INDUSTRIAL HISTORY, MUTAGENICITY, AND HYDROLOGIC TRANSPORT OF POLLUTANTS IN THE ABERJONA WATERSHED

by

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Submitted to the Department of Civil Engineering
in Partial Fulfillment of
the Requirements for the Degrees of

MASTER OF SCIENCE IN CIVIL ENGINEERING

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ABSTRACT

There is concern that hazardous chemical wastes that have been discarded in the Aberjona watershed in eastern Massachusetts may constitute a human health risk. For the past three years research has been conducted by investigators from the Massachusetts Institute of Technology (MIT) to better understand the basic processes involved in the transport and transformation of hazardous chemical wastes in the Aberjona watershed. A principal goal of the research is to elucidate the mechanisms by which pollutants are transformed, the pathways by which they are transported, and the likely routes leading to human exposure. This thesis describes work in three areas of the investigation: historical chemical usage and industry waste disposal practices, environmental mutagenicity, and streamflow monitoring.

In order to determine which chemicals have been most widely used in the watershed, historical and present-day industrial records were analyzed. The leather industry - once a dominant industry in the watershed - was identified as a major generator of toxic metals. It was found that between 1838 and 1988, nearly 100 tanneries, leather finishing companies, and rendering factories operated at over 67 sites in the watershed. Considerable documentation was also discovered indicating that, prior to the completion of the sewer system in the mid-1930s, most leather industry firms routinely discharged their wastes to surface waters and dumps in the watershed. Mass balance techniques were used to estimate the amounts of four metals - chromium, copper, lead, and zinc - generated in tanning and leather finishing wastes. The estimates suggest that 2,000-4,000 tons of chromium, 65-140 tons of copper, 85-175 tons of lead, and 40-75 tons of zinc were produced in leather industry wastes between 1900 and 1936. It is hypothesized that a significant fraction of the total quantities of metals discharged are still present in the watershed.

Extracts of water samples were tested in a *Salmonella typhimurium* forward mutation assay to determine if water-borne organic chemicals were biologically active. One-liter samples from 32 surface water sampling sites and 10 ground water monitoring wells were concentrated by a factor of 2,000, and 11, 250 mL sediment pore water samples were concentrated by a factor of ~500 using solid-phase extraction techniques. Two, 60 L reverse osmosis deionized water samples and one, 60 L water sample from the East Drainage Ditch were also concentrated using a large-volume concentration procedure designed to achieve a concentration factor of 50,000. Water sample extracts were tested in the assay in both the absence and presence of an exogenous metabolizing enzyme system (PMS). It was found that six extracts from one-liter surface water samples and one sediment pore water sample were toxic (i.e. survival < 20%) in the presence of PMS, and one extract from a one-liter surface water sample was toxic in the absence of PMS. Although high mutant fractions were observed in four one-liter surface water sample extracts, none of these extracts nor extracts from any of the other ground water, sediment pore water, or other one-liter surface water samples was considered mutagenic. Extracts from the 60 L reverse osmosis deionized water system blank were toxic indicating that biologically active artifacts were being generated by the extraction system. Extracts of suspended particles filtered from the 60 L East Drainage Ditch sample were both toxic and potentially mutagenic in the presence of PMS, and potentially mutagenic in the absence of PMS. This result suggests that biologically active chemicals sorbed to suspended particles may be present in surface waters.

Streamflow measurements were recorded at four gauging sites in the watershed to provide a data-base from which the temporal and spatial variability of the surface hydrology can be inferred, and from which both present-day and historical fluxes of surface water pollutants can be estimated. Open channel flow recording gauges equipped with programmable data-loggers were used to make point measurements of depth and velocity at 15- to 30-minute intervals, depending on the power source. Established point velocity discharge measurement (PVDM) methods were used to calculate flows from the depth and velocity data. Calibration curves comparing measured and calculated flows suggest that PVDM methods more accurately predict flows under high flow conditions (i.e. > 15 cfs). Daily average depth and velocity measurements and calculated flows for each gauging site are presented for the period of record (January, 1989 - October, 1990).

Thesis Supervisor: Dr. Harold F. Hemond
Title: Professor of Civil Engineering

ACKNOWLEDGEMENTS

A large number of people helped me in my research in one way or another, and it is with considerable gratitude that I wish to publicly acknowledge their efforts. Al Balestrieri, Randy Bairnsfather, and Sylvia Pope provided valuable information in the investigation of the history of the leather industry in Woburn and Winchester. Also, Rosemary Rochio deserves credit for meticulously researching and helping to locate former leather industry sites in the watershed.

Peter Monchamp provided guidance and invaluable assistance on countless occasions in preparing water samples for mutagenicity testing. Also, Jennifer Zemach, Dharni Vasudevan, and Shahnaz Islam exhibited extreme competence in concentrating the water samples. I am indebted to Lata Shirname-More, Alexandra Hawiger, Barbara Menten, Henny Smith, and Woody Bishop for performing the mutagenicity assays, and to Bill Thilly for generously taking the time to explain the intricacies of data interpretation. I would also like to thank Barbara Newman (EPA Region I) for allowing me access to ground water monitoring wells.

Ed Brainard provided skilled assistance in installing the streamgauges and was a sustaining force during his tenure on the project. Bill Nieman (Woburn DPW) allowed me access to 120-volt AC power at Well F, loaned me tools, and gave me free advice on hockey and other matters. Don Grossman and Chris Newman (Coastal Leasing, Inc.) provided much appreciated technical support in keeping the streamgauges operating.

I am greatly indebted to Gretchen Latowsky for all the support (both material and spiritual) she has given me these last three years. She has been a valued friend to the MIT Aberjona Project. My advisor, Harry Hemond, provided guidance and was at all times patient, insightful, and a vast reservoir of knowledge. I also want to thank Linda Olsson for letting me install a well in her backyard - and, in doing so, causing no small disturbance. Lastly, I thank my friends and family who have sustained me through this undertaking, and most of all Elizabeth Simons, who has been a loyal companion, trusted advisor, and constant inspiration.

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CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF DATA DISKS

1. INTRODUCTION

1.1 Motivation

Hazardous chemical wastes of industrial origin have been discharged into the Aberjona watershed in eastern Massachusetts for over 150 years (Figure 1.1). Large quantities of these wastes have recently been discovered at disposal sites in the watershed, and there is growing concern that residents may be at risk of adverse health effects by exposure to toxic chemicals. To date, investigators from the Massachusetts Department of Environmental Protection (DEP) and the U.S. Environmental Protection Agency (EPA) have found or strongly suspect contamination at over 50 sites in the watershed (1-3). Of these, approximately 20 sites have been "confirmed" by the state as containing oil and/or hazardous materials. Also, two sites - Industriplex and Wells G&H - have been designated EPA "Superfund" sites, and, thus, federal funds are available for their remediation (Figure 1.2). In addition to locating waste disposal sites, researchers have shown that waste chemicals are being transported through the watershed, and are present in areas far from the point of their environmental release. For example, researchers from the Massachusetts Institute of Technology (MIT) have shown that toxic waste metals are widely distributed in surface sediments in the watershed (Figures 1.3 - 1.6) (4), and organic solvents are frequently encountered in several surface water bodies (Figure 1.7) (5).

In order to determine whether residents of the watershed have been adversely affected by exposure to waste chemicals, several human health studies have been conducted. Lagakos et al. (6), for example, carried out an epidemiological study in which the incidence of reproductive and childhood health problems in Woburn was compared to exposure to water from two contaminated municipal supply wells (Wells G&H). The researchers showed that there were positive statistical associations between access to well water and the incidence rates of childhood leukemia, perinatal deaths, congenital anomalies, and childhood disorders. Two additional epidemiological studies are currently being performed by researchers from the Massachusetts Department of Public Health (DPH). A principal component of the investigations is the compilation of a comprehensive data base indicating the location of all past and present sources of environmental contamination in Woburn, and the identity of all the hazardous chemicals which have been found at these sites and in environmental samples collected in areas not necessarily associated with any particular site (e.g. rivers, streams, lakes, ground water,

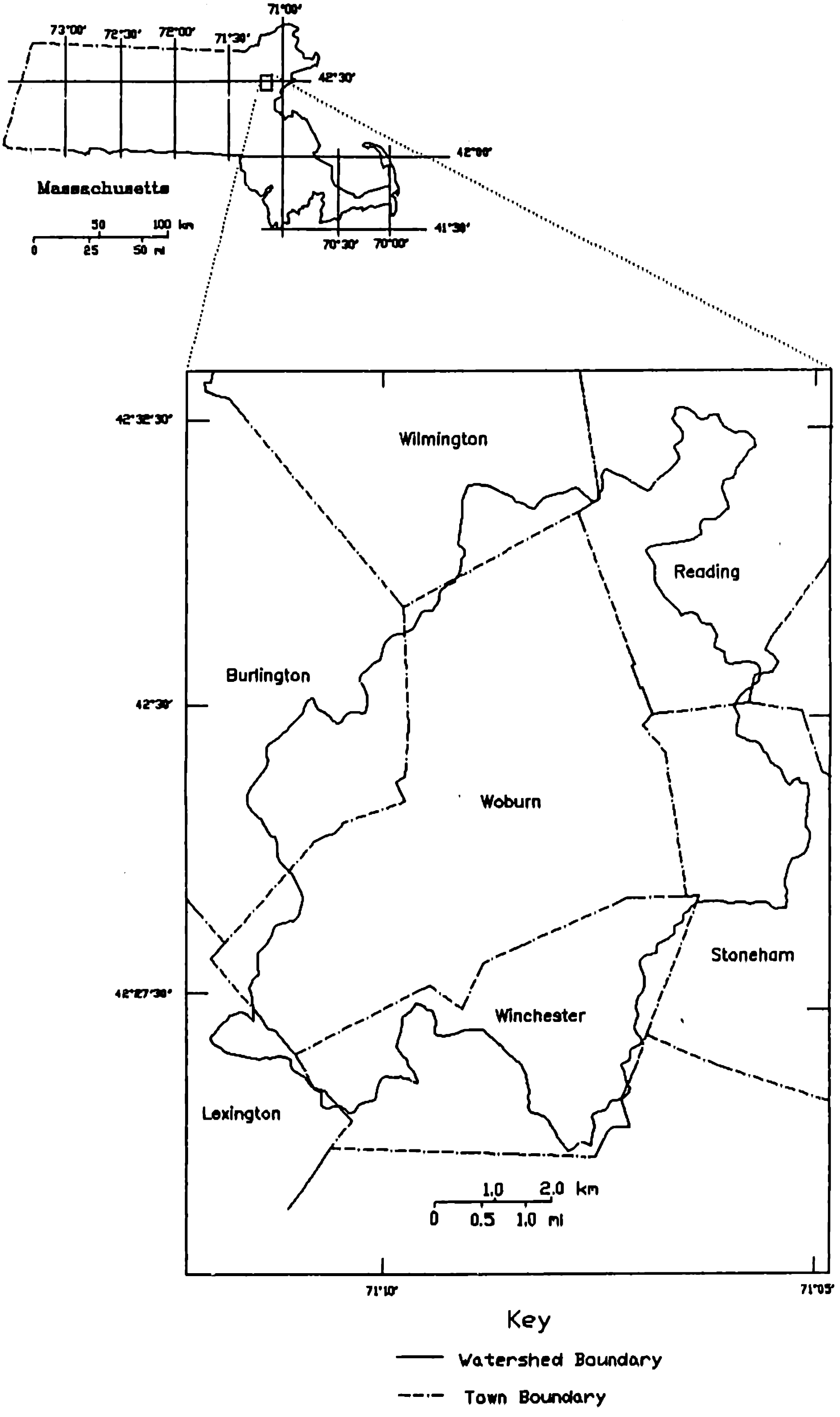

Figure 1.1 Location of Aberjona Watershed

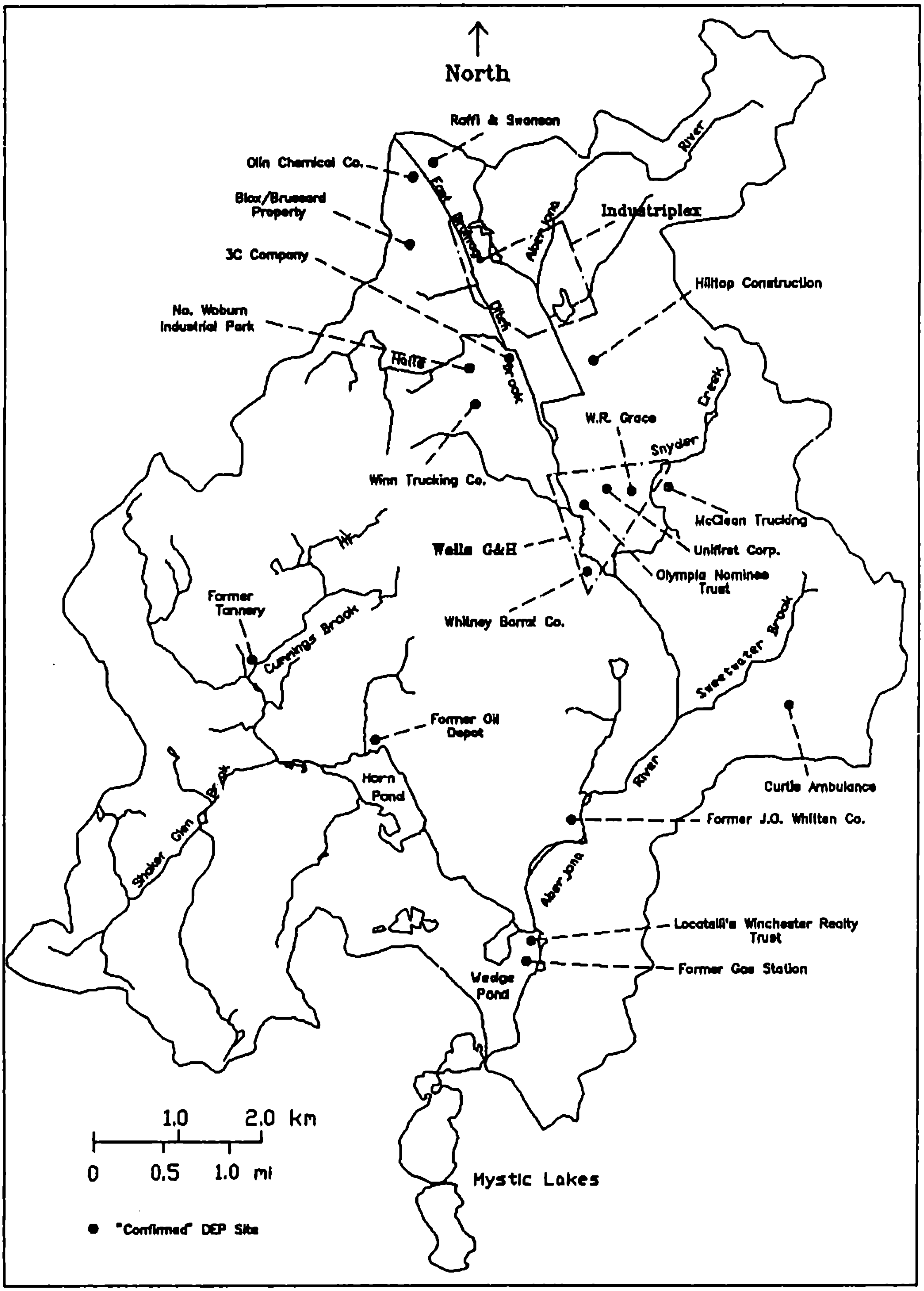

Figure 1.2 Location of Confirmed DEP Sites and EPA Superfund Sites in the Aberjona Watershed

