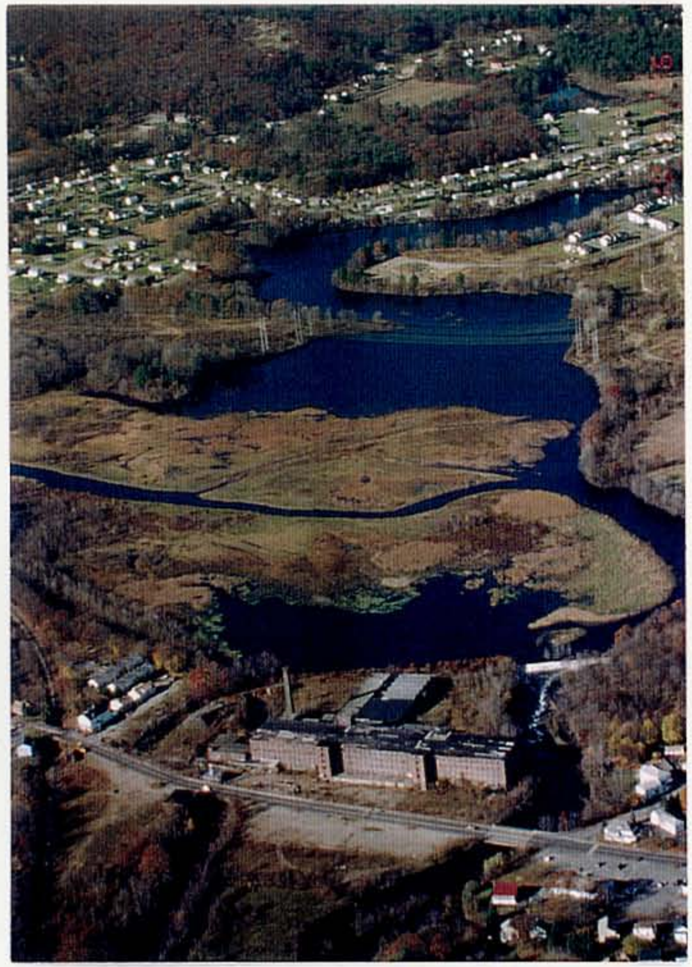
No information is available about fisheries resources in the pond. At one time a local sportsmen's club stocked the pond with trout for a put and take fishery. Mallards, a few Canada geese, and great blue heron were noted on the pond during March and April site visits. The small pond at the base of the slope provides potential nesting habitat for mallard.

4.7 Worcester Diversion

This project is located on Kettle Brook in Auburn and Millbury. It is comprised of a concrete control dam on Kettle Brook, a diversion structure, a 4,205-foot long tunnel, and an 11,000-foot long diversion channel that flows into the Blackstone River in Auburn. Most of the time water flows through a gate in the control dam. During high flows, the diversion structure behind the dam is overtopped, allowing some water to flow through the tunnel and into the diversion channel. The diversion channel has a bottom width of about 40 - 50 feet and according to Matt Labovites of the WDPW and Lee McGlauglin of the MDFW it is generally wet year round. Flow is apparently maintained by several small streams which flow into the channel and base flow.

Near the mouth of the tunnel, the channel passes through a deep, well shaded rock cut. Further downstream the channel passes through open areas with little cover. Sideslopes are vegetated with grasses, herbs, and small shrubs and trees. Trees and shrubs are periodically cut to prevent potential flow obstructions. There is little shade and stream temperature during the summer is probably high. Sideslopes are eroding in some locations. The Worcester DPW regularly removes a large amount of sediment from lower reaches of the channel. Additional sediment undoubtedly reaches the Blackstone River.

No information is available about fisheries resources in the channel. Large numbers of crayfish are harvested commercially near the Route 20 crossing. Mallards commonly nest in the channel. Upstream of Route 20, the channel abuts a large undeveloped area that provides valuable wildlife habitat .



Photographs 4-1 and 4-2: Fisherville Pond

Photographs 4-3 and 4-4: Lonsdale Drive-In

4.1.2 **Fish Studies**

SURVEY OF THE FISHERY COMMUNITY OF FISHERVILLE POND, BLACKSTONE AND QUINSIGAMOND RIVERS, GRAFTON, MASSACHUSETTS

October 15-16,1996

Prepared by:

Robert W. Davis
J. Michael Penko
U.S. Army Corps of Engineers
New England Division
Environmental Resources Branch
424 Trapelo Road
Waltham, MA 02254-9149

and

Kenneth M. Levitt
U.S. Army Corps of Engineers
New England Division
Environmental Laboratory
476 Coldbrook Road
Hubbardston, MA 01452-9743

April 1997

1.0 INTRODUCTION

The US Army Corps of Engineers (Corps) has been tasked to conduct a General Investigation focused on environmental restoration in the Blackstone River watershed which includes the mainstem and all tributaries (i.e. sub-basins). The Corps guidance describes environmental restoration projects eligible for Corps funding as "restoration of degraded ecosystem functions and values, including its hydrology, plant and animal communities, and/or portions thereof, to a less degraded ecological condition." Accordingly, the Federal interest may be defined as fish and wildlife habitat restoration which includes the enhancement and/or restoration of resident and anadromous fisheries, waterfowl, wildlife and wetland resources.

The restoration of Fisherville Pond has been selected by the Corps as one of several prototype projects for the Blackstone River watershed because it exhibits many of the problems identified for the entire watershed (i.e. degraded waterfowl habitat, contaminated sediments, degraded water quality, inadequately-maintained dam that poses a safety concern, etc;). Restoration of Fisherville Pond will improve waterfowl and fisheries habitat and create a safe recreational area for residents to boat, swim, hunt and fish.

McLaren/Hart Environmental Engineering Corp (McLaren/Hart) was subcontracted by Battelle Ocean Sciences under contract to the Corps to conduct a Preliminary Baseline Ecological (ERC) and Human Health Risk Characterization (HHRC) for Fisherville Pond. The ultimate goal of the ERC and HHRC is to provide the Corps with an understanding of the baseline risks of the Chemicals of Concern (COCs) historically identified in the sediments at Fisherville Pond. The risk characterization will focus on existing sediment and surface water chemical data, sediment bioassay data, fish tissue data, and benthic macroinvertebrate and fish community surveys.

Preliminary results of the fish community survey, conducted by the Corps on October 15-16, 1996, are provided herein for incorporation, as appropriate, into the ERC/HHRC and the Blackstone River Reconnaissance Investigation Report. The objectives of the Corps survey was to provide current fisheries data to qualitatively assess the status and subsequent needs of the existing fishery and to determine the appropriate representative fish receptors (assessment endpoints) for the ERC and HHRC.

2.0 MATERIALS AND METHODS

Field Collections

Adult and juvenile fishes were collected from Fisherville Pond on

October 15-16, 1996 using four methods: gill nets, hoop net, beach seine, and backpack electrofishing. Samples were collected at various locations throughout the Fisherville Pond System (i.e. Fisherville Pond, Blackstone River and Quinsigamond River complex).

Experimental sinking gill nets were set and picked up during the day at various locations in order to minimize sampling mortality; in addition, two gill nets were deployed as overnight sets. The lead lines were tied to shore and/or anchored and lobster buoys were attached to the floating lines. The smallest mesh panels were deployed first at the shoreline sets. Each experimental gill net was 125 ft in total length and consisted of five 25 ft long x 5 ft deep variable mesh panels. Mesh sizes ranged from 0.5 inch to 2 inch.

One triple wing hoop net was set overnight on fence posts in a shallow water area less than five feet deep and retrieved the following day. The net was deployed with the cod end attached upstream so that the mouth of the net faced downstream. The net opening (i.e. first hoop) was 32 inches in diameter.

Two adjacent seine hauls were made with a 25 x 4 ft seine of 1/4 inch bar mesh at the beach at the boat ramp. A Smith-Root Type VII backpack electrofisher was used at three shoreline vicinity locations in the pond. Pulsed direct current (DC) was used on the 300 output voltage with output amperage generally ranging from 0.5 to 1 amps.

<u>Field Analyses</u>

All fish collected were transferred as quickly as possible to holding buckets where they were immediately processed. All juvenile and adult fishes were identified to species and counted. When large numbers of fishes were collected (35/species) during a single sample event, a minimum of 30 individuals were randomly selected and measured for total length (nearest mm) and weighed (nearest gram or ounce), and released alive or properly discarded (dead). In addition, all fish were examined for the presence and nature of external parasites and/or physical abnormalities during the field analyses.

3.0 RESULTS AND DISCUSSION

A total of 161 fishes representing 6 families and 7 species were collected by gill netting, hoop netting, seining, and backpack electrofishing from Fisherville Pond during the October 15-16, 1996 fall survey (Tables 1 and 2). A summer gill netting survey conducted by the Massachusetts Division of Fisheries & Wildlife (MADFW 1992) on August 18-19, 1992 yielded a total of 356 fishes representing 8 families and 13 species (Tables 1 and 3). The increase in abundance and species diversity may be due to the more intensive gill netting efforts and/or differences in field collection methods, and/or may also reflect seasonal considerations (i.e. summer versus fall sampling).

The families Cyprinidae (carp and minnows), Catostomidae (suckers), Ictaluridae (bullhead and catfishes), Esocidae (pikes and pickerels), Centrachidae (sunfishes and basses) and Percidae (perches) were represented both years while representatives from Salmonidae (trout and salmon) and Percicthyidae (true basses) were only collected during 1992. The family Centrachidae was represented by four species (pumpkinseed, bluegill, largemouth bass and black crappie) while the families Cyprinidae (carp and golden shiner) and Salmonidae (rainbow and brook trout) were represented by two species.

The fish community of Fisherville Pond, dominated by warm water species, is similar to that reported for other impoundments and ponds within the Blackstone River watershed. Two of the species, rainbow trout and brook trout, are coldwater species. The two individuals collected during 1992 were considered stocked holdovers from the Quinsigamond River (Table 1). The top six species (based on abundance), representing over 94% of the total (517 individuals), were (in rank order) white sucker (47.2%), bluegill (18.4%), golden shiner (11.4%), yellow perch (8.7%), largemouth bass (4.6%), and carp (3.9%) (Table 4).

Many of the species collected are considered to be valuable as food or sport fishes. These species, which are preceded by an asterisk in Table 4, comprised 34.8% of the total catch.

Observations concerning the presence and nature of external parasitism and/or physical abnormalities during the field analyses were noted during the 1996 survey. The incidence of conspicuous external parasites and/or abnormalities were noted on the field forms. The most common form of parasitism observed was blackspot, a trematode that encysts in the integument. This form of parasitism is common and is not considered lethal to fishes.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Fisherville Pond supports a moderately diverse and abundant warm water fish community based on the results of the two limited fishery surveys conducted in 1992 and 1996. The dominance of the fish population by more pollution tolerant species (white sucker, golden shiner and carp) indicates that the Fisherville Pond System (i.e. Fisherville Pond, Blackstone River and Quinsigamond River complex) is somewhat degraded by a combination of water and sediment quality and less than stable pool height. However, the presence in good numbers of less pollution tolerant species (largemouth bass, yellow perch, and bluegill) demonstrates potential for the development of a more balanced fish community.

Since moderate numbers of fish were collected in Fisherville Pond, it is evident that the existing surface water and sediment quality do not cause significant acute effects to fish that are readily observable (e.g. fish kills). Apparently, the contaminant concentrations in the water and sediment have not adversely impacted reproduction and recruitment of fish, since juveniles (young-of-the-year) as well as adults of two species (i.e. bluegill, largemouth bass) were collected during the fall 1996 survey, albeit the potential significance of any adverse impacts to any of the species present can not be determined by existing data.

Based upon a review of the limited survey data and analyses, it is apparent that we do not know enough about the fish population of the Fisherville Pond System to predict effects of existing water and sediment quality and water level management to the fish community. Accordingly, the Central District Aquatic Biologist recommended (in their review comment letter provided as Appendix C) that the Massachusetts Division of Fisheries & Wildlife, with Corps assistance, design and conduct a more intensive survey and analysis of selected species and a survey of the Blackstone and Quinsigamond Rivers immediately above the Fisherville Pond impoundment during the late summer or early fall time period.

An appropriate representative fish receptor (assessment endpoint) for the Environmental Risk Characterization (ERC) is the bluegill or largemouth bass. However, selection of a bottom feeding fish (e.g. white sucker) must also be considered due to the presence of contaminated sediments. The bluegill and largemouth bass are also appropriate fish species for the human fish consumption pathway in the Human Health Risk Characterization (HHRC) albeit the availability of existing fish contaminant tissue data is an overriding factor for final selection.

5.0 REFERENCES

Massachusetts Division of Fisheries and Wildlife (MADFW). 1992. Gill Net Survey of Fisherville Pond, Grafton, Massachusetts, August 18-19, 1992. Prepared by Charles L. McLaughlin, District Aquatic Biologist, MADFW, Central Wildlife District.

TABLE 1

Species Inventory of Fish Collected in Fisherville Pond,
Blackstone and Quinsigamond Rivers, Grafton, Massachusetts
August 18-19, 1992(1) and October 15-16, 1996

Family	Scientific Name	Common Name	1992	1996
Cyprinidae	Cyprinus carpio	Common carp	X	
	Notemigonus crysoleucas	Golden shiner	X	X
Catostomidae	Catostomus commersoni	White sucker	X	X
Ictaluridae	Ameiurus natalis	Yellow bullhead	X	X
Esocidae	Esox niger	Chain pickerel	X	X
Salmonidae	Oncorhynchus mykiss	Rainbow trout	X(2)	
	Salvelinus fontinalis	Brook trout	X(2)	
Percicthyidae	Morone americana	White perch	X	
Centrachidae	Lepomis gibbosus	Pumpkinseed	X	
	Lepomis macrochirus	Bluegill	X	X
	Micropterus salmoides	Largemouth bass	X	X
	Pomoxis nigromaculatus	Black crappie	X	
Percidae	Perca flavescens	Yellow perch	X	X

NOTES:

(1) August 18-19, 1992 fishery survey conducted, using five gill nets set overnight for 18 hours, by Charles L. McLaughlin, Central District Aquatic Biologist, Massachusetts Division of Fisheries & Wildlife (MADFW 1992).

(2) Stocked holdovers from the Quinsigamond River, personal communication, Charles L. McLaughlin, Central District Aquatic Biologist, Massachusetts Division of Fisheries & Wildlife.

TABLE 2

Total Abundance and Percent Composition of Combined Fishery Collections, Fisherville Pond, Blackstone and Quinsigamond Rivers, Grafton, Massachusetts, October 15-16, 1996

	Fishery Gear Types											
Species	GN1	GN2	GN3	GN4	GN5	HN1	BS1	BP1	BP2	BP3	Total	Percent
BG			4				43	5	23	18	93	57.8
CP			2								2	1.2
GS			4								4	2.5
LMB				2			4		3		9	5.6
WS	13	4	6	7	1	3					34	21.1
YB			1								1	0.6
YP		15	1	2							18	11.2
Totals	13	19	18	11	1	3	47	5	26	18	161	100.0

Species Codes:
- BG = Bluegill
- CP = Chain pickerel
- GS = Golden shiner
- LMB = Largemouth bass
- WS = White sucker
- YB = Yellow bullhead
- YP = Yellow perch

Gear Codes:
- GN = Gill Net
- HN = Hoop Net
- BS = Beach Seine
- BP = Backpack Electrofish

TABLE 3

Comparison of Total Abundance, Percent Composition, and Total Lengths of October 15-16, 1996 and August 18-19, 1992 Fishery Collections, Fisherville Pond, Blackstone and Quinsigamond Rivers, Grafton, Massachusetts

	1996(1)			1992(2)		
Species	No.	%	TL in mm Mean(Range)	No.	%	TL in mm Mean(Range)
Bluegill	93	57.8	46(23-186)	2	0.6	---(150-199)
White sucker	34	21.1	343(233-428)	210	60.0	---(200-459)
Yellow perch	18	11.2	200(153-220)	27	7.6	---(170-249)
Largemouth bass	9	5.6	124(57-312)	15	4.2	---(180-379)
Golden shiner	4	2.5	200(143-242)	55	15.4	---(160-249)
Chain pickerel	2	1.2	251(197-305)	2	0.6	---(390-439)
Yellow bullhead	1	0.6	190	13	3.6	---(180-279)
Carp				20	5.6	---(140-579)
Black crappie				5	1.4	---(190-229)
White perch				3	0.8	---(210-269)
Pumpkinseed				2	0.6	---(140-159)
Brook trout				1	0.3	---(300-309)
Rainbow trout				1	0.3	---(340-349)
Totals	161			356		

NOTES:

(1) All fish collected were measured for total length to the nearest millimeter (mm); see Appendix A for individual lengths.

(2) Mean total length (TL) not available since all fish collected were categorized into length-frequency intervals of ten millimeters, e.g. 100-109mm, 110-119mm, etc; see Appendix B for length-frequencies.

TABLE 4

Total Abundance and Percent Composition of the Combined Fishery Collections, Fisherville Pond, Blackstone and Quinsigamond Rivers, Grafton, Massachusetts
August 18-19, 1992 and October 15-16, 1996

Species	Number	Percent
White sucker	244	47.2
* Bluegill	95	18.4
Golden shiner	59	11.4
*Yellow perch	45	8.7
*Largemouth bass	24	4.6
Carp	20	3.9
Yellow bullhead	14	2.7
*Black crappie	5	1.0
*Chain pickerel	4	0.8
*White perch	3	0.6
*Pumpkinseed	2	0.4
*Brook trout	1	0.2
*Rainbow trout	1	0.2
Totals	517	100

NOTES:

* Important as food or sport fish

COMMONWEALTH OF MASSACHUSETTS

DIVISION OF FISHERIES & WILDLIFE

Chris Thurlow, Manager

March 7, 1997

Mr. Bob Davis
U S Army Corps of Engineers
New England Div, Environmental Resource Br.
424 Trapelo Rd.
Waltham MA 02254-9149

Dear Bob:

Thank you for forwarding the survey data from Fisherville Pond. A cursory review of the data certainly indicates that we do not know enough about the fish population of the Fisherville Pond, Quinsigamond River and Blackstone River complex to predict effects of water level management.

The dominance of the fish population by more tolerant species (white sucker, golden shiner and carp) indicates that the Fisherville System is somewhat degraded by a combination of water quality and less than stable pool height. However the presence in good numbers of less tolerant species (largemouth bass, yellow perch, bluegills) shows potential for the development of a more balanced community.

I suggest that Fish & Wildlife, with your assistance if available, conduct a more intensive analysis of selected species and a survey of the Blackstone and Quinsigamond Rivers immediately above the Fisherville impoundment. Hopefully our Westboro staff can assist with survey design and equipment.

Late summer or early fall would probably be the ideal survey period. Please let ne know your thoughts.

Sincerely,

Lee McLaughlin

Charles L. McLaughlin

cc: Todd Richards, Westboro

Central Wildlife District
Temple Street, West Boylston, Massachusetts 01583
508-835-3607 Voice 508-792-7420 Fax Email CThurlow@STATE.MA.US
An Agency of the Department of Fisheries, Wildlife & Environmental Law Enforcement

QUALITATIVE ASSESSMENT OF THE BENTHIC MACROINVERTEBRATE COMMUNITY OF FISHERVILLE POND GRAFTON, MASSACHUSETTS

Submitted to:

Department of the Army
U.S. Army Corps of Engineers
New England Division

Contract No. DACW33-96-005

January 1997

Prepared by:

McLaren/Hart Environmental Engineering Corporation
25 Independence Boulevard
Warren, New Jersey 07059
(908) 647-8111

Under Contract To:

Battelle Ocean Sciences
397 Washington Street
Duxbury, Massachusetts 02332-0601
(617) 934-0571

1.0 INTRODUCTION

Benthic macroinvertebrates include organisms which inhabit the substrate surface or burrow within sediments for food or shelter (Odum, 1971). The occurrence, density, and distribution of invertebrates has been suggested as indicative of the overall water quality of aquatic ecosystems (Plafkin et al., 1989; APHA, 1989). Furthermore, benthic macroinvertebrates function as strong indicators of extant environmental (local) conditions as many taxa have limited migration patterns and are excellent indicators of existing conditions due to the relatively short life cycle of larval stages (Plafkin et al., 1989). Natural factors may also influence the type and abundance of benthic macroinvertebrate species in that season. Natural factors such as water temperature, dissolved oxygen, anaerobic sediments, organic loading to the system, and chemical contamination are all important in structuring benthic communities.

The following report evaluates the existing benthic macroinvertebrate community inhabiting Fisherville Pond. The report consists of the following sections: 1) laboratory methods used for the identification, enumeration, and evaluation of the benthic macroinvertebrates; 2) results of the sediment and benthic community characterization; 3) an assessment of the functional attributes of each major benthic taxa; 4) summary and conclusions; and 5) recommendations.

2.0 LABORATORY METHODS

Organisms were removed from the sample containers, rinsed throughly with water, and spread out in white enamel trays with shallow water and backlighting. The samples were sorted by eye; infaunal organisms were removed from the mineral or plant material residue, and placed into 40 ml amber glass vials for identification. After sorting all of the samples, the organisms were identified to lowest practical identification level (LPIL) using dissecting and compound microscopes to facilitate observing key taxonomic features. All taxa identification and counts were recorded on handwritten data sheets (Appendix A) and subsequently transferred to an electronic spreadsheet format preliminary to data analysis. Summary statistics were limited to reporting the relative abundance (as percent) of taxa for all of the sampled locations. For quality assurance an quality control (QA/QC) purposes, one of the five samples was randomly selected and resorted to evaluate sorting efficiency.

2.1 SOURCES OF INFORMATION

Several references were used to identify organisms and describe the life history of major taxa observed in the samples. The following is a list of reference materials and invertebrate identification keys used to complete this section of the report:

- Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. Environmental Monitoring Systems Laboratory, Office of Research and Development USEPA, Cincinnati Ohio. EPA/600/4-90/030. 256p.

- MADEP. 1996. Benthic macroinvertebrate master taxa and tolerance list. Office of Watershed Management. North Grafton, MA.

- Merritt, R.W. and K.W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co., Dubuque, Iowa. 722p.

- Needham, J.G. and P.R. Needham. 1978. A guide to the study of freshwater biology. Holden -Day, Inc., San Francisco. 108p.

- Peckarsky, B.L., P.R. Fraissinet, M.A. Penton, and D.J. Conklin Jr. 1990. Freshwater macroinvertebrates of northeastern North America. 442p.

- Pennak, R.W. 1978. Freshwater invertebrates of the United States. John Wiley and Sons, New York, NY. 803p.

- Rosenberg, D.M. and V.H. Resh. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, Inc., New York, NY. 488p.

- Smith, D.G. 1991. Keys to the freshwater macroinvertebrates of Massachusetts. University of Massachusetts Department of Zoology, Amherst, Massachusetts. 236p.

3.0 RESULTS

3.1 SEDIMENT CHARACTERIZATION

Sediments at each Station were consistently dominated by aquatic and terrestrial vegetation, with virtually no representation of silt or clay-like fractions. For example, Stations 96-01, 96-02, 96-04, and 96-05 were each consistently comprised of approximately 70% organic fines, and 30% vegetative stalks and rhizomes from aquatic vegetation. Contrary to these findings, Station 96-03 had principally larger, leafy vegetation with some twigs (95%), and a very small fraction of organic fines (≤ 5%). Although different from other stations with regards to observed vegetation, the benthic community assemblage at Station 96-03 did not appear to be different from that observed at other locations. All Stations had little or no sand/silt/clay fractions, and there were no signs of streaking, staining, or odor associated with the sediments.

3.2 BENTHIC COMMUNITY CHARACTERIZATION

Table 1 is a list of the benthic taxa observed at each Station sampled in Fisherville Pond. The majority of invertebrate taxa observed are common to northeastern freshwater systems; particularly low-flowing or lentic systems like ponds and/or lake shallows that receive a relatively large amount of natural organic loading. Most of the stations were dominated (in decreasing order) by aquatic earthworms (Annelida), chironomid midges and damselflies (Insecta), snails (Mollusca), and amphipods (Crustacea). The Order Insecta were represented by the most taxa, whereas the Order Annelida had the highest number of organisms.

Taxa Abundance and Distribution

Actual counts sampled from a petite ponar (with a surface area of $0.023m^2$) were adjusted to square meter estimates of invertebrate abundance (Table 2). The results indicate that aquatic earthworms were the most abundant organisms, ranging from 43 - 2,913 individuals/m^2. Oligochaetes account

TABLE 1
OBSERVED BENTHIC MACROINVERTEBRATE TAXA
FISHERVILLE POND, GRAFTON, MASSACHUSETTS

	Station				
Taxa	**96-01**	**96-02**	**96-03**	**96-04**	**96-05**
Annelida					
Oligochaeta					
Naidae					
Nais communis	67	7	48	2	
Hirudinea					
Erpobdellidae					
Erpobdella punctata			1		1
Mollusca					
Gastropoda					
Planorbidae					
Helisoma sp.	1	3			
Pelecypoda					
Sphaeriidae					
Pisidium sp.					1
Crustacea					
Amphipoda					1
Talitridae					
Hyalella azteca					1
Insecta					
Emphemeroptera					
Caenidae					
Caenis sp.	1				
Odonata					
Zygoptera		1			
Coenagrionidae					
Amphiagrion sp.	1	1			
Diptera					
Chironomidae					1
Chironominae					
Chironomus sp.	3		5		3
Cryptochironomus sp.	1	1		1	4
Tanypodinae					
Procladius sp.				1	
Heleidae					
Stilobezzia sp.	1	2			2
Coleoptera					
Haliplidae					
Haliplus sp.		1			
Number of Taxa:	7	7	3	3	8

TABLE 2
BENTHIC MACROINVERTEBRATE ABUNDANCE (ACTUAL AND SQUARE METER COUNTS)
FISHERVILLE POND, GRAFTON, MASSACHUSETTS

Stations

Major Taxa	96-01		96-02		96-03		96-04		96-05	
	Count		Count		Count		Count		Count	
	Actual	Sq.M	Actual	Sq.M	Actual	Sq.M	Actual	Sq.M	Actual	Sq.M
Annelida	67	2,913	7	304	49	2,130	2	87	1	43
Mollusca	1	43	3	130	0	0	0	0	1	43
Crustacea	0	0	0	0	0	0	0	0	2	87
Insecta	7	304	6	261	5	217	2	87	10	435
Total	75	3,261	16	696	54	2,348	4	174	14	609

TABLE 3
RELATIVE ABUNDANCE (%) OF BENTHIC MACROINVERTEBRATES WITHIN STATIONS
FISHERVILLE POND, GRAFTON, MASSACHUSETTS

Stations

Major Taxa	96-01	96-02	96-03	96-04	96-05
Annelida	89.3%	43.8%	90.7%	50.0%	7.1%
Mollusca	1.3%	18.8%	0.0%	0.0%	7.1%
Crustacea	0.0%	0.0%	0.0%	0.0%	14.3%
Insecta	9.3%	37.5%	9.3%	50.0%	71.4%
Total	100%	100%	100%	100%	100%

for over 75% of the total number of organisms identified. Crustacea were the least represented group, with an estimated 87 individuals/m^2.

With regards to the relative abundance of taxa within Stations (Table 3), annelids were the most representative taxa in Stations 96-01, 96-02, 96-03, and 96-04. In contrast, Station 96-05 was primarily represented by insects, particularly dipterans. Stations 96-01 and 96-03 were most similar to each other in terms of overall abundance and distribution of major (Order) taxa, whereas few taxa characterized the remaining stations and the dominance of a single group was not as apparent.

As illustrated in Table 4, taxa were patchy in distribution among the Stations. Almost all of the annelids observed in the samples were located at Stations 96-01 and 96-03 (total; 92%). Molluscs were found at higher abundance at Station 96-03 (60%), but it should be noted that the abundance of these organisms was limited to only a few individuals, and the relative percent calculated on such numbers could be misleading with so few representatives. Similarly, crustaceans (2 amphipods) were only observed at Station 96-05. Insects were perhaps the most evenly distributed taxa among the Stations with no clear preference for any particular location. The results of the survey indicate that densities are somewhat lower than might be expected in similar unimpacted systems, however, sample variability makes firm conclusions difficult. The overall results indicate that the macroinvertebrate community is, as are most benthic assemblages, patchy in regards to the distribution of organisms within and between stations.

Taxa Richness

Taxa richness was calculated simply as the total number of individual taxa observed at each station. As shown in Table 1, the results indicate that taxa richness ranged between 3 - 8 taxa per station. Station 95-05 had the most taxa (n = 8); whereas Stations 96-03 and 96-04 had the lowest number of taxa (n = 3). The Diptera (e.g. *Chironomus* sp., *Cryptochironomus* sp., *Procladius* sp., and *Sitobezzia* sp.) were the most common taxa observed in the samples.

TABLE 4

RELATIVE ABUNDANCE OF BENTHIC MACROINVERTEBRATES WITHIN TAXA

FISHERVILLE POND, GRAFTON, MASSACHUSETTS

	Major Taxa			
Station	Annelida	Mollusca	Crustacea	Insecta
96-01	53%	20%	0%	23%
96-02	6%	60%	0%	20%
96-03	39%	0%	0%	17%
96-04	2%	0%	0%	7%
96-05	1%	20%	100%	33%
Total	100%	100%	100%	100%

3.3 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

To comply with Quality Assurance and Quality Control (QA/QC) procedures, one benthic sample was chosen at random for re-evaluating sorting efficiency. Station 96-03 was selected, and re-sorted. Two oligochaete "fragments" were removed from the sample. No other invertebrates were identified in the sample. For QA/QC purposes, both fragments were conservatively assumed to represent one individual. That given, the number of individuals identified in the re-sorted sample represented less than four percent (2 organisms $_{re\text{-}sort}$ / 54 organisms $_{sort}$); an acceptable range of error for sorting procedures used in evaluating benthic communities.

4.0 FUNCTIONAL ATTRIBUTES OF MAJOR BENTHIC TAXA

Oftentimes, the functional attributes (ie. life history, etc.) of benthic taxa will reveal additional information for evaluating the composition of benthic taxa through identification of preferred habitat and trophic level. Furthermore, many of these organisms have been evaluated based on their sensitivity to anthropogenic wastes, and a comparison of taxa using this evidence can add additional information in regards to possible stressors in the ecosystem. By examining the taxa through these approaches, it is sometimes possible to make inferences about the general "health" of the overall ecosystem. To accomplish this, the functional attributes of some of the major taxa are briefly described in the following sections.

4.1 ANNELIDA

Oligochaeta

The aquatic representatives of the Class Oligochaeta are morphometrically and functionally similar to their terrestrial counterparts. Aquatic earthworms are small, elongate and cylindrical in shape, and like terrestrial earthworms, utilize aquatic sediments for food and shelter. Most species are deposit feeders, detritivores, algivores, carnivores, or even parasites (Pecharsky et al., 1990). Oligochaetes are hermaphroditic and cross-fertilization usually takes place between two individuals (Pennak, 1978). Taxonomic delineation within these organisms is difficult, often requiring tissue sectioning for some genus-species level identification. The most frequently occurring representatives of this class occur in the Naididae, Tubificidae and Enchytraeidae (Pennak, 1978). These organisms may represent an abundant food source for many species of small fish, and larger macroinvertebrates.

Hirudinea

The leeches are commonly known as "bloodsuckers" but in fact many representatives of this class are predators and scavengers, and only a few species take blood from warm-blooded animals. The leeches are typically dorsoventrally flattened, and can be characterized by the oral sucker at the anterior end which may be small or large depending on species. All leeches are mobile, and can move about on substrate by creeping or crawling movements. The Hirudinae and Erpobdellidae are excellent swimmers but the Glossiphonidae are not.

Leeches are typically found in shallow, warm, protected areas where there is little wave action, and plants, stones, and debris are adequately present to provide concealment as well as substrate for attachment. For the most part, leeches are nocturnal, and can be found under substrates during the day. Most species of leeches attach to the substrate and undulate the body as a way of facilitating respiration, but little is known about the ability of leeches to tolerate low dissolved oxygen levels.

Leeches may persist in intermittent ponds because some species are able to burrow into the mud to tide over dry periods. If the water level of a lake or pond is dropped considerably during the fall, cold temperatures of -6 C or less have been shown to kill estivating leeches in the mud.

4.2 Mollusca

Gastropoda

The great majority of species of Gastropods occur in shallows of lakes, ponds, and rivers. Shallow areas are typically more abundant in food and this may be one reason why this is a preferred habitat by these organisms.

Most of the freshwater snails are uncommon in lakes and streams whose surface waters are more acidic than about 6.0. Dissolved oxygen is also important in the distribution of these snails which appear to require high concentrations. Generally, most gastropods are not active at freezing point water temperatures and where these conditions exist (such as in perennial lakes and streams) relatively few individuals exist.

Pelecypoda

Pelecypods, which include the freshwater bivalve clams and mussels, are all strictly aquatic. Representatives of this Order are most abundant in large rivers, however they can also occur in smaller, unpolluted habitats, including lakes. Bivalves usually occur in the shallows, especially less than 2m deep. The occurrence of mussels in large numbers where current is sufficient has been attributed to abundant food supply, oxygen, water quality, sufficient substrate, or a combination of these factors. Most species favor stable substrates like gravel and sand, or a mixture of these two.

The Sphaeriidae are one group of bivalves which are less specific in their requirements for suitable substrate and can be found on most any surface with the possible exception of rock and clay. This group is also more tolerant of unfavorable conditions. Sphaeriid bivalves can tolerate a pH as low as 6.0 and a CO2 content of 2.0 mg/liter. Perhaps one of the most common species in freshwater lentic systems, Sphaeridae bivalves are able to enhance their survival by burrowing into the substrate to overwinter or escape drought.

4.3 CRUSTACEA

Crustaceans include some of the more common decapods such as crabs, shrimp, lobsters, and crayfish. But in addition, this phylum includes many species of smaller organisms of which amphipods are one of the most well represented taxa. Most amphipods are found in the marine environment, however there are about 800 species of freshwater amphipods worldwide. The majority of these species can be found in unpolluted lakes, ponds, streams, and are usually associated with substrate. Most amphipods are extremely pollution sensitive, and the presence of these suggest that sediments are reasonably "clean" or if contaminated, the chemical is largely not bioavailable.

Amphipods are typically between 5-20 mm long and are shrimp-like in structure. Often referred to as "scuds" these organisms are usually more active at night, and can be found crawling around stones, pebbles, and sand in search of food. Amphipods generally feed on plant and decaying animal matter (detritus), and can best be described as scavengers.

4.4 INSECTA

Ephemeroptera

Mayflies are organisms which are widely distributed and can oftentimes be found in great numbers in the vicinity of freshwater systems. Adult mayflies have delicate, transparent wings, long and slender legs, two large eyes, and long conspicuous antennae. This uniform appearance of the adults is not true of nymphal stages where there is great morphological variation relative to specific habitats. Mayfly nymphs emerge from the aquatic environment as adults in the late spring or early summer.

Larval and nymphal stages of mayflies are spent in the freshwater environment. The mayfly is characterized at these stages as elongated, well-defined mouthparts, long antennae and conspicuous lateral and dorsal gills. These tracheal gills vary greatly in morphology, and are used in classifying the organisms.

Mayfly nymphs are the most abundant insects in streams and are important food items for fish, particularly trout. They are equally important in ponds and lakes as a food source for other species of fish.

Odonata

Another order of insect that may be common at the Site are the Odonata, which include the dragonflies and damselflies. Adults are usually found in great abundance around marshes, ponds, rivers and lakes (Pennak, 1978). In the adults, the bodies are elongate, and the head supports large compound eyes. The wings are intricately veined, colorful, and at rest are usually left horizontally outward (dragonflies) or folded upward (damselflies).

The nymphal stages of these organisms are usually associated with unpolluted ponds, marshes, streams, and in lake shallows. Odonate nymphs are carnivorous, and can be identified by their modified mouthparts used for feeding on a variety of organisms including other aquatic insects, annelids, and other small invertebrates. Most of the Odonate genera in the United States are represented by only a few major species (Pennak, 1978).

Diptera

One of the largest orders of the aquatic insects are Diptera which include the flies, mosquitoes, and the midges. The adults are never aquatic, but the majority of the larvae within the group are, and typically inhabit freshwater environments. Many of the Dipteran families have immature stages that occur in freshwater streams, rivers, ponds, and lakes. Female Dipterans typically deposit eggs just below the surface of the water on vegetation, debris, or in the case of black flies, on the surface of rocks (Pennak, 1978).

Larvae creep about the substrate and feed on a variety of plant and animal matter which include periphyton, minute organisms, and debris. Representatives of one family of the Diptera, the Chironomidae or midges, can withstand low oxygen concentrations. It is common to see them among some of the tubificid oligochaetes that are associated with organic enrichment. The majority of chironomids often increase as one moves further from the sewage-fungus zone.

Chironomids thrive in anaerobic conditions and can even tolerate fairly high concentrations of salt, sulphur, and ammonia. Like some of the oligochaetes, these organisms find an abundance of food in rich organic mud. They are typically herbivorous, feeding on a variety of algae, higher aquatic plants, and organics. Chironomids live in tubes which they construct from detritus, algae, or small grains of sand cemented together by mucus that they secrete (Pennak, 1978).

Coleoptera

Coleoptera comprise the largest order of the Insecta, as represented by the over 350,000 species described in this group (Peckarsky et al., 1990). Two major groups of aquatic beetles exist: one group occurs in aquatic habitat where water is flowing slowly or stagnant; the second group occurs in the riffles of fast flowing streams. Haliplid larvae are often found on the leaves and stems of aquatic vegetation where they may lay their eggs (Merritt and Cummins, 1984). Typically, this family of aquatic beetles is associated with slow-moving areas of streams, or are commonly found in ponds (Peckarsky et al.,1990). Adult haliplids are herbivorous, and store air under their well-adapted hind coxal plates for prolonged submersion in the aquatic environment.

4.5 SUMMARY OF FUNCTIONAL ATTRIBUTES

As indicated through an examination of species functional attributes, many of the organisms found in Fisherville Pond are predominately those that are associated with slow-moving waters, with adequate aquatic vegetation. Table 5 illustrates the overall habitat preferences of the observed taxa: most generally prefer lentic (e.g., ponds) systems, but several can be found in lotic (e.g., rivers and stream) systems as well. In addition, a wide-range of trophic levels are represented, even though relatively few samples have been collected. For example, detritivores, parasites, grazers, filterers, collectors, herbivores, and predators all represent a reasonably balanced food web within the benthic community.

Table 5 illustrates that most taxa are suitably tolerant of organic wastes, with the majority being facultative, and only one taxa of mayfly (*Caenis* sp.) shows some level of sensitivity to organics. Overall, based on the benthic data evaluated thus far, the benthic organisms appear to be predominately tolerant of organic enrichment (EPA, 1990). Furthermore, based on tolerance values derived from the State of Massachusetts Department of Environmental Protection (MADEP), most of the taxa identified in this evaluation are tolerant of anthropogenic conditions in the Pond. Tolerance values ranged from 5 - 10 (10 representing the most tolerant taxa), with the average tolerance equal to 7.7. This interpretation may be somewhat misleading in that overall, representative taxa that are typically sensitive (e.g. Ephemeroptera, Plecoptera, and Trichoptera), and would presumably have lower scores, emerge from the pond in the spring and summer months. Recognizing the temporal limitations of this data set, it would be difficult to accurately determine the overall presence or absence of key "indicator" organisms without considering samples collected during these times of the year. In addition, other factors that include geographical, physico-chemical, and functional attributes of the ecosystem (e.g., niche availability) may limit the proliferation of new sensitive species as well (Rosenberg and Resh, 1993).

TABLE 5
FUNCTIONAL BIOLOGY AND TOLERANCE OF BENTHIC MACROINVERTEBRATES
AT FISHERVILLE POND, GRAFTON, MASSACHUSETTS

Taxa	Habitat	Trophic Status	EPA, 1990 Tolerant	EPA, 1990 Facultative	EPA, 1990 Sensitive	MADEP 1996
Annelida						
Oligochaeta						
Naididae						
Nais communis	Lentic or Lotic	Detrivores	X			8
Hirudinea						
Erpodellidae						
Erpobdella punctata	Generally Lentic	Parasites	X			8
Mollusca						
Gastropoda						
Planorbidae						
Helisoma sp.	Lentic	Scrapers/Grazers	X			6
Pelecypoda						
Sphaeriidae						
Pisidium sp.	Lentic or Lotic	Filter Feeders	X	X		7
Crustacea						
Amphipoda						
Talitridae						
Hyalella azteca	Lentic or Lotic	Omnivores/Scavengers		X		8
Insecta						
Emphemeroptera						
Caenidae						
Caenis sp.	Lentic or Lotic	Collectors/Scrapers		X	X	8
Odonata						
Zygoptera						
Coenagrionidae						
Amphiagrion sp.	Lentic - Vascular	Predators	X			9
Diptera						
Chironomidae						
Chironominae						
Chironomus sp.	Lentic or Lotic	Collectors/Herbivores	X	X		10
Cryptochironomus sp.	Lentic or Lotic	Predators		X		8
Tanypodinae						
Procladius sp.	Lentic or Lotic	Predators		X		9
Heleidae						
Stilobezzia sp.	Generally Lentic	Predators	X			6
Coleoptera						
Haliplidae						
Haliplus sp.	Lentic - Vascular	Herbivores		X		5

5.0 SUMMARY AND CONCLUSIONS

Macroinvertebrate communities are inherently variable, particularly seasonally, but also on both shorter (e.g., monthly) and longer (e.g., annual) scales. In addition, macroinvertebrate communities are spatially variable, often occurring in "patches" of varying size. Consequently, it was recognized some time ago that the use of macroinvertebrates as an assessment tool must be approached cautiously, and that often the level of effort necessary to obtain meaningful information that incorporates natural and spatial variation is considerable. In the presence of anthropogenic factors, interpreting inherent differences within and between stations becomes even more difficult, and may require suitable replication to substantiate observed trends in the benthic community. Given the current level of benthic community sampling and analysis at Fisherville Pond, it would be difficult to interpret the overall pattern of the benthic community assemblage with the spatial and temporal limitations of the existing data set.

The sampling and analysis of benthic macroinvertebrates conducted in this study indicate that the benthic community is probably dominated (or co-dominated) by oligochaete/chironomid assemblages throughout most of the year. The predominance of these two groups is typical of most lentic, shallow, freshwater systems. The species composition is also not atypical of other lotic systems with organic rich sediments. Both groups are common to northeast freshwater systems, and can tolerate a wide range of chemical and physico-chemical stressors. However, their presence and abundance in the Fisherville Pond samples described in this report cannot be contributed to extant conditions of the sediments, surface waters, or any other parameter at this time.

Overall, the composition of the benthic community, abundance of organisms, and number of taxa at each location suggest that the community is not necessarily stressed, but more likely imbalanced. The evidence for this conclusion is with particular regards to the dominance of the chironomids; high abundance of these organisms is typically associated with imbalanced communities. Moreover, the species of oligochaete in this system (*Nais communis*), is extremely tolerant of organic conditions, and is similar to tolerance values assigned to oligochaetes commonly associated with anthropogenic effects (e.g. *Tubifix tubifex* and *Limnodrilus* spp.; EPA, 1990). However, the number of taxa observed at these stations is not altogether different from what would be expected during the time of year the samples were collected. The lack of ETP could be present in the system in the fall, however, as early instars the organisms may not be well represented in ponar grab samples. Again, it is difficult to associate the sediment metal concentrations with these observations in the community structure. The distribution and abundance of individual taxa may be positively or negatively influenced by metals, whereas the number of taxa are generally lower in metal-stressed environments (Hare, 1992).

Perhaps the most compelling conclusions can be drawn from the evaluation of functional attributes of the benthic community. The overall diversity observed in the Fisherville Pond samples indicates that the benthic community is characterized by a dozen or more taxa that represent a wide range of trophic levels. Although there are limited data from which to support steadfast conclusions, the preliminary observation is that the macroinvertebrate productivity of Fisherville Pond appears to be functionally similar to macroinvertebrate communities observed at other "unimpacted" lentic systems in the northeast. However, observations on the community structure in Fisherville Pond indicate that although functionally well-represented, the abundance and tolerance of several key taxa suggest that the system is potentially imbalanced.

6.0 RECOMMENDATIONS

Despite some of the rigorous sampling requirements to address inherent variability, benthic communities can be a valuable assessment tool in determining the ecological health of an aquatic system. Evaluating the benthic community is probably one of the most widely accepted aspect of any aquatic monitoring program, whether applied in marine, estuarine, or freshwater environments. Given the current level of sampling in Fisherville Pond, there are two recommendations for continued efforts in this monitoring program.

For lentic systems like ponds and marshes, equally important communities can be present in the neuston (surface water interface) and particularly in the nekton (water column) portions of the system. Examples of neustonic organisms include the water striders, mosquitoes, and some species of aquatic beetles. Nektonic organisms may be represented by gastropods and bivalves, several species of aquatic diptera, dragonflies, damselflies, caddisflies, and hemipterans. In systems where submerged aquatic vegetation is abundant, many of these species may be present at abundances which can exceed those observed in the benthic community. Therefore, for Fisherville Pond, it is recommended that these communities are sampled to account for many of the species that were not observed in samples collected thus far. Furthermore, sampling all communities during three seasons (e.g., spring, summer, and fall) will greatly add to the confidence of interpreting the structure and composition of the invertebrate community at Fisherville Pond.

Based on the overall goals of the project, a quantitative assessment of the benthic macroinvertebrate community should also be conducted at locations in the pond to determine whether the indigenous communities appear normal, or if there is evidence to suggest that current anthropogenic factors (in sediments) are influencing community structure and function. Results from a quantitative sampling program (e.g., replicate samples taken at each station) account for inherent variability in the macroinvertebrate community, and can be evaluated using descriptive population statistics, biological indices, and multivariate tests. These tests can be used to compare suspected "impact" sites with reference sites of similar attributes or with historical sampling efforts from comparable ecosystems. Even more importantly, a quantitative benthic assessment can be designed to parallel the sediment chemistry sampling program used in this restoration study, in an attempt to integrate the analytical results with the structural and functional attributes of the benthic community.

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Section 5.0

Lakes and Impoundments

Table 5-1: Large Ponds, Lakes and Reservoirs in the Blackstone River Basin: Massachusetts

Name	Location	Size Acres	Trophic Status
Carpenter Reservoir	Northbridge	86	M
Coes Reservoir	Worcester	90	E
Crystal Lake	Douglas	90	E
Dark Brook Reservoir (Lower)	Auburn	57	M
Dark Brook Reservoir (Upper)	Auburn	256	E
Dorthy Pond	Milbury	148	E
Eddy Pond	Auburn	134	E
FishervillePond	Grafton	57	U
Flint Pond (North)	Grafton, Shrewsbury, Worcester	84	E
Harris Pond	Blackstone	93	E
Lake Hiawatha	Bellingham, Blackstone	63	E
Holden Reservoir # 1	Holden	119	U
Holden Reservoir # 2	Holden	46	U
Hopedale Pond	Hopedale	95	E
Indian Lake	Worcester	193	E
Kettle Brook Reservoir # 4	Paxton	119	O
Lackey Pond	Uxbridge, Sutton	117	U
Leesville Pond	Auburn, Worcester	96	H
Linwood Pond	Northbridge	61	E
Lynde Brook Reservoir	Leicester	132	O
Manchaug Pond	Douglas, Sutton	348	U
Meadow Pond	Northbridge, Sutton	45	E
Misco Lake	Wrentham	43	E
Newton Pond	Shrewsbury, Boylston	48	M
Nipmuck Pond	Mendon	239	M
Pondville Pond	Auburn	41	E
Pratt Pond	Upton	38	E
Lake Quinsigamond	Worcester, Grafton, Shrewsbury	475	M
Ramshorn Pond	Suton, Milbury	117	U
Rice City Pond	Northbridge, Uxbridge	91	E
Lake Ripple	Grafton	63	E
Silver Lake	Bellingham	70	M
Singletary Lake	Sutton, Millbury	330	M
Stevens Pond	Sutton	84	M
Stoneville Pond	Auburn	43	E
Stoneville Reservoir	Auburn	61	M
Waite Pond	Leicester	54	M
Wallum Lake	Douglas	322	O
Whitin Reservoir	Douglas	309	M
Whitins Pond	Northbridge Sutton	167	M

O: Oligiotrophic; M: Mesotrophic; E: Eutrophic; H: Hypereutrophic, U: Unknown

Source: Unpublished MA DEP report.

Table 5-2: Large Ponds, Lakes and Reservoirs in the Blackstone River Basin: Rhode Island

Name	Location	Size Acres	Trophic Status
Bowdish Reservoir	Glocester	226	M
Burlingame Reservoir	Glocester	67	M
Georgeiaville Pond	Smithfield	104	M
Keech Pond	Glocester	49	M
Killingly Pond	Glocester		
Lake Washington	Glocester	41	E
Lower Sprague Reservoir	Smithfield		
Pascoag Reservoir	Burrillville, Glocester	349	O/M
Pawtucket Reservoir	Cumberland		
Ponaganset Reservoir	Glocester		
Olney Pond	Lincoln	129	M
Smith and Sayles Reservoir	Glocester	173	M
Slack Reservoir	Smithfield, Johnston	134	M
Slateresville Reservoir	North Smithfield, Burrillville	138	E
Sneech Pond	Cumberland		
Sprague Reservoir	Smithfield		
Spring Lake	Burrillville	95	O/M
Tarkiln Pond	North Smithfield		
Wakefield Pond	Burrillville	75	M
Waterman Reservoir	Glocester, Smithfield		
Wallum Lake (RI waters)	Burrillville	115	O
Wenscott Reservoir	Lincoln, North Providence	82	M/E
Wilson Reservoir	Burrillville	109	M
Woonesquatucket Reservoir	Smithfield		
Woonsocket Reservoir	North Smithfield, Smithfield		

O: Oligiotrophic; M: Mesotrophic; E: Eutrophic; H: Hypereutrophic; U: Unknown

Source: RIDEM 305b report (August 1992)

APPENDIX F

SEDIMENT QUALITY

1. Summary of Existing Data

This section summarizes available sediment quality data from the Blackstone River basin. Sources of data include the Central Massachusetts Regional Planning Commission (CMRPC) (1976), McGinn (1981), Rojko (1990), USGS (1993), URI et al. (1996), Snook (1996), and this study. Most of the available data is from impoundments on the Blackstone River in Massachusetts. Few of the natural ponds, lakes or small impoundments on tributary stream have been tested.

Early studies by the CMRPC (1976) and McGinn (1981) found high metal concentrations in sediment at several major impoundments. The CMRPC study analyzed sediment from two riverine stations upstream of Singing Dam, the Singing Dam impoundment, the former Rockdale (Northbridge Mill Dam) impoundment, Fisherville Pond, and Rice City Pond (Table F-1). Sediment from the Singing Dam impoundment was most heavily contaminated and contained very high levels of nickel, zinc, copper, cadmium, and chromium.

McGinn (1981) collected sediment samples from 8 areas, including those sampled in the CMRC study, Riverdale Mill Pond, and Lackey Pond on the Mumford River. Numerous core samples were analyzed from each site. Average values are provided in Table F-2. Once again, very high metal levels were found at Blackstone River impoundments. Metal levels were much lower at Lackey Pond on the Mumford River than Blackstone River stations. The study summarized data from other Massachusetts river basins and concluded that Blackstone River sediments were much more severely contaminated than those from any other major river system in the state.

The McGinn study also conducted ten day (chronic) biotoxicity tests on sediment from Singing Dam impoundment, Fisherville Pond, Rice City Pond, Sutton Street in Northbridge (downstream of the former Rockdale impoundment), and a reference station. Test organisms were the fathead minnow (*Pimephales promelas*) and a daphnid (*Daphnia magna*). Sediments from Singing Dam and Fisherville Pond were not toxic, while those from Rice City Pond and the former Rockdale impoundment were highly toxic to daphnids, but not to fathead minnow.

Rojko (1990) summarized available data from numerous Massachusetts lakes and ponds, including several located in the Blackstone River Basin (Table F-3). Metal levels in the ponds were generally much lower than reported for sediments in mainstem impoundments by McGinn (1981).

The USGS tested core samples from within the former Rockdale Impoundment in 1993 (Table F-4). Samples were collected from the Blackstone River embankment and from unvegetated interior sites away from the river. Metal levels were highest at the interior stations and decreased with depth at the riverbank station. At the interior sites, an oily sludge layer was found at 2 ft. depth, and the sediments seemed somewhat unstable.

The Blackstone River Initiative (URI et al. 1996) conducted sediment testing from mainstem Blackstone River impoundments and two impoundments on the Mumford River in 1991 and 1993. Surficial grab samples were collected from open water areas and analyzed for metals, total PAHs, and whole sediment and pore water toxicity.

All mainstem impoundments and the Mumford River impoundments contained high levels of one or more metal (Figures F-1 through F-6, from draft BRI report). Sediments at Singing Dam, Fisherville Pond, Rice City Pond, Gilboa Pond, and Grey's Pond were most highly contaminated. PAH levels were highest at Gilboa Pond, followed by Singing Dam, Fisherville, and Rice City Pond (Figure F-7).

Two rounds of whole sediment toxicity testing were conducted in 1991 using the midge *Chironomis tentans* and the amphipod *Hyallela azteca.* Results are shown in figures F-8 and F-9. Results of the first round are considered invalid due to high mortality in control sediment (station LC). During the second round, significant mortality of the amphipod *Hyallela* occurred at all Blackstone and Mumford river stations. Mortality in most samples was greater than 80 %. Whole sediment toxicity testing in 1993 (Round 3) using found significant mortality only at Singing Dam and Rockdale Pond. Pore water toxicity testing conducted in 1993 using the daphnid *Ceriodaphnia* dubia and fathead minnow (*Pimephales promelas)* found significant mortality at Singing Dam, Fisherville Pond, and Rockdale Pond, Tupperware Dam, and Manville Dam (Tables F-5 and F-6).

Snook (1996) conducted extensive testing of sediments in the Rice City pond floodplain, canal, and ponded area. Twenty one 18" core samples were collected and analyzed for metals, PCBs, total petroleum hydrocarbon, and semi-volatiles. Toxicity Characteristic Leaching Procedure (TCLP) tests were also conducted on a few samples. Metal levels were high, as reported in other studies of Rice City Pond. TCLP regulatory limits, however, were not exceeded. In addition to high metal levels, a sediment layer saturated with oily residues was found in most core samples, generally at a depth of 10-14". Jet black sediment and strong sulfur odors suggested the presence of ferrous sulfides capable of binding divalent metals. Three core samples were sectioned and tested for metals. Metal levels decreased dramatically below the oily layer in all three samples.

In an effort to determine the source of the oily sediment layer at Rice City pond Snook (1996, and unpublished data) tested sediments at the former Rockdale impoundment (Coz Chemical), Farnumsville Pond, and Fisherville Pond (Table F-7). The results suggest that the source of the PCBs and petroleum hydrocarbons contamination is downstream of the Fisherville impoundment.

This study collected surficial grab samples from 5 stations within open water areas at Fisherville Pond in November of 1996 (see Appendix I, Figure 1-2, for sample locations). The samples were analyzed for acid volatile sulfide, extractable metals, organic carbon, and grain size (Table F-8). Benthic invertebrate data was also collected from the same stations (see Appendix A, Section 4.1). The AVS/SEM ratio from all stations was above one, suggesting that sediment is likely to be toxic (see below). The AVS/SEM ratio of sample F-1 from the open water area near the old mill building was extraordinarily high.

2. Sediment Quality Assessment

General Considerations

Determining the ecological significance of sediment contamination is a difficult task. Effects of sediment contamination include possible impacts on the survival, growth, and reproduction of individual organisms, impacts on populations, and ultimately impacts to communities. Also of great concern is the potential for contaminants to biomagnify in aquatic and terrestrial food chains, potentially affecting both wildlife and human health. Assessing impacts becomes increasing problematic and speculative as consideration shifts from individual organisms to populations, and communities.

Aquatic life is exposed to contaminants in sediment in several ways. These include direct absorption of contaminant from interstitial (pore) water in sediment, absorption of contaminants released for surface waters, ingestion of contaminated sediments, and ingestion of prey items which have accumulated contaminants from the sediment. Absorption from interstitial water and ingestion of sediment are the most important pathways for benthic invertebrates, while ingestion of contaminated prey is generally the most important pathway for fish.

The effect of a contaminant on aquatic life will depend on several factors. These include the availability of the contaminant, the toxicity of the contaminant to organisms (receptors) present in the environment, the persistence of the contaminant in the environment, and synergistic effects with other contaminants.

Availability of contaminants to biota is strongly related to the concentration of the contaminants in sediment interstitial (pore) water. The concentration of organic contaminates in interstitial water depends largely on the affinity of the contaminant to organic carbon and the organic carbon content of the sediment. The availability of a given organic contaminant will generally increase as sediment organic content decreases. Metal concentration in interstitial water seems strongly related to the acid volatile sulfide (AVS) content of the sediments, and to a lesser extent organic carbon content and other binding sites (U.S. EPA 1994). Metals such as copper, lead, cadmium, zinc, and nickel will bind to AVS to form insoluble metal sulfides. Since excess metals in solution are available to biota and potentially toxic, the ratio of extractable metals (SEM) to AVS is may be a good predictor of toxicity. Studies suggest that sediments with SEM/AVS ratios greater than unity (1) are often, but not always, toxic (Hansen et al., 1996).

Evaluation

To determine if sediment contamination is impacting aquatic communities several lines of evidence are usually evaluated. These include comparison of contaminant levels to published sediment quality criteria, the SEM/AVS ratio, whole sediment and sediment pore water toxicity studies, and benthic invertebrate community studies.

Unlike water quality, there are few criteria available for sediment quality. The USEPA (1995) has proposed sediment quality criteria for three PAHs (acenaphthene, flouranthene, and phenanthene) and two pesticides (dieldrin and endrin). The proposed criteria are protective of benthic organisms in permanently flooded sediments or those inundated sufficiently to allow development of benthic invertebrate communities. The EPA criteria are intended to protect benthic invertebrates which are exposed to hydrophobic organic compounds in interstitial water. Toxicity is assumed to depend on availability of the contaminants which varies inversely with sediment organic carbon concentration according to equilibrium partitioning theory.

In addition to these criteria, several studies have attempted to correlate contaminant concentration in sediments with observed biological effects and use this information to develop guidance for assessing ecological risk.

Long and Morgan (1990) and Long et al. (1995) developed threshold values above which adverse effects on benthic organisms are likely to occur for metals, Pasha, PCBs, and pesticides based on field data from mostly marine and estuarine sediments. "Effect Range-Low" (ERL) values represent the concentration of a contaminant above which adverse effects on sensitive species or early life stages may occur. "Effect Range-Median" (ERM) values represent the concentration above which most species would frequently be affected. Concentrations of contaminants below ERL values should be protective of sensitive species or early life stages. Concentrations above ERM will frequently adversely effect both sensitive and more tolerant species.

The Ontario Ministry for the Environment developed guidelines for screening freshwater sediment (Persaud et al., 1993). Guidance values were calculated using field data to determine the highest concentration of a contaminant that can be tolerated by a specific proportion of benthic invertebrates. Lowest Effect Level (LEL) represent the concentration of a contaminant that can be tolerated by most (95%) of benthic species.

Severe Effect Level (SEL) values indicate the level at which most invertebrates in the community would be impacted. If contaminant levels exceed SEL values, testing to determine whether or not the sediments are acutely toxic is advisable.

Available EPA criteria along with the literature-based guidance are summarized in Table F-9.

The concentration of metals in Blackstone River and Mumford River impoundments generally well exceed established ERM and SEL values. This suggests, at a minimum, that a significant risk to most benthic species may exist.

Although ERL and SEL criteria are exceeded and adverse affects on biota are likely, bioavailablity of contaminants and toxicity can be low even in highly contaminated sediment. SEM/AVS sediment testing, biotoxicity testing, and macroinvertebrate studies help to further access sediment quality.

SEM/AVS data from Fisherville Pond suggests that metal availability is high and that benthic communities may be at risk. For all samples tested at Fisherville the SEM/AVS ratio was well above 1. A very high ratio (ca. 390) for one sample collected near the old mill suggests that a hot spot (or spots) may be present. As discussed above, sediment is generally, but not always, toxic when the SEM/AVS ratio is above 1.

Existing toxicity data suggests that sediment from many Blackstone River mainstem impoundments is toxic and may be adversely impacting benthic communities. Benthic invertebrate data is lacking, however, except for Fisherville, where the benthic community does not appear severely degraded. Similar studies to evaluate risk to benthic communities at other impoundments are needed. Overall, the results suggest that the benthic invertebrate communities at Fisherville Pond and other impoundments may be at risk, but additional sediment testing (particularly SEM/AVS testing), toxicity testing, and biological sampling is needed is needed to fully characterize sediment quality and evaluate risk.

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Table F-1: Summary of CMRPC (1976) Sediment Testing (from McGinn, 1981)[1]

Site	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Mercury
Milbury St., Milbury[2]	-	32	160	176	160	51	320	0.89
McCracken Rd., Milbury[2]	-	9.2	130	200	150	40	140	0.71
Singing Dam	5	100	750	1300	980	2900	1700	0.48
Fisherville Pond	2	37	240	540	340	71	570	0.40
Rockdale Impoundment	0.48	65	1100	1100	1000	160	970	0.36
Rice City Pond	-	17	210	220	190	110	370	0.52

Notes: 1. Average values (mg/g) in composite grab samples of river bottom sediment.
2. Blackstone River station.

Table F-2: Summary of McGinn (1981) Sediment Testing[1]

Site	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Milbury St., Milbury[2]	29	50	695	968	889	106	1022
McCracken Rd., Milbury[2]	11	43	82	270	257	69	98
Singing Dam	36	48	497	1311	1091	110	1144
Fisherville Pond	29	29	398	914	814	73	667
Rockdale Impoundment	40	33	330	3251	1045	67	681
Riverdale Mill Dam	22	40	595	951	645	65	1221
Rice City Pond	29	50	695	968	889	106	1022
Lackey Pond	8	1	108	57	42	14	232

Note: 1. From Table II-4 of McGinn report. Average values (mg/g) for core samples taken to variiable depth (refusal) from multiple locations at each site. Sample location and data for indvidual samples is provided in the McGinn report.
2. Blackstone River station.

Table F-3: Summary of Blackstone Rive Basin Sediment Data Reported by Rojko (1990)

Lake/Town		Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Mercury	Zinc
Cedar Swamp Pond	Uxbridge	88	9.3	9.9	20.3	173	9.9	0.46	171
Dorothy Pond	Milbury	14.8	1.4	6.3	24.2	84	11.1	0.32	193
Dudley Pond	Douglas	2.1	2.0	9.5	44.7	480	17.0	0.42	290
Indian Lake	Worcester	-	2.2	2.6	120	400	10.6	0.21	390
North Pond	Milford	-	0.4	1.5	2.9	21	-	-	19
Lake Ripple	Grafton	88.0	0.6	6.1	22.6	22	2.3	0.2	55
Salisbury Pond	Worcester	18.8	5.6	80.4	198	542	36.8	0.61	449
Singletary Pond	Milbury/Sutton	-	1.5	28	38.0	125	-	-	165

Note: All data reported as mg/kg.

Table F-4: USGS Sediment Data from the Former Rockdale Impoundment

Location	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Riverbank						
1.5' Depth	20	300	1000	300	20	200
3' Depth	N	150	700	200	20	N
4' Depth	N	70	150	30	20	N
Poorly Vegetated Area						
Sample 1	30	300	1000	500	30	200
Sample 2	30	500	1500	300	30	200
Detection Limit	20	10	5	10	20	200

Note: All data from core samples. Data reported as mg/kg. N: Not detected at limit of detection.

Table F-5 48 Hour Toxicity (% Survival) *Ceriodaphnia dubia*

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 F-6 48 Hour Toxicity (% Survival) *Pimephales promelas*

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

Table F-7: Snook 1995 PCB and PAH Data

Parameter	Fisherville Pond	Former Rockdale Impoundments	Farnumsville Impoundment
PAHs (ug/g)			
Acenaphthene	380	-	-
Phenanthrene	910	-	-
Anthracene	310	-	-
Fluoranthene	300	-	-
Pyrene	500	-	-
Benzo-a-anthracene	200	-	-
Chrysene	180	-	-
Benzo-a-fluoranthene	130	-	-
Benzo-a-pyrene	170	-	-
PCBs ((ug/g)			
A1254	ND	9.8	2.3
A1260	ND	7.2	ND
TPH (g/g)	11000	15000	310000

ND: Not detected at minimum detection level of 0.081 ug/g for A1254 and 0.13 ug/l for A1260 (USEPA method 8080.29).

Table F-8: Corps 1995 Sediment Testing at Fisherville Pond

Parameter	Sample Location				
	F-1	F-2	F-3	F-4	F-5
SEM (umoles/g)					
Copper	36.00	14.6	0.800	9.07	16.70
Lead	5.57	4.34	0.508	1.82	4.62
Cadmium	0.207	0.420	0.052	0.233	0.187
Zinc	7.84	9.17	3.86	11.33	7.04
Nickel	0.0142	0.0142	0.0796	0.3163	0.0142
Total Metals	49.631	28.544	5.300	20.98	28.561
AVS	0.128	5.49	2.39	3.067	5.21
SEM/AVS Ratio	387.7	5.2	2.2	11.8	5.5
TOC (%)	16.0	13.7	3.8	10.7	9.9
% Fines	67.9	29.4	14.7	48.7	66.7

See Appendix I, Figure 1-2 for sample locations.

Table F-9: Sediment Quality Criteria

ANALYTE	PROPOSED CRITERIA AND GUIDELINES				
	Proposed USEPA SQC	NOAA (ERL)	NOAA (ERM)	Ontario (LEL)	Ontario (SEL)
INORGANICS (mg/kg)					
Arsenic	-	8.2	70	6	33
Cadmium	-	1.2	9.6	0.6	10
Chromium	-	81	370	26	110
Copper	-	34	270	16	110
Lead	-	47	218	31	250
Nickel	-	0.15	0.71	0.2	2
Mercury	-	21	52	16	75
Zinc	-	150	410	120	820
PAHs (mg/kg)					
Acenaphthene	13	0.016	0.5	-	-
Acenaphthylene	-	0.044	0.64	-	-
Anthracene	-	0.085	1.1	0.22	37
Benzo(a)anthracene	-	0.261	1.6	0.32	148
Benzo(a) pyrene	-	0.43	1.6	0.37	144
Benzo (b)fluroanthene	-	-	-	-	-
Benzo(k)fluroanthene	-	-	-	0.24	134
Benzo (g,h,i)perylene	-	-	-	0.17	32
Chrysene	-	0.384	2.8	0.34	46
Dibenz(a,h)anthracene	-	0.063	0.26	0.06	13
Fluoranthene	62	0.6	5.1	0.75	102
Fluorene	-	0.019	0.54	0.19	16
Indeno(1,2,3-cd)pyrene	-			0.2	32
2-methylnapthalene	-	0.07	0.67	-	-
Napthalene	-	0.16	2.1	-	-
Phenanthrene	18	0.24	1.5	0.56	95
Pyrene	-	0.665	2.6	0.49	85
Total PAHs (mg/kg)		4.02	44.8	4	1000
PCBs (mg/kg)	-	O.O23	0.18	0.05	53
PESTICIDES (ug/kg)					
DDD	-	-	-	8	600
DDE	-	2	27	5	1900
DDT	-	2	46	7	1200
Chlordane	-	-	-	7	600
Endrin	4.2	-	-	3	13000
Heptachlor	-	-	-	-	-

References:

1. Proposed USEPA Criteria: FR59(11): 2652-2656.
2. NOAA: Long et al. 1995
3. Ontario: Persaud et al. 1993

Table F-9: Sediment Quality Criteria

ANALYTE	PROPOSED CRITERIA AND GUIDELINES				
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Cadmium	-	1.2	9.6	0.6	10
Chromium	-	81	370	26	110
Copper	-	34	270	16	110
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Nickel	-	0.15	0.71	0.2	2
Mercury	-	21	52	16	75
Zinc	-	150	410	120	820
PAHs (mg/kg)					
Acenaphthene	13	0.016	0.5	-	-
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Anthracene	-	0.085	1.1	0.22	37
Benzo(a)anthracene	-	0.261	1.6	0.32	148
Benzo(a) pyrene	-	0.43	1.6	0.37	144
Benzo (b)fluroanthene	-	-	-	-	-
Benzo(k)fluroanthene	-	-	-	0.24	134
Benzo (g,h,i)perylene	-	-	-	0.17	32
Chrysene	-	0.384	2.8	0.34	46
Dibenz(a,h)anthracene	-	0.063	0.26	0.06	13
Fluoranthene	62	0.6	5.1	0.75	102
Fluorene	-	0.019	0.54	0.19	16
Indeno(1,2,3-cd)pyrene	-			0.2	32
2-methylnapthalene	-	0.07	0.67	-	-
Napthalene	-	0.16	2.1	-	-
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PCBs (mg/kg)	-	O.O23	0.18	0.05	53
PESTICIDES (ug/kg)					
DDD	-	-	-	8	600
DDE	-	2	27	5	1900
DDT	-	2	46	7	1200
Chlordane	-	-	-	7	600
Endrin	4.2	-	-	3	13000
Heptachlor	-	-	-	-	-

References:

1. Proposed USEPA Criteria: FR59(11): 2652-2656.
2. NOAA: Long et al. 1995
3. Ontario: Persaud et al. 1993

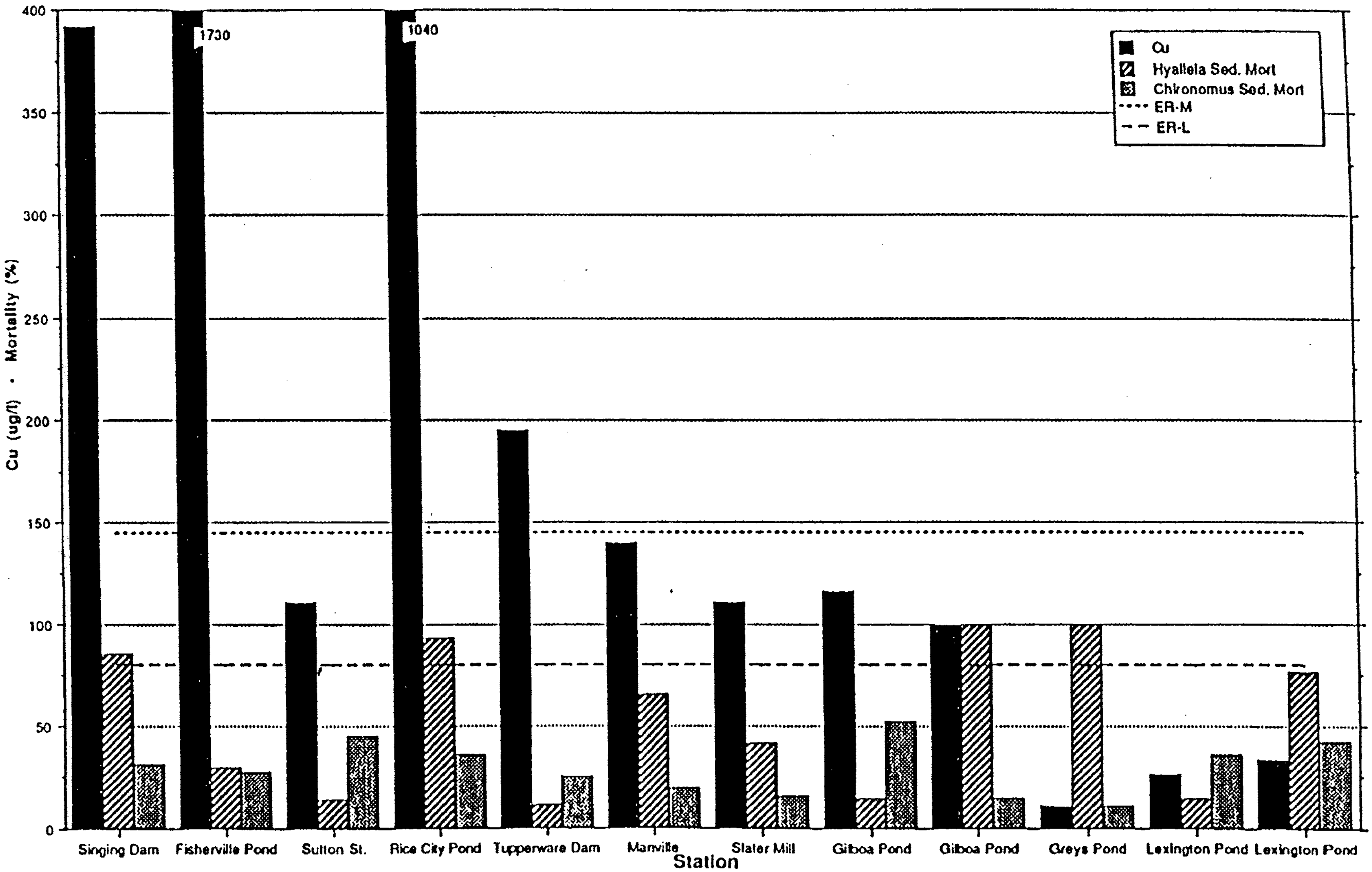


Figure F-1 Copper in Blackstone River Sediments

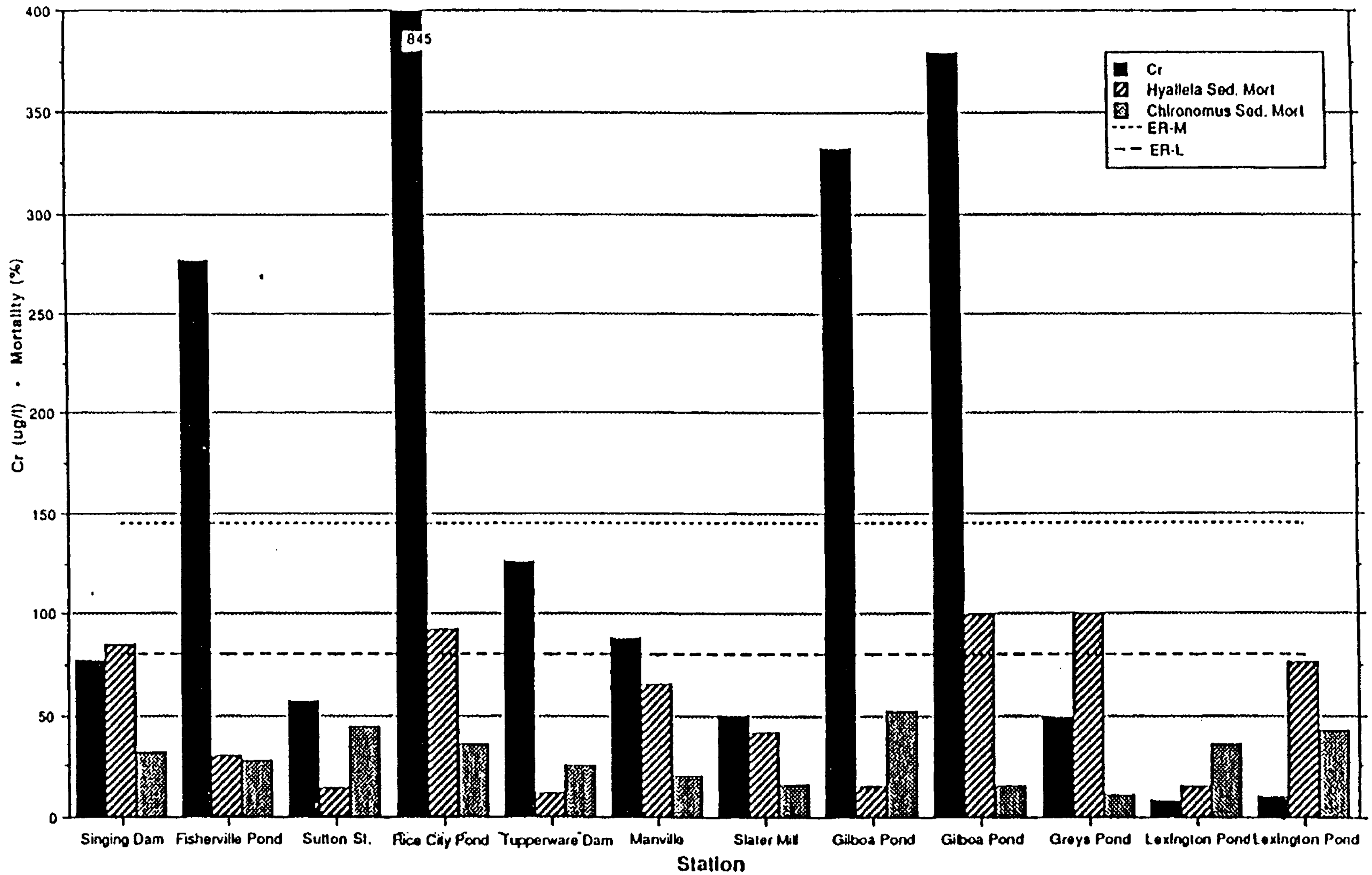


Figure F-2 Chromium in Blackstone River Sediments

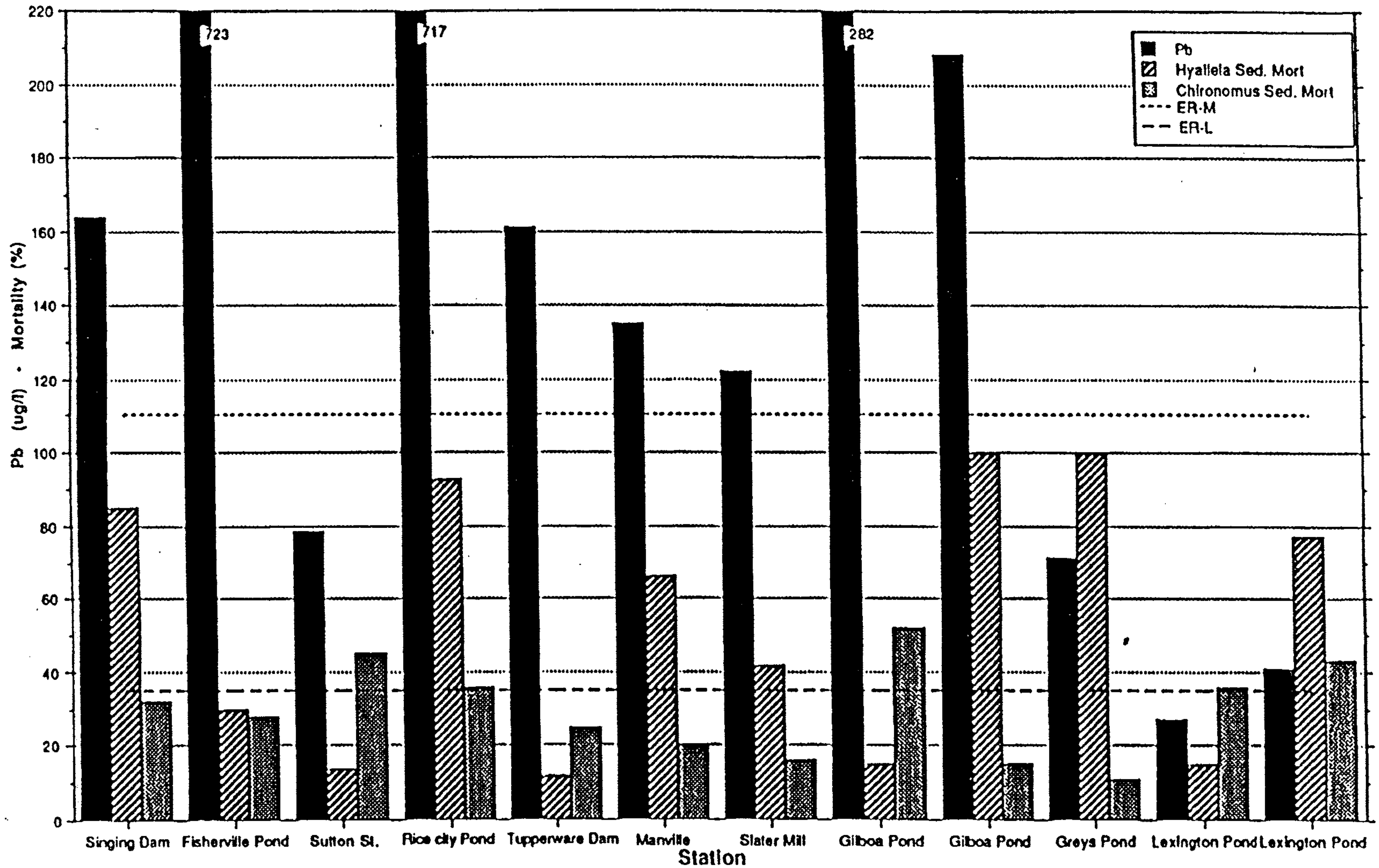


Figure F-3 Lead in Blackstone River Sediments

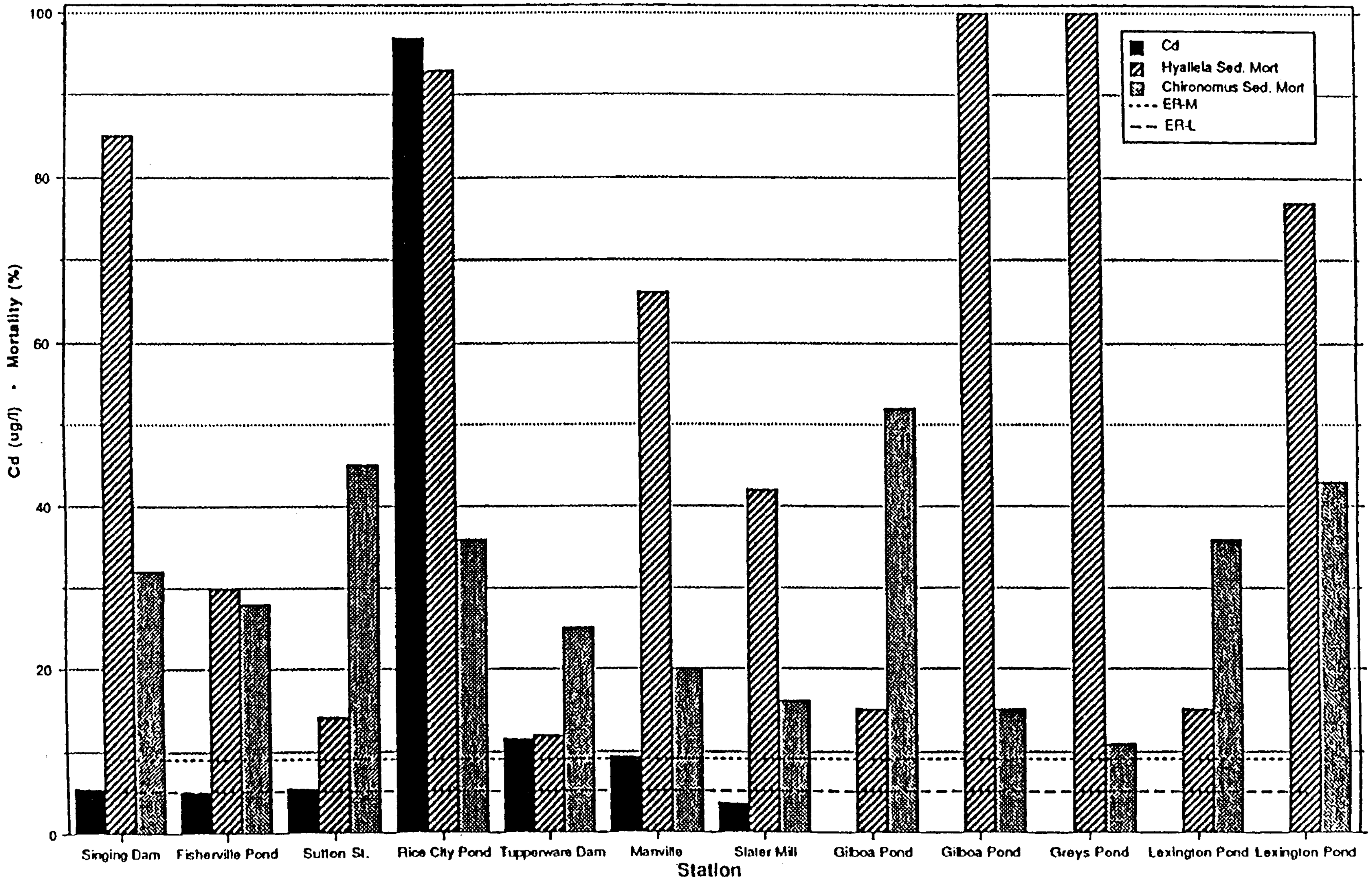


Figure F-4 Cadmium in Blackstone River Sediments

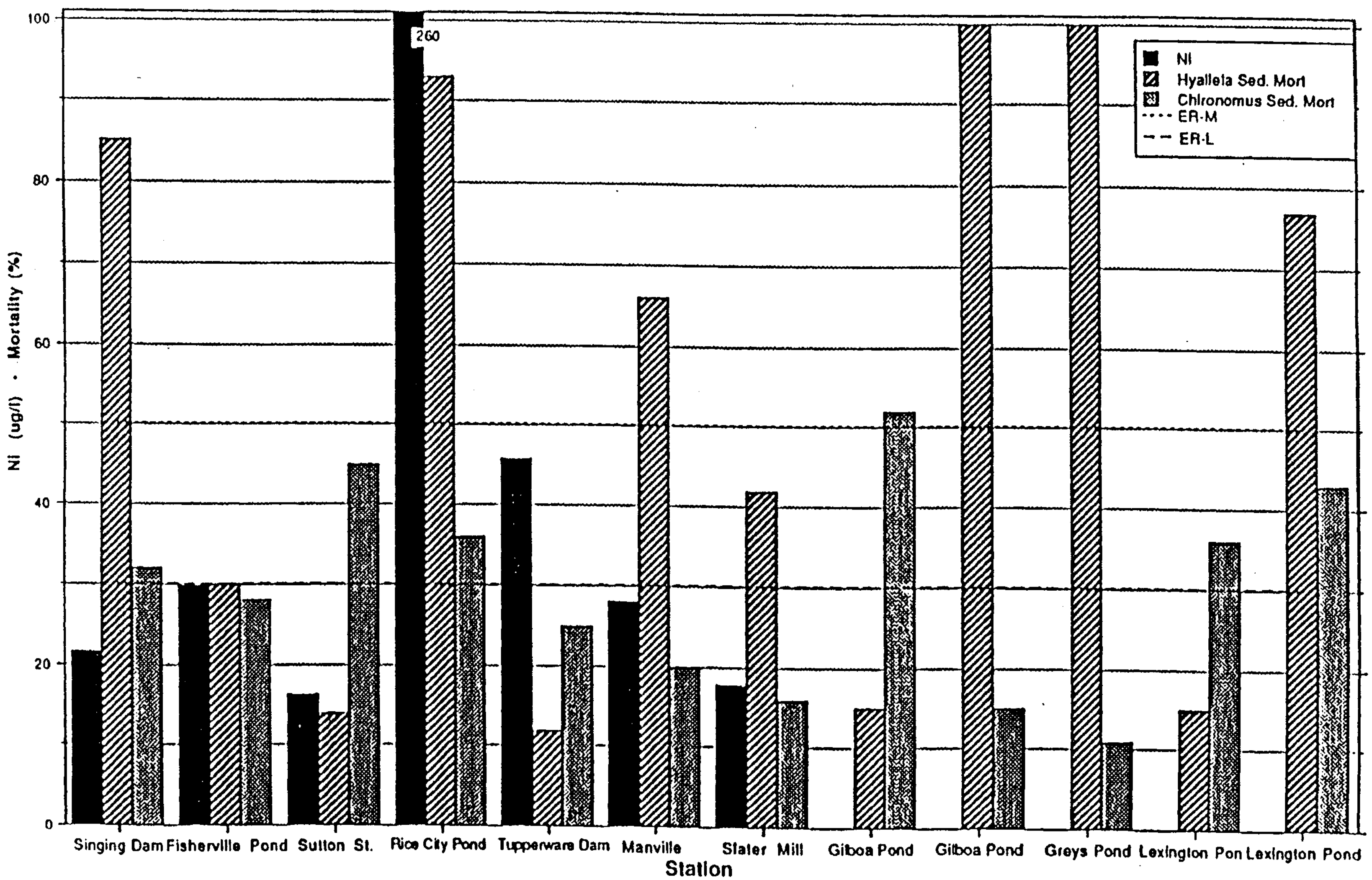


Figure F-5 Nickel in Blackstone River Sediments

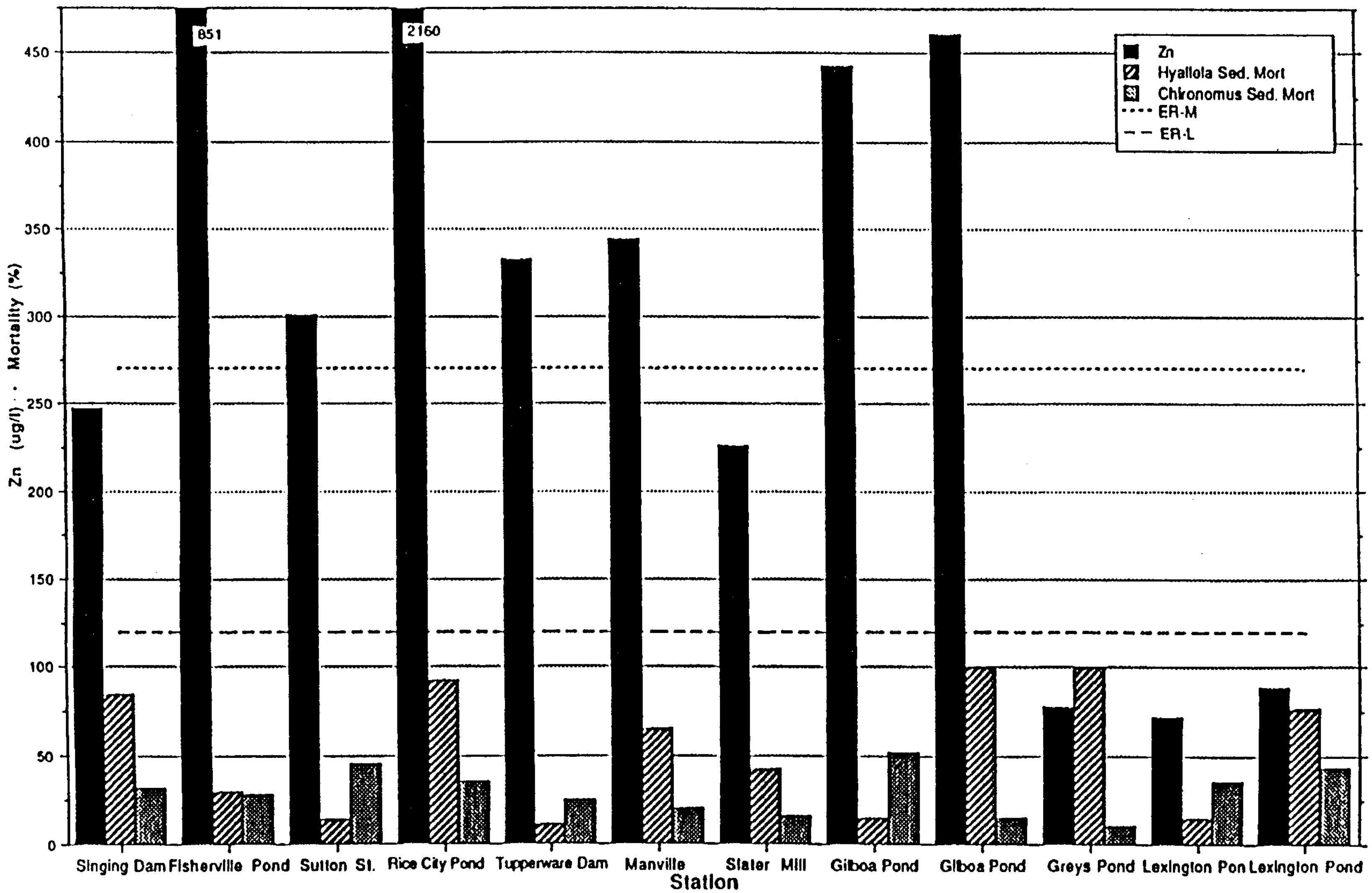


Figure F-6 Zinc in Blackstone River Sediments

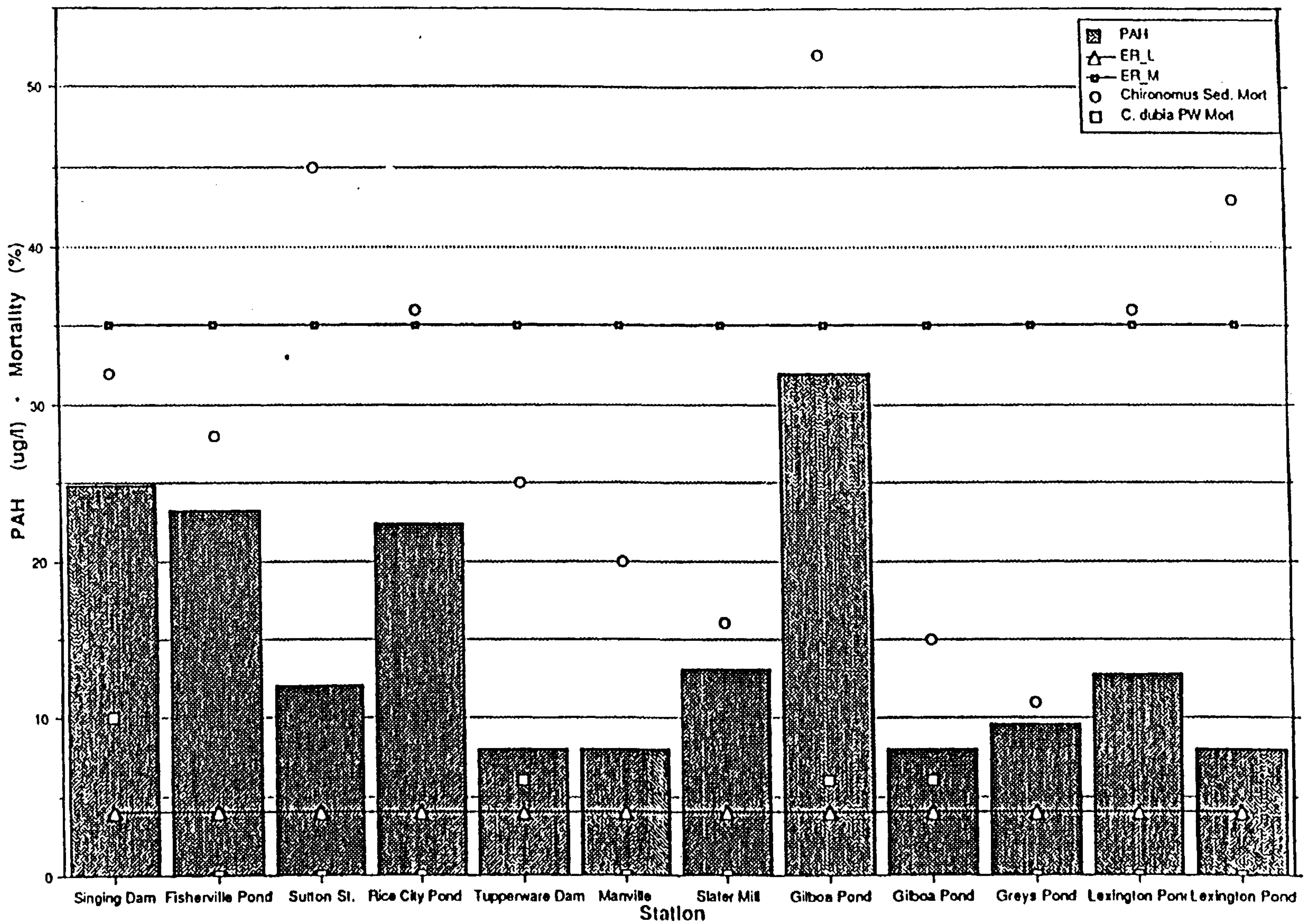


Figure F-7 Polyaromatic Hydrocarbons and *Chironomus* and *Hyallela* Mortality

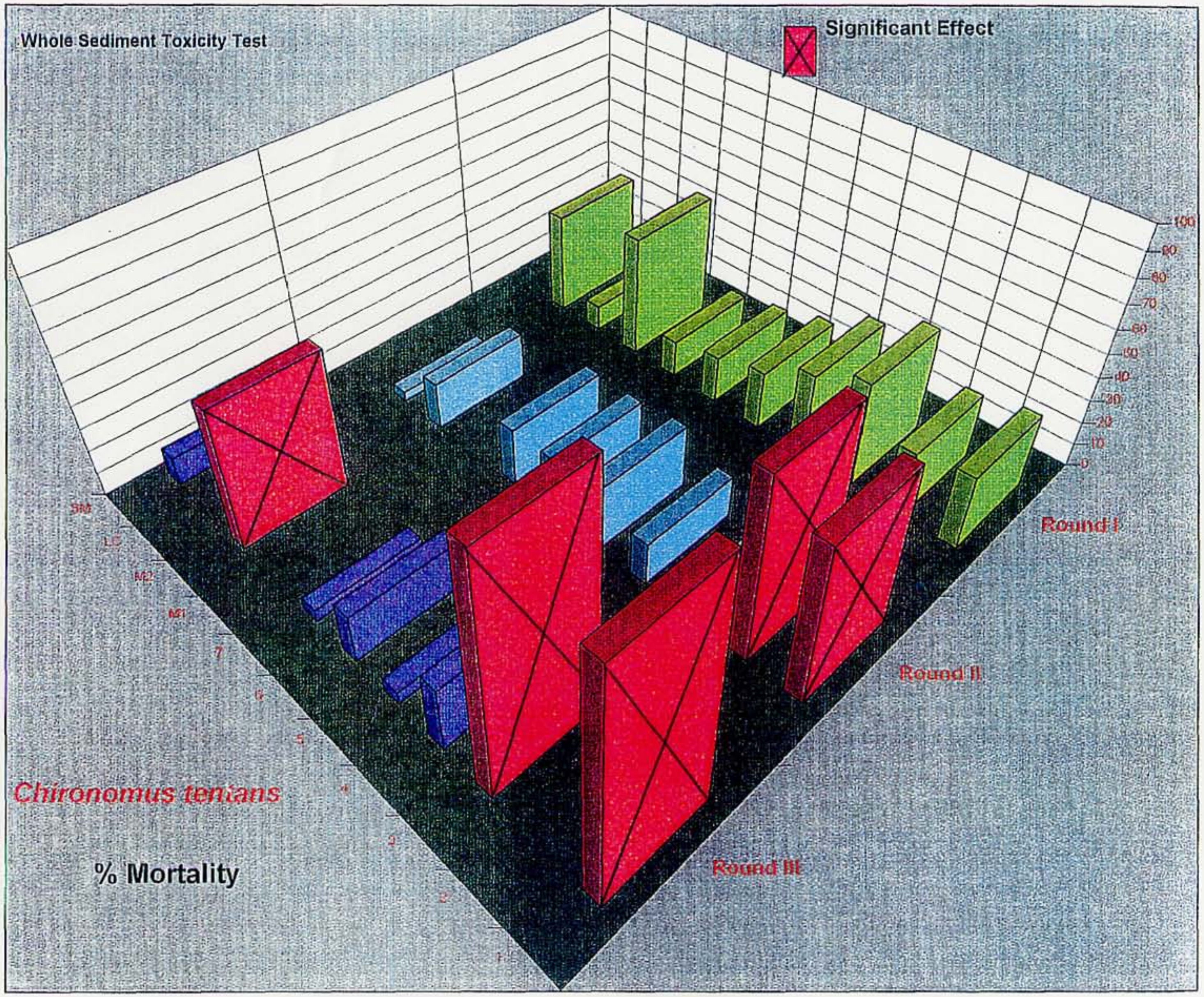


Figure F-8 Results of the Whole Sediment Toxicity Test *Chironomus tentans*

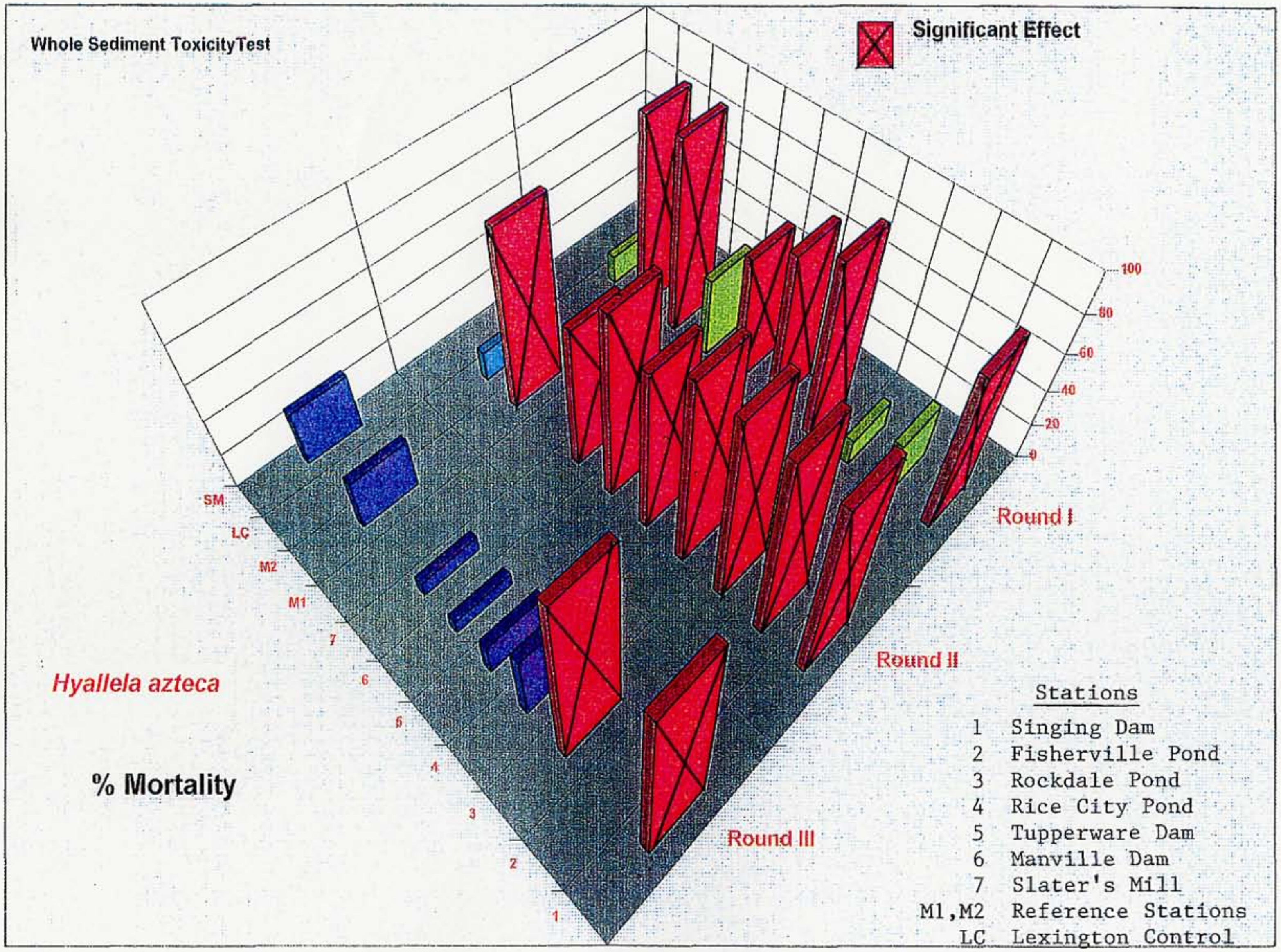
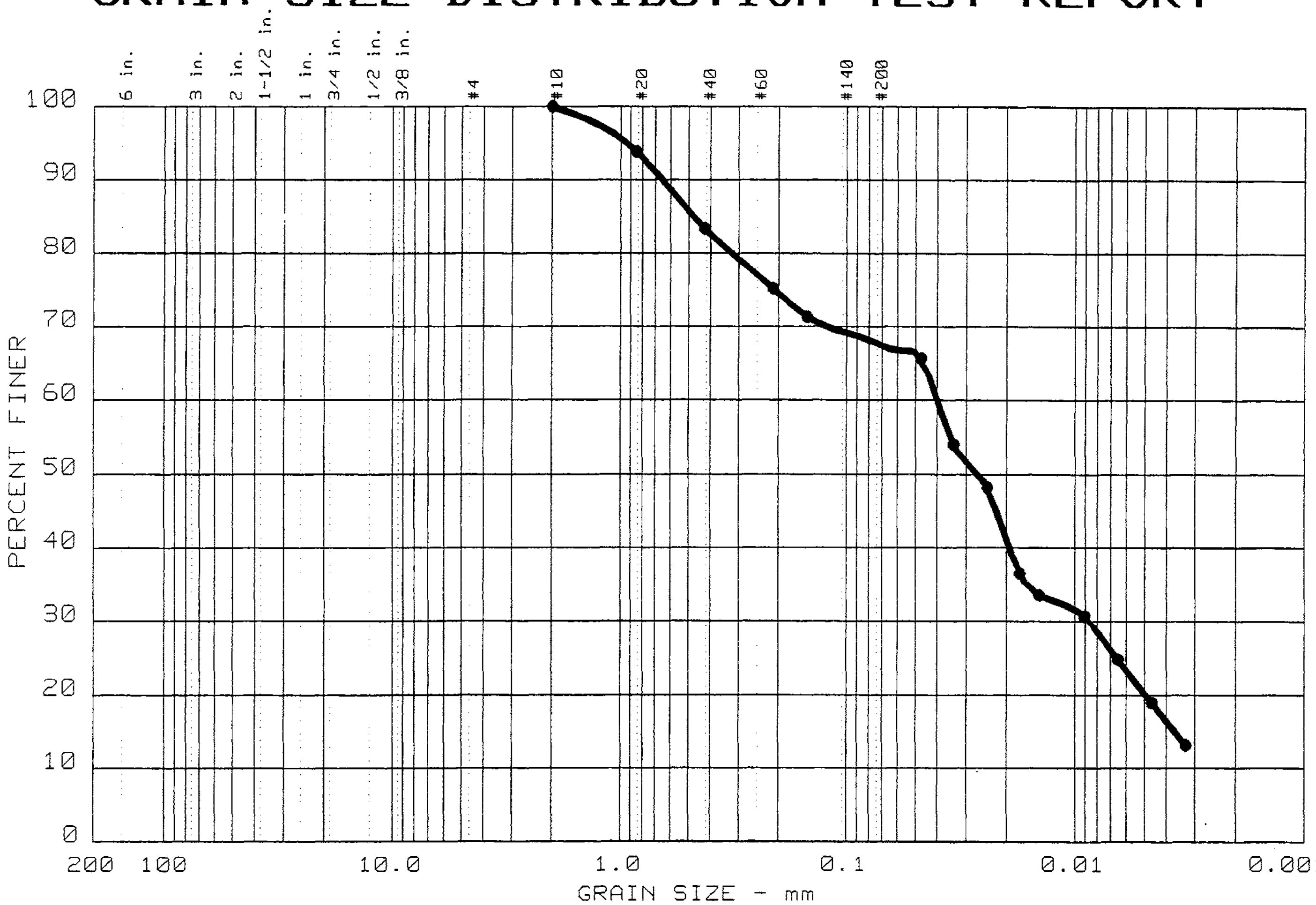


Figure F-9 Results of the Whole Sediment Toxicity Test *Hyallela azteca*

Grain Size Curves for 1995 Corps Fisherville Pond Samples

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	8	0.0	0.0	32.1	47.6	20.3

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.473		0.0266	0.0086	0.0037			

MATERIAL DESCRIPTION	USCS	AASHTO
● Dk. Brown Sandy Silt w/ organics	ML	

Project No.: 446-60488

Project: Fisherville Pond/ Blackstone River

● Location: ENV 36226 F-1

Date: Oct. 31, 1996

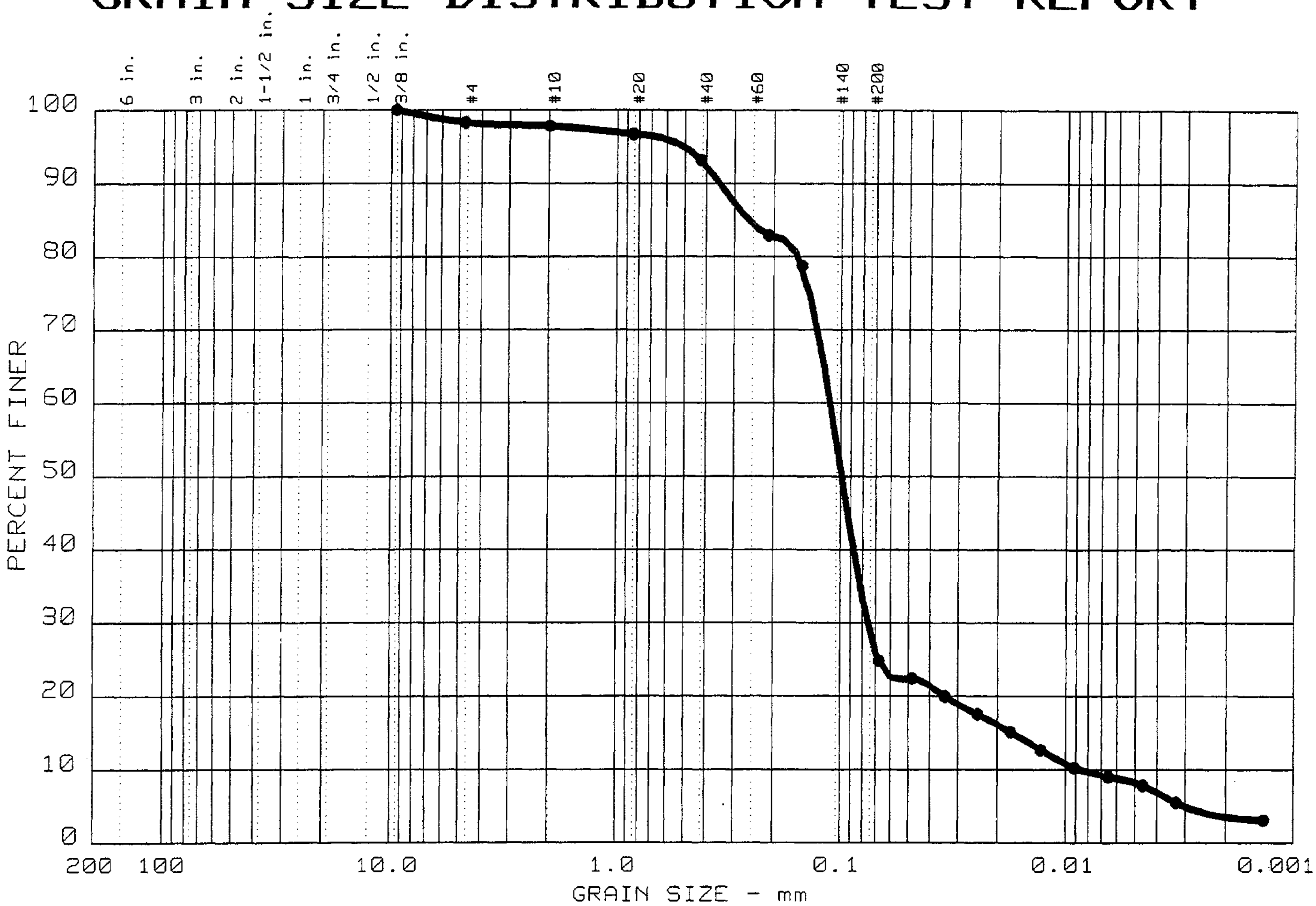
GRAIN SIZE DISTRIBUTION TEST REPORT

PSI
Canton, MA

Remarks:

Figure No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	9	0.0	1.8	68.8	21.2	8.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.260	0.112	0.0990	0.0757	0.0171	0.0086	5.98	13.0

MATERIAL DESCRIPTION	USCS	AASHTO
● Dk. Brown Sandy Silt w/organics	SM	

Project No.: 446-60488
Project: Fisherville Pond/ Blackstone River
● Location: ENV 36227 F-2

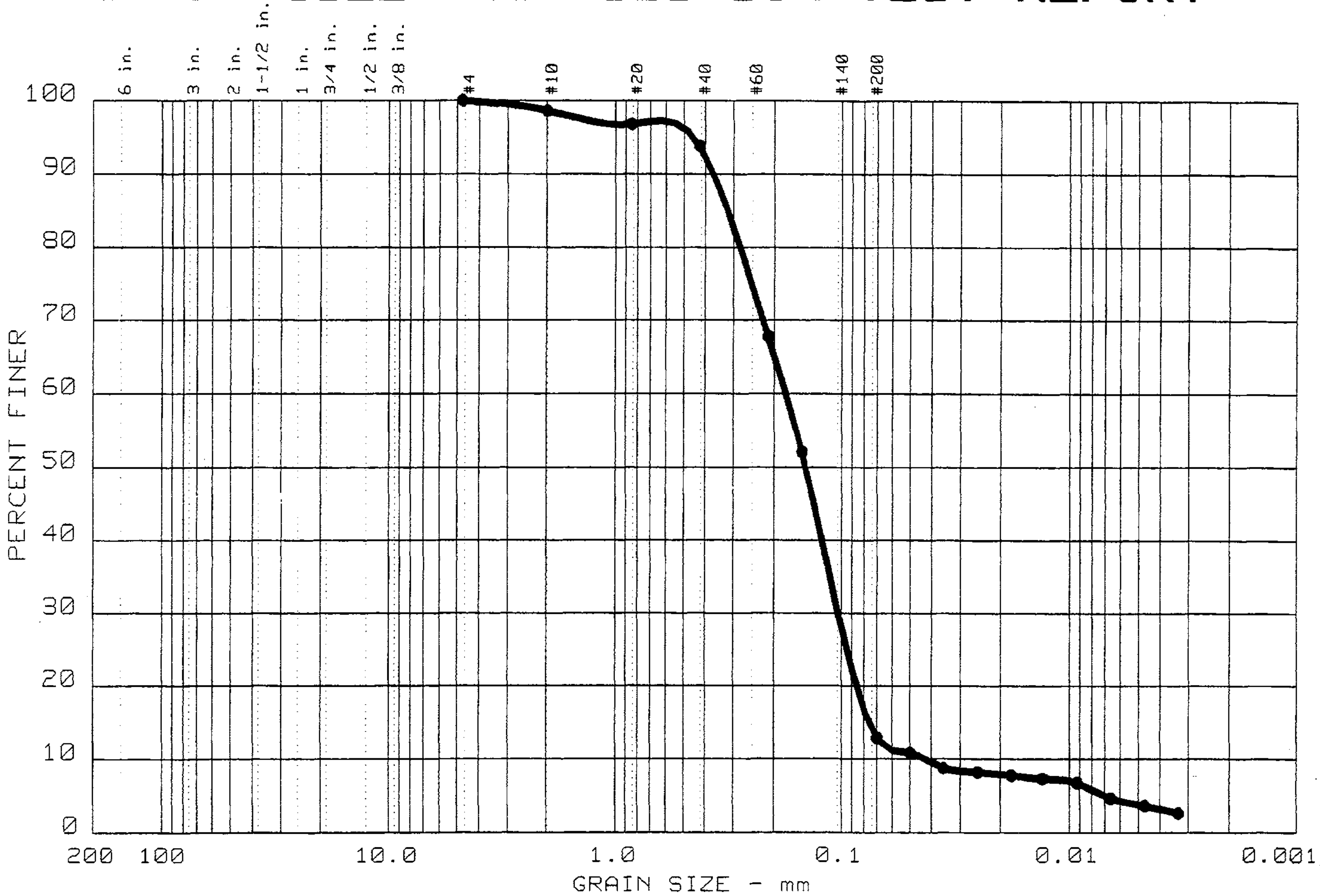
Date: Oct. 31, 1996

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
PSI
Canton, MA

Figure No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	10	0.0	0.0	85.3	10.9	3.8

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.318	0.177	0.144	0.103	0.0757	0.0426	1.42	4.2

MATERIAL DESCRIPTION	USCS	AASHTO
● Dk. Brown Silty Sand w/ organics	SM	

Project No.: 446-60488
Project: Fisherville Pond/ Blackstone River
● Location: ENV 36228 F-3

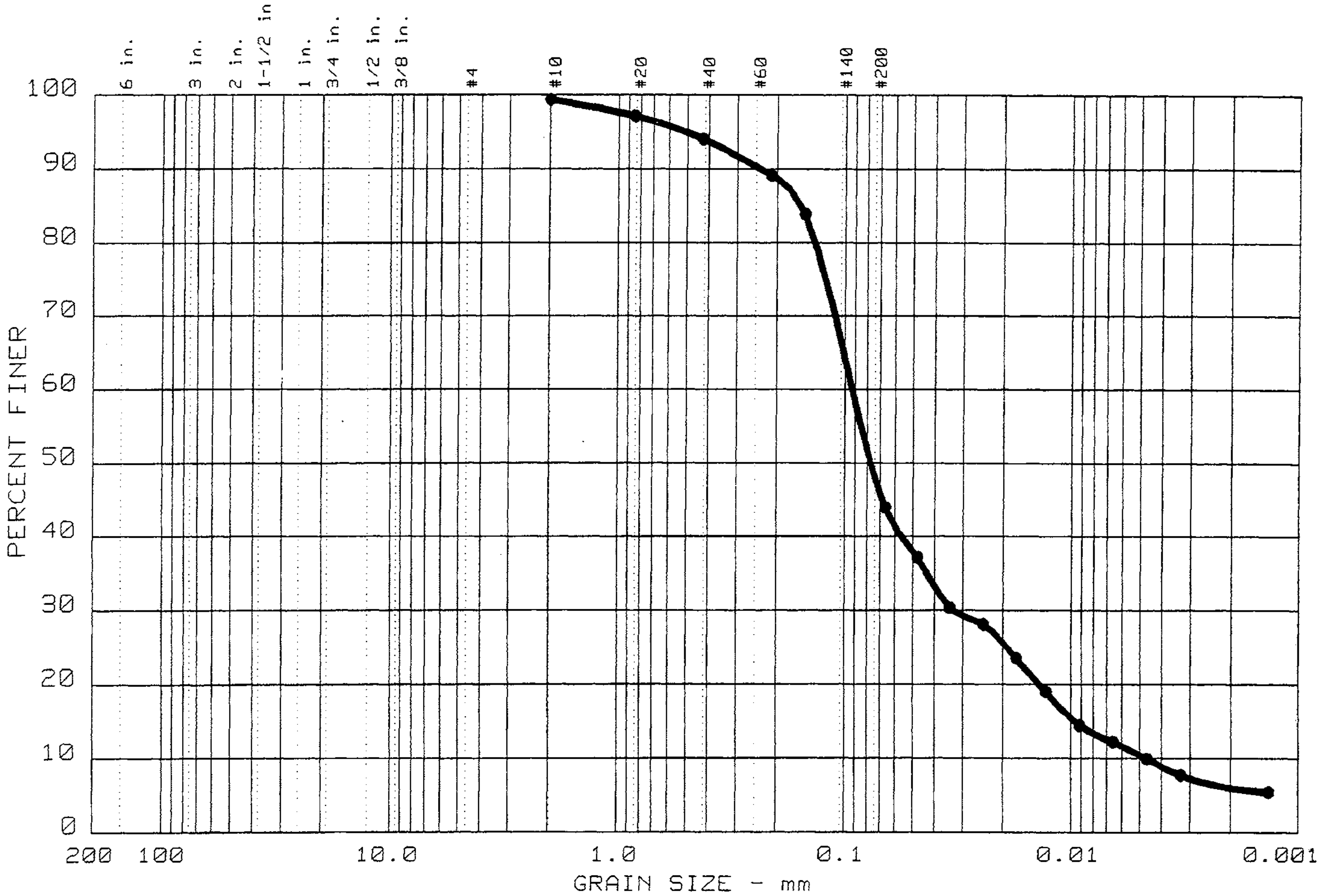
Date: Oct. 31, 1996

GRAIN SIZE DISTRIBUTION TEST REPORT
PSI
Canton, MA

Remarks:

Figure No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	7	0.0	0.0	51.3	38.3	10.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.156	0.0929	0.0770	0.0332	0.0096	0.0046	2.56	20.0

MATERIAL DESCRIPTION	USCS	AASHTO
● Dk. Brown Sandy Silt w/ organics	SM	

Project No.: 446-60488

Project: Fishervelle Pond/Blackstone River

● Location: ENV 36229 F-4

Date: Oct. 31, 1996

GRAIN SIZE DISTRIBUTION TEST REPORT

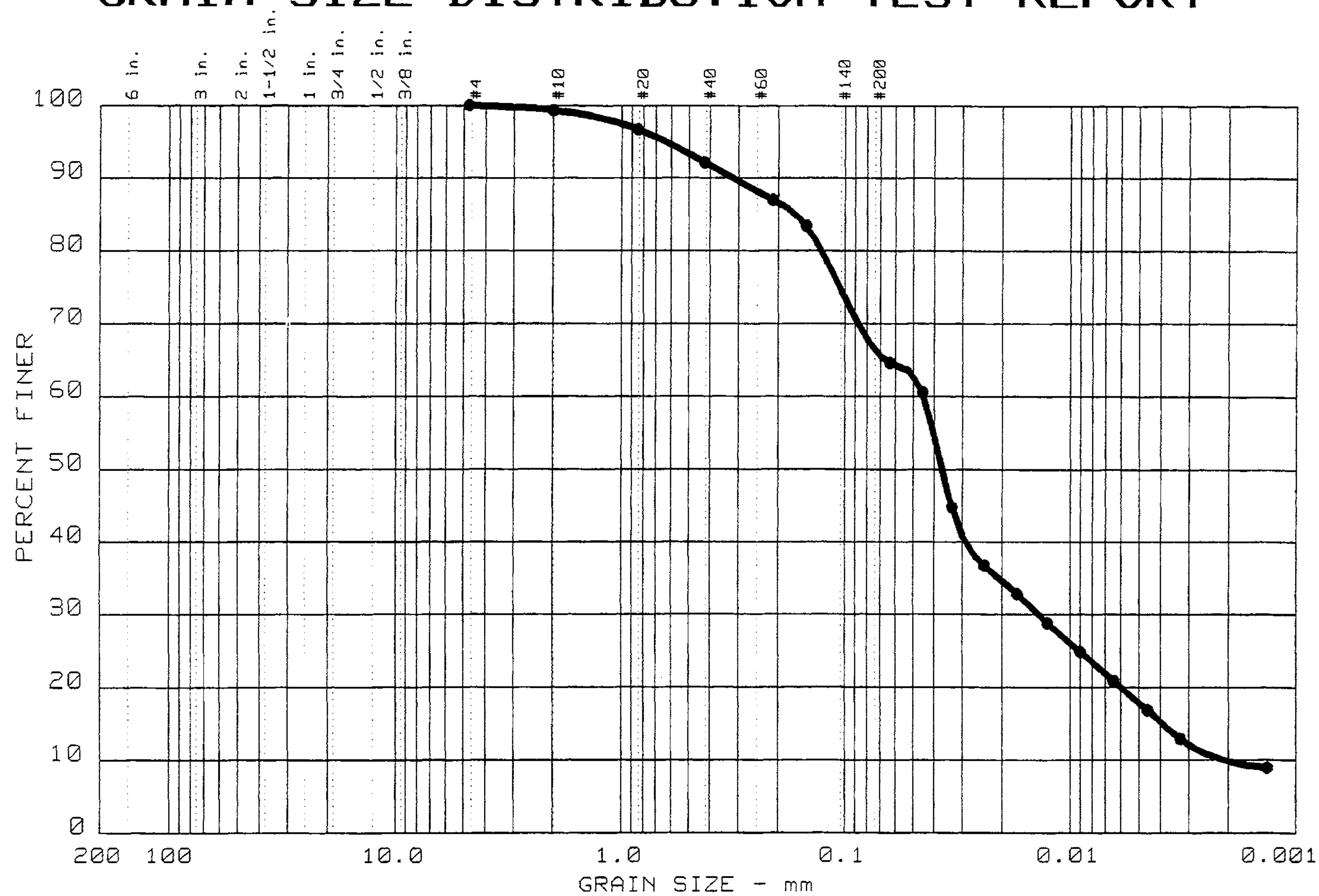
PSI

Canton, MA

Remarks:

Figure No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	11	0.0	0.0	33.3	48.8	17.9

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.166		0.0369	0.0139	0.0039	0.0021	2.10	21.7

MATERIAL DESCRIPTION	USCS	AASHTO
● Dk. Brown Silty Sand w/organics	ML	

Project No.: 446-60488
Project: Fisherville Pond/ Blackstone River
● Location: ENV 36230 F-5

Date: Oct. 31, 1996

GRAIN SIZE DISTRIBUTION TEST REPORT
PSI
Canton, MA

Remarks:

Figure No. ______

APPENDIX G

WATER QUALITY APPENDIX
BLACKSTONE RIVER WATERSHED
RECONNAISSANCE INVESTIGATION

PREPARED BY
WATER MANAGEMENT BRANCH
GEOTECHNICAL AND WATER
MANAGEMENT DIVISION
ENGINEERING DIRECTORATE

DEPARTMENT OF THE ARMY
NEW ENGLAND DISTRICT, CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

AUGUST 1997

APPENDIX G

WATER QUALITY APPENDIX
BLACKSTONE RIVER WATERSHED
RECONNAISSANCE INVESTIGATION

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WATER QUALITY APPENDIX
BLACKSTONE RIVER WATERSHED
RECONNAISSANCE INVESTIGATION

1. EXECUTIVE SUMMARY

The Blackstone River begins in Worcester, Massachusetts and discharges into the Seekonk River in Rhode Island. Considered the "birthplace of America's industrial revolution", the Blackstone River was lined with industries by the mid-1800's. The textile industry predominated but many others existed including tanneries and steel and wire mills. For many years these industries, along with towns in the watershed, discharged their wastes and sewage directly into the Blackstone River and its tributaries, creating polluted sediments, poor water quality, and degraded fish and wildlife habitat. The purpose of this water quality assessment is to provide a summary of water quality and sediment data based on existing studies, an evaluation of what can be done by State and local agencies to improve water quality, and an evaluation of the impact on water quality of potential restoration alternatives proposed by the Corps. Although alternatives were chosen primarily for their ability to enhance/restore fish and wildlife habitat, most will have a positive impact on water quality.

Due to its highly contaminated nature, many studies have been conducted in the watershed. These studies, performed by several groups including the US Environmental Protection Agency, Massachusetts Department of Environmental Protection, Rhode Island Department of Environmental Management, University of Rhode Island, and Narragansett Bay Project have recognized the Blackstone River watershed in Massachusetts and Rhode Island as highly polluted and one of the major sources of pollutants to Upper Narragansett Bay.

Water quality sampling conducted from 1977 to 1993 indicates that main stem Blackstone River contains high levels of fecal coliforms, BOD, nutrients, and metals. Violations of EPA toxic metal criteria occurred for many metals during many studies. Dry and wet weather sampling identified two major point sources of metals and nutrients - the Upper Blackstone Water Pollution Abatement District (UBWPAD) and Woonsocket Wastewater Treatment Facility (WWTF). Nonpoint sources identified include storm loads from Worcester, urban runoff, and resuspension of contaminated sediments accumulated behind old dams.

Sediment sampling found highly contaminated sediments behind several of the old dams on the Blackstone River. Singing, Fisherville, and Rice City Pond Dams were found to be the most contaminated, containing high metal concentrations.

With or without future Corps projects, several ideas are presented which can be implemented by State and local agencies. Point source contamination could be reduced through tighter regulations on NPDES permits and educational programs. Massachusetts Department of Environmental Protection (MADEP), Rhode Island Department of Environmental Management (RIDEM), and Environmental Protection Agency (EPA) are currently in the process of evaluating NPDES permits in the Blackstone River watershed. Nonpoint source contamination reduction may be achieved through best management practices including street and catch basin cleaning, and storm drain and outfall evaluation. Alternatives proposed by the Corps for fish and wildlife habitat restoration/enhancement include wetland restoration/creation, streambank stabilization, stormwater capture ponds, dam rehabilitation, and dredging and/or capping of contaminated sediments. Many alternatives evaluated would be effective basin-wide, while others were evaluated for a specific site. This appendix evaluated the alternatives with respect to their impact on water quality.

2. INTRODUCTION

a. Purpose. This water quality assessment is an appendix to the Blackstone River Reconnaissance Investigation. It is based on a review of existing water quality investigations conducted by the Narragansett Bay Project, Massachusetts Department of Environmental Protection, Environmental Protection Agency, Rhode Island Department of Environmental Management, University of Rhode Island, and others.

The purpose of this assessment is to evaluate current water quality/contaminated sediment conditions based on existing work and recommend measures State and local agencies can perform for water quality improvement. In addition, the assessment should evaluate the impacts on water quality of alternatives proposed by the Corps for restoration of fish and wildlife habitat.

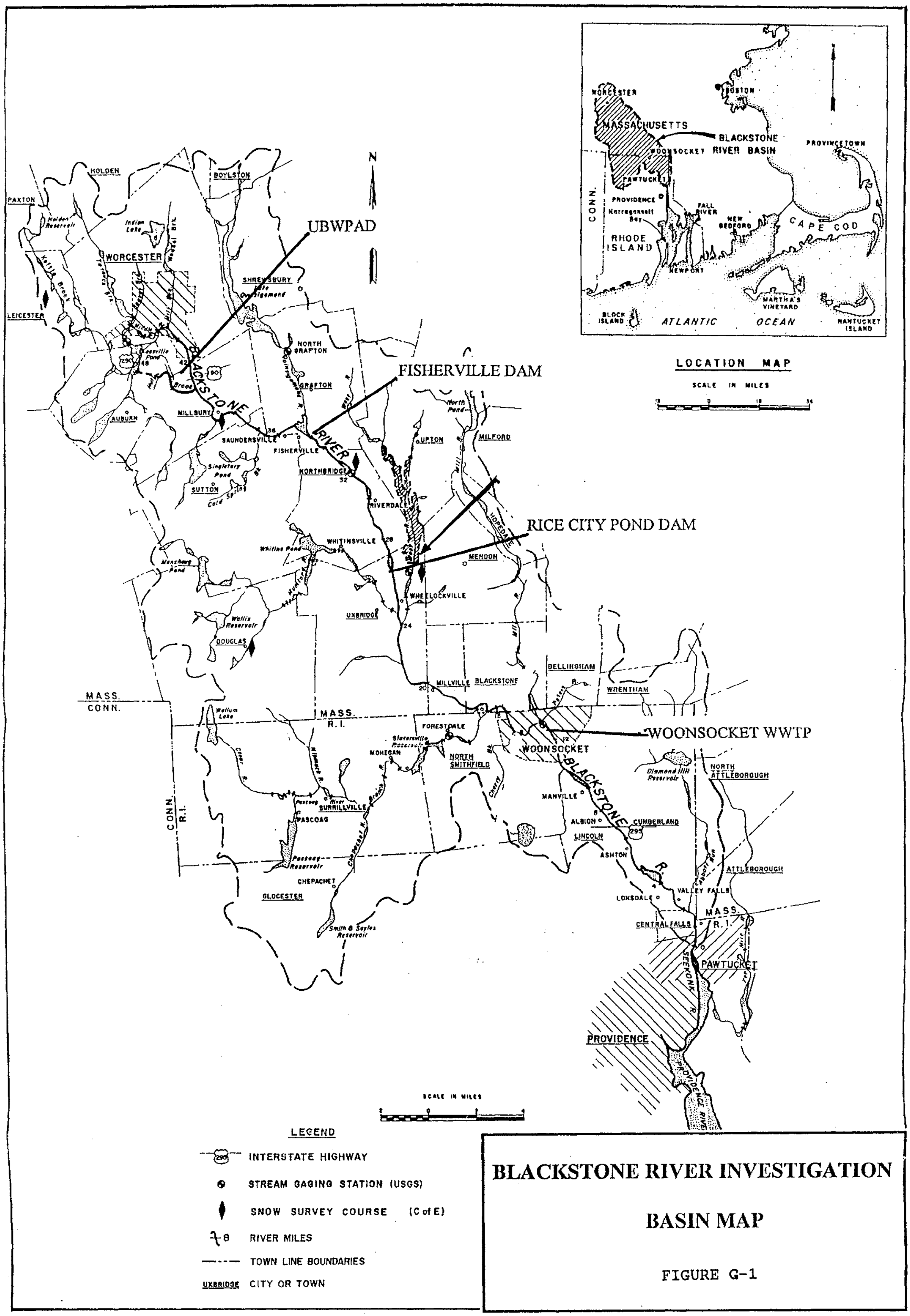
States categorize waters according to water use classification based on considerations of public health, recreation, propagation of fish, shellfish, and wildlife, and economic and social development. Any water where quality falls below criteria corresponding to its classification is considered in violation of its water quality standards and unsatisfactory for the uses indicated in that class. In addition, Federal criteria are also established for protection of human health and aquatic life. Once water quality conditions are identified, an evaluation of what can be done to improve water quality to enhance ecosystem restoration is necessary. This report attempts to accomplish that purpose by comparing water quality conditions to applicable criteria, identifying problem areas, and determining what steps can reasonably be taken to address those problems in light of the watershed's history, geography, and other constraints.

b. Background. The Blackstone River begins in Worcester, Massachusetts, at the confluence of the Middle River and Mill Brook, and flows through south-central Massachusetts, entering Rhode Island near Woonsocket, discharging into the Seekonk River, and from there to Narragansett Bay (see figure C-1 for basin map). It is the largest source of freshwater to Narragansett Bay. Roughly 84 percent of the Blackstone's length is within urban areas, including the major cities of Worcester, Massachusetts, and Woonsocket, Rhode Island. The principal tributaries of the Blackstone River are Kettle Brook and the Quinsigamond, Mumford, West, Branch, Mill, and Peters Rivers. The Blackstone River and its tributaries include approximately 472 square miles of drainage area.

The Blackstone River is considered the "birthplace of America's industrial revolution". The cotton manufacturing industry in America had its start in Pawtucket with the construction of "Old Slater Mill" in 1793. Following this start, the textile industry spread along the river and its tributaries, using water as a source of power. By the 1830s, most of the river was used for hydropower, with one dam for every mile of river. Seventeen of these dams and impoundments remain on the main stem river; several are still used for hydroelectric generation purposes.

The development of industry in the basin created a need for improved transportation of goods and passengers. In 1828, a canal was completed along the Blackstone River between Providence and Worcester. By 1848, however, soon after the completion of the first railroad between Providence and Worcester, the canal was abandoned. Currently, all but six miles of the former canal have been dewatered or abandoned.

High levels of industrial activity along the Blackstone River resulted in an increase in pollutants to the river. The textile industry predominated, but others flourished,



BLACKSTONE RIVER INVESTIGATION

BASIN MAP

FIGURE G-1

including tanneries, metal platers, wire and steel mills, woodworking companies, and textile machinery manufacturers. These industries contributed heavy metals from plating, dyes from textile plants, petroleum products from manufacturing, organics and metals from tanneries, solvents and paints from woodworking, and sanitary waste. Prior to enactment of the Federal Water Pollution Control Act (Clean Water Act) in 1972, sewage and wastes were inadequately regulated, and as a result, were usually discharged into the river in large quantities. With the establishment of the Massachusetts Division of Water Pollution Control in 1966, several wastewater treatment plants were constructed along the Blackstone. Despite significant improvements, including closure of many industries and water pollution control measures such as pretreatment and upgrading of treatment plants, water quality remains one of the major problems of the watershed. Point sources include industrial and municipal wastewater discharges and combined sewer outfalls. Nonpoint sources include direct overland runoff, groundwater infiltration, and resuspension of contaminated sediments accumulated behind the dams. Water quality loadings from nonpoint sources can often be correlated with land use. The Blackstone River watershed is comprised of many land uses. Rural land uses include agricultural activities, woodland, and idle land. Nutrients and pesticides are often derived from agricultural uses. Urban uses include residential septics, commercial land, transportation corridors, and land development.

3. WATER QUALITY CLASSIFICATION

Water bodies are classified according to the goals they should support (fishable, swimmable, etc.). Definitions of water quality classifications vary between States, but generally Class A is defined as a high quality water that supports all desirable uses, including drinking water supply. Class B designates a lower quality water that supports all uses except drinking water including the protection and propagation of fish, other aquatic life, and wildlife, and primary and secondary contact recreation. Class C waters are designated for secondary contact recreation and the protection and propagation of fish, other aquatic life, and wildlife.

The water quality classifications of the Blackstone River vary between the two States. The water quality classification of the Blackstone River in Massachusetts is the responsibility of the Massachusetts Department of Environmental Protection (MADEP), and in Rhode Island, it is the responsibility of the Rhode Island Department of Environmental Management (RIDEM).

The Massachusetts portion of the river is designated Class B. Massachusetts Class B standards require a minimum dissolved oxygen (DO) concentration of 5.0 mg/l for warm water fisheries, pH in the range of 6.5 to 8.0 standard units or as naturally occurs, fecal coliform not to exceed a geometric mean of 200 organisms per 100 ml in any representative set of samples, nor shall more than 10 percent of the samples exceed 400 organisms per 100 ml, and color, turbidity, and suspended solids in concentrations that do not exceed recommended limits of the most sensitive receiving water use. Also, the waters shall be free of floating oils, grease, and petrochemicals, and pollutants that form objectionable deposits or nuisances. Twenty-five miles, nearly the entire length in Massachusetts, is not supporting the designated uses associated with this classification (fishable, swimmable). This is due to high coliforms, nutrients and metals, along with low levels of dissolved oxygen. Rhode Island has classified its portion of the river as Class C. Rhode Island Class C standards require a minimum dissolved oxygen (DO) of 5.0 mg/l, pH in the range of 6.0 to 8.5 standard units or as naturally occurs, and color and turbidity in concentrations that would not impair any usages assigned to this class. Eighteen of the twenty-five miles in Rhode Island are considered nonsupporting of Class C uses due to metals (cadmium, copper, lead, mercury, silver, and zinc); nutrients and coliforms have also been identified as areas of concern.

4. WATER QUALITY CRITERIA

Water quality criteria for the Blackstone River were taken from the Massachusetts and Rhode Island Water Quality Standards and Quality Criteria for Water, U.S. Environmental Protection Agency, 1986. Criteria have been selected on the basis that all uses will be protected; therefore, the use with the lowest required pollutant concentration controls criteria selection. Criteria for dissolved oxygen, fecal coliforms, and pH have been taken from Massachusetts and Rhode Island water quality standards. Although there are no numerical limits for suspended solids, criteria for freshwater fish and other aquatic life indicate that settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life (USEPA, 1986). Parameters which are considered to affect sensitive resident aquatic species include ammonia-nitrogen, nitrite-nitrogen, cadmium, chromium, copper, lead, nickel, and zinc. Criteria for phosphate and nitrate were set to protect recreational and aesthetic uses of the river.

In addition, typical levels in streams for BOD_5, chloride, and alkalinity have been researched. BOD_5 values above 2.0 mg/l are indicative of polluted water (MADEP-DWPC, February 1987). Chloride levels range from 2.0 to 13 mg/l in typical surface and groundwater samples in the United States (Snoeyink and Jenkins, 1980). Alkalinity in typical surface and groundwater samples in the United States ranges from 18.3 to 339 mg/l, with the lower range typical of many New England rivers and lakes in granite basins (Snoeyink and Jenkins, 1980). Alkalinity is important for fish and other aquatic life in freshwater organisms because it buffers pH changes. Components of alkalinity, such as carbonate and bicarbonate, complex with some toxic heavy metals, often reducing metal toxicity. A minimum alkalinity of 20 mg/l is recommended to protect freshwater aquatic life (USEPA, 1986). Table G-1 lists water quality criteria applicable to Blackstone River watershed.

5. POLLUTION SOURCES

a. General. Water quality in the Blackstone River watershed is degraded by both point and nonpoint sources. Point sources include industrial and municipal wastewater discharges and combined sewer outfalls. Major point source contributors are the Upper Blackstone Water Pollution Abatement District (UBWPAD) and the Woonsocket WWTF. These are especially significant under low flow conditions. Nonpoint sources include direct overland runoff, groundwater infiltration, and resuspension of contaminated sediments accumulated behind the dams.

b. Historical Classification. Because point and nonpoint source discharges are regulated in different ways, a review of the basis for classification is important in planning their control. Point sources are distinguished from nonpoint sources in that, historically, only point sources were regulated, although both can have equally adverse effects on receiving stream water quality. One reason nonpoint sources were not regulated in the past was that, in general, nonpoint sources are more diffuse and difficult to quantify than point sources.

The distinction between nonpoint and point sources is sometimes unclear. For example, runoff originating as a nonpoint source may ultimately be channelized to become a point source. Technically, the term "nonpoint source" is defined by EPA to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. That definition states:

TABLE G-1

WATER QUALITY CRITERIA
APPLICABLE TO BLACKSTONE RIVER WATERSHED

PARAMETER	LIMITING VALUE	SOURCE
Alkalinity	20 mg/l minimum	AL
BOD	2.0 mg/l	MADEP
Chloride	2.0 to 13 mg/l	Snoeyink
Dissolved oxygen	5.0 mg/l minimum	MA, RI
pH	6.5 to 8.0	MA, RI
Temperature	Maximum 83 F	MA, RI
Nitrogen, ammonia, unionized	0.1 mg/l as N	AL
Nitrogen, nitrite, total	0.06 mg/l as N	AL
Nitrogen, nitrate, total	0.3 mg/l as N	AR
Phosphorus, total	0.1 mg/l	AR
Coliform bacteria, fecal	200 per 100 ml	MA, RI
Cadmium, acute*	exp(1.128(lnH)-3.828)	AL
Cadmium, chronic**	exp(0.7852(lnH)-3.49)	AL
Chromium, acute	exp(0.819(lnH)+3.688)	AL
Chromium, chronic	exp(0.819(lnH)+1.561)	AL
Copper, acute	exp(0.9422(lnH)-1.464)	AL
Copper, chronic	exp(0.8545(lnH)-1.465)	AL
Lead, acute	exp(1.273(lnH)-1.46)	AL
Lead, chronic	exp(1.273(lnH)-4.705)	AL
Nickel, acute	exp(0.846(lnH)-3.3612)	AL
Nickel, chronic	exp(0.846(lnH)+1.1645)	AL
PCBs, acute	2,000 ng/l	AL
PCBs, chronic	14 ng/l	AL
Zinc, acute	exp(0.8473(lnH)+0.8604)	AL
Zinc, chronic	exp(0.8473(lnH)+0.7614)	AL

* Acute criteria indicate levels at which death or severe damage can occur to an organism from a brief exposure period.

** Chronic criteria indicate levels at whch death or damage to an organism can occur from prolonged exposure.

LEGEND
H - Hardness
MA - Massachusetts Class B standard
RI - Rhode Island Class C standard
AL - Criteria to protect sensitive resident aquatic life
AR - Criteria to protect aesthetic and recreation water uses

NOTE
During Blackstone River Initiative sampling, hardness was measured at each sampling location and used to calculate acute and chronic criteria. Measured hardness values ranged from 11.5 to 73.9 mg/l.

"The term "point source" means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharge and return flows from irrigated agriculture."

Congress amended the Clean Water Act in 1987 to focus greater national efforts on nonpoint sources. It enacted Section 319 to control nonpoint sources of water pollution and Section 402(p) to control stormwater. Section 319 authorized EPA to issue grants to States to assist in implementing management programs or portions approved by EPA. States address nonpoint source pollution by assessing problems caused within the State and adopting management programs to control nonpoint source pollution.

Under phase I of Section 402(p) of the Clean Water Act, National Pollutant Discharge Elimination System (NPDES) permits are required to be issued for municipal separate storm sewers serving large or medium sized populations (greater than 250,000 or 100,000 people, respectively) and for stormwater discharges associated with industrial and construction activities. Permits are also to be issued, on a case by case basis, if EPA or a State determines that a stormwater discharge contributes to a violation of a water quality standard, or is a significant contributor to pollution loads to waters of the United States. EPA published a rule implementing phase I on 16 November 1990.

Stormwater runoff that may be ultimately covered by phase II of the 402(p) Stormwater Permit Program is intended to be subject to the Nonpoint Source Pollution Control Program. Runoff from wholesale, retail, service, or commercial activities, including gas stations, and construction activities on sites less than five acres, not covered by phase I of the NPDES stormwater program, would be subject instead to a State's Nonpoint Pollution Control Program, once established. States have the option to implement management measures in conformity with this guidance as long as NPDES stormwater requirements continue to be met by phase I sources in that area.

EPA also administers the National Estuary Program under Section 320 of the Clean Water Act. This program focuses on point and nonpont pollution in geographically targeted, high priority estuarine waters. In this program, EPA assists State, regional, and local governments in developing comprehensive conservation and management plans that recommend priority corrective actions to restore estuarine water quality, fish populations, and other designated uses of the waters. In 1989 Narragansett Bay was selected as a participant in the National Estuary Program.

On 3 January 1992, the Narrangansett Bay Project, a partnership formed by representatives from Federal, State, and local agencies, businesses, citizens' groups, and universities, submitted the draft Narragansett Bay Comprehensive Conservation and Management Plan to EPA for review and comment. Among key actions outlined in the plan are updating State Regulations for siting, design, construction, and maintenance of onsite sewage disposal systems; and guidance for municipal officials on the control of nonpoint source pollution, environmentally protective land, growth management practices, and development of stormwater management plans.

c. <u>Point Sources.</u> There are several major pollutant discharge permits on the Blackstone River in Massachusetts including Uxbridge, UBWPAD, Northbridge, Grafton, and Millbury WWTFs, and the Worcester CSO facility. Studies have shown the UBWPAD to be one of the major sources of pollutants during low flow conditions. In Rhode Island, permits on the Blackstone include Central Falls CSO, Smithfield Corporation, Woonsocket WWTF, GTE, and Okonite Company.

d. <u>Nonpoint Sources.</u> Potential nonpoint sources of contaminants in the Blackstone River watershed include stormwater, runoff from highways, parking lots, farmlands and lawns, landfills, seepage from on-site sewage disposal systems, accidental chemical spills, and resuspension of sediments.

(1) <u>Urban Runoff</u>

(a) <u>General.</u> The principal types of pollutants found in urban runoff are sediments, nutrients, oxygen-demanding substances, pathogens, hydrocarbons, and heavy metals. Detrimental effects of urban runoff are often exacerbated by hydrologic modifications, such as runoff diversion and channelization.

(b) <u>Pathogens.</u> Urban runoff typically contains elevated levels of bacteria and pathogenic organisms. Rainfall can sweep feces, deposited on the ground by pets, domestic animals, wildlife, and waterfowl, directly into streams. The presence of pathogens in runoff may result in waterbody impairments such as closed beaches, contaminated drinking water, and shellfish bed closings.