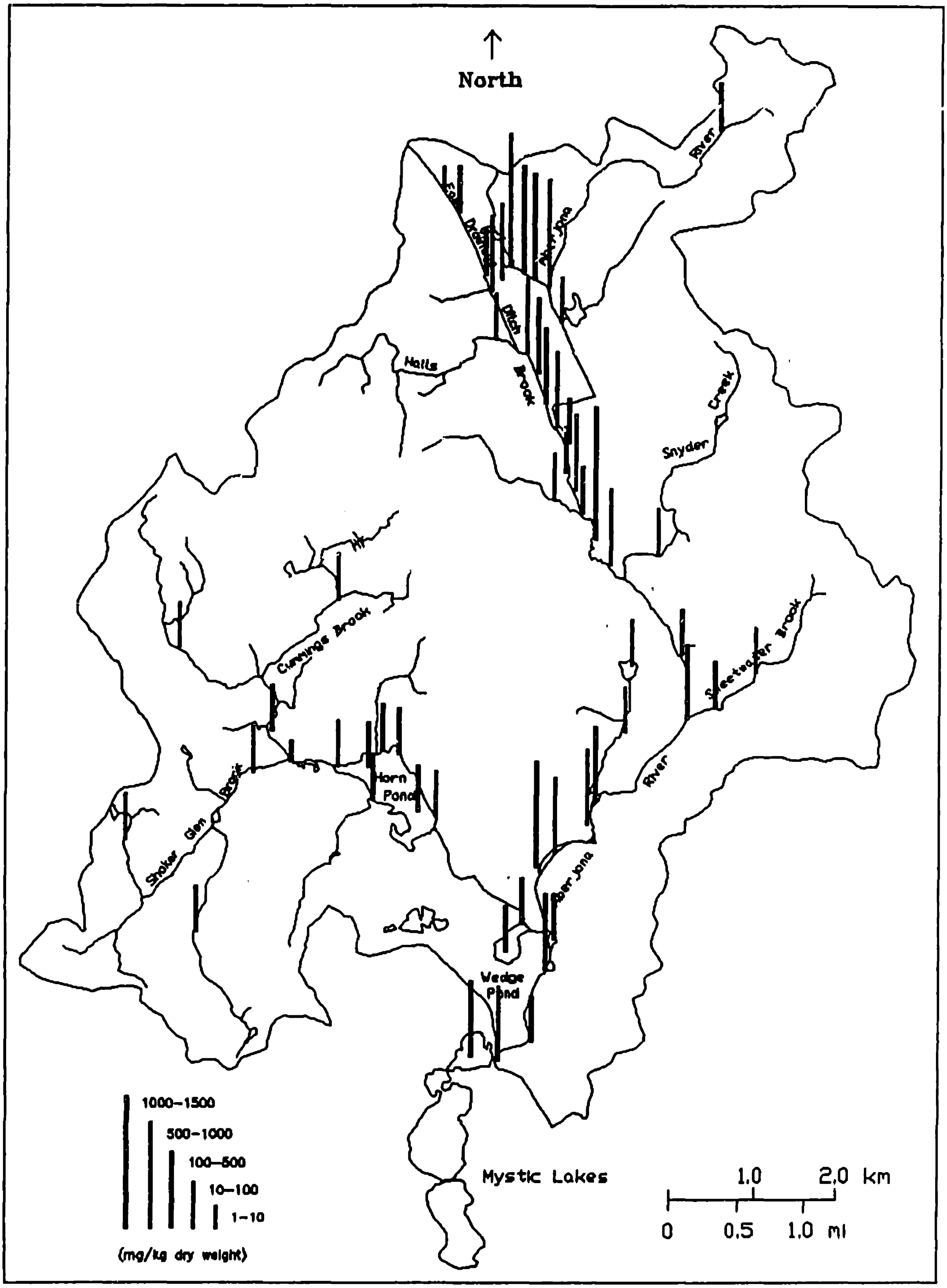

Figure 1.3 Distribution of Chromium in Surface Sediments in the Aberjona Watershed

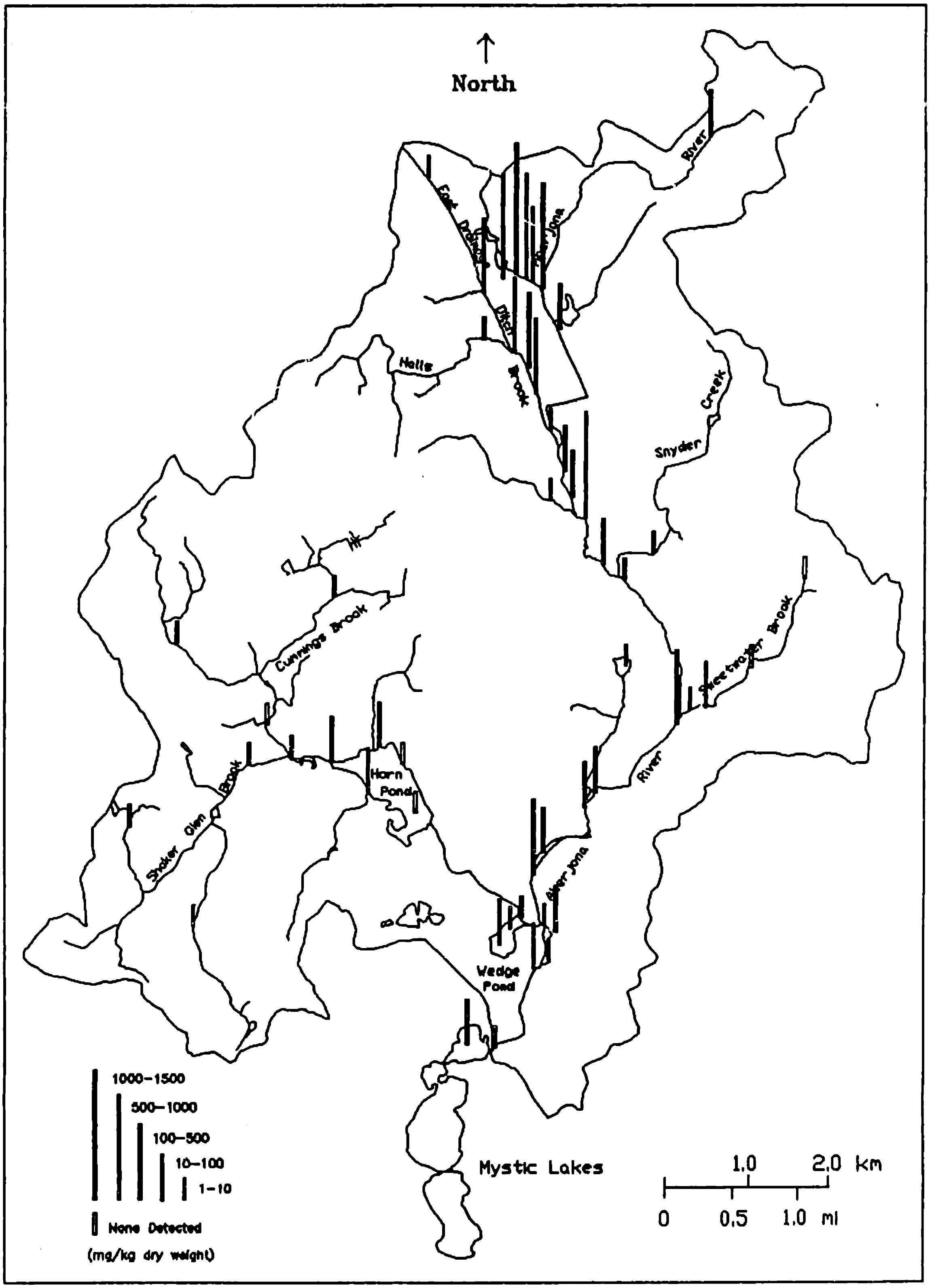

Figure 1.4 Distribution of Arsenic in Surface Sediments in the Aberjona Watershed