Several serious diseases such as typhoid and cholera are caused by enteric (intestinal) bacteria, and it would be very expensive and time consuming to test them all. Instead, tests are run for indicator organisms. A good indicator would be an organism originating in the intestines, that exists in far larger numbers and lasts longer outside the host than pathogens. Coliform bacteria are the most commonly used indicator organisms to give information about the aquatic environment and the possibility that pathogenic organisms may be present. If coliform counts in a body of water are high, there is a greater likelihood that harmful organisms are also present.

Two coliform values are used - fecal and total. Fecal coliforms are principally from feces of warm-blooded animals, including humans; total coliforms are from decaying matter as well as feces, and are used as a more conservative measure for things such as finished drinking water. Fecal coliforms are more commonly used to measure the safety of swimming or shellfish harvesting areas.

(c) <u>Septic Systems</u>. Poorly designed or operating systems can cause ponding of partially treated sewage on the ground and can reach surface waters through runoff. In addition to oxygen-demanding organics and nutrients, these sources contain bacteria and viruses that present problems to human health.

(d) <u>Existing Development.</u> Maintenance of good water quality is increasingly difficult as more surface area becomes urbanized. Increased peak runoff volumes and pollutant loadings from impervious surfaces permanently alter stream channels, natural drainage ways, and instream and adjacent riparian habitat. Runoff and infiltration from agricultural land, golf courses, and industrial, commercial, and residential land can contribute nutrients and toxic compounds from fertilizers, pesticides, chemical spills, as well as sediments from soil erosion. Freshwater flows due to increased runoff can impact estuaries, especially if they occur in pulses and disrupt the natural salinity of an area.

Parking lots, roads, highways, and bridges concentrate runoff flows and cause erosion and sedimentation problems unless prevented by special measures. Dead ends of streets, commonly used for piling snow, especially following heavy storms, later release snowmelt carrying sand and salt. Stormwater runoff in erodible bed channels exacerbate erosion and sedimentation problems in wetlands and tributary streams. Suspended sediments, which constitute the largest mass of pollutant loadings to surface water, have both short and long term adverse impacts on surface waters and aquatic life.

High concentrations of organic matter in urban runoff can severely depress dissolved oxygen levels in receiving streams after storm events. Proper levels of dissolved oxygen are critical to maintaining water quality and aquatic life.

Excessive nutrient loadings can result in eutrophication and depressed oxygen levels. Surface discoloration and the release of toxins from sediments may also occur. Heavy metals and many different toxic compounds, including petroleum hydrocarbons, are also associated with urban runoff.

6. EXISTING WATER QUALITY CONDITIONS

a. General. Numerous surveys and studies have been conducted within the last several years to determine water quality conditions within the Blackstone River Basin. All studies prior to the comprehensive Blackstone River Initiative in 1991, collected for various State agencies, provide only a snapshot of water quality conditions in the river at the time of sampling. Mainly, the studies show metals and nutrients as serious problems, entering the Blackstone River in large numbers even during dry weather. The following sections summarize, in chronological order, some significant water quality studies in the watershed at the time of sampling.

b. Massachusetts Division of Water Pollution Control (MDWPC) Water Quality Data of Blackstone River Tributaries, 1977. In 1977 MDWPC published water quality data pertaining to major tributaries of the Blackstone River. Samples were collected in 1977 on the Quinsigamond, Mumford, West, Branch, Mill, and Peters Rivers. Study results indicate that most major tributaries were polluted. The major causes of pollution were estimated to be untreated domestic and industrial waste discharges throughout the watershed.

(1) Quinsigamond River. The water quality of the Quinsigamond River was generally polluted with high BOD_5, fecal coliforms, chloride, and nitrate-nitrogen concentrations throughout the sampling reach. Dissolved oxygen concentrations ranged from 4.1 to 11.2 mg/l, with only one sample below the 5 mg/l Class B standard. BOD_5 values ranged from 2.1 to 5.1 mg/l, indicative of polluted waters. Twenty percent of Quinsigamond stations exceeded the Class B fecal coliform geometric mean standard. The highest instream level, 820 coliforms per 100 ml, occurred in Grafton. Chloride levels ranged from 19 to 72 mg/l, which are elevated compared to the 2 to 13 mg/l in typical surface and groundwater samples. Elevated chloride levels could be

associated with raw sewage, wastewater from septic systems, and road salting operations. Ammonia-nitrogen and phosphorus concentrations were low for the entire reach, nitrate-nitrogen concentrations were highest upstream and had concentrations as high as 0.5 mg/l near the Blackstone River. Alkalinity, pH, and turbidity were generally within acceptable ranges.

(2) West River. In general, the water quality of the West River in 1977 was poor with low DO values and high BOD_5, fecal coliform, chloride, and phosphorus concentrations. Dissolved oxygen concentrations ranged from 3.0 to 15.5 mg/l, with several samples below 5 mg/l. Lowest readings were located downstream of the Corps of Engineers West Hill Dam. BOD_5 values ranged from 1.2 to 4.8 mg/l with 90 percent of samples greater than 2.0 mg/l. Forty percent of West River stations exceeded the Class B fecal coliform geometric mean standard, ranging from 10 to 5,600 coliforms per 100 ml. Chloride levels were also elevated in the West River, ranging from 23 to 91 mg/l. Ammonia-nitrogen and nitrate-nitrogen concentrations were low and phosphorus concentrations were high upstream of West Hill Dam but low near the Blackstone River. Alkalinity levels were low for the entire reach, ranging from 7 to 14 mg/l. Turbidity levels were within acceptable limits while pH levels were low, many below the 6.5 to 8 range.

(3) Mumford River. Water quality of the Mumford River in 1977 was generally degraded with low DO and high BOD_5, fecal coliform, and ammonia- and nitrate-nitrogen concentrations. The area around Gilboa Pond and Brook had the poorest water quality. Dissolved oxygen concentrations ranged from 3.0 to 14.5 mg/l, with several samples below 5 mg/l. Lowest concentrations were observed at Gilboa Brook. BOD_5 levels ranged from 1.8 to 51 mg/l, with extremely high levels at Gilboa Brook. Fecal coliform levels were extremely high on the Mumford River, ranging from 10 to 4,000 coliforms per 100 ml. Highest instream concentrations were located at the station nearest the Blackstone River. Chloride levels were lower in the Mumford River than the Quinsigamond and West Rivers, ranging from 5 to 25 mg/l. Ammonia-nitrogen and nitrate-nitrogen concentrations and turbidity were high at Gilboa Brook but were at or near recommended criteria near Blackstone River. Alkalinity was low at most stations and pH levels were at or near 6.5 near the Blackstone River.

(4) Branch River. Water quality at the one sampling station on the Branch River was poor with high BOD_5, fecal coliform, chloride, and ammonia- and nitrate-nitrogen concentrations. Dissolved oxygen data at the one Branch River station ranged from 5.5 to 9.2 mg/l. BOD_5 values

ranged from 2.7 to 3.3 mg/l, indicative of polluted waters. Fecal coliform levels were elevated, ranging from 200 to 1,000 coliforms per 100 ml. All sampling dates exceeded the Class B fecal coliform standard. Chloride levels were slightly elevated, ranging from 14 to 29 mg/l. Ammonia-nitrogen and nitrate-nitrogen concentrations were slightly above criteria while phosphorus levels were low. Alkalinity levels were low, ranging from 5 to 10 mg/l. Both pH and turbidity levels were within acceptable limits.

(5) Mill River. Water quality on the Mill River was poor. The entire sampling reach had high BOD_5, fecal coliform, chloride, and ammonia-nitrogen concentrations. Dissolved oxygen concentrations on the Mill River ranged from 3.6 to 14.8 mg/l, with lowest concentrations observed at Mill Street in Hopedale. BOD_5 values ranged from 2.1 to 11 mg/l, with highest levels at Mill Street. Twenty percent of Mill River stations exceeded Class B fecal coliform geometric mean standards. The highest instream concentration, 1,000 coliforms per 100 ml, was located at Summer Street bridge. Chloride levels were also elevated in the Mill River, ranging from 13 to 71 mg/l. Mill Street also had high ammonia-nitrogen, nitrate-nitrogen, and phosphorus concentrations. Nitrate-nitrogen and phosphorus concentrations were below criteria near Blackstone River while ammonia-nitrogen was still above. Alkalinity levels ranged from 5 to 36 mg/l, with less than one-half of samples greater than 20 mg/l. Turbidity levels were low in the entire river while pH levels were below 6.5 in upstream reaches. PH levels were at or within the 6.5 to 8 range at the station nearest the Blackstone River.

(6) Peters River. Three sampling stations along the Peters River found water quality degraded by low DO and high BOD_5, fecal coliform, and ammonia- and nitrate-nitrogen concentrations. Dissolved oxygen concentrations on the Peters River ranged from 0.9 to 10.9 mg/l. BOD_5 levels ranged from 1.8 to 19 mg/l, indicative of polluted waters. Fecal coliform levels ranged from 40 to 600 coliforms per 100 ml, with 40 percent of stations above Class B geometric mean standards. Chloride levels ranged from 15 to 29 mg/l, slightly elevated. Ammonia-nitrogen and nitrate-nitrogen concentrations were above criteria at most stations and phosphorus concentrations were below criteria at all stations. Both pH and turbidity were within acceptable limits. Most alkalinity readings were above 20 mg/l.

c. Massachusetts Department of Environmental Quality Engineering (MA DEQE) 1985 Dissolved Oxygen Survey. In 1985 MA DEQE sampled 33 stations along the Blackstone River in Massachusetts for dissolved oxygen during dry weather (steady state). The flow during this study was approximately four times the 7Q10. A total of 297 DO measurements were taken. Of these, 36 were below the 5.0 mg/l standard for Class B waters. The lowest measurement, 3.2 mg/l, occurred in Grafton. One finding of the study was an apparent oxygen sag beginning above the UBWPAD discharge and ending just below it.

d. Rhode Island Trace Metals Survey, 1985. Three dry weather (steady state) surveys were performed in July, August, and October 1985 that included sampling eight stations, four times each survey. Flows were two times the 7Q10 for two of the surveys and seven times the 7Q10 for the third survey. The study found high levels of metals with many violations of chronic and acute criteria. With the exceptions of lead and PCBs, sampling indicated concentrations decreased from the state line to the mouth of the river.

(1) Cadmium. Daily averages ranged from 0.4 ug/l to 1.5 ug/l. Of 24 daily averages, one was above acute criteria (1.31 ug/l) and 14 were above chronic criteria (0.53 ug/l). Concentrations declined from the State line to the mouth of the Blackstone.

(2) Chromium. Measurements ranged from 2.5 ug/l to 32.5 ug/l. All chromium concentrations were below acute (783 ug/l) and chronic (93.3 ug/l) criteria.

(3) Copper. Measurements, ranging from 7.5 ug/l to 16 ug/l, exceeded both acute (7.09 ug/l) and chronic (5.15 ug/l) criteria. In general, copper concentrations decreased from the State line to the mouth of the Blackstone.

(4) Lead. All samples were above chronic criteria but below acute. Gradual increases were noted near Central Falls in RI.

(5) Nickel. None of the data, ranging from 17 ug/l to 35 ug/l, were in violation of acute (623 ug/l) or chronic (69.2 ug/l) criteria. In general, concentrations in Rhode Island gradually decline from state line levels.

(6) PCBs. Of the 24 daily averages, ranging from 0.0 to 59 ng/l, none were above the acute criteria of 2,000 ng/l. However, 19 were above the chronic criteria of 14 ng/l. There appeared to be a general decline from values at the State line to Central Falls. Concentrations increased at Central Falls for all three surveys.

e. SINBADD and SPRAY Cruises, 1985-87. These two surveys were funded by the NBP to determine relative importance of various pollutant sources to the Narragansett Bay. SINBADD cruises sampled 22 stations in the Narragansett Bay watershed in October and November 1985 and April and May 1986. Only one station was on the Blackstone River. SPRAY cruises, in March, April, June, and August, had several sampling locations along five rivers, with one on the Blackstone River. From these two studies, the NBP estimated that the Blackstone was the single largest riverine source of solids and petroleum hydrocarbons, and a significant source of polycyclic aromatic hydrocarbons (PAHs) to Narragansett Bay.

f. Rhode Island Department of Environmental Management (RIDEM) Dissolved Oxygen Survey, 1987. In August 1987 RIDEM collected samples once at four locations for DO measurements. Flows for the dry weather (steady state) survey were near the 7Q10. The lowest DO concentration, 3.4 mg/l, occurred below the Woonsocket WWTF, at Manville Dam. Measurements above and below the WWTF indicated a significant DO sag.

g. Ecology and Environment (EE) Rhode Island Dissolved Oxygen Study, 1987/1988. EE performed dry weather monitoring for Ocean State Power to evaluate the removal of 4 mgd from the Blackstone River. Nine stations were monitored every four hours for two days for a total of 108 DO measurements. No violations of the 5.0 mg/l standard were recorded. The lowest measurement, 5.6 mg/l, occurred at the Route 122 bridge. Flows were estimated at three times the 7Q10.

h. Rhode Island Department of Environmental Management Survey, 1988. A 24-hour survey was performed at nine stations along the Blackstone River in Rhode Island on 2-3 August 1988. Parameters measured were DO, BOD_5, total suspended solids, pH, cadmium, chromium, copper, nickel, lead, and total and fecal coliforms. Results indicated that chronic criteria for copper, cadmium, and lead were exceeded at all stations, copper exceeded acute criteria from the Massachusetts border to Albion dam, and cadmium exceeded acute criteria from the MA border to just upstream of the Woonsocket WWTF. There appeared to be a source of pollutants entering the river between the State line and Route 122. The increase in metal concentrations coincided with a recorded flow surge at the Woonsocket gage, indicating the increased metals may have been due to sudden flushing, resuspending contaminated sediments in the riverbed.

i. Massachusetts Division of Water Pollution Control 1988 West River Survey. Water quality samples were collected in June and August 1988 from six stations on the West River and analyzed for pH, DO, BOD_5, total solids, total suspended solids, alkalinity, chloride, hardness, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, fecal coliforms, and total metals (June survey only) including aluminum, cadmium, chromium, copper, lead, nickel, silver, and zinc. Flows during the June and August surveys were 18 and 34 cubic feet per second, respectively. The study found water quality of the West River degraded by low dissolved oxygen and high BOD_5, copper, and zinc. Dissolved oxygen levels were above 5 mg/l during the June survey but many violations occurred during the August survey; 2.6 mg/l at the Pleasant Street bridge, Upton station, 4.5 mg/l at West Hill Dam, 3.1 mg/l above the dam at Route 16, and 4.5 mg/l at the furthest downstream station. PH levels were low throughout the reach for both surveys. BOD_5 concentrations ranged from 1.8 to 8.1 mg/l with most samples above 2 mg/l. Fecal coliform levels were much lower in June than August with one violation of Class B standards on the main stem in August (240 coliforms per 100 ml). Chloride levels were slightly elevated, ranging from 19 to 55 mg/l. An increase in ammonia-nitrogen, nitrate-nitrogen, and phosphorus concentrations was measured downstream of the Upton WWTP, with decreasing concentrations downstream to the Blackstone River. Concentrations of all three nutrients were below criteria at the furthest downstream station. Loading values, calculated by MDWPC indicate that instream loadings were higher in August than June. Due to increased flow, this can be attributed to nonpoint sources. Based on a hardness of 25 mg/l, chronic and acute criteria for copper were exceeded at all West River stations except Pleasant Street bridge in Upton. Chronic and acute criteria for zinc were exceeded at all stations.

j. Massachusetts Water Quality Sampling, 1988 and 1989. In 1988 the MDWPC sampled 25 stations in the Blackstone River Basin. Samples were analyzed for BOD_5, suspended solids, alkalinity, specific conductance, chloride, hardness, total kjeldahl-nitrogen, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, and total metals. In addition, six stations were sampled once in July, August, and September 1989 for cadmium, chromium, copper, lead, nickel and zinc. These samples were analyzed using electrothermal atomic absorption spectrometry (graphite furnace) instead of the convention flame atomic absorption used in 1988. The graphite furnace method gives lower detection limits and metal concentrations presented below are from the 1989 survey.

(1) DO, pH and Alkalinity. Dissolved oxygen concentrations measured in June and August 1988 were lowest in Mill Brook, downstream of UBWPAD, and around Rice City Pond. Levels in Mill Brook and Rice City Pond were well below 5 mg/l. In June pH levels were below 6.5 on the

Mumford and West Rivers. In August pH levels below 6.5 were recorded on the Mumford and West Rivers and all main stem stations downstream of the confluence with Mill Brook. Thirty percent of main stem alkalinity concentrations were below 20 mg/l, with lowest values downstream of Route 122 bridge. Lowest values for the entire survey were measured on the Mumford and West Rivers.

(2) <u>BOD_5, Fecal Coliform, and chloride.</u> Eighty five percent of BOD_5 measurements were above 2.0 mg/l. Fecal coliform levels ranged from 5 to 90,000 coliforms per 100 ml. Highest concentrations were located in Mill Brook. Blackstone River concentrations were highest at Millbury Street in Worcester. Levels were low in the Quinsigamond and West Rivers and high in the Mumford River. Chloride concentrations reached 135 mg/l in Mill Brook, while main stem concentrations ranged from 10 to 360 mg/l.

(3) <u>Suspended Solids.</u> Total suspended solids concentrations ranged from 1 to 26 mg/l. Highest concentration was measured on Mill Brook, while main stem concentrations reached 16 mg/l and were highest at McCracken Road and Rice City Pond.

(4) <u>Nutrients.</u> Ammonia-nitrogen levels were lowest in Kettle Brook and downstream of West River, with a peak from Mill Brook to Fisherville Dam. A few ammonia-nitrogen concentrations in the Quinsigamond, Mumford, and West Rivers were above criteria but were much lower than main stem concentrations. Nitrate-nitrogen concentrations ranged from 0.1 to 5.2 mg/l, with highest levels downstream of UBWPAD. Concentrations in the Quinsigamond, Mumford, and West Rivers were higher than criteria but lower than main stem concentrations. Phosphorus levels ranged from 0.02 to 1.4 mg/l, with the highest concentrations also measured downstream of the UBWPAD. Phosphorus concentrations in the Quinsigamond, Mumford, and West Rivers were generally low.

(5) <u>Cadmium.</u> Measurements, ranging from 0.5 ug/l to 22.0 ug/l, indicated that the Upper Blackstone Water Pollution Abatement District (UBWPAD) causes a dramatic increase in instream cadmium concentrations. Of the 18 daily observations, 11 were above acute criteria (1.31 ug/l) and 14 above chronic (0.53 ug/l).

(6) <u>Chromium.</u> Measurements ranged from 1.5 ug/l to 14.5 ug/l. All chromium concentrations were below acute (783 ug/l) and chronic (93.3 ug/l) criteria.

(7) <u>Copper.</u> Measurements ranged from 0.0 ug/l to 60 ug/l. Similar to cadmium, the UBWPAD caused a dramatic

increase in copper. Thirteen of the 18 measurements exceeded both acute (7.09 ug/l) and chronic (5.15 ug/l) criteria.

(8) Lead. Most of the 18 observations were below the detection limit of 2.0 ug/l.

(9) Nickel. Nickel levels ranged from 1.0 ug/l to 6 60 ug/l. During the July and August surveys, the UBWPAD discharge was shown to be a significant source of nickel. For the September survey, very high concentrations were measured coming into the UBWPAD. None of the measurements were in violation of acute (623 ug/l) or chronic (69.2 ug/l) criteria.

(10) Zinc. Zinc concentrations ranged from 0 to 88 ug/l. Six of 18 observations were above chronic (47 ug/l) criteria.

k. Narragansett Bay Project Wet Weather Survey, 1989. In Rhode Island, the Narragansett Bay Project (NBP) funded a major sampling effort to determine wet weather contributions from both point and nonpoint sources of pollution to the Providence River. Two locations were sampled on the Blackstone during May and June 1989, one at the State line and one at Slater's Mill. Concentrations indicate that for total loads of cadmium, copper, chromium, and nickel, levels were much higher at the State line than Slater's Mill, which is near the mouth of the Blackstone River. Wet weather concentrations of copper and nickel were equal at the State line and Slater's Mill, while wet weather concentrations of cadmium and chromium were much higher at the State line than Slater's Mill.

(1) Cadmium. Concentrations ranged from 0.36 to 1.5 ug/l at the two stations. Acute criteria (1.31 ug/l) was exceeded at least six times at the State line. Concentrations at Slater's Mill exceeded chronic criteria (0.53 ug/l) but did not exceed acute criteria.

(2) Chromium. All chromium concentrations, ranging from 0.1 to 10 ug/l were below acute (783 ug/l) and chronic criteria (93.3 ug/l).

(3) Copper. All copper concentrations, ranging from 7.1 to 19 ug/l were in excess of acute (7.09 ug/l) and chronic (5.15 ug/l) criteria.

(4) Lead. Measurements, ranging from 2 ug/l to 13.5 ug/l were in excess of chronic criteria (0.92 ug/l).

(5) Nickel. All nickel concentrations, ranging from 3.5 to 9 ug/l were below acute (623 ug/l) and chronic (69.2 ug/l) criteria.

(6) PCBs. PCB concentrations were above chronic criteria but below acute criteria.

l. Rhode Island 305b Report, 1990. This report summarized data collected by RIDEM at the USGS gage at Manville from 1985-1989. Sampling indicates high levels of nitrate-nitrogen and phosphorus, suggesting that the river is nutrient enriched. Median total and fecal coliform values were extremely elevated and turbidity, color, sodium, and chloride were also high. Gage data show that criteria for cadmium, copper, lead, mercury, silver and zinc were violated.

m. Commonwealth of Massachusetts Summary of Water Quality, 1992. MA DEP report based on surveys on the Blackstone from 1965 to 1985. The assessment broke the main stem river into four reaches: American Steel Dam, Worcester to Fisherville Dam in Grafton, Fisherville Dam to Rice City Pond in Uxbridge, Rice City Pond to Water Quality (WQ) Monitor in Millville, and WQ Monitor to the Rhode Island border. Reach 1, 9 miles of Class B warm water fisheries, was nonsupporting because of pathogens, toxicity, organics, ammonia-nitrogen, metals, thermal modifications, and dissolved oxygen. These were assumed due to natural sources, industrial point sources, combined sewer overflows, urban runoff, and storm sewers. Reach 2, 8.7 miles of Class B warm water fisheries, was nonsupporting because of metals, nutrients, dissolved oxygen and pathogens. These were assumed due to municipal point sources, urban runoff, storm sewers, in-place contaminants, and combined sewer overflows. Reach 3, 7.4 miles Class B warm water fisheries, was partially supporting because of nutrients, metals and pH. These were assumed due to in-place contaminants, non-urban runoff, natural sources, municipal point sources, and combined sewer overflows. Reach 4, 3.7 miles of Class B warm water fisheries, supported but threatened its classification because of pH and nutrients due to municipal point sources, in-place contaminants, urban runoff, storm sewers, and natural causes.

Also evaluated in the report are the major tributaries to the Blackstone River - Kettle Brook and Middle, Quinsigamond, Mumford, West, Mill and Peters Rivers. Kettle Brook is partially supporting Class B because of toxicity, salinity, chlorides, thermal modifications, pathogens, nutrients, pH, and metals. Middle River is nonsupporting Class B because of pathogens, nutrients, turbidity, toxicity, pH, and metals.

Another Class B tributary, the Quinsigamond River, supports its uses but threatens several due to pH, nutrients, and toxicity. The lower nine miles of the Mumford River, also Class B, are partially supporting due to pH, dissolved oxygen, pathogens, and metals. The lower 8.8 miles of the West River, which are designated Class B, are non (2 miles) and partially (6.8 miles) supporting due to pH, nutrients, dissolved oxygen, salinity, and chlorides. The Mill River supports but threatens its Class B standards for 0.8 mile, partially supports for 9.2 miles, and is non-supporting for 1 mile due to metals, suspended solids, toxicity, chlorine, nutrients, salinity, chlorides, and pathogens. The Peters River supports its Class B uses for 2 miles and is non-supporting due to pathogens for 5.1 miles.

n. Summary of Surveys Prior to Blackstone River Initiative. A major weakness in the review of existing water quality conditions is the inability to evaluate a single survey which covers the entire Blackstone River. The following is based on data available from segmented surveys in Massachusetts and Rhode Island prior to 1991:

(1) Dissolved Oxygen. During dry weather surveys, violations were noted in three key locations: downstream of the UBWPAD and Woonsocket WWTF, and in Rice City Pond. DO levels were generally low in the impoundments. Dissolved oxygen violations occurred in the Quinsigamond, West, Mumford, Mill and Peters Rivers in 1977, and in the Mumford and West Rivers in 1988.

(2) BOD_5 and Fecal Coliform. BOD_5 and fecal coliform levels exceed recommended levels during most studies on the main stem Blackstone River. 1977 tributary surveys found high levels of both on all major tributaries. Fecal coliform levels were elevated in 1988 on the Quinsigamond and West Rivers.

(3) Ammonia-nitrogen. Early studies indicate that ammonia-nitrogen was at toxic levels instream, but nitrification at the UBWPAD has significantly reduced this problem. Ammonia-nitrogen levels in later studies were lower but generally still exceeded recommended criteria. In 1977, the Mumford, Mill and Peters Rivers had elevated ammonia-nitrogen levels and the Quinsigamond, Mumford, and West Rivers were high in 1988.

(4) Nitrate-nitrogen. Nitrate-nitrogen is a serious water quality problem along most of the main stem Blackstone River. Nutrient input is attributed to CSOs, bottom sediments, and municipal discharges. 1977 surveys found high nitrate-nitrogen levels on the Quinsigamond and Mumford Rivers, and 1988 surveys found high levels on the Quinsigamond, Mumford, and West Rivers.

(5) Phosphorus. Phosphorus and its contribution to algal blooms is a serious water quality problem. Although better management practices have reduced the levels of phosphorus, the problem still exists with nutrient input from CSOs, bottom sediments, and the combined input of municipal discharges.

(6) Metals. During dry weather surveys, violations of acute and chronic criteria recommended by the Environmental Protection Agency (US EPA) occurred for cadmium, copper, lead, and zinc. Concentrations of cadmium, copper, nickel, and zinc increased downstream of the UBWPAD, indicating point source contamination of these metals. In general, studies in Rhode Island indicate that maximum concentrations of cadmium, chromium, copper, and nickel occurred at the State line and declined towards Slater's Mill. No significant increases could be associated with the Woonsocket WWTF for any metal. The minimal amount of wet weather data from Rhode Island confirms dry weather violations of acute and chronic criteria for cadmium, copper, and lead. Problems, in most cases, already exist at prestorm conditions. These concentrations rise as much as an order of magnitude higher during storms. Unlike the dry, steady state conditions, where point sources seemed to be the largest contributor, resuspension may be the major component in the wet weather load. Available data, however, does not provide a separation of wet weather components (runoff, resuspension) and cannot confirm this.

(7) PCBs. Nonpoint sources appear equally as important as point sources for the contribution of PCBs in the Blackstone River. In Rhode Island, concentrations under several surveys exceeded chronic criteria under both wet and dry weather conditions; wet weather concentrations were a magnitude higher than dry.

Any interpretation between states is subjective because the amount of data is inadequate and there are several variable conditions between the Massachusetts and Rhode Island sampling efforts including streamflows, season, year, and frequency of sampling. A 1990 report by Wright for Narragansett Bay Project recommended that a comprehensive sampling effort for both dry and wet weather conditions that encompasses both States be conducted. The Blackstone River Initiative provided this survey.

o. Blackstone River Initiative (BRI). The BRI, coordinated by the University of Rhode Island, US EPA, MADEP, and RIDEM, is a basin-wide assessment of the river, tributaries, and point and nonpoint source discharges under both low flow and storm conditions. The BRI attempted to characterize current water quality conditions and quantify the problems which needed to be solved.

(1) Sampling Stations and Dates. Dry weather sampling occurred during three 48-hour periods in 1991: 10-11 July, 14-15 August, and 2-3 October. Twenty-one stations were sampled during the dry weather events, 15 along the main stem Blackstone and six near the mouth of major tributaries. In addition, two direct discharges were sampled; the UBWPAD and Woonsocket WWTF. Wet weather sampling occurred during three storms: 22 September and 2 November 1992, and 14 October 1993. For wet weather events, 19 stations and five point source discharges were sampled; CSO facility in Worcester, UBWPAD, Woonsocket WWTF, and two direct discharges to the Seekonk River below the mouth of the Blackstone River. Sampling stations, significant discharge locations, tributaries, and dams are listed in table G-2.

Samples from both wet and dry surveys were analyzed for biochemical oxygen demand (BOD_5), total suspended solids (TSS), chloride, total Kjeldahl-nitrogen (TKN), dissolved ammonia-nitrogen (NH3), dissolved nitrate-nitrogen (NO3), dissolved orthophosphate (PO4), total and dissolved metals (cadmium, chromium, copper, lead, nickel, and zinc) and hardness. Acute and chronic criteria for metals were developed for each sample based on hardness.

(2) Flows during Sampling Events. Blackstone River and major discharge flows for dry and wet weather sampling are presented in tables G-3 and G-4. During the three dry weather events, flow from the UBWPAD was a large percentage of Blackstone River flow. Pollutants in this discharge could have a significant impact on the river. During the wet weather events, UBWPAD flow was a lower percentage of peak river flows and some dilution of pollutants would be expected. Woonsocket WWTF discharge flows are small compared to river flows and dilution of pollutants in the discharge stream would be expected.

(3) Dry Weather Interpretation

(a) Dissolved Oxygen. DO measurements can vary throughout the day as a result of algae production and respiration. Algae produce oxygen during the day through photosynthesis, and use it up during the night through respiration. Algae generally produce more oxygen than they consume on sunny days. On cloudy days, algal respiration may exceed photosynthetic oxygen production. Large diurnal swings of dissolved oxygen were observed throughout the

TABLE G-2

WATER QUALITY SAMPLING, TRIBUTARY, DISCHARGE, AND DAM LOCATIONS

DRY WEATHER	WET WEATHER	RIVER	LOCATION	RIVER MILE*
	BWW00	Blackstone	Greenwood St	49.9
BLK01	BWW01	Blackstone	Millbury St	45.7
UPPER BLACKSTONE WATER POLLUTION ABATEMENT DISTRICT				44.4
BLK02	BWW02	Blackstone	McCraken Rd	43.9
BLK03		Blackstone	Riverlin St	40.9
BLK04	BWW04	Blackstone	Singing Dam	39.8
QUINSIGAMOND RIVER				37.7
BLK05	BWW05	Quinsigamond	Millbury St	
FISHERVILLE DAM				36.5
BLK06	BWW06	Blackstone	Route 122A	36.3
BLK07	BWW07	Blackstone	Riverdale Dam	31.9
BLK08	BWW08	Blackstone	Rice City Pond	27.8
MUMFORD RIVER				25.5
BLK09	BWW09	Mumford	Mendon St	
WEST RIVER				24.2
BLK10	BWW10	West	Centerville	
BLK11	BWW11	Blackstone	Route 122 Bridge	23.2
BLK12		Blackstone	Route 122 (near USGS gage)	19.3
TUPPERWARE DAM				17.8
BRANCH RIVER				17.4
BLK13	BWW14	Branch	Route 146A	
BLK14	BWW13	Blackstone	State line	17.4
SARANAC MILL DAM				16.5
WOONSOCKET FALLS DAM				14.3
MILL RIVER				13.3
BLK15	BLK15	Mill	Winter St	
PETERS RIVER				13.1
BLK16	BLK16	Peters	Route 114	
BLK17	BWW17	Blackstone	Hamlet Ave	12.8
WOONSOCKET WWTF				12.5
BLK18	BWW18	Blackstone	Manville Dam	9.9
BLK19		Blackstone	Albion Dam	8.3
ASHTON DAM				6.8
BLK20	BWW20	Blackstone	Lonsdale Ave	3.7
VALLEY FALLS DAM				2.0
CENTRAL FALLS DAM				0.8
BLK21	BWW21	Blackstone	Slater's Mill	0.2

* River mile 0.0 at Slater's Mill Dam

TABLE G-3

SUMMARY OF FLOWS FOR THE BRI DRY WEATHER SURVEYS

Gaging Station	Flow (cfs)		
	10-11 July 1991	14-15 August 1991	2-3 October 1991
Blackstone River			
U.S. Steel[a]	13.5	14	69.1
Northbridge[a]	77.4	84.5	236
Millville[a]	98.7	118	483
Woonsocket[b]	137	152	625
Lonsdale[a]	189	200	760
Tributaries			
Quinsigamond[b]	7.3	8.6	60.5
Branch[b]	26	30.5	122
Point Sources			
UBWPAD[c]	38.4	44.6	64.7
Woonsocket WWTP[d]	8.3	11.5	13.4

a - USGS temporary gaging station
b - USGS permanent gaging station
c - located between U.S. Steel and Northbridge gages
d - located 0.5 mile downstream of Woonsocket gage

TABLE G-4

SUMMARY OF FLOWS FOR THE BRI WET WEATHER SURVEYS

RUN	STORM 1 - STATION, FLOW (cfs)						
	BWW00	BWW01	UBWPAD (ave)	BWW02	BWW17	WOON-SOCKET WWTF (ave)	BWW18
P	15.3	16.5	50	73.3	162	9.48	181
0	38.3	41.2	50	107	163	9.48	205
3	172	185	50	268	292	9.48	250
6	59.5	64	50	156	250	9.48	210
9	53.7	57.8	50	142	205	9.48	226
12	43.1	46.4	50	118	214	9.48	226
16	33.8	36.3	50	88.9	215	9.48	186
24	21.9	23.5	50	49.6	209	9.48	226
32	15.3	16.5	50	49.6	209	9.48	226
40	21.9	23.5	50	80.8	289	9.48	315

TABLE G-4 (cont'd)

SUMMARY OF FLOWS FOR THE BRI WET WEATHER SURVEYS

RUN	STORM 2 - STATION, FLOW (cfs)						
	BWW00	BWW01	UBWPAD (ave)	BWW02	BWW17	WOON-SOCKET WWTF (ave)	BWW18
P	72	77.4	51.9	107	259	10	295
0	72	77.4	51.9	107	286	10	272
3	62	70.5	51.9	130	282	10	265
6	172	185	51.9	245	288	10	272
19	228	245	51.9	453	310	10	451
12	163	175	51.9	264	328	10	395
16	193	208	51.9	268	365	10	500
20	116	125	51.9	222	445	10	451
24	118	122	51.9	177	529	10	526
28	128	138	51.9	150	675	10	597
32	126	135	51.9	142	693	10	767
36	126	135	51.9	142	663	10	712
40	181	130	51.9	156	640	10	712
44	121	130	51.9	156	660	10	730
48	113	122	51.9	177	600	10	628
72	57	61.5	51.9	103	569	10	568

TABLE G-4 (cont'd)

SUMMARY OF FLOWS FOR THE BRI WET WEATHER SURVEYS

RUN	STORM 3 - STATION, FLOW (cfs)						
	BWW00	BWW01	UBWPAD (ave)	BWW02	BWW17	WOON-SOCKET WWTF (ave)	BWW18
P	38	41.2	49.6	60.4	165	9.91	140
0	38	41.2	49.6	73.3	172	9.91	180
9	530	570	49.6	829	204	9.91	118
12	407	438	49.6	637	246	9.91	180
16	140	150	49.6	165	207	9.91	136
20	128	138	49.6	153	223	9.91	202
24	122	131	49.6	147	420	9.91	303
28	109	117	49.6	130	797	9.91	582
32	48.4	52	49.6	130	551	9.91	329
36	160	108	49.6	107	416	9.91	320
44	76	81.7	49.6	103	416	9.91	238
52	76	81.7	49.6	105	406	9.91	295
72					280	9.91	

entire main stem, an indication of heavy algae growth caused by excessive loads of nitrogen and phosphorus. Concentrations met water quality standards (5 mg/l) at all main stem stations with one exception; 4.9 mg/l at Millbury Street. Several locations were close to the standard. Any sag due to the UBWPAD discharge, anticipated due to BOD_5 levels as high as 5.7 mg/l in the discharge, would have been missed due to access restrictions on the location of the sampling stations. The first two sampling stations below the UBWPAD discharge were located immediately downstream of dams where oxygen would have recovered due to reaeration over the dam. In general, the highest DO measurements observed were taken during the day, and the lowest during late night/early morning. Average dissolved oxygen concentrations are shown in plate C-1. Several DO measurements at the Mumford and Peters River stations were below 5 mg/l. Chlorophyll levels, associated with large diurnal swings of dissolved oxygen, indicated abundant growth in the impoundments where riverflows slowed. Growth was highest in Riverdale and Rice City Pond impoundments.

(b) pH. On the main stem, large diurnal swings in pH were recorded, with some values outside of Class B standards range of 6.5 to 8. PH levels vary diurnally since nighttime respiration of the algae will use up oxygen and produce carbon dioxide. Algal photosynthesis can also raise the pH by using up the carbon dioxide in bicarbonate and converting it to hydroxide. The largest ranges occurred in the impoundments. In general, highest pH values occurred in the late afternoon and coincided with high dissolved oxygen concentrations.

(c) BOD_5. BOD_5 values showed improvement in the Massachusetts portion compared to the 1988 MDWPC survey, although the same trends were evident; lower levels in the upstream portions, then increases caused by algae blooms and resuspension of organic material as the water passed through Riverdale and Rice City Pond, with increases at several locations downstream. The largest average concentration, 3.6 mg/l, was located just below the Woonsocket WWTF. Generally, just downstream of UBWPAD, in Rice City Pond, around Route 122, and downstream of Woonsocket WWTF, concentrations were above 2.0 mg/l. BOD_5 concentrations in UBWPAD discharge ranged from 1.73 to 5.7 mg/l during the three sampling dates. Average main stem BOD_5 concentrations are shown on plate C-1. BOD_5 values measured on the tributaries were generally low.

(d) Fecal Coliforms. Violations of the Class B fecal coliform geometric mean standard occurred upstream of UBWPAD, from Riverlin Street to Rice City Pond Dam, and from

Woonsocket WWTF to Slaters Mill Dam. Violations occurred on the Mumford, Branch, and Peters Rivers.

(e) Nutrients. Sampling indicated that the major source of ammonia-nitrogen is the Woonsocket WWTF. Ammonia-nitrogen concentrations in the discharge stream ranged from 6.1 to 33.8 mg/l during the July, August, and October surveys. A large reduction in ammonia-nitrogen from earlier surveys results from advanced treatment (nitrification), installed in the UBWPAD in 1986. Measurements from the UBWPAD discharge ranged from 0.1 to 1.1 mg/l. During the July survey, values increased from approximately 0.2 mg/l upstream of the UBWPAD to 0.4 mg/l downstream, then reduced to 0.2 mg/l upstream of Woonsocket WWTF and increased to 1 mg/l downstream. These increases were consistent through all three surveys. In general, average ammonia-nitrogen concentrations, shown on plate C-2, were high and exceeded recommended criteria of 0.1 mg/l at all main stem stations.

Nitrate-nitrogen concentrations were generally lowest above the UBWPAD at McCracken Road and increased at the next two downstream stations. Values generally were less than 1 mg/l above the UBWPAD and increased to over 4 mg/l below the discharge. Discharge concentrations ranged from 5.7 to 31.6 mg/l, with highest concentrations during the October sampling. Slight increases were noticed below the Woonsocket WWTF, which had discharge concentrations ranging from 0.9 to 58.5 mg/l. Average nitrate-nitrogen concentrations, shown on plate C-2, exceeded 0.3 mg/l at all main stem stations.

Phosphorus was measured as orthophosphate for the survey. Orthophosphate is the form of phosphorous which can readily be assimilated by plants. Although orthophosphate concentrations may be slightly less than total phosphorus, for the purposes of this study concentrations were compared to the recommended criteria for total phosphorus. Phosphorous is usually the nutrient in shortest supply, and becomes the limiting factor in plant growth, since nitrogen can be acquired from the atmosphere by nitrifying bacteria. Values were very high, greater than 1 mg/l for a few stations downstream of the UBWPAD, then decreased in the impoundments. This was likely due to removal by the biological community and sedimentation in impoundments. An increase occurred just below the Woonsocket WWTF. UBWPAD discharge concentrations ranged from 1.89 to 2.97 mg/l, Woonsocket WWTF discharge concentrations from 2.97 to 4.91 mg/l. Average concentrations during July and August were above recommended criteria at all stations downstream of UBWPAD. In October average concentrations exceeded criteria at all stations downstream of UBWPAD except near Route 122. Average concentrations are presented on plate C-3.

Ammonia-nitrogen, nitrate-nitrogen, and orthophosphate levels measured at tributary stations were low for all three surveys.

(f) Total Suspended Solids (TSS). Under dry weather conditions, sources of TSS to the water column include headwaters, point sources, resuspension, and algal growth. During the July and August surveys, a large increase (approximately 1 mg/l to 3 - 4 mg/l) between Riverlin Street and below Fisherville Dam was measured. This was likely due to resuspension since point sources and algae growth between the stations were negligible. Concentrations increased again between Fisherville Dam and Rice City Pond (up to 12 mg/l), due to resuspension and plant growth. Concentrations decreased after Rice City Pond to the mouth of the river. During the October event, which had higher flows, there were two major sources of TSS - Rice City Pond and a source between Central Street and Saranac Mill Dam. Both of these were probably due to sediment resuspension. Main stem total suspended solids concentrations are shown on plate C-3. Concentrations on the Quinsigamond, Mumford, West, and Branch Rivers were below 3.1 mg/l. Concentrations reached 5 mg/l on the Mill and Peters Rivers.

(g) Cadmium. July and August surveys showed low headwater concentrations of total cadmium, a large increase from UBWPAD, a decrease after UBWPAD, and a slight increase after Rice City Pond. A small increase was also noted after the Woonsocket WWTF. During July and August surveys, UBWPAD discharge cadmium concentrations ranged from 2.1 to 6.8 ug/l and Woonsocket WWTF discharge concentrations ranged from 2.7 to 5.9 ug/l. During the October survey, which had higher flows, the impact from UBWPAD was less due to dilution and lower effluent concentrations in the effluent. Discharge concentrations from the UBWPAD and Woonsocket WWTF were slightly lower in October, ranging from 2.4 to 2.5 and 1.1 to 1.7, respectively. Concentrations measured at all tributary stations were very low. Dissolved cadmium profiles were similar to total cadmium. Average total and dissolved main stem concentrations are shown on plate C-4. Data indicates that under low flow conditions, cadmium concentrations are dominated by point sources, specifically the UBWPAD. Violations of chronic criteria occurred during all three surveys - in July from UBWPAD to Route 122, in August from UBWPAD to Albion Dam, and in October from UBWPAD to Slaters Mill Dam. Acute criteria violations occurred from UBWPAD to Singing Dam in July, from

UBWPAD to Fisherville Dam in August and October, and also from Route 122 to Saranac Mill Dam in October.

(h) Chromium. In July total chromium concentrations rose significantly at Rice City Pond, then decreased gradually in downstream samples, with a slight increase at the Woonsocket WWTF, to the mouth of the Blackstone. In August there was a source of chromium in the headwaters, indicated by very high concentrations. Concentrations decreased to Rice city Pond where a significant rise occurred, then decreased gradually to Woonsocket WWTF where a slight increase was noted. An increase in TSS concentrations supports bottom resuspension occurring at Rice City Pond. This is supported by a large increase in total chromium and a small increase in dissolved chromium around Rice City Pond. In October concentrations were flat with a slight increase around Route 122. Dissolved chromium profiles were similar to total chromium profiles. The decrease in concentrations after UBWPAD indicates that under low flows, the impoundments act as settling basins. Generally, under low flows, a source was identified above Rice City Pond Dam. The UBWPAD was also a significant source. Under higher flows, nonpoint sources dominated with the largest source between Rice City Pond and Route 122. Average total and dissolved main stem concentrations are shown on plate C-5. During all three surveys, concentrations measured at tributary stations were low and did not appear to be a source in the main stem. There were no violations of acute or chronic criteria.

(i) Copper. During the July and August surveys, significant increases in total copper occurred below UBWPAD and at Rice City Pond. Slight increases occurred at Woonsocket WWTF. Effluent concentrations from UBWPAD and Woonsocket WWTF ranged from 24.6 to 61.1 ug/l and 33 to 147 ug/l, respectively, during the July and August surveys. During the October survey, high concentrations occurred at Rice City Pond through Route 122 then decreased to headwaters. Similar dissolved copper profiles occurred. From the dry weather surveys, it is summarized that UBWPAD is a significant source of copper. There is also a large source of copper, similar to chromium, around Rice City Pond. Average total and dissolved concentrations are shown on plate C-6. Violations of chronic criteria for copper occurred throughout the entire main stem reach for all three surveys. Acute violations occurred from UBWPAD through Woonsocket WWTF in July and for the entire reach for August and October. Greatest violations were below UBWPAD and Rice City Pond. In the Branch River, October concentrations exceeded acute criteria and in the Peters River, concentrations measured in July exceeded chronic criteria.

(j) Lead. During the July survey there was one major source of lead located between Fisherville and Riverdale Dams. In August, a source between Riverdale and Rice City Pond dominated and in October, a source between Central Street and Saranac Mill Dam dominated. Average total and dissolved concentrations are shown on plate C-7. The profiles indicate that nonpoint sources control lead concentrations under low flow conditions. Lead concentrations exceeded chronic criteria for the entire main stem reach during all three surveys and acute criteria from Fisherville Dam to Riverdale Dam in July. Concentrations measured in the tributaries also exceeded chronic criteria for all three surveys.

(k) Nickel. In July and August, nickel concentrations increased significantly with input from UBWPAD. Concentrations then decreased rapidly to Fisherville Dam, followed by a more gradual decrease to Woonsocket WWTF. Concentrations increased slightly at the Woonsocket WWTF and decreased afterwards. July and August effluent concentrations from the UBWPAD and Woonsocket WWTF ranged from 21 to 163 ug/l and 121 to 263 ug/l, respectively. In October, the same type of profile occurred with less of an effect from UBWPAD. October effluent concentrations were much lower ranging from 17.1 to 25.8 ug/l from UBWPAD and 16 to 79 ug/l from Woonsocket WWTF. A source was also noted above Slaters Mill. During the October survey, slightly elevated concentrations were measured at the Branch River station. Average total and dissolved main stem concentrations are shown on plate C-8. There were no violations of chronic or acute nickel criteria.

From the three surveys, it appears that nickel concentrations are controlled by point sources under low flow conditions, specifically UBWPAD.

(4) Wet Weather Interpretation.

(a) Dissolved Oxygen. There were no violations of oxygen on the main stem Blackstone during the three surveys. At the Quinsigamond station, 1 out of 16 samples violated the 5 mg/l criteria during the November 1992 sampling and on the Mill River, 2 violations of 13 samples occurred during October 1993 sampling.

(b) pH. During wet weather measurements, pH showed less variation than the dry weather events, with values generally within the 6.2 to 6.8 range, lower than Class B standards. The narrower range may result from rainfall runoff influence on the river or cloudy weather limiting algal activity. At least 60 percent of pH values in the tributaries were less than 6.5 mg/l.

(c) <u>BOD_5.</u> BOD_5 concentrations during wet weather surveys were greater than 2.0 mg/l from the headwaters to Route 122 bridge. Highest concentrations were in the upstream stations indicating a source in Worcester, probably a result of storm drain releases and overland runoff. Concentrations on the tributaries were well below 2.0 mg/l.

(d) <u>Fecal Coliforms.</u> Fecal coliform measurements in the headwaters were the highest measured during September 1992 and October 1993 sampling and appear to be a major source to the Blackstone River under wet weather conditions. From the headwaters, concentrations decreased significantly after the UBWPAD and continued to decrease to Singing Dam where a slight increase occurred. Notable increases also occurred at Fisherville, Rice City Pond, and between Route 122 and Woonsocket. During November 1992 sampling, when higher flows occurred, concentrations increased after UBWPAD. Violations of Class B geometric mean standard occurred for the entire main stem reach. Violations occurred during each sampling event on the Branch and Peters Rivers.

(e) <u>TSS.</u> In general, headwater concentrations, reaching 54 mg/l, were some of the highest measured for the entire river. This was opposite dry weather findings showing significance of urban runoff. During September 1992 and October 1993 sampling, when nitrification was occurring at UBWPAD, longer detention times in the plant provided removal of solids and concentrations decreased. During November 1992 sampling, however, when nitrification was not occurring, solids concentrations increased after UBWPAD. Concentrations in the effluent ranged from 1.4 to 9.8 mg/l during September 1992 and October 1993 sampling and 3.8 to 16.8 mg/l during November 1992 sampling. During all sampling events, a significant increase was noted between McCracken Road and Singing Dam, where concentrations reached 130 mg/l. From Singing Dam, concentrations decreased gradually to Rice City Pond where a small increase occurred, bringing concentrations back up to 63 mg/l. A slight increase was also observed after the Woonsocket WWTF. Concentrations in the Quinsigamond, Mumford, West, Branch, and Mill Rivers were generally low while the Peters River had elevated TSS concentrations.

(f) <u>Nutrients.</u> During the wet weather events, ammonia-nitrogen concentrations as high as 0.4 mg/l were observed in the most upstream stations, originating in Worcester. The UBWPAD had varying effects on ammonia-nitrogen levels. During the September 1992 and October 1993 events, a high short term spike was observed and concentrations below UBWPAD reached 3 mg/l. Concentrations in the discharge effluent reached 4.4 mg/l. This indicates a poor response of the facility to high flows. During the November 1992 event, the UBWPAD was not providing nitrification. Ammonia-nitrogen levels were high, independent of the storm, and reached 7 mg/l below the discharge. Discharge concentrations reached 20.6 mg/l. Two other sources of ammonia-nitrogen were apparent during the storms, one from Riverdale Dam to Route 122 and one just below Woonsocket WWTF. Two peaks occurred in the samples from Riverdale to Route 122, one from sediment resuspension and runoff, and one from the Worcester headwaters. In general, most ammonia-nitrogen readings were above the recommended concentration of 0.1 mg/l. Ammonia-nitrogen concentrations at the tributary stations were lower than the main stem during all three sampling events although some measurements in the Branch, Mill, and Peters Rivers exceeded 0.1 mg/l.

Nitrate-nitrogen concentrations exceeded 0.3 mg/l (recommended criteria) at all main stem stations, with the highest concentration occurring downstream of UBWPAD during September 1992 and October 1993 sampling, 3.9 mg/l, when nitrification was occurring. During November 1992 sampling, instream nitrification caused a delayed peak of nitrate-nitrogen around Rice City Pond. Nitrate-nitrogen concentrations decreased after the Saranac Mills Dam sampling location. One reason could be dilution from three tributaries entering upstream of this point. Nitrate-nitrogen levels increased downstream of Woonsocket WWTF. Concentrations at tributary stations were lower than those on the main stem but some concentrations on the Mumford, Branch, Mill, and Peters Rivers exceeded 0.3 mg/l.

High levels of phosphate, released from UBWPAD were continuous in all three storms. Concentrations downstream of UBWPAD reach 1.2 mg/l, greatly exceeding the 0.1 mg/l recommended level. Concentrations decreased below Rice City Pond, increased at Woonsocket WWTF, and decreased to Slaters Mill. UBWPAD and Woonsocket WWTF discharge concentrations reached 2.1 and 7.2 mg/l, respectively. Decreases below Rice City Pond and Woonsocket were likely due to dilution from tributaries and uptake due to plant productivity. Most measurements downstream of the UBWPAD were significantly above 0.1 mg/l. Concentrations measured at tributary stations were low.

(g) Cadmium. Consistent with dry weather surveys, a significant increase occurred between the headwaters and Singing Dam. Sources in this reach were UBWPAD and nonpoint sources including resuspension. Concentrations were much smaller than dry weather concentrations, resulting from dilution. Another increase occurred just above, in, and below Rice City Pond and was likely due to sediment resuspension. Concentrations increased slightly below Woonsocket WWTF but again, were less than concentrations during dry weather surveys. Concentrations measured at tributary stations were negligible in most cases.

Chronic violations started below UBWPAD and continued to Woonsocket. Acute violations started below UBWPAD and continued for several stations downstream.

(h) Chromium. Consistent with dry weather surveys, a significant increase occurred between the headwaters and Singing Dam. Sources in this reach were UBWPAD and nonpoint sources. Concentrations were nearly double the dry weather concentrations, indicating sources triggered in the system. Another increase occurred just above, in, and below Rice City Pond and was likely due to sediment resuspension. Concentrations increased slightly below Woonsocket WWTF and were similar to those measured during dry weather surveys. Concentrations measured at tributary stations were low for all three storms.

Chromium concentrations were below acute and chronic criteria for all wet weather events.

(i) Copper. Consistent with dry weather surveys, a significant increase occurred between the headwaters and Singing Dam. Sources in this reach were UBWPAD and nonpoint sources. Concentrations were similar to dry weather concentrations at UBWPAD. Another increase occurred just above, in, and below Rice City Pond and was likely due to sediment resuspension. Concentrations increased slightly below Woonsocket WWTF and were significantly higher than those measured during dry weather surveys. Concentrations measured at tributary stations were low compared to main stem concentrations for all three storms.

Violations of chronic criteria occurred at all main stem stations for all three storms. The greatest violations occurred below UBWPAD and Rice City Pond. Chronic violations also occurred in several samples on the Branch, Mill, and Peters River. Acute violations on the main stem started at UBWPAD and continued past Woonsocket WWTF. A few acute violations occurred at the Branch, Mill, and Peter's River samples.

(j) Nickel. Consistent with dry weather surveys, a significant increase occurred between the headwaters and Singing Dam. Sources in this reach were UBWPAD and nonpoint sources. Concentrations were slightly lower than dry weather concentrations at UBWPAD, likely from runoff dilution. Another increase occurred just above, in, and below Rice City Pond and was likely due to sediment resuspension. Concentrations increased slightly below Woonsocket WWTF. Nickel concentrations in the tributaries were generally low.

Nickel concentrations were well below acute and chronic criteria levels for all three storms.

(k) Lead. Lead concentrations were very high upstream of UBWPAD, indicating a source in the headwaters. Input from UBWPAD was not significant compared to this source. A second source was observed from Riverdale to Route 122 and was most likely due to sediment resuspension. Concentrations in the tributaries were generally lower than in the main stem.

Violations of chronic criteria occurred at all main stem and tributary stations for all three storm events. Concentrations were highest at the headwater station and around Rice City Pond. Acute violations occurred on the main stem starting at the headwaters through Rice City Pond. Few acute violations were recorded at tributary stations.

(5) Point vs. Nonpoint Discharges. One objective of the BRI was to evaluate point and nonpoint sources of contaminants in the Blackstone River watershed. The report had several conclusions based on dry and wet weather monitoring. Ammonia-nitrogen and orthophosphate were clearly governed by point sources. Lead had the highest nonpoint percentage, with highest loadings from Worcester headwaters and Rice City Pond.

(1) TSS, BOD_5, and Fecal Coliforms. Looking at both point and nonpoint sources, McCracken Road to Singing Dam, the headwaters, and Woonsocket are the major contributors of total suspended solids and UBWPAD, headwaters, and Millbury Street to McCracken Road are the major contributors of BOD_5. The headwaters, UBWPAD, and Ashton Dam to Slaters Mill Dam supply the most fecal coliforms to the Blackstone River. Eliminating point sources, the headwaters to Singing Dam is identified as contributing over 50 percent of total suspended solids.

Other important reaches are Route 122 to Woonsocket WWTF, Rice City Pond, and immediately downstream of Rice City Pond. The majority of nonpoint sources of BOD_5 and fecal coliforms are in the reach from the headwaters to Singing Dam. Other sources are located between Ashton and Slaters Mill Dams and Route 122 to Woonsocket WWTF.

(2) Nutrients. The UBWPAD is the most important source for nutrients (ammonia-nitrogen, nitrate-nitrogen, and orthophosphate) for wet and total loads and delivers almost one-third of the total loads for ammonia-nitrogen. The second most important source of ammonia-nitrogen and orthophosphate is the Woonsocket WWTF. Important nonpoint sources of ammonia-nitrogen were identified in the headwaters, between McCracken Road and Singing Dam, between Fisherville and Riverdale, and between Ashton and Slaters Mill Dams. Major nonpoint source gains of nitrate-nitrogen were observed between Route 122 and Saranac Mill Dam and between Manville and Slaters Mill Dams. Also contributing nonpoint sources, although not as significant, were McCracken Road to Fisherville Dam and Saranac Mill Dam to Woonsocket WWTF. Major increases of orthophosphate were measured around Rice city Pond and between Woonsocket WWTF and Pratt Dam. Less significant increases were observed between McCracken Road and Singing Dam, between Fisherville and Riverdale Dams, and in the headwaters.

(3) Metals. The headwaters and resuspension in Rice City Pond are the most important sources of lead. The UBWPAD and Woonsocket are not important sources of lead. Lead also originates from Millbury Street to McCracken Road, from Route 122 to Woonsocket WWTF, and from Ashton Dam to Slaters Mill Dam. UBWPAD is the major source of the other five metals analyzed in this study. Woonsocket WWTF is an important source of copper and zinc but not nickel, cadmium, or chromium. Rice City Pond and the headwaters are also significant sources for all trace metals. Other reaches of significance include McCracken Road to Singing Dam for copper and cadmium and Millbury Street to McCracken Road for cadmium and chromium. In general, the headwaters, Rice City Pond, and Millbury Street to Singing Dam are the most important reaches for nonpoint source metal contribution.

p. Rice City Pond 319 Project, 1996. The Blackstone River Initiative identified Rice City Pond as one of the most significant nonpoint source contributors of heavy metals, nutrients, and suspended solids to the river. The Rice City Pond project was funded to further examine the river segment which encompasses Rice City Pond in greater detail. The BRI made flow a suspect in dry weather metal fluctuations but did not record flow during each sampling interval. The Rice City project conducted a survey analyzing metals and suspended solids in conjunction with continuous flow measurements. Two sampling locations were set up, one upstream of Rice City Pond and the other upstream of the primary spillway outlet to determine if contaminants were being resuspended in the shallow pool area of Rice City Pond or coming from an unknown source further upstream. Concentrations of cadmium, copper, and zinc all increased at the spillway station at approximately the same time hydropower flow reached Rice City Pond. Increases at the upstream station did not occur until river stage started to recede, seven to eight hours later. Chromium and lead concentrations followed the same trend at the spillway station but no changes were noticed at the upstream station.

Sampling showed that physical processes are significant contributors to water quality conditions. Resuspension of contaminated sediments and sloughing of banks are induced and exacerbated from upstream hydropower activities and from flow characteristics which result from urbanized headwaters during wet weather.

q. <u>Impacts of Blackstone River on Narragansett Bay.</u> The National Estuary Program was developed in 1984 because of concern for the health and ecological integrity of the nation's estuaries and estuarine resources. Narragansett Bay was selected for the program in 1985 and was designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP), established in 1985, established seven priority issues for the bay; fisheries, nutrients and potential for eutrophication, toxic contaminants, living resources, contaminated seafood, water quality, and recreational uses. Several studies, performed for the NBP and others, were conducted to evaluate the significance of the Blackstone River to Narragansett Bay.

In 1988 and 1989 the Narragansett Bay Project directed a wet weather study to analyze the impact of the Blackstone River on Narragansett Bay. Five tributaries to the Providence River and Upper Narragansett Bay - Blackstone, Moshassuck, Pawtucket, Ten Mile, an Woonasquatucket Rivers, were sampled during three storm events. The study concluded that the Blackstone River is ranked first for seven of fourteen constituents. These include total suspended solids, four metals, and two nutrients.

A similar ranking for these tributaries was developed as part of the Blackstone River Initiative. Blackstone River ranked first for all constituents except ammonia, for which it was second.

Loading information from both studies is provided in table G-5.

TABLE G-5

NARRAGANSETT BAY PROJECT, TOTAL OF 3 STORMS									
STAT	**TSS**	**NO3**	**PO4**	**NH4**	**CU**	**PB**	**CD**	**CR**	**NI**
	lbs	**lbs**	**lbs**	**lbs**	**lbs**	**lbs**	**lbs**	**lbs**	**lbs**
BRSM	684000	127000	13700	7160	468	433	36.4	331	315
MOSH	68900	5980	241	419	45.7	46.2	0.84	29.5	30.7
PAWT	643000	32900	5070	12100	148	127	9.52	87.1	143
TENM	28800	20200	1260	856	92.8	28.5	5.79	92.2	217
WOON	115000	6780	691	650	51.0	67.7	1.72	18.6	47.0
NBP - WET LOADS, STORM AVERAGE									
STAT	**TSS**	**NO3**	**PO4**	**NH4**	**CU**	**PB**	**CD**	**CR**	**NI**
	lb/mcf	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**
BRSM	904	356	43.1	18.5	0.86	0.61	0.06	0.71	0.89
MOSH	2319	119	9.67	12.0	1.82	1.63	0.03	1.02	0.64
PAWT	2342	226	47.9	105	1.05	0.54	0.08	0.31	1.36
TENM	354	234	8.47	5.24	0.91	0.20	0.06	0.55	2.94
WOON	1414	188	18.2	10.8	0.57	0.74	0.01	0.23	0.52
1992-1993 STORM AVERAGE ESTIMATES									
STAT	**TSS**	**NO3**	**PO4**	**NH4**	**CU**	**PB**	**CD**	**CR**	**NI**
	lb	**lb**	**lb**	**lb**	**lb**	**lb**	**lb**	**lb**	**lb**
BRSM	21970	6080	1050	2600	37.4	34.8	1.80	7.85	20.8
MOSH	7550	388	31.5	38.9	5.94	5.29	0.10	3.33	2.10
PAWT	40200	3880	823	1800	18.1	9.26	1.45	5.29	23.3
TENM	2310	1530	55.2	34.2	5.94	1.32	0.42	3.56	19.1
WOON	6080	806	78.2	46.5	2.47	3.18	0.06	0.99	2.25
1992-1993 STORM AVERAGE LOADING ESTIMATES									
STAT	**TSS**	**NO3**	**PO4**	**NH4**	**CU**	**PB**	**CD**	**CR**	**NI**
	lb/mcf	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**	**lb/mcf**
BRSM	523	145	25	62	1	1	0	0.2	0.5
MOSH	2316	119	10	12	2	2	0	1	0.6
PAWT	2337	226	48	105	1	0.5	0.1	0.3	1.4
TENM	354	235	8	5	0.9	0.2	0.1	0.5	3
WOON	1414	187	18	11	0.6	0.7	0	0.2	0.5

BRSM-Blackstone River, MOSH-Moshassuck, PAWT-Pawtucket, TENM-Ten Mile, and WOON-Woonasquatucket
lb/mcf = pounds per million cubic feet

r. Toxicity. Acute and chronic criteria of many metals are exceeded in the Blackstone River watershed. There is ongoing discussion, however, as to whether the elevated metals are actually toxic in the Blackstone River. The presence of metal binding agents in ambient water can prevent toxicity from occurring as expected. Examples of water characteristics which alter biological activity and/or toxicity of metals are hardness, alkalinity, pH, suspended solids, and organic carbon. Acute and chronic criteria are based on hardness and are derived from tests performed in water that is low in particulate and organic matter. The water is also free of metal-binding agents so the metals are more bioavailable. There are no modifiers in the acute and chronic criteria for total organic carbon, suspended solids, and other factors which can attenuate toxicity. A chemical may exceed toxic criteria but may not exhibit toxicity. EPA metal criteria may also have been developed for species which are not representative of those in the Blackstone River.

Chronic toxicity testing, performed as part of the Blackstone River Initiative, indicated that, based on metal concentrations and EPA water quality criteria alone, the water samples collected from the Blackstone River were predicted to produce greater toxicity than actually occurred in the laboratory tests. These results have prompted site specific criteria studies for the Blackstone River in Massachusetts and underscored the importance of toxicity testing to be performed in conjunction with metals testing for determination of water quality impacts and issuance of permits.

7. SEDIMENT QUALITY

a. General. Neither EPA nor MADEP have established criteria for metals in sediments. The Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (1993) establish three levels of effect - no effect, lowest effect, and severe effect levels. The no effect level is the level where chemicals in the sediment do not affect fish or sediment-dwelling organisms. At this level, no transfer of chemicals through the food chain is expected. The lowest effect level indicates a level of contamination which has no effect on the majority of the sediment-dwelling organisms. The sediment is clean to marginally polluted. At the severe effect level, sediment is considered heavily polluted and likely to affect the health of sediment-dwelling organisms. No effect levels have not been calculated for many parameters, including metals. Long et al. also compiled values to indicate potential for biological effects from sediment-bound contaminants (Long et al, 1995). They named ER-L, the effects range-low, and ER-M, the effects range-median, representing contaminant concentrations in sediment that showed significant effects in 10 and 50 percent of the studies evaluated. Tables G-7 through G-14 show criteria used for evaluation of Blackstone River sediments.

b. Sediment Sampling Studies. In the 1981 Sediment Control Plan for Blackstone River (McGinn), eight sites were selected for investigation to determine the volume of sediment contaminated, assess the impacts of the sediment on the ecology of the river, and to describe alternative methods of treatment/removal. Seven sites were located on the main stem Blackstone; Millbury Street bridge, McCracken Road bridge, Singing Dam, Fisherville Pond, Northbridge Mill Dam (formerly called Rockdale Pond), Riverdale Mill Dam, and Rice City Pond and one site on the Mumford River at Lackey Pond.

In addition to water column testing, river sediments were analyzed twice in 1991 and once in 1993 by EPA as part of the Blackstone River Initiative. 1993 sampling was conducted after ASTM whole sediment toxicity methods had been refined and adopted by EPA. Sampling locations and dates are shown in table G-6. Metal concentrations from McGinn and BRI studies are presented in tables G-7 through G-14.

TABLE G-6

SEDIMENT SAMPLING LOCATIONS AND DATES

SED ID	STATION	SAMPLING DATES
1	Singing Dam	7/91, 10/91, 12/93
2	Fisherville Pond	7/91, 10/91
3	Rockdale Pond	7/91, 10/91, 12/93
4	Rice City Pond	7/91, 10/91, 12/93
5	Tupperware Dam	9/91, 10/91, 12/93
6	Manville	9/91, 10/91, 12/93
7	Slaters Mill	9/91, 10/91, 12/93
M1*	Gilboa Pond, Mumford River	7/91, 9/91, 12/93
M2*	Grey's Pond, Mumford River	10/91
LC*	Lexington Pond control	7/91, 9/91, 10/91
S*	Saw Mill Brook, Concord MA	12/93

* Reference stations

(1) Cadmium. 1981 and BRI average cadmium concentrations at all main stem stations except one were above the 1.2 mg/l ER-L concentration, while concentrations at Rice City Pond were as high as 141 mg/l. Most samples in 1981 were above the ER-M and in the severe effect level. Rice City Pond concentrations exceeded and Tupperware and Manville Dam concentrations were close to the ER-M and severe

effect level concentrations during BRI sampling. In 1981 there were noticeable increases in cadmium at Singing Dam compared to Millbury Street and McCracken Road and at Rice City Pond. In general, Rice City Pond had the highest average cadmium concentrations.

TABLE G-7

AVERAGE CADMIUM CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	0.6	10	1.2	9.6	10	
Millbury St. Bridge Channel	0.6	10	1.2	9.6	26	
McCracken Rd Bridge Bank	0.6	10	1.2	9.6	52	
McCracken Rd Middle of River	0.6	10	1.2	9.6	7	
Singing Dam Upstream	0.6	10	1.2	9.6	38	5
Singing Dam in marsh	0.6	10	1.2	9.6	58	
Fisherville River	0.6	10	1.2	9.6	25	
Fisherville Marsh	0.6	10	1.2	9.6	34	
Northbridge Mill River (Rockdale)	0.6	10	1.2	9.6	1	5
Northbridge Mill Bank (Rockdale)	0.6	10	1.2	9.6	29	
Riverdale Mill Riverbed	0.6	10	1.2	9.6	4	
Riverdale Mill Floodplain	0.6	10	1.2	9.6	44	
Rice City Pond Sediments	0.6	10	1.2	9.6	141	96
Rice City Pond Floodplain	0.6	10	1.2	9.6	36	
Tupperware Dam	0.6	10	1.2	9.6		9
Manville Dam	0.6	10	1.2	9.6		9
Slaters Mill	0.6	10	1.2	9.6		4
Gilboa Pond	0.6	10	1.2	9.6		
Grey's Pond	0.6	10	1.2	9.6		
Lackey Pond	0.6	10	1.2	9.6	1	
Lexington Pond						

(2) Chromium. 1981 chromium concentrations exceed ER-M criteria at Singing Dam, Fisherville Pond, Riverdale, and Rice City Pond. BRI concentrations in Fisherville Pond,

Rice City Pond, Tupperware Dam, Manville, and Gilboa Pond were above the ER-L, Rice City and Gilboa Ponds were above the ER-M. During BRI sampling, Fisherville, Rice City Pond, Tupperware Dam, and Gilboa Pond samples exceeded Severe Effect Level for chromium. Similar to cadmium, there were significant increases in chromium concentrations at Singing Dam and Rice City Pond. In general, Rice City Pond had the highest average chromium concentrations.

TABLE G-8

AVERAGE CHROMIUM CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	26	110	81	370	90	
Millbury St. Bridge Channel	26	110	81	370	153	
McCracken Rd Bridge Bank	26	110	81	370	79	
McCracken Rd Middle of River	26	110	81	370	92	
Singing Dam Upstream	26	110	81	370	320	75
Singing Dam in marsh	26	110	81	370	675	
Fisherville River	26	110	81	370	318	275
Fisherville Marsh	26	110	81	370	504	
Northbridge Mill River (Rockdale)	26	110	81	370	16	55
Northbridge Mill Bank (Rockdale)	26	110	81	370	288	
Riverdale Mill Riverbed	26	110	81	370	16	
Riverdale Mill Floodplain	26	110	81	370	668	
Rice City Pond Sediments	26	110	81	370	1250	845
Rice City Pond Floodplain	26	110	81	370	527	
Tupperware Dam	26	110	81	370		125
Manville Dam	26	110	81	370		85
Slaters Mill	26	110	81	370		50
Gilboa Pond	26	110	81	370		375
Grey's Pond	26	110	81	370		50
Lackey Pond	26	110	81	370	108	
Lexington Pond						15

(3) Copper. 1981 copper concentrations exceeded ER-M criteria at most stations while BRI concentrations at all main stem stations exceeded ER-L criteria and Singing and Fisherville Dams and Rice City Pond copper levels were above the ER-M. During both studies, all stations except Northbridge Mill river and Slaters Mill were above severe effect level. In general, significant increases in copper at Singing Dam, Northbridge Mill Dam, and Rice City Pond were observed. Northbridge Mill Dam bank sediments had the highest average copper concentrations.

(4) Nickel. 1981 ER-M criteria was exceeded at most stations while BRI concentrations in Singing Dam, Fisherville Pond, Rice City Pond, Tupperware Dam, and Manville Dam exceed ER-L criteria, Rice City Pond concentrations greatly exceed ER-M criteria. In 1981 many stations were above the severe effect level for nickel, while only Rice City Pond concentrations were high enough during BRI sampling. Significant increases were measured at Singing Dam and Rice City Pond. In general, Rice City Pond had the highest average nickel concentrations.

(5) Lead. In 1981 most lead concentrations were above the ER-M and the severe effect level. BRI concentrations at all stations except Lexington Pond were above the ER-L and Fisherville Dam, Rice City Pond, and Gilboa Pond were above the ER-M and Severe Effect Level. Significant increases in concentration were measured at Singing Dam and Rice City Pond. In general, Rice City Pond and Fisherville Dam had the highest lead concentrations.

(6) Arsenic. Arsenic concentrations measured in 1981 exceeded ER-L criteria at most stations, while none of the stations exceeded ER-M criteria. Singing Dam, Fisherville, Northbridge Mill, and Rice City Pond sediments were above the severe effect level for arsenic. In general, Rice City Pond had the highest arsenic concentrations.

(7) Zinc. 1981 zinc concentrations at most stations exceeded ER-M criteria and concentrations in Singing Dam, Riverdale Mill, and Rice City Pond were well above the severe effect level. BRI zinc concentrations at all main stem stations and Gilboa Pond exceeded ER-L criteria and concentrations at all main stem stations except Singing Dam, Slater's Mill, and Grey's and Lexington Ponds exceeded ER-M criteria. Highest concentrations were found in Riverdale and Rice City Pond sediments. Only Fisherville and Rice City Pond concentrations were above severe effect level for zinc during BRI sampling.

TABLE G-9

AVERAGE COPPER CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Ontario Guidelines Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	16	110	34	270	947	
Millbury St. Bridge Channel	16	110	34	270	418	
McCracken Rd Bridge Bank	16	110	34	270	286	
McCracken Rd Middle of River	16	110	34	270	207	
Singing Dam Upstream	16	110	34	270	548	390
Singing Dam in marsh	16	110	34	270	2075	
Fisherville River	16	110	34	270	964	1730
Fisherville Marsh	16	110	34	270	848	
Northbridge Mill River (Rockdale)	16	110	34	270	22	105
Northbridge Mill Bank (Rockdale)	16	110	34	270	2798	
Riverdale Mill Riverbed	16	110	34	270	346	
Riverdale Mill Floodplain	16	110	34	270	1027	
Rice City Pond Sediments	16	110	34	270	1860	1040
Rice City Pond Floodplain	16	110	34	270	759	
Tupperware Dam	16	110	34	270		195
Manville Dam	16	110	34	270		140
Slaters Mill	16	110	34	270		105
Gilboa Pond	16	110	34	270		110
Grey's Pond	16	110	34	270		10
Lackey Pond	16	110	34	270	57	
Lexington Pond						30

TABLE G-10

AVERAGE NICKEL CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Ontario Guidelines Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	16	75	21	52	61	
Millbury St. Bridge Channel	16	75	21	52	67	
McCracken Rd Bridge Bank	16	75	21	52	81	
McCracken Rd Middle of River	16	75	21	52	22	
Singing Dam Upstream	16	75	21	52	108	21
Singing Dam in marsh	16	75	21	52	112	
Fisherville River	16	75	21	52	66	30
Fisherville Marsh	16	75	21	52	82	
Northbridge Mill River (Rockdale)	16	75	21	52	17	16
Northbridge Mill Bank (Rockdale)	16	75	21	52	61	
Riverdale Mill Riverbed	16	75	21	52	13	
Riverdale Mill Floodplain	16	75	21	52	71	
Rice City Pond Sediments	16	75	21	52	417	260
Rice City Pond Floodplain	16	75	21	52	46	
Tupperware Dam	16	75	21	52		46
Manville Dam	16	75	21	52		29
Slaters Mill	16	75	21	52		18
Gilboa Pond	16	75	21	52		
Grey's Pond	16	75	21	52		
Lackey Pond	16	75	21	52	14	

TABLE G-11

AVERAGE LEAD CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Ontario Guidelines Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	31	250	47	220	419	
Millbury St. Bridge Channel	31	250	47	220	892	
McCracken Rd Bridge Bank	31	250	47	220	287	
McCracken Rd Middle of River	31	250	47	220	138	
Singing Dam Upstream	31	250	47	220	778	165
Singing Dam in marsh	31	250	47	220	1400	
Fisherville River	31	250	47	220	835	723
Fisherville Marsh	31	250	47	220	793	
Northbridge Mill River (Rockdale)	31	250	47	220	16	78
Northbridge Mill Bank (Rockdale)	31	250	47	220	903	
Riverdale Mill Riverbed	31	250	47	220	22	
Riverdale Mill Floodplain	31	250	47	220	722	
Rice City Pond Sediments	31	250	47	220	1582	717
Rice City Pond Floodplain	31	250	47	220	634	
Tupperware Dam	31	250	47	220		160
Manville Dam	31	250	47	220		132
Slaters Mill	31	250	47	220		120
Gilboa Pond	31	250	47	220		282
Grey's Pond	31	250	47	220		70
Lackey Pond	31	250	47	220	41	
Lexington Pond						40

TABLE G-12

AVERAGE ARSENIC CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Ontario Guidelines Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	6	33	8.2	70	14	
Millbury St. Bridge Channel	6	33	8.2	70	22	
McCracken Rd Bridge Bank	6	33	8.2	70	12	
McCracken Rd Middle of River	6	33	8.2	70	7	
Singing Dam Upstream	6	33	8.2	70	21	
Singing Dam in marsh	6	33	8.2	70	51	
Fisherville River	6	33	8.2	70	33	
Fisherville Marsh	6	33	8.2	70	23	
Northbridge Mill River (Rockdale)	6	33	8.2	70	14	
Northbridge Mill Bank (Rockdale)	6	33	8.2	70	36	
Riverdale Mill Riverbed	6	33	8.2	70	9	
Riverdale Mill Floodplain	6	33	8.2	70	24	
Rice City Pond Sediments	6	33	8.2	70	57	
Rice City Pond Floodplain	6	33	8.2	70	21	
Lackey Pond	6	33	8.2	70	8	

TABLE G-13

AVERAGE ZINC CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Ontario Guidelines Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	1981 Conc mg/kg	BRI Conc mg/kg
Millbury St. Bridge bank	120	820	120	270	627	
Millbury St. Bridge Channel	120	820	120	270	402	
McCracken Rd Bridge Bank	120	820	120	270	96	
McCracken Rd Middle of River	120	820	120	270	109	
Singing Dam Upstream	120	820	120	270	797	249
Singing Dam in marsh	120	820	120	270	1490	
Fisherville River	120	820	120	270	691	851
Fisherville Marsh	120	820	120	270	635	
Northbridge Mill River (Rockdale)	120	820	120	270	113	300
Northbridge Mill Bank (Rockdale)	120	820	120	270	694	
Riverdale Mill Riverbed	120	820	120	270	4650	
Riverdale Mill Floodplain	120	820	120	270	792	
Rice City Pond Sediments	120	820	120	270	4138	2160
Rice City Pond Floodplain	120	820	120	270	3204	
Tupperware Dam	120	820	120	270		330
Manville Dam	120	820	120	270		347
Slaters Mill	120	820	120	270		225
Gilboa Pond	120	820	120	270		455
Grey's Pond	120	820	120	270		80
Lackey Pond	120	820	120	270	233	
Lexington Pond						95

(8) PAHs. Sediment samples from all stations contained polynuclear Aromatic Hydrocarbon (PAH) concentrations higher than the ER-L and lowest effect level but lower than the ER-M. Highest concentrations were found in Gilboa Pond, Singing Dam, Fisherville Pond, and Rice City Pond.

TABLE G-14

AVERAGE PAH CONCENTRATIONS

Station	Ontario Guidelines Lowest Effect mg/kg	Ontario Guidelines Severe Effect mg/kg	ER-L, mg/kg	ER-M mg/kg	BRI Conc mg/kg
Singing Dam	4	10,000	4	45	25
Fisherville Pond	4	10,000	4	45	23
Rockdale Pond	4	10,000	4	45	12
Rice City Pond	4	10,000	4	45	22
Tupperware Dam	4	10,000	4	45	18
Manville	4	10,000	4	45	18
Slaters Mill	4	10,000	4	45	13
Gilboa Pond	4	10,000	4	45	31
Grey's Pond	4	10,000	4	45	9
Lexington Pond	4	10,000	4	45	8

c. Rice City Pond 319 Project, 1996. In addition to water column sampling, 24 sediment samples were analyzed as part of the Rice City Pond study. Samples were extracted from random locations in the flood plain and analyzed for nine metals, PCBs, TPH, and semi-volatiles. Twenty-one of the samples were 18-inches long and only the first 12 inches were analyzed. Three deep core samples were also analyzed to determine if contaminants were localized in the upper 12 inches of sediment, uniformly distributed, or confined to stratigraphic layers. The study came up with the following conclusions:

- Metals and organic concentrations within the flood plain sediments were much higher and more spatially distributed than originally considered.

- Organics in the form of heavy fuel oils can be found in all areas of the impoundment and chlorinated organics were found in the present flow regime.

- Metals were well distributed and showed correlation among each other, and overall metal concentrations showed a relationship to the percentage of organic material in the sediment.

- High iron and organic material were attributed to being significant sinks in limiting downstream metal transport.

d. Summary. Studies conducted have shown Blackstone River sediments to contain high levels of metals. Most contaminated sites appear to be Singing Dam, Fisherville, and Rice City Pond. Water quality studies have linked water quality contamination throughout the main stem to resuspension of sediments as a result fluctuating water levels caused by wet weather events and hydropower releases.

8. WATER QUALITY SUMMARY BY REACHES

a. General. In general, current water quality problems in the Blackstone River are typical of older, highly urbanized river basins. These problems include suspended solids, fecal coliforms, algal growth problems associated with excessive nutrients (significant variations in pH, DO, turbidity, etc,) and heavy metals. The contaminants originate from point and nonpoint sources, and, during storm events, stress the stream's natural capacity to assimilate waste. Another problem is water quality degradation from historical accumulation of polluted sediments.

Based on available sampling information, the Blackstone River Basin was broken into nine reaches and six tributaries for analysis. Reach 1 extends from Blackstone River headwaters to Millbury Street in Worcester, reach 2 from Millbury Street to Singing Dam, reach 3 from Singing Dam to Fisherville Dam, reach 4 from Fisherville Dam to Rice City Pond Dam, reach 5 from Rice City Pond Dam to Route 122, reach 6 from Route 122 to MA/RI State line, reach 7 from the State line to Woonsocket WWTF, reach 8 from Woonsocket WWTF to Pratt Dam, and reach 9 from Pratt Dam to Slaters Mill. Table G-15 presents water quality classification, status, water quality problems, and possible sources of these problems for each reach. Table G-16 presents violations of acute, chronic, State, and recommended criteria for BRI sampling events.

b. Reach 1. This section of the Blackstone River, extending from the headwaters to Millbury Street in Worcester, is nonsupporting of Massachusetts Class B uses. General problems are low dissolved oxygen, high ammonia-nitrogen, nitrate-nitrogen, and fecal coliforms, and violations of metal toxicity criteria. Under low flow conditions, most constituent loadings in the headwaters are small compared to point sources in downstream reaches. Exceptions to this are fecal coliforms, ammonia-nitrogen, copper, and lead, which are high in concentration under all conditions. BOD_5 and total suspended solids concentrations were the highest of the entire river during wet weather flows, showing the significance of urban runoff and the

TABLE G-15

WATER QUALITY CLASSIFICATION, STATUS, PROBLEMS AND SOURCES BY REACH

REACH	CLASS	STATUS	PROBLEMS	POSSIBLE SOURCES IN REACH
1	MA B	NS	Fecal Coliforms Low DO Ammonia-nitrogen Lead and Copper	Urban runoff Storm sewers Worcester CSO
2	MA B	NS	BOD Suspended solids Fecal coliforms Nutrients Metals	UBWPAD Storm sewers Urban runoff
3	MA B	NS	Nutrients Metals	Resuspension of sediment
4	MA B	NS	BOD Fecal coliforms Nutrients Metals	Resuspension of sediments Overland runoff Storm sewers
5	MA B	PS	Fecal coliforms Nutrients Metals Low pH	Overland runoff
6	MA B	PS	Fecal coliforms Nutrients Metals	
7	RI C	NS	Nutrients Metals	
8	RI C	NS	Nutrients Metals Fecal coliforms	Woonsocket WWTF Overland runoff Storm sewers
9	RI C	NS	Nutrients Metals Fecal coliforms	Overland runoff Storm sewers

NS - nonsupporting
PS - partially supporting

TABLE G-16

VIOLATIONS OF ACUTE, CHRONIC, STATE, AND RECOMMENDED CRITERIA PER REACH

REACH	DISSOLVED OXYGEN	BOD	FC	AMMONIA-NITROGEN	NITRATE-NITROGEN	ORTHO-PHOSPHATE	Cd	Cr	Cu	Ni	Pb
1	SD	RW	SW	SD SW	RD RW	RD			AD AW		CD AW
2		RD RW	SD SW	SD SW	RD RW	RD RW	AD AW		AD AW		CD AW
3		RW	SD SW	SD SW	RD RW	RD RW	AD AW		AD AW		AD AW
4		RD RW	SD SW	SD SW	RD RW	RD RW	CD AW		AD AW		AD AW
5		RD RW	SW	SD SW	RD RW	RD RW	CD AW		AD AW		CD AW
6		RD RW	SW	SD SW	RD RW	RD RW	AD AW		AD AW		CD CW
7		RD RW	SD SW	SD SW	RD RW	RD RW	CD CW		AD AW		CD AW
8		RD RW	SD SW	SD SW	RD RW	RD RW	CD AW		AD AW		CD AW
9		RD RW	SD SW	SD SW	RD RW	RD RW	CD CW		AD AW		CD CW
Quin	SW			SD	RD	RD					CD CW
Mumford	SD		SD	SD	RD RW	RD			AD		CD AW
West				SD	RD				AD		CD CW
Branch			SD SW	SD SW	RD RW				AD AW		CD AW
Mill	SW			SD SW	RD RW				AD AW		CD CW
Peters	SD		SD SW	SD SW	RD RW		AW		AD AW		CD AW

A - VIOLATION OF ACUTE CRITERIA
C - VIOLATION OF CHRONIC CRITERIA
S - VIOLATION OF MA/RI STATE WATER QUALITY STANDARDS
R - VIOLATION OF RECOMMENDED CRITERIA FOR AESTHETIC AND RECREATION USES
W - BRI WET WEATHER SAMPLING
D - BRI DRY WEATHER SAMPLING

Worcester CSO. There is a significant source of lead and ammonia-nitrogen in this reach. Overall, this reach is a major source of TSS, BOD, fecal coliforms, lead, and ammonia. These are attributed to both point and nonpoint sources.

c. Reach 2. This 5.9-mile stretch of river, starting at Millbury Street and continuing downstream to Singing Dam, includes the Upper Blackstone Water Pollution Abatement District (UBWPAD), New England Power Company Dam, Millbury WWTP, and Singing Dam impoundment. Water quality is generally degraded with high BOD_5, total suspended solids, fecal coliforms, and nutrients and several violations of metal criteria. This reach generally has the highest cadmium, nickel, lead, copper, phosphate, and nitrate-nitrogen concentrations on the main stem Blackstone River and is nonsupporting of Massachusetts Class B uses. Several sampling efforts have shown that, under high and low flow conditions, the UBWPAD is a major source of metals and nutrients to the Blackstone River. Its discharge affects the concentrations of these parameters downstream to Rice City Pond (reaches 3 and 4). The UBWPAD is also a source of TSS, BOD, and fecal coliforms in this reach. Nonpoint source increases of TSS, fecal coliform, BOD, nutrients, and metals were also observed. Sediments in the Singing Dam impoundment were some of the most polluted of those sampled.

d. Reach 3. This 3.5-mile section of river, beginning below Singing Dam and ending at Fisherville Dam, contains the breached Saundersville Dam, the confluence with the Quinsigamond River, and Fisherville Dam impoundment. Under low flow conditions, this reach has high nutrient concentrations and some metal criteria violations. Metal concentrations, though still high, decreased slightly through the reach. This could have been due to settling in the impoundments or uptake of biomass. Under high flows, there were no significant increases in any parameter. There were, however, slight increases in TSS which were attributed to sediment resuspension. The entire reach was nonsupporting of Class B designated uses. Sediments in Fisherville Dam impoundment were found to be highly contaminated with metals.

e. Reach 4. Included in this 8.5-mile, which starts below Fisherville Dam and continues downstream to Rice City Pond Dam, are Farnumsville Dam, Grafton WWTP, Northbridge WWTF, Coz Chemical, Riverdale Dam, and Rice City Pond. Water quality is degraded in this reach by high BOD_5, suspended solids, fecal coliform, nutrients, and metal concentrations. Metal concentrations around Rice City Pond were some of the highest measured on the entire main stem river. Concentrations of many constituents including TSS, ammonia-nitrogen, orthophosphate, and metals increased around Rice

City Pond, indicating that sediment resuspension is a major source of contamination. This reach is nonsupporting of its designated Class B uses. Sediment quality in this reach was the most polluted of those sampled with extremely elevated metal concentrations in Rice City Pond.

f. Reach 5. This 4.6-mile section of river, which begins below Rice City Pond Dam and continues downstream to Route 122, includes the confluences of the West and Mumford Rivers. This reach generally has high fecal coliform and total suspended solids concentrations. Nutrient and metal concentrations, though still high, decrease from upstream to downstream indicating no significant point or nonpoint source exist in this reach. Metal concentrations on the Mumford and West Rivers were lower than main stem concentrations and did not seem to be a major source of metals contamination. This reach is partially supporting of Massachusetts Class B uses due to low pH, nutrients, and metals.

g. Reach 6. Most of this 6.6-mile section of the Blackstone River, which begins below Route 122 and ends at the State line, support but threaten Massachusetts Class B designated uses. Most pollutant concentrations in this reach are level or declining but still generally above recommended criteria. Concentrations of metals decrease gradually through this reach with no apparent point or nonpoint sources.

h. Reach 7. The Mill and Peters Rivers merge into the Blackstone in this 3.8-mile reach, which begins at the State line and ends above the Woonsocket WWTF. This reach generally has slightly elevated BOD_5 and nutrient concentrations and metal criteria violations. Nutrient and metal concentrations generally stayed the same or decreased slightly indicating no significant point or nonpoint sources exist in the reach. The entire section is not supporting of its Rhode Island Class C designation due to high metals.

i. Reach 8. This 9.6-mile section of river begins just above the Woonsocket WWTF and continues downstream to Pratt Dam. Along with the Woonsocket WWTF, it includes Manville, Albion, and Ashton Dams. The reach has high BOD_5, fecal coliform, nutrient, and metal concentrations. Water quality conditions in this reach appear to be slightly degraded by both pollutants discharging from the Woonsocket WWTF and nonpoint sources. The Woonsocket WWTF is a major source of ammonia-nitrogen, TSS, and fecal coliforms to the river. Nonpoint sources contribute additional TSS, ammonia-nitrogen, nitrate-nitrogen, and orthophosphate. Reach 8 is nonsupporting of RI Class C uses due to high metals.

j. Reach 9. This 2.9-mile section of river, which begins below Pratt Dam and concludes at Slaters Mill, includes the Valley Falls, Central Falls, and Slaters Mill Dams and approaches the end of the main stem Blackstone River. This reach is degraded by high BOD_5, nutrients, and metals. Nonpoint sources in this reach contribute fecal coliforms and nutrients to the river. Reach 9 is nonsupporting of RI Class C uses due to high metals.

k. Quinsigamond River. From the 1977 and 1991 surveys, the biggest concerns of the Quinsigamond River appear to be elevated nutrients, fecal coliforms, copper, and lead. Suspended solids and BOD_5 do not appear to be a concern on the Quinsigamond. According to MDWPC, the Quinsigamond supports but threatens Class B uses due to pH, nutrients, and toxicity.

l. West River. Studies indicate that, overall, the West River previously had, and may still have, low dissolved oxygen, and has high ammonia-nitrogen, nitrate-nitrogen, copper, zinc, and lead concentrations. Metal concentrations were generally lower than those on the main stem Blackstone and did not seem to be a major source of metal contamination.

m. Mumford River. Generally, the water quality of the Mumford River is degraded by low dissolved oxygen and high BOD_5, fecal coliforms, nutrients, copper, and lead. Metal concentrations were generally lower than those on the main stem Blackstone and did not seem to be a major source of metal contamination.

n. Branch River. Limited sampling data available on the Branch River indicates high ammonia-nitrogen, nitrate-nitrogen, fecal coliforms, copper, and lead.

o. Mill River. Overall, the Mill River has elevated ammonia-nitrogen, nitrate-nitrogen, copper, and lead concentrations.

p. Peters River. Limited sampling indicates that the Peters River is degraded by low dissolved oxygen and high BOD_5, fecal coliforms, ammonia-nitrogen, nitrate-nitrogen, cadmium, copper, and lead.

9. WATER QUALITY IMPROVEMENT PROJECTS

a. Measures Which Can Be Performed by State and Local Agencies.

(1) General. The following discussion focuses on various measures which can be implemented by State and local

agencies to improve water quality and the riverine habitat within the basin. The Corps of Engineers does not presently have the authority to participate in improvements for water quality alone. Whether Corps projects are implemented in the watershed or not, State and local agencies can perform the following measures to improve water quality.

(2) Source Control. One way to improve water quality in the Blackstone River Basin is to eliminate pollutants at their source. However, implementation of source control projects for an older urban watershed is extremely difficult due to high cost and lack of available land.

Source control through regulation of effluent concentrations in NPDES permits could provide great opportunity for water quality improvement. EPA, MADEP, Office of Watershed Management, and RIDEM are in the process of reviewing and reissuing NPDES permits along the Blackstone River. Their goal is to do the reissuing every five years, using a point source waste load allocation model to get permit effluent limits. This model, developed as part of the Blackstone River Initiative, is also used to predict the effect of upgrades and changes to plants on water quality. The predicted outcome, if treatment plants are upgraded to meet stricter effluent limits, would be an overall reduction of the amount of nutrients and metals in the river.

Small communities are often unable to afford expensive upgrades to treatment plants. The town of Northbridge, Massachusetts developed a cost-effective methodology for reducing toxic water pollution. In response to renewal of Northbridge's NPDES permit with stricter metals effluents in 1992, the town developed "The Toxic Free Diet" to address the sources contributing to loadings of compounds of concern at their treatment plant. The first phase of the strategy was to do a source assessment of four categories of discharges: the drinking water supply and conveyance system, residential waste water, commercial and industrial sources, and infiltration and inflow. Once loadings from sources were developed, an alternative, effective system of toxics management was implemented (phase II). This involved community outreach and education, business outreach, and audits. The town has measured a 17 percent decrease in copper and 78 percent decrease in zinc to the wastewater treatment facility. The plan indicates that adoption of pollution prevention, increased community responsibility, and resource conservation can help towns get closer to meeting goals set for them.

Another city emphasizing best management practices is Worcester. The headwaters in Worcester have been shown to be a source of many contaminants. Studies, including the Blackstone River Initiative and extensive sampling performed by the city of Worcester in applying for their NPDES stormwater permit, indicated storm drains and the Worcester CSO as major sources of pollution. The impact of storm drain discharges can be dramatic over the long term as these effects result in oxygen depletion, algae bloom conditions, and accumulation of toxic metals and oils in the Blackstone River ecosystem.

The city applied for their stormwater permit in two phases, phase I in 1992 and phase II in 1993. The permit application required a map of the entire stormwater/sewer system, industrial activities, prediction of pollutants, the likely source of pollutants, materials exposed to stormwater, and a spill history. Worcester's permit application identified 263 storm drain outfalls, 93 of which were considered major. Seventy-one of the 93 major outfalls were sampled in 1991 for pH, chlorine, copper, phenol, detergents, turbidity, temperature, and conductivity. Sampling found that all storm outfalls were contaminated with at least one pollutant. One possible reason for this is that, in many cases, stormwater and sewage are carried in separate conduits through common manholes. There is a high potential for cross contamination as surcharges can easily rise above or blow out the dividing wall.

Another problem identified in Worcester is the CSO facility. Built in 1981, the facility pumps to UBWPAD. During wet weather events, if flow exceeds the ability to pump or UBWPAD's ability to treat, overflow is routed to a rectangular basin. If flow exceeds this capacity, it is chlorinated and discharged. This happens in many wet weather events.

Stormwater permit applicants are also required to develop a list of best management practices and recommendations. Worcester's current management programs include street sweeping, sewer maintenance, recycling, hazardous waste collection, and hazardous/chemical spill response. On the residential/commercial issues, Worcester's proposed management plan included structural control operation and maintenance including increased effort on existing programs and modification of dual manholes, regulations on new development, street operation and maintenance, flood control device analysis, landfill monitoring, and pesticide/herbicide/fertilizer use reduction. To reduce illicit discharges, the city proposed more inspections and enforcement, field screening, storm sewer investigation, spill prevention and containment, public reporting, and analysis of potential sanitary seepage. On the industrial issues, the plan recommended inspections, control measures, and monitoring. For construction activities, the proposed management plan recommended construction plan review, best management practice requirements, site inspection, and operator training. Worcester was 1 of 4 cities in Massachusetts required to apply for the stormwater permit. Worcester's efforts, once implemented, should have a significant impact on water quality, reducing total fecal coliform, suspended solids, ammonia, and lead loads.

There are other sources of stormwater runoff throughout the watershed. All communities should perform routine street sweeping, storm drain and sewer maintenance, catch basin cleaning, reduced road salting for deicing, reduced fertilizer application, and erosion control measures.

In 1994 the Massachusetts Department of Environmental Protection published the "Massachusetts Nonpoint Source Management Manual," a guidance document for Government officials. The purpose of the manual is to provide basic information to local officials on how to identify, inventory, and control nonpoint source pollution sources through environmental planning, local bylaws, and regulations. It gives a comprehensive list of causes of nonpoint source pollution, steps for preparing a nonpoint source pollution plan, best management practices for many of the pollution sources, checklists, and resources.

Rhode Island's Nonpoint Source Pollution Management Program was established by RIDEM in 1989. Revision of their original 1989 NPS plan was developed in 1995. The revised plan addressed the protection and restoration of all State waters threatened or impacted by nonpoint sources of pollution. The major goals for nonpoint source pollution management in Rhode Island, as shown in the plan, are listed below.

- Maintain a balanced approach between mitigating and preventing nonpoint source pollution in high priority watersheds and aquifers.

- Continue to address Statewide nonpoint source pollution problems, while placing increased emphasis on watershed-based management.

- Monitor and assess existing water quality and land use conditions, and based on this information, develop and implement specific nonpoint source pollution management strategies in high priority watersheds and aquifers.

- Strengthen public education efforts to increase awareness of nonpoint source pollution concerns and the role of citizens addressing these concerns.

- Provide technical assistance and training to facilitate implementation of nonpoint source pollution management activities.

- Test and promote the use of new or alternative methods for managing nonpoint source pollution.

- Improve the effectiveness of nonpoint source pollution management by enhancing coordination and collaboration among all applicable parties and programs.

Although source control through permitting and best management practices should reduce some total loading to the river, especially fecal coliforms, suspended solids, BOD_5, and nutrients, it is not expected that this alone will eliminate all pollutants entering the river. As a result, other watershed alternatives were evaluated by the Corps.

b. Alternatives Evaluated by the Corps. The Corps looked at specific projects for restoration/enhancement of fish and wildlife habitat including streambank stabilization, wetland creation, restoration of a paved lot in Lincoln, RI, and several alternatives at Fisherville Pond. Water quality improvement is not a direct goal, but will result from implementation of these alternatives.

(1) Fisherville Dam Options. Fisherville Dam, located in reach 3, was selected as a location for several prototype projects for fish/wildlife habitat restoration. It has an old dam with contaminated sediments behind it, poor water quality, and degraded habitat. This reach was found to have high nutrient and metal concentrations under all flows and high BOD_5 and TSS under high flows. The pond is essentially full of sediments and wet weather sampling indicated probable resuspension, releasing contaminants downstream. If sediments are found to pose minimal ecological risk, habitat restoration could be obtained with minimal work on the sediments. If risk analyses find that the existing contaminated sediments require remediation, additional alternatives would be required. Options evaluated include rehabilitation of the dam and control structure with minimal regrading of the pond bottom to create small pools and rehabilitation of the dam and control structure with

extensive dredging. Flow diversion was also evaluated as an option which could be used with either of the first two.

(a) Rehabilitation of Control Structure and Dam with Minimal Regrading. This alternative would restore habitat to its former configuration or expand upon it and could be effective alone if sediment remediation is found unnecessary. It would involve rehabilitating the dam and control structure so that water levels can be optimized, excavating or grading the site in selected locations to optimize emergent vegetation and waterfowl feeding opportunities, and planting to reestablish habitat.

Water quality impacts would include possible removal of nutrients and suspended solids as water passes through wetland vegetation.

(b) Rehabilitation of Control Structure and Dam with Extensive Dredging and Regrading. In combination with alternative one, dredging could be performed to deepen the pond in additional areas. If sediments are found to pose a risk to waterfowl or fish, this alternative would require capping contaminated sediments. Extensive planting to replace vegetation destroyed during dredging and placing of the cap would be performed as part of this alternative.

Benefits to water quality would include elimination of contaminated bottom sediment resuspension from dredged areas. A deeper pond would also provide more storage for sediment and may cause more settling of suspended solids. The impact of dredging on dissolved oxygen is uncertain. While an increase in pond volume may cause a decrease in dissolved oxygen deep within the impoundment, existing sediments may currently be reducing dissolved oxygen. Dredging of the sediments may eliminate the sediment oxygen demand and not cause an overall decrease in dissolved oxygen. Any decrease in dissolved oxygen would only impact pond concentrations, as the river is reaerated as it passes over Fisherville Dam. The same applies to algae. While a deeper pond may contribute to more algae as deep anaerobic layers allow for the release of nutrients, dredging existing sediments which may be supplying nutrients could counteract this.

(c) Flow Diversion. Used in conjunction with alternatives one or two, this alternative would allow for some flow to be routed around the contaminated area through the historic canal. This alternative would provide recreation, historic, and fish passage benefits but impacts on water quality would be minimal. While complete diversion would prevent resuspension of contaminated sediments, the overall water quality in the impoundment would be deteriorated. The limited capacity of the canal itself would minimize any benefits to water quality to the river passing through.

(2) Raising Dams. Many of the impoundments on the Blackstone River have sediments behind them which are contaminated with metals, organics, and hydrocarbons. These contaminants are subject to flashy flows as a result of urban headwaters, wastewater discharges, and hydropower facilities and are chronically transported downstream, potentially reaching Narragansett Bay. One alternative for containment of impounded sediments is raising dams. This alternative would involve raising dams to facilitate inundation of sediments. Since most of the impoundments are silted in, dams would have to be raised significantly. Periodic dredging may also be required.

Inundation of sediments would promote burial of currently exposed contaminants with upstream sediments. Sediment resuspension would be significantly reduced, minimizing transport of contaminants from impoundments. In a deeper impoundment flows would be reduced, increasing hydraulic retention time. This could result in a decrease in dissolved oxygen in the depths of the impoundment.

(3) Dam Breaching. This alternative involves breaching dams along the main stem to avoid costs associated with dam rehabilitation and remediation of contaminated sediments. It would include removal of the existing dam, capping of the sediments in combination with sediment removal, dredging to create waterfowl and fisheries habitat, and planting.

This would result in a lowering of the detention time in existing ponds, which would have a positive impact on oxygen by decreasing the impacts of SOD. Reaeration of water passes over dams, however, would be eliminated. Breaching dams along the river would also reduce the time available for initiation of algal productivity, thereby reducing the potential of algae growth. If sediments are capped before breaching the dam, contaminated sediments would be prevented from washing downstream.

(4) Lonsdale Drive In. Located in reach 8, Lonsdale Drive-in is a former theater located next to the Blackstone River. The abandoned site, now paved, was formerly wet meadow. Restoration at this site would include excavation to a lower elevation than existed at the site to create wetlands, deepened pools, stream meanders, plantings, and disposal to create upland habitat. Sampling of the

Blackstone River in this reach found high levels of metals and nutrients. As water flows through created wetlands, vegetation will remove some nutrients as well as slow flows and allow for settling of suspended solids.

(5) Singing Dam Sediment Capture Pond. During wet weather events, the headwaters cause a significant increase in suspended solids, fecal coliforms, BOD_5, and nutrients. A sediment capture pond at Singing Dam, which is one of the most upstream dams in reach 2, would remove some of these pollutants before they continue downstream, degrading the rest of the river. This alternative would require dredging of the filled in pond, and maintenance dredging when it fills again.

(6) Wetlands. These could be constructed/restored throughout the watershed. Along with providing aquatic and wildlife habitat, wetland values also include flood mitigation, storm abatement, aquifer recharge, and water quality. Wetlands are effective for water quality improvement for a number of reasons. Removal of BOD_5 can occur by bacteria attached to the submersed roots and stems of wetland plants. Temperature is a significant factor in the removal of BOD_5, as warmer temperatures support more bacteria. A reduction in velocity as streams enter wetlands is also conducive to sedimentation of suspended solids and chemicals. Nutrient removal, especially nitrogen, occurs in wetlands. The processes which can alter the amount of nitrogen or phosphorus in the ecosystem include uptake and release from plants as well as microbial conversions. Nitrogen fixation results in the conversion of nitrogen gas to organic nitrogen thorough the activity of organisms in the presence of the enzyme nitrogenase. Nitrogen fixation, an aerobic process, favors low oxygen environments because nitrogenase activity is inhibited by high oxygen. Denitrification, the conversion of nitrate nitrogen to atmospheric nitrogen, has been found in many marshes (Kadlec). Shallow waters with fluctuations in oxygen status and organic substrates are sites of high denitrification. Plants uptake nitrogen and phosphorus but may also release them back to the water. Nitrogen release occurs in decomposition, ammonification, and nitrification.

Aquatic and semi-aquatic plant species absorb heavy metals from water and incorporate them in various structures such as leaves, roots, and stems. Sediments may also act as a sink for sorption of heavy metals. Most reaches along the Blackstone are degraded by high concentrations of nutrients and metals. Wetland systems along the river would help reduce these loadings.

Wetlands would also aid in the reduction of flashy flows, reducing the source of much erosion leading to habitat degradation and release of contaminants.

(7) Streambank Stabilization. This is applicable to a variety of locations in the Blackstone River watershed. Traditional methods of bank and shoreline stabilization, such as riprap, would benefit water quality by reducing erosion of banks which are generally contaminated with metals and oils. Riprap, however, is not environmentally sensitive, destroying vegetation as it is placed and requiring removal of vegetative growth through the riprap. This growth is necessary for restoration of a viable ecosystem. Bioengineering techniques for shoreline protection should be evaluated as an alternative. They utilize plant material or native rock that enhance habitat as well as decrease erosion and sediment releases, improving water quality. Vegetative techniques provide a durable, natural-looking appearance while providing habitat and water quality benefits. Plants would reduce stream velocity, stabilize banks, and reduce sediment loads from entering the stream system. Water quality benefits would include reduction of downstream pollutants.

(8) Stormwater Capture Pond. Urban stormwater runoff from Worcester is suspected to be a problem, creating flashy flows and increased contaminants in the headwaters. Several methods can be utilized to detain this stormwater. Retention ponds usually contain a permanent pool whose main purpose is the retention of storm water runoff and for settlement of particulate pollutants. They are extremely effective water quality best management practices. Stormwater retention ponds, which can be lined with vegetation, contribute to high removal of BOD_5, organic nutrients, and trace metals and can also remove soluble nutrients through the use of aquatic plants and algae. The permanent pool reduces the occurrence of resuspension of already settled out particles. Another benefit of the ponds are additional habitat for fish and wildlife. This watershed alternative could be located down gradient of any small urban runoff site.

10. CONCLUSIONS AND RECOMMENDATIONS

Due to the highly contaminated nature of the Blackstone River and its direct impact on Narragansett Bay, many studies have been conducted in the watershed. Water quality sampling conducted from 1977 to 1993 indicates that the main stem Blackstone River contains high levels of fecal coliforms, BOD, nutrients, and metals. Studies directed by the Narragansett Bay Project conclude that the Blackstone River is the primary source of nutrients and metals to Upper Narragansett Bay.

Sediment sampling found highly contaminated sediments behind several of the old dams on the Blackstone River. Singing, Fisherville, and Rice City Pond Dams were found to be the most contaminated, containing high metals and organics. Water level flow fluctuations caused by hydropower facilities and wet weather events cause resuspension and sloughing of these contaminated sediments.

Dry and wet weather sampling identified two major point sources of metals and nutrients - the Upper Blackstone Water Pollution Abatement District (UBWPAD) and Woonsocket Wastewater Treatment Facility (WWTF). Nonpoint sources identified include storm loads from Worcester and resuspension of contaminated sediments accumulated behind old dams.

With or without Corps-implemented projects, several ideas could be implemented by State and local agencies for water quality improvement. These ideas include reduction of point source contamination through tighter regulations on NPDES permits, educational programs, and reduction of nonpoint source pollution through best management practices in urban areas. Efforts in these areas would reduce nutrient, metal, and solid loadings to the river.

In order to restore/enhance fish and wildlife habitat along with improving water quality, several alternatives are proposed by the Corps. These include wetland restoration/creation, streambank stabilization, stormwater capture ponds, dam rehabilitation or breaching, and dredging and/or capping of contaminated sediments. Many alternatives evaluated would be effective basin-wide, while others were evaluated for a specific site. Although the alternatives were proposed for fish and wildlife habitat restoration/enhancement, most would have beneficial impacts on water quality.

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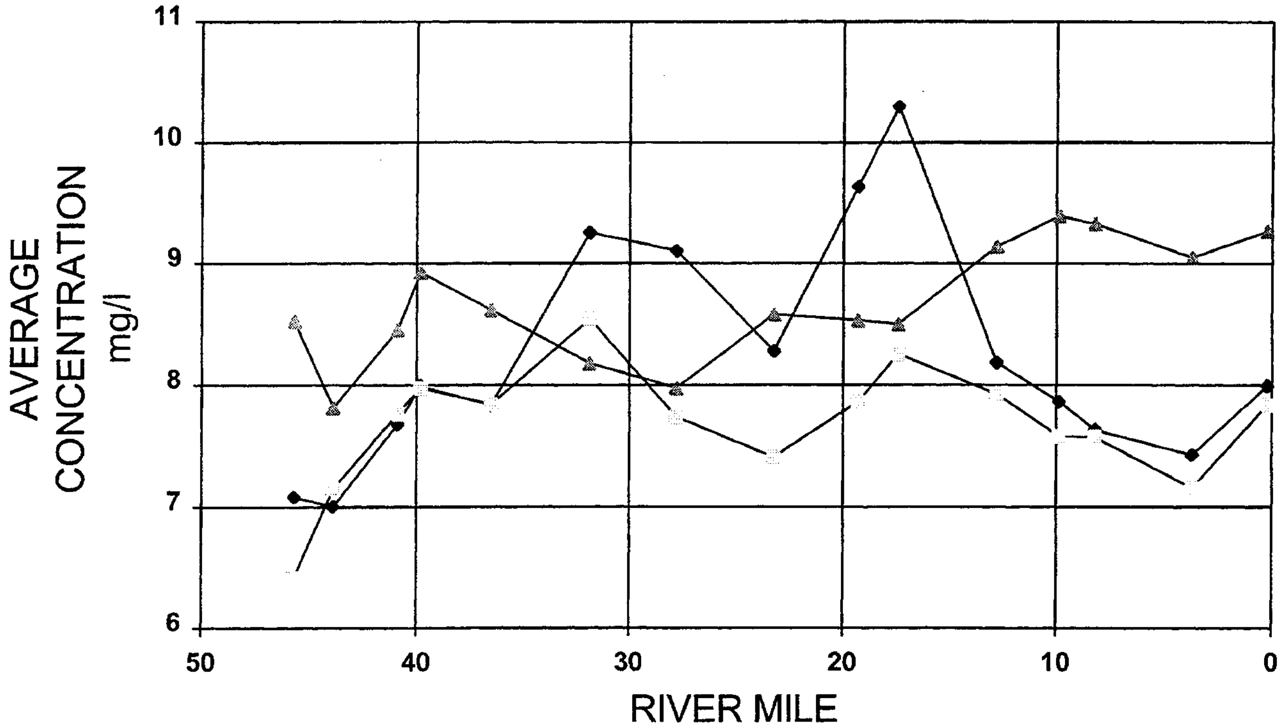


BOD$_5$

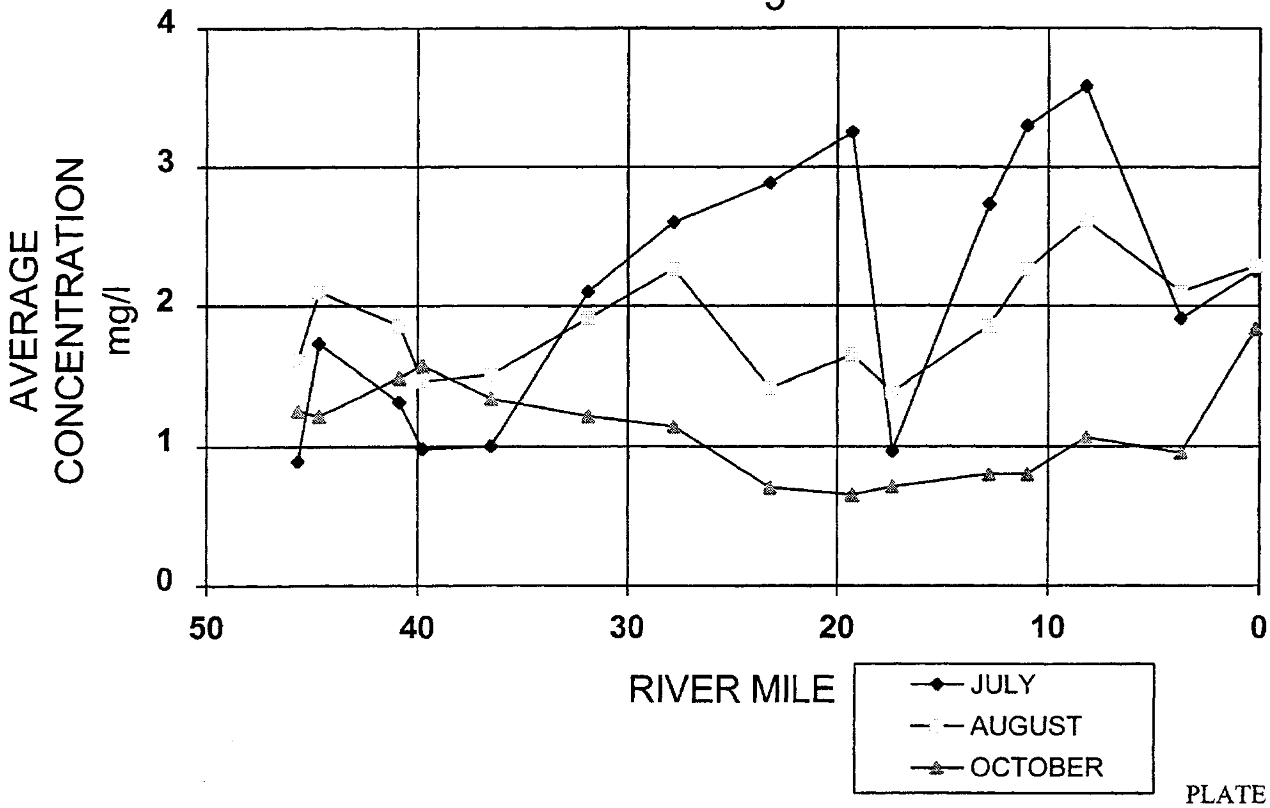
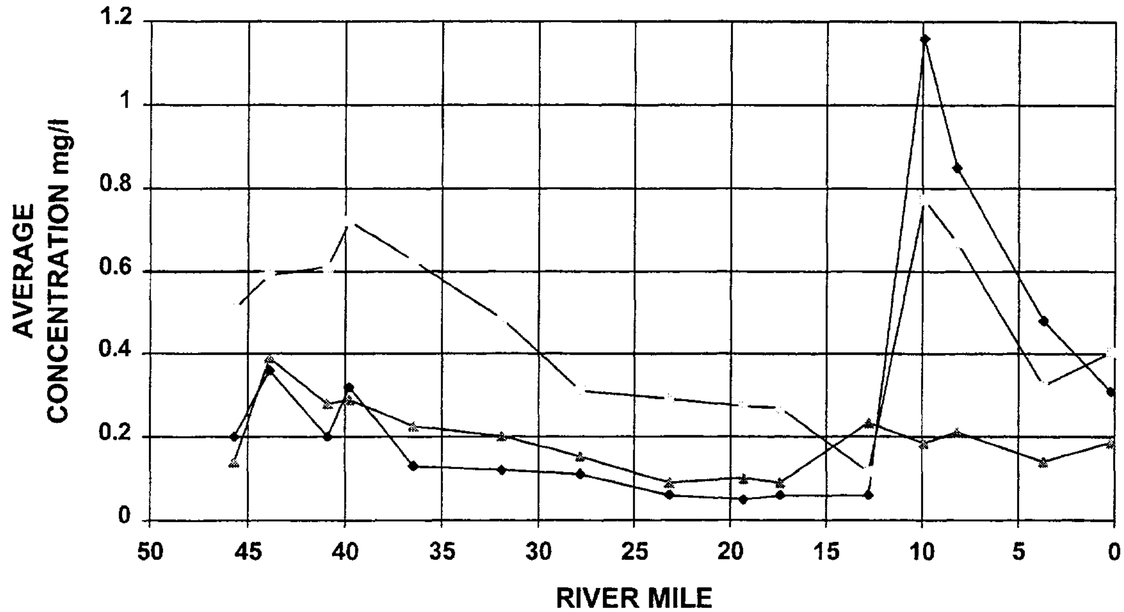


PLATE G-1

AMMONIA-NITROGEN



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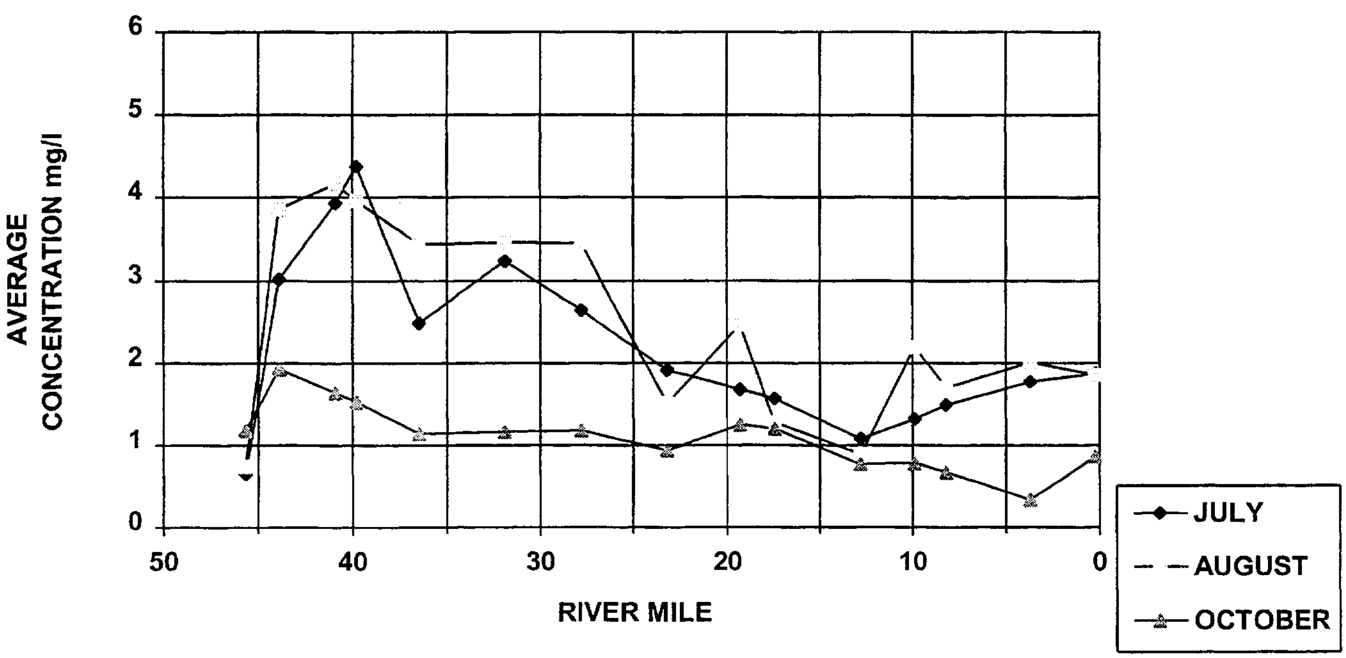
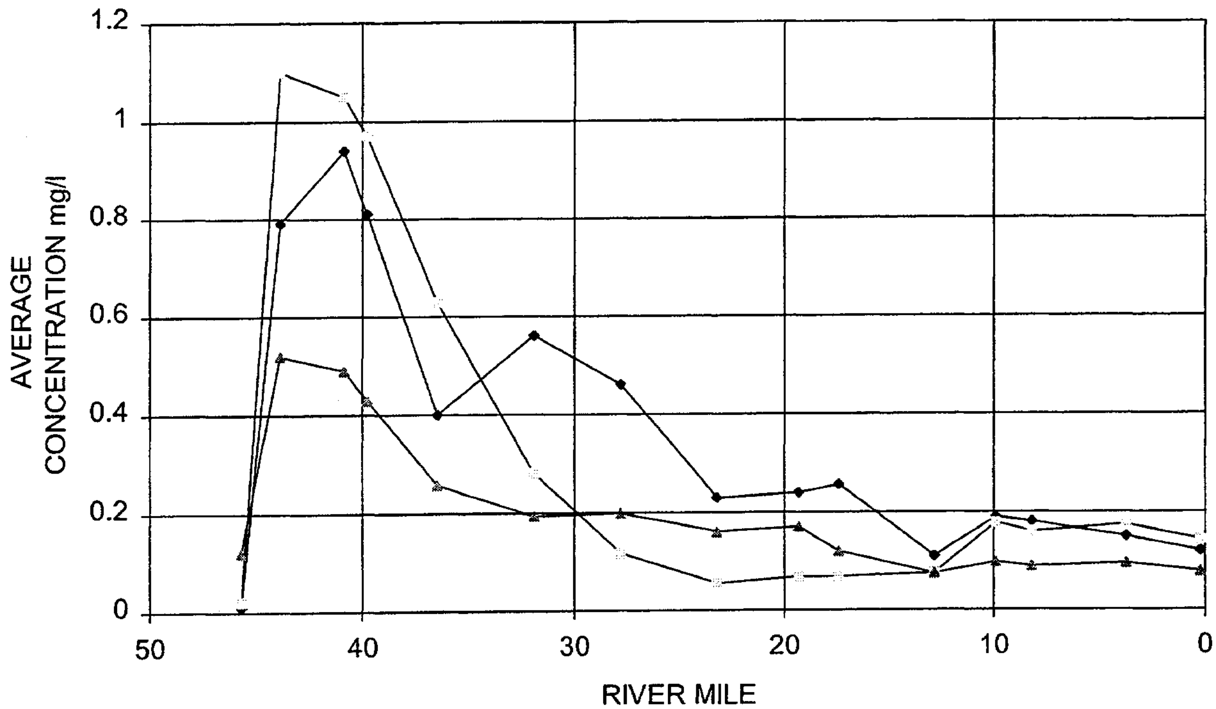


PLATE G-2

ORTHOPHOSPHATE



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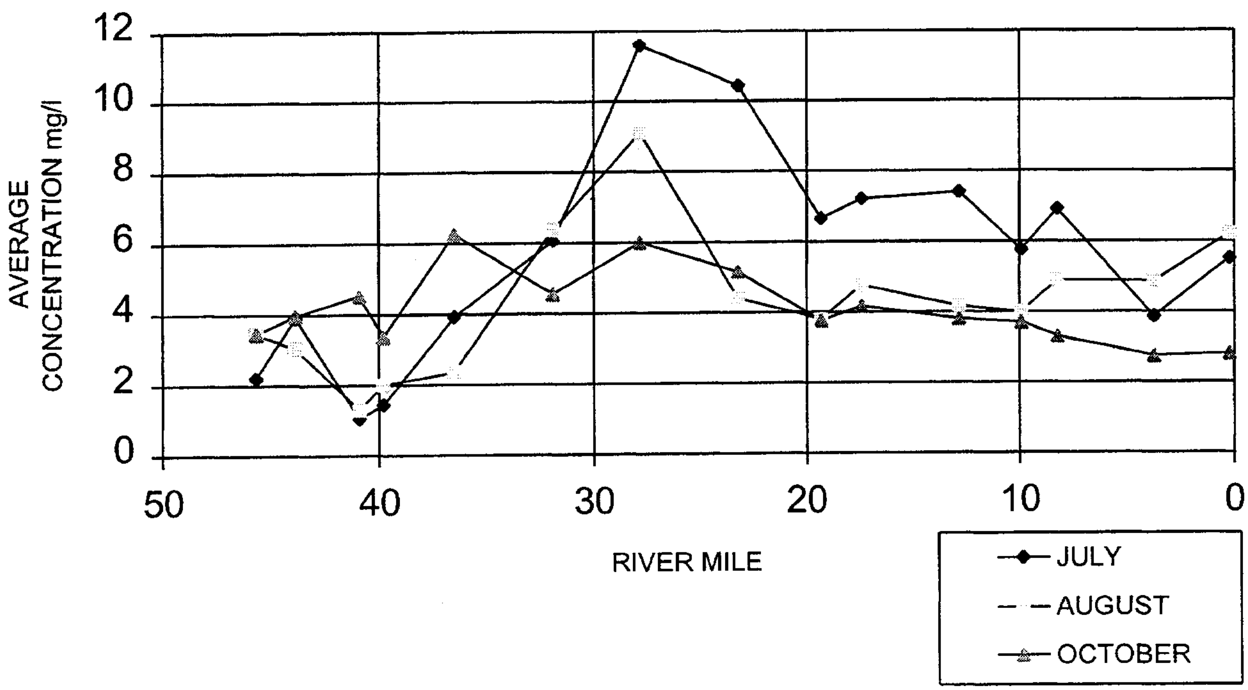

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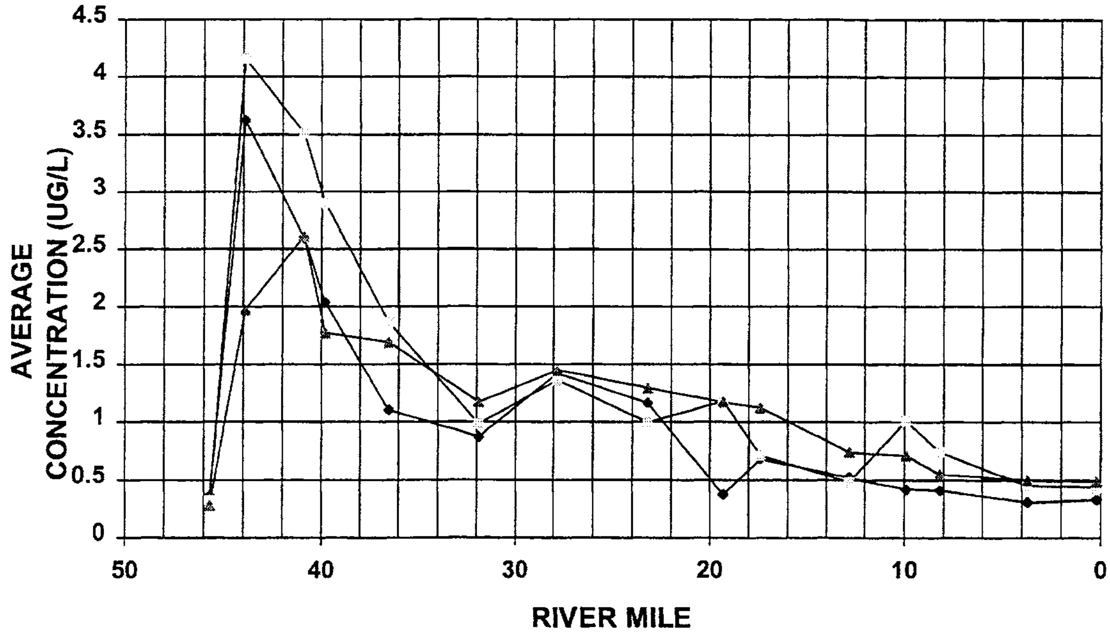
TOTAL CADMIUM



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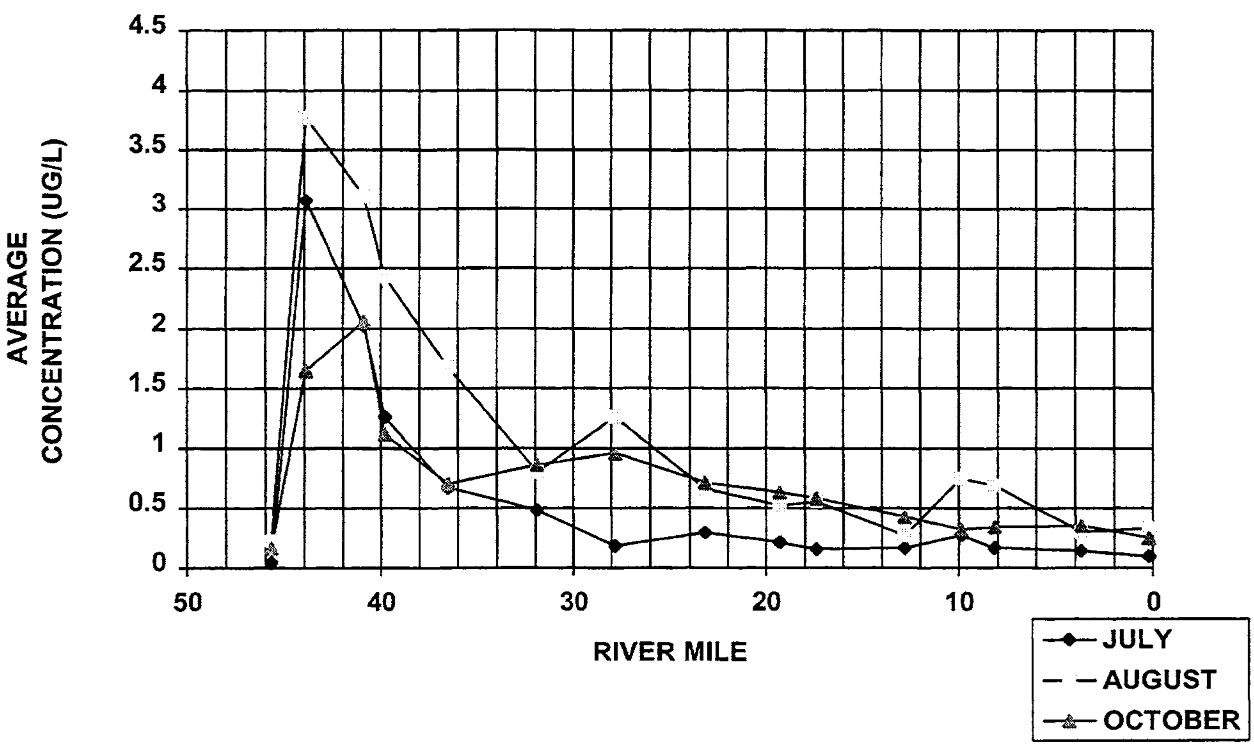

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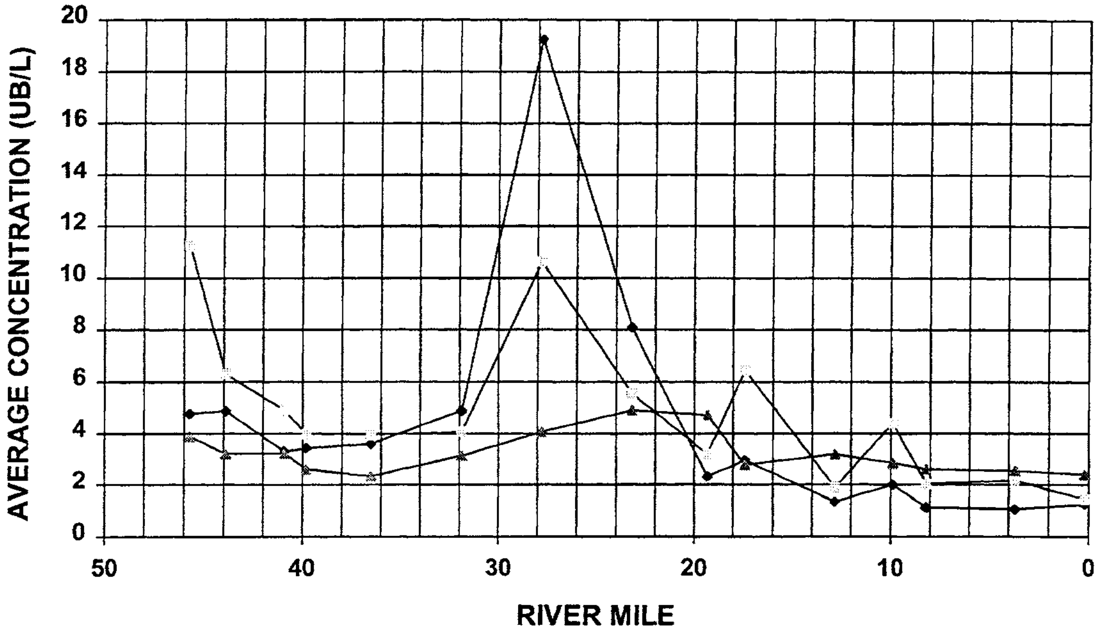

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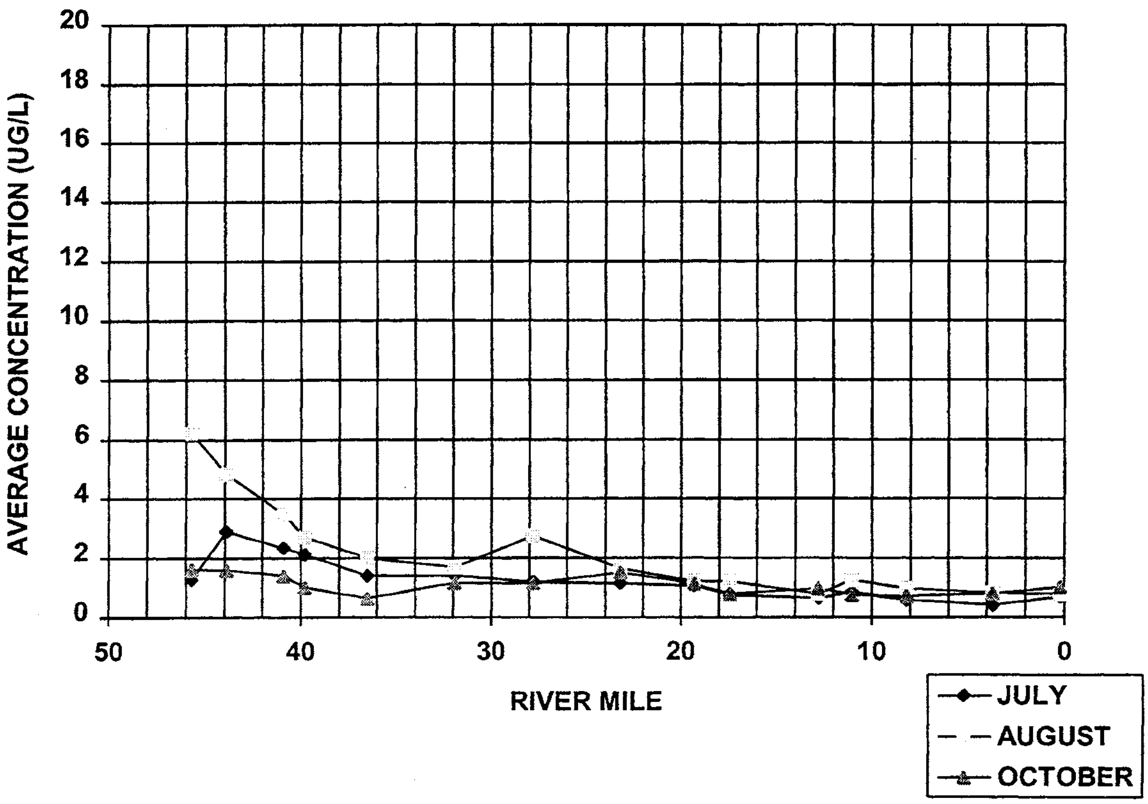

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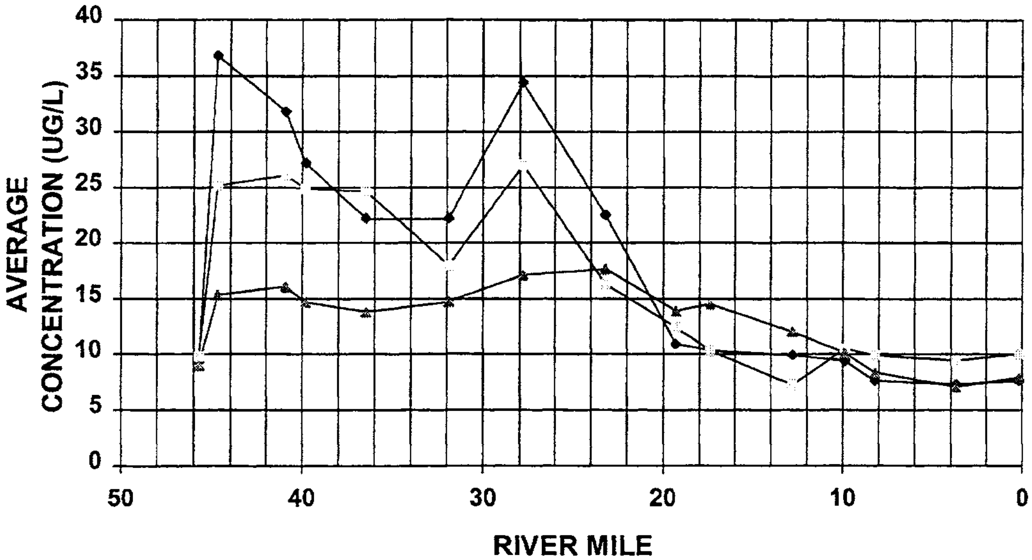

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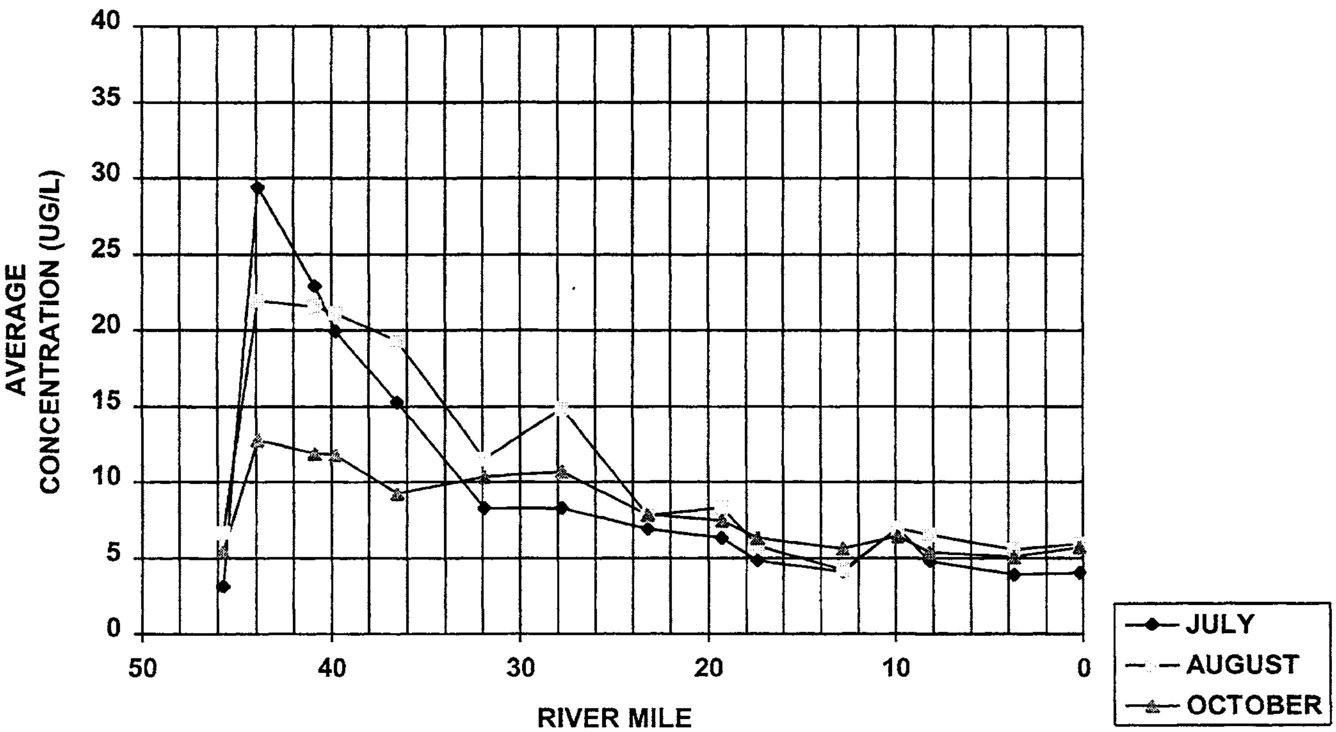

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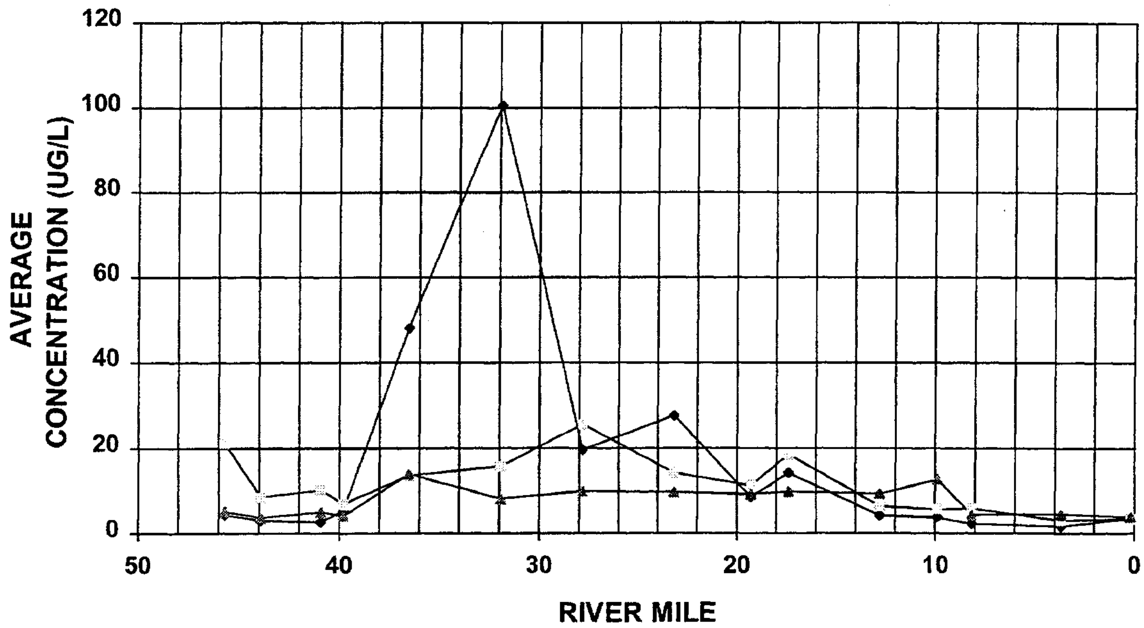

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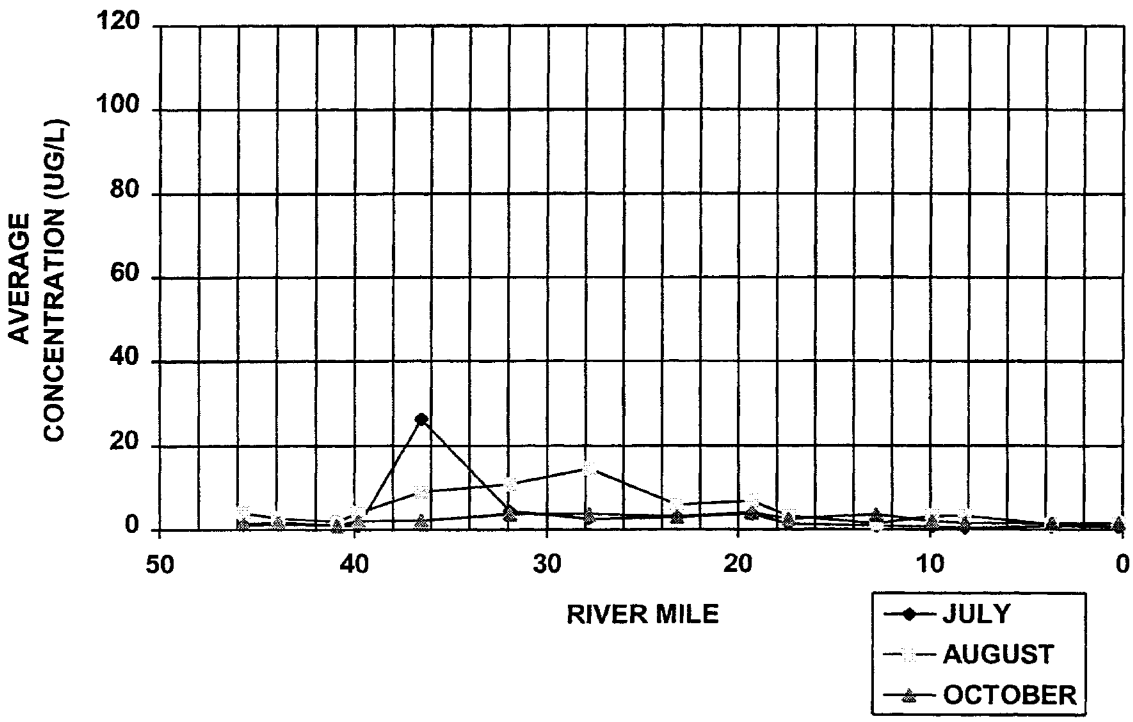

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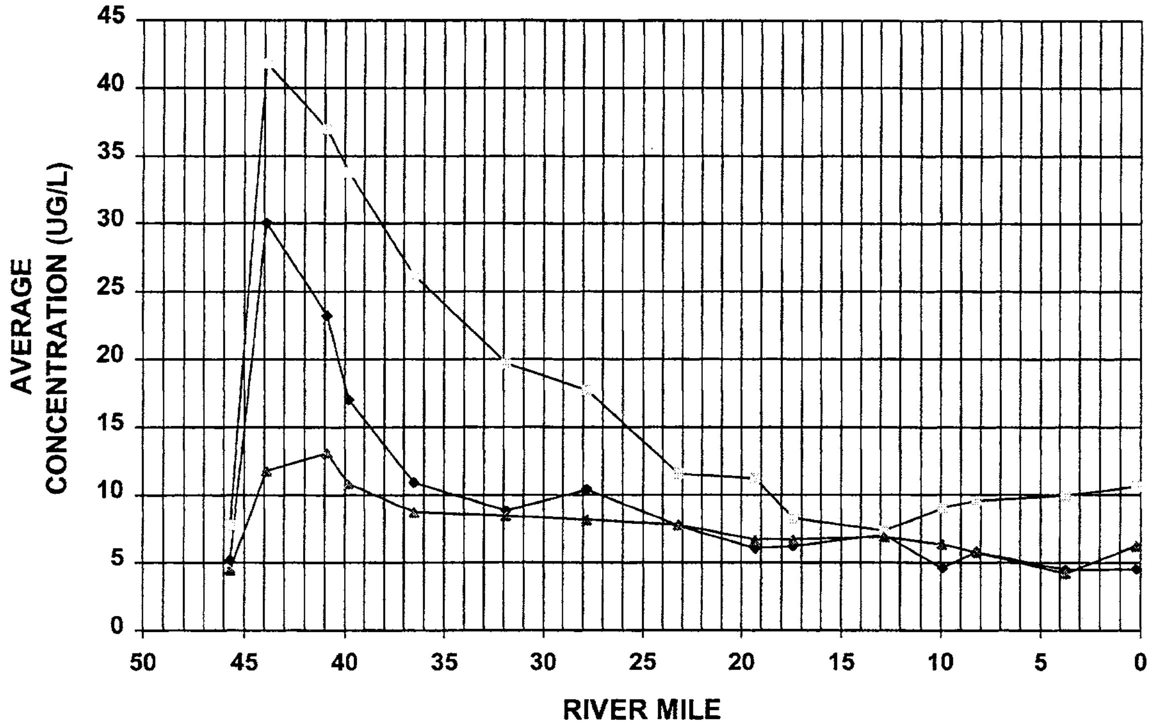

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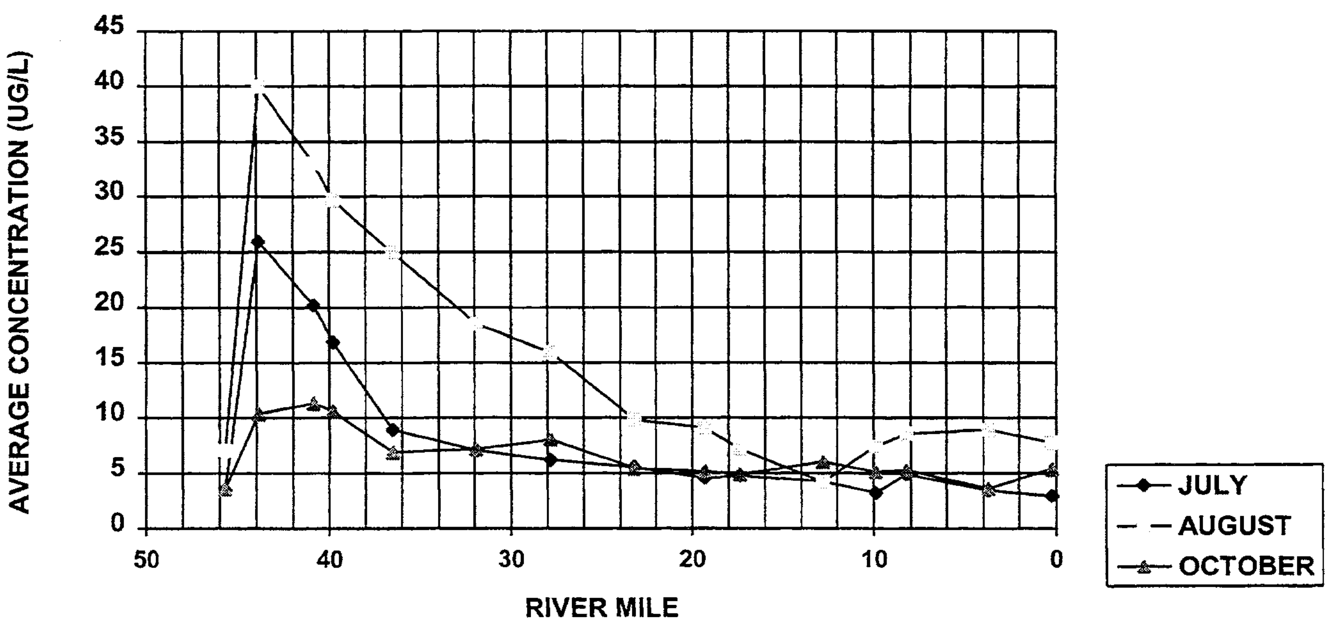


PLATE G-8

APPENDIX H - HYDROLOGY

BLACKSTONE RIVER RECONNAISSANCE INVESTIGATION
HYDROLOGIC ANALYSIS

1. BLACKSTONE RIVER BASIN DESCRIPTION

The Blackstone River basin, located in south-central Massachusetts and northern Rhode Island, is generally elongated in shape, with a length of about 46 miles, average width of 12 miles, and a total drainage area of 475 square miles to tidewater at the Seekonk River. The topography is generally hilly or rolling with higher elevations lying in the northwestern portion, some of which are in excess of 1,300 feet NGVD. Steep tributaries are located in the upper reaches of the watershed with relatively longer ones in the lower reaches. A general basin map of the Blackstone River is shown on plate 1.