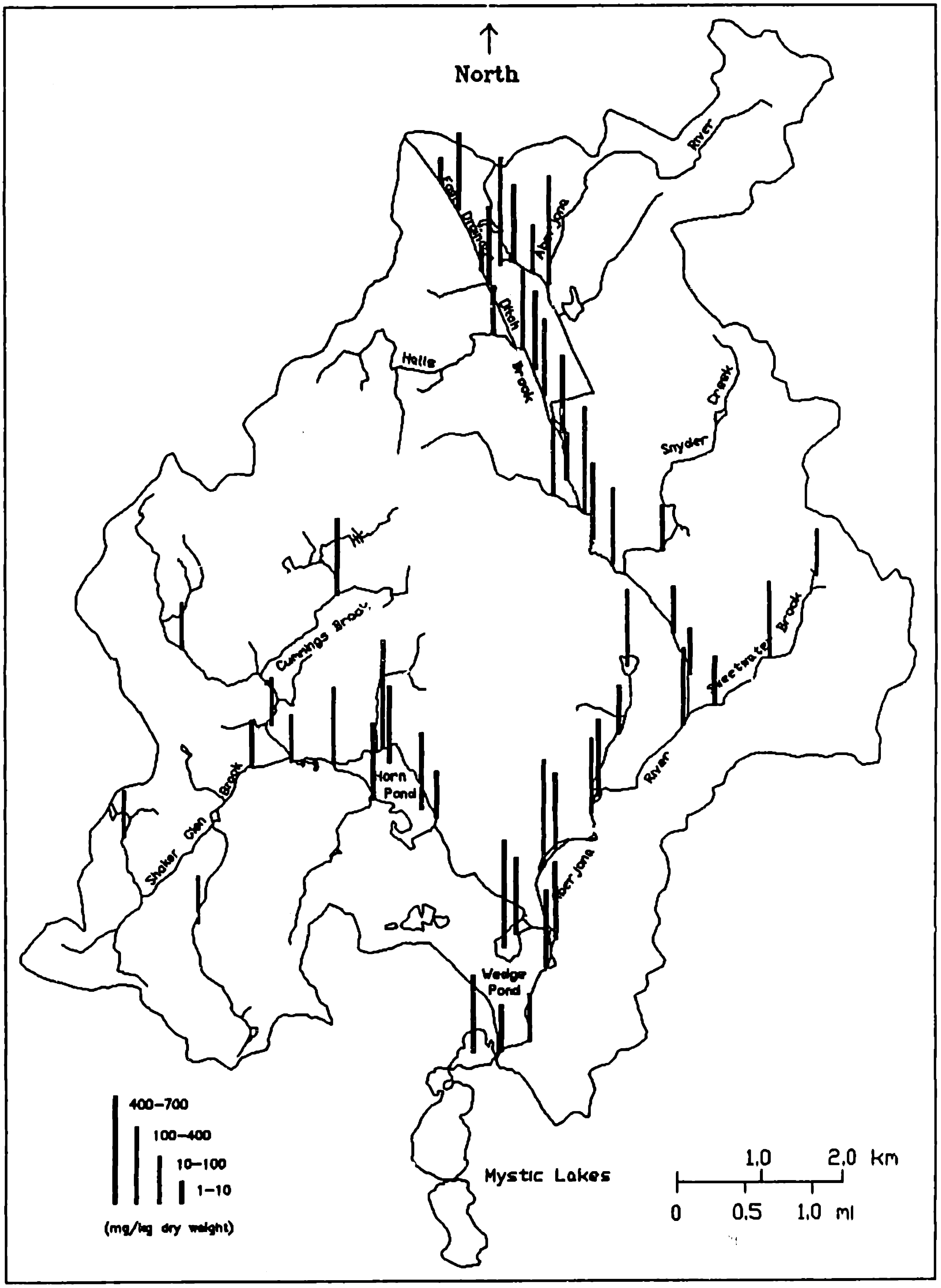

Figure 1.5 Distribution of Lead in Surface Sediments in the Aberjona Watershed

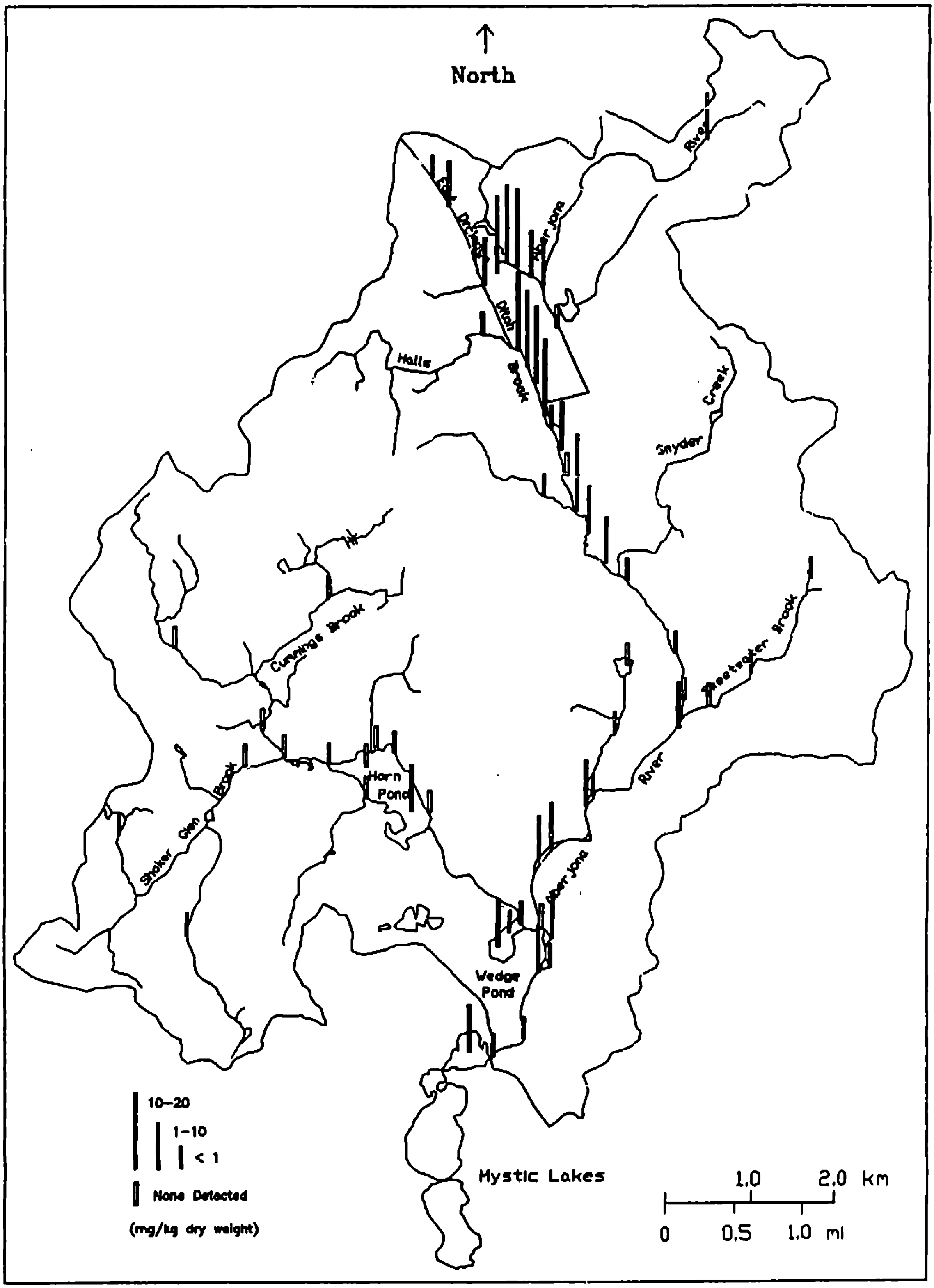

Figure 1.6 Distribution of Cadmium in Surface Sediments in the Aberjona Watershed

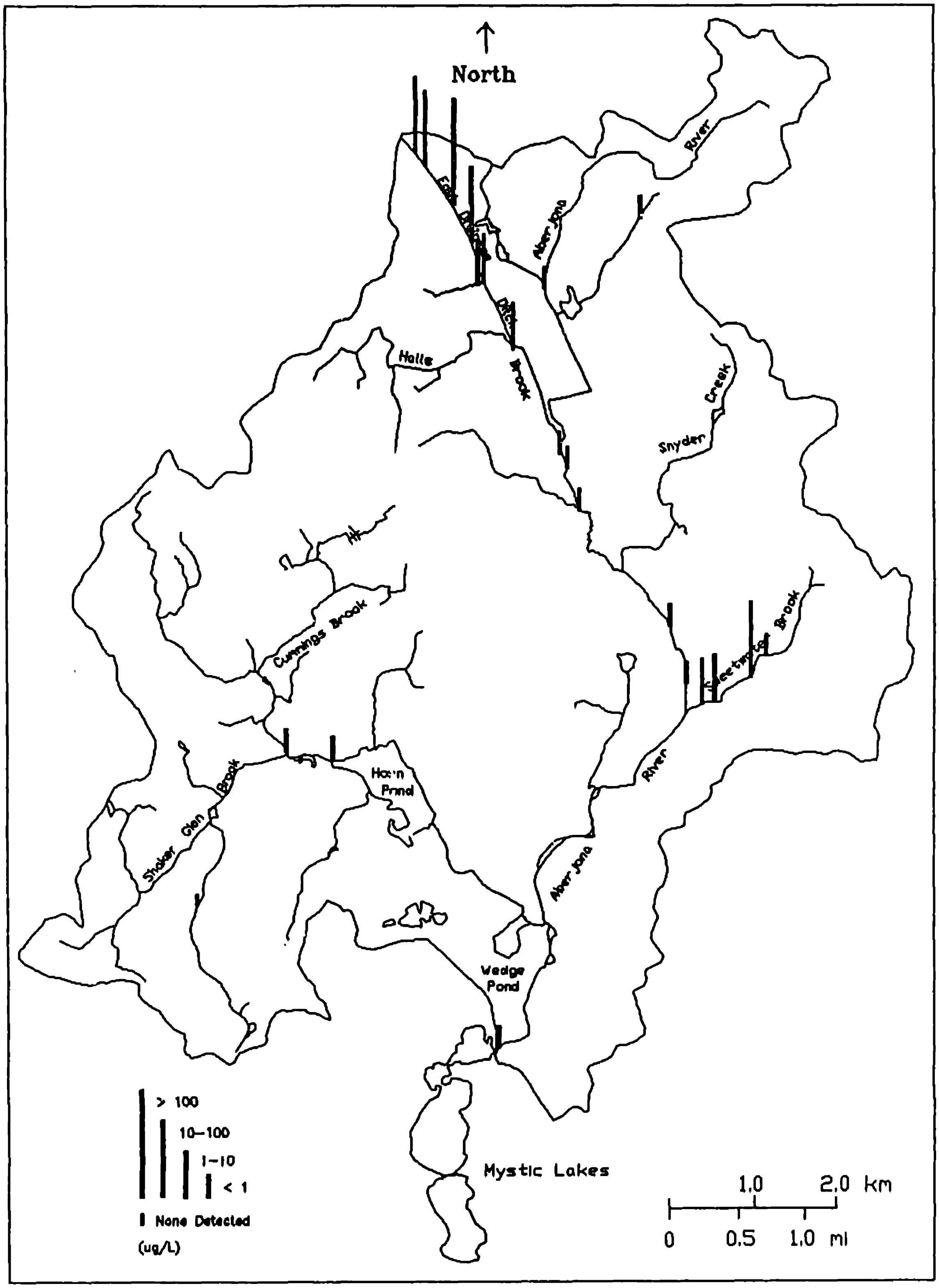

Figure 1.7 Distribution of Total Volatile Organic Compounds in Surface Waters in the Aberjona Watershed

air, etc.) (8). The data base will then be used to determine the statistical significance of potential exposure to these hazardous chemicals to the incidence rates of adverse birth outcomes and childhood leukemia in Woburn children.

Although these studies significantly further the understanding of associations between exposure to hazardous environmental chemicals and adverse health effects, their results cannot be used as evidence of direct causal linkage between specific health outcomes and exposure to specific chemicals. At best, positive statistical associations reinforce the need for more direct human health effects research in which exposure to hazardous environmental chemicals is measured and the mechanisms of human health change are specifically elucidated.

1.2 Goals of the MIT Aberjona Project

For the past three years researchers from MIT have been investigating the distribution and extent of hazardous waste pollution in the Aberjona watershed. The overall goal of the MIT effort is to better understand the basic processes involved in the transport and transformation of chemicals released into the environment, and the kinds, amounts, and actual biological effects of hazardous chemical wastes in humans. Specifically, the aim is to investigate the "pathway of impact" of hazardous chemicals, from the point of their discharge or disposal, through the myriad of possible environmental transport and transformation processes, leading to human exposure, and to elucidate direct causal mechanisms that result in toxicity, genetic change and adverse human health effects (7).

The investigation is currently being conducted by two different groups of MIT researchers: civil engineers and toxicologists. Civil engineers are investigating the distribution and extent of hazardous chemical wastes in the Aberjona watershed, chemical transport and transformation processes, and the pathways leading to human exposure; toxicologists are studying the mechanisms by which human health could be adversely impacted by exposure to hazardous chemicals. Some of the environmental projects that are now in progress include:

- **Characterization of the hydrology of the watershed.** Developing a water balance is essential for quantifying transport and chemical mass balance at a watershed-scale. In-situ measurements of water fluxes (i.e. precipitation, surface water flows, ground water elevation fluctuations, etc.) are being made to calculate chemical fluxes and to calibrate watershed-scale hydrologic models.

- **Measurement of present-day levels of pollution.** Surface water, ground water, and sediment samples are being collected and analyzed for the presence of chemical pollutants, with particular emphasis on toxic industrial metals, and volatile organic compounds. Work is also being done to identify pollutants that are biologically active in bacterial and human cell mutagenicity assays.

- **Determination of the historical pattern of environmental releases.** Research is being conducted on two different fronts to identify sources from which hazardous chemicals are released and areas where chemicals tend to accumulate. In-situ salt-dilution measurements coupled with laboratory analysis of surface water samples for the presence of industrial solvents are being used to locate stream reaches from which ground water contaminants are emanating. Also, historical records of industrial activities and waste disposal practices are being analyzed to identify the chemicals most widely used, likely routes of their environmental release, and locations where they may have been dumped or at present have accumulated.

1.3 Thesis Structure

This thesis is composed of three major sections, each of which was researched independently and is written to stand alone. The first section (Chapter 2) details the history and waste disposal practices of the leather industry, one of the oldest and most productive industries in the watershed. Tanning, leather finishing, and rendering activities are described, leather industry wastes are characterized, and mass balance techniques are used to quantify the amounts of four metals - chromium, copper, lead, and zinc - generated in tanning and leather finishing wastes. Because leather industry wastes were routinely discharged to surface waters and dumps in the watershed, considerable quantities of metals remain, and there is concern that they may pose risks to human health and the environment.

The second section (Chapter 3) describes the results of testing extracts of water samples from the watershed in a bacterial mutation assay. Surface water, sediment pore water, and groundwater samples collected throughout the watershed were preconcentrated using solid-phase extraction, and the extracts were tested in the assay to determine if chemicals recovered from the water samples could induce measurable genetic change. The measurement of mutagenic activity and relative toxicity in water samples is useful both in assessing water quality in general, and in linking exposure to chemicals present in water to biological effects.

The third section (Chapter 4) describes streamflow monitoring activities in the watershed. Gauging stations were established at four sites at which point-velocity and depth measurements were recorded at 15- to 30-minute intervals. Discharges were calculated using established point-velocity-discharge-measurement approximations, and are presented as daily average values for each site. Streamflow measurements are necessary indicators of temporal and spatial hydrologic variability, and, when coupled with chemical data, can be used to estimate chemical fluxes.

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2.

THE HISTORY OF LEATHER INDUSTRY WASTE CONTAMINATION IN THE ABERJONA WATERSHED:

A MASS BALANCE APPROACH

Published in *Civil Engineering Practice*, Fall, 1990.

Co-authors: Jennifer J. Zemach and Harold F. Hemond

2.1 Introduction

There is concern that leather industry wastes that were discarded in the Aberjona watershed in eastern Massachusetts may constitute a potential human health risk. Chemicals used in hide and skin tanning and chemicals found in tannery wastes (in particular, chromium, which is a common tanning agent) have been shown to be toxic to aquatic organisms and humans (1,2), mutagenic and carcinogenic in animal assays (3-5), and carcinogenic in human epidemiology studies (4). The Aberjona watershed, a 25 square mile area 10 miles north of Boston (Figure 2.1), was once a major center for tanning, leather finishing, and hide and leather rendering. Between 1838 and 1988 approximately 100 tanneries, leather finishing companies, and rendering factories operated at over 67 sites in Woburn, Winchester, and Stoneham (Figure 2.2, Table 2.1, Appendix 2.1).

Records from as early as 1871 to the mid-1930s indicate that the Aberjona River and its tributaries were the main conduits by which tannery and rendering factory wastewater was discarded. Tannery and rendering factory sludges were commonly disposed on-site or at centrally located dumping areas (7,9,23-42). At present, there are six sites in the watershed which are being investigated for the presence of leather industry wastes (15,16,22,43-45). Five sites are being investigated by the Massachusetts Department of Environmental Protection (DEP) under the provisions of Massachusetts General Law, Chapter 21E, section 3(A)b and the Massachusetts Contingency Plan (310 CMR 40.00); the sixth site, the "Industriplex" Superfund site, is being investigated by the Environmental Protection Agency (EPA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and is currently ranked fifth on the National Priorities List.