2. BLACKSTONE RIVER AND ITS TRIBUTARIES

a. General. The Blackstone River originates at the junction of the Middle River and Mill Brook in Worcester, Massachusetts and meanders southeasterly direction for about 44 miles to its mouth at the Main Street Dam in Pawtucket, Rhode Island. From here the river enters the Seekonk River tidal estuary. The Blackstone River has a total fall of about 440 feet from its source to sea level. From Worcester to Fisherville, a distance of approximately 10 miles, the river falls 150 feet, or about 15 feet per mile. In the next 18 miles to Blackstone, Massachusetts the average fall is about 5 feet per mile. The river valley in this reach is broad and flat and has a marked modifying effect on floods in the basin. Downstream of Blackstone, the river drops 75 feet in 3 miles, then flattens out to become a rather uniform slope of approximately 11 feet per mile to tidewater. A profile of the Blackstone River is shown on plates 2 to 4.

The principal tributaries of the Blackstone River are Kettle Brook, Quinsigamond, Mumford, West, Branch, and Mill Rivers. The largest headwater tributary is Kettle Brook, which has its origin about 7 miles northwest of the city of Worcester. Kettle Brook terminates at Curtis Pond where Tatnuck and Beaver Brooks join it to form the Middle River, which in turn is joined by Mill Brook to form the Blackstone River. Following is a brief discussion of the major tributaries.

b. Kettle Brook. Kettle Brook has its source near Paxton Center and follows a southeasterly course to Stoneville, where it turns in a northeasterly direction before entering Leesville Pond. From there it flows northwesterly into Curtis Pond and joins Tatnuck and Beaver Brooks to form the Middle River. Kettle Brook falls approximately 650 feet in its 13 mile length and a large percentage of the total drainage area of 34 square miles is controlled by natural lakes and water supply reservoirs. In addition, a Corps Local Protection Project (LPP) completed in 1960, the Worcester Diversion Project, diverts floodflows from 30.5 square miles of Kettle Brook to the Blackstone River, bypassing a flooprone section of Worcester.

From the period 1923 to 1978, the USGS operated a streamflow gaging station at Worcester on Kettle Brook. Average daily flow for this period is about 53 cfs. The record for this 31.3 square mile drainage area has been adjusted for estimated diversions through the Worcester Diversion Project. Extremes for the period of record include a peak flow of 3,970 cfs in August 1955 and a low flow of 0.2 cfs in May 1940.

c. Quinsigamond River. The Quinsigamond River watershed has an area of 35 square miles, a length of about 12 miles and a maximum width of 4.5 miles. with many hills and numerous lakes and ponds. The largest body of water is the 5-mile long Lake Quinsigamond, located in the headwaters of the watershed, with a water surface area of about 1 square mile. This lake and the ponds downstream, coupled with the flat slope of the Quinsigamond River, have a decided effect on the timing and attenuation of peak floodflows at the mouth of the river. From the outlet of Lake Quinsigamond, the river falls approximately 65 feet in its 5-mile length, joining the Blackstone River in Fisherville.

The USGS has operated a streamflow gaging station at North Grafton, Massachusetts since 1939. Average daily flow for this 25.6 square mile drainage area is about 41 cfs. The highest recorded peak discharge was 820 cfs in August 1955; lowest recorded flow was zero in August 1966.

d. Mumford River. The Mumford River with an area of 58 square miles flows from the outlet of Manchaug Pond in Sutton, Massachusetts and follows a meandering course in a general easterly direction to its confluence with the Blackstone River at

Uxbridge, Massachusetts. In this 17-mile course the river falls approximately 450 feet. Several large ponds and lakes in the headwaters provide considerable natural storage, and in addition, many small dams and reservoirs developed by textile and machinery industries reduce and retard flood discharges.

The USGS operated a streamflow gaging station on this river from 1939 to 1951 at East Douglas, Massachusetts. For this period of record, average daily discharge is about 45 cfs for this 27.8 square mile drainage area. The highest peak discharge recorded at this gage was 420 cfs in March 1948; lowest recorded flow was 2 cfs in both February and August 1944.

e. West River. The West River watershed, with an area of 35 square miles, is elongated in shape with a length of about 12 miles and a width varying from about 5 miles in the upper portion to about 2 miles in the lower portion. The basin consists of low, rolling wooded hills and broad valleys with scattered lake and swamp areas. The Corps flood control project, West Hill Dam, was constructed in 1961 on the West River in Uxbridge, Massachusetts, and controls 27.9 square miles of drainage area during flood events. Elevations range from over 600 feet in the headwaters to 200 feet NGVD at the mouth. The river has its origin at Silver Lake, approximately 2 miles southeast of Grafton, Massachusetts. The West River flows southeasterly from its source through Upton, where it is joined by Warren Brook, then gradually turns to a more southerly course to its mouth about one mile south of Uxbridge. The length of the river is approximately 16 miles, during which it falls about 150 feet.

The USGS operated a streamflow gaging station on the West River in Uxbridge, Massachusetts, just below West Hill Dam, with a drainage area of 27.9 square miles. Average daily discharge for the period 1962 to 1990 was about 49 cfs (adjusted for storage). Maximum peak discharge, affected by flood control regulation, was 607 cfs in June 1984; lowest discharge was zero flow during August 1967, due to unusual upstream regulation.

f. Branch River. The Branch River, Blackstone's largest tributary has a triangular-shaped watershed of 96 square miles, of which 13 are in Massachusetts and 83 in Rhode Island. The mouth of the river is near the Massachusetts-Rhode Island state line, about 1.5 miles north of the city of Woonsocket. The

Branch River is formed by the confluence of the Pascoag and Chepachet Rivers near the town of Mapleville, Rhode Island and flows northeasterly for about 9 miles to its mouth. The Chepachet River drains the southern part of the watershed, whereas the Pascoag River and its principal tributary, the Clear River, drain the northwestern section. Elevations range from 800 feet in the headwaters to 200 feet NGVD ar the mouth. In spite of a hilly terrain, there are many lakes, ponds, and reservoirs which attenuate floodflows.

The USGS has operated a streamflow gaging station on the Branch River at Forestdale, Rhode Island since 1940 with a drainage area of 91.2 square miles. Average daily discharge for the period of record is 175 cfs. Maximum recorded instantaneous flow was 5,470 cfs in January 1979; lowest recorded flow was 5 cfs in October 1948.

g. Mill River. The Mill River has its source at North Pond in Milford, Massachusetts and flows southerly to its confluence with the Blackstone River at Woonsocket. In its 18-mile length, Mill River has a fall of about 230 feet, of which 23 feet occur within a one-mile reach in Woonsocket. The watershed has a drainage area of 35 square miles, about 16 miles long and 2 miles wide, comprised of rolling wooded hills and broad valleys with scattered lake and swamp areas which have a large modifying effect on floods. Harris Pond, impounded by a 36-foot high dam and located at the Massachusetts-Rhode Island state line, failed during the August 1955 flood and destroyed all dams on the lower Mill River within the city of Woonsocket. None of these dams have been replaced.

3. CLIMATOLOGY

a. General. The Blackstone River basin has a variable, temperate climate with frequent weather changes, although a prolonged drought may occur lasting a month to a year or more. The basin usually experiences moderate local showers or thunderstorms during the summer, but in the fall, winter, and spring months, storms of extra-tropical origin produce longer periods of precipitation. However, some of these storms can intensify over the ocean and produce coastal storms with strong winds and heavy rain (or snow) that are known locally as "Northeasters." Infrequently, during the late summer or early fall a tropical storm or hurricane may pass up the Atlantic coastline near enough to produce copious amounts of amounts of rainfall with damaging winds. Hurricanes can produce severe river and stream flooding over the entire basin.

b. Temperature. The average annual temperature of the basin is about 49 degrees Fahrenheit. Average monthly temperatures vary widely throughout the year, from between 25 and 30 degrees Fahrenheit in January and February, to between 69 and 73 degrees Fahrenheit in July and August. Extremes in temperature range from occasional highs slightly in excess of 100 degrees Fahrenheit to infrequent lows in the minus twenties, particularly in the northern portions. Mean, maximum, and minimum monthly temperatures are listed in table 1.

c. Precipitation. the mean annual precipitation is about 41 inches distributed quite uniformly throughout the year. The annual range between maximum and minimum values of mean monthly precipitation does not exceed one inch. Monthly precipitation extremes at Providence range from a minimum of 0.07 inch in March to a maximum of 12.24 in August 1955, and at Worcester 0.04 inch in March to 18.58 in August 1955. The maximum 24-hour precipitation recorded at Worcester and Providence was 8.67 and 6.67 inches, respectively, during the 18-19 August 1955 storm. Mean, maximum, and minimum monthly precipitation are listed in table 2.

d. Snow. About one-third of the precipitation during the winter months is in the form of snow. Annual snowfall average from 35 to 40 inches, with extremes ranging from less than one foot in the southern portions of the basin to over 100 inches at northern inland points. Average water content of the snow cover rarely exceeds 3 inches, however, maximum water contents of over 7 inches have been experienced in the Blackstone River basin.

Moderately high springtime discharges frequently occur as the result of melting snow, but runoff from this source alone has been insufficient to cause any major floods during the period of record. However, serious flooding from a combination of melting snow and heavy rain is an annual possibility.

TABLE 1

Monthly Temperatures
(degrees Fahrenheit)

	Worcester, Massachusetts Elevation 990 feet NGVD 1948-1995			Providence, Rhode Island Elevation 50 feet NGVD 1949-1995		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	24	69	-19	29	68	-13
February	25	67	-24	29	69	-17
March	33	84	-6	38	90	1
April	45	91	8	48	98	11
May	56	93	25	58	95	29
June	65	96	33	67	101	39
July	70	102	41	73	101	49
August	68	99	38	71	104	40
September	60	100	26	63	99	33
October	51	89	18	54	90	20
November	39	81	3	43	82	9
December	27	67	-17	33	69	-12
Annual	47	102	-24	50	104	-17

TABLE 2

Monthly Precipitation
(inches)

	Worcester, Massachusetts Elevation 990 feet NGVD 1948-1995			Providence, Rhode Island Elevation 50 feet NGVD 1949-1995		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	3.69	11.16	0.59	3.89	11.66	0.50
February	3.27	8.37	0.25	3.59	7.20	0.39
March	4.06	8.59	0.74	4.29	8.84	0.56
April	3.97	8.79	1.26	4.10	12.74	1.48
May	4.11	9.94	0.86	3.44	8.38	0.71
June	3.64	12.17	0.79	2.89	11.08	0.05
July	3.79	8.11	0.74	3.07	8.08	0.32
August	4.27	18.68	1.03	3.92	11.12	0.71
September	3.97	13.13	0.69	3.49	7.92	0.77
October	4.15	10.98	1.24	3.51	11.89	0.40
November	4.61	10.40	0.67	4.47	11.01	0.81
December	4.01	9.83	0.68	4.39	10.75	0.58
Annual	47.63	71.66	31.91	45.17	67.52	25.44

4. NON-FEDERAL MAINSTEM DAMS

a. General. The Blackstone River has been harnessed for waterpower since 1793. In the 200 years of development on the river, many dams have been built and removed or destroyed. Presently, there are no federally-owned dams on the mainstem.

Table 3 lists all of the dams on the mainstem Blackstone River for which information was available. The list progresses from upstream to downstream.

TABLE 3

Mainstem Blackstone River Non-Federal Dams

Dam	Location	Height (ft)	Normal Storage (Ac-ft)	Hazard*
New England Power	Millbury, MA	15	29	Low
Singing	Sutton, MA	10	50	Low
Fisherville Pond	Grafton, MA	10	250	High
Farnumsville	Grafton, MA	?	85	Low
Riverdale[F]	Northbridge, MA	14	88.5	Low
Rice City Pond	Uxbridge, MA	21	1762	High
Tupperware[F]	Blackstone, MA	12	305	Low
Saranac Mill	Blackstone, MA	17	20	?
Thundermist[F]	Woonsocket, RI	40	300	Signif
Manville	Lincoln, RI	19	58	Signif
Albion	Lincoln, RI	25	495	Signif
Ashton	Lincoln, RI	10	35±	Low
Pratt (Lonsdale)	Lincoln, RI	?	?	Signif
Valley Falls[F]	Central Falls, RI	10	80	Signif
Elizabeth Webbing[F]	Pawtucket, RI	10	150	Signif
Slater Mill	Pawtucket, RI	7	?	Signif
Main Street[F]	Pawtucket, RI	7	2.5	Low

NOTES: F denotes FERC licensed facility. Hazard classification is from Phase I inspection reports or FERC licensing applications.

b. Impact on Flows. All of the dams in the above table are run-of-river facilities. The non-FERC licensed dams pass inflow, either through gates or spillway discharge. Their only effect on flows is minor attenuation of flood flows by storage behind the dam or augmentation of low flows when water is released from storage. According to published USGS reports, the effects of storage releases on low flows was probably significantly greater prior to 1952, when most of the mill dams were still operating on the Blackstone.

The FERC licensed facilities are also run-of-river hydropower projects. There have been reports, however, of surging flows and fluctuating water levels downstream of some of these projects, which impact fish and waterfowl habitat. This phenomenon has been attributed to trash rack cleaning, and sudden start-up/shut-down of the turbines. These fluctuations also appear to be consistent with cycling of headponds to maximize power production. Water is stored in a project up to spillway crest, then the turbines are turned on and run until the pool drops below the spillway by one or two feet. The project is then shut down, and water stored for the next cycle. Often, during the period when water is stored, a minimum discharge (often 10 to 20 cfs) is passed downstream to maintain minimum fisheries levels.

Generally, none of these mainstem dams are operated for flood control purposes, except Thundermist Dam (formerly Woonsocket Falls Dam). Thundermist Dam was reconstructed by the Corps in 1959 and equipped with tainter gates which are operated to increase spillway capacity and decrease upstream stages. The dam is presently owned and operated by the City of Woonsocket. There is negligible flood control storage at this project. Incidental flood control benefits at the other mainstem dams come from the natural attenuation of peak flows due to limited spillway and outlet capacity and use of surcharge storage.

c. Impact on Sediment Transport. Since all of the mainstem dams impound water behind them and have relatively tranquil pools, they all act as sedimentation basins. During average to low flow periods, velocities decrease in the pools, causing sediment from runoff to drop out. One exception to this is in areas where breaches connect the canal and river (Fisherville, Rice City Pond, etc.). When river levels drop in the vicinity of the breach, the head differential between the canal and river often causes relatively fast flows through the breach areas. This flow resuspends solids in this area and transports the sediments into the main river channel and eventually downstream.

At flood flow velocities, deposited sediment is resuspended from overbank areas where erodible soils are scoured and transported downstream. In general, movement of sediment can be expected to begin at velocities of about 2 feet per second in loose, non-cohesive sediment. By the time velocities exceed 3.5 feet per second, much of the sediment (including silty clays) is resuspended. See section 7 below for further discussion about sediment loading in the river.

5. FLOOD CONTROL PROJECTS

a. West Hill Dam. Completed in 1961 by the Corps of Engineers, West Hill Dam is a flood control reservoir located on the West River, about 3.5 miles upstream of its confluence with the Blackstone River (see plates 5 and 6). This project is operated to control flood discharges from its 27.9 square mile drainage area. There is no seasonal or permanent pool at West Hill, however, the project does have 12,440 acre-feet of available flood control storage (equivalent to 8.3 inches of runoff).

Since being placed in operation in 1961, the maximum impoundment at West Hill Dam occurred in April 1987 when the project was filled to a 25.5 foot stage (67 percent full), which was 4.5 feet below spillway crest elevation 264.0 feet NGVD. The maximum flow released from the dam was about 610 cfs in June 1982.

Water quality in the West River is not affected by the existence or normal operation of West Hill Dam. During normal operation, the gates are left open and pass inflow, without impounding any water. During flood control operations, the gates are shut to temporarily store water behind the dam, decreasing peak downstream flows and stages. Minor effects are expected due to this temporary storage of floodwater during operations, however, such occurrences are infrequent and of short duration. Generally, water is evacuated from storage as quickly as possible after the storm without causing downstream flooding or unstable bank conditions in the reservoir.

b. Local Protection Projects. Four local protection projects (LPPs) have been completed by the Corps of Engineers in the Blackstone River basin. Although design and construction was federally funded, operation and maintenance of these projects was turned over to local governments. These projects consist of floodwalls, earthen dikes, pumping stations, a tunnel, concrete dams, and channel improvements at: Auburn and Millbury, Massachusetts on Kettle Brook; Blackstone, Massachusetts on the Blackstone River; Upper and Lower Woonsocket, Rhode Island on the Blackstone River. All of these projects were designed to reduce flood damages in the river basin.

(1) Worcester Diversion Project. This project is located on Kettle Brook in Auburn and Millbury, and was completed in 1960. It is comprised of a concrete control dam on Kettle Brook, a diversion structure, a 4,205-foot long tunnel, and an 11,000-foot long channel as shown on plate 7. The project diverts flood flows from Kettle Brook to the Blackstone River, bypassing 7 miles of congested river channel in Worcester, thereby, reducing flooding within that reach. During normal operations, this project is expected to have little or no impact on water quality, since flow continues on its natural course. During flood events, some flow still passes downstream through Worcester, however, excess flood flows pass through the diversion and enter the Blackstone River downstream of the flood prone area.

(2) Blackstone LPP. Completed in 1971, this dike in Blackstone provides protection against flooding for the town hall, courthouse and residential and park areas as shown on plate 8. The projects consists of a 860-foot long earthen dike with stone protection on the riverside and grass cover on the landside. The toe of the dike extends into the river for all of its length.

(3) Upper Woonsocket LPP. This project was completed in 1960 and consists of 8,300 feet of channel improvement with a trapezoidal channel section and stone slope protection; replacement of the Woonsocket Falls Dam (Thundermist Dam) with a new dam having four tainter gates; modification of two railroad bridges; a pumping station for a 44-acre interior drainage area,

four dikes, and a floodwall. In addition, a highway bridge across the river was replaced as part of the project (see plate 9).

(4) Lower Woonsocket LPP. This project consists of three units: Social District, Hamlet District, and Bernon as shown on plate 10.

(a) Social District Unit. This unit consists of 6 dikes, 3 floodwalls, excavation of 2 channels, 2 pressure conduits, and a pumping station. There are 1,100 feet of concrete T-walls on the Blackstone River averaging 13 feet high, 610 feet of concrete walls with an average height of 30 feet on the Mill River, and two channels totaling 610 feet. In addition, there are 1,870 feet of dike on the Blackstone, 2,410 feet on the Mill River, and 630 feet on the Peters River. The Mill River pressure conduit passes flows from a 34.7 square mile watershed, while the Peters River pressure conduit handles flows from a 12.7 square mile drainage area. The pumping station handles 284 acres of drainage area.

(b) Hamlet District Unit. There are three dikes totaling 3,100 linear feet with 75 feet of floodwall. The channel improvement is about 2,000 feet long. There is also a pumping station and gravity conduit.

(c) Bernon Unit. This unit consists of removal of Bernon Dam and 600 feet of channel improvements.

6. STREAMFLOW

a. General. There is limited gaged streamflow information available within the Blackstone River basin. The U.S. Geological Survey (USGS) operates and maintains two river gaging stations on the mainstem Blackstone River, at Northbridge, Massachusetts and at Woonsocket, Rhode Island. Flows recorded at these two gaging stations were considered to be representative of flows throughout the river basin for this study.

The USGS gaging station at Northbridge was operated continuously from 1940 to 1977. In addition, peak annual discharges are available for 1936 and 1979, and the USGS began collecting streamflow records again in 1996. The river has a drainage area of 141 square miles at the gage.

The station at Woonsocket has been operated continuously from 1929 to present. The Blackstone has a drainage area of 416 square miles at this gage location.

In addition to changes in storage and operation at many mill dams and increasing urban areas in Worcester and Woonsocket, flow regimes on the Blackstone River below Northbridge have been influenced by the Corps flood control project, West Hill Dam. Completed in 1961, the dam is located on the West River in Uxbridge, Massachusetts, about 3.5 miles above the confluence with the Blackstone, and controls 27.9 square miles (15 percent) of the Blackstone River's watershed during flood events. The project is operated in a manner which minimizes impacts on normal and low flows by passing inflow. Water is stored behind the dam only during flood events or during periods with high flood potential (i.e., spring runoff when the snowpack is ripe and heavy rains are anticipated).

b. Monthly Flows. Monthly flows on the Blackstone for the period of record at the two gage locations are shown in table 4. Average annual flows at Northbridge and Woonsocket are 267 and 774 cfs (1.89 and 1.86 csm), respectively. These average flows include the average return flow from the Upper Blackstone Water Pollution Abatement District of 60.7 cfs, of which about 14 cfs is an interbasin transfer from the Nashua River basin for water supply.

Based on a regional analysis of other gaged waterways which flow into Narragansett Bay, average annual flow from the Blackstone is considered to be average for that area. Mean annual flows into the bay ranged from 1.7 to 2.1 csm. As stated above, average annual flow in the Blackstone River at Woonsocket is about 1.86 csm.

c. Low Flows. Due to funding constraints, low flow analyses were not performed for this study, however, in 1984 the USGS published low flow data in the "Gazetteer of Hydrologic Characteristics of Streams in Massachusetts - Blackstone River Basin." The following table was developed from this published data.

TABLE 4

Discharges
(cfs)

	Northbridge, Massachusetts 141 square miles 1940-1979			Woonsocket, Rhode Island 416 square miles 1929-1995		
Month	Mean Monthly	Maximum Daily	Minimum Daily	Mean Monthly	Maximum Daily	Minimum Daily
January	282.0	2,120	14	950.9	12,500	109
February	324.5	2,930	22	987.5	7,140	109
March	514.8	3,910	74	1,507.0	14,200	187
April	475.1	2,280	101	1,424.0	8,960	302
May	302.5	1,780	60	879.6	5,770	139
June	225.2	1,590	8.7	605.3	10,900	44
July	141.9	2,220	4.7	330.0	13,700	29
August	144.7	8,850	2	316.9	25,900	21
September	145.6	3,680	2	330.4	8,530	29
October	156.7	2,640	8	419.4	8,310	36
November	224.3	1,990	5	668.5	5,640	36
December	263.3	1,590	8.7	866.3	5,300	79
Annual	266.7	2,965	25.8	773.8	10,570	93.3

TABLE 5

Low Flow Frequency Data
(cfs)

	Northbridge, Massachusetts 141 square miles 1940-1979	Woonsocket, Rhode Island 416 square miles 1929-1980
${}_7Q_2$	72	134
${}_7Q_{10}$	45	101

In addition to this information, in 1990 the EPA collected flow data from the Upper Blackstone Water Pollution Abatement District. This information shows that the District discharges about 60.7 cfs on average to the Blackstone River. Average monthly return flows vary from a low of 45 cfs in July and September to a high of about 77 cfs in May. Included in this return flow is about 14 cfs taken in an interbasin transfer from the Nashua River for water supply. As can be seen, during low flow periods, return flow from the plant accounts for most of the flow in the Blackstone River above Northbridge.

d. Flood Flows. Flood flows were analyzed at the two mainstem USGS river gaging station location on the Blackstone River. Peak annual flows at Northbridge and Woonsocket were ranked and fitted with a log Pearson Type III distribution.

The Northbridge gage has a drainage area of 141 square miles and a period of record from 1940 to 1977, with additional peak annual discharges known for 1936 and 1979. The resulting log Pearson Type III distribution, shown on plate 11, has a mean of 3.3395, a standard deviation of 0.2208, and an adopted skew of 1.0000. The resulting 10, 50, 100, and 500-year discharges are 4,300, 7,950, 10,200, and 17,300 cfs, respectively. FEMA's 1982 Flood Insurance Study for Northbridge reports discharges of 4,100, 8,000, 10,000, and 17,300 for these same return periods.

The Woonsocket gage, with a drainage area of 416 square miles, has a period of record from 1929 to present. However, in 1961, the Corps of Engineers completed West Hill Dam flood control reservoir upstream of this location on the West River which controls 27.9 square miles of this drainage area. As a result, peak annual flows at Woonsocket were analyzed for the period from 1961 to present. In addition, peak annual flows for 1936, 1938, and 1955, as expected to have been modified by West Hill Dam, were included in the analysis. The USGS reports that the flood of August 1955 is the largest flood experienced on the Blackstone in Woonsocket since 1645, however, our analysis considers it the flood of record since 1936. Statistics for the resulting log Pearson Type III distribution, shown on plate 12, are a mean 3.8206, standard deviation of 0.2269, and an adopted skew of 0.3000. The 10, 50, 100, and 500-year flows were computed to be 13,100, 21,000, 25,000, and 36,000 cfs, respectively. FEMA's 1981 Flood Insurance Study for Woonsocket reports discharges of 10,170, 17,300, 22,400, and 40,700 for these same events. The differences between our computed values and FEMA's is likely due to the longer period of record, an additional 16 years, included in our analysis.

e. Flow Depths. During flood flows, the Blackstone River below Worcester generally flows with depths greater than 5 feet (greater than 10 feet during significant floods). In Worcester, the river is steeper and has approximate flood flow depths of 3 to 5 feet (up to 10 feet during significant events).

During normal to low flow periods, reaches of the river can become quite shallow. Some of the low flows of record on the tributaries are zero, representing an essentially dry bed. On the mainstem, average flow depths at Northbridge and Woonsocket are about 3.5 and 3 feet, respectively. During low flow periods, these depths drop to less than 2 feet and less than a foot, respectively.

7. SEDIMENT

a. Sediment Loading. No sediment loading studies have been performed in the Blackstone River watershed. In September 1992, the USGS published "Sediment Deposition in U.S. Reservoirs, Summary of Data Reported 1981-85." Based on sediment loading rates from other similar watersheds in New England, the range of annual sediment loading for the Blackstone is likely between 260 and 650 cubic yards per square mile (cy/sm). From previous New England Division studies on watersheds with similar physical watershed characteristics within Massachusetts, an annual loading of about 400 cy/sm was adopted for the Blackstone River basin. During the height of industry in the watershed, sediment loading rates were probably much higher. However, it appears that sediment load to the river is decreasing despite increasing urbanization due to improved stormwater management practices and the decline of manufacturing in the region. In addition, sediment quality is also reported to be improving. Newly deposited sediments are relatively "cleaner" than older, deeper sediments.

b. Existing Sediment Volumes. Based on visual field observations, much of the storage behind most of the mainstem dams and some of the tributary dams has been filled with accumulated sediment. Table 6 summarizes, to the extent available, the best estimates of accumulated sediment behind many of the mainstem Blackstone River dams and Quinsigamond Pond Dam on the Middle River. Since much of this sediment has been accumulating for 100 to 200 years, many of these deposits are grossly contaminated with metals, organics, and PCBs.

c. Dredging. In the event that dredging of these contaminated sediments is adopted as a remedy at some of the locations of interest, several techniques should be used to minimize adverse impacts. Flows should be diverted around the locations to the extent possible. Even if complete dewatering cannot be achieved, flow velocities should be minimized using engineered controls. If excavating in the wet, a toothless bucket should be used to limit the amount of resuspension which occurs. Based on past reports, it appears that much of the contaminated sediment consists of fine grain sands, silts, clays, and organics. Dewatering will be difficult and may require mechanical processes or soil amendments. Limited Toxicity Characteristic Leaching Procedure (TCLP) tests performed to date indicate that this material can potentially be disposed of locally. However, if further testing reveals heavier contamination with metals, PCBs, and organics, disposal costs may be very high (up to $700 per cubic yard for out-of-state disposal at a licensed facility). In this case, on-site remediation may be more cost effective.

TABLE 6

Estimated Accumulated Sediment in Reservoir Storage

Location	City/Town	Estimated Sediment Volume* (cy)
Quinsigamond Pond	Worcester	20,000
Singing Pond	Sutton	260,000
Fisherville Pond	Grafton	780,000
Farnumsville Pond	Grafton	215,000
Riverdale Mill Pond	Northbridge	225,000
Rice City Pond	Uxbridge	544,000

*NOTE: For all locations except Quinsigamond Pond, volumes are taken from "A Sediment Control Plan for the Blackstone River," Joseph McGinn, 1981. Volume at Quinsigamond Pond developed from information in the Phase I Inspection Report and site visits. Based on review of pond geometry, areal extent of sedimentation observed, and reported depth of sediments, McGinn's volumes of sediment appear to be high.

d. Downstream Impacts. As previously stated, sediment settles out in the reservoir areas during typical flows and is scoured and resuspended during flood flows. Since much of the usable sediment storage in the reservoirs has been filled, it appears that much of the incoming sediment load is passed downstream. Due to this fact, it is unclear whether the sediments will cap themselves, with the newer, cleaner, sediments being deposited on the older, more contaminated, deposits.

In the event of a dam failure at any of the mainstem dams with significant accumulated sediment behind them, large amounts of sediment could potentially be carried downstream. Depending on inflows and the size of the breach, much of the accumulated sediment can be expected to be carried downstream in the initial flood wave. Immediate impacts from this would be sedimentation in all slow moving river reaches, especially in the floodplains and within existing impoundments, and re-introduction of older, more highly contaminated sediments to the water column.

In addition, after the dam failure and prior to reconstruction of the dam, bottom sediments not transported downstream during the breach will be subject to riverine flow velocities rather than the slower moving velocities in the former impoundment. This will likely result in resuspension of these sediments and continued downstream transport of sediments in the newly formed river channel at the breach location.

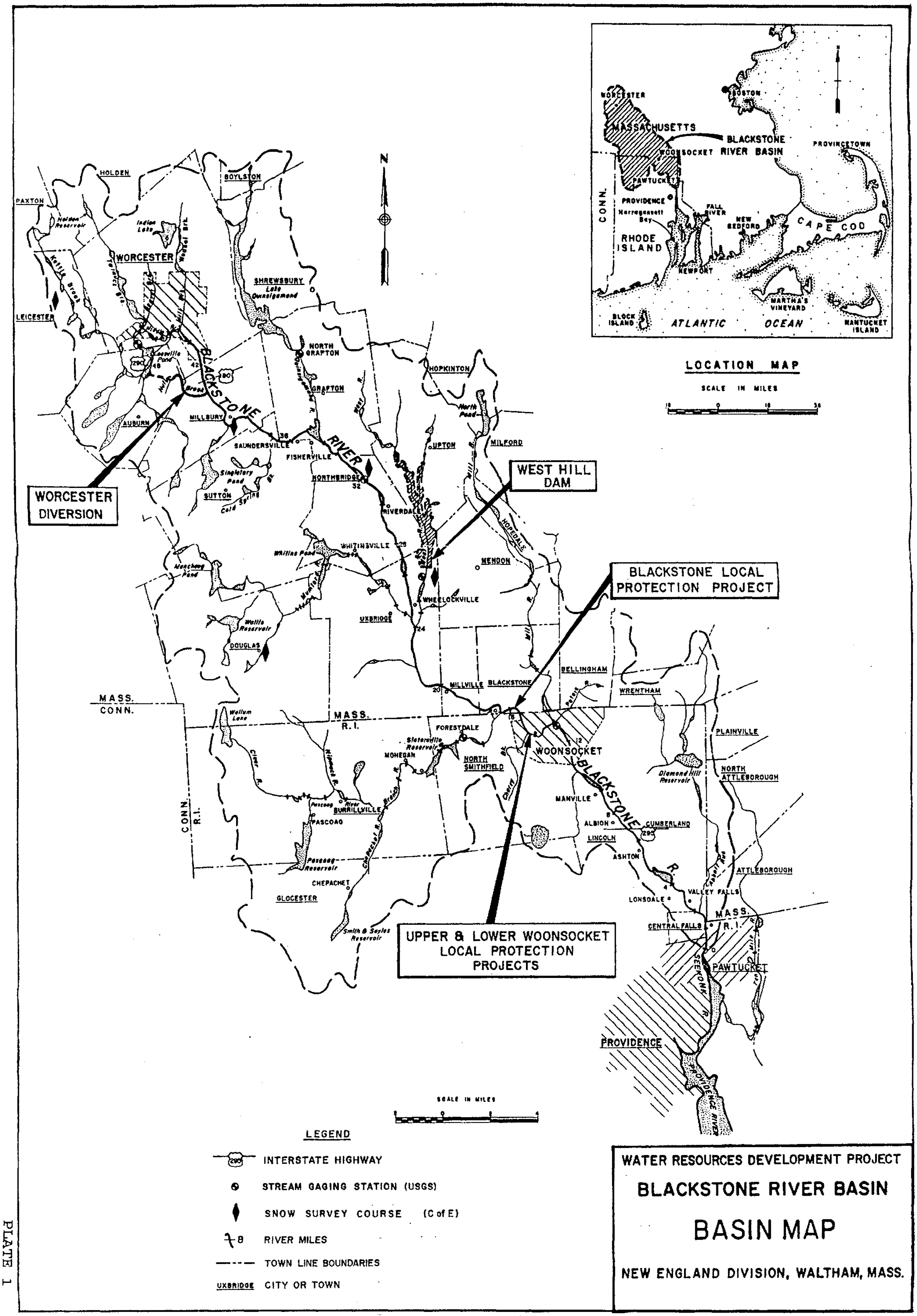

WATER RESOURCES DEVELOPMENT PROJECT
BLACKSTONE RIVER BASIN
BASIN MAP
NEW ENGLAND DIVISION, WALTHAM, MASS.
LOCATION MAP
SCALE IN MILES
WORCESTER
MASSACHUSETTS
BOSTON
BLACKSTONE RIVER BASIN
WOONSOCKET
PAWTUCKET
PROVIDENCE
Narragansett Bay
FALL RIVER
NEW BEDFORD
PROVINCETOWN
CAPE COD
CONN.
RHODE ISLAND
NEWPORT
BLOCK ISLAND
ATLANTIC
OCEAN
MARTHA'S VINEYARD
NANTUCKET ISLAND
N
WORCESTER DIVERSION
WEST HILL DAM
BLACKSTONE LOCAL PROTECTION PROJECT
UPPER & LOWER WOONSOCKET LOCAL PROTECTION PROJECTS
BLACKSTONE RIVER
HOLDEN
PAXTON
BOYLSTON
LEICESTER
WORCESTER
SHREWSBURY
Lake Quinsigamond
NORTH GRAFTON
GRAFTON
HOPKINTON
AUBURN
MILLBURY
SAUNDERSVILLE
FISHERVILLE
NORTHBRIDGE
UPTON
MILFORD
SUTTON
RIVERDALE
HOPEDALE
WHITINSVILLE
MENDON
WHEELOCKVILLE
UXBRIDGE
DOUGLAS
BELLINGHAM
MILLVILLE
BLACKSTONE
WRENTHAM
MASS.
CONN.
R.I.
FORESTDALE
PLAINVILLE
WOONSOCKET
NORTH SMITHFIELD
NORTH ATTLEBOROUGH
MOHEGAN
MANVILLE
ALBION
CUMBERLAND
LINCOLN
ASHTON
BURRILLVILLE
PASCOAG
CHEPACHET
GLOCESTER
ATTLEBOROUGH
VALLEY FALLS
LONSDALE
CENTRAL FALLS
PAWTUCKET
PROVIDENCE
SCALE IN MILES
LEGEND
INTERSTATE HIGHWAY
STREAM GAGING STATION (USGS)
SNOW SURVEY COURSE (C of E)
RIVER MILES
TOWN LINE BOUNDARIES
UXBRIDGE CITY OR TOWN

PLATE 1

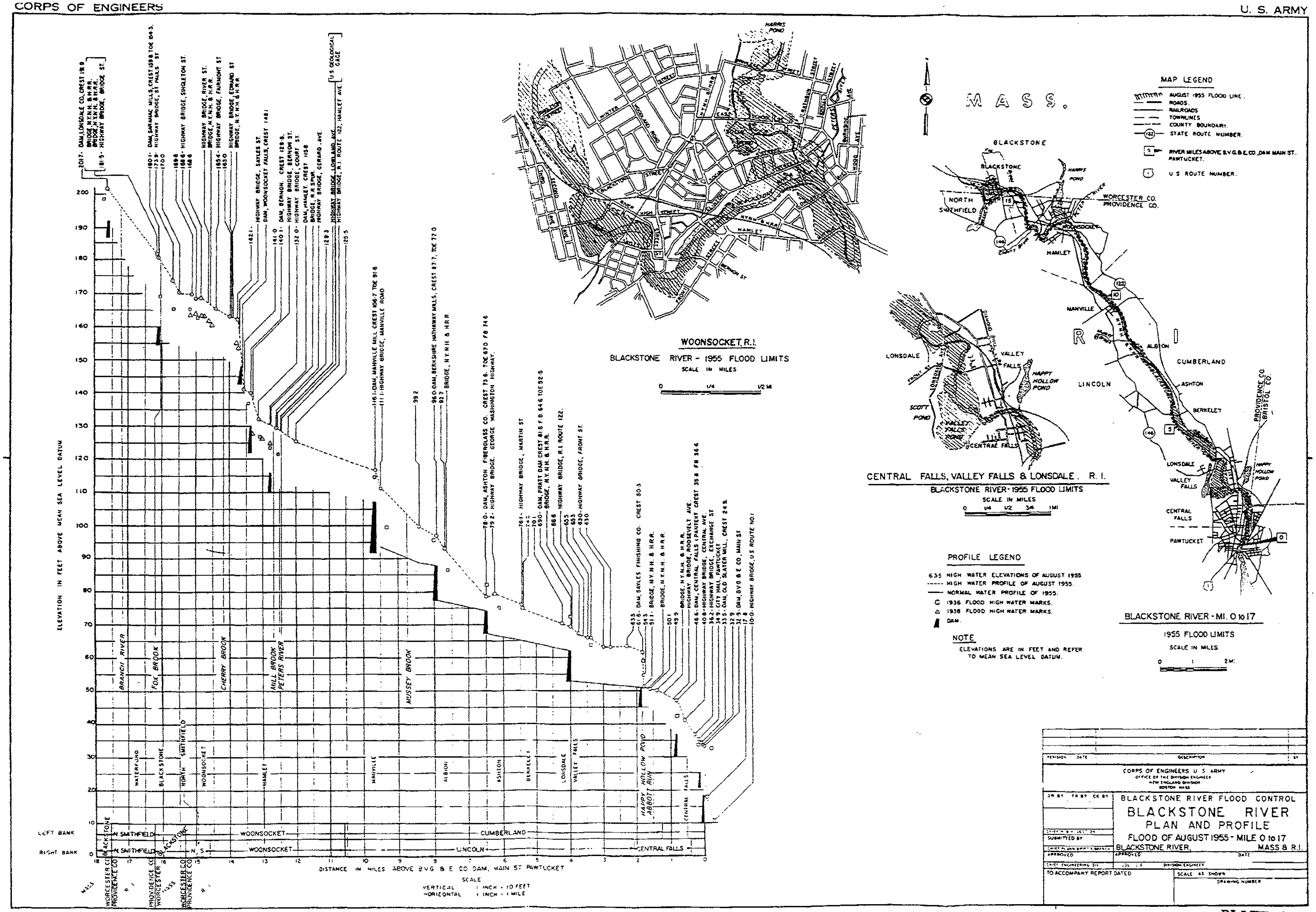

WOONSOCKET, R.I.
BLACKSTONE RIVER - 1955 FLOOD LIMITS
SCALE IN MILES
CENTRAL FALLS, VALLEY FALLS & LONSDALE, R. I.
BLACKSTONE RIVER - 1955 FLOOD LIMITS
SCALE IN MILES
MASS.
R. I.
MAP LEGEND
AUGUST 1955 FLOOD LINE.
ROADS.
RAILROADS
TOWNLINES
COUNTY BOUNDARY.
STATE ROUTE NUMBER.
RIVER MILES ABOVE B.V.G.& E.CO.,DAM MAIN ST. PAWTUCKET.
U S ROUTE NUMBER.
BLACKSTONE
NORTH SMITHFIELD
WORCESTER CO.
PROVIDENCE CO.
HAMLET
MANVILLE
ALBION
CUMBERLAND
LINCOLN
ASHTON
BERKELEY
LONSDALE
VALLEY FALLS
CENTRAL FALLS
PAWTUCKET
PROVIDENCE CO.
BRISTOL CO.
BLACKSTONE RIVER - MI. 0 to 17
1955 FLOOD LIMITS
SCALE IN MILES
PROFILE LEGEND
63.5 HIGH WATER ELEVATIONS OF AUGUST 1955.
HIGH WATER PROFILE OF AUGUST 1955.
NORMAL WATER PROFILE OF 1955.
1936 FLOOD HIGH WATER MARKS.
1938 FLOOD HIGH WATER MARKS.
DAM.
NOTE
ELEVATIONS ARE IN FEET AND REFER TO MEAN SEA LEVEL DATUM.
ELEVATION IN FEET ABOVE MEAN SEA LEVEL DATUM
BRANCH RIVER
FOX BROOK
CHERRY BROOK
MILL BROOK
PETERS RIVER
MUSSEY BROOK
HAPPY HOLLOW POND
ABBOT RUN
LEFT BANK
RIGHT BANK
WOONSOCKET
CUMBERLAND
LINCOLN
CENTRAL FALLS
DISTANCE IN MILES ABOVE B.V.G. & E. CO. DAM, MAIN ST. PAWTUCKET
SCALE
VERTICAL 1 INCH = 10 FEET
HORIZONTAL 1 INCH = 1 MILE
CORPS OF ENGINEERS U. S. ARMY
BLACKSTONE RIVER FLOOD CONTROL
BLACKSTONE RIVER
PLAN AND PROFILE
FLOOD OF AUGUST 1955 - MILE 0 to 17
BLACKSTONE RIVER, MASS & R.I.
TO ACCOMPANY REPORT DATED
SCALE AS SHOWN

PLATE 2

CORPS OF ENGINEERS

U. S. ARMY

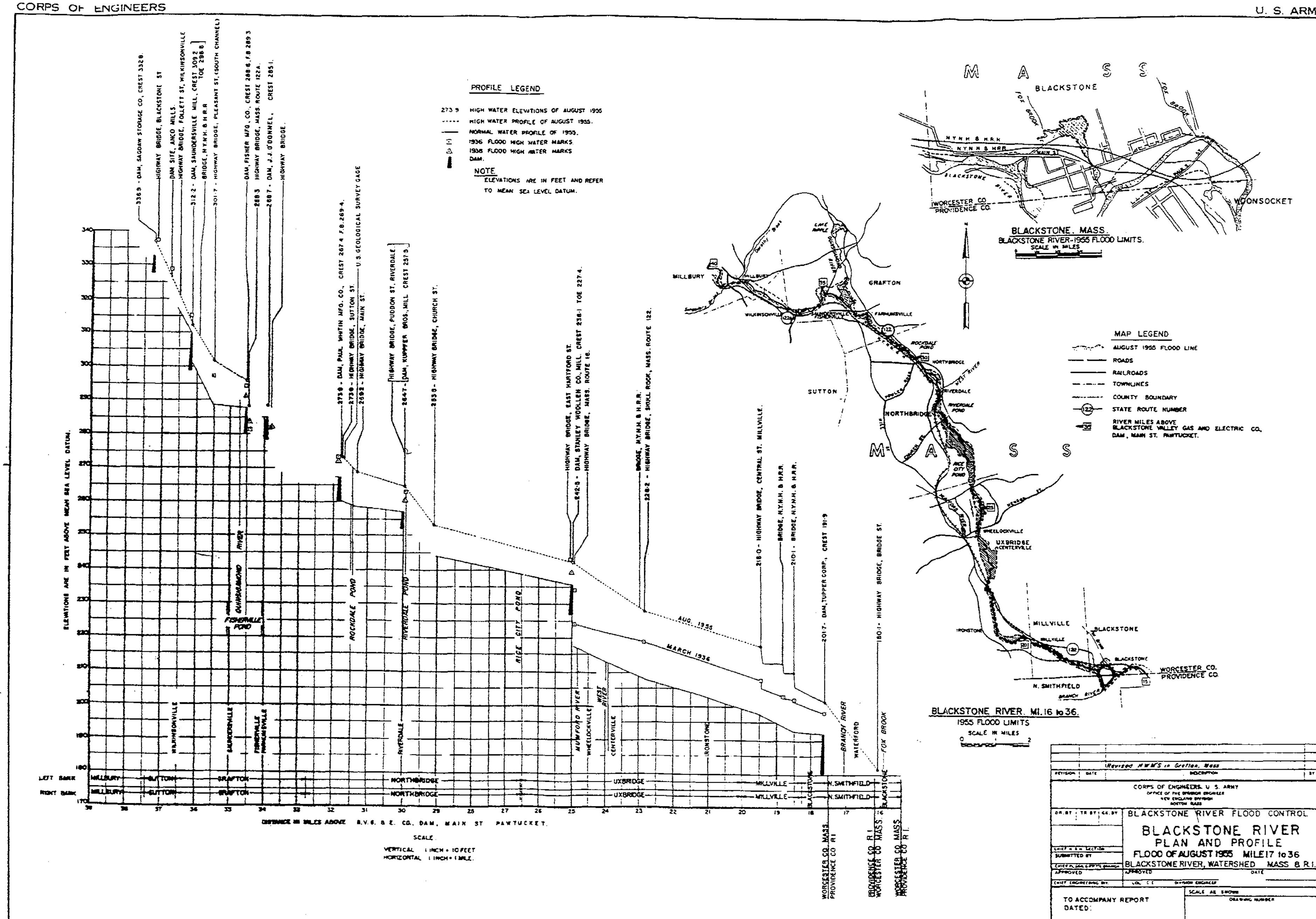
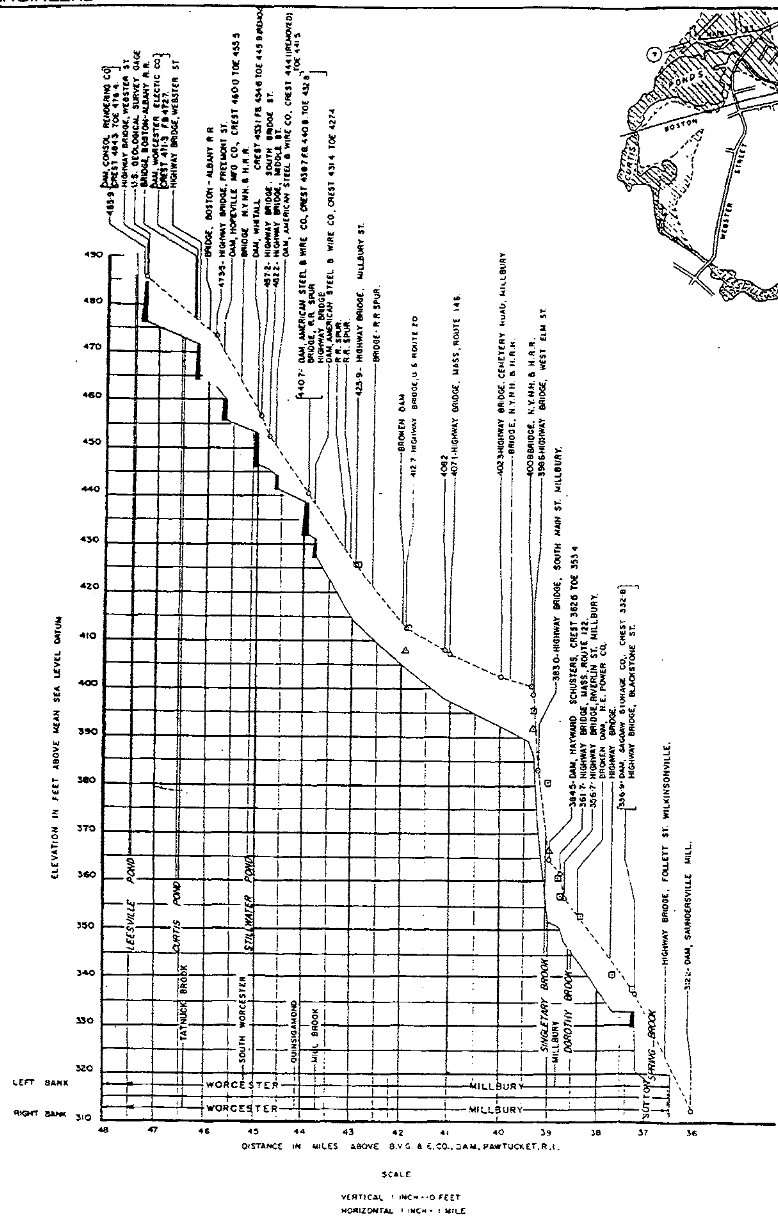
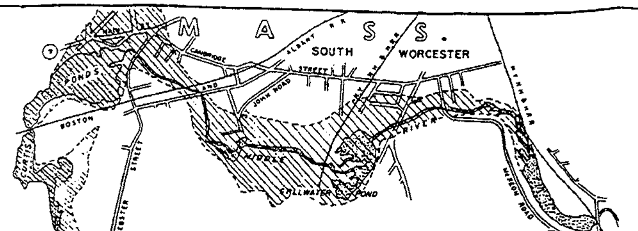


PLATE 3





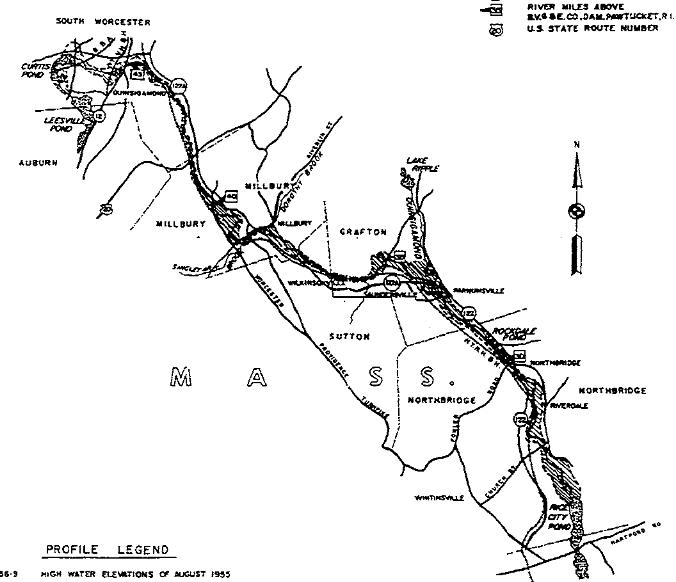
WEBSTER STREET AREA, STH. WORCESTER

BLACKSTONE RIVER - 1955 FLOOD LIMITS.

SCALE IN MILES

MAP LEGEND

- AUGUST 1955 FLOOD LINE
- ROADS
- RAILROADS
- TOWN LINES
- COUNTY BOUNDARY
- STATE ROUTE NUMBER
- RIVER MILES ABOVE B.V.G & E.CO. DAM, PAWTUCKET, R.I.
- U.S. STATE ROUTE NUMBER



PROFILE LEGEND

- 336.9 HIGH WATER ELEVATIONS OF AUGUST 1955
- HIGH WATER PROFILE OF AUGUST 1955.
- NORMAL WATER PROFILE OF 1955
- 1936 FLOOD HIGH WATER MARKS.
- 1938 FLOOD HIGH WATER MARKS.
- DAM.

NOTE

ELEVATIONS ARE IN FEET AND REFER TO MEAN SEA LEVEL DATUM.

BLACKSTONE RIVER - MI. 36 to 48

1955 FLOOD LIMITS

SCALE IN MILES

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
BOSTON, MASS.

BLACKSTONE RIVER FLOOD CONTROL

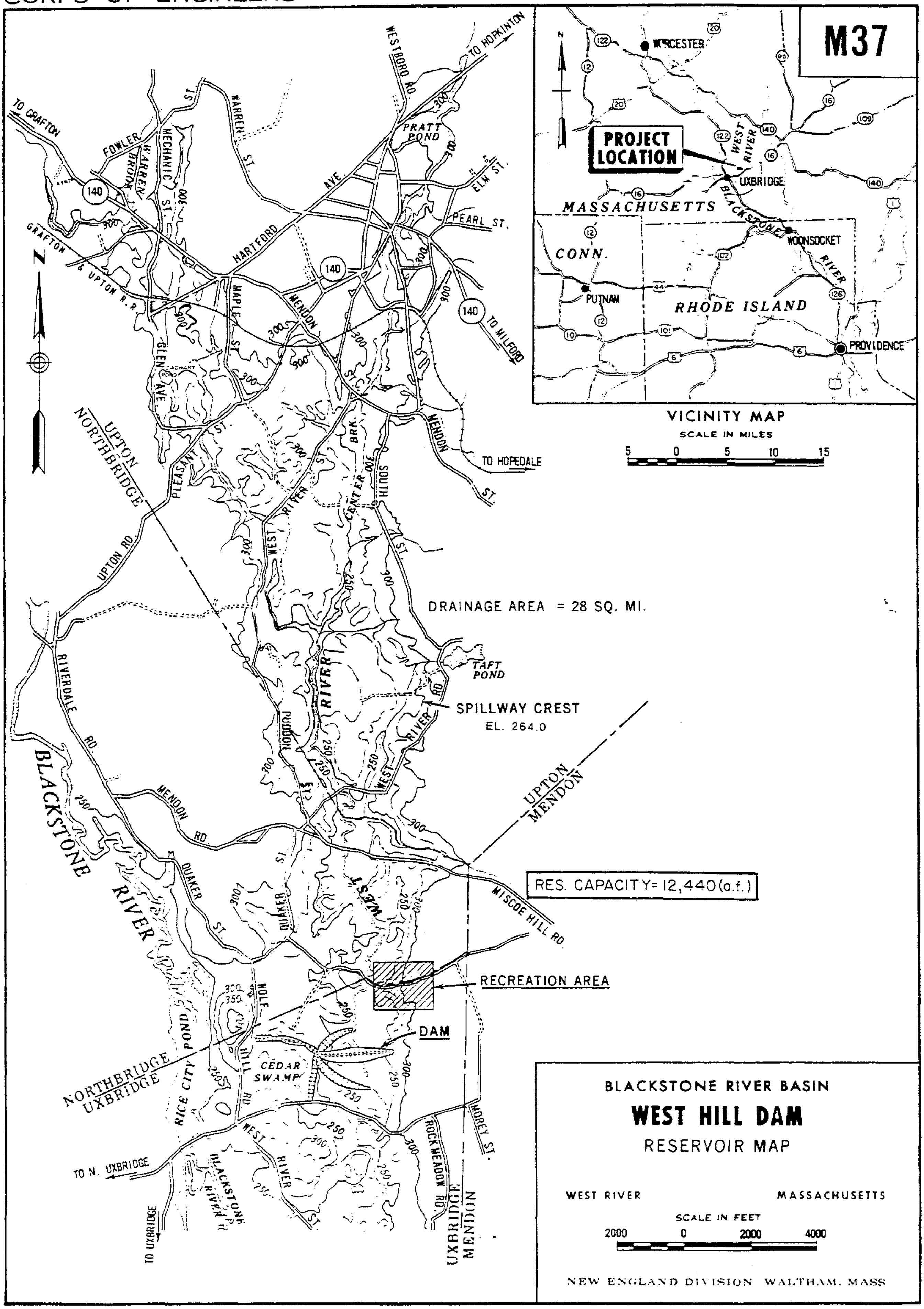
BLACKSTONE RIVER
PLAN AND PROFILE
FLOOD OF AUGUST 1955 - MILE 36 to 48

BLACKSTONE RIVER — MASS & R.I.

SCALE: AS SHOWN

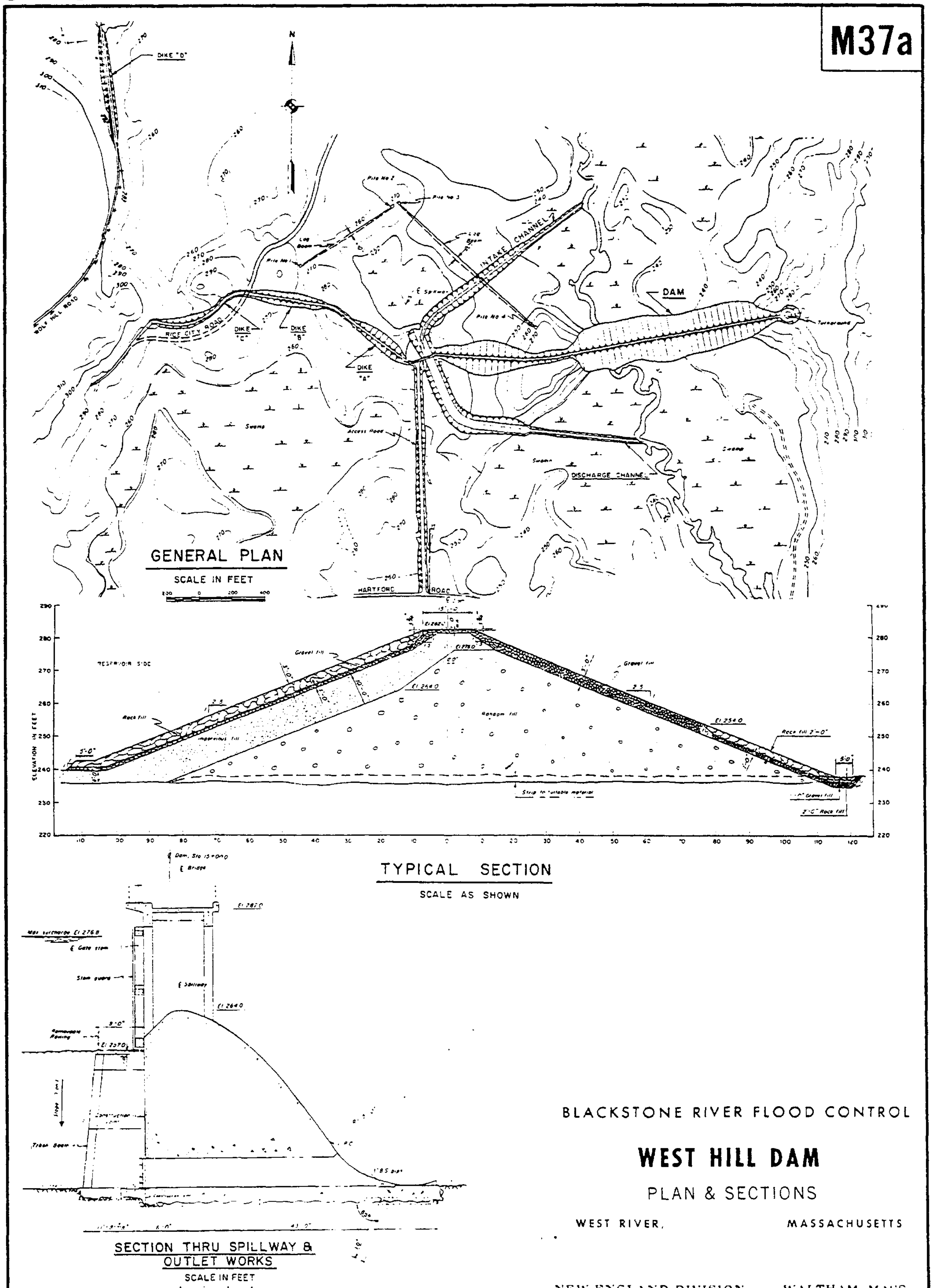
TO ACCOMPANY REPORT
DATED:

PLATE 4


M37
PROJECT LOCATION
WORCESTER
UXBRIDGE
WOONSOCKET
PUTNAM
PROVIDENCE
MASSACHUSETTS
CONN.
RHODE ISLAND
WEST RIVER
BLACKSTONE RIVER
VICINITY MAP
SCALE IN MILES
5 0 5 10 15
TO GRAFTON
TO HOPKINTON
TO MILFORD
TO HOPEDALE
TO N. UXBRIDGE
TO UXBRIDGE
PRATT POND
TAFT POND
CEDAR SWAMP
RICE CITY POND
DRAINAGE AREA = 28 SQ. MI.
SPILLWAY CREST
EL. 264.0
RES. CAPACITY= 12,440 (a.f.)
RECREATION AREA
DAM
UPTON NORTHBRIDGE
UPTON MENDON
NORTHBRIDGE UXBRIDGE
UXBRIDGE MENDON
BLACKSTONE RIVER
WEST RIVER
BLACKSTONE RIVER BASIN
WEST HILL DAM
RESERVOIR MAP
WEST RIVER
MASSACHUSETTS
SCALE IN FEET
2000 0 2000 4000
NEW ENGLAND DIVISION WALTHAM, MASS

CORPS OF ENGINEERS U. S. ARMY

M37a



BLACKSTONE RIVER FLOOD CONTROL

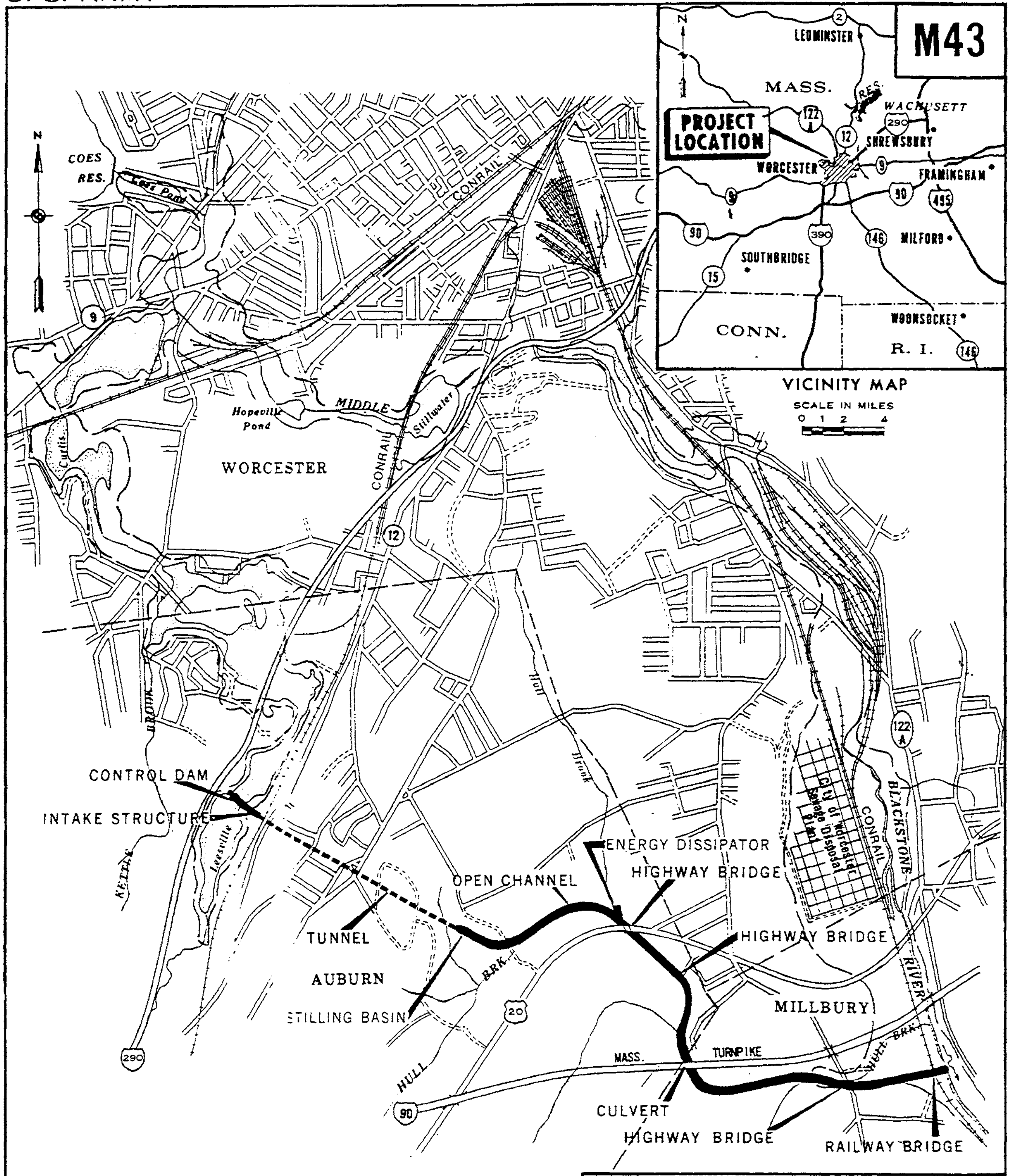
WEST HILL DAM

PLAN & SECTIONS

WEST RIVER, MASSACHUSETTS

NEW ENGLAND DIVISION WALTHAM, MASS.

U. S. ARMY CORPS OF ENGINEERS



BLACKSTONE RIVER FLOOD CONTROL

WORCESTER DIVERSION

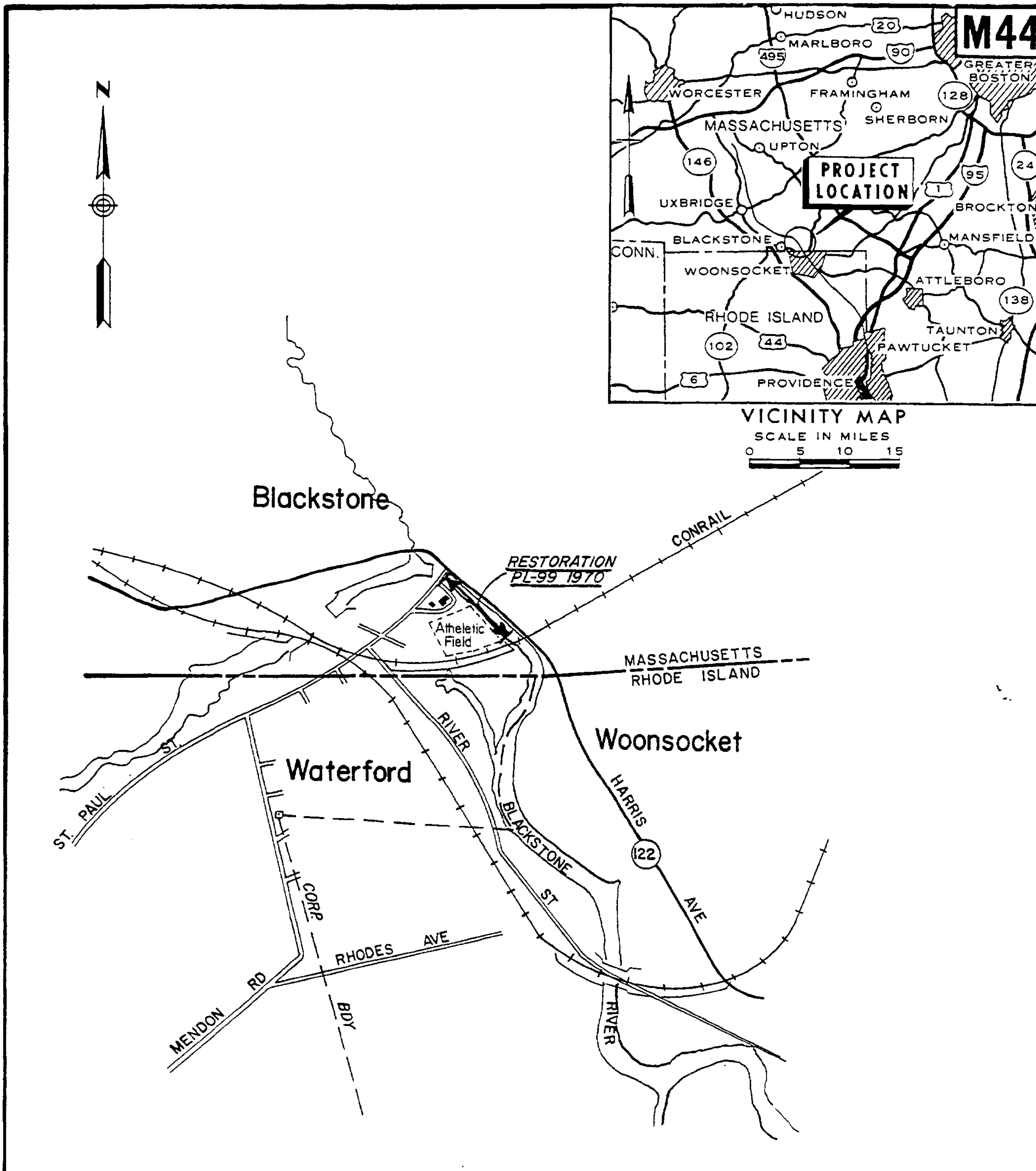
LOCAL PROTECTION PROJECT

GENERAL PLAN

BLACKSTONE RIVER MASSACHUSETTS

SCALE IN FEET
1000 0 1000 2000

NEW ENGLAND DIVISION WALTHAM, MASS.



BLACKSTONE RIVER BASIN
FLOOD CONTROL PROJECT

BLACKSTONE RIVER, BLACKSTONE, MA.