Civil engineers and toxicologists at the Massachusetts Institute of Technology are investigating possible links between environmental contaminants and human health effects in the Aberjona watershed. Work is being done to determine how hazardous chemical wastes are distributed in and move through the watershed, and how humans may be exposed to and affected by particular waste chemicals. In order to help identify which hazardous chemicals are most widely distributed in the watershed, mass balance techniques are being employed to quantify chemical consumption and waste generation by specific industries. This paper focuses on the leather industry. A history of the industry is presented, manufacturing

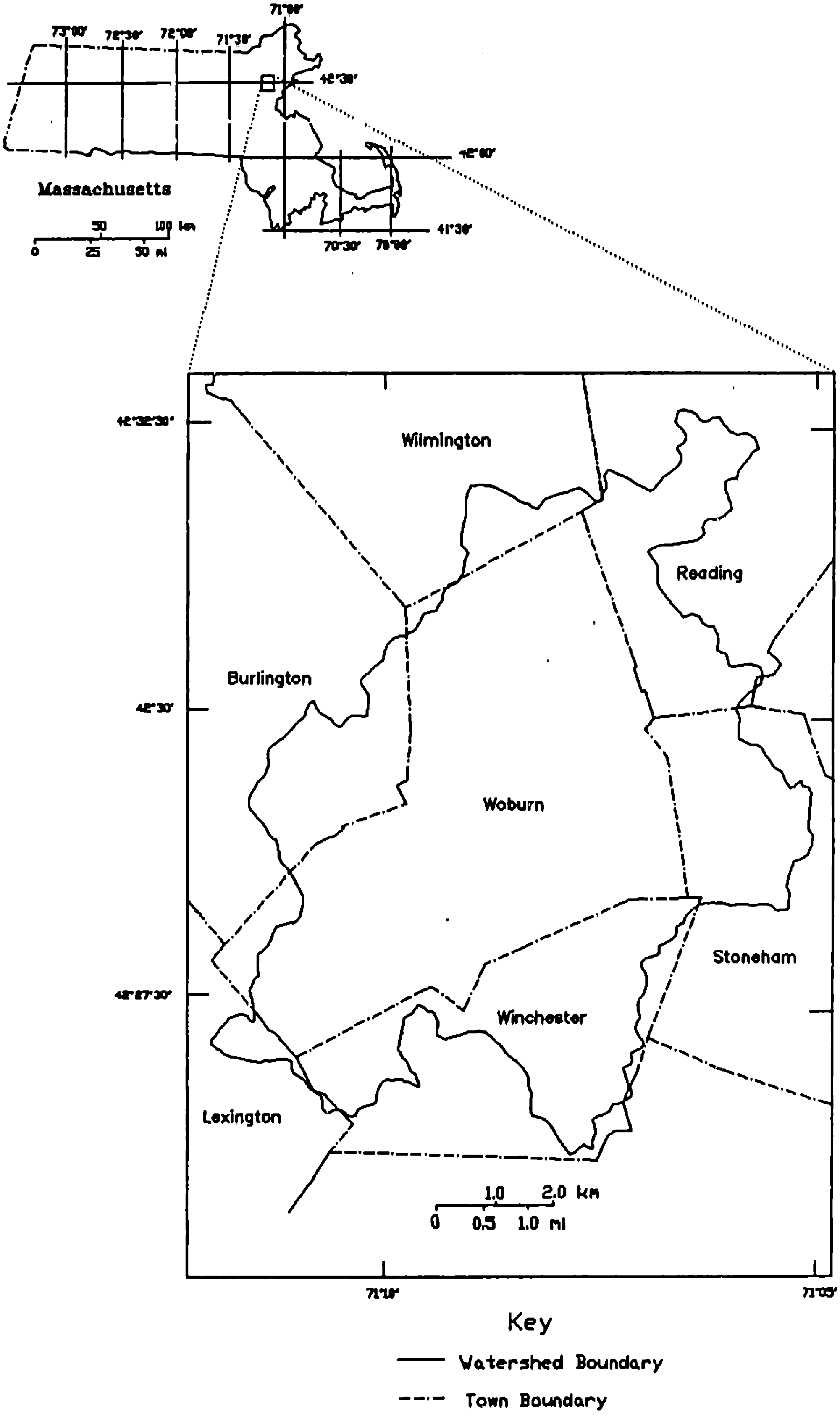

Figure 2.1 Study Area Location Map

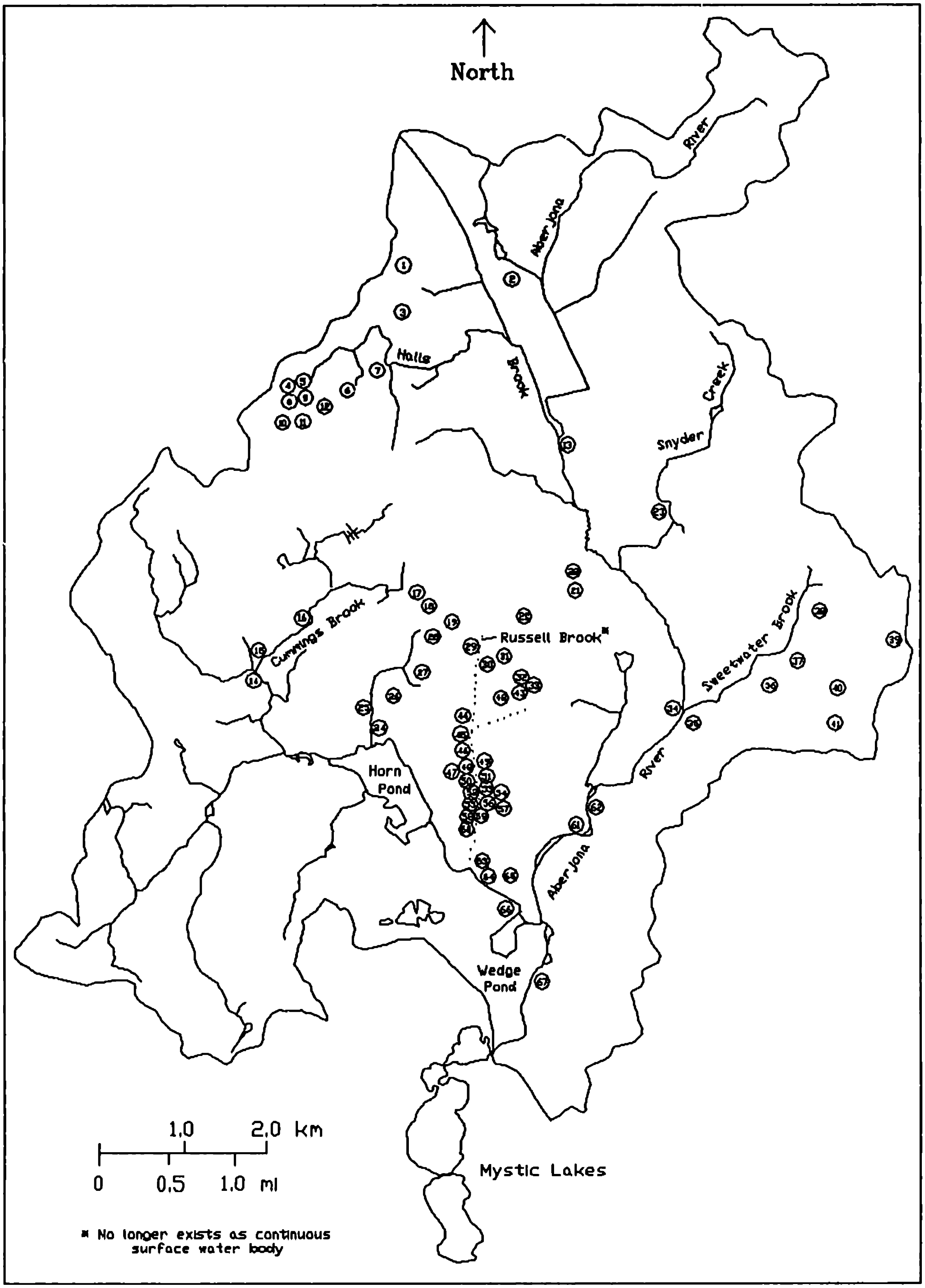

Figure 2.2 Location of Tanneries, Leather Finishing Companies, and Renderers in the Aberjona Watershed (1838-1988)

Table 2.1: Tanneries, Leather Finishing Companies, and Renderers in the Aberjona Watershed (1838-1988).

Site	Last Company to Operate at the Site	Operation	Approx. Dates	Ref.
1	Woburn Hide & Leather Co.	Tanning	1957-1960	17,21
2	Stauffer Chemical Co.	Rendering	1934-1968	15
3	Algonquin Leather Co.	Tanning	1918-1926	6
4	Foucar Leather Co.	Finishing	1918-1926	6
5	Rathburn Leather	Tanning	1875-1939	6,46
6	Eaton, Winn & Co.	Tanning	1875- ?	46
7	North Star Japanning Co.	Finishing	1926- ?	6
8	Porter Japanning Factory 2	Finishing	1918-1939	6
9	Porter Japanning Factory 1	Finishing	1894-1939	6
10	Linscott Heel Manufacturers	Tanning	1888-1926	6
11	Bond & Tidd	Tanning	1875- ?	46
12	Bond Leather Specialists	Tanning	1918-1926	6
13	H.W. Clark Patent Leather	Finishing	1904- ?	6
14	Woburn Degreasing Co.	Rendering	1871-1977	7,20
15	Bacon's Patent Leather Co.	Finishing	1871- ?	7
16	Colgate & Son Tannery	Tanning	1871- ?	7
17	E.G. Place Split Leather	Tanning	1888- ?	6
18	W.P. Fox Grain & Split	Tanning	1888-1904	6
19	Kinney & Murphy	Tanning	1875-1894	6,46
20	Paterson Patent Leather	Finishing	1926- ?	6
21	Murray Leather Co.	Finishing	1918-1979	6,8
22	J.J. Riley Co.	Tanning	1918-1988	6,8
23	Crescent Tanning Co.	Tanning	1918-1940	6,18
24	Morocco Manufactory	Tanning	1871- ?	7
25	Stephen Dow & Co.	Tanning	1875-1894	6,46
26	Prime Tanning Co.	Tanning	1888-1926	6
27	Bay State Japanning Co.	Finishing	1913-1926	6,8
28	Amer. Hide & Leather Fact. H	Tanning	1875-1904	6,46
29	Winn Tannery	Tanning	1875- ?	46
30	J.H. Connolly	Tanning	1875- ?	46
31	Murray Leather Co.	Finishing	1875-1961	6,19,46
32	Woburn Japanning Co.	Finishing	1875-1961	6,19,46
33	Griffin Place Curry Shop[1]	Tanning	1894-1918	6
34	Tanners Degreasing Co.	Rendering	1939-1977	6,20
35	Atlantic Gelatin	Rendering	1875-Pres.	6,10,46

Table 2.1: Continued

Site	Last Company to Operate at the Site	Operation	Approx. Dates	Ref.
36	A. Buckman Co.	Tanning	1924- ?	6
37	J.H. Murphy Curriers	Tanning	1924- ?	6
38	Blank Brothers Curry Shop	Tanning	1887-1903	6
39	Best Leather Nut Co.	Tanning	1924- ?	6
40	W.H. Tidd	Tanning	1840-1903	6
41	Van Tassel Co.	Tanning	1897-1924	6
42	Ballard Japanning Co.	Finishing	1904-1926	6
43	J. Kendall Chrome Tannery[1]	Tanning	1888-1918	6
44	Prime Tanning Co.	Tanning	1875-1934	6,44,46
45	Tolman-Fox Corp.	Tanning	1875-1938	6,43,46
46	W.P. Fox Leather[2]	Tanning	1875-1918	6,46
47	Dorrington Leather Co.	Tanning	1888-1939	6
48	Amer. Hide & Leather Fact. D	Tanning	1875-1939	6,46
49	E. Cummings Leather Co.	Tanning	1888-1926	6
50	E.C. Cottle[3]	Tanning	1888-1894	6
51	Watauga Tanning Co.	Tanning	1888-1894	6
52	Middlesex Leather Co.[3]	Tanning	1888-1904	6
53	Cottle Leather Co.	Tanning	1888-1918	6
54	American Hide & Leather	Rendering	1918-1926	6
55	B.H. Nichols Grease Factory	Rendering	1888-1904	6
56	Beggs & Cobb Factory 1	Finishing	1888-1926	6
57	Beggs & Cobb Factory 2	Finishing	1888-1926	6
58	Kean Brothers & Bedell	Finishing	1926- ?	6
59	Amer. Hide & Leather Fact. E	Tanning	1875-1926	6,46
60	Amer. Hide & Leather Fact. S	Tanning	1875-1939	6,46
61	J.O. Whitten Co.	Rendering	1872-1980	9,11,14,16
62	A.H. McLatchy Co.	Finishing	1916-1929	6,9
63	Pantasote Leather Co.	Tanning	1899- ?	6
64	Haley Patent Leather Co.	Finishing	1904-1916	6
65	Beggs & Cobb	Tanning	1871-1957	7,9,11,13
66	Blank Brothers Tannery	Tanning	1876-1910	11,12,14
67	Waldmyer Tannery	Tanning	1838-1894	11

[1] In 1918 was incorporated into Woburn Japanning Co. at Site 32.

[2] In 1918 was incorporated into Fox & Sons, Inc. at Site 45.

[3] In 1904 was incorporated into Amer. Hide & Leather Fact. D at Site 48.

records are analyzed, and a mass balance approach is used to estimate the amounts of four metals - chromium, copper, lead, and zinc - produced as by-products of tanning and leather finishing. It should be noted that there were insufficient records to properly characterize the rendering industry, and, therefore, wastes generated by rendering operations were not included in the mass balance.

2.2 A Brief History of the Leather Industry in the Aberjona Watershed

2.2.1 Early Years of the Leather Industry

The history of tanning in the Aberjona watershed spans over 320 years. The first tannery was built in Woburn in 1666 (47). During the 1700s several more tanneries were constructed in Woburn, but it was not until after the Middlesex canal was completed in 1803 that the tanning industry became firmly established. Built to facilitate the exchange of raw materials and manufactured goods between Boston and the city of Lowell to the north, the canal had a significant impact on the economies of the smaller communities which developed along its banks. The canal ran through what is now Woburn center, providing Woburn's tanneries direct access to markets from which they could acquire new hides and skins, and to which they could distribute finished leather products. By 1837 there were four tanneries in Woburn employing over 75 workers (48).

The early development of the leather industry in the watershed was helped considerably by the concurrent development of machine making, chemical production, and shoe and boot manufacturing. Machinists produced new and innovative tanning machinery; chemical companies both supplied chemicals to and derived raw materials from tanning operations; and shoe and boot manufacturers provided a steady market for finished leather. Although all three support industries were important to the early success and growth of the tanning industry, the making of shoes and boots had perhaps the most significant impact. Along with Philadelphia and Lynn, Massachusetts, the Aberjona watershed was one of the nation's largest manufacturing centers for leather footwear. In 1850, there were 26 shoe and boot manufacturing shops in Woburn alone (48).

By the 1860s the production of leather had become the dominant industry in the watershed. The construction of the Woburn branch-line to the Boston & Maine railroad (1844), the increasing supply of skilled tannery workers, the continued demand for finished leather by local shoe and boot manufacturers, and the growing reputation of the quality of Woburn leather goods all contributed to the prosperity of the leather industry (In 1865, there were 21 tanneries and four leather finishing companies in Woburn, and at least one tannery in both Stoneham and Winchester (49)). In explaining the dominance of the leather industry in the watershed, historians also suggest that the quality and supply of water was an important factor. In 1920, one historian wrote:

> From the beginning of tanning in this city [Woburn], it has become a well known fact that the opportunities here presented for tanning were unexcelled, and that better results could be obtained here because of the water properties, than in any other known locality (47).

Not only were there abundant supplies of surface water from which to draw water for production and in which to discharge wastes, but there were considerable ground water reservoirs as well. According to the U.S. Geological Survey, the Aberjona watershed has some of the most transmissive aquifers in the northeast Massachusetts coastal drainage basin (50).

2.2.2 Peak Years of the Leather Industry

The most productive period in the history of the leather industry lasted from the late 1870s to the 1920s. During that period 15-20 tanneries and leather finishing companies were consistently in business, nearly 55% of all wage earners were employed in the leather industry, and the value of tanned and finished leather accounted for over half of the total annual value of goods produced in the watershed (51).

Two factors which had a significant impact on the growth and success of the industry in this period were the introduction of chrome tanning methods, and the increased specialization of the industry in the production of "upper" leather (i.e. leather from which the upper parts of shoes are made). Prior to 1900, most tanning was done with tanning agents derived from plants - principally, tannins from wood, leaf, and bark extracts. “Vegetable” tanning, as it is known, was performed in vats of tannin solution in which hides and skins were soaked for as long as several weeks, depending on the thickness of the leather and the desired qualities of the tanned product. The introduction of chrome tanning methods to the watershed around the turn of the century, however, revolutionized the production of light leathers by greatly reducing the time necessary for tanning. Chrome tanning, in which chromium salts - usually, basic chromium sulfate - are used as the principal tanning agents, is completed within 6 to 24 hours, and produces a leather which has greater heat and abrasion resistance than vegetable tanned leather.

The specialization of the tanning industry in the production of upper leather was influenced not only by the development of chrome tanning methods, but also by technological innovations and market demand. Such inventions as the belt knife splitting machine, which is used to separate the grain side of the leather from the flesh side or "split," the staking machine, which is used to soften leather, the shaving machine, and the embossing and buffing machines increased the productivity of upper leather tanneries greater than tenfold (47). Likewise, the use of trucks instead of railroad cars and horse-drawn wagons to deliver leather to market both increased the speed of distribution and allowed access to new distribution centers. In response to market demands for new types and styles of finished leather goods, tanneries and leather finishers produced patent leather for shoes, and special grades of upper leather such as glove grain, pebble grain, and crimping splits. By the 1920s, tanneries and finishers had markets in England, Europe, and South America, and in the United States, Woburn and Winchester were referred to as the nation's "home of upper leather manufacturing" (52). In order to keep up with demand, it was estimated that in the late 1920s tanneries in Woburn were producing approximately 30 thousand sides of leather per day, or 7 million sides annually (47).

2.2.3 Decline of the Leather Industry

The finished leather industry had its best years in 1927 and 1928, and then experienced significant losses as a result of the stock market crash in 1929 and the depressed national economy in the early 1930s. In 1928, the value of leather goods produced in Woburn was just over $10 million, 1299 wage earners were employed in the leather industry, and 24 tanneries and leather finishing companies were in business. By 1932, however, the value of leather goods produced in Woburn had decreased by two-thirds to just over $3.2 million, the number of employees had been reduced to 759, and the number of tanning and leather finishing businesses had fallen to 16. The leather industry hit bottom in 1940 when only six tanneries remained and the value of goods produced was $380 thousand (51).

Despite the downturn in the finished leather economy in the 1930s, other sectors of the leather industry - specifically, leather and hide rendering - still managed to post modest gains. Rendering companies took advantage of the cheap surpluses of hides and unfinished leather, and built large factories to manufacture grease, gelatin, and glue. By 1939 five rendering plants were operating in the watershed.

In 1940 there were 11 tanneries, leather finishing companies, and rendering factories in the watershed. Between 1940 and 1948, the industry posted modest gains as the value of products reached its highest level since 1929. By the 1950s, however, it was clear that the industry was stagnating. No new establishments were going into business, and industry profits were not keeping pace with growth in other sectors of the local economy. Increasing competition from foreign companies for market share, fluctuations in wholesale prices, and rising production costs also contributed to the slow demise of the industry. The remaining companies began going out of business one by one in the late 1950s. The last company to go out of business, the J.J. Riley Company, closed in January, 1988, thus ending the long tenure of the leather industry in the watershed.

2.3 Record of Leather Industry Waste Contamination

2.3.1 Surface Water Contamination

There is a substantial historical record documenting leather industry waste contamination of surface water bodies in the watershed. Much of this history was documented by the Massachusetts State Board of Health and later by the body that replaced it, the State Department of Public Health. In one of its first investigations of the relationships between industrial and municipal waste disposal practices and the contamination of drinking water supplies, the Board of Health studied the problems in the Upper Mystic Lake watershed. In 1871 a report was issued on the condition of Upper Mystic Lake (which then provided drinking water to Charlestown, Somerville, and East Boston), its main tributary, the Aberjona River, and other water bodies in the watershed. Although no industrial or municipal waste contamination was found in Upper Mystic Lake, the report indicated that tannery wastes were present in Horn Pond (which was then part of Woburn's water supply) and its tributaries (7). Subsequent reports by the Board of Health in 1874 and 1875 described the extent of tannery waste contamination in Russell Brook, a tributary to Horn Pond Brook (23,24). Investigators identified eight tanneries that were directly discharging effluent to the brook. Sewage from nearby homes and coal degassing wastes were also adding to the foul condition of the brook, leading Board of Health officials to speculate that the contaminated water had contributed to the recent increase in mortality rates in the community:

> Within the last ten years, there has been a large number of deaths in this district, especially from consumption, typhoid fever, diptheria and scarlet fever. During the past summer and fall, when the brook [Russell Brook] was in its worst condition, there was sickness in most of the houses. It is fair to infer that the prevalence of disease was influenced, if not caused, by the polluted stream... (24).

In 1876, just five years after declaring Upper Mystic Lake water "unquestionably good and wholesome," Board of Health investigators returned to the watershed to assess conditions in the Aberjona River. Fueled by growing concerns that discharges of municipal and industrial wastes would lead to the contamination of Upper Mystic Lake, investigators found that a one and a half mile long section of the river directly upstream of Upper Mystic Lake received inputs of glue manufacturing wastes, "putrescent animal matter and lime" from tanneries, and sewage. Fifty-five factories (of which twenty were "leather-works") were identified on tributaries to Upper Mystic Lake, and it was estimated that "about seven percent of the water that flows in upper Mystic Pond is drainage from [these] factories." In their report, Board of Health investigators also observed that "fish have been killed in this pond, and cattle have refused to drink the water of the 'Abajonna' River" (25).

The Board of Health (and later the Department of Public Health) continued to make examinations of surface water conditions in the watershed between the late 1870s and the 1950s. During that period, health officials focussed much of their attention on promoting the establishment of legislation that would prevent further pollution of surface waters in the watershed, and on the construction of a sewer system that could meet both municipal and industrial waste disposal needs. Particular emphasis was given to Russell Brook and the Aberjona River, where tannery and rendering wastes were frequently found. Investigations of Russell Brook in 1904 and 1907, and again in 1915 and 1921 revealed widespread contamination by tannery effluent discharges (9,26,27,29). Likewise, leather industry waste contamination was reported in the Aberjona River in 1912, 1915, 1922, 1927-1929, 1931-1934, 1936, and 1939 (9,28-33,35-40).

2.3.2 Development of the Sewer System

The development of the sewer system in the watershed has a complex and interesting history. The first major sewer line in the watershed was constructed in Winchester in 1878, along the course of the Aberjona River. Fearing that discharges of industrial wastes and raw sewage would contaminate drinking water supplies in Upper

Mystic Lake, the city of Boston built the "Old Mystic Valley Sewer," complete with a precipitation facility to separate liquid and settleable wastes. Sewage and industrial effluent from Winchester center and factories operating on the Aberjona River were treated in settling tanks and mixers before being discharged into Lower Mystic Lake. From its inception, the Old Mystic Valley sewer system proved inadequate to handle the volume of wastes generated by its users. Also, the water quality of Lower Mystic Lake rapidly deteriorated, leading the Board of Health to write in its 1884 annual report that the sewer provided "but a partial remedy for the evil of the Mystic Valley" (60). The Old Mystic Valley sewer was used until 1895 when connections were finally completed to sewer lines that discharged at Deer Island into Boston Harbor (17).

After the turn of the century, worsening pollution problems in the watershed prompted area residents to issue complaints against Woburn and Winchester companies found to be discharging waste into surface waters (48). In addition, Board of Health investigators continued to document the extent of contamination in Russell Brook and in the Aberjona River, and made concerted efforts to identify the offending dischargers (26,27). In response to increasing public pressure to take action, the Massachusetts General Court passed two pieces of pollution control legislation. One piece of legislation, passed in 1907 (Chapter 235), prohibited the pollution of Horn Pond Brook and its tributaries; the other law, passed in 1911 (Chapter 291), prohibited the pollution of the Aberjona River (17). The Chapter 291 Acts were intended to prohibit:

> [T]he entrance or discharge of sewage into any part of the Aberjona River, or its tributaries, and to prevent the entrance or discharge therein of any substance which might be injurious to public health or might tend to create a public nuisance.

The Acts established a maximum fine of $500 for each offense. In addition, the Board of Health was instructed to provide technical advice to assist companies in reducing discharges to the Aberjona River or its tributaries (61).

Despite the clear mandate of the 1907 and 1911 legislation, the implementation and enforcement of the Acts were made difficult because many tanneries and rendering companies were either unable or unwilling to comply with the pollution control laws. Prior to the passage of the Acts, leather industry firms that were not sewered typically stored their wastewater in lagoons to allow settling of solids before discharging the effluent to surface waters. Because the Metropolitan District Commission (MDC) sewer system (formerly the Mystic Valley sewer system) did not extend into north Woburn, where many leather industry firms were located, companies had no alternative but to discharge their wastes into surface waters. Furthermore, with pressure mounting at both the local and state level to prevent further pollution of the Aberjona River from sources in north Woburn, leather industry firms recognized that the extension of the MDC sewer was inevitable, and they were therefore reluctant to invest in expensive waste treatment technology.

Although there was almost universal support for the development of the Woburn extension sewer, conflicts over the allocation of costs significantly delayed its construction. Between 1921 and 1923, several bills were introduced in the state legislature to provide for the construction of the sewer as part of the MDC system, but in each case the bills were defeated because other communities felt the cost of the sewer extension should be borne by the city of Woburn and not the state. After considerable debate, a compromise was reached in which the legislature agreed to share the costs of constructing the sewer extension (48). Work on the sewer line finally began in 1927, but due to problems caused by excessive ground water infiltration, the sewer was not put into operation until 1932 (17).

2.3.3 Land Disposal of Waste Sludge

The disposal of waste sludges presented an additional problem for tanneries and rendering factories in the watershed. Tanning and rendering wastewater contain high concentrations of solids - mainly hide and leather residues such as fleshings, hair, trimmings, shavings, buffing dust, etc. - which readily settle and create dense sludges. Because these sludges frequently caused sewer lines to become clogged and to eventually overflow, tanneries and rendering factories in the watershed were required to pre-treat their wastewater in settling lagoons before discharging it to the sewer. Sludges were then removed from the lagoons and placed in either on-site dumps or in public landfills.

Several problems caused by these sludge dumps were reported by the Department of Public Health and other investigators. For example, in 1915 the Department of Health observed in its annual report that:

> In the course of many years large quantities of organic matter, chiefly from tanneries, have been deposited upon the ground at many places in this valley, and the natural effect of the rainfall is to carry matters from these deposits, partly in solution and partly in suspension, into the streams (29).

In 1920, a Red Cross investigator reporting on health and sanitary conditions in Woburn noted:

> Because of the fact that chrome tanning sludge is not allowed to flow into the Metropolitan Sewerage system, this material is kept in catch basins for two months and then piled upon a dump which is near Russell Brook. From this material a very irritating, obnoxious odor goes forth (41).