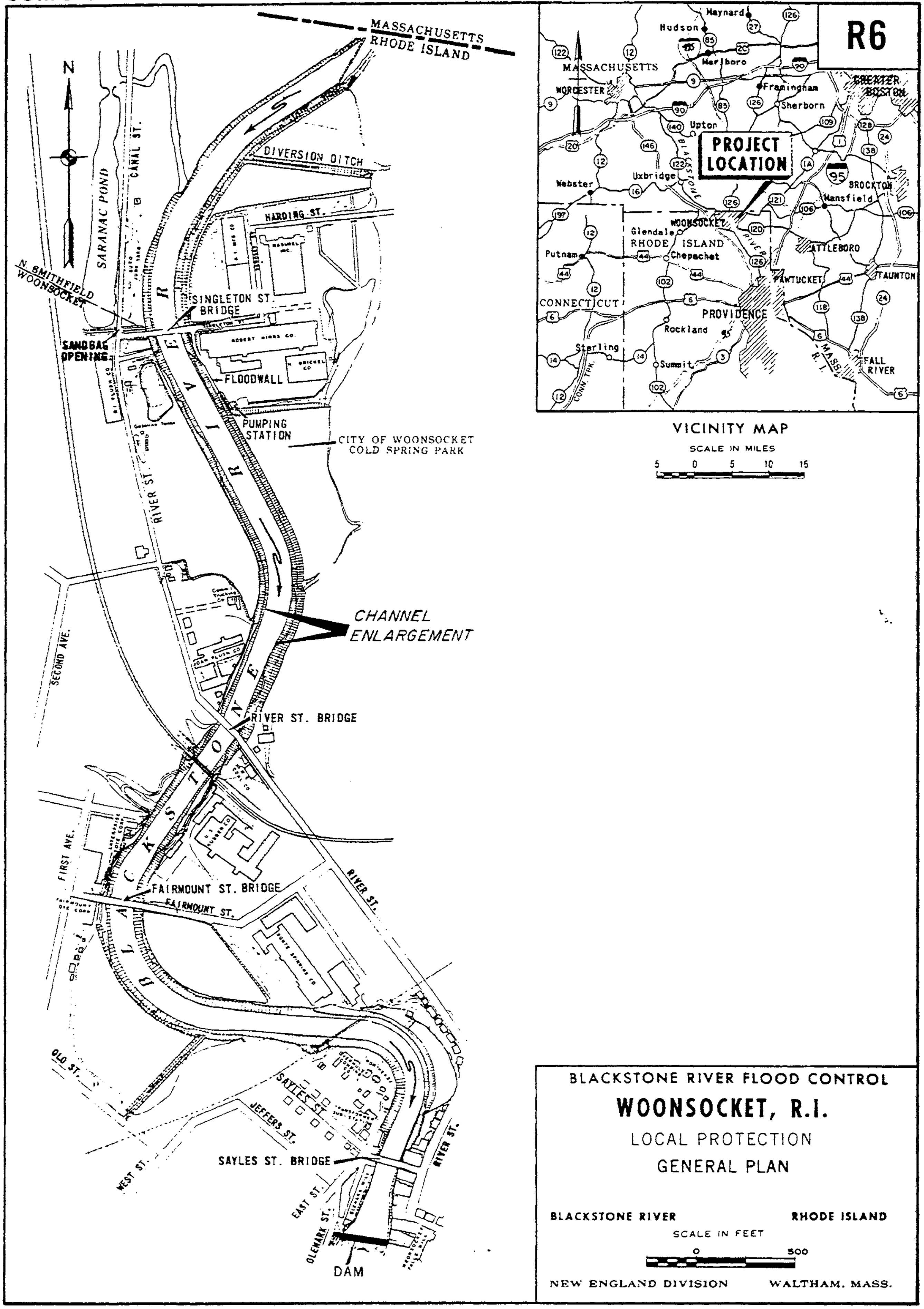
EMERGENCY FLOOD CONTROL PROJECT
NOT SPECIFICALLY AUTHORIZED BY CONGRESS

BLACKSTONE RIVER — MASSACHUSETTS

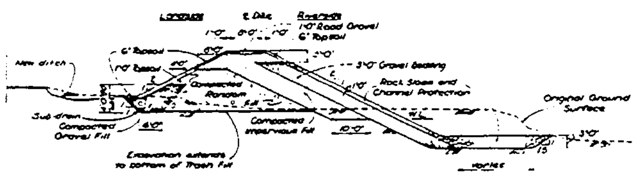
SCALE IN FEET (APPROX.)
1000' 0 1000'

NEW ENGLAND DIVISION — WALTHAM MA.

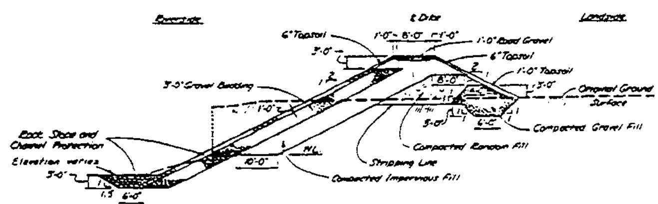
PLATE 8


R6
MASSACHUSETTS
RHODE ISLAND
N
SARANAC POND
CANAL ST.
DIVERSION DITCH
HARDING ST.
N. SMITHFIELD
WOONSOCKET
SINGLETON ST. BRIDGE
SANDBAG OPENING
FLOODWALL
PUMPING STATION
CITY OF WOONSOCKET COLD SPRING PARK
RIVER ST.
BLACKSTONE RIVER
CHANNEL ENLARGEMENT
SECOND AVE.
RIVER ST. BRIDGE
FIRST AVE.
FAIRMOUNT ST. BRIDGE
FAIRMOUNT ST.
OLD ST.
SAYLES ST.
JEFFERS ST.
WEST ST.
SAYLES ST. BRIDGE
EAST ST.
OLEMARK ST.
DAM
PROJECT LOCATION
MASSACHUSETTS
WORCESTER
Hudson
Maynard
Marlboro
Framingham
Sherborn
GREATER BOSTON
Upton
Webster
Uxbridge
BLACKSTONE RIVER
BROCKTON
Mansfield
WOONSOCKET
Glendale
RHODE ISLAND
Chepachet
Putnam
ATTLEBORO
PAWTUCKET
TAUNTON
CONNECTICUT
PROVIDENCE
Rockland
Sterling
Summit
CONN. TPK.
MASS.
R.I.
FALL RIVER
VICINITY MAP
SCALE IN MILES
5 0 5 10 15
BLACKSTONE RIVER FLOOD CONTROL
WOONSOCKET, R.I.
LOCAL PROTECTION
GENERAL PLAN
BLACKSTONE RIVER
RHODE ISLAND
SCALE IN FEET
0 500
NEW ENGLAND DIVISION
WALTHAM, MASS.

R2



TYPICAL SECTION - SOCIAL DISTRICT DIKE



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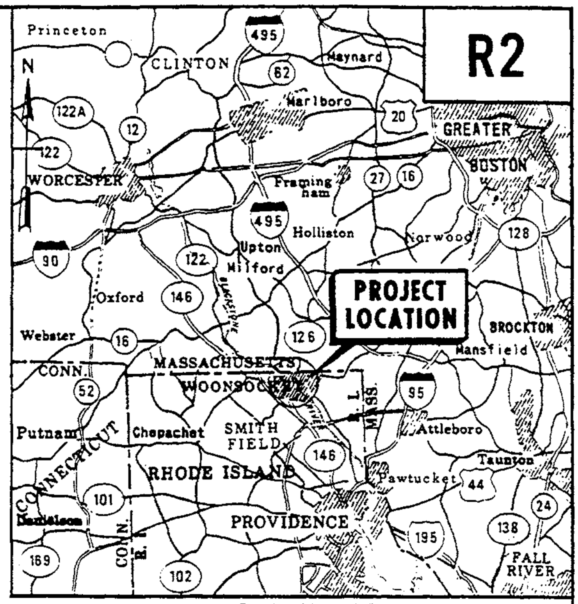
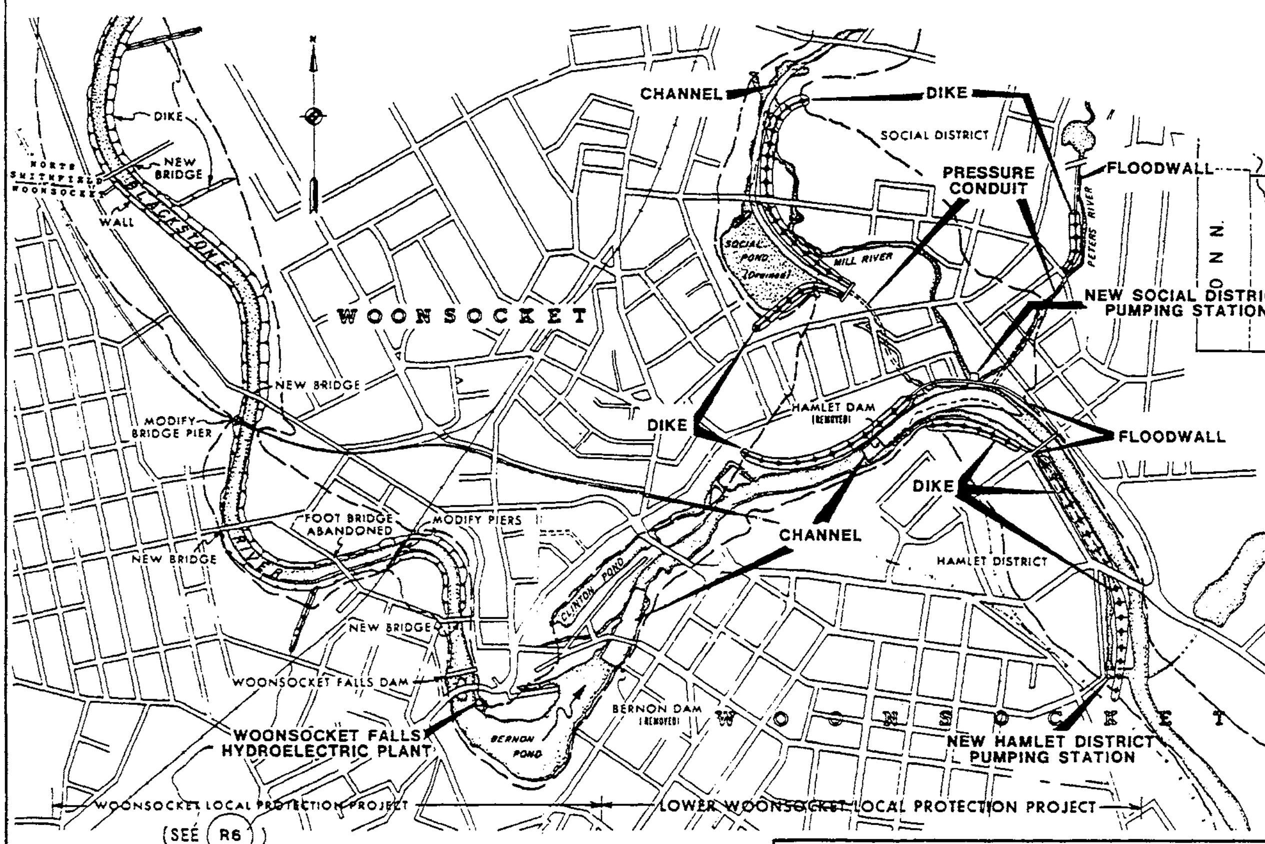


VICINITY MAP

SCALE IN MILES

5 0 5 10



LEGEND

APPROXIMATE LIMITS OF AUGUST 1955 FLOOD

BLACKSTONE RIVER FLOOD CONTROL

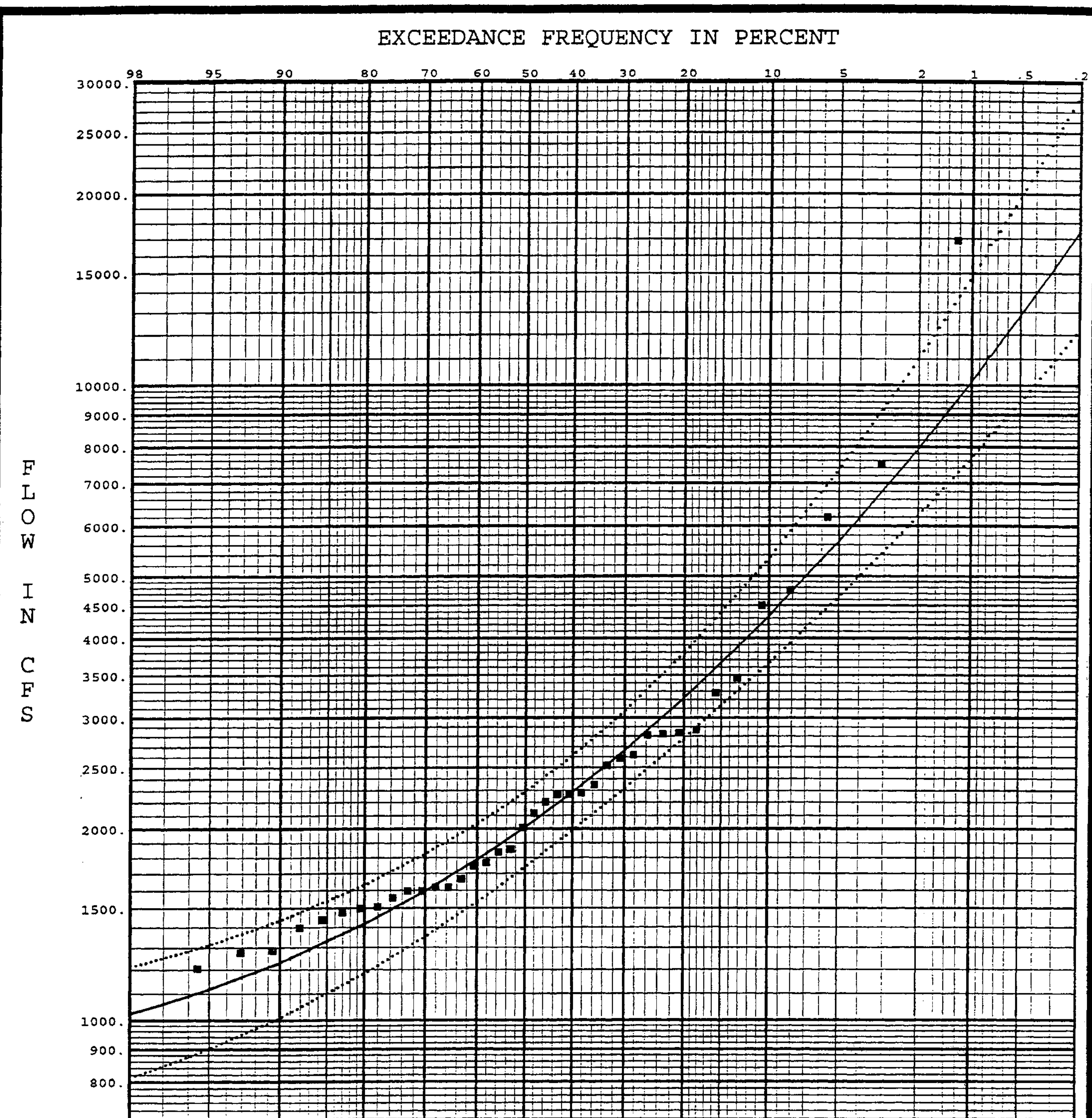
LOWER WOONSOCKET
LOCAL PROTECTION PROJECT

PROJECT PLAN

BLACKSTONE, MILL & PETERS RIVERS, RHODE ISLAND

SCALE IN FEET
300 0 300 600 900 1200

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.



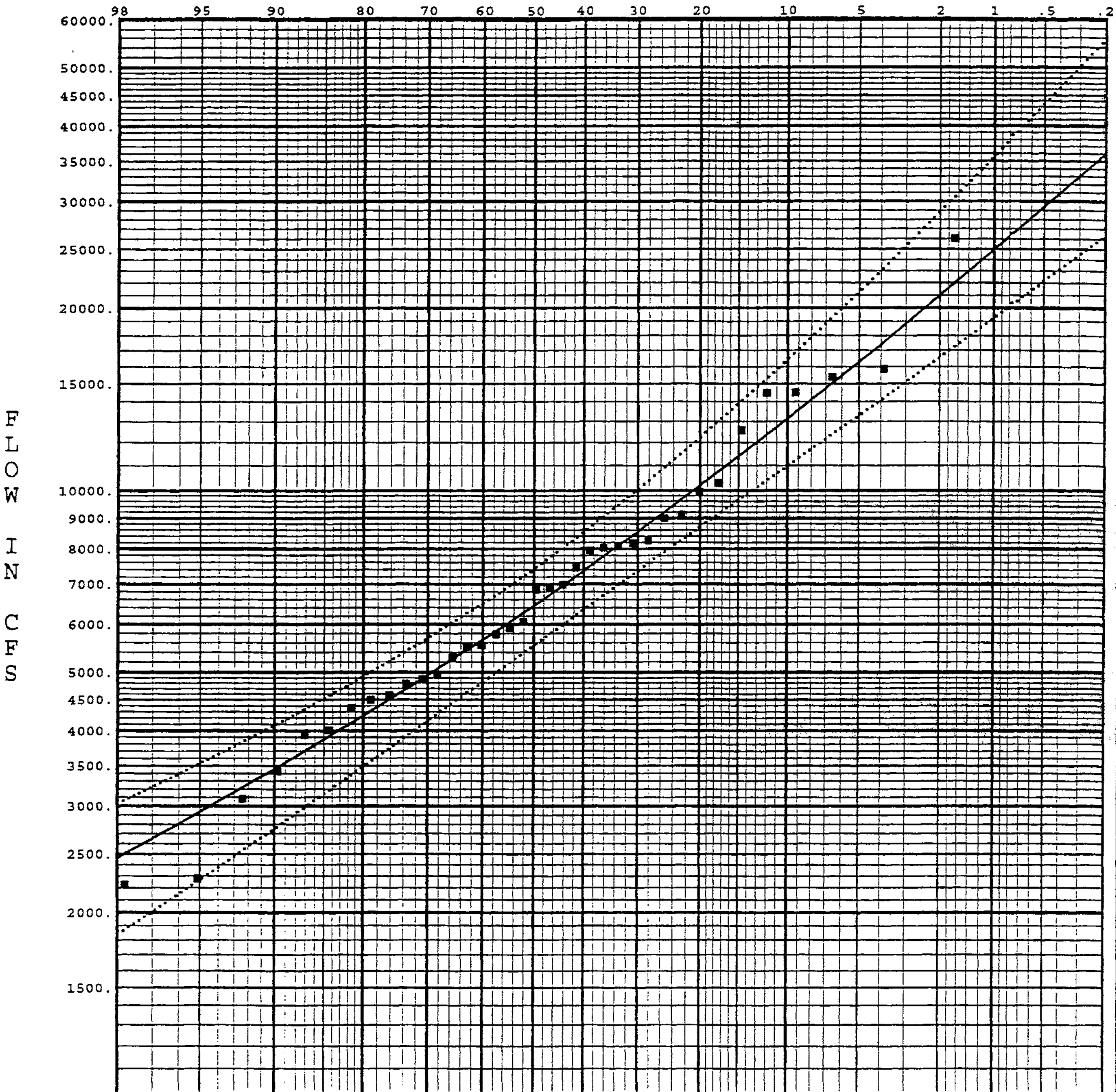
—— FLOW Frequency (without Exp. Prob.)
■ Weibull Plotting Positions
······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS

		NUMBER OF EVENTS	
MEAN	3.3395	HISTORIC EVENTS	1
STANDARD DEV	.2208	HIGH OUTLIERS	0
SKEW	1.2343	LOW OUTLIERS	0
REGIONAL SKEW	.7000	ZERO OR MISSING	0
ADOPTED SKEW	1.0000	SYSTEMATIC EVENTS	39
		HISTORIC PERIOD(1900-1979)	80

FLOOD FLOW FREQUENCY
BLACKSTONE RIVER
AT NORTHBRIDGE, MA
BASIN AREA = 141 SQ MI
WATER YEARS IN RECORD
1936,1940-1977,1979

EXCEEDANCE FREQUENCY IN PERCENT



—— FLOW Frequency (without Exp. Prob.)
■ Weibull Plotting Positions
.... 5% and 95% Confidence Limits

FREQUENCY STATISTICS

LOG TRANSFORM OF FLOW, CFS		NUMBER OF EVENTS	
MEAN	3.8206	HISTORIC EVENTS	1
STANDARD DEV	.2269	HIGH OUTLIERS	0
SKEW	.1248	LOW OUTLIERS	0
REGIONAL SKEW	.7000	ZERO OR MISSING	0
ADOPTED SKEW	.3000	SYSTEMATIC EVENTS	36
		HISTORIC PERIOD(1936-1994)	59

FLOOD FLOW FREQUENCY
BLACKSTONE RIVER
AT WOONSOCKET, RI
BASIN AREA = 416 SQ MI
WATER YEARS IN RECORD
1936,1938,1955,1961-1994

APPENDIX I - FISHERVILLE POND RISK CHARACTERIZATION

FISHERVILLE POND PRELIMINARY BASELINE ECOLOGICAL AND HUMAN HEALTH RISK CHARACTERIZATION

Submitted to:

Department of the Army
U.S. Army Corps of Engineers
New England Division

Contract No. DACW33-96-005

April 1997

Prepared by:

McLaren/Hart Environmental Engineering Corporation
25 Independence Boulevard
Warren, New Jersey 07059
(908) 647-8111

Under Contract To:

Battelle Ocean Sciences
397 Washington Street
Duxbury, Massachusetts 02332-0601
(617) 934-0571

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Note: The Benthic Invertebrate Survey (Appendix E) is included in the "Environmental Resources" Appendix of this report. Other appendices to the Preliminary Baseline Risk Characterization Report are on file with New England District, U.S. Army Corps of Engineers, 424 Trapelo Rd. Waltham, MA. 02254

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACOE	Army Corps of Engineers
ARARs	Applicable, Relevant, and Appropriate Requirements
AWQC	Ambient Water Quality Criteria
AVS	Acid Volatile Sulfide
BCF	Bioconcentration Factor
BEDS	Biological Effects Database for Sediments
BRI	Blackstone River Initiative
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COCs	Chemicals of Concern
COPECs	Chemicals of Potential Ecological Concern
CSFs	Cancer Slope Factors
DO	Dissolved Oxygen
EC20	Effective Concentration for 20 %
EC25	Effective Concentration for 25 %
ERC	Ecological Risk Characterization
HEAST	Health Effects Assessment Summary Table
HHRC	Human Health Risk Characterization
HI	Hazard Index
HQ	Hazard Quotient
IEUBk	Integrated Exposure Uptake and Biokinetic Model
IRIS	Integrated Risk Information System
K_d	Distribution Coefficient
K_{ow}	Octanol Water Partitioning Coefficient
LCV	Lowest Chronic Value
LD50	Lethal Dose for 50 % of the population
LEL	Lowest Effect Level
LMS	Linear Multistage
LOAEL	Lowest Observed Adverse Effects Levels
LOEC	Lowest Observed Effect Concentration
LPIL	Lowest Practical Identification Level
MA DEP	Massachusetts Department of Environmental Protection
MCLs	Maximum Contaminant Levels
MCP	Massachusetts Contingency Plan
MOE	Ministry of Environment
NED	New England Division
NCP	National Contingency Plan
NH_3	Ammonia
NO_3	Nitrate

LIST OF ACRONYMS (continued)

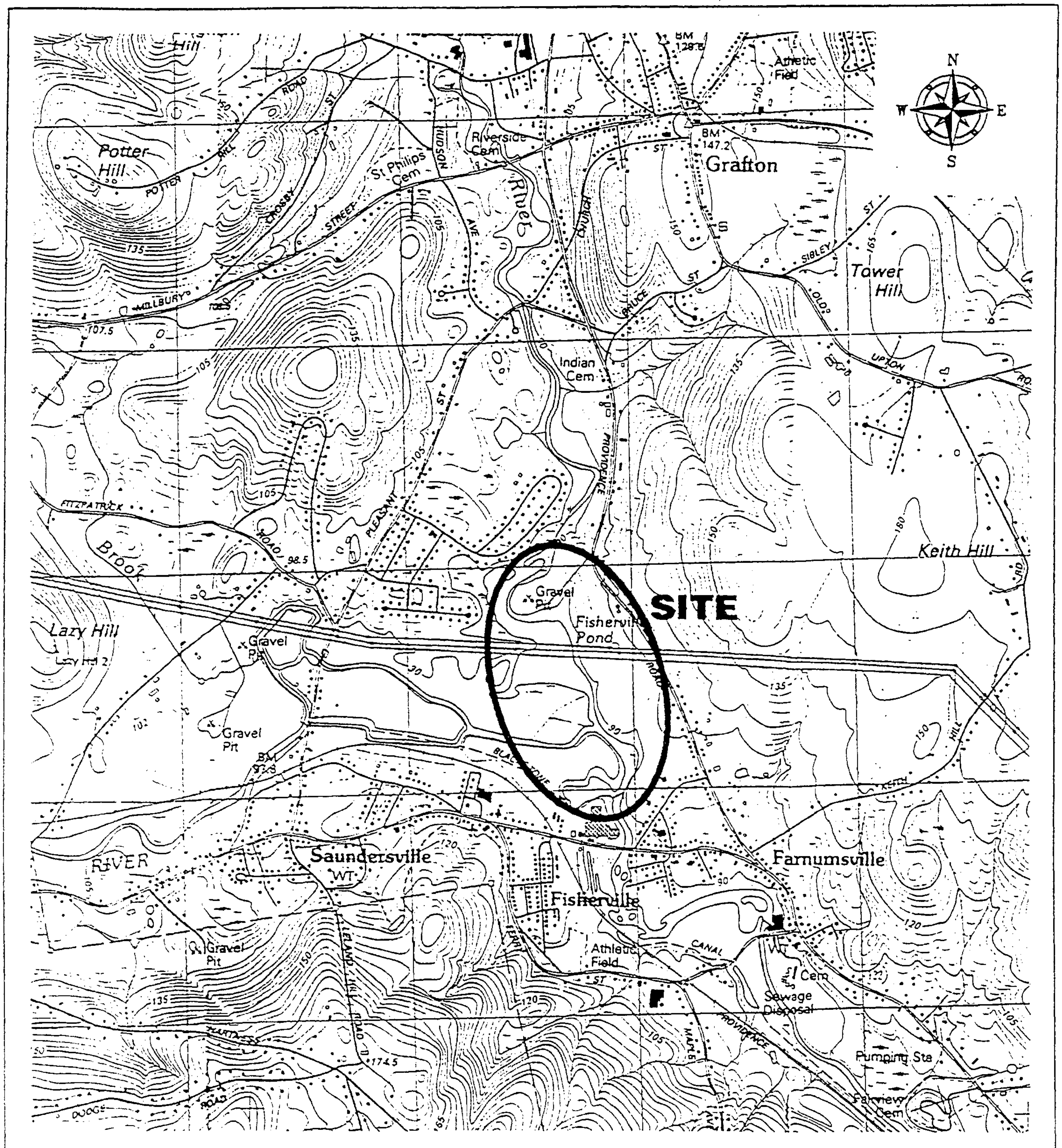
NOAEL	No Observed Adverse Effects Levels
NOEC	No Observed Effect Concentration
NPS	National Park Service
ORNL	Oak Ridge National Laboratory
PCBs	Polychlorinated Biphenyls
PAHs	Polycyclic Aromatic Hydrocarbons
PEL	Probable Effects Level
PO_4	Phosphate
QA/QC	Quality Assurance/Quality Control
RBCs	Risk-Based Concentrations
RFDs	Reference Doses
RfC	Reference Concentration
RME	Reasonable Maximum Exposure
SEL	Severe Effects Level
SEM	Simultaneously Extracted Metals
SCV	Secondary Chronic Value
SLC	Screening Level Concentrations
SSLC	Species Screening Level Concentrations
SSLs	Soil Screening Levels
TC	Toxicity Characteristics
T&E	Threatened and Endangered Species
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TU	Toxic Unit
$\sum$TUs	Sum of Toxic Units
TVS	Total Volatile Sulfide
UCL	Upper Confidence Limit
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
VSS	Volatile Suspended Solids

1.0 INTRODUCTION

McLaren/Hart Environmental Engineering Corporation (McLaren/Hart) has been subcontracted by Battelle to complete a Preliminary Baseline Ecological (ERC) and Human Health Risk Characterization (HHRC) at the Fisherville Pond/Blackstone River System in Grafton, Massachusetts on behalf of the U.S. Army Corps of Engineers (ACOE), New England Division. A site map is included as Figure 1-1.

The purpose of the ERC is to provide an estimation of the ecological risks to the aquatic and terrestrial environment associated with contaminants in Fisherville Pond and Blackstone River sediments and surface water. The purpose of the HHRC is to provide an estimation of human health risks associated with the use of Fisherville Pond by children and adult recreational users. MADEP and USEPA guidance, both composed of a tiered approach involving sequentially more sophisticated and complex evaluations, were used as appropriate (given acknowledged data limitations and gaps) to assess current and future risk associated with exposure to contaminants under baseline conditions. These conditions assume that no actions are taken to remove contaminants and/or prevent their migration.

The aquatic ecosystem to be evaluated in this assessment includes Fisherville Pond and a portion of the Blackstone River above the Fisherville Dam. The ERC and HHRC were developed utilizing chemical and biological data collection from: chemical analyses of surface water, pore water, sediment and fish tissue; sediment and surface water ambient toxicity tests; or fish and benthic macroinvertebrate community surveys. The data utilized in the completion of the ERC and HHRC are presented in Appendix A. The types of data are summarized below in Table 1-1. The source of the data and the year in which the data were collected are also provided. Figure 1-2 identifies the sampling locations utilized in the collection of the data.



SOURCE: USGS QUADRANGLE (MILFORD, MA)

FIGURE 1-1	
SITE LOCATION MAP FOR THE FISHERVILLE POND/BLACKSTONE RIVER SYSTEM	
BATTELLE OCEAN SCIENCES GRAFTON, MASSACHUSETTS	
McLaren Hart® ENVIRONMENTAL ENGINEERING CORPORATION	
DRWN: S.F.H.	CHK'D: S.S.
SCALE: AS SHOWN	DATE: 01/27/97

FIGURE 1-2

SITE LAYOUT AND SAMPLING LOCATIONS FOR RISK CHARACTERIZATION OF FISHERVILLE POND

BATTELLE OCEAN SCIENCES
GRAFTON, MASSACHUSETTS

McLaren Hart® ENVIRONMENTAL ENGINEERING CORPORATION

DRWN: S.F.H.	CHK'D: S.S.
SCALE: NONE	DATE: 04/21/97

Table 1-1: Data Utilized for the Preliminary Baseline ERC and HRC

Media/Type of Data	Date Collected	Source [a]
Surface Water (Dry Weather)		
Total and Dissolved Metals	1991	BRI (1996)
Chronic Toxicity Tests (Fathead Minnow [*Pimephales promelas*] and *Ceriodaphnia dubia*)	1991	BRI (1996)
Physical Parameters: Total suspended solids (TSS) and dissolved oxygen (DO)	1991	BRI (1996)
Fecal coliform	1991	BRI (1996)
Surface Water (Wet Weather)		
Total Metals	1992/1993	BRI (1996)
Chronic Toxicity Tests (Fathead Minnows and *Ceriodaphnia dubia*)	1992/1993	BRI (1996)
Physical Parameters: TSS and DO	1992/1993	BRI (1996)
Fecal coliform and *Escherichia coli*	1992/1993	BRI (1996)
Sediment		
Metals	1981	McGinn (1981)
10 Day Whole Sediment Toxicity Tests (*Hyallela azteca* and *Chironomous tentans)*	1991	BRI (1996)
Polycyclic aromatic hydrocarbons (PAHs)	1991	BRI (1996)
Total organic carbon (TOC)	1996	ACOE (1996a)
Acid volatile sulfide/simultaneously extracted metals (AVS/SEM)	1996	ACOE (1996a)
Total volatile sulfide (TVS)	1981	McGinn (1981)
Grain size (% gravel, % sand, % silt)	1981	McGinn (1981).
Grain size	1996	ACOE (1996a)

Table 1-1 (Continued)

Media/Type of Data	Date Collected	Source [a]
Semivolatiles, polychlorinated biphenyls (PCBs), PAHs	1994	Snook (1995)
Pore Water		
Total Metals	1991	BRI (1996)
48 Hour Toxicity Tests (Fathead Minnow and *Ceriodaphnia dubia*)	1991	BRI (1996)
Fish Filets		
Metals	1992/1993	BRI (1996)
Pesticides (detected, but no concentrations provided)	1992/1993	BRI (1996)
PCBs	1992/1993	BRI (1996)
Benthic macroinvertebrate Survey	1996	ACOE (1996a)
Fish Survey	1992	MA DFW (1992)
	1996	ACOE (1996a)

[a] BRI: Blackstone River Initiative
MA DEP: Massachusetts Department of Environmental Protection
MA DFW: Massachusetts Division of Fisheries and Wildlife

The ERC is structured following the standard paradigm for risk assessment as proposed by the general framework for ecological risk assessments (USEPA 1992; 1996f). The development of the ERC was also guided by the *Disposal Site Risk Characterization in Support of the Massachusetts Contingency Plan* (MCP) (1995). The ERC consists of the following elements:

- Ecological problem formulation;
- Ecological exposure assessment;
- Ecological effects assessment; and
- Ecological risk characterization.

The HHRC will provide a semi-quantitative risk assessment of the potential human health risk associated with the Fisherville Pond under the no-action scenario. The methodology employed will be consistent with the *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A* (USEPA, 1989a) and *Guidance for Disposal Site Risk Characterization in Support of the MCP* (MA DEP, 1996). In accordance with USEPA guidance, requirements for this assessment will include the following elements:

- Data evaluation;
- Toxicity Assessment;
- Exposure Assessment; and
- Risk characterization.

A detailed discussion of the processes used in the preparation of the ERC and the HHRC is provided in *Fisherville Pond Study Work Plan* (McLaren/Hart, 1996; Appendix B).

1.1 OBJECTIVES AND SCOPE

The objectives and scope of the ERC and the HHRC are presented in Section 1.1.1 and 1.1.2, respectively.

1.1.1 Ecological Risk Characterization

The objective of the ERC is to evaluate the likelihood of impacts to aquatic and terrestrial ecological receptors from the chemicals of potential ecological concern (COPECs) associated with Fisherville Pond and Blackstone River sediments and surface water. The ERC evaluated those site-related COPECs and assessed the magnitude of risks to the ecological resources from contaminated media.

This assessment was performed in two stages. First, chemicals historically detected within the Fisherville Pond/Blackstone River system were screened against ecotoxicological benchmarks to determine COPECs. Second, a more definitive assessment was conducted to estimate the nature and magnitude of ecological risk associated with the presence of COPECs in surface water and sediments. This assessment analyzed the relationship of the estimated exposure to effects with consideration of site-specific conditions such as the physicochemical properties and bioavailability of the chemicals. An evaluation of biological surveys prepared by the ACOE was conducted to determine the current status of fish and benthic macroinvertebrate communities in the river. Toxicity tests results were also evaluated to determine the bioavailability of chemical constituents measured in the media.

To further support the ERC, a field survey of the Fisherville Pond was conducted in October 1996. The objective of the survey was to familiarize McLaren/Hart biologists with the area, and to collect information on the predominant flora and fauna found in the vicinity. All of the described data will be utilized to evaluate the potential risks to the fish, benthic macroinvertebrate communities, amphibians, herbivores, piscivores, and omnivores found in and around Fisherville Pond and a portion of the Blackstone River.

1.1.2 Human Health Risk Characterization

The objective of the HHRC is to evaluate the potential carcinogenic risk and noncarcinogenic hazard associated with human exposure to the chemicals of concern (COCs) detected in surface water, sediment, and fish tissue in the Fisherville Pond/Blackstone River system.

This assessment was performed in two stages. First, chemicals historically detected within the Fisherville Pond/Blackstone River system were compared to chemical-specific to determine the COCs for this evaluation. Second, based on the future recreational use of the area by both children and adults, several exposure pathways were identified and the potential carcinogenic risk and noncarcinogenic hazard was estimated for each COC in each medium.

1.2 ENVIRONMENTAL DESCRIPTION

The purpose of the environmental description is to characterize the receiving ecosystem and identify ecological and human receptors which can or could have been adversely impacted by COPECs from the site. This section will describe the aquatic and terrestrial environment and associated ecological resources based on a review of available literature, visual observations made during the site survey, and discussions with ACOE personnel.

The Fisherville Pond/Blackstone River system consists of various habitat types including shallow open water (< 3 feet), deep open water, wooded riparian zones, emergent/wet meadow wetlands (Wetlands A and B), developed areas, and agricultural fields.

1.2.1 Ecological and Recreational Resources

The valley through which the Blackstone River flows was designated a National Heritage Corridor by the U.S. Congress. Currently, the North American Waterfowl Management Plan considers the Blackstone River an important flyway for migratory waterfowl and one of the last significant black duck (*Anas rubripes*) production areas in Worcester County, Massachusetts.

Prior to the drawdown of the reservoir in the early 1980's, shallow emergent/open water habitat at Fisherville Pond provided important resting and feeding habitat for migratory waterfowl. The emergent vegetation died after the drawdown and has not recolonized the area after restoration of normal water levels. According to H. Heuseman, of the MA Division of Fisheries and Wildlife (DFW), the habitat value of the pond as a staging area for migratory waterfowl declined by 80 percent. The area has limited value as brood habitat due to the lack of potholes and interspersion of open water and emergent habitat. Lack of woody cover or nest boxes along the river also limits the value of the area for wood duck brood production. Therefore, the existing wetland habitat within the Fisherville Pond/Blackstone River system, if enhanced, may be used as a nesting area for the black duck, wood duck, and other waterfowl species. This unique habitat is especially important in Massachusetts since only 7 percent of the ponds contain permanent shallow wetlands.

Although the Fisherville Pond has not been designated as a recreational area, the pond and surrounding vicinity may be utilized for fishing, swimming, and boating. Currently, the area is utilized by local residents for recreational purposes, as evidenced by the many boat ramps and access points on the river and pond (Appendix C, Figure C-1) noted during the field survey. Several boats were observed docked in the area during the October 1996 site visit (Figures C-2 and C-3). The National Park Service (NPS) is also currently developing trails, brochures, recreational and interpretive programs along the river.

1.2.2 Hydrologic Characteristics

Fisherville Pond (Figures C-4 and C-5) is located downstream of the Quinsigamond River, just above the confluence of the Blackstone River (Figure 1-1 and Figure 1-2). Fisherville Dam, a 12 foot high earthen and granite block structure, is located approximately 1,000 ft downstream of the confluence and serves to hold the water for the pond. The entire dam is 650 foot long, and the spillway is 200 feet long (Figure C-6). The pond covers 185 acres and holds 250 acre-feet of water. At the top of the dam, storage is 1360 acre-feet and the drainage area for the Blackstone River above the pond is 134 square miles (BRI, 1996). Just beyond the confluence of the Blackstone and the Quinsigamond, water levels are very shallow (2-3 feet). Depths in other parts of the study area are approximately 5 feet, while upstream areas of Fisherville Pond along the Quinsigamond River are deeper, reaching a depth of 15 feet.

1.2.3 Sediment Characteristics

In 1982, water was drained and sediment was dredged in the upstream portion of Fisherville Pond along the Quinsigamond River (Figure 1-2). Since 1986, the area has reflooded and sediment has slowly accumulated behind the dam. The study area in Fisherville Pond and downstream areas of the Blackstone River was never dredged. Specifically, the undredged wet meadow/marsh areas, which are the focus of the ERC, were developed from shallow water habitat between 1938 and 1952.

Sediment collected from Fisherville Pond and the Blackstone River in 1981 (McGinn, 1981) was composed of silty fine to coarse sands and sandy fine gravel with a trace of silt. Sediment from the marsh area, south of the Blackstone River, consisted of silty fine to coarse sand with a trace of gravel. Sediment from bars in the river were composed of silty fine to coarse sand with a trace of gravel. Sediment taken in the marsh north of the Blackstone River consisted of gravelly, silty coarse to fine sand. Physical parameters (i.e., %Total volatile sulfides (TVS), % gravel, % silt, % sand) measured in sediments collected in 1981 are presented in Table A-1 (Appendix A).

It is very important to note that current 1997 sediments may be very different in physical and chemical composition than the historical data used to prepare this report. Additionally, it is reasonable to expect that the sediments of more recent deposition would be cleaner due to general environmental trends over the last 15 years and would have buried the more historically contaminated native sediment.

Sediment samples collected in October 1996 by the ACOE indicate that the total organic carbon (TOC) content ranged from 3.81% to 15.95% (ACOE, 1996a). The grain size distribution results indicate that the sediment samples collected in 1996 were predominantly composed of sand (32.1-85.3%) and silt (10.9-48.8%) with some clay (3.8-20.3%) (ACOE, 1996a).

McGinn (1981) and Snook (1995) reported elevated concentrations of metals and polycyclic aromatic hydrocarbons (PAHs) in the Fisherville Pond/Blackstone River System. Concentrations of each organic and inorganic chemical detected in sediments are presented in Tables A-5 and A-6. The AVS/SEM concentrations measured in sediments provides information on the bioavailability of specific divalent metals to benthic organisms inhabiting the Fisherville Pond/Blackstone River System. The AVS concentration measured in sediments collected during 1996 ranged from 0.128 to 5.55 μmoles/g (Table A-9). The total SEM concentration, including cadmium, copper, lead, nickel, and zinc, ranged from 5.3 to 49.631 μmoles/g. A ratio of SEM:AVS of greater than one suggests the potential bioavailability and toxicity of these metals in sediments. AVS/SEM results are discussed in detail in Section 2.3.5.

1.2.4 Vegetative Characteristics

A vegetative survey was conducted during the site visit in October 1996 by McLaren/Hart biologists. The vegetative species observed in the wooded riparian zone and the wetland areas of Fisherville Pond downstream to the dam were identified.

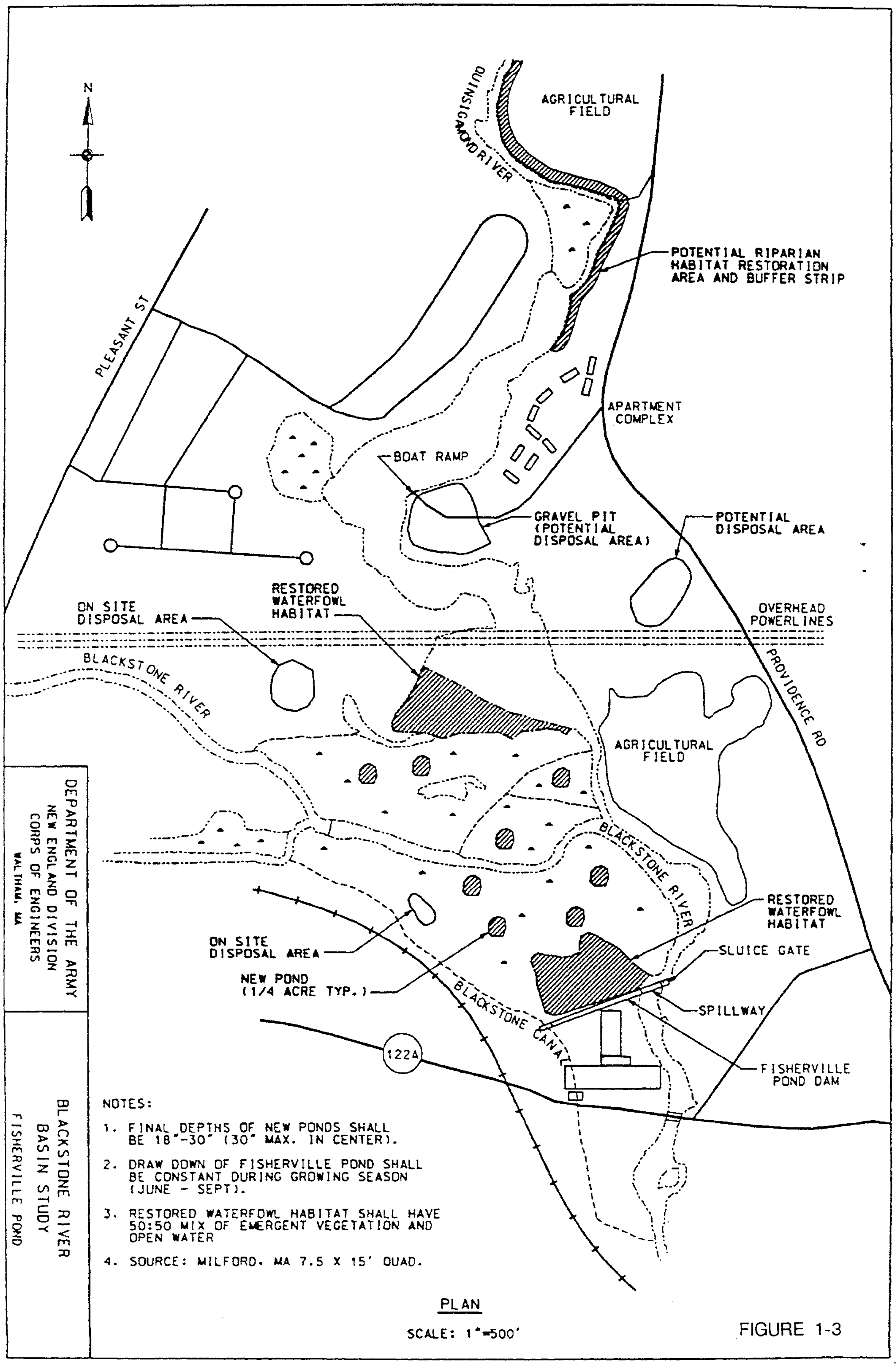
The riparian area bordering most of the study area was dominated by black willow (*Salix nigra*), heart leaf willow (*Salix cordata*), pussy willow (*Salix discolor*), silky dogwood (*Cornus amomum*), pin oak (*Quercus palustrus*), white oak (*Quercus alba*), red oak (*Quercus rubra*), grey birch (*Betula populifolia*), and arrow arum (*Peltanda virginica*) (Figures C-7 and C-8). Pussy willows and black willows, as well as buttonbush (*Cephalanthus occidentalis*), were observed growing in standing water (Figure C-9).

Two wetland areas (Figure 1-2), designated as Areas A (Figure C-10 to C-12) and B (Figure C-13 to C-15) were dominated by herbaceous species, including switchgrass (*Panicum virgatum*), woolgrass (*Scirpus cyperinus*), common reed (*Phragmites australis*), and cattails (*Typha latifolia*). Grey birch saplings were also observed in these areas. The ACOE's plan for the restoration of the study area, specifically within wetlands A and B, is presented as Figure 1-3.

Other vegetative species which were observed during the site visit are listed in Table D-1 (Appendix D). Although no threatened or endangered species were observed during the site visit, a list of threatened and endangered vascular plant species identified in Worcester County is presented in Table D-3.

1.2.5 Wildlife Characteristics

Several species were observed in and around the site during the October 1996 site visit. A great blue heron (*Ardea herodias*) (Figure C-16 and C-17), a leopard frog (*Rana pipiens*) (Figure C-18), and several mallard ducks (*Anas platyrhynchos*) were observed during the visit. Other waterfowl, mammals, fish and vertebrates historically observed and/or surveyed at Fisherville Pond by McLaren/Hart, ACOE, and MADFW personnel are listed in Table D-2. Threatened and endangered wildlife species (vertebrates and invertebrates) identified in Worcester County are presented in Table D-3.



NOTES:

1. FINAL DEPTHS OF NEW PONDS SHALL BE 18"-30" (30" MAX. IN CENTER).
2. DRAW DOWN OF FISHERVILLE POND SHALL BE CONSTANT DURING GROWING SEASON (JUNE - SEPT).
3. RESTORED WATERFOWL HABITAT SHALL HAVE 50:50 MIX OF EMERGENT VEGETATION AND OPEN WATER
4. SOURCE: MILFORD, MA 7.5 X 15' QUAD.

PLAN

SCALE: 1"=500'

FIGURE 1-3

The aquatic species inhabiting the shallow open water were identified during biological surveys. Fish community surveys were conducted by the MA DFW and the ACOE in 1992 and 1996, respectively. Fish (356 individuals) collected in 1992 were members of eight families and 13 species. Fish (161 individuals) collected in 1996 represented 6 families and 7 species. The dominant species inhabiting the Site included white sucker (47.2%), bluegill (18.4%), golden shiner (11.4%), yellow perch (8.7%), and largemouth bass (4.6%). The benthic macroinvertebrate community survey conducted by ACOE in 1996 identified more than 12 taxa at the Site. Aquatic earthworms (Annelida), chironomid midges and damselflies (Insecta), snails (Mollusca), and amphipods (Crustacea) dominated most locations. See Sections 2.3.3.1 and 2.3.3.2, ACOE (1996b), and Appendix E for details regarding the fish and benthic macroinvertebrate surveys.

1.3 EXPOSURE POINT SOURCES

The major points of exposure that could result in potential impacts to ecological or human receptors are the sediments and surface water of the Fisherville Pond/Blackstone River system. The chemical constituents in the water and sediments originated from historic industrial operations along the Blackstone River. The Blackstone River headwaters are located in Worcester, upstream from Fisherville Pond. It has been suggested that textile mills and other industries in Worcester disposed of metals and organic compounds into the Blackstone River. These chemicals have moved downstream via the water column or attached to sediment particles. Sediment particles resuspended during storm events may present additional risks to fish and wildlife. Other potential risks to piscivorous wildlife (i.e., great blue heron) and humans may result from the consumption of fish which have bioaccumulated chemicals originating in the surface water and sediment.

2.0 ECOLOGICAL RISK CHARACTERIZATION

2.1 ECOLOGICAL PROBLEM FORMULATION

The problem formulation utilizes the description of the relevant environmental features (Section 1.2) and the description of the sources of contamination (Section 1.3) to identify ecological receptors and endpoints at the Site. This information is then summarized in the form of a site conceptual model. The conceptual model presents hypothetical hazards posed by the contaminants to the endpoint biota.

2.1.1 Ecological Endpoints

The problem formulation identifies ecologically based endpoints that are relevant to protecting the Fisherville Pond/Blackstone River environment. Assessment endpoints are the explicit statements of the valued characteristics or attributes of the environment that are to be protected. For example, species richness and abundance of the fish community or other valuable resources of the river may be evaluated as assessment endpoints. When an assessment endpoint can be directly measured, the measured and assessment endpoints are the same. However, most assessment endpoints cannot be directly measured. Therefore, a measurement endpoint is selected that can be related, either quantitatively or qualitatively, to the valued characteristic chosen as the assessment endpoint. General considerations for selecting assessment and measurement endpoints include ecological relevance, policy goals and societal values, and susceptibility to chemical stressors (USEPA, 1992; 1996f).

2.1.1.1 Assessment Endpoints

Aquatic and terrestrial assessment endpoints have been selected for this ERC and represent the environmental attributes or characteristics to be protected. The assessment endpoints used in this ERC include the reduction in species richness and diversity of:

- Fish communities;
- Benthic macroinvertebrate communities;
- Amphibian communities;
- Dabbling duck communities;
- Piscivorous wildlife communities; and
- Omnivorous wildlife communities.

2.1.1.2 Measurement Endpoints

Since the above assessment endpoints generally can not be measured directly, measurement endpoints must be identified. There are usually several types of measurement endpoints which can be used to assess the status and potential changes in the attributes of the environment. Qualitative or quantitative biological surveys can be performed to indicate the effects of stressors on population abundance or species composition. The most typical measurement endpoint is an ecotoxicological benchmark or threshold used to indicate the potential for adverse effects on the assessment endpoints. Ecotoxicological benchmarks were derived from chemical toxicity data found in the literature. This assessment has three types of effects data potentially available to serve as measurement endpoints: chemical toxicity data found in the literature, results of benthic invertebrate and fish biological surveys, and surface water and sediment toxicity tests. The specific measurement endpoints used for each assessment endpoint in this ERC are described below.

2.1.1.2.1 Fish Community

A fish community survey was performed within the Fisherville Pond and Blackstone River by the ACOE (Appendix D). Species richness and abundance parameters were recorded for this assessment. These measurement endpoints are assumed to be direct estimates of the assessment endpoint.

Chronic toxicity thresholds for freshwater fish expressed as chronic National Ambient Water Quality Criteria (NAWQC) (USEPA, 1996d), acute NAWQC values, fish LCVs (lowest chronic values), daphnid LCVs, nondaphnid invertebrate LCVs, Lowest Test EC20s (effective concentration), and Population E25s (Suter, 1996) were used as measurement endpoints for the fish community. These test endpoints correspond to the assessment endpoint for this community. That is, the sensitivity of the tested individual is assumed to approximate that of other individuals in the population inhabiting the study area.

Chronic toxicity tests were performed on water samples collected during both wet and dry weather surveys. The dry weather sample consisted of a composite of four subsamples collected at one location for six-hour intervals. The wet weather testing included samples collected at the time of the first flush as well as the peak of each of the three storms at one location. Samples were tested using the Fathead minnow (*Pimephales promelas*) larval growth and survival test and *Ceriodaphnia dubia* survival and reproduction test (BRI, 1996) [Collected in 1992]. This test indicates how bioavailable or toxic the chemical is to fish or pelagic invertebrates.

2.1.1.2.2 Benthic Invertebrates

A quantitative benthic invertebrate survey was performed at 5 locations within Fisherville Pond (Appendix E). Species richness and abundance of benthic invertebrates were recorded for each location. These measurement endpoints are assumed to be direct estimates of the assessment endpoint for this community.

Freshwater sediment guidelines (Lowest Effect Levels (LELs), Probable Effect Levels (PELs) and Severe Effect Levels (SELs)) (Batts and Cubbage, 1995) were used to determine if sediment concentrations have the potential to adversely impact benthic invertebrates. The LELs and SELs were developed by the Ontario Ministry of the Environment (MOE) (Persuad et al., 1993). Probable Effect Levels (PELs) were developed as Interim Sediment Quality Assessment Values.

Reductions in survival of the amphipod *Hyalella azteca* in ten day exposures to sediment were evaluated. Reductions in survival of the dipteran *Chironomous tentans* in ten day exposures to whole sediment were evaluated. Responses that are significantly different or are inhibited by 20% or greater, relative to reference sediments, are assumed to be indicative of sediments that are toxic to benthic biota. Surface sediments (upper 4 inches) were collected at location SED2 (Figure 1-2) two times in 1991 and once in 1993.

2.1.1.2.3 Amphibians (Bullfrog)

To evaluate the potential risks to amphibians, the bullfrog (*Rana catesbiena*) was selected as a representative species for the taxa.

Toxicity data documented in the literature were used to determine if surface water or sediment concentrations found in the Fisherville Pond/Blackstone River System would pose a risk to amphibian species. If toxicity information was not available specifically for amphibian species, toxicological information and benchmarks for freshwater aquatic biota were used.

The results of the aquatic and sediment chronic toxicity tests were used to interpret potential effects to amphibian species during early life stages. During this time, tadpoles would be impacted similarly to benthic and aquatic organisms, having extensive contact with the sediments and transpiring through gills. Therefore, the reduction in survivability and larval growth in laboratory test species may be applicable to amphibian species inhabiting the Site.

2.1.1.2.4 Piscivorous Wildlife (Great Blue Heron)

To evaluate the potential risks to piscivorous wildlife, the great blue heron (*Ardea herodias*) was selected as a representative species for this trophic level.

Point estimates of exposure were calculated and compared with ecotoxicological benchmarks derived at Oak Ridge National Laboratory (ORNL) (Sample et al., 1996). These benchmarks were derived using chronic toxicity thresholds for contaminants of concern in birds and mammals. Greater weight was given to data from long-term feeding studies with wildlife species. Preference was also given to tests that included reproductive endpoints. The benchmarks used for the great blue heron were derived from avian toxicity tests which do not warrant the use of a body scaling factor.

2.1.1.2.5 Herbivorous Wildlife (Dabbling Duck, Mallard)

To evaluate the potential risks to herbivorous wildlife, the mallard (*Anas platyrhynchos*) was selected as a representative species for this trophic level. Point estimates of exposure were calculated and compared with similar ecotoxicological benchmarks described in Section 2.1.1.2.4 (Sample et al., 1996).

2.1.1.2.6 Omnivorous Wildlife (Muskrat)

To evaluate the potential risks to omnivorous wildlife, the muskrat (*Ondatra zibethica*) was selected as a representative species for this trophic level.

Point estimates of exposure were calculated and compared with chemical toxicity tests in the form of ecotoxicological benchmarks derived at ORNL (Sample et al., 1996). Most chemical toxicity test data were derived from rodent reproductive studies. After allometric body scaling factors for the endpoint species were applied, the test endpoints are assumed to correspond to effects on individuals that could result in exceedence of the population-level assessment endpoint.

2.1.2 Conceptual Model

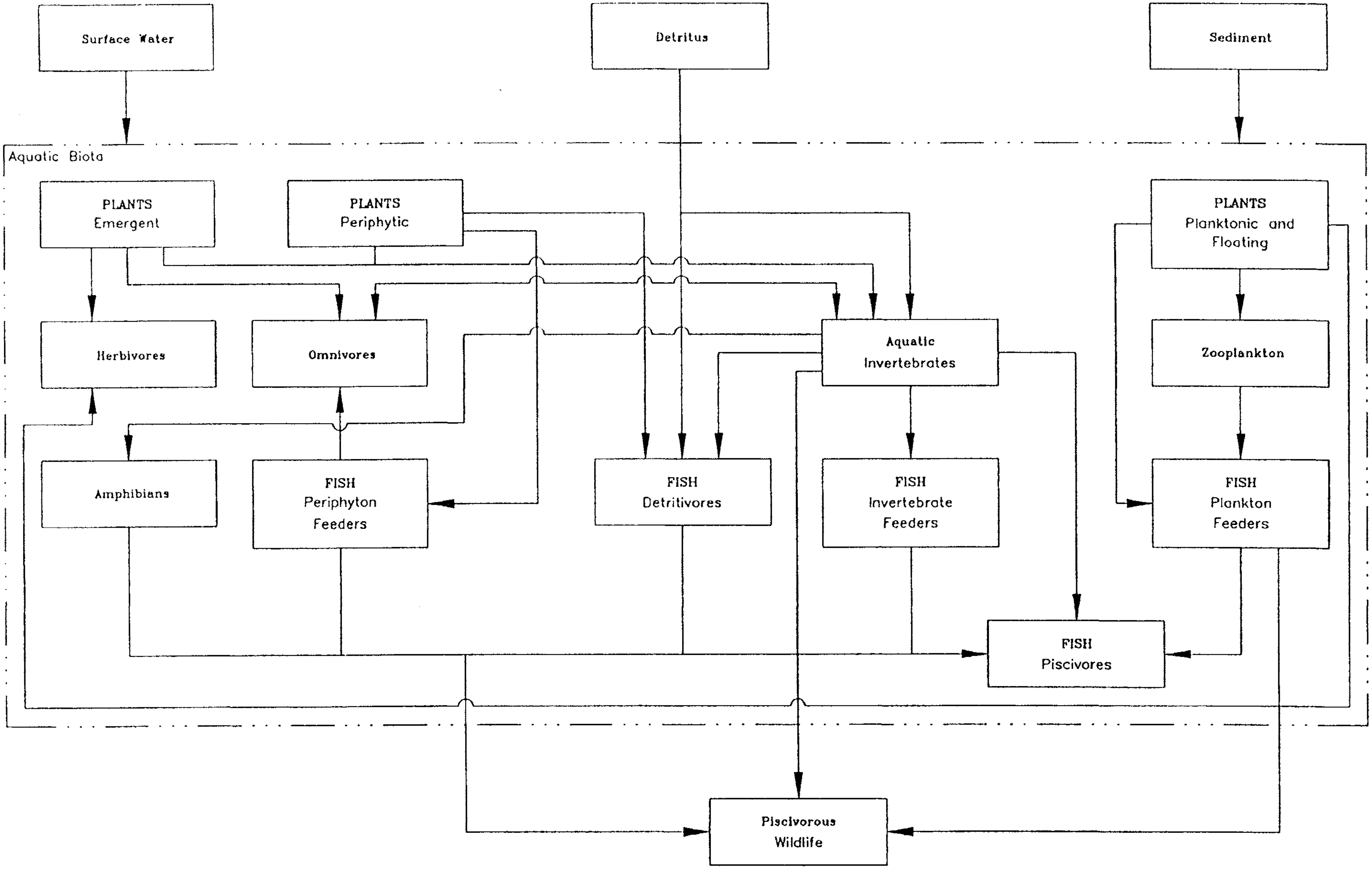
The conceptual model describes the hypothesized sources of contaminants, routes of transport of contaminants, contaminated media, routes of exposure, and ecological endpoint receptors. A conceptual model of exposure of the aquatic food web to contaminants for the current baseline condition in the Fisherville Pond is depicted in Figure 2-1. As discussed in Section 1.3, there could be many sources contributing to the contaminant loading in the river. COPECs in both the surface water and sediment, if bioavailable, could potentially affect fish, benthic invertebrates, plants, and wildlife inhabiting the Fisherville Pond/Blackstone River System.

Contaminants may enter the water column or sediments from upland areas surrounding the Fisherville Pond/Blackstone River system through overland flow, stormwater runoff, or erosion. Pollutants may travel downstream to the study area in the water column or attached to suspended sediment. Once in the study area, these contaminants may affect biota via sediment or water.

Aquatic biota are directly exposed to any contaminants in the water or suspended sediments. These contaminants may accumulate in fish after respiration or swallowing suspended sediments. Benthic invertebrates are directly exposed to contaminants in the sediments. Pollutants may accumulate in the tissues of benthic invertebrates or detritivorous fish which consume contaminated organic matter or sediment. The chemicals may bioaccumulate up the food chain through aquatic biota (i.e., fish, frogs or invertebrates) to waterfowl or terrestrial predators from the consumption of contaminated prey.

Plants may accumulate chemical constituents through contaminated soil or sediment. Chemicals may bioaccumulate up the food chain via herbivorous wildlife or omnivorous wildlife which consume the plants, to the top predators which feed on these herbivores and omnivores.

FIGURE 2-1
CONCEPTUAL SITE MODEL FOR THE FISHERVILLE POND \ BLACKSTONE RIVER SYSTEM



Conceptual model for the exposure of wildlife to contaminants

McLaren Hart INC.

2.2 ECOLOGICAL EXPOSURE ASSESSMENT

This section describes the modes of potential exposure that can occur within the Fisherville Pond/Blackstone River area for the selected assessment endpoints, describes how exposure is estimated, and presents the exposure data available for the ERC.

2.2.1 Fish Community

Fish may be exposed to chemicals through transpiration of waterborne contaminants across the gill membrane, dermal contact, or ingestion of contaminated water and food. No appropriate quantitative models exist given data limitations at this Site to calculate dermal contact or dietary exposure for fish. Therefore, the primary route of exposure was assumed to be respiratory uptake of surface water. The AWQCs used in this assessment were also derived under this assumption. Benthic fish which may be exposed to sediments through direct contact and ingestion are indirectly evaluated in the assessment of risks to benthic macroinvertebrates.

Since fish are mobile within the water column and water in the system is replaced over space and time, the mean water concentration within the area is an appropriate estimate of chronic exposure experienced by fish. The upper 95% confidence limit (UCL) on the mean is an appropriately conservative estimate of exposure. For data sets of 10 or more values, the lower of the maximum concentrations and 95% UCL was used. For smaller data sets (i.e., wet weather events), the maximum concentration was used.

Dry weather samples were collected in 1991 and wet weather samples were collected during storm events in 1992 and 1993. For the purposes of this risk assessment, it was assumed that this data is representative of current (1997) water quality. Additionally, chemical concentrations detected in the surface water at the sampling locations were assumed to be representative of the contaminant exposure experienced by the fish community.

Dry weather samples were collected at one location (Figure 1-2) during three 48 hour surveys (July 10-11, 1991, August 14-15, 1991, October 2-3, 1991) and analyzed for inorganic and physical parameters (Appendix A, Table A-1). Analyses included dissolved oxygen, volatile suspended solids (VSS), total Kjeldahl-nitrogen (TKN), dissolved ammonia-nitrogen (NH_3), dissolved nitrate-nitrogen (NO_3), dissolved orthophosphorus (PO_4), total and dissolved metals (cadmium, chromium, copper, lead, and nickel), and chlorophyll-a. Chemical data collected during dry weather events are presented in Table A-2.

Wet weather samples were collected at one location (Figure 1-2) during three storm events (September 22, 1992, November 2, 1992, October 14, 1993). Each storm event met the following criteria in order to characterize the runoff and determine the impact on receiving water quality: 1) at least 6 hours long, 2) produced a minimum of 0.5 inches of rain, 3) occurred after a dry period of 3 days, and 4) had a post storm period of three days. Wet weather samples were analyzed for TSS, VSS, BOD, chloride, sodium, NH_3, NO_3, PO_4, total trace metals (cadmium, chromium, copper, lead, nickel, and zinc), pH and conductivity (Table A-3). Chemical data collected during wet weather events are presented in Table A-4.

Additional details relating to sample collection, analytical methods, quality assurance/quality control (QA/QC), and data results may be found in the Blackstone River Initiative (1996).

2.2.2 Benthic Invertebrates

Benthic invertebrates can be exposed to contaminants found adhered or absorbed to sediment particles or dissolved in pore water between sediment particles. Primary routes of exposure for benthic invertebrates are generally absorption and respiration of sediment pore water and ingestion of contaminated sediment and sediment-associated food. Compared to surface water, sediment contaminant concentrations have low temporal variability. Benthic invertebrates are also less mobile than water-column species thereby localizing contaminant exposure. Therefore, it was assumed that sediment-associated biota received 100% of their exposure from contaminated sediments at each location. Furthermore, no appropriate quantitative models for exposure through dermal contact, ingestion of contaminated sediment, and consumption of contaminated food are available. Therefore, measured concentrations of contaminants in sediment and/or pore water constitutes a complete model of exposure for the benthic invertebrate community. The abiotic data used for the estimation of exposure are presented below.

Data from sediments collected during the dry (base flow) weather sampling scenario were used to assess chemical exposure to benthic invertebrates. A total of 14 sediment samples were collected in 1981 using a hand auger. Six samples were collected downgradient of the confluence with the Blackstone River (< 1,000 ft from the dam) and eight samples were collected upstream of the confluence the Blackstone River to Fisherville Pond (> 1,000 ft from the dam). Borings collected in the water covered area were taken to depths of one foot; in all other areas, borings were taken to depths of two feet (McGinn, 1981).

Sediment samples were analyzed for metals (aluminum, arsenic, cadmium, chromium, copper, lead, nickel, zinc, and iron), PAHs (McGinn, 1981) and AVS/SEM (ACOE, 1996a). The historical chemical concentrations and physical parameters measured in sediments are presented in Tables A-5 and A-6. Chemical concentrations in pore water collected in 1991 were also utilized to determine exposure to benthic invertebrates (Table A-8). Additionally, sediments collected in 1996 were analyzed for AVS/SEM to determine the bioavailability of the several metals (divalent cations). AVS/SEM data are presented in Table A-9 and evaluated in Section 2.3.5.

2.2.3 Amphibians

Amphibians may be exposed to contaminants by direct contact with surface water, sediment, or soil, or ingestion of contaminated water and food. In the winter the bullfrog is in direct contact with sediments continuously, hibernating in the mud or leaf litter. As an adult, the bullfrog is an integral member of the food chain, consuming algae, plankton, detritus in the larval stage, invertebrates, small tadpoles, and small fish. Since there are no appropriate quantitative models available to calculate dermal contact or dietary exposure for amphibians, it was assumed that the primary route of exposure was direct contact with surface water and sediments. Exposure of the bullfrog to chemicals in Fisherville Pond was assessed using chemical concentrations measured in surface water (Section 2.2.1) and sediment (Section 2.2.2).

2.2.4 Wildlife

Wildlife may be exposed to contamination through dermal contact with water, sediment, or soil, or through ingestion of contaminated water or food. However, since there are no conceptual models to estimate dermal contact, only dietary exposure was assessed. The total oral exposure experienced by an individual is the sum of exposures attributable to each source and may be described as:

$$E_{total} \approx E_{food} + E_{water} + E_{soil}$$

Where:

E_{total} = total exposure from all pathways
E_{food} = exposure from food consumption
E_{water} = exposure from water
E_{soil} = exposure from soil

For exposure estimates to be useful in the assessment of risks to wildlife, exposures must be expressed in terms of body weight-normalized daily dose or mg contaminant per kg body weight per day (mg/kg/d). Exposure estimates expressed in this manner may then be compared with toxicological benchmarks for wildlife, such as those derived by Sample et al. (1996), or to doses reported in the toxicological literature.

Estimation of the daily contaminant dose an individual may receive from a particular medium for a particular contaminant may be calculated using the following equation:

$$E_j = \sum_{I=1}^{m} \frac{(IR_i \times C_{ij})}{BW}$$

Where:

E_j	=	total exposure to contaminant (j) (mg/kg/d)
m	=	total number of ingested media (e.g., food, water, sediment/soil)
IR_j	=	consumption rate for medium (I) (kg/d or L/d)
C_{ij}	=	concentration of contaminant (j) in medium (I) (mg/kg or mg/L)
BW	=	body weight of endpoint species (kg).

Exposure estimates were calculated for all contaminants detected within the Fisherville Pond/ Blackstone River System. Because wildlife are mobile, their exposure is best represented by the mean contaminant concentration in media. To be conservative, the 95% upper confidence limit (UCL) is used in exposure estimates. However, since there are a limited number of sediment or fish samples, the maximum concentration was used to calculate exposure.

2.2.4.1 Herbivorous Wildlife (Mallard)

Herbivorous wildlife may be exposed to contaminants through their diet via ingestion of vegetation, surface water, or incidental ingestion of sediment. The mallard primarily consumes aquatic plants, seeds, and invertebrates, and often filters soft sediments for food (EPA, 1993).

Parameters used to calculate chemical exposure to the mallard were extracted from the EPA's Wildlife Exposure Factors Handbook (1993); however, the primary citation is indicated adjacent to the parameter. To estimate contaminant exposure potentially experienced by the mallard, the following assumptions were made:

- Body weight (BW)= 1.171 kg (Average for males and females; EPA, 1993);
- Food ingestion rate (FI)= 0.0645 kg/day
  (Calculated using the following equation: FI= $0.0582(BW)^{0.651}$ (Nagy, 1987));
- Soil/sediment consumption = 0.00129 kg/d . (Approximately 2% of daily intake is sediment; therefore, the FI was multiplied by 0.2 to derive a soil/sediment ingestion rate.);
- Surface water ingestion rate = 0.0662 L/day
  (Calculated using water ingestion of 0.057 g/g-day and 1171 g BW); and
- Diet consists of 100% vegetation . (Breeding female mallards consume insects and benthic invertebrates, however, for the purposes of this assessment, 100% vegetation was assumed.)

The 95% UCL chemical concentration measured in surface water collected in dry weather sampling events was used to calculate surface water consumption. The chemical concentrations detected in surface water samples are described in Section 2.2.1.

The maximum sediment concentration was used to calculate incidental ingestion of sediment for the endpoint species. The chemical concentrations detected in sediment samples used in the calculations are described in Section 2.2.2.

Contaminant concentrations in vegetation were estimated using the maximum sediment concentration and the soil-plant uptake factors (Appendix F, Table F-1). Documented soil-plant uptake factors were assumed to be equivalent to sediment-plant uptake factors. Plant uptake factors for inorganic constituents (arsenic, cadmium, chromium, and zinc) were derived using data from co-located soil and vegetation samples collected at Oak Ridge National Laboratory within the vicinity of East Fork

Poplar Creek (Sample et al., 1995). Other inorganic uptake factors were derived by Bates et al., (1984). Soil-plant uptake factors for PAHs were derived from the log octanol-water partition coefficient (log K_{ow}) using the following equation (Travis and Arms, 1988):

$$\text{Log soil-plant uptake factor} = 1.588 - 0.578 (\log K_{ow})$$

Using the generalized wildlife model, exposure assumptions and data described above, exposure to chemicals were estimated for the mallard (Tables F-2; Appendix F).

2.2.4.2 Piscivorous Wildlife (Great Blue Heron)

Piscivorous wildlife such as the great blue heron may come in contact with chemicals via ingestion of aquatic biota, surface water, or incidental ingestion of sediment. The heron's diet primarily consists of fish (68 %), crustaceans, amphibians, and insects. For the purposes of this ERA, concentrations measured in fish were assumed to be similar to those measured in other aquatic biota.

Parameters used to estimate exposure for the Great Blue Heron were extracted from Sample and Suter (1994); however, the primary citation is indicated adjacent to the parameter. To estimate contaminant exposure potentially experienced by the great blue heron, the following assumptions were made:

- Body weight =2.39 kg (Dunning, 1984).;
- Food consumption rate =0.42 kg/d (Kushlan, 1978);
- Soil/sediment consumption =As a piscivore, assumed to be negligible;
- Surface water consumption =0.1058 L/d; and
- Diet consists of 100% fish or other aquatic prey;

Chemical concentrations measured in fish tissue contribute the majority of the total exposure to herons foraging at the Site. White sucker, yellow bullhead, largemouth bass, yellow perch, and bluegill were collected during July 1993 using an electroshocker within Fisherville Pond, downstream of the Blackstone-Quinsigamond confluence. Chemical concentrations measured in composite and individual fish filets were used to calculate dietary exposure. Fish filet concentrations were converted to whole body concentrations using filet to whole body ratios (Sample et al., 1996). The average filet to whole body ratios were calculated based on whole body and filet concentrations measured in fish from several water bodies collected at Oak Ridge National Laboratory.

The fish species which were collected and the respective chemical concentrations are presented in Table A10. Concentrations measured in surface water (Sections 2.2.1) were used to assess exposure from surface water consumption. Using the generalized wildlife model, the exposure assumptions and data described above, exposure to chemicals were estimated for the great blue heron (Table F-3; Appendix F).

2.2.4.3 Omnivorous Wildlife (Muskrat)

Omnivorous wildlife may be exposed to chemicals through dermal contact with water and sediments or through ingestion of contaminated food. The mammal chosen for this ERC, the muskrat spends most of its life in or near water. The muskrat mainly lives in marshes, at the edges of ponds, lakes, or streams. The muskrat builds its home in shallow water or digs burrows in banks alongside the water body. The muskrat's diet mainly consists of aquatic vegetation, but a small percentage consists of fish, freshwater mussels, insects, crayfish, and snails.