Also, between 1921 and 1922, while conducting a survey of the watershed to assess the condition of fish populations in the Aberjona River and its tributaries, State Department of Fisheries and Wildlife biologists identified three tanning sludge dumps that were draining into either Russell Brook or its tributaries (9). Similarly, in 1970 a Department of Public Health investigator found that leachate emanating from rendering residue dumps on the Stauffer Chemical Company property was draining into Halls Brook (42).

Even though tanneries and rendering companies in the watershed were required to perform primary treatment to remove settleable materials prior to discharging wastewater into sewer lines, solids were invariably introduced into the sewerage. As a result, the deposition and accumulation of solids in the sewers contributed to several incidents of sewer line overflow. Between 1927 and 1929, for example, the MDC sewer in Winchester regularly overflowed, causing raw sewage and industrial wastes to drain directly into the Aberjona River (31-33). Also, for several years after it went on line, the Woburn extension sewer repeatedly overflowed and, as a result, tanning and rendering wastes from companies in north Woburn spilled into the river (39,62-64). In order to reduce the frequency of sewage overflows, the Department of Public Health tried to institute a program of periodic sewer cleaning (39,64). The program successfully decreased the incidence of overflowing; however, in its report on sanitary conditions in the Aberjona River and the Mystic Lakes in 1957, the Department of Public Health noted that material removed from sewer lines during cleaning was often left in piles near the manholes from which it was removed and, therefore, was a potential source of surface water pollution (17).

2.3.4 Leather Industry Waste Sites

There are currently six sites in the watershed that are being investigated for the presence of leather industry waste contamination. The Massachusetts DEP is investigating two former rendering factory sites and three former tannery sites under the

Oil and Hazardous Materials Release Prevention and Response Act of 1983 (i.e. MGL c.21E). The federal EPA is directing the investigation and remediation of the "Industriplex" site - where a large rendering factory once operated - under CERCLA. The following is a discussion of the nature of the waste materials found at the six sites.

The 60 South Bedford Street Site

Tanning and rendering wastes were first discovered at 60 South Bedford Street (Site 14, Figure 2.2) in October, 1984. Water from a brick vault uncovered during the installation of a swimming pool in a residential area was found to contain low concentrations of metals and volatile organic compounds. A second vault was later found that contained "a red sludge with animal hairs." Sludge samples were analyzed and found to be contaminated with high concentrations of chromium and lead. A title search revealed that from the mid-1830s until the turn of the century a tannery operated on the site, and that between the 1900s and 1977, the site was used by a hide and leather degreasing company.

Following the discovery of the vaults, emergency measures were taken to reduce risks posed by the contaminants present on the site. A trench was excavated from which contaminated ground water was pumped, the sludge materials and vaults were removed, and wells were installed to monitor the migration of pollutants in the ground water. A Phase II "Comprehensive Site Investigation" has been planned to determine whether additional waste materials are present on the site and whether contaminant migration in ground water could impact local drinking water supplies (22). The site was placed on the DEP's list of "Confirmed" hazardous materials sites in January, 1987 (65).

The 5 Green Street Site

An assessment of the 5 Green Street Site (Site 45, on Figure 2.2) was performed in October, 1984 to determine whether petroleum products or other hazardous materials were present on the property. Six test pits were excavated and soil samples from one of the test pits were found to contain elevated concentrations of chromium. Site investigators attributed the chromium to tanneries that had operated on the site from before 1875 until 1938. Although other metals including beryllium, thallium, and barium were also detected in soil samples, investigators concluded that the contamination does not pose a threat of off-site migration, and it was recommended that no further action be taken on the site (43). The DEP placed the site on its "Remedial Sites List" in January, 1987 (65).

The 8 Green Street Site

The results of an investigation of the 8 Green Street site (Site 44, on Figure 2.2), performed in December, 1986, indicate that ground water beneath the property is contaminated with petroleum products and metals. Both oil and grease were detected, as well as low concentrations of arsenic, cadmium, mercury, and lead. Historical records indicate that tanneries operated on the site from around 1875 until 1934. A number of filled pits were also discovered on the property, and investigators speculated that "the pits contain materials associated with the tanning business such as leather scraps, wood, animal remains, minor amounts of grease and solvents, etc." (44). As a result of the investigation, the DEP was notified, and in October, 1988, the site was placed on the DEP's list of "Locations to be Investigated" (65).

The J.O. Whitten Company Site

An evaluation of the former J.O. Whitten Company property in Winchester (Site 61, on Figure 2.2) was performed in December, 1984. A total of 33 test pits were excavated, 8 monitoring wells were installed, and numerous soil, soil gas, sludge, and ground water samples were collected. In addition, surface water and sediment samples were taken from the Aberjona River which abuts the eastern edge of the property. It was found that the soils and sediment samples were contaminated with arsenic, chromium, and mercury, the ground and surface water samples contained arsenic, barium, cyanide, toluene, and benzene, and the soil gas samples had concentrations of mercury vapor. Historical records indicate that a tannery operated on the site from 1872 until around the turn of the century. The property was then purchased by the J.O. Whitten Company which operated a gelatin and later a glue manufactory there until 1980 (16). The DEP placed the site on its list of confirmed sites in January, 1987. Two years later, the site was given "Phase III" status, indicating that the development of the remedial response plan was underway (65).

The J.J. Riley Company Site

The J.J. Riley Company tannery (Site 22, on Figure 2.2) was first investigated by the EPA in 1980 to determine whether waste disposal practices at the site had resulted in violations of Resource Conservation and Recovery Act or Clean Water Act standards. During a site inspection, EPA investigators were told by company officials that two lagoons had been used until 1970 for the separation of settleable solids from chrome tanning wastewater prior to discharging the wastewater to the MDC sewer. Although the lagoons were no longer in use, the investigators noted that materials leaching from the lagoons could pose a threat to ground water. The investigators were also told that waste sludge from an existing sedimentation tank was routinely piled on the ground near the lagoons (66). In 1983, officials from the DEP inspected the tannery. In their report the state inspectors wrote:

> With reference to non-hazardous sludges, John J. Riley Co. appears to be in violation of M.G.L. c.24 section 43 which prohibits the discharge of pollutants to the waters of the Commonwealth without a valid permit....The Company also appears to be in violation of Chapter III, section 150A, of the Solid Waste Disposal Act (67).

As a result of the EPA and the DEP investigations, the site was placed on the state's "Locations to be Investigated" list in January, 1987 (65).

The Industriplex Site

The Industriplex Site (Site 2, on Figure 2.2) is one of the oldest industrial sites in the watershed. It was first developed in 1853 by the Chemical Works Company, which made acids and other chemicals for textiles, paper, and leather producers. In 1863, the Chemical Works Company was acquired by Merrimac Chemical, a manufacturer of arsenic and lead-based insecticides and explosives such as trinitrotoluene (TNT). By the turn of the century, Merrimac Chemical had developed over 400 acres of the site and it soon became one of the largest chemical producers in New England. Between 1927 and 1936, ownership of the chemical works changed three more times as the Monsanto Company (1927-1934), the New England Chemical Company (1934-1936), and Consolidated Chemical Industries rebuilt the facility into a rendering factory. The companies used hides and leather scraps from tanneries in the watershed as raw materials to make glue and grease. Consolidated Chemical used the site until 1960, when it was purchased by the Stauffer Chemical Company. Stauffer maintained the glue manufactory until it went out of business in 1968.

Shortly after Stauffer abandoned the glue works, the property was acquired by the Mark Phillip Realty Trust. The trust wanted to develop the entire 400 acre site into an industrial park. As development proceeded into the northern end of the site, workers began to uncover piles of waste materials that the chemical companies had buried. In June, 1979, the Army Corps of Engineers took action against the realty trust when it was discovered that dredging spoils and fill material were being dumped into the Aberjona River and adjacent wetlands. Acting under the authority of section 404 of the Federal Water Pollution Control Act, the Corps served a cease and desist order to the developer, thereby temporarily barring work on the site. In its preliminary assessment of wetlands violations by the developer, the Corps noted that there were increased levels of heavy metals, biochemical oxygen demand (BOD), bacteria, and sedimentation in the Aberjona River. Suspecting that additional waste materials were also present on the site, DEP and EPA officials conducted their own investigations. These investigations revealed sludge lagoons contaminated with high levels of chromium, an earthen pit filled with lead and arsenic laden soil, twenty acres of rendering residue piles which were generating large quantities of hydrogen sulfide and methane gas, and plumes of benzene and toluene in the ground water. As a result of these discoveries, EPA obtained a court order to prevent further development on the property. In October, 1981, the site was named to the EPA Superfund Interim Priorities List of sites eligible for federal funding. In December, 1982, the site was added to the final EPA National Priorities List (68).

2.4 Mass Balance Analysis of Leather Industry Wastes

In this section, the chemical characteristics of wastes produced by tanning, leather finishing, and rendering operations are described, historical manufacturing records are presented, and mass balance techniques are used to estimate the amounts of waste chemicals produced by tanning operations. Because much of the tanning industry in the watershed specialized in making chrome-tanned upper leather for shoes, the focus will be on the chrome tanning of cattlehide.

2.4.1 Cattlehide Tanning and Leather Finishing

Tanning is the chemical process by which hides and skins are converted into non-putrescible leather. Tanning is performed by first removing the epidermal layer and subcutaneous flesh layer of the hide, followed by chemically stabilizing the remaining middle layer which is composed mainly of the protein collagen. Leather finishing involves any of several chemical processes such as bleaching, fat-liquoring, and coloring, or mechanical operations such as drying, staking, and buffing. Finishing is performed to alter the surface characteristics of leather, such as thickness, texture, feel, etc., for making specific leather goods. In the following discussion, the basic steps required to produce finished, chrome-tanned leather from raw cattlehide are described. It should be noted that among the many tanneries in the watershed there was perhaps wide variation in tanning practices. In the absence of a complete record of each company's methods, this discussion is provided to fill in the gaps in the history and to describe the general practices of the industry as a whole.

When hides are removed from freshly slaughtered cattle they are typically salt-cured to prevent bacterial decay. As a result, upon arriving at a tannery, cattlehides are often dehydrated, and contain large amounts of undissolved salt, as well as dirt, blood, manure, and non-fibrous protein. In order to prepare the hides for tanning, new hides are first processed in the "beamhouse" where they are rehydrated and cleaned (Figure 2.3). After being "sided" or cut in half along the backbone, new hides are soaked to restore lost moisture and then washed to remove extraneous matter. The flesh layer is then cut away to allow easier penetration and more effective action of the tanning agents. Finally, the hair and epidermis are removed from the hide. Unhairing is frequently done by soaking hides in a series of successively stronger lime baths. Lime causes collagen fibers to separate, thereby allowing the dissolution of non-fibrous proteins. Lime-softened hides are then immersed in solutions of sodium sulfide, the strength of which can be controlled to either loosen hair for subsequent hair recovery or pulp hair if hair recovery is not desired.

Once hides have been prepared in the beamhouse, they are transferred to the "tanyard" where tanning is performed. In the first tanyard process, called "bating," the surface properties of the lime-soaked hides are adjusted to facilitate tanning. Hides are soaked in solutions of buffering salts, such as ammonium sulfate or ammonium chloride, and proteolytic enzymes, such as trypsin and chymotrypsin. Bating reduces the pH and swelling of the hide, peptizes protein fibers, and removes protein degradation products. It also softens the hide texture by removing unhairing chemicals and non-fibrous proteins. After bating, hides are typically immersed in pickling solutions of salts and acids to reduce the pH of the hides so that chrome-tanning salts do not precipitate on the protein fibers during tanning.

Once bating and pickling have been completed, the hide is ready for tanning. Tanning is accomplished by milling the hides in baths containing chrome liquor (i.e. high concentrations of chromium salts dissolved in water). Trivalent chromium in the liquor binds with the carboxyl groups (-COOH) on different peptide chains, thus increasing the chemical stability of collagen molecules. In chrome tanning, the most widely used process is the "one-bath" method, in which basic chromium sulfate is the tanning agent. Following tanning, hides are split into two distinct layers: the upper layer or grain layer,

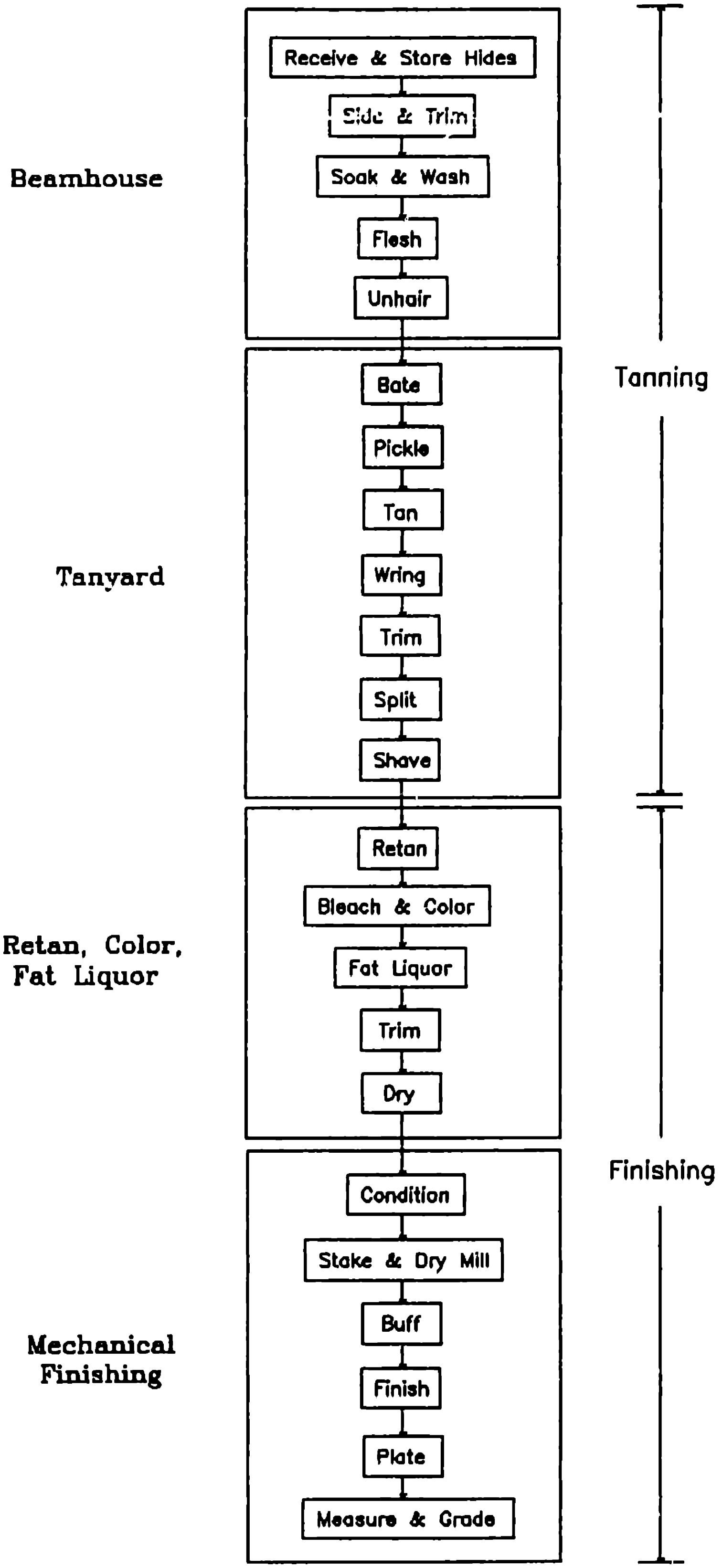

Figure 2.3 Process Flow Diagram for a Complete Chrome Tannery

and the lower layer or split. The grain layer is more valuable than the split, and thus many tanneries process only the grain layer, selling the splits to split-finishers or rendering factories. In the final tanyard step, the grain layer is shaved on a shaving machine to uniform thickness.

After tanning, most cattlehide leather requires considerable finishing work before it can be made into leather goods. Typical finishing processes include vegetable retanning, bleaching, coloring, and fat-liquoring. Vegetable retanning, in which chrome-tanned leather is given short baths in weak solutions of vegetable tannins, results in leather that is in general fuller, plumper, more easily tooled, and more water resistant than non-retanned leather. In bleaching and coloring processes, pigments and synthetic dyes - many of which contain cadmium, chromium, iron, lead, titanium, and zinc (69) - are used to give leather a desired appearance. Fat-liquoring is a procedure in which oils, greases, and waxes are applied to leather to keep it soft and pliable, and to increase the strength and tear resistance of the leather fibers.

A number of mechanical operations are also performed during leather finishing. The most common are trimming, drying, staking, dry milling, and buffing. Trimming removes rough edges, improves the appearance of the leather, and makes the sides easier to handle for subsequent finishing steps. Trimming is often repeated several times during leather finishing; as a result, trimming scraps can become a sizeable fraction of the solid waste stream. Because unfinished leather typically contains a significant amount of water, sides are dryed until the desired residual moisture content is achieved. In drying processes, sides are either stretched on metal frames, pasted on large plates, or hung on racks and then placed in low-temperature ovens, heated rooms, or outdoors in direct sunlight. Buffing or light sanding of the grain side is typically done to improve the final appearance of the leather.

2.4.2 Characterization of Chrome Tanning and Finishing Wastes

The chemical properties of chrome tanning and leather finishing wastes have been well characterized. In studies by the New England Interstate Water Pollution Control Commission (56) and the EPA (55,59), which were conducted in order to assist the leather industry and pollution abatement agencies in their efforts to reduce waste pollution, tanning and finishing wastes were chemically analyzed. The results of these analyses indicate that tanning and finishing wastes are composed of complex mixtures of dissolved chemicals and settleable and nonsettleable solids. Wastewater samples were found to contain dirt, blood, manure, bactericides, salt, fleshings, grease, lime, acids, enzymes, hair, unfixed tanning agents, dyes, pigments, oils, and buffing dust. Waste solids were shown to be composed mainly of protein and fat from fleshings, trimmings, shavings, and buffing dust, in addition to undissolved tanning and finishing chemicals. A list of tanning and finishing chemicals used in a typical complete chrome tannery is shown in Figure 2.4. The figure also shows the amounts of waste solids produced in each tanning and finishing component process.

Efforts have been made to identify the hazardous chemicals in tanning and finishing wastes that pose the greatest risks to human health and the environment. In assessing the chemical composition of tanning and finishing wastes, EPA-contracted investigators classified wastes as "potentially hazardous" if hazardous constituents were present at levels exceeding a selected threshold. "Potentially hazardous waste" was defined as:

> [W]aste or combinations of waste which pose a substantial present or potential hazard to human health or living organisms because such waste is lethal, non-degradable, or persistent in nature; may be biologically magnified; or otherwise cause or tend to cause detrimental cumulative effects (59).

Waste constituents were considered hazardous if they were radioactive, infectious, explosive, flammable, irritants or strong sensitizers, corrosive, or toxic. The hazardous concentration threshold for various constituent chemicals was selected as the mean of background concentrations in soils in the United States.

In their study, the investigators analyzed waste samples collected at different points in the solid waste streams of 28 tanneries in the U.S. It was found that chromium (trivalent), copper, lead, and zinc were present in several waste samples at levels that exceeded their hazard thresholds. Citing the well-established toxic properties of chromium, copper, lead, and zinc, the investigators concluded that the solid wastes that contained these metals were "potentially hazardous." Other hazardous constituents including arsenic, beryllium, cadmium, mercury, selenium, zirconium, phenols, and pesticides were also found in the waste samples, but at concentrations that were below the selected thresholds (55).

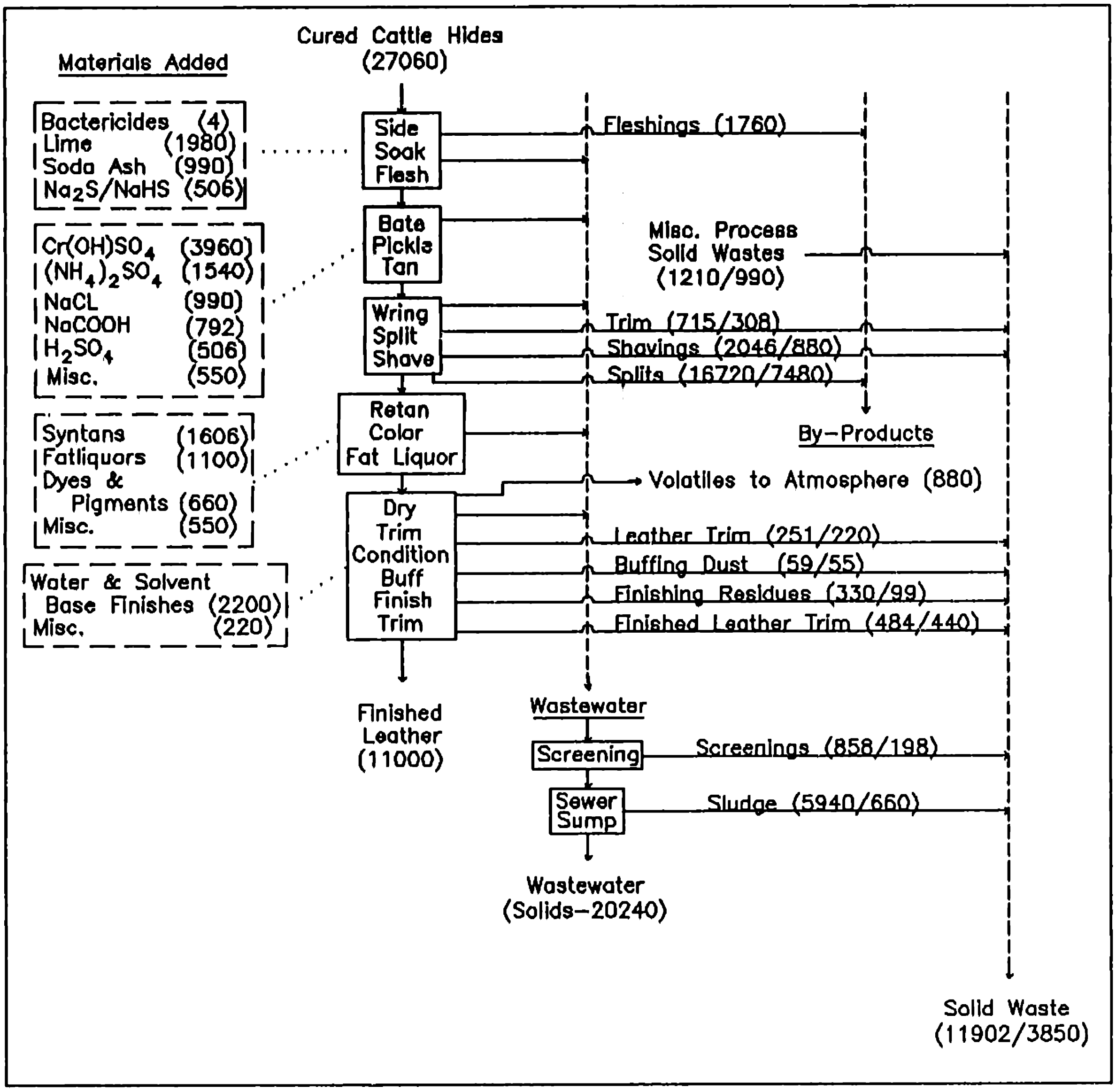

Figure 2.4 Materials Used and Wastes Generated by a Complete Chrome Tannery

(All units are lb/1000 equivalent hides on a dry weight basis, except solid wastes which are given on a wet weight/dry weight basis. An equivalent hide = 40 ft^2.)

(Source: Reference 59)

Concentrations of chromium, copper, lead, and zinc in wastewater and waste solids samples from complete chrome tanneries (i.e. a tannery in which both tanning and finishing are performed) are shown in Table 2.2. In general, average levels of chromium are an order of magnitude greater than levels of the other metals. Although concentrations of these metals have been shown to be fairly steady in equalized discharges, unequalized effluent can have a widely varying composition. Bailey (70), for example, found that the chemical properties of tannery effluent fluctuated considerably as a function of discharge rate. Samples collected over a 24 hour period from a catch basin in which effluent was held prior to discharge to the sewer showed the following variations: suspended solids - 0 to 8,500 mg/l; BOD - 100 to 10,000 mg/l; sulfide - 0 to 500 mg/l; and pH - 3.0 to 11.0. Samples of equalized effluent, however, showed considerably less variation: suspended solids - 100 to 500 mg/l; BOD - 600 to 900 mg/l; sulfide - 0 to 24 mg/l; and pH - 7.5 to 8.5. The concentrations shown in Table 2.2 are for equalized discharges of wastewater and waste solids.

In addition to the rate of discharge, chemical interactions in raw tannery wastes can have a large effect on concentrations of dissolved constituents. Chelation by organic matter and dissolution due to the presence of carbonates can cause concentrations of metals - especially chromium - to deviate significantly from predicted levels. In order to compensate for the effect of such interactions, the amounts of metals generated in tannery wastes are normalized by the weight of hide tanned. Normalized concentrations will be used in the mass balance analysis to predict the total amounts of metals generated in tanning and finishing wastes.

2.4.3 Hide and Leather Rendering

Rendering is the process by which grease and glue are extracted from animal hides, bones, and leather. Rendering is typically performed by cooking raw materials in vats of water in order to liquefy fats and collagen. Grease is recovered by skimming off the fat layer that forms on the water surface. Glue is made by concentrating the dissolved collagen in the glue-stock.

When chrome-tanned leather (i.e. scraps, trim, and splits) is used in rendering, it is typically treated with acids so that rendering products are free of chromium. Leather is

Table 2.2. Concentrations of Metals in Complete[1] Chrome Tannery Wastes.

Metal[3]	Concentration Range (lb/1000lb)[4]	Weighted Mean Concentration (lb/1000lb)	Concentration Range (mg/l)	Weighted Mean Concentration (mg/l)
		Wastewater[2]		
Chromium[5]	3.3-5.8	4.0	40-120	76
Cooper	$1.2x10^{-1}$	$1.2x10^{-1}$	2.3	2.3
Lead	$7.7x10^{-2}$-$1.4x10^{-1}$	$1.3x10^{-1}$	1.5-1.7	2.5
Zinc	$4.2x10^{-2}$-$6.7x10^{-2}$	$6.2x10^{-2}$	0.8-1.3	1.2
		Waste Solids[6]		
			(mg/kg)	(mg/kg)
Chromium	$1.2x10^{-1}$-3.2	$8.9x10^{-1}$	$7.5x10^{2}$-$2.0x10^{4}$	$5.4x10^{3}$
Copper	$4.6x10^{-5}$-$7.7x10^{-1}$	$3.5x10^{-2}$	$4.8x10^{-1}$-$7.9x10^{3}$	$3.6x10^{2}$
Lead	$8.6x10^{-4}$-$4.0x10^{-1}$	$5.6x10^{-2}$	7.1-$3.3x10^{3}$	$4.6x10^{2}$
Zinc	$8.6x10^{-4}$-$2.2x10^{-2}$	$1.7x10^{-2}$	7.3-$1.9x10^{2}$	$1.5x10^{2}$

[1] In a "complete" tannery, both tanning and finishing are done.

[2] Includes concentration in settleable suspended solids. In converting units it is assumed that 6300 gallons of water are used per 1000 pounds of hide tanned. From Reference 55.

[3] Chromium is used primarily in tanning agents; copper is used in bactericides; lead and zinc are used in dyes and pigments.

[4] Units are expressed as pounds of constituent in waste per 1000 pounds of hide tanned.