Exposure assumptions and chemical concentrations measured in abiotic (surface water and sediment) and biotic (vegetation and fish) media were used to calculate exposure to the muskrat are presented below. Exposure parameters were extracted from the EPA's Wildlife Exposure Factors Handbook

(1993); however, the primary citation is indicated adjacent to the parameter. To estimate contaminant exposure potentially experienced by the muskrat, the following assumptions were made:

- Body weight =1.275 kg (Average for males and females; EPA, 1993);
- Food consumption rate= 0.0489 kg/d
  (Calculated using consumption rate- greens 0.00034 kg/g-day and body weight);
- Soil/sediment consumption = 0.0 kg/d (value unavailable);
- Surface water consumption =1.134 L/day
  (Calculated using the following equation: 0.98 g/g-day and body weight); and
- Diet mainly consists of vegetation (95%) with a small amount of fish and other aquatic biota (5%).

Chemical concentrations measured in surface water and sediment are described in Sections 2.2.1 and 2.2.2, respectively. Chemical concentrations in vegetation are estimated using maximum sediment concentrations (Table A-5) and sediment-plant uptake factors (Table F-1). Section 2.2.4.1 describes the derivation of the estimated vegetation concentrations. Concentrations measured in fish tissue are presented in Sections 2.2.4.2 and Table A-9. Using the generalized wildlife model, the exposure assumptions and data described above, exposure to chemicals were estimated for the muskrat (Table F-4).

2.3 ECOLOGICAL EFFECTS ASSESSMENT

The effects assessment involves the determination of the relationship between concentrations of COPECs in surface water and sediments and the previously described assessment and measurement endpoints. The first mechanism for determining the potential for effects is a comparison of identified concentrations of COPECs to appropriate ecotoxicological benchmarks. The second mechanism is the evaluation of ecotoxicological profiles that have been developed for each COPEC. The third mechanism influencing potential effects is the bioavailability of each COPEC. Several factors affecting the bioavailability of chemicals in the aquatic system are also addressed in this section.

2.3.1 Ecotoxicological Benchmarks

Ecotoxicological benchmarks represent "safe values" or threshold criteria identified in the literature. Exceedence of these values may indicate the potential for ecological risks for the specified endpoint community. The ecotoxicological benchmarks that were utilized in the preparation of this ERC are discussed in the following sections.

2.3.1.1 Benchmarks for Aqueous Toxicity

USEPA chronic NAWQC (USEPA, 1986; 1996d) for freshwater aquatic life were used in the evaluation of COPECs identified in surface water samples. NAWQCs were developed based upon the use of the LD_{50} (a statistically or graphically estimated dose that is expected to be lethal to 50% of a group of organisms under specified conditions) results associated with standard acute and chronic toxicity tests.

The NAWQC for the protection of aquatic life are based on thresholds for statistically significant effects on individual responses of fish and aquatic invertebrates. Those thresholds correspond to approximately 25% reductions in the parameters of chronic fish tests (Suter et al., 1987). Because of the compounding individual responses across life stages, the chronic NAWQC frequently correspond to much more than a 20% effects on a continuously exposed fish population (Barnthouse et al., 1990). Therefore, the exceedence of the NAWQC are assumed to correspond to 20% or greater effect on the survivorship, growth, or fecundity of the fish community.

Fish LCVs (Lowest Chronic Values), Daphnid LCVs, Lowest Test EC20s (Effective Concentration) for fish, and Population EC25s for freshwater aquatic life were also used in the evaluation of COPECs identified in surface water samples. The Fish LCV is the lowest value, from acceptable fish chronic toxicity tests, of the geometric mean of the Lowest Observed Effect Concentration (LOEC) and the No Observed Effect Concentration (NOEC). The Daphnid LCV is the lowest value, from acceptable daphnid chronic toxicity tests, of the geometric mean of the LOEC and NOEC. The Lowest Test EC20 is the lowest value, from acceptable fish chronic toxicity tests, of the lowest concentration causing at least a 20% reduction in the weight of young fish per female or the weight of young per egg. The Lowest Test EC20 is intended to evaluate fish population production. The Population EC25 is an estimate of the continuous concentration that would cause a 25% reduction in the recruitment abundance of largemouth bass.

2.3.1.2 Benchmarks for Sediment Toxicity

Freshwater sediment guidelines (Lowest Effect Levels (LELs), Probable Effect Levels (PELs) and Severe Effect Levels (SELs)) were used to determine if sediment concentrations have the potential to adversely impact benthic invertebrates (Batts and Cubbage, 1995).

LELs and SELs were developed using the Screening Level Concentrations (SLC) Approach (Persuad et al., 1993). In this method, individual species screening level concentrations (SSLCs) are calculated for each organism for each chemical. Sites are ranked and plotted according to increasing chemical concentration and the 90th percentile concentration is calculated. Then all species are ranked and plotted according to increasing SSLCs. Fifth and 95th percentile contaminant concentrations are determined from the plot.

The 5th percentile SLC is the contaminant concentration above which 95% of the SSLCs are distributed. It is the highest level of a contaminant that can be tolerated by 95% of the benthic infaunal species. The 95th percentile SLC is the level of contaminant concentration that can be tolerated by 5% of the benthic infaunal species.

These screening values present a conservative estimate of the potential for ecological effects. The chemical concentration data were also compared to available No Observed Adverse Effects Levels (NOAEL) and Lowest Observed Adverse Effects Levels (LOAEL) data identified in the scientific literature. These values, although derived under artificial laboratory conditions that may often maximize exposure, provide valuable information regarding the potential for ecological effects.

Aquatic benchmarks were also used to screen the pore water concentrations. The NAWQC chronic and acute values and the LCV for daphnids and nondaphnid invertebrate (Section 2.3.1.1) were used to determine if sediment associated biota would be adversely impacted by inorganic chemicals measured in pore water.

2.3.1.3 Benchmarks for Wildlife Toxicity

To determine if the contaminant exposure experienced by herbivorous, piscivorous, and omnivorous wildlife in Fisherville Pond and the surrounding area could produce adverse effects, exposure estimates from Section 2.2.4 were compared to NOAELs and LOAELs derived according to the methods outlined by Sample et al. (1996) and EPA (1993). NOAELs represent the highest exposure at which no adverse effects were observed among the animals tested. LOAELs represent the lowest exposure at which significant adverse effects are observed.

NOAELS and LOAELS were derived from toxicological studies obtained from the open literature. Only studies of the effects of long-term, chronic oral exposures, whether in food, water, or by oral intubation, were used. To make the NOAELs and LOAELs relevant to possible population effects, preference was given to studies that evaluated effects on reproductive parameters. In the absence of a reproduction endpoint, studies that considered effects on growth, survival, and longevity were used.

In cases where a NOAEL for a specific chemical was not available, but a LOAEL had been determined experimentally or where the NOAEL was from a subchronic study, the chronic NOAEL was estimated. EPA (1993) suggests the use of uncertainty factors of 1 to 10 for subchronic to chronic NOAEL and LOAEL to NOAEL estimation. Because no data were available to suggest the use of lower values, uncertainty factors of 10 were used in all instances in which they were required.

Smaller animals have higher metabolic rates and are usually more resistant to toxic chemicals because of more rapid rates of detoxification. It has been shown that metabolism is proportional to body surface area which, for lack of direct measurements, can be expressed in terms of body weight (bw) raised to the 1/4 power ($bw^{1/4}$) (EPA, 1980). If the dose (d) itself has been calculated in terms of unit body weight (i.e., mg/kg), then the dose per unit body surface area (D) equates to:

$$D = \frac{d \ x \ bw}{bw^{3/4}} = d \ x \ bw^{1/4} \tag{1}$$

The assumption is that the effective dose per body surface area for species "a" and "b" would be equivalent. Therefore, knowing the body weights of two species and the dose (d_b) producing a given effect in species "b," the dose (d_a) producing the same effect in species "a" can be determined. Using this approach, if a NOAEL was available , or could be calculated for the test species ($NOAEL_t$), the equivalent NOAEL for a wildlife species ($NOAEL_w$) was calculated by using the adjustment factor for differences in body size:

$$NOAEL_w = NOAEL_t \left(\frac{bw_t}{bw_w} \right)^{1/4} \tag{2}$$

This methodology is equivalent to that the EPA uses in their carcinogenicity assessments and Reportable Quantity documents for adjusting from animal data to an equivalent human dose. This body scaling correction is a unnecessary for avian endpoints. The test species is considered to have similar effects from chemical exposure regardless of body weight (Sample, et al., 1996).

2.3.2 Ambient Chronic Toxicity Data

This section includes a summary of the results of the surface water, sediment, and pore water chronic toxicity tests (BRI, 1996) [Collected in 1991].

2.3.2.1 *Surface Water Toxicity Testing*

Aquatic chronic toxicity was assessed using the standard fathead minnow (*Pimephales promelas*) larval growth and survival test and the *Ceriodaphnia dubia* survival and reproduction test. The young of each test species were exposed to surface water samples collected from the Site for a seven day period (BRI, 1996).

Surface water was collected during dry weather conditions in July, August and October of 1991. Four subsamples were collected and composited from one location (BLK06). Surface water was also collected at one location (BWW06) during wet weather conditions in September and November of 1992 and October of 1993. Samples were collected at the time of first flush and the peak of three storm events.

Mean survival and growth of fathead minnows and mean survival and reproduction of *Ceriodaphnia* are presented in Table A-11. Mean survival for minnows ranged from 83% to 100%; growth ranged from 0.329 to 0.673 mg/fish. Mean survival for *Ceriodaphnia* was consistently 100% while the number of offspring per female ranged from 14.6-28.4. There were no significant differences between the endpoint effects of control samples and ambient samples during the three sampling events (BRI, 1996) [Collected in 1991]. Therefore, the lack of a significant reduction in these measurement endpoints suggests that surface water collected during the three sampling events were not toxic to the laboratory test species, under the conditions of these assays.

Ceriodaphnia dubia survival was significantly reduced during storm event 2 during the first flush collection, but not during the wet weather peak. Reproduction was not significantly reduced in any other samples. The BRI (1996) reported that the potential reduction in survival during first flush collection may have resulted from the decreased hardness at or near peak flows (i.e., peak dilution from runoff). A decrease in hardness of the surface water causes the metal to reduce, potentially increasing acute and chronic toxicity of the metals measured in surface water. The data for the percent survival and reproduction for this particular test were not presented.

2.3.2.2 *Whole Sediment Toxicity Testing*

River sediments were collected from location SED2 in Fisherville Pond during July and October of 1991 (Figure 1-2). The upper four inches of substrate were collected for the toxicity testing. Sediment toxicity was assessed using *Chironomous tentans* and *Hyallela azteca* during a 10 day period.

The July 1991 toxicity test using *Chironomous tentans* was considered invalid due to inadequate survival measurements. Significant mortality (28%) of Chironomous *tentans* was observed from the sediment sample collected in October 1991. Mortality for *Hyallela azteca* was not significantly higher in the July 1991 sediment sample, but was elevated (40%) in the October 1991 sediment sample. Based on the results of the limited toxicity tests conducted in 1991, the sediments within Fisherville Pond may be toxic to sediment associated biota.

2.3.2.3. *Sediment Pore Water Toxicity Testing*

Pore water was extracted by centrifugation of the sediment samples collected at location SED2 in July and October 1991. Sediment pore water toxicity was assessed using the fathead minnow and *Ceriodaphnia dubia*. Three replicates consisting of ten fish were exposed for 48 hours to each of the seven pore water stations, the reference, control, and the culture water. Thirty *Ceriodaphnia* were exposed (fifteen test tubes containing two individuals each) to the pore water samples.

Table A-12 presents the results from the pore water toxicity tests. Survival of fathead minnows and *Ceriodaphnia* was significantly reduced (0% survival) when exposed to pore water collected from samples in November 1991. In contrast, sediment pore water did not adversely impact the minnows or Ceriodaphnia (100% survival) during July toxicity tests. An explanation for this reported reduction in survival was not presented within the BRI (1996).

The pore water samples were diluted with control water to determine the concentration (% of full strength pore water) necessary for survival of fathead minnows. Results of this 48 hour toxicity test (Table A-13) indicated that it was necessary to dilute the pore water by 75% for adequate minnow survival.

2.3.3 Biological Survey Data

Fish and benthic macroinvertebrate community surveys were conducted at the Fisherville Pond during 1996. The complete fish and benthic macroinvertebrate survey reports are presented in ACOE (1996b) and Appendix E. This section summarizes the results and conclusions of these surveys.

2.3.3.1 Fish Community Survey

Adult and juvenile fish were collected in Fisherville Pond during two sampling events: August 18-19, 1992 (MA DFW, 1992) and October 15-16, 1996 (ACOE, 1996b). Fish were collected using gill nets, hoop nets, beach seining, and backpack electrofishing. All adults and juveniles were identified to the species level and counted. If over 35 individuals of a species were collected during one sampling event, a minimum of 30 individuals were randomly selected, measured for total length, and weight. Fish were also examined for external parasites and physical abnormalities.

During the 1992 event, 356 fish were collected. The fish were members of eight families and 13 species. During the 1996 sampling event, a total of 161 fish were collected. These fish represented 6 families and 7 species. Based on combined abundance, the top six species representing over 94% of the total were white sucker (47.2%), bluegill (18.4%), golden shiner (11.4%), yellow perch

(8.7%), largemouth bass (4.6%), and carp (3.9%). Table D-2 lists all fish species collected during the two community surveys.

Most of the fish caught in Fisherville Pond were warm water species. However, two cold water species, rainbow trout and brook trout, were also collected. It is likely that these trout species migrated from upstream regions of the Quinsigamond River, which is stocked with rainbow and brook trout.

Based on the two fish surveys, Fisherville Pond supports a moderately diverse and abundant warm water fish community. The dominance of the fish population by more tolerant species (white sucker, golden shiner and carp) indicates that the Fisherville Pond System (i.e., Fisherville Pond, Blackstone River, and Quinsigamond River complex) is somewhat degraded by a combination of water and sediment quality and less than stable pool height. However, the presence in good numbers of less tolerant species (largemouth bass, yellow perch, and bluegill) demonstrates potential for the development of a more balanced fish community.

Since moderate numbers of fish were collected in Fisherville Pond, it is evident that chemicals measured in the sediments or surface water do not cause significant acute effects to fish that are readily observable (i.e., fish kill). Apparently, these chemicals have not adversely impacted reproduction and recruitment of fish, since juveniles (young-of-the-year) as well as adults of two species (e.g., bluegill, largemouth bass) were collected during the fall 1996 survey. Albeit, the potential significance of any adverse impacts to any of the species present can not be determined by existing data.

Based upon a review of the limited survey data and analyes, it is apparent that we do not know enough about the fish population of the Fisherville Pond System to predict effects of existing water and sediment quality and water level management to the fish community.

2.3.3.2 Benthic Macroinvertebrate Survey

Sediment samples were collected at five locations in Fisherville Pond during October 1996. Benthic macroinvertebrates found in the sediment were classified down to the lowest practical identification level (LPIL). Diversity (number of taxa) and abundance (number of individuals in each taxa) of the organisms identified in each sample were recorded (Appendix E).

Most of the invertebrates identified were common to northeastern freshwater lentic (low-flowing) systems. A total of twelve taxa were identified at the Site. The majority of the locations were dominated by aquatic earthworms (Annelida), chironomid midges and damselflies (Insecta), snails (Mollusca), and amphipods (Crustacea). The density of these organisms observed at the Site were somewhat low relative to similar unimpacted systems. However, natural sample variability at each location makes data interpretation difficult.

Aquatic earthworms accounted for over 75% of the total number of organisms identified. These organisms tend to be tolerant of organic pollutants. However, since invertebrates sensitive to contamination (i.e., ETP taxa) emerge in the spring and summer, no conclusions can be drawn on the extent of contamination. ETP taxa could be present in the system in the fall, however, early instars may not be well represented in ponar grab samples.

Sediments in Fisherville Pond appear to contain macroinvertebrate communities similar to those in other "unimpacted" northeastern lentic systems. Additionally, the species composition of the community are not atypical of lotic (actively moving water) systems with organic rich sediment. Therefore, based on the collection of 5 sediment samples, the existing data suggests that the benthic macroinvertebrate community within Fisherville Pond is not severely impacted. However, additional sampling is necessary to determine if sediment contamination adversely impacts the benthic invertebrate community.

2.3.4 Ecotoxicological Profiles

Ecotoxicological profiles are presented in Appendix G for those chemicals that exceed benchmarks for either aquatic endpoints (fish and benthic invertebrate communities) or terrestrial endpoints (avian and mammalian wildlife). The toxicity profiles summarize the existing toxicity information for each chemical including concentrations causing acute and chronic lethal and sublethal effects, and physicochemical conditions that may modify toxicity.

2.3.5 Bioavailability

Aquatic organisms in the Fisherville Pond/Blackstone River system may take up metals from the environment through exposure pathways identified in Sections 2.2.1 and 2.2.2. However, the degree of exposure and the concentration of inorganic chemicals in fish and invertebrates is highly dependent on the bioavailability of particulate-bound chemicals, the metal speciation, and the chemical characteristics of the surrounding matrix (USEPA, 1992; Ankley et al., 1994a; and Anderson et al., 1984).

The simple presence of a COPEC is not necessarily indicative of an ecological impact to surrounding receptors. Exceedences of sediment screening criteria does not infer effects at a particular site. If COPECs in sediments are not biologically available to ecological receptors for uptake, then the risks afforded by their presence is limited. In many situations, inorganic constituents can tend to bind to non-hazardous materials in sediments such as clay particles or organic material, thereby limiting their availability for uptake. This concept is documented in Power and Chapman (1992) which states:

> "there are many circumstances when field collected sediments that are highly contaminated, based on bulk chemistry data, are not toxic. Sediment chemical measures only provide information on contamination because the toxicity of a chemical substance in sediment varies with its concentration and with conditions encountered within a specific sediment."

Numerous studies have shown that dry weight concentrations of metals in sediments cannot be used to predict toxicity to benthic organisms.

Studies by Di Toro et al. (1990) demonstrated that the toxicity of cadmium to marine amphipods was linked to metals and acid volatile sulfide (AVS) ratios. In this experiment, significant mortality was not observed when the acid-extractable cadmium concentration was less than or equal to the AVS concentration. Since then, many studies using freshwater and saltwater sediments spiked with cadmium, copper, lead, nickel and zinc (Carlson et al., 1991; Di Toro et al., 1992; and Casas and Crecelius, 1994) have demonstrated the utility of these parameters in causally linking toxicity to metals in sediments.

AVS is a reactive pool of solid phase iron and manganese sulfide that binds to metals rendering them biologically unavailable, and therefore nontoxic to biota. Simultaneously extracted metal (SEM), the metal extracted by the AVS analytical method (not total metals), is the best estimate of potentially bioavailable metal concentrations for comparison to AVS. Cadmium, copper, lead, nickel, zinc or divalent mixtures have been shown to contain little interstitial metal and were found to be nontoxic to saltwater or freshwater snails, oligochaetes, polychaetes or amphipods when the molar concentration of AVS exceeded the molar concentration of SEM (SEM/AVS ratio <1.0). Toxicity was often, but not always, observed at SEM/AVS >1.0 (Hansen et al., 1996).

Table A-8 presents the AVS and SEM concentrations for the five samples collected in Fisherville Pond in 1996. The SEM/AVS ratios were calculated to determine the bioavailability of the sediments collected in Fisherville Pond. The SEM/AVS ratios were significantly higher than 1 at all five sampling locations, ranging from 2.2 to 387.7. These ratios indicate that divalent metals measured in sediments within Fisherville Pond may be toxic to sediment associated biota. This is especially evident at location 1 which had the highest SEM copper concentration (36 μmoles/g) relative to the AVS concentration (0.128 μmoles/g).

As noted by USEPA (1994a), the metals included in this analysis have differing binding affinities for AVS, with copper having the highest affinity and nickel the lowest. At equilibrium, copper will preferentially bind to AVS, displacing all other metals. If the available AVS is not completely saturated by copper, then the remaining metals will bind in the order of lead, cadmium, zinc, and nickel. Table A-6 indicates that the SEM copper concentration exceeds the AVS concentration in 4/5 sampling locations. Therefore, the copper will bind to all the available AVS resulting in an excess of bioavailable copper (at 4 locations), cadmium, nickel, lead and zinc. These remaining metals would not be present as sulfides, but still could be bound by organic complexing agents.

Other physico-chemical properties of sediment including TOC and grain size may affect the bioavailability of the metals or organic constituents. TOC is a measure of the quantity of organic material present in the sediment which can bind organic compounds, such as PCBs. In Fisherville Pond, TOC ranged from 3.81 - 15.85 %. The elevated concentrations of TOC suggests that PCBs or other organic chemicals in sediments may be bound and rendered unavailable. Grain size will determine the percentage of small particle size sediments that metals would tend to adhere to. Förstner (1990) noted that pollutants mainly bind to small particles, such as those characteristic of silts and clays. Sediments in Fisherville Pond were predominantly sands (32.1-85.3%) and silts (10.9-48.8%) with some clay (3.8-20.3%). The presence of silts and some clay material in sediments of Fisherville Pond may decrease the bioavailability of metals measured in sediments.

All of the physico-chemical factors mentioned above, including metal speciation, AVS, TOC, and grain size, may decrease the bioavailability of COPECs in sediments of the Fisherville Pond/Blackstone River System. Any decrease in the availability of inorganic or organic chemicals would decrease the exposure to the ecological receptors. Less exposure to these receptors will minimize the potential for adverse effects.

Additionally, the bioavailability of COPECs measured in surface water in the Fisherville Pond/Blackstone River System is dependent on the fraction (dissolved or total) of the surface water in which the COPEC is found. The consensus of the scientific community and of the EPA Office of Water is that aquatic biota are exposed to the dissolved fraction of the chemicals in water. The COPECs in the dissolved fraction of surface water is considered to be the bioavailable form (Prothro, 1993). However, in order to be conservative, both total and dissolved phase surface water concentrations of metals were used in the calculation of exposure to aquatic biota.

2.4 RISK CHARACTERIZATION

Risk characterization is the phase of risk assessment in which the information concerning exposure (Section 2.2) and the information concerning the potential effects of exposure (Section 2.3) are integrated to estimate risks (the likelihood of effects given the exposure). Risk characterization in ecological risk assessment is performed by a weight-of-evidence analysis. Procedurally, the risk characterization in this assessment is performed for each assessment endpoint by (1) screening measured chemical concentrations to ecotoxicological benchmarks, (2) estimating the effects of the contaminants retained by the screening analysis, (3) estimating the toxicity of the ambient media based on the media toxicity test results, (4) estimating the effects of exposure on the endpoint biota based on the results of the biological survey data, (5) logically integrating the evidence to characterize risks to the endpoint, and (6) listing and discussing the uncertainties in the assessment.

2.4.1 Risks to Fish Communities

The risks presented to fish communities located in the Fisherville Pond/Blackstone River System, as determined by the various lines of evidence, are discussed in the following sections.

2.4.1.1 Screening of Chemicals Against Benchmarks

All chemicals detected in surface water collected from Fisherville Pond during dry and wet sampling events were screened against ecotoxicological benchmarks (Section 2.3.1) to determine the potential risk to aquatic biota. This was conducted by dividing the 95% UCL of the arithmetic mean concentration or the maximum by the ecotoxicological benchmarks (Table F-5). Hazard Quotients (HQs) were calculated using the following equation:

$$\text{Hazard Quotient} = \frac{\text{Chemical Exposure Concentration (mg/L or } \mu g/L)}{\text{Ecotoxicological Benchmark}}$$

If the HQ is less than or equal to 1, then the probability of adverse ecological impacts to aquatic receptors from the chemical exposure is negligible. HQs greater than one indicate that a chemical is a COPEC and may potentially produce adverse ecological impacts to aquatic biota. However, chemicals which are associated with particulate material, or detected primarily in the total surface water samples, may not be credible COPECs for the fish community. Particulate bound chemicals which are detected at much lower levels in filtered samples, are likely not bioavailable to aquatic biota.

Surface Water Collected During Dry Weather Events

Surface water exposure concentrations (95% UCLs), ecotoxicological benchmarks, and associated HQs are presented in Table F-5. COPECs which had HQs greater than 1, included cadmium, copper, lead, and nickel. The total chemical concentrations were all slightly higher than the dissolved fraction, indicating chemicals which are particulate-bound. The dissolved fraction, which is considered bioavailable, also exceeded the benchmarks. Since the use of the 95% UCL is considered conservative for the screening process, the distribution of all surface water data collected within Fisherville Pond is presented for each COPEC. The ecotoxicological benchmarks are also presented in the figure to indicate the frequency of Exceedences throughout different times of the year (samples 1-4 were collected in July; samples 5-9 were collected in August; samples 10-12 were collected in October).

Cadmium: Figure 2-2 illustrates the distribution of all cadmium concentrations measured in 12 surface water samples collected during dry weather sampling events. Approximately 33% of the samples contained dissolved cadmium concentrations in excess of the NAWQC chronic value. Comparison with other ecotoxicological benchmarks indicated that only one dissolved sample exceeded the lowest Test EC20 for fish (1.8 μg/L). This concentration has been shown to cause a less than 20% reduction in the weight of young fish per initial female fish in a life-cycle or partial life-cycle test. All cadmium concentrations measured in surface water exceeded the LCV for daphnids. In contrast, all concentrations were below the Population EC25, indicating that cadmium in surface water would not impact recruitment abundance of largemouth bass. Overall, the distribution of cadmium measured in surface water indicates that aquatic biota may experience chronic adverse effects from exposure in Fisherville Pond.

Copper: Figure 2-3 illustrates the distribution of copper concentrations measured in the 12 surface water samples. Total copper concentrations ranged from 8.4 to 50 μg/L, while dissolved copper concentrations ranged from 8 to 20.6 μg/L. Approximately 33% and 83% of the samples contained dissolved copper concentrations in excess of the NAWQC acute and chronic values, respectively. Comparison with other ecotoxicological benchmarks indicated copper concentrations also exceeded the lowest Test EC20 for fish (0.26 μg/L- not presented), the LCV for fish (3.8 μg/L) and the Population EC25 (8.6 μg/L). Copper concentrations measured at the site have been shown to cause less than 20% reduction in the weight of young fish per initial female fish in a life-cycle or partial life-cycle test. These concentrations have also been shown to impact the recruitment abundance of largemouth bass. Overall, the distribution of copper measured in surface water indicates that aquatic biota may experience chronic or acute adverse effects from copper exposure in Fisherville Pond.

Figure 2-2. Cadmium Concentrations Measured in Surface Water in Fisherville Pond

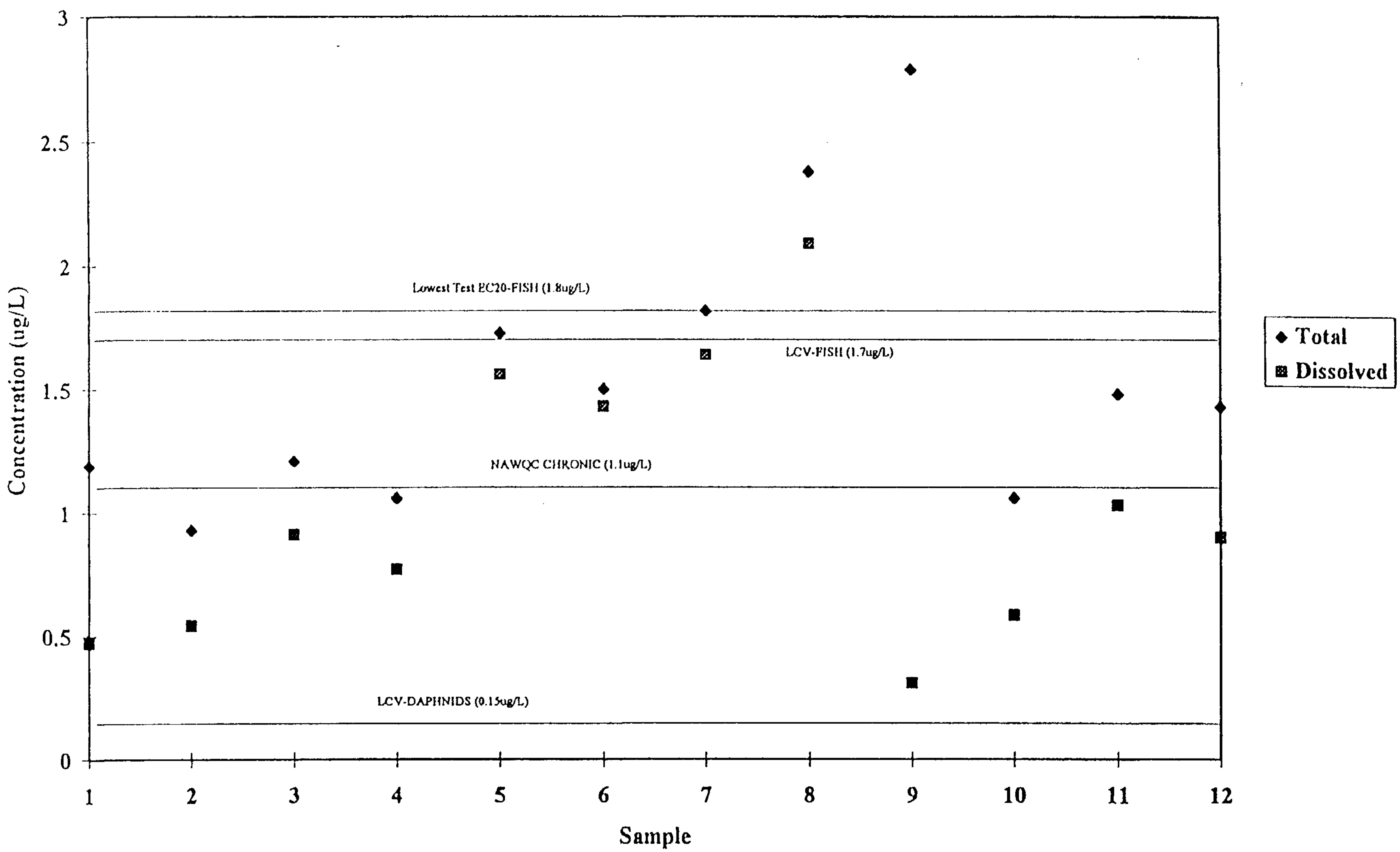
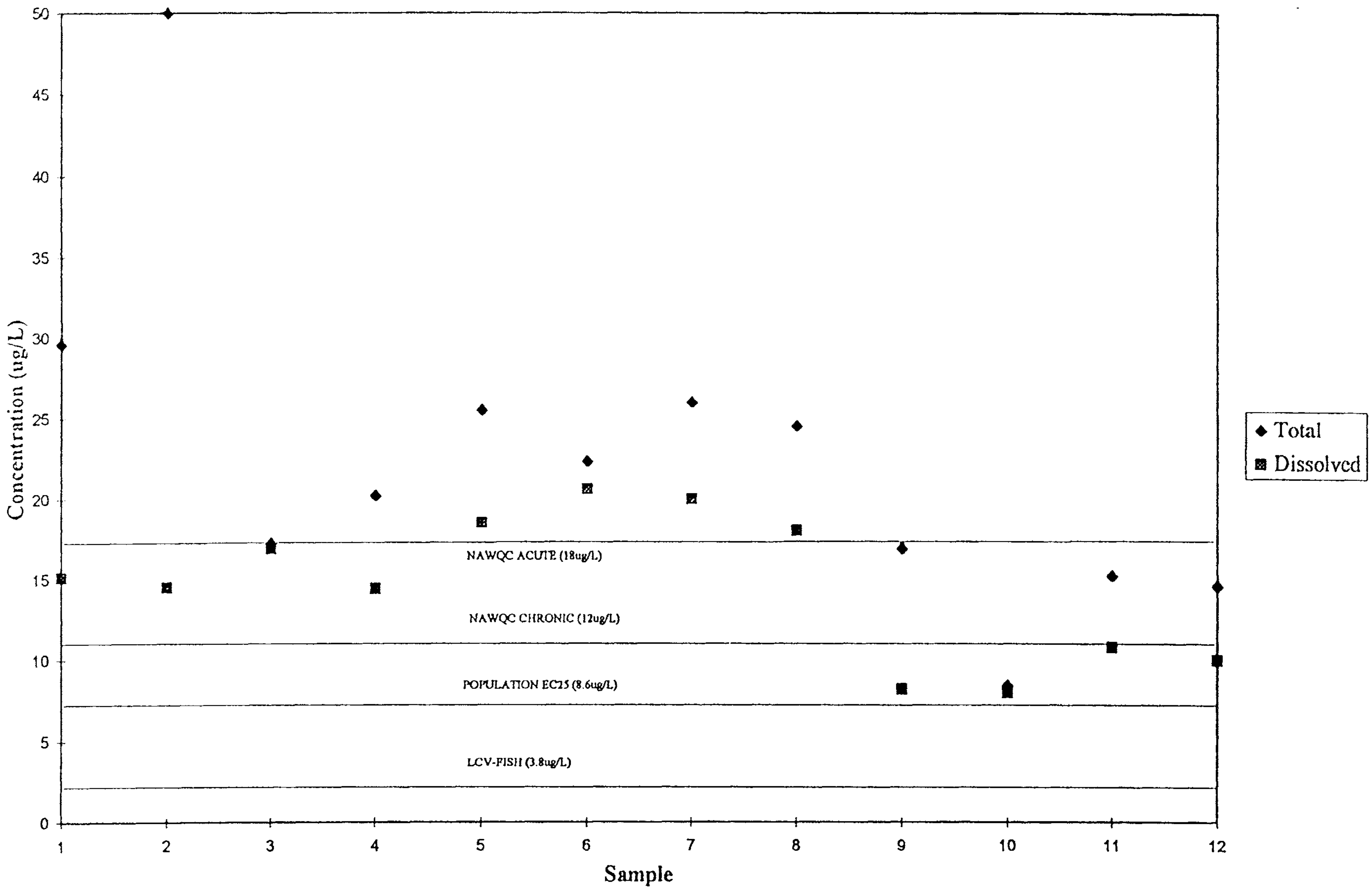


Figure 2-3. Copper Concentrations Measured in Surface Water in Fisherville Pond



Lead: Figure 2-4 illustrates the distribution of lead measured in the 12 water samples. The figure shows that the NAWQC acute value (82 μg/L) was exceeded by only one dissolved and one total water sample. Four dissolved samples exceeded the NAWQC chronic value (3.2 μg/L). Comparison with other ecotoxicological benchmarks indicated that only one total sample exceeded the LCV for fish (1.8 μg/L). This concentration has been shown to cause a less than 20% reduction in the weight of young fish per initial female fish in a life-cycle or partial life-cycle test. All lead concentrations measured in surface water were below the Population EC25, indicating that lead in surface water would not impact recruitment abundance of largemouth bass. Overall, the distribution of lead measured in surface water indicates that aquatic biota may experience chronic adverse effects from exposure in Fisherville Pond.

Nickel: Figure 2-5 illustrates the distribution of nickel measured in the 12 water samples. The figure shows all samples were below the NAWQC chronic value of 160 μg/L. All water samples (both total and dissolved) were below the LCV for fish (<35 μg/L). All water samples exceeded the LCV for Daphnids (<5 μg/L). As such, the measured nickel concentrations are not expected to impact the fish community of Fisherville Pond. There is a potential for impacts to the benthic macroinvertebrate community, however.

Surface Water Collected During Wet Weather Events

The maximum concentration in surface water measured during wet weather sampling events were screened against ecotoxicological benchmarks (Table F-6). Potential increases of chemicals during storm events may occur from the resuspension of chemicals in sediment or the transport of chemicals from terrestrial sources (i.e., surface soils, overland run-off, storm-drain outfalls). The data collected in 1992 and 1993 indicate that metals were detected at slightly lower concentrations during wet weather sampling events compared to baseflow conditions. This suggests that the metals detected during baseflow conditions were diluted during these sampling events. Although metal concentrations in surface water decreased, cadmium, copper, lead, nickel and zinc continued to

Figure 2-4. Lead Concentrations Measured in Surface Water in Fisherville Pond

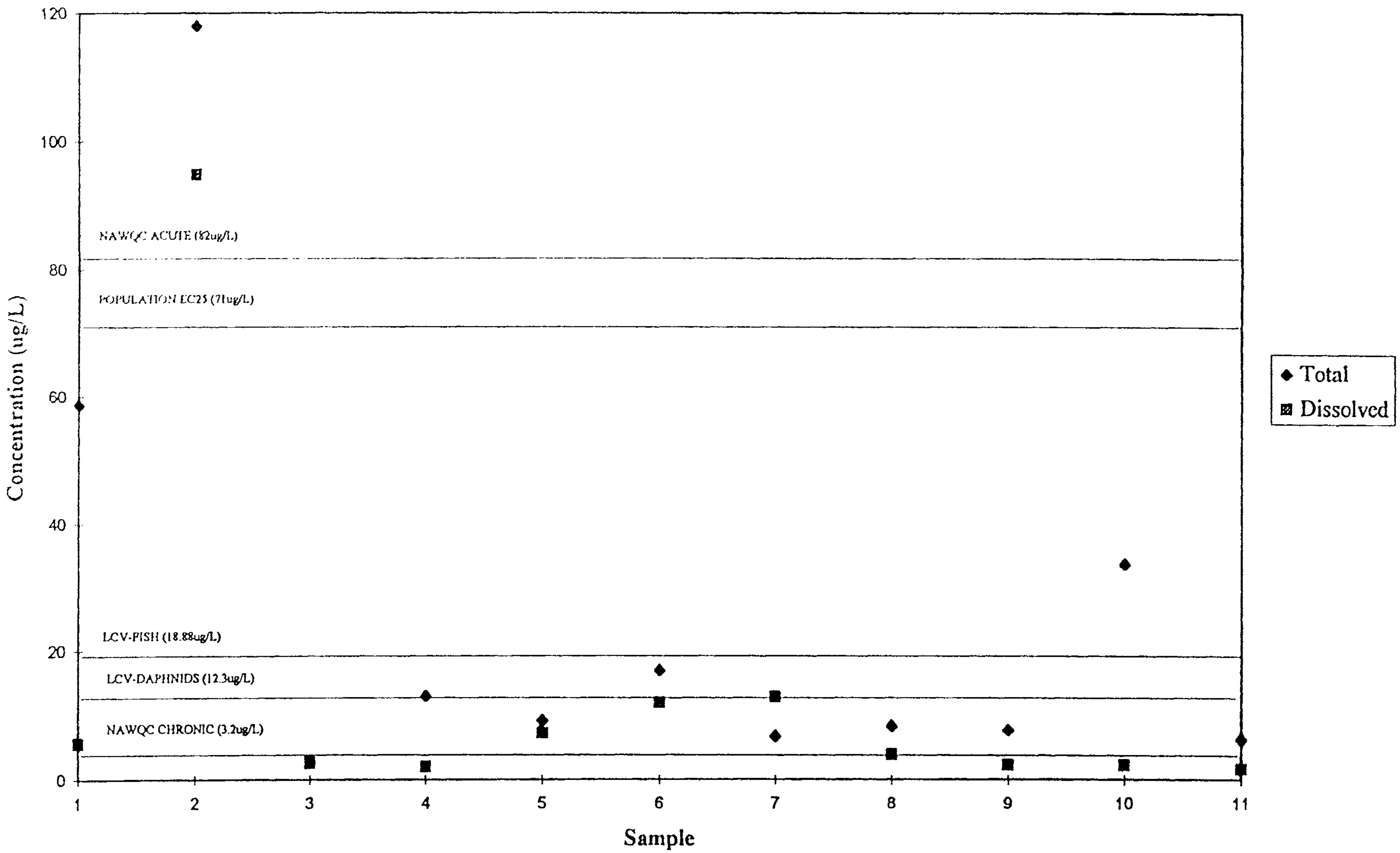
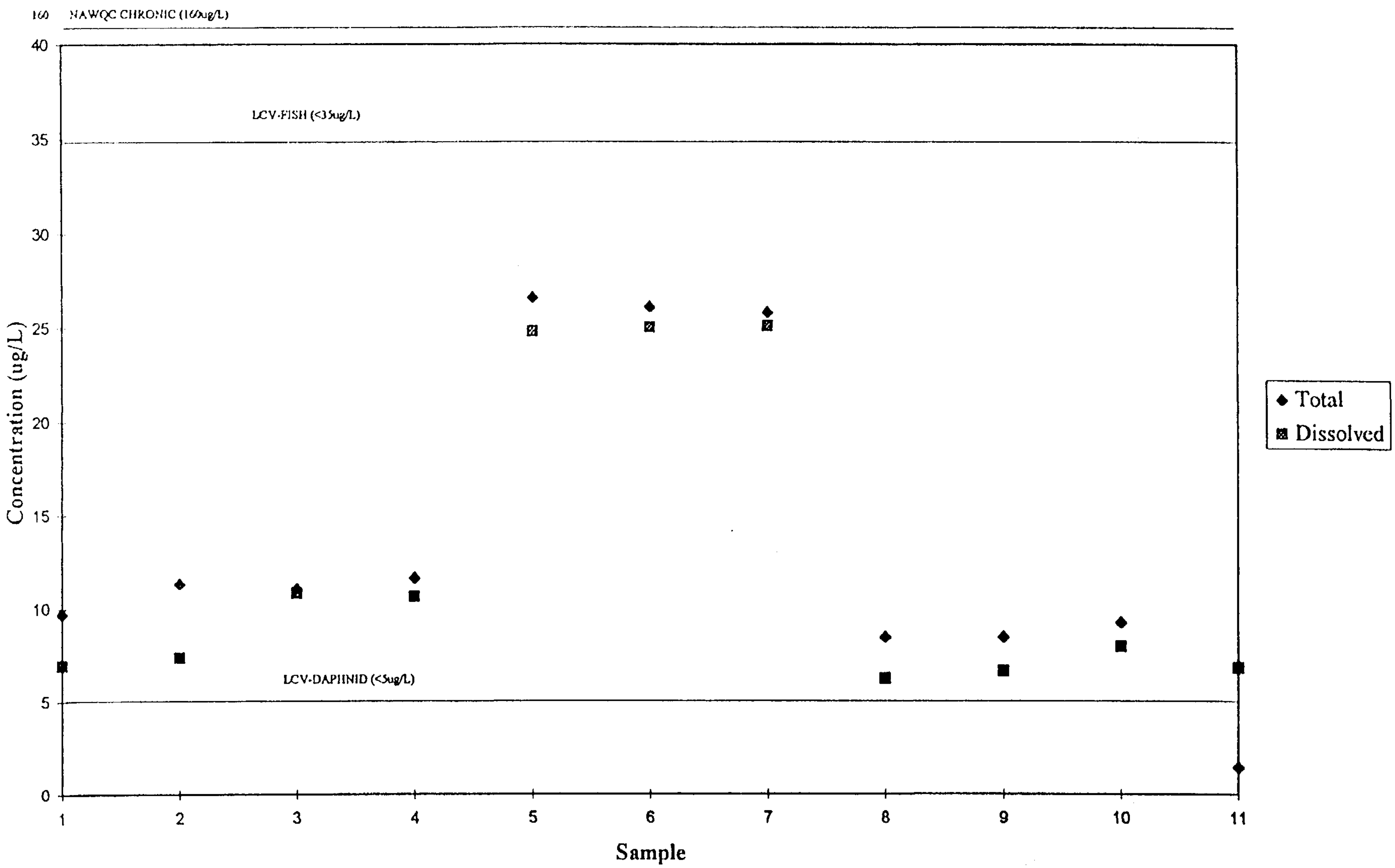


Figure 2-5. Nickel Concentrations Measured in Surface Water in Fisherville Pond



exceed ecotoxicological benchmarks. Consequently, a potential risk to aquatic biota may still result from exposure; although the magnitude of potential adverse impacts would likely be minimized during storm events in Fisherville Pond.

2.4.1.2 Ambient Toxicity Testing

The surface water toxicity tests (Section 2.3.2.1) did not show evidence of toxic impacts to fathead minnows or *Ceriodaphnia dubia.* There were no reductions in the survival or growth of fathead minnows, nor were there reductions in the survival and reproduction of *Ceriodaphnia*. Therefore, the ambient toxicity test results suggests that the surface water in Fisherville Pond is likely not toxic to fish and pelagic invertebrates. However, *Ceriodaphnia dubia* survival was significantly reduced during storm event 2 during the first flush collection. Reproduction was not significantly reduced in any other samples. *Ceriodaphnia dubia* survival was significantly reduced during storm event 2 during the first flush collection, but not during the wet weather peak. Reproduction was not significantly reduced in any other samples. The BRI (1996) reported that the potential reduction in survival during first flush collection may have resulted from the decreased hardness at or near peak flows (i.e., peak dilution from runoff). A decrease in hardness of the surface water causes the metal to reduce, potentially increasing acute and chronic toxicity of the metals measured in surface water.

2.4.1.3 Fish Community Survey

Based on the two fish surveys, Fisherville Pond supports a moderately diverse and abundant warm water fish community. The dominance of the fish population by more tolerant species (white sucker, golden shiner and carp) indicates that the Fisherville Pond System (i.e., Fisherville Pond, Blackstone River, and Quinsigamond River complex) is somewhat degraded by a combination of water and sediment quality and less than stable pool height. However, the presence in good numbers of less tolerant species (largemouth bass, yellow perch, and bluegill) demonstrates potential for the development of a more balanced fish community.

Since moderate numbers of fish were collected in Fisherville Pond, it is evident that chemicals measured in the sediments or surface water do not cause significant acute effects to fish that are readily observable (i.e., fish kill). Apparently, these chemicals have not adversely impacted reproduction and recruitment of fish, since juveniles (young-of-the-year) as well as adults of two species (e.g., bluegill, largemouth bass) were collected during the fall 1996 survey. Albeit, the potential significance of any adverse impacts to any of the species present can not be determined by existing data.

Based upon a review of the limited survey data and analyes, it is apparent that we do not know enough about the fish population of the Fisherville Pond System to predict effects of existing water and sediment quality and water level management to the fish community.

2.4.1.4 Weight of Evidence Summary

Three lines of evidence were evaluated to assess the potential for ecological impacts to the fish community of Fisherville Pond. Those lines included biological surveys, toxicity tests and media analysis. Media analysis was further subdivided into total water concentrations under dry weather sampling, dissolved water concentrations under dry weather sampling, and total water concentrations under wet weather sampling. Table 2-1 summarizes the lines of evidence evaluated to assess the overall potential for ecological impacts to the fish community. The final weight-of-evidence indicates that surface water does not appear to pose a significant risk to the fish community.

2.4.2 Risks to Benthic Macroinvertebrates

The risks presented to benthic communities residing in sediments located in the Fisherville Pond/Blackstone River System, as evaluated by the various lines of evidence, are discussed in the following sections.

TABLE 2-1

FISH COMMUNITY WEIGHT OF EVIDENCE RISK CHARACTERIZATION SUMMARY

Evidence	Result[a]	Explanation
Biological Surveys	+/-	Fish community and abundance were moderate and typical for freshwater ponds of this type. However, population was dominated by tolerant species, potentially indicating degraded system.
Toxicity Tests	-	Surface water was not toxic to the fathead minnow (*Pimephales promelas*) or *Ceriodaphnia dubia*.
Media Analyses (total water; dry weather sampling)	+	Cadmium exceeded the NAWQC chronic value, fish LCV, daphnid LCV, and Lowest Test EC20 for fish. Copper exceeded the NAWQC acute, NAWQC chronic, fish LCV, daphnid LCV, nondaphnid invertebrate LCV, Lowest Test EC20 for fish, and population EC25 for fish. Lead exceeded the NAWQC chronic value, fish LCV, daphnid LCV, nondaphnid invertebrate LCV, and Lowest Test EC20 for fish. Nickel exceeded the daphnid LCV.
Media Analyses (dissolved water; dry weather sampling)	+/-	Cadmium exceeded the NAWQC chronic value and daphnid LCV. Copper exceeded the NAWQC chronic value, fish LCV, daphnid LCV, nondaphnid invertebrate LCV, Lowest Test EC20 for fish, and Population EC25 for fish. Lead exceeded the NAWQC chronic value, fish LCV, daphnid LCV, nondaphnid invertebrate LCV, and Lowest Test EC20 for fish. Nickel exceeded the daphnid LCV

Evidence	Result[a]	Explanation
Media Analyses (total water; wet weather sampling)	+/-	Cadmium exceeded the NAWQC chronic value and daphnid LCV. Copper exceeded the NAWQC acute, NAWQC chronic, chronic, Fish LCV, daphnid LCV, nondaphnid invertebrate LCV, Lowest Test EC20 for fish, and Population EC25 for fish. Lead exceeded the NAWQC chronic value and daphnid LCV. Nickel exceeded the daphnid LCV. Zinc exceeded the fish LCV.
Weight-of-Evidence	-	Although, media analyses show that metals in the surface water may pose a risk to the fish community, the benchmarks which were used to screen the metals were conservative. Overall, surface water does not appear to pose a significant risk to the fish community.

[a] + Indicates that the evidence may cause a significant reduction in species richness and abundance.

\- Indicates that the evidence most likely will not cause a significant reduction in species richness and abundance.

+/- Indicates that the evidence is ambiguous and not conclusive.

2.4.2.1 Screening of Chemicals Against Benchmarks

Sediments

All maximum chemical concentrations detected in the Fisherville Pond sediments were compared to several available ecotoxicological benchmarks (i.e., Ministry of the Environment (MOE) LELs, PELs, and SELs) to evaluate potential risks to benthic macroinvertebrates. Two techniques of risk characterization were used to apply the literature toxicity information to the chemical concentrations measured in the sediments. The techniques include the calculation of HQs and the calculation and plotting of sums of toxic units (∑TUs). HQs are calculated using the following equation:

$$HQ = \frac{\text{Chemical Concentration in Sediment (mg/kg)}}{\text{Ecotoxicological benchmark}}$$

Hazard Quotient (HQs > 1) for chemicals which exceed the sediment low effects level may indicate the possibility for apparent ecotoxic effects. However, the LEL is a level of sediment contamination that can be tolerated by the majority of benthic organisms. Chemical concentrations which exceed the MOE SEL indicate probable adverse effects where a pronounced disturbance of the sediment-dwelling community can be expected. This is the sediment concentration of a compound that would be detrimental to the majority of benthic species (Persaud et al., 1993).

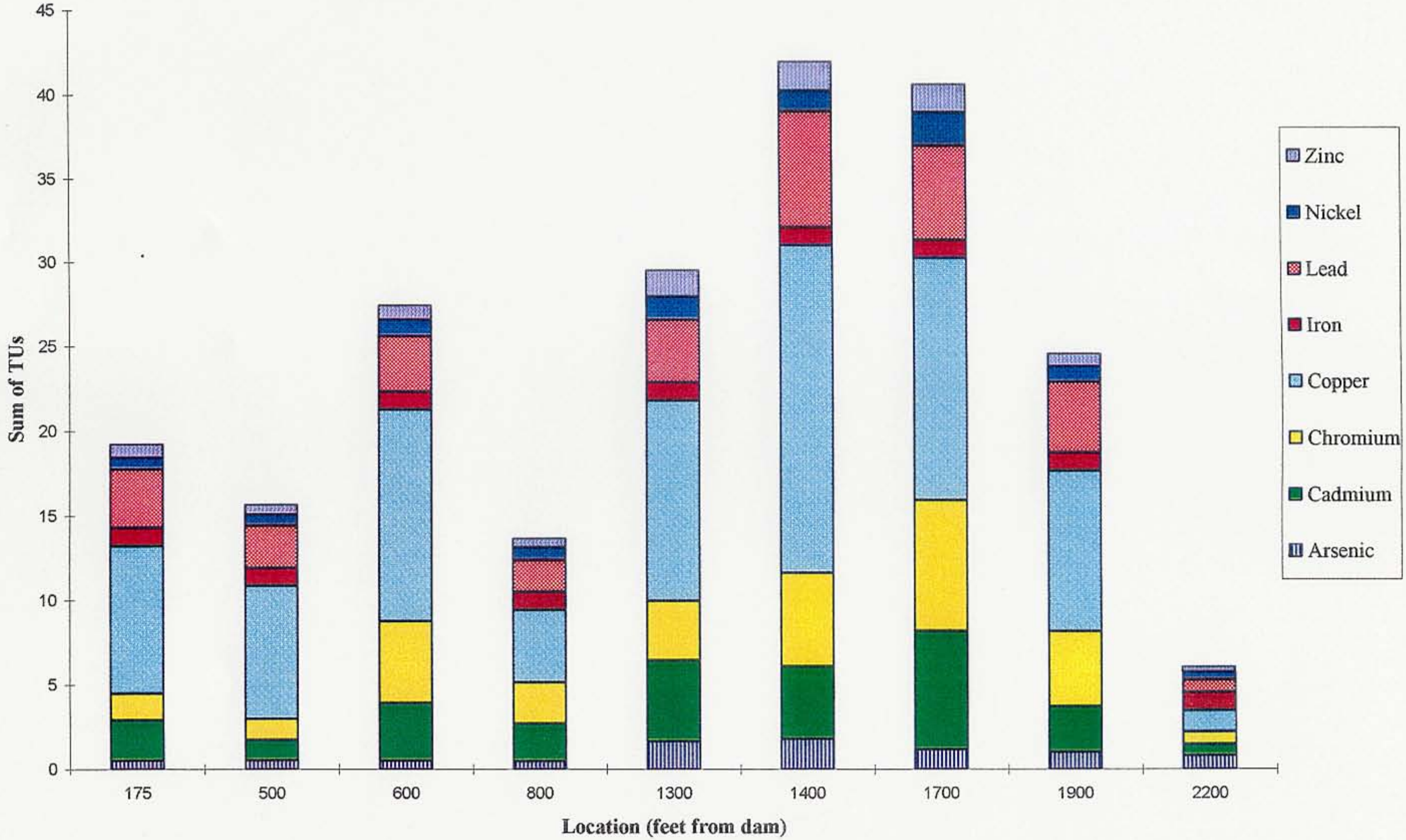
The second technique of risk characterization is calculating and plotting the ∑TUs. This technique results in the view of the COPECs compared to each other and their distribution within Fisherville Pond proceeding upstream from the dam. Since the relative importance of COPECs is a function of their potential toxicity rather than their concentration, toxicity normalized concentrations or toxic units (TUs) were calculated. This is a common technique for presenting exposures to multiple chemicals by expressing concentrations relative to a standard test endpoint. In this case, TUs are the hazard quotients of each chemical concentration compared to the severe effects benchmarks. The

∑TUs represents the magnitude of the total toxicity which may be experienced at each location and indicates the major contributors to that toxicity.

Table A-5 presents the chemicals detected in the Fisherville Pond/Blackstone River system. Fourteen sediment samples were collected at nine locations starting 150 feet from the dam proceeding upstream to the middle of Fisherville Pond. Sediments were collected within the channel of the river, on the bars adjacent to the shoreline, and in the middle of the Pond. These chemical concentrations were screened against ecotoxicological benchmarks and COPECs in sediments were identified (Table F-7). Arsenic (HQ= 0.55), cadmium (HQ=3.4), chromium (HQ=4.9), copper (HQ= 12.5), iron (HQ= 1.1), lead (HQ= 3.4), nickel (HQ=1.0), and zinc (HQ= 0.85) were identified as COPECs for benthic macroinvertebrates inhabiting the Fisherville Pond/Blackstone River System. The HQs presented in parentheses above, are the maximum SEL HQ which was observed for sediments collected upstream or downstream of the Blackstone River confluence. If this HQ is in excess of 1, severe and evident adverse impacts to the benthic community is likely. Figure 2-6 presents the ∑TUs utilizing the SEL benchmark and each chemical detected in sediments throughout the Fisherville Pond/Blackstone River System. The high ∑TUs (6-42) suggests that severe effects may be possible for benthic macroinvertebrates. The primary contributors to the total toxicity was copper, lead, cadmium and chromium. Furthermore, the potential risks to benthic invertebrates are similar above and below the confluence of the Blackstone River. However, total toxicity was much lower at the midpond location within Fisherville Pond (2200 ft from the dam).

Semivolatile organic compounds (SVOCs) and PCBs measured in sediment collected in 1994 (Table A7; Snook, 1994) in the Blackstone River (Figure 1-2) were also screened against ecotoxicological benchmarks (Table F-8). Concentrations of phenanthrene (HQ=10.1), anthracene (HQ=8.8), fluoranthene (HQ=3.1), pyrene (HQ=6.1), chrysene (HQ=4.1), benzo(a)pyrene (HQ=1.2), total petroleum hydrocarbons (TPH) (HQ=11.6) exceeded the SEL benchmarks. These compounds are also identified as COPECs in sediments of the Blackstone River. Consequently, these COPECs may contribute to potential risks to benthic macroinvertebrates at this location. The presence of these

Figure 2-6: Sum of Toxic Units for Sediments in the Fisherville Pond/Blackstone River System



COPECs in upstream areas of the Blackstone also suggests the potential for migration and transport into the Fisherville Pond System.

It is important to note that these potential risks from sediments, as identified in this risk characterization, are likely not representative of current exposures at the site. Most of the chemical concentrations used for this evaluation were measured in sediments collected more than 16 years ago. These chemicals have likely been transported over the dam, settled directly behind the dam, and/or are buried under sediments which have been deposited from upstream locations. It is highly likely that the present chemical concentrations in sediments are much lower than that observed 16 years ago.

<u>Pore Water</u>

Since benthic macroinvertebrates are primarily exposed to the interstitial water (i.e., pore water) concentration, pore water concentrations measured in 1991 were also compared to aqueous ecotoxicological benchmarks. Table F-9 presents the maximum chemical concentration detected in pore water, the ecotoxicological benchmarks` (i.e., NAWQC, daphnid LCV, or LCV non-daphnid LCV; Section 2.3) and associated hazard quotients. Maximum aluminum, cadmium, chromium, copper and lead concentrations measured in pore water exceeded the NAWQC chronic and/or acute values. Additionally, copper (HQ= 521.7), cadmium (HQ= 40) and lead (HQ= 4.4) exceeded the lowest chronic value for daphnids. The exceedence of these ecotoxicological benchmarks indicates that the pore water concentration measured from sediments collected in 1991 may have caused chronic or acute adverse impacts to sediment-associated biota in Fisherville Pond.

2.4.2.2 Ambient Toxicity Testing

<u>Sediment</u>

Significant mortality (28%) of *Chironomous tentans* was observed from the sediment sample collected in October 1991. Mortality for *Hyallela azteca* was not significantly higher in the July 1991 sediment sample, but was elevated (40%) in the October 1991 sediment sample. Based on the limited results presented for the toxicity tests conducted in 1991, the sediments within Fisherville Pond may be toxic to sediment associated biota.

Pore Water

Survival of fathead minnows and *Ceriodaphnia* was significantly reduced (0% survival) when exposed to pore water collected from samples in November 1991. In contrast, sediment pore water did not adversely impact the minnows or Ceriodaphnia (100% survival) during July toxicity tests. These results suggests that the pore water may be toxic to benthic fish or benthic macroinvertebrates. However, the variability of the potential for impacts during different sampling events is likely a factor of the heterogeneity of the sediments present in the Fisherville Pond.

2.4.2.3 Benthic Macroinvertebrate Survey

Most of the invertebrates identified were common to and similar to those in other "nonimpacted" northeastern freshwater lentic (low-flowing) systems. Additionally, the species composition of the community are not atypical of lotic (actively moving water) systems with organic rich sediment. A total of twelve taxa were identified at the Site. The majority of the locations were dominated by aquatic earthworms (Annelida), chironomid midges and damselflies (Insecta), snails (Mollusca), and amphipods (Crustacea). Aquatic earthworms accounted for over 75% of the total number of organisms identified. The density of these organisms observed at the Site were somewhat low relative to similar unimpacted systems. The lack of ETP could be present in the system in the fall, however, as early instars the organisms may not be well represented in ponar grab samples. However, natural sample variability at each location makes data interpretation difficult. In summary, the existing data (based on the collection of 5 sediment samples) suggests that the benthic macroinvertebrate community within Fisherville Pond is not severely impacted. However, additional sampling is necessary to determine the magnitude of potential adverse impacts to the benthic invertebrate community.

It is important to note that the suggestion by the biological survey data of the relative lack of impacts to the benthic community is very meaningful from a temporal evaluation. The chemical and bioassay data developed in the past indicates that historic sediment concentrations pose a risk to benthic invertebrates. However, the more recent biological data (1996) suggests that fate and transport mechanisms and pond sedimentation may have reduced the level of risk posed by sediments.

2.4.2.4 Weight of Evidence Summary

Three lines of evidence were evaluated to assess the potential for ecological impacts to the benthic community of Fisherville Pond. Those lines included benthic macroinvertebrate surveys, toxicity tests and media analysis. Table 2-2 summarizes the lines of evidence evaluated to assess the potential for ecological impacts to the benthic macroinvertebrate community. The final weight-of-evidence indicates that chemicals measured in sediments on Site may pose a significant risk to the benthic macroinvertebrate community.

2.4.3 Risks To Amphibians

There are no benchmarks or criteria that have been published for bullfrogs specifically, or amphibians in general. Data in the scientific literature is limited regarding the potential effects of COPECs on amphibians. As noted in Section 2.2.3, the bullfrog will be compared to surface water and sediment concentrations identified in Fisherville Pond, with direct contact as the primary route of exposure.

TABLE 2-2

BENTHIC MACROINVERTEBRATE COMMUNITY WEIGHT OF EVIDENCE RISK CHARACTERIZATION SUMMARY

Evidence	Result[a]	Explanation
Biological Surveys	-	The benthic community diversity and abundance is similar to that of "unimpacted" northeastern lentic systems.
Toxicity Tests	+/-	Significant mortality of *Chironomous tentans* was seen in one sample. Mortality of *Hyallela azteca* was significantly higher in one sample, but was not significantly higher in a second sample.
Media Analyses	+	Sediments exceeded the LEL and PEL for arsenic, cadmium, chromium, copper, lead, nickel and zinc. Iron exceeded the LEL and SEL. Cadmium, chromium, copper, lead, and nickel exceeded their respective SELs. SVOCs (phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo(a)pyrene, and total petroleum hydrocarbons) exceeded the SELs in upstream areas of the Blackstone River.
Weight-of-Evidence	+	While the benthic survey suggests that the community is viable, as a result of the media analyses and toxicity test data, it is concluded that sediments may pose a significant risk to the benthic invertebrate community. Again, the biological survey data does indicate that this is a conservative risk estimation.

[a] + Indicates that the evidence may cause a significant reduction in species richness and abundance.
- Indicates that the evidence most likely will not cause a significant reduction in species richness and abundance.
+/- Indicates that the evidence is ambiguous and not conclusive.

Assuming that amphibians are as sensitive as fish, the HQ discussion presented in Section 2.4.1.1 suggests that bullfrogs would potentially be at risk from exposure to cadmium, copper, lead, and nickel in surface water, and arsenic, cadmium, chromium, copper, iron, lead, nickel, and zinc, as discussed for aquatic biota in Section 2.4.2.1. However, Mason (1991) notes that amphibians are generally less sensitive to chemical contamination than fish. Hall and Mulhern (1984) suggest that Anuran amphibians may accumulate certain heavy metals, such as copper, cadmium, and lead. Concentrations of COPECs in both total and dissolved surface water samples are generally lower that natural body burdens identified in Hall and Mulhern (1984). Concentrations of sediment COPECs, however, all exceed the natural body burdens for heavy metals identified in their study. This suggests that bullfrogs may accumulate metals from exposure to sediments, but not to surface water.

2.4.4 Risks To Herbivorous, Piscivorous, and Omnivorous Wildlife

The risks presented to herbivorous, piscivorous, and omnivorous wildlife living in the Fisherville Pond/Blackstone River System are discussed in the following sections.

2.4.4.1 Screening of Chemicals Against Benchmarks

COPECs for herbivorous (mallard), piscivorous (great blue heron) and omnivorous (muskrat) wildlife were identified by comparing the total chemical exposure experienced by each endpoint (Section 2.2.4.1 to 2.2.4.3) to ecotoxicological benchmarks (Section 2.3.1). Two types of single chemical toxicity data are available with which to evaluate wildlife contaminant exposure: NOAELs and LOAELs. The total chemical exposure estimates for each endpoint were first compared to estimated NOAELs to determine if adverse effects are possible from foraging in Fisherville Pond. If the chemical exposures exceed the NOAEL, the total exposures were then compared to LOAELs. If the LOAEL is lower than the exposure, then portions of the endpoint population may experience contaminant exposures from COPECs that are likely to produce adverse effects. Consequently, the *individuals* foraging within Fisherville Pond may be at risk due to hazardous exposures.

Hazard Quotients (HQs) were calculated to identify COPECs and quantify the magnitude of the potential hazard in Fisherville Pond. HQs were calculated using the following formula:

$$HQ = \frac{\text{Estimated Chemical Exposure (mg/kg/day)}}{\text{NOAEL}}$$

HQs greater than one indicate that individuals foraging at the site may experience adverse effects. NOAEL HQs for the mallard, great blue heron, and muskrat are presented in Tables F-2, F-3 and F-4, respectively (Appendix F). COPEC exposures, identified by an exceedance of the NOAEL, were then compared to the LOAEL to estimate potential effects (Table 2-3).

The results of this risk screening process identified the following COPECs from ingestion of contaminated plants, fish, sediment, and/or surface water for each endpoint.

Herbivorous Wildlife (Mallard): The total exposures for herbivorous wildlife are based on the assumption that surface sediments/soils in the terrestrial habitat on site are equivalent to the maximum sediment concentration measured in the Fisherville Pond/Blackstone River system. Based on this assumption, chromium and lead were the only COPECS which may pose a risk to herbivorous wildlife foraging in the wetland and riparian areas. Total exposures of these COPECs experienced by the mallard exceeded NOAELs, indicating a potential for the occurrence of adverse effects. However, total exposures from chromium and lead were only 11.9% and 57 % of the LOAELs, respectively (Table 2-3). Therefore, it is unlikely that mallards are experiencing adverse effects due to foraging on wetland vegetation in the Fisherville Pond/Blackstone River system.

Piscivorous Wildlife (Great Blue Heron): Mercury was the only COPEC detected in fish collected from Fisherville Pond. Total exposures of this COPEC experienced by the great blue heron exceeded NOAELs, indicating a potential for the occurrence of adverse effects. However, exposures from the consumption of mercury in fish were 82.9% of the LOAEL (Table 2-3). Therefore, it is unlikely

Table 2-3: Total Chemical Exposure, LOAEL Benchmarks, and Associated
Hazard Quotients (HQs) for Wildlife Foraging in the Fisherville Pond/Blackstone River System

Chemical	Exposure Estimate (mg/kg/d)					NOAEL[a] Benchmark (mg/kg/day)	NOAEL HQ	LOAEL[b] Benchmark (mg/kg/day)	LOAEL HQ
	Plant	Fish	Water	Sed/Soil	Total				
MALLARD									
Chromium	0.9033	NA	0.0002	0.4406	1.3442	1.000	**1.344**	11.3	0.1190
Lead	1.9829	NA	0.0028	0.8813	2.8670	1.130	**2.537**	5	0.5734
GREAT BLUE HERON									
Mercury	0.0000	0.053	0.000	0.0000	0.0531	0.006	**8.292**	0.064	0.8292
MUSKRAT									
Aluminum	1.9384	0.0000	0.0000	47.8800	49.8184	0.756	**65.907**	7.56	**6.5897**
Arsenic	0.0041	0.0002	0.0000	0.1008	0.1050	0.049	**2.129**	0.49	0.2144
Copper	13.1167	0.0015	0.0213	3.2400	16.3796	11.011	**1.488**	14.49	**1.1304**

[a] NOAEL: No Observable Adverse Effects Levels (Sample et. al., 1996)

[b] LOAEL: Lowest Observable Adverse Effects Levels (Sample et. al., 1996)

Bolded Chemicals are considered Chemicals of Potential Ecological Concern.

that great blue herons are experiencing adverse effects due to fish consumption from Fisherville Pond.

Omnivorous Wildlife (Muskrat): Aluminum, arsenic and copper were identified as COPECs which were detected in sediments and plants (estimated concentrations) along the riparian and wetland areas of the Fisherville Pond/Blackstone River system. Exposure from fish consumption (only 5 % of the diet) contributed minimally to the total exposure potentially experienced from these COPECs. Exposures experienced by the muskrat exceeded NOAELs, indicating a potential for the occurrence of adverse effects. Exposure from arsenic was only 21 % of the LOAEL (Table 2-3). Therefore, it is unlikely that muskrats are experiencing adverse effects due to foraging within Fisherville Pond from this chemical. In contrast, estimated total exposures for aluminum and arsenic were 6.6 and 1.1 times the LOAEL, respectively. Consequently, individuals foraging exclusively within Fisherville Pond may possibly experience adverse effects from aluminum and arsenic.

Effects Estimation of Retained COPECs

Aluminum: The NOAEL and LOAEL for the muskrat are based upon a study of the reproductive success of mice for three generations (Ondreicka et al., 1966). The study was considered to represent chronic exposure. A single oral dose level (19.3 mg/kd/d) was administered causing a significant reduction in growth rate or body weight of the second and third generation of mice. This dose did not cause effects on the number of litters or number of offspring per litter. This dose level was selected as the chronic LOAEL. Because an experimental NOAEL was not established, the NOAEL was estimated by multiplying the chronic LOAEL by a LOAEL-NOAEL uncertainty factor of 0.1 (Sample et al., 1996). The NOAEL and LOAEL for the muskrat are 0.756 and 7.56 mg/kg/d, respectively.

A reduction in offspring growth for individual muskrats may potentially result from the exposure to aluminum in surface soils/sediments and plants surrounding the Fisherville Pond/Blackstone River system (LOAEL HQ= 6.6). However, the occurrence of potential adverse effects are dependent on the bioavailability of aluminum in soil/sediments. The study used to derive the LOAEL is based on administration of aluminum chloride in a water solution. The actual bioavailability of aluminum from soil is much lower than that of the laboratory study. Overall, risks to offspring growth may be reduced due to low bioavailability within soils/sediments of the site.

Arsenic: The NOAEL and LOAEL for the muskrat are based upon a study on the reproductive success of mice (Schroeder and Mitchner 1971) during 3 generations. A single oral dose (5 mg/L in water + 0.06 mg/kg in food= 1.26 mg/kg/d) was administered causing a declining litter size with each successive generation. Since the study considered exposure over a year and included a critical life stage, this dose was considered to be a chronic LOAEL. Because an experimental NOAEL was not established, the NOAEL was estimated by multiplying the chronic LOAEL by a LOAEL-NOAEL uncertainty factor of 0.1 (Sample et al. 1995). The NOAEL and LOAEL for the muskrat are 0.049 and 0.49 mg/kg/d, respectively.

Estimated arsenic exposure to the muskrat was below the LOAEL (HQ=0.21). Therefore, impacts on reproductive success on individuals foraging within these areas are unlikely. Because an experimental NOAEL was not established, the nature and exposure level at which effects to individuals may become evident cannot be defined. Also, the effects which may possibly occur, are likely to be less pronounced than that displayed by individuals where exposure is greater than the LOAEL.

Chromium: The mallard NOAEL and LOAEL for chromium were derived from a study of black ducks fed Cr+3 for ten months. (Haseltine et al., Unpublished. Data). Consumption of 5 mg/kg/day chromium reduced duckling survival. However, no adverse effects were observed at an exposure level of 1 mg/kg/day. Since this study was considered to represent a chronic exposure, no subchronic-chronic correction factor was employed. The 1 mg/kg/day exposure was considered to be a chronic NOAEL. The 5 mg/kg/day exposure was considered to be a chronic LOAEL. Based on the results of Haseltine et al. (Unpublished Data), mallards experiencing exposure ≥ LOAEL are likely to have reduced survival of offspring.

Copper: Both the NOAEL and LOAEL for the muskrat are based on a study in which mink were fed copper sulfate for 357 days (including a critical life stage) (Aulerich et al., 1982). Consumption of 15.14 mg/kg/day copper increased the percentage of mortality in mink kits. However, no adverse effects were observed at a 11.71 mg/kg/day exposure level. Based on the results of Aulerich et al. (1982), muskrats experiencing exposures ≥ LOAEL may display a reduction in offspring survival.

Lead: Both the NOAEL and LOAEL for the mallard are based on a study in which Japanese quail were fed lead acetate for 12 weeks (including a critical life stage) (Edens et al., 1976). Doses of 1, 10, 100, and 1000 ppm of lead in the diet was administered. Egg hatching success was reduced in birds consuming the 100 ppm lead dose. Reproduction was not impaired in birds receiving the 10 ppm lead dose. Based on a kg/day of food consumed, the NOAEL was calculated by Edens et al. (1976) to be 1.13 mg/kg/day and the LOAEL was 11.3 mg/kg/day. Both are considered chronic values since the birds were exposed over 12 weeks and through a critical life stage (reproduction). Since the total mallard lead exposure was only 57% of the LOAEL, reproduction is unlikely to be impaired

Mercury: To be conservative, it was assumed that 100 % of the mercury to which piscivores are exposed consists of methylmercury. Both the NOAEL and the LOAEL are based upon a study of mallard ducks fed methylmercury for three generations (Heinz 1979). Since, this study was considered to represent a chronic exposure, no subchronic-chronic correction factor was used. The only dose level administered, 0.064 mg/kg/day, caused hens to lay fewer eggs, lay more eggs outside the nest box, and produce fewer ducklings. This dose level was considered to be a LOAEL. No experimental NOAEL was established. The NOAEL was estimated using a LOAEL-NOAEL correction factor of 0.1. Based on the results of Heinz (1979), birds experiencing exposures ≥

LOAEL are likely to display impaired reproduction. Although the total exposure was approaching the LOAEL (HQ=0.83), great blue herons are not likely to experience reproductive impairment due to their mobility and large home range. It is unlikely that great blue herons would consistently feed for extended periods of time on maximally contaminated fish.

2.4.5 Risk Characterization Summary

A summary of the risk characterization of this ERC for each endpoint receptor is presented in Table 2-4.

2.5 UNCERTAINTIES

The following uncertainties were considered in the development of this ERC.

2.5.1 Uncertainties Concerning Risks to the Fish Community

- **Temporal Variability**. The dry weather surface water samples were collected from one location in the Fisherville Pond in 1991. Because of the brevity of the sampling event, the total and dissolved concentrations measured at that time may not be representative of the current exposures experienced by the fish or pelagic invertebrate community inhabiting the Fisherville Pond/Blackstone River system.

- **Chemical Screening**. The comparison of laboratory toxicity data for individual chemicals to measured concentrations of individual chemicals in the environment does not address the potential for combined effects of multiple chemicals, the effects of site-specific conditions on contaminant availability and toxicity, or the range of responses of individual species of different life stages. Additionally, test organisms used in the development of the benchmarks may not be representative of species found in the pond.

TABLE 2-4

WEIGHT OF EVIDENCE
RISK CHARACTERIZATION SUMMARY

Endpoint	Result[a]	Explanation
Fish Community	-	Although, media analyses show that metals in the surface water may pose a risk to the fish community, the benchmarks which were used to screen the metals were conservative. Overall, surface water does not appear to pose a significant risk to the fish community.
Benthic Macroinvertebrate Community	+	While the benthic survey suggests that the community is viable, as a result of the media analyses and toxicity test data, it is concluded that sediments may pose a significant risk to the benthic invertebrate community. The biological survey data does indicate that this is a conservative risk estimation.
Herbivorous Wildlife (Mallard)	-	Potential mallard exposures to chromium and lead exceeded NOAELs. However, total exposures from chromium and lead were only 11.9% and 57% of the LOAELs, respectively. It is unlikely that mallards are experiencing adverse effects.
Piscivorous Wildlife (Great Blue Heron)	-	Although potential great blue heron exposures exceed the NOAEL for mercury, exposures did not exceed the LOAEL. It is unlikely that great blue herons are experiencing adverse effects.

Endpoint	Result[a]	Explanation
Omnivorous Wildlife (Muskrat)	+	Potential muskrat exposures exceed the NOAELs for aluminum, arsenic, and copper. Potential muskrat exposure to aluminum and arsenic were 6.6 and 1.1 times the LOAEL, respectively. Muskrats may possibly experience adverse effects from aluminum and arsenic.

[a] + Indicates that the evidence may cause a significant reduction in species richness and abundance.

\- Indicates that the evidence most likely will not cause a significant reduction in species richness and abundance.

+/- Indicates that the evidence is ambiguous and not conclusive.

- **Multiple Benchmarks**. Water toxicity data is much more standardized than soil or sediment toxicity data. However, alternative methods for calculating thresholds for aquatic toxic effects from laboratory tests produce benchmarks that vary over a range greater than two orders of magnitude (Suter et al., 1992).

2.5.2 Uncertainties Concerning Risks to Benthic Macroinvertebrate Community

- **Chemical Concentrations Measured in Sediment Samples.** Risks to the benthic community were evaluated based on the concentrations found in sediment samples collected in 1981. Due to sedimentation and transport of historical sediments within the Fisherville Pond/Blackstone River system, these concentrations in sediments may not be representative of current exposure to the benthic invertebrate community.

- **Toxicity Tests**. The relationship between observed sediment toxicity and the chemical and physical data are uncertain. Because sediment contamination may be very heterogeneous, the exposures received by test organisms may be different from those estimated using the chemical analyses data.

2.5.3 Uncertainties Concerning Risks to Wildlife

- **Soil Concentrations Equivalent to Sediment Concentrations.** The relationship between soil samples collected in Areas A and B in the riparian zones and the sediments to sediments collected in 1981 is uncertain. The use of sediment data to infer soil exposures for wildlife may tend to either overestimate or underestimate the levels of risk.

- **Soil to Vegetation Uptake Factors**. There is a large degree of uncertainty when using soil to vegetation uptake factors to model chemicals found in vegetation. Uptake factors of inorganics will vary by soil condition (i.e., pH, water availability, organic matter content, texture, aeration, elemental concentrations, etc.) (Sommers et al., 1987; Chaney et al., 1984). Using plant uptake factors assumes that all species and all soil conditions will result in the same uptake rate. Also, using uptake factors assumes that the uptake rate is best estimated by taking the average of all observed values. The Site specific factors within each AOI were not taken into consideration for the uptake factors which were used. Therefore, the predicted contaminant concentrations in vegetation may be overestimated or underestimated; thus overestimating or underestimating contaminant exposure for herbivorous wildlife.

- **Bioavailability of Chemicals.** It was assumed that 100% of the chemical concentrations reported in soil and modeled vegetation were bioavailable. The double acid extraction method used to determine soil concentrations reflects the total potential pool of contaminants. The future bioavailability of these contaminants, which is dependent upon the chemical (e.g., pH, organic carbon) and physical (e.g., clay, moisture content) nature of the soil, can not be addressed for this assessment. Therefore, exposure estimates based upon the contaminant concentrations in media are highly conservative and are likely to overestimate the actual contaminant exposure experienced.

- **Extrapolation from Published Toxicity Data.** To estimate toxicity of contaminants at the Site, it was necessary to extrapolate from NOAELs observed for test species (i.e., rats and mice). While it was assumed that toxicity could be estimated as a function of body size, the accuracy of the estimate is not known. For example, great blue herons may be more or less sensitive than rats or mice to a particular chemical.

  Additional extrapolation uncertainty exists for those chemicals for which data consisted of either LOAELs or was subchronic in duration. For either case, an uncertainty factor of 0.1 was employed to estimate NOAELs or chronic data. The uncertainty factor of 0.1 may either over- or underestimate the actual LOAEL-NOAEL or subchronic-chronic relationship.

Due to the limitations of the toxicity data used to calculate the NOAEL and LOAEL, the exact level at which adverse effects may occur is unknown. The specific exposure concentration which may adversely impact the endpoint species may actually lie between the NOAEL and LOAEL. Therefore, there is a potential for impacts to occur to individuals if exposures to the receptor are below the LOAEL. However, impacts on the endpoint population are highly unlikely.

- **Variable Food and Water Consumption.** While food consumption by wildlife was assumed to be similar to that reported for the same species in other locations, the validity of this assumption cannot be determined. Food consumption may be greater or less than that reported in the literature, resulting in either an increase or decrease in chemical exposure. Similarly, water consumption was estimated according to the allometric equations of Calder and Braun (1983). The accuracy with which the estimated water consumption represents actual water consumption is unknown.

- **Wildlife Home Range Within Territory of the Study Area.** From a conservative standpoint, it was assumed that the three species used in the assessment would be exposed to the COPECs for 100% of their life span. In actuality, Fisherville pond will account for only a fraction of the area utilized by the organisms for foraging as a result of migration and home range patterns.

3.0 HUMAN HEALTH RISK CHARACTERIZATION

3.1 INTRODUCTION

This Human Health Risk Characterization (HHRC) evaluates the potential carcinogenic risk and noncarcinogenic hazard associated with human exposure to the COCs detected in surface water, sediment, and fish tissue in the Fisherville Pond. The quantitative estimate of potential risk presented here was developed using conservative exposure assumptions in accordance with USEPA (USEPA Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A [EPA/540/1-89/002]) (1989a) and Massachusetts Department of Environmental Protection (Guidance for Disposal Site Risk Characterization in Support of the Massachusetts Contingency Plan, (1995)) risk assessment methodology. This characterization employed the following four steps in developing risk estimates for each COC detected in surface water, sediment, and fish tissue in the Fisherville Pond.

- Data Evaluation
- Toxicity Assessment
- Exposure Assessment
- Risk Characterization

3.2 DATA EVALUATION

An evaluation of historical data collected by the ACOE was conducted to identify the chemicals detected in surface water, sediment, and fish tissue samples from the Fisherville Pond. The data incorporated into the HHRC was obtained from the following sources and is in Appendix A:

- Surface Water

  Surface water samples were collected and submitted for analysis for inorganics. Results of these analyses are presented in the *Blackstone River Initiative: Water Quality Analysis of the Blackstone River Under Wet and Dry Weather Conditions*, The University of Rhode Island, the Massachusetts Department of Environmental Protection and U.S. EPA Lexington in cooperation with the U.S. EPA Region I and the Rhode Island Department of Environmental Management, 1996.

- Sediment

  Sediment samples collected in 1981 were submitted for analysis of inorganics. Analytical results are presented in *A Sediment Control Plan for the Blackstone River*, Joseph M. McGinn, Department of Environmental Quality Engineering, Office of Planning and Program Management, 1981. Additional sediment samples were collected from the Blackstone River in December 1994 and January 1995. These samples were submitted for analysis of PAHs, PCBs and TPH. Results of this sampling effort are presented in *Gas Chromatography-Mass Spectrometry Analysis of Semivolatile Organic Compounds and Special Analysis*, H. Snook, Massachusetts Department of Environmental Protection, Division of Environmental Analysis, William Wall Experiment Station, 1995.

- Fish Tissue

  Fish tissue samples were collected and submitted for analysis of inorganics, pesticides, and PCBs. The data are presented in the *Blackstone River Initiative: Water Quality Analysis of the Blackstone River Under Wet and Dry Weather Conditions*, The University of Rhode Island, the Massachusetts Department of Environmental Protection and U.S. EPA Lexington in cooperation with the U.S. EPA Region I and the Rhode Island Department of Environmental Management, 1996.

3.2.1 Determination of Chemicals of Concern (COCs)

The maximum detected concentration of chemicals in the sediments and surface water in Fisherville Pond were compared to several chemical-specific criteria to determine the COCs likely to contribute the majority of potential risk for this evaluation. These comparison criteria included the USEPA

Region III Risk-Based Concentrations (RBCs) for tap water, residential soil ingestion, and fish consumption; the USEPA Maximum Contaminant Levels (MCLs) for drinking water; the MA DEP Drinking Water Standards; and the MA Contingency Plan Method I soil standards. Tables H-1 through H-3 (Appendix H) present the standards to which the maximum detected concentrations were compared.

The maximum concentrations of inorganics detected in surface water were compared with MCLs for drinking water, the RBCs for tap water, and the MA DEP Drinking Water Standards. Lead was the only analyte detected at a maximum concentration which exceeds the screening criteria. Subsequently, lead represents the single COC identified in surface water.

The maximum concentrations of PAHs and inorganics detected in sediments were compared to RBCs for residential soil ingestion, the MA Contingency Plan Method I soil standards and the MA DEP background levels for inorganic compounds. Several compounds were detected at maximum concentrations which exceed the screening criteria. Although one of the PAHs detected, phenanthrene, does exceed the MA soil standard for this compound, no RBC is available because no toxicity criteria have been developed for this compound. Subsequently, quantitative analysis of the potential risks associated with exposure to phenanthrene in sediment is not possible. The COCs identified in sediment include benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, chrysene, arsenic, cadmium, chromium, and lead.

The maximum concentrations of inorganics and PCBs detected in edible fish tissue were compared with RBCs for fish. The maximum detected concentrations of PCBs exceeded the screening criteria and the COCs identified in fish tissue include Aroclors 1254 and 1260.

3.3 TOXICITY ASSESSMENT

As noted above, the COCs examined in this risk characterization include: PAHs (benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, and chrysene), inorganics (arsenic, cadmium, chromium, and lead) and PCBs (Aroclors 1254 and 1260). The quantification of potential risk is ultimately based upon the chemical-specific toxicity criteria for the individual COCs. These toxicity criteria are represented by cancer potency or slope factors (CSFs) for assessing potential carcinogenic risks and reference doses (RfDs) for the evaluation of the noncarcinogenic hazards associated with exposure to the COCs. The toxicity criteria for COCs identified in the Fisherville Pond water and sediments were primarily referenced from the USEPA Integrated Risk Information System (IRIS) (USEPA, 1997). The USEPA Region III RBC Table (USEPA, 1996c) was also consulted when adequate data were not available through IRIS.

For noncarcinogenic COCs, NOAELs and LOAELs derived from both animal and human studies are used by the USEPA to establish chronic RfDs for humans. The USEPA (1989a) defines the chronic RfD "...as an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime." Uncertainty factors are incorporated into RfDs in an attempt to account for limitations in the quality or quantity of available data. For the purposes of this HHRC, RfDs established by the USEPA provide the basis for assessing potential noncarcinogenic chronic health risks for receptor populations.

Carcinogenesis is currently considered to be a non-threshold phenomenon by USEPA. Therefore, it is assumed that any dose of a carcinogen, no matter how small, presents some degree of risk. Cancer slope factors (CSFs) are considered to represent plausible upper bounds of risk at a 95 percent upper confidence level (95% UCL). Thus, there is a 95% probability that the actual risks will not exceed these calculated values, and are likely to be much lower. Table 3.1 presents the toxicity criteria used to estimate the potential noncarcinogenic and carcinogenic risks associated with the exposure pathways evaluated for this assessment.

Table 3.1 Carcinogenic and Noncarcinogenic Toxicity Criteria

Chemical of Concern	Oral Chronic Reference Dose (RfD) (mg/kg-day)	Oral Cancer Slope Factor (CSF) (mg/kg-day)	Reference
Benzo(a)anthracene	NE	7.3 E-01	USEPA, 1997
Benzo(b)fluoranthene	NE	7.3 E-01	USEPA, 1997
Benzo(a)pyrene	NE	7.3 E+00	USEPA, 1997
Chrysene	NE	7.3 E-03	USEPA, 1997
Arsenic	3.00 E-04	1.5 E+00	USEPA, 1996c
Cadmium	5.00 E-04	6.3 E+00[1]	USEPA, 1996c
Chromium	5.00 E-03	4.2 E +01[1]	USEPA, 1996c
Lead	NE	NE	
Aroclor 1254	2.00 E-05	2.0 E+00	RfD: USEPA, 1996c CSF: EPA, 1996b
Aroclor 1260	2.00 E-05	2.0 E+00	RfD: USEPA, 1996c CSF: EPA, 1996b

NE: None established.
[1] The inhalation CSF is used in the absence of an oral CSF for these analytes.

3.3.1 Toxicity Profiles for COCs in Surface Water, Sediment, and Fish Tissue

The potential adverse health effects in humans that may be associated with exposure to COCs are presented in the following toxicity profiles. These profiles include a brief discussion of the use of each chemical, and its adverse effects on humans.

3.3.1.1 Arsenic

Arsenic is used as a chemical intermediate to produce pesticides and feed additives, in the manufacture of glass, nonferrous alloys, electronic devices, as a catalyst in the chemical industry, and as an intermediate in veterinary medicine (ATSDR, 1987). It is generally well-absorbed, distributed, and metabolized by both humans and animals, but is not thought to accumulate in the body to any appreciable extent (USEPA, 1984a). Acute exposure to high-levels of arsenic can result in severe gastrointestinal tract damage and general vascular collapse. Inhalation exposure to arsenic can produce irritation to the nasal mucosa, larynx, and bronchi. Chronic exposure via oral and inhalation pathways is associated with a number of skin conditions, as well as neurological and cardiovascular impacts (USEPA, 1984b). Epidemiologic studies have associated human exposure to arsenic, via inhalation, with increased incidence of lung cancer. In addition, drinking water containing high levels of arsenic have been associated with increased incidence of skin cancer in several populations studies, notably in Taiwan (ATSDR, 1987).

3.3.1.2 Cadmium

Cadmium is a naturally occurring metal which is used for a number of industrial purposes including electroplating, color pigmenting of plastics and paints, as an electrode component in batteries, and in production of copper-cadmium alloys (Friberg et al., 1986). It is poorly absorbed after exposure via ingestion, but inhaled cadmium, particularly the soluble compounds, is more extensively absorbed. Once absorbed it has a strong affinity for the kidney and liver and tends to accumulate in the body (USEPA, 1984c). The primary adverse health effect associated with long-term cadmium exposure is kidney dysfunction, which can lead to disturbances in mineral metabolism and ultimately to the formation of kidney stones. An association between lung cancer and inhalation exposure to cadmium has been suggested by epidemiologic studies of occupational exposures. No epidemiologic studies of cancer induction in humans due to exposure to the oral route have been conducted (ATSDR, 1987). Although studies with experimental animals have also demonstrated cadmium to be carcinogenic by inhalation, oral studies in animals have found no significant carcinogenic potential.

3.3.1.3 Chromium

Chromium is a naturally occurring metal used primarily in the metallurgic, refractory, and chemical industries. It is also used in leather tanning, pigment production, graphics, and industries using chromium alloys or plated materials (USEPA, 1984e). Chromium can be ingested or inhaled, but inhalation exposure appears to be the primary route of exposure. (USEPA, 1984d; USEPA, 1984e). Absorbed chromium can be distributed throughout the body and temporarily stored in a variety of soft tissues. The lungs are the only tissue which appear to accumulate chromium with age. In concentrations below those associated with adverse effects, chromium is an essential element in human nutrition. The daily requirement for chromium has been estimated to be approximately 50 μg/day (USEPA, 1984e). Inhalation exposures to chromium compounds have been associated with nasal damage, such as perforated septum, nosebleeds, and inflamed mucosa. Skin contact with high levels of chromium compounds has been reported to produce an eczema-like condition (USEPA, 1984e). Experimental studies of oral exposure to hexavalent chromium (Cr^{+6}) have not conclusively demonstrated any adverse effects by this route. However, large doses have been associated with kidney damage (USEPA, 1984e), and the primary toxic effect of concern for Cr^{+6} is respiratory cancer. Numerous studies of occupational inhalation exposures in the chromate, chrome-plating, and chrome pigment industries have found increased incidence of respiratory cancers in groups exposed to chromium compounds via inhalation.

3.3.1.4 Lead

Lead is a naturally occurring metal which is widespread in the environment. It has been used industrially in the manufacture of batteries, various metal products, paints, and in leaded gasoline.

Due to the adverse health effects associated with lead, there has been a reduction in use in recent years (ATSDR, 1990). Lead is stored in humans in bone, kidney, and the liver. The primary adverse effects in humans include alterations in heme synthesis and nervous system development. Toxic blood concentrations in children and in sensitive adults can cause severe, irreversible brain damage, encephalopathy, and possible death. Physiological and biochemical effects that may occur even at low levels include enzyme inhibition, interference with vitamin D metabolism, cognitive dysfunction in infants, electrophysiological dysfunction, and reduced childhood growth (ATSDR, 1990). Exposure to lead has also been associated with developmental effects in humans such as reduced birth weight, gestational age, and neurobehavioral deficits or delays (ATSDR, 1990). Suspected carcinogenic potential is based on a number of animal studies showing increased numbers of kidney tumors following exposure to soluble lead salts (IRIS, 1992). However, human data from epidemiological studies are inconclusive (IRIS, 1992).

3.3.1.5 PCBs - Aroclor 1254 and Aroclor 1260

Polychlorinated biphenyls (PCBs) are a class of compounds comprised of 209 individual congeners. Commercial PCBs were manufactured in the United States by Monsanto Chemical Company and sold under the industrial trade named, Aroclor® (ATSDR, 1995). Commercially used PCBs are mixtures of individual PCB congeners that contain specified percentages of chlorine; for example, Aroclor 1254 contains 54 percent chlorine by weight. Until their ban in July 1979, Polychlorinated biphenyls were largely used in electrical capacitors and transformers. Additionally, PCBs were used as electrical insulators, lubricants, hydraulic fluids, diffusion pump oils, cutting oils, plasticizers, liquid seals, and paint additives (ATSDR, 1995). The environmental fate and transport of PCBs involve absorption to particulate and organic matter, volatilization, biodegradation, and photolysis. Reported half-lives in soil for PCBs range from 2 months for lower chlorinated congeners to 2 to 6 years for higher chlorinated congeners (Iwata et al., 1973, McClure, 1976, Edulje, 1987). Rats exposed to PCBs via oral exposure for acute durations have been reported to result in hepatotoxicity (Kling et al., 1978; Kato and Yoshida, 1980; Carter, 1984, 1985; Carter and Koo, 1984; Price et al., 1988). Intermediate-duration studies with several species indicate that liver, kidneys, and skin are the primary toxicity targets (Treon et al., 1956; Vos and Beems, 1971; Kimbrough et al., 1972; Vos and Notenboom-Ram, 1972; Allen, 1975; Bleavins et al., 1980; Tryphonas et al., 1986; Byrne et al., 1987; Brunner et al., 1996; Norback and Weltman, 1985). Available chronic investigations with animals exposed to PCBs via inhalation or dermal exposures are inconclusive. Results from oral exposure studies, however, resemble intermediate-duration exposures (ATSDR, 1995).

Among humans, epidemiological studies of occupational exposures to PCBs have been conducted (Fischbein et al., 1979; Humphrey, 1983; Fein et al., 1984; Taylor et al., 1984; Rogan et al., 1986; Kalina et al., 1991; Tryphonas et al., 1991a, 1991b). However, these studies have reported inconsistent findings and are not adequate for quantitative risk assessment purposes. Therefore, evaluation of adverse health effects for PCBs are based on studies of laboratory animals.

3.3.1.6 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a class of compounds containing two or more benzene rings. Most PAHs in the environment are formed during the combustion of organic compounds. Major sources of PAHs include incomplete combustion of fuels for heat, manufacturing and burning of coal, gasoline, diesel exhaust, and burning of municipal and agricultural wastes. Cigarette smoke also contains PAHs. To a limited extent, these compounds also occur naturally. Plants and bacteria synthesize PAHs during growth, and naturally-caused brush and forest fires produce PAHs (ATSDR, 1993).

The physical-chemical properties of PAHs are roughly correlated with their size and molecular weight; thus, PAHs may be grouped by molecular weight for the purpose of describing their environmental fate (ATSDR, 1993). The medium and high molecular weight PAHs have relatively high K_{oc} values, indicating a strong tendency to bind to organic matter (ATSDR, 1993). In addition, these PAHs have limited solubility in water. Unless these PAHs encounter organic liquids in which they might be transported, they are essentially immobile in water. High molecular weight PAHs are: benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-c,d)pyrene.

In surface waters, PAHs may be removed by volatilization, binding to suspended solids or sediments, photodegradation, or accumulation in aquatic biota. Higher molecular weight PAHs have very low Henry's Law constants, high K_{oc} values, and a tendency to bioaccumulate (ATSDR, 1993); these PAHs preferentially sorb to sediments or accumulate in biota.

The PAHs identified as COCs in sediment samples collected in the Blackstone River include: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, and chrysene. The USEPA has classified benzo(a)pyrene (B(a)P) as B2: probable human carcinogen, based on sufficient data in animals and inadequate data in humans. B(a)P has been shown to be carcinogenic in experimental animals (rodent and non-rodent species) following administration by oral, intratracheal, inhalation, and dermal routes (ATSDR, 1993). Oral administration of B(a)P to rats and hamsters produces stomach tumors.

The USEPA has classified benzo(a)anthracene, benzo(b)fluoranthene, and chrysene as Group B2 carcinogens, (probable human carcinogens), based on sufficient data in animals and no data in humans. Although these compounds are well-studied as carcinogens, the data are insufficient for the purpose of developing cancer slope factors (USEPA, 1993). In the absence of compound-specific cancer slope factors, the USEPA has developed guidance on "order of potential potency" (relative to the potency of B(a)P) for the quantitative risk assessment of the carcinogenic PAHs) (USEPA, 1993). This interim guidance provides order of magnitude relative potency estimates which are multiplied by the slope factor for B(a)P to estimate slope factors for the carcinogenic PAHs.

As previously discussed, phenanthrene was also detected in sediment of the Blackstone River at a maximum concentration of 910 mg/kg (ppm). Although PAHs have been associated with a variety of health effects including carcinogenicity, to date, phenanthrene has not been classifiable as to its carcinogenicity in humans (USEPA, 1997). A comparison of the RBCs developed for other PAHs with a similar classification regarding carcinogenicity (e.g. acenaphthene, anthracene, fluoranthene and pyrene) and the maximum detected concentration of phenanthrene (see Appendix H), would suggest that exposure to phenanthrene in sediments is not likely to result in unacceptable risk estimates. Subsequently, phenanthrene was not considered as a COC for purposes of this assessment.

3.4 EXPOSURE ASSESSMENT

The potential receptors evaluated for this characterization include the child and adult recreational users of the Fisherville Pond. Exposure pathways describe unique mechanisms by which a population or an individual may be exposed to a chemical. Exposure pathways are determined by environmental conditions, by the potential for the chemical to move from one medium (e.g., soil, water, or air) to another, and by the general lifestyles and work activities of the potentially exposed population. Although several pathways may potentially exist, only a few may actually be complete. For an exposure pathway to be complete, each of the following must exist:

- a source and mechanism for chemical release;
- an environmental transport medium (e.g., air, water, soil);
- a point of potential human contact with the medium; and,
- a route of uptake for the chemical at the contact point (e.g., inhalation, ingestion, dermal contact).

3.4.1 Characterization of Exposure Setting

A detailed description of the physical characteristics of the area surrounding the Fisherville Pond area of the Blackstone River is presented in Chapter 1. Although this area has not been designated for recreational use, currently the pond and surrounding vicinity appears to be utilized for recreational purposes, as evidenced by the many boat ramps and access points on the river and pond. As such, it is anticipated that the area will continue to support such activities as fishing, swimming, and boating in the pond and the adjacent river areas.

3.4.2 Identification of Exposure Pathways

Several exposure pathways were selected for evaluation in this HHRC based on future recreational use of the area by both children and adults. The health hazards associated with exposure to a chemical are directly related to the degree of intake. For any route of exposure, intake (I) is the product of exposure (E) and the absorption efficiency or bioavailability (B):

$$I = E \times B$$

Although the various exposure parameters may make this equation appear more complex, the mathematical relationship holds true for all exposure routes, and is expressed as mass of chemical per mass of body weight per day (mg/kg/day). The exposure pathways considered in this HHRC and the intake equations are presented below:

Incidental Ingestion of Surface Water

$$Intake\ (mg/kg\text{-}day) = (CW \times IR \times ET \times EF \times 1/BW \times 1/AT)$$

where:

CW	=	chemical concentration in surface water (milligrams/liter)
IR	=	ingestion rate (liters/hour)
ET	=	exposure time (hours/day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BW	=	average body weight (kilograms)
AT	=	average time (days)

Dermal Contact with Surface Water

$$Intake\ (mg/kg\text{-}day) = (CW \times SA \times PC \times ET \times EF \times ED \times CF \times 1/BW \times 1/AT)$$

where:

CW	=	chemical concentration in surface water (milligrams/liter)
SA	=	skin surface area available for contact (squared centimeters)
PC	=	chemical-specific permeability coefficient (centimeters/hour)
ET	=	exposure time (hours/day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
CF	=	volumetric conversion factor for water (1 liter/1000 cm^3)
BW	=	average body weight (kilograms)
AT	=	average time (days)

Incidental Ingestion of Sediment

$$Intake\ (mg/kg\text{-}day) = (CS \times IR \times FI \times ABS \times EF \times ED \times CF \times 1/BW \times 1/AT)$$

where:

CS	=	chemical concentration in sediment (milligrams/kilogram)
IR	=	ingestion rate (milligrams/day)
FI	=	fraction ingested from the contaminated source (unitless)
ABS	=	relative absorption factor (unitless)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
CF	=	conversion factor (10^{-6} kilograms/milligrams)
BW	=	average body weight (kilograms)
AT	=	average time (days)

Dermal Contact of Sediment

$$Intake\ (mg/kg\text{-}day) = (CS \times SA \times AF \times ABS \times EF \times ED \times 1/BW \times 1/AT)$$

where:

CS	=	chemical concentration in sediment (milligrams/kilogram)
SA	=	skin surface area available for contact (squared meters)
AF	=	soil adherence factor for contact (kilograms/squared meter-day)
ABS	=	relative absorption factor (unitless)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BW	=	average body weight (kilograms)
AT	=	average time (days)

Fish Consumption

$$Intake\ (mg/kg\text{-}day) = (CF \times IR \times FI \times ABS \times EF \times ED \times 1/BW \times 1/AT)$$

where:

CF	=	chemical concentration in fish (milligrams/kilogram)
IR	=	ingestion rate (kilograms/day)
FI	=	fraction ingested from the contaminated source (unitless)
ABS	=	relative absorption factor (unitless)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BW	=	average body weight (kilograms)
AT	=	average time (days)

3.4.2.1 Exposure Parameters

Tables 3.2 through 3.4 present the exposure parameters associated with the exposure pathways considered in this HHRC. However, no exposure parameters are presented for incidental ingestion or dermal contact with surface water. This is due to the fact that lead is the only COC identified for surface water exposures and no toxicity criteria are available for the development of a quantitative risk estimate associated with exposure to this analyte. Subsequently, the potential risk associated with exposure to lead in surface water, sediments and fish tissues is presented as a qualitative discussion in Section 3.5.

Ingestion rates for the various environmental media, as well as recommendations for exposure frequencies and durations for the various exposure pathways, have been identified or developed in accordance with USEPA risk assessment methodology. USEPA's standard default exposure factors (USEPA, 1989c; 1991a) are used in calculating the pathway-specific intakes where appropriate.

3.4.2.1.1 Exposure Frequency

Regarding exposure frequency (EF), the HHRC incorporates the assumption that children and adults will spend 2 days per week for 6 months out of the year or 52 days each year (2 days x 26 weeks) engaged in recreational activities at the Fisherville Pond area. This parameter is somewhat conservative, in that it assumes that much of the leisure time, available to either the child or adult recreator throughout the six months, would be spent at this activity.

3.4.2.1.2 Exposed Skin Surface Area

The surface area assumed to be exposed and in contact with contaminated sediment varies depending on the site, exposure scenario, type of activity, and potentially exposed populations. For this analysis, the exposed dermal surface area was estimated using values provided in the *Exposure Factors Handbook* (USEPA, 1995a). Surface areas were conservatively estimated based upon the 95 percentile of total body surface area for 5 - 6 year olds of 9,350 cm^2 (average 95 percentile total body surface for males and females age 5 - 6 years). The hands, forearms, lower legs, and feet were estimated to comprise 4.71%, 4.11%, 8.92%, and 6.9% of this total body surface area for 6 year olds. Using this approach, an exposed surface area of 2,299 cm^2 or 0.2299 m^2 was derived for the child recreator. Similarly for the adult recreator, a surface area of 3,377 cm^2 or 0.3377 m^2 was estimated based upon exposure of the hands (904 cm^2), forearms (1310 cm^2), 50% of the head (570 cm^2), and the lower legs (593 cm^2).

3.4.2.1.3 Bioavailability

Bioavailability is a measure of the degree to which a chemical is absorbed following exposure (Paustenbach, 1987). Bioavailability is an important exposure parameter because it determines the actual dose (intake) via each route of exposure, i.e., the actual dose received is the product of exposure and bioavailability. Bioavailabilities are reported as the percentage of the applied or administered chemical that is ultimately absorbed into the body. For example, complete absorption of 1 mg of a chemical upon dermal contact with 100 mg of soil represents a dermal bioavailability of 1%. Bioavailabilities or absorption of COCs are conservatively assumed to be 100% for the ingestion of sediment and fish tissue scenarios (i.e., ABS is set equal to 1). For exposure via dermal contact, relative absorption factors have been developed to estimate dermal uptake of chemicals in sediment based upon the chemical properties of various classes of compounds. For the purposes of this HHRC, the dermal absorption factors employed by USEPA Region III have been incorporated into the estimation of uptake via this route of exposure (USEPA, 1995). The absorption factors applied are as follows:

- PAHs: 0.1 (10%)
- Arsenic: 0.032 (3.2%)
- Other Metals: 0.01 (1%)

3.4.2.1.4 Adherence Factor

Adherence of soil to exposed skin is an integral consideration in assessing dermal exposure to contaminated soil and/or sediment. The literature provides a range of soil adherence factors from four studies (Lepow et al., 1975; Roels et al., 1980; QueHee et al., 1985; Driver et al., 1989). In evaluating these studies, the USEPA indicated that each study has some degree of associated uncertainty (USEPA, 1992a). While a range of 0.17 mg/cm^2 to 1.5 mg/cm^2 was reported from these studies, because the data are only derived from hand measurements, the range overestimates the average adherence for the entire exposed skin area. USEPA (1992a) states that "...the lower end of this range (0.2 mg/cm^2) may be the best value to represent an average over all exposed skin and 1 mg/cm^2 may be a reasonable upper value." This reasonable upper value of 1 mg/cm^2 or 0.01 kg/m^2 (10^{-6} kg/mg x 10^4 cm^2/m^2) was used in this analysis. This value likely overestimates the amount of sediment that adheres to the skin, since water may wash the sediment off the skin (USEPA, 1989b).

3.4.2.1.5 Sediment Ingestion Rate

The default soil/sediment ingestion rates of 50 mg/day for adults and 100 mg/day for children (ages 1-6) recreators were employed. This ingestion rate for children is consistent with the USEPA's most recent exposure assessment draft guidance (USEPA, 1996d). This rate is based upon the results of studies performed by Binder et al. (1986), Clausing et al., (1987), Davis et al. (1990), Calabrese et al. (1989) and Van Wingen et al. (1990). The mean soil ingestion values from these studies ranged from 39 mg/day to 245.5 mg/day, averaging 165 mg/day. The USEPA justification for recommending a rate lower than the average is the observation that the high values were obtained using highly variable titanium as a tracer, and also that the Calabrese study included a pica child.

The ingestion rate of 50 mg/day used in this assessment for adult recreators was based on the results of the Calabrese (1990), Hawley (1985), and Krablin (1989) studies. This value represents a reasonable measure of central tendency among the three studies, and is consistent with the USEPA 1996 draft exposure guidance (USEPA, 1996a).

3.4.2.1.6 Fish Ingestion Rate

To evaluate the potential risk associated with the consumption of fish, ingestion rates of 6 grams per day (0.006 kg/day) for children (1-6 years) and 16 grams per day (0.016 kg/day) for adults were employed. These values represent the mean intake value for children (0-9 years) and the mean intake value for adults from the New England census region as presented in the *Exposure Factors Handbook* (USEPA, 1996a). The mean intake values were incorporated into the risk calculations rather than the 95 percentile intake values. Since the exposure point concentration for each COC was set equal to the maximum detected concentration, as discussed in section 2.4.2.2, use of 95 percentile intake values was considered to represent an overly conservative ingestion rate for consumption of fish tissue.

Table 3.2 Exposure Parameters Associated with Incidental Ingestion of Sediment

$$Intake\ (mg/kg\text{-}day) = (CS \times IR \times FI \times ABS \times EF \times ED \times CF \times 1/BW \times 1/AT)$$

Exposure Parameter	Value	Explanation/source
CS = Concentration in sediments	Chemical-specific (mg/kg)	Maximum detected concentration
IR = Ingestion rate	100 mg/day or 50 mg/day	Child (USEPA, 1996a) Adult (USEPA, 1996a)
FI = Fraction ingested from contaminated source	1 (unitless)	Maximum value; equivalent to 100%
ABS=Relative Absorption Factor	1 (unitless)	Maximum value; equivalent to 100%
EF = Exposure Frequency	52 days/year	Equivalent to 2 days/week x 26 weeks exposure per year.
ED = Exposure Duration	6 years 24 years	Child exposure (USEPA, 1989c) Adult exposure (USEPA, 1989c)
CF= Conversion Factor	10^{-6} kg/mg	unit conversion factor
BW = Body Weight	15 kg 70 kg	Child (USEPA, 1991a) Adult (USEPA, 1991a)
AT = Averaging Time	365 days/year x ED 365 days/year x 70 years	Averaging time for non-carcinogens Averaging time for carcinogens (USEPA, 1989c)

Table 3.3 Exposure Parameters Associated with Dermal Contact of Sediment

$$Absorbed\ Intake\ (mg/kg\text{-}day) = (CS \times SA \times AF \times ABS \times EF \times ED \times 1/BW \times 1/AT)$$

Exposure Parameter	Value	Explanation/source
CS = Concentration in sediment	Chemical-specific (mg/kg)	Maximum detected concentration
SA = Exposed skin surface area	0.2299 m^2 0.3377 m^2	Child (USEPA, 1995) Adult (USEPA, 1995)
AF = Adherence factor	0.01 kg/m^2	Unit-adjusted adherence factor for soil 1.0 mg/cm^2 (10^{-6} kg/mg x 10^4 cm^2/m^2) (USEPA 1992a)
ABS = Absorption factor	chemical-specific (unitless)	(USEPA Region III Guidance, 1995b)
EF = Exposure Frequency	52 days/year	Equivalent to 2 days/week x 26 weeks exposure per year.
ED = Exposure Duration	6 years 24 years	Child exposure (USEPA, 1989c) Adult exposure (USEPA, 1989c)
BW = Body Weight	15 kg 70 kg	Child (USEPA, 1991a) Adult (USEPA, 1991a)
AT = Averaging Time	365 days/year x ED 365 days/year x 70 years	Averaging time for non-carcinogens Averaging time for carcinogens (USEPA, 1989c)

Table 3.4 Exposure Parameters Associated with Ingestion of Fish

$$Intake\ (mg/kg{\cdot}day) = (CF \times IR \times FI \times ABS \times EF \times ED \times 1/BW \times 1/AT)$$

Exposure Parameter	Value	Explanation/source
CF = Concentration in fish fillets	Chemical-specific (mg/kg)	Maximum detected concentration
IR = Ingestion rate	0.006 kg/day 0.016 kg/day	Child, ages 0-9 Adult, New England (USEPA, 1996a)
FI = Fraction ingested	0.5 (unitless)	Equivalent to 50%
ABS = Relative absorption factor	1 (unitless)	Maximum value; equivalent to 100%
EF = Exposure Frequency	350 days/year	Maximum value; near daily exposure
ED = Exposure Duration	6 years 24 + 9 = 33 years	Child exposure (USEPA, 1989c) Adult exposure (USEPA 1996b)
BW = Body Weight	15 kg 70 kg	Child (USEPA, 1991a) Adult (USEPA, 1991a)
AT = Averaging Time	365 days/year x ED 365 days/year x 70 years	Averaging time for non-carcinogens Averaging time for carcinogens (USEPA, 1989c)

3.4.2.2 Derivation of Exposure Point Concentrations

An exposure point is simply a location of potential contact between a receptor and a chemical (USEPA, 1989a). Estimates of the potential chemical concentration at locations of likely human contact are necessary for evaluating the dose to exposed individuals. Potential exposure points for the Fisherville Pond area include surface water, sediment, and fish tissue for the future recreator. In this assessment, exposure point concentrations are based on measured concentrations of the chemicals in surface water, sediment, and fish tissue. Typical exposure point concentrations are assumed equal to the arithmetic mean, while RME exposure point concentrations are assumed equal to the maximum concentration detected. Because of the small data set available for this assessment, the maximum detected concentrations of surface water, sediment, and fish tissue COCs were used as the exposure point concentrations. Table 3.5 presents the exposure point concentration for each COC in each of the media evaluated.

Table 3.5 Exposure Point Concentrations for Chemicals of Concern

Chemical of Concern	Surface Water Maximum Concentration (mg/L)	Sediment Maximum concentration (mg/kg)	Fish Tissue Maximum Concentration (mg/kg)
Benzo(a)anthracene	NA	200	NA
Benzo(b)fluoranthene	NA	130	NA
Benzo(a)pyrene	NA	170	NA
Chrysene	NA	180	NA
Arsenic	NA	59	NA
Cadmium	NA	48	NA
Chromium	NA	850	NA
Lead	0.118	1,727	NA
Aroclor 1254	NA	NA	0.38
Aroclor 1260	NA	NA	0.33

NA: Not Applicable. The chemical is not identified as a COC for this media.

3.5 RISK CHARACTERIZATION

As the final step of the risk assessment process, risk characterization is the point at which a scientific interpretation of the assessment is provided. The purpose of the risk characterization section is to integrate and summarize the information, results, conclusions and uncertainties presented in the data evaluation, toxicity assessment and exposure assessment. The risk characterization is designed to provide both a quantitative and qualitative evaluation of the potential risks associated with the chemicals and exposure pathways for the Site.

To characterize the potential noncarcinogenic effects, comparisons are made between projected intakes of substances and their associated noncarcinogenic toxicity criteria (*i.e.*, reference doses [RfDs]). The potential carcinogenic risks are characterized as the probability than an individual will develop cancer over a lifetime of exposure. This probability is estimated from projected chemical intake and the chemical-specific dose-response criteria used to evaluate the carcinogenic potential of the individual chemicals evaluated (*i.e.*, cancer slope factors [CSFs]). Major assumptions, scientific judgement, and to the extent possible, estimates of the uncertainties embodied in the assessment are presented in this section. (USEPA, 1989a)

3.5.1 Noncarcinogenic Risk Characterization

Noncarcinogenic hazards are estimated by dividing calculated chemical intakes for each noncarcinogen by the appropriate RfD. The resulting ratio is termed the hazard quotient. Hazard quotients (HQs) for each exposure pathway (as identified in Section 3.4.2 Potential Exposure Pathways) are summed to yield chemical-specific HQs for each compound. Finally, HQs for each chemical are summed for each media contaminated with more than one compound, yielding cumulative hazard indices. These hazards are generally summed only for those compounds that effect the same target organ. However, for the purposes of this assessment, all chemicals were summed to provide a conservative estimate of the overall hazard presented. The summation of these hazards are presented at the end of this section in Tables 3.6 through 3.8.

3.5.2 Carcinogenic Risk Characterization

Carcinogenic risks are estimated by multiplying the estimated chemical intake for each carcinogen by its CSF. The result is a chemical-specific lifetime incremental cancer risk. This value represents a conservative upper-bound probability of developing cancer during a 70-year lifetime as a result of exposure to the chemical concentrations and media evaluations. Within each media, cancer risks associated with multiple pathways of exposure are summed to yield a chemical-specific lifetime incremental cancer risk for the receptor populations identified. In addition, in cases where an individual from a given scenario could be exposed to multiple chemicals in one media, chemical-specific total risks are also summed to yield a total media-specific risk estimate.

Cancer risks are summed regardless of differences in target organ, weight-of-evidence for human carcinogenicity, or potential chemical interactions (e.g., antagonistic or synergistic effects). This approach is consistent with USEPA's current approach to carcinogenic effects, which is to assume effects are additive unless adequate information to the contrary is available (USEPA, 1989a). The summation of carcinogenic risks are presented at the end of this section in Tables 3.9 through 3.11.

The significance of the potential risks estimated for this Site are evaluated by comparing the calculated risks to established target levels or acceptable risk benchmarks. Federal agencies have adopted human health risk benchmarks that have been deemed acceptable based on several factors, notably the benefits of the chemical being regulated, the ability to avoid risk from other sources and the cost factors involved in reducing that risk. The target hazard level for noncarcinogenic effects is an overall Hazard Index of 1 (USEPA, 1989a). For risks associated with developing cancer, USEPA guidelines suggest that the total incremental carcinogenic risk for an individual resulting from multiple-pathway exposures should not exceed a range of 10^{-6} to 10^{-4} (USEPA, 1989a).

Revisions to the National Contingency Plan (NCP) (USEPA, 1990) set the acceptable risk range between 10^{-6} and 10^{-4} at hazardous waste sites regulated under CERCLA. Since the NCP revisions, the USEPA has selected and promulgated a single risk level of 10^{-5} in the Hazardous Waste Management System Toxicity Characteristics (TC) Revisions (55 FR 11798-11877). In their justification, the USEPA cited the following rationale:

> *"The chosen risk level of 10^{-5} is at the midpoint of the reference risk range for carcinogens (10^{-6} to 10^{-4}) targeted in setting MCLs. This risk level also lies within the reference risk range (10^{-6} to 10^{-4}) generally used to evaluate CERCLA actions. Furthermore, by setting the risk level at 10^{-5} for TC carcinogens, USEPA believes that this is the highest risk level that is likely to be experienced, and most if not all risks will be below this level due to the generally conservative nature of the exposure scenario and the underlying health criteria. For these reasons, the Agency regards a 10^{-5} risk level for Group A, B, and C carcinogens as adequate to delineate, under the Toxicity Characteristics, wastes that clearly pose a hazard when mismanaged."*

In summary, while this risk assessment compares potential risk estimates to the range 10^{-6} to 10^{-4}, an acceptable cancer risk level of 10^{-5} is most consistent with state and federal policies.

3.5.3 Characterization of Risk at the Fisherville Pond

Estimates of potential carcinogenic risk and noncarcinogenic hazard were calculated on a media-specific basis for each COC, based on the exposure scenarios described and evaluated in the exposure assessment. Specifically, the potential receptor populations evaluated in this assessment included a child and adult recreator. Risk and hazard calculations for each of the exposure scenarios evaluated are presented in Appendix H. Summaries of the results of the risk and hazard evaluations conducted for each of the environmental media examined are presented in the following subsections.

3.5.3.1 Surface Water

The potential risk associated with exposure to surface water, via incidental ingestion and dermal contact pathways, was not quantified due to the fact that the only COC identified for the media was lead for which no toxicity criteria are established.

In order to qualitatively evaluate the potential risk to the child and adult recreator associated with the incidental ingestion of lead in surface water, a weight of evidence approach was employed. For the purpose of this analysis, it was assumed that the health risks associated with ingestion of lead in surface water will be greater than that associated with dermal exposure to surface water. The only available benchmark for ingestion of lead in surface water is the USEPA MCL Action Level. For lead, this value is currently 15 μg/L. The maximum concentration of lead measured in surface water in the Fisherville Pond/Blackstone River Area was 118 μg/L.

If it can be safely determined that surface water from the Site will not be used as a source of drinking water, but rather exposure will be via incidental ingestion, the volume of water ingested each day can safely be reduced from 2L/day to perhaps 50 ml/day.

Since lead is noncarcinogenic, the concept of a threshold (safe level) of exposure to lead has been recognized by USEPA. Ingestion of 2L of water containing 15 μg of lead/L yields a total daily exposure of 30 μg of lead/day. For the recreator at Fisherville Pond ingestion of 50 ml/day of surface water containing 118 μg/l (the maximum concentration of lead detected in surface water) yields a total daily exposure of 5.9 μg of lead/day. Assuming that dermal exposure provides only a limited additional contribution to lead exposure (USEPA informal policy in Regions 3 and 5 suggest that only 1% of soluble lead will be dermally absorbed), surface water at Fisherville Pond should not represent an unacceptable risk to the child or adult recreator.

3.5.3.2 Sediment

Adult and child recreators were assumed to be exposed to the maximum concentrations of the COCs identified in sediments at the Fisherville Pond via incidental ingestion of and dermal contact with this media. The estimated hazards and risks associated with exposure to sediments is described below.

Noncarcinogenic hazard quotients were calculated for both an adult and a child recreator for exposure to COCs in sediment via incidental ingestion and dermal contact pathways. As is evidenced in Tables 3.6 and 3.7, the chemical-specific and total hazard quotients calculated for recreational exposure to the COCs in sediments are less than 1 for both adults and children based on the exposure parameters evaluated. Noncarcinogenic toxicity criteria is not available for the PAHs identified as COCs in sediment, therefore, the assessment of risk associated with exposure to these compounds focussed only on their potential carcinogenicity. For exposures to lead in sediment, as previously discussed, it is not possible to quantify the potential health hazards due to the lack of available toxicity criteria for this analyte.

Consistent with the approach employed for lead exposure in surface water, the risk associated with exposure of the child or adult recreator to lead in sediments will be performed using a weight of evidence technique. For the purposes of evaluating impacts to human health, there is currently no USEPA guidance describing an acceptable concentration of lead in sediments. Therefore, in order to qualitatively evaluate the potential risks to human health, lead concentrations in sediments were conservatively compared to the USEPA soil screening levels (SSLs) (USEPA, 1996g). The SSL for lead in residential soil is 400 mg/kg. The maximum concentration of lead measured in sediments at the Site was 1,727 mg/kg. Exposure parameters used in the derivation of the SSL for residential ingestion of lead in soil are: an ingestion rate of 200 mg of soil/day for 350 days/year resulting in an acceptable lead concentration in soil of 400 mg/kg. This calculation yields an average daily ingestion rate for lead of 0.077 mg lead/day. For recreational exposure to site sediments, the exposure parameters employed in estimating risk are as follows: an ingestion rate of 100 mg/day; for 52 days/year (2 days/week for 26 weeks); and a maximum exposure concentration of 1727 mg of lead/kg of soil. The average daily ingestion rate for site sediments is 0.025 mg lead/day.

Under the conditions defined in this analysis, incidental recreational exposure of the child or adult recreator to sediments in the Fisherville Pond/Blackstone River Area would not be expected to result in unacceptable hazards associated with exposure to lead from sediment ingestion.

The COCs in sediment identified as potential carcinogens include PAHs (benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, and chrysene) and several metals (arsenic, cadmium and chromium). The chemical and pathway-specific estimated cancer risks associated with the exposure pathways evaluated are identified in Tables 3.9 and 3.10 for both the adult and child receptors.

The cumulative risk estimate for ingestion of sediments is 3.06×10^{-3} and 1.31×10^{-3} for child and adult recreators, respectively. These risk estimates exceed the USEPA acceptable risk range of 10^{-6} to 10^{-4} and are primarily attributed to maximum concentrations of chromium and benzo(a)pyrene in sediment. These same COCs are primarily responsible for the majority of risk presented in the cumulative risk estimate associated with dermal contact of sediments. The cumulative risks associated with exposure via this pathway are 9.57×10^{-4} for children recreators and 1.20×10^{-3} for adult recreators. These risk estimates exceed the USEPA acceptable risk range of 10^{-6} to 10^{-4} and are primarily attributed to maximum concentrations of chromium and benzo(a)pyrene in sediment.

It should, however, be recognized that the chromium (Cr) concentrations reported were assumed to represent Cr VI since the analyses performed for this analyte did not provide for the speciation of chromium detected. Cr VI is a suspect carcinogen and is considered to be more toxic than other species of chromium, therefore, a greater risk would be associated with exposure to this form of chromium. The potential carcinogenic risks associated with the remaining COCs identified in sediment are within USEPA's target risk range, with risk estimates for sediment ingestion of 4.58×10^{-8} to 1.06×10^{-5} in adults and 1.0×10^{-7} to 2.46×10^{-5} in children. Similarly, risks associated with dermal contact of sediments for the remaining COCs range from 3.10×10^{-7} to 3.44×10^{-5} and 2.46×10^{-7} to 2.73×10^{-5} in adults and children, respectively.

3.5.3.3 Fish Tissue

Adult and child receptors were assumed to be exposed to the maximum concentrations of the COCs identified in fish tissue via ingestion. The estimated hazards and risks associated with exposure to sediments is described below.

As previously discussed, fish tissue samples were analyzed for metals and PCBs. Of these, only PCBs (Arolors 1254 and 1260) were detected at maximum concentrations that exceeded the screening criteria. The potential noncarcinogenic hazards and carcinogenic risks posed by the consumption of fish tissues containing the maximum concentrations of Aroclor 1254 (0.38 mg/kg) and Aroclor 1260 (0.33 mg/kg) were evaluated for both children and adults. The chemical-specific and total hazard quotients calculated for recreational exposure to the PCBs in fish tissue are presented in Tables 3.6 and 3.7. For both children and adults, this exposure pathway presents noncancer HQs exceeding USEPA's target of unity (*i.e.*, greater than 1). The total noncarcinogenic hazard estimate for the child and adult receptors evaluated in this pathway are 6.81 and 3.89, respectively.

As discussed in conjunction with surface water and sediments, no quantitative evaluation of risk associated with lead in fish was conducted due to the lack of toxicity criteria established for this analyte. The maximum concentration of lead in fish tissue collected at the Site was 2.2 mg/kg. Although no specific action level has been defined for the acceptable level of lead in edible freshwater fish tissue, the U.S. Food and Drug Administration (USFDA) has conducted studies on lead in shellfish. Results of these studies suggest that a conservative acceptable concentration of lead in shellfish intended for human consumption is 1.7 mg/kg. The maximum concentration of lead reported in fish tissues from the Fisherville Pond is 2.2 mg/kg. Therefore, it is assumed that the consumption of fish containing this maximum the concentration of 2.2 mg/kg of lead would likely result in a marginally unacceptable hazard under the conservative exposure parameters employed in this assessment.

Carcinogenic risk estimates were calculated for both an adult and a child recreator for the consumption of edible fish tissue exposure pathway. The estimated cancer risks associated with this pathway are presented in Tables 3.9 and 3.10. Adult cancer risks were estimated at 3.93×10^{-5} and 3.41×10^{-5} for Aroclors 1254 and 1260, respectively. Potential risks to children from this pathway were estimated at 1.25×10^{-5} for Aroclor 1254 and 1.08×10^{-5} for Aroclor 1260. These risk estimates fall within the USEPA's generally acceptable carcinogenic risk range of 10^{-6} to 10^{-4}.

3.5.3.4 Risk Characterization Summary for Lead

Due to the lack of available toxicity criteria (RfDs and CSFs), a quantitative evaluation of the health risks associated with exposure to lead in surface water, sediments and fish tissue could not be performed. In order to provide information which could be used for risk management purposes, a qualitative weight of evidence approach was employed for lead in each media. This qualitative approach indicated that under the conditions described in these analyses lead is not anticipated to produce unacceptable health risks for incidental ingestion of surface water or sediments and only marginally for ingestion of fish tissue. As noted previously, not all pathways for each media were evaluated and individual pathway/media specific risk factors were not summed to produce a overall "HI type value".

Table 3.6 Noncarcinogenic Hazard Quotient Estimates for the Adult Recreator

Chemical of Concern	Sediment Ingestion	Sediment Dermal Contact	Fish Consumption	Total Hazard
Benzo(a)anthracene	NE	NE	NA	NE
Benzo(b)fluoranthene	NE	NE	NA	NE
Benzo(a)pyrene	NE	NE	NA	NE
Chrysene	NE	NE	NA	NE
Arsenic	2.00E-02	4.33E-02	NA	6.33E-02
Cadmium	9.77E-03	6.60E-03	NA	1.64E-02
Chromium	1.73E-02	1.17E-02	NA	2.90E-02
Lead	NE	NE	NE	NE
Aroclor 1254	NA	NA	2.08E+00	2.08E+00
Aroclor 1260	NA	NA	1.81E+00	1.81E+00
Total Hazard	**4.71E-02**	**6.15E-02**	**3.89E+00**	**4.00E+00**

Table 3.7 Noncarcinogenic Hazard Quotient Estimates for the Child Recreator

Chemical of Concern	Sediment Ingestion	Sediment Dermal Contact	Fish Consumption	Total Hazard
Benzo(a)anthracene	NE	NE	NA	NE
Benzo(b)fluoranthene	NE	NE	NA	NE
Benzo(a)pyrene	NE	NE	NA	NE
Chrysene	NE	NE	NA	NE
Arsenic	1.87E-01	1.37E-01	NA	3.24E-01
Cadmium	9.12E-02	2.10E-02	NA	1.12E-01
Chromium	1.61E-01	3.71E-02	NA	1.99E-01
Lead	NE	NE	NE	NE
Aroclor 1254	NA	NA	3.64E+00	3.64E+00
Aroclor 1260	NA	NA	3.16E+00	3.16E+00
Total Hazard	**4.39E-01**	**1.95E-01**	**6.81E+00**	**7.44E+00**

Table 3.8 Combined Hazard Quotient Estimates for the Child & Adult Recreator

Chemical of Concern	Total Hazard Adult	Total Hazard Child	Total Hazard Adult+Child
Benzo(a)anthracene	NE	NE	NE
Benzo(b)fluoranthene	NE	NE	NE
Benzo(a)pyrene	NE	NE	NE
Chrysene	NE	NE	NE
Arsenic	6.33E-02	3.24E-01	1.15E-01
Cadmium	1.64E-02	1.12E-01	3.55E-02
Chromium	2.90E-02	1.99E-01	6.29E-02
Aroclor 1254	2.08E+00	3.64E+00	2.39E+00
Aroclor 1260	1.81E+00	3.16E+00	2.08E+00
Total Hazard	**4.00E+00**	**7.44E+00**	**4.69E+00**

NE: None established

Table 3.9 Carcinogenic Risk Estimates for the Adult Recreator

Chemical of Concern	Sediment Ingestion	Sediment Dermal Contact	Fish Consumption	Total Risk
Benzo(a)anthracene	5.09E-06	3.44E-05	NA	3.95E-05
Benzo(b)fluoranthene	3.31E-06	2.24E-05	NA	2.57E-05
Benzo(a)pyrene	4.33E-05	2.92E-04	NA	3.36E-04
Chrysene	4.58E-08	3.10E-07	NA	3.55E-07
Arsenic	3.09E-06	6.67E-06	NA	9.76E-06
Cadmium	1.06E-05	7.13E-06	NA	1.77E-05
Chromium	1.25E-03	8.41E-04	NA	2.09E-03
Aroclor 1254	NA	NA	3.93E-05	3.93E-05
Aroclor 1260	NA	NA	3.41E-05	3.41E-05
Total Risk	**1.31E-03**	**1.20E-03**	**7.34E-05**	**2.59E-03**

Table 3.10 Carcinogenic Risk Estimates for the Child Recreator

Chemical of Concern	Sediment Ingestion	Sediment Dermal Contact	Fish Consumption	Total Risk
Benzo(a)anthracene	1.19E-05	2.73E-05	NA	3.92E-05
Benzo(b)fluoranthene	7.73E-06	1.78E-05	NA	2.55E-05
Benzo(a)pyrene	1.01E-04	2.32E-04	NA	3.33E-04
Chrysene	1.07E-07	2.46E-07	NA	3.53E-07
Arsenic	7.20E-06	5.30E-06	NA	1.25E-05
Cadmium	2.46E-05	5.66E-06	NA	3.03E-05
Chromium	2.91E-03	6.68E-04	NA	3.57E-03
Aroclor 1254	NA	NA	1.25E-05	1.25E-05
Aroclor 1260	NA	NA	1.08E-05	1.08E-05
Total Risk	**3.06E-03**	**9.57E-04**	**2.33E-05**	**4.04E-03**

Table 3.11 Combined Risk Estimates for the Child & Adult Recreator

Chemical of Concern	Total Risk Adult	Total Risk Child	Total Risk Adult & Child
Benzo(a)anthracene	3.95E-05	3.92E-05	7.87E-05
Benzo(b)fluoranthene	2.57E-05	2.55E-05	5.12E-05
Benzo(a)pyrene	3.36E-04	3.33E-04	6.69E-04
Chrysene	3.55E-07	3.53E-07	7.08E-07
Arsenic	9.76E-06	1.25E-05	2.23E-05
Cadmium	1.77E-05	3.03E-05	4.80E-05
Chromium	2.09E-03	3.57E-03	5.66E-03
Aroclor 1254	3.93E-05	1.25E-05	5.18E-05
Aroclor 1260	3.41E-05	1.08E-05	4.49E-05
Total Risk	**2.59E-03**	**4.04E-03**	**6.63E-03**

Physiologically based pharmacokinetic models such as the O'Flaherty model have proved to be an effective mechanism to evaluate health risks associated with multi-media exposure to lead (O'Flaherty, 1994). Additionally, the USEPA Integrated Exposure Uptake and Biokinetic Model (IEUBK) offers a less flexible method to evaluate the health risks associated with multi-media exposure to lead (USEPA, 1994b).

In order to more accurately and completely evaluate the potential health risks associated with multi-media exposure to lead at the Site, it is recommended that an analysis using one or both of these models be conducted.

3.5.4 Risk Perspective

This HHRC seeks to estimate the probability that an adverse health effect will result from exposure to chemicals. Carcinogenic risks are generally expressed as a probability ranging from zero (absolute certainty that the event will not occur) to one (absolute certainty that the event will occur). Humans have a high probability (e.g., approximately 20%) of dying of cancer within their lifetime (American Cancer Society, 1985); however, the probability of developing cancer due to environmental exposure is usually quite low.

There is now general consensus that personal and cultural habits (i.e., cigarette smoking, consumption of alcohol, diet, etc.) of individuals are the predominant determinants of human cancer. (Ames, 1990; Tierney, 1988). Even in the most highly industrialized countries, it appears that very few cancers can be attributed to exposure to synthetic chemicals. The total contribution of environmental pollution is estimated to account for only 1-2% of human cancers (Wilkinson, 1987).

Humans assume risks of various types and magnitudes throughout the normal course of their daily lives. A substantial amount of historical data exist that describe the risks associated with certain common activities (Crouch, 1982). Risks associated with environmental exposure to chemicals are much more difficult to assess for two primary reasons. First, the exposure itself is often difficult to document and quantify. Second, the exposure does not always produce immediately observable effects. Due to these difficulties, risks associated with environmental exposure must be estimated via hypothetical scenarios and mathematical calculations. The methods used to estimate these risks are based on current knowledge of biology, chemistry and toxicology and have been used extensively to define the acceptable exposure concentration to common products such as food additives, drugs and pesticides.

The risk of exposure to a substance cannot be accurately described with a point estimate (single number). In order to effectively understand a risk assessment, quantitative estimates of risk must be evaluated in conjunction with important qualitative factors. These factors include the strength of the evidence which indicates that a substance produces a particular toxic effect, the accuracy and completeness of the site-specific data used to determine potential exposures, and uncertainties and assumptions inherent to the assessment of risk. Such information is as important as the quantitative risk estimation and, as such, should be considered when making risk management decisions. The risk assessment does not characterize absolute risk; rather, it seeks to highlight potential sources of unacceptable risk so that they may be effectively addressed.

3.5.5 Qualitative Uncertainty Analysis

While risk estimates calculated using quantitative risk assessment methodologies offer plausible estimates of the upper bound of risk, such estimates *are not actual predictions of risk*, because of the numerous conservative assumptions upon which they are based. Conservative assumptions regarding chemical toxicity, Site characteristics, and human exposure potential are applied such that any uncertainty in the risk assessment process will be likely to over estimate rather than underestimate potential risks. The differences between estimated risks based on such conservative assumptions and actual risks often lead to confusion when interpreting risk assessments. For example, a concentration that produces a risk estimate which exceeds a risk level and triggers protective action does not necessarily pose a significant public health threat. Thus, the estimated risk must be evaluated in conjunction with the uncertainties and assumptions in the risk assessment, in order to understand the true meaning of the estimated risk.

Some assumptions are based on defensible scientific research, while others are less justifiable. Clearly, assumptions based on strong scientific evidence contribute relatively little uncertainty to the process, while assumptions with weaker scientific bases contribute much greater uncertainty to the overall assessment. Assumptions with relatively weak scientific basis are addressed through the adoption of conservative estimates for various exposure and toxicity criteria. Some of the assumptions which introduce uncertainty to this risk assessment are described below.

3.5.5.1 Representative Chemical and Exposure Point Concentrations

A major assumption incorporated into this assessment involves the determination of representative exposure point concentrations for each of the COCs. The use of the maximum detected concentrations for the COCs evaluated provides for the most conservative estimate of risk associated with exposure to that chemical within a given media. It is very unlikely that an individual would be continually exposed to the maximum concentration of a given chemical. Therefore, this approach is likely to overestimate the potential risk associated with exposure to the individual COCs identified for the Site.

3.5.5.2 Environmental Fate and Transport

Migration and dilution of chemicals in surface water and sediment present additional sources of uncertainty in the HHRC. While it is improbable that any of the COCs are completely resistant to degradation, the chemical reactions which cause degradation are sufficiently complex as to disallow calculation of chemical- and site-specific degradation rates. Consequently, exposure point concentrations do not account for natural attenuation over time.

3.5.5.3 Exposure Assumptions

Several conservative assumptions relating to the exposure assessment may not, in fact, reflect actual conditions at this Site; as a result, levels of chemical intake are likely overestimated. For example, some of the exposure pathways evaluated may not be complete. That is, exposure is not possible in the absence of any one of the following four elements: (a) source and mechanism of chemical release to the environment; (b) an environmental transport medium; (c) a point of potential human contact with that medium; and (d) a human contact route at the contact point.

In addition, several conservative assumptions regarding human behavior have been incorporated into the exposure assessment. In all cases, conservative values were employed to describe human behavior. For example, it was assumed that 50% of the total amount of fish ingested by the child and adult receptors would come from the Fisherville Pond. This assumption likely overestimates the fraction of fish ingested from the contaminated source.

Finally, the exposure scenarios developed for this risk assessment do not account for exposure to chemicals not related to the Site. Rather, it was assumed that exposure to non-site-related chemicals is insignificant relative to exposure to site-related chemicals. Acceptable risk benchmark values were not adjusted to allow for exposures to chemicals originating off-site.

3.5.5.4 Absorption Factor

An absorption factor of 100% was assumed in the evaluation of ingestion of COCs in sediment and fish tissue. This conservative value was selected to reflect uncertainty in gastrointestinal absorption for each of the COCs considered. This 100% factor implies that each chemical ingested will be completely absorbed by the body, an assumption likely to result in an overestimation of risk.

3.5.5.5 Noncarcinogenic Health Effects

In addition to the uncertainty inherent in the derivation of NOAELs and LOAELs, development of noncarcinogenic health criteria involves route-to-route extrapolation, use of subchronic studies to derive chronic health criteria, and differences in sensitivity between individuals within the exposed population. In an effort to compensate for these uncertainties in a health protective manner, "safety" or modifying factors are applied by USEPA to the NOAELs selected for derivation of the RfD or RfC. Application of these uncertainty factors may be overly protective by several orders of magnitude.

For many compounds, animal studies provide the only reliable information on which to base an estimate of adverse human health effects. The practice of extrapolating effects observed in experimental animals to predict human toxic response to chemicals incorporates a number of conservative assumptions and safety factors. As a result, health effects in humans are likely overestimated, rather than underestimated, introducing additional uncertainty into the development of the RfD. For example, among the safety factors often incorporated into the development of RfDs, a factor of 10 is generally used to account for the presumed greater sensitivity of humans to chemicals; relative to laboratory animals. In fact, the opposite may be true for some chemicals; laboratory animals may be more sensitive than humans to some chemicals.

Extrapolation from high to low doses also adds considerable uncertainty to the development of RfDs, and hence, risk assessments. The concentrations of chemicals to which people are exposed in the environment are usually much lower (sometimes by several of orders of magnitude) than concentrations used in studies from which dose-response relationships have been developed. Predicting effects, therefore, often requires the use of models containing assumptions that allow for extrapolation of effects from high to low doses. A great uncertainty in any risk assessment process involves the characterization of human health effects based on studies performed in rodents.

3.5.5.6 Carcinogenic Health Risks

Usually, the level of uncertainty is larger for carcinogens than non-carcinogens; because of inherent uncertainties in development of the CSFs. CSFs calculated by USEPA are based on the Linear Multistage (LMS) model, which assumes that risk can be extrapolated in a linear manner from the high doses used in animal bioassays to the low doses characteristic of human environmental exposures. However, use of the LMS model for the determination of CSFs completely ignores the concepts of threshold dose, initiation/promotion, and epigenetic mechanisms of carcinogenesis. As such, CSFs are considered to represent potential risks at the 95 percent upper confidence level. The accuracy of risk estimates at low doses predicted by the LMS model is unknown, but the risks associated with low levels of environmental exposure may actually be zero (USEPA, 1986).

In the absence of evidence of synergistic or antagonistic effects of chemical mixtures, the assumption was made, in accordance with USEPA guidance that the effects of chemical mixtures are additive. This assumption, however, does not account for dissimilarities in mechanisms of action. Furthermore, compounds may actually induce different toxic effects in different species or in different systems within a given species.

3.5.6 Summary of Risk Characterization

Exposure to COCs in surface water, sediment and fish tissue at the Fisherville Pond have been evaluated to determine if the maximum concentrations of chemicals of concern present in these media pose a potential risk to the human health of local recreators. Based on the benchmark levels of acceptable carcinogenic risk (10^{-6} to 10^{-4}) and a noncarcinogenic hazard index of 1.0, the majority of the COCs identified in surface water, sediments, and fish tissue are not associated with an excess health risk or hazard for current and future recreators.

However, some of the identified exposures do result in elevated risks and hazard quotients. In particular, these exposures include ingestion of PCBs in fish for noncarcinogenic hazards and ingestion of and dermal contact with chromium and benzo(a)pyrene in sediment for carcinogenic risks. In evaluating these risks and hazards, it is important to note that the quantitative assessment of risk incorporates numerous conservative assumptions (*i.e.*, the assumption that concentrations of chromium represented Cr VI speciation) to compensate for various uncertainties in the actual conditions at the Site. Although some uncertainty is inherent in the calculations of noncarcinogenic hazards and carcinogenic risks, the overwhelming tendency of risk assessment is to err on the side of safety. Therefore, although the estimated hazards and risks calculated for potential exposures at the Site may be viewed as upper-bound estimates, it is likely that actual exposures will result in significantly less risk than those presented in this assessment.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 ECOLOGICAL RISK CHARACTERIZATION CONCLUSIONS

The following conclusions can be made concerning the potential for impacts to ecological receptors from exposure to COPECs in surface water and sediments.

- Using total and dissolved surface water samples collected during historic dry weather events, COPECs with HQs greater than 1 include cadmium, copper, lead, and nickel. The total fraction were slightly higher than the dissolved fractions.

- Using total surface water samples collected during a historic wet weather event, COPECs with HQs greater than 1 include cadmium, copper, lead, nickel and zinc.

- Ambient toxicity testing of surface water samples did not show any evidence of toxicity to fathead minnows or *Ceriodaphnia dubia*.

- Fish community surveys indicate the presence of a moderately diverse and abundant fish community in Fisherville Pond. However, the dominance of the fish population by more tolerant species indicates that the Fisherville Pond System may be somewhat degraded. Based upon the limited survey data and analyes, it is difficult to predict effects of existing water and sediment quality and water level management to the fish community.

- The weight of evidence evaluation suggests that COPECs present in surface water do not present a significant ecological risk. However, the ACOE (1996b) recommends that the MADFW and the ACOE design and conduct a more intensive fish community survey and analysis during the late summer or early fall to further evaluate risks to the fish community.

- Comparison of concentrations of COPECs in sediment samples collected in 1981 (McGinn, 1981) and 1994/1995 (Snook, 1995) indicate that arsenic, cadmium, chromium, copper, iron, lead, nickel, zinc, phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo(a)pyrene, and total petroleum hydrocarbons pose a risk to ecological receptors in the benthic macroinvertebrate community.

- A comparison of sediment interstitial pore water to relevant benchmarks indicates that aluminum, cadmium, chromium, copper, and lead concentrations from historic samples exceeds NAWQC acute criteria. Copper, cadmium and lead exceed the chronic criteria.

- In historic sediment toxicity tests, significant mortality was observed in *Chironomous tentans*. Mortality was also seen in *Hyallela azteca*. In historic pore water toxicity tests, survival of fathead minnows or *Ceriodaphnia dubia* was significantly reduced in a test conducted in October 1991, but not in July 1991. This is mostly likely a result of the heterogeneity of the sediments in Fisherville Pond.

- Sediments in Fisherville Pond appear to contain macroinvertebrate communities similar to those in "unimpacted" northeastern lentic systems. The biological survey data of the relative lack of impacts to the benthic community is very important from a temporal evaluation. The chemical and bioassay data developed in the past indicates that historic sediment concentrations pose a risk to benthic invertebrates. However, the more recent biological data (1996) suggests that fate and transport mechanisms and pond sedimentation is reducing the level of risk posed by sediments.

- The weight of evidence evaluation indicates that COPECs in sediments (based on historic data) may pose a significant ecological risk to benthic macroinvertebrates.

- It is very important to note that current 1997 sediments may be different in physical and chemical composition than the historical data used to prepare this report. Sediment accumulation would have resulted in the deposition of finer silts over the native coarse sediment. Additionally, it is reasonable to expect that the sediments of more recent nature would be cleaner due to general environmental trends over the last 15 years and would have buried the more historically contaminated native sediment. However, for the purposes of this assessment, it is assumed that current sediments have the same physical and chemical composition as sediments analyzed in 1981.

- COPECs in sediments (based on historic data: 1981 and 1995) may pose a significant ecological risk to amphibians.

- It is unlikely that mallards or great blue herons are experiencing adverse effects due to foraging in Fisherville Pond.

- Muskrats foraging exclusively in Fisherville Pond may be experiencing adverse ecological effects from aluminum and arsenic.

4.2 HUMAN HEALTH RISK CHARACTERIZATION CONCLUSIONS

The following conclusions can be made regarding the results of the HHRC for recreational exposure to COCs in surface water, sediment and fish tissue consumption at the Fisherville Pond.

- The noncarcinogenic hazards identified as potentially unacceptable are associated with consumption of fish containing maximum concentrations of PCBs, specifically Aroclor 1254 and 1260.

- The carcinogenic risks identified as potentially unacceptable are associated with incidental ingestion of and dermal contact with benzo(a)pyrene and chromium in sediment (assuming chromium concentrations represent Cr VI).

- Qualitative assessments of the maximum concentration of lead detected in surface water, sediment and fish tissue suggest that recreational surface water and sediment exposures are not anticipated to result in unacceptable hazard estimates. Maximum concentrations of lead detected in fish may produce marginally unacceptable risks based on the conservative exposure assumptions presented herein.

4.3 RECOMMENDATIONS

- To develop an understanding of the current chemical characterization of the sediments, it is recommended that additional sediment samples be collected and analyzed for metals. Additionally, because PCBs were identified in fish, with no data to indicate the source of the PCBs, it is recommended that the sediments also be analyzed for PCBs.

- A more thorough understanding of the risks posed by metals in sediments to humans and ecological receptors would be made by conducting speciation tests for certain metals in sediments. For example, chromium has been detected in sediments, but there is no information on whether it is the trivalent form, or the more toxic hexavalent form.

- Lead exposures were evaluated qualitatively comparing sediments to residential soil values, surface water concentrations to drinking water MCLs, and fish tissue concentrations to FDA action levels. The best approach would be to run an USEPA IEUBK or an O'Flaherty model to develop more accurate risk levels associated with lead.

5.0 REFERENCES

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