[5] Values for chromium in wastewater are from References 56 and 57.

[6] Values from Reference 59. Based on 1.625 lb/ft^2 average hide density.

first placed in lime baths to allow fibers to swell, thereby increasing the surface area over which detanning agents can act. The limed leather is then washed in solutions of sulfuric acid, which cause chromium to dissolve from the leather. Because leather contains chromium in concentrations of 1-2 grams/ft^2, considerable amounts of dissolved chromium may be present in rendering effluent.

Although it is generally known when and where rendering activities took place in the watershed, detailed records documenting rendering operations could not be located for the majority of rendering companies. The only information that was found was from the Stauffer Chemical Company, which operated a rendering factory at the Industriplex site from 1960 to 1968. Records from the late 1960s indicate that chrome-tanned leather accounted for approximately 25% (or around 29 tons annually) of the raw materials used by the company, and that nearly 50,000-60,000 pounds of rendering wastes (25% solids) were generated per day (15). Information concerning the operations of other rendering companies in the watershed could not be obtained because the companies had either gone out of business or never kept such records. Because there was not enough production or raw materials consumption data to accurately characterize the rendering industry in the watershed, chromium from rendering wastes was not included in the mass balance analysis.

2.4.4 Mass Balance of Metals in Tanning and Leather Finishing Wastes

Mass balance (or chemical accounting) techniques were used to estimate the amounts of four metals - chromium, copper, lead, and zinc - produced in tanning and leather finishing wastes in the watershed between 1900 and 1936. The 36 year period was selected for three reasons: 1) during this period chrome-tanning was the dominant tanning method practiced in the watershed; 2) it was the period during which the leather industry was most productive; and 3) during this period most tanning and leather finishing wastes were discharged into surface water bodies and dumps (after 1936, the majority of tanning and leather finishing companies in the watershed were connected to the sewers, and sewer overflowing was no longer persistently occurring). Two mass balance methods were used in the analysis. The first method, called the "Value Method," is based on the gross value of finished leather produced by the leather industry. The second method, the "Labor Method," is based on the amount of hide tanned and finished per manhour worked. Data used in the two mass balance methods was obtained from Census of Manufacturers records for the city of Woburn and from national statistics.

Manufacturers records for Winchester and Stoneham were not available for the period of interest.

The two mass balance methods were used to generate independent estimates of the annual amounts of leather produced in Woburn. In the Value Method, shown in Table 2.3, the total annual value of products ($) made by tanners and leather finishers in Woburn was compared to the national average unit price of leather ($\$/ft^2$). In the Labor Method, shown in Table 2.4, the average number of wage earners employed in tanneries and leather finishing companies in Woburn (# of employees) was compared with national statistics for average number of hours worked per week (hr/employee) and production per manhour (ft^2/hr). The amounts of leather (ft^2) predicted by the two methods are shown in column 4 of Table 2.3 and column 5 of Table 2.4. In applying both methods it was assumed that 85% of the leather produced was chrome-tanned. The total amounts of chrome-tanned leather estimated by the Value Method and the Labor Method for the 36 year period are 550 million and 1630 million ft^2, respectively.

In order to predict the amount of metals produced in tanning and leather finishing wastes, effluent concentrations from Table 2.2 were used. The amount of chrome-tanned leather (ft^2) produced annually was first multiplied by the average density of an equivalent hide, 1.625 lb/ft^2 (58), to determine the total weight of hide tanned (lb). The weighted mean concentrations of chromium, copper, lead, and zinc in wastewater and waste solids (lb/1000lb) were then multiplied by the weight of hide tanned to estimate the total amounts of metals (tons) generated in tanning and leather finishing effluent. The amount of chromium in tannery wastewater and waste solids estimated by the two mass balance methods is shown in columns 5 and 6 of Table 3 and columns 6 and 7 of Table 2.4. The two mass balance methods indicate that between 1900 and 1936 on the order of 2000-4000 tons of chromium was generated in tannery wastewater, and on the order of 400-800 tons of chromium was generated in tannery waste solids. It is further estimated that during this period, tanning and leather finishing companies produced on the order of 50-110 tons of copper, 60-120 tons of lead, and 30-60 tons of zinc in wastewater, and on the order of 15-32 tons of copper, 26-52 tons of lead, and 8-16 tons of zinc in waste solids. The results of these estimates are plotted in Figures 2.5 - 2.7. The total amounts of the four metals in both wastewater and waste solids predicted by the two mass balance methods are shown in Figure 2.8.

Table 2.3 Amount of Chromium in Tannery Wastes as a Function of the Gross Value of Finished Leather Produced

Year	1 Total Value ($1000)	2 Cost per sq. foot ($/ft2)	3 sq. feet chrome-tanned leather (1000)	4 Chromium in waste-water (tons)	5 Chromium in waste solids (tons)
1900	3352	0.299	9529	31	7
1901	3252	0.299	9245	30	7
1902	3152	0.299	8961	29	6
1903	3052	0.299	8676	28	6
1904	2952	0.299	8392	27	6
1905	2852	0.299	8108	26	6
1906	2932	0.299	8335	27	6
1907	3012	0.299	8563	28	6
1908	3092	0.299	8790	29	6
1909	3172	0.299	9017	29	7
1910	3252	0.299	9245	30	7
1911	3332	0.299	9472	31	7
1912	3412	0.299	9700	32	7
1913	3567	0.256	11844	38	9
1914	3451	0.268	10945	36	8
1915	6169	0.278	18862	61	14
1916	7397	0.325	19346	63	14
1917	7244	0.439	14026	46	10
1918	7232	0.412	14920	48	11
1919	8465	0.640	11243	37	8
1920	4818	0.617	6637	22	5
1921	2909	0.312	7925	26	6
1922	6409	0.258	21115	69	15
1923	8376	0.260	27383	89	20
1924	8999	0.264	28974	94	21
1925	8561	0.274	26558	86	19
1926	9363	0.253	31457	102	23
1927	10021	0.320	26618	87	19
1928	10019	0.369	23079	75	17
1929	7134	0.288	21055	68	15
1930	5277	0.238	18846	61	14
1931	4341	0.204	18088	59	13
1932	3214	0.162	16864	55	12
1933	3743	0.194	16400	53	12
1934	3631	0.188	16417	53	12
1935	3136	0.188	14179	46	10
1936	3322	0.196	14407	47	10
		Totals:	553219	1798	400

1. Ref. 51 (1900-1904, 1906-1913 values interpolated from 1895, 1905 data).
2. Ref. 53 (Values for 1900-1912 are average of 1913-1936 data).
3. It is assumed that 85% of the leather produced is chrome-tanned (54,55).
4. An "equivalent" raw cattle hide is 40 sq. feet in area.
   It is assumed that the average weight of an equivalent hide is 65 lb (58). The average amount of chromium in wastewater of a complete chrome tannery is 4.0 lb/1000 lb of raw cattle hide (56,57).
5. The average amount of chromium in sludge generated by a complete chrome tannery is .891 lb/1000 lb of raw cattle hide tanned (59).

Table 2.4 Amount of Chromium in Tannery Wastes as a Function of the Amount of Finished Leather Produced Per Manhour

Year	1 Ave. # Wage Earners	2 Ave. # Hours/ Week	3 Product per Man hr (ft2/hr)	4 sq. feet chrome-tanned leather (1000)	5 Chromium in waste-water (tons)	6 Chromium in waste solids (tons)
1900	915	39.50	25.56	40832	133	30
1901	901	39.50	25.56	40207	131	29
1902	887	39.50	25.56	39583	129	29
1903	873	39.50	25.56	38958	127	28
1904	859	39.50	25.56	38333	125	28
1905	845	39.50	25.56	37708	123	27
1906	843	39.50	25.56	37619	122	27
1907	842	39.50	25.56	37574	122	27
1908	840	39.50	25.56	37485	122	27
1909	839	39.50	25.56	37441	122	27
1910	837	39.50	25.56	37351	121	27
1911	835	39.50	25.56	37262	121	27
1912	833	39.50	25.56	37173	121	27
1913	832	39.50	25.56	37128	121	27
1914	919	39.50	25.56	41011	133	30
1915	1274	39.50	25.56	56853	185	41
1916	1264	39.50	25.56	56406	183	41
1917	1100	39.50	25.56	49088	160	36
1918	1040	39.50	25.56	46410	151	34
1919	1140	39.50	25.56	50873	165	37
1920	865	39.50	25.56	38601	125	28
1921	593	39.50	25.56	26463	86	19
1922	1200	39.50	25.56	53550	174	39
1923	1568	39.50	25.56	69972	227	51
1924	1453	42.54	23.90	65296	212	47
1925	1223	43.07	25.81	60091	195	44
1926	1259	43.18	24.30	58390	190	42
1927	1379	41.19	24.63	61836	201	45
1928	1299	41.71	23.53	56350	183	41
1929	1105	44.18	23.69	51118	166	37
1930	911	40.89	24.69	40652	132	29
1931	795	42.74	26.98	40520	132	29
1932	759	42.74	24.68	35387	115	26
1933	842	41.29	27.02	41521	135	30
1934	916	37.75	27.84	42550	138	31
1935	814	34.08	28.94	35485	115	26
1936	762	17.99	26.26	15911	52	12
			Totals:	1628987	3677	819

1. Ref. 51 (1900-1904, 1906-1912 values interpolated from 1895, 1905 data).
2. Ref. 53 (Values for 1900-1923 are the average of 1924-1936 data).
3. Ibid.
4. It is assumed that 85% of the leather produced is chrome-tanned (54,55).
5. An "equivalent" raw cattle hide is 40 sq. feet in area. It is assumed that the average weight of an equivalent hide is 65 lb (58). The average amount of chromium in wastewater of a complete chrome tannery is 4.0 lb/1000 lb of raw cattle hide (56,57).
6. The average amount of chromium in sludge generated by a complete chrome tannery is .891 lb/1000 lb of raw cattle hide tanned (59).

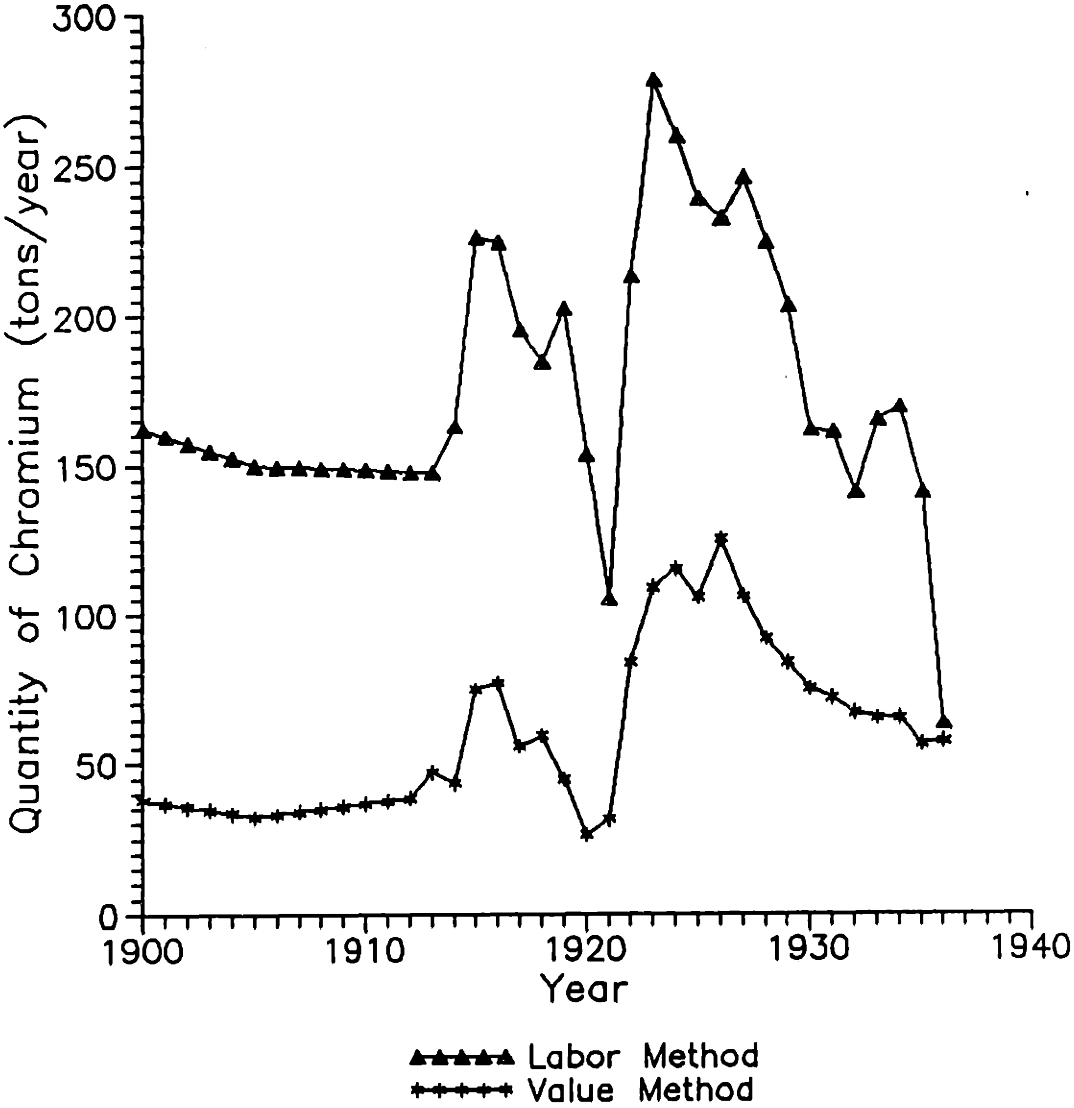

Figure 2.5 Comparison of the Total Quantity of Chromium in Tannery Wastes Predicted by Two Mass Balance Methods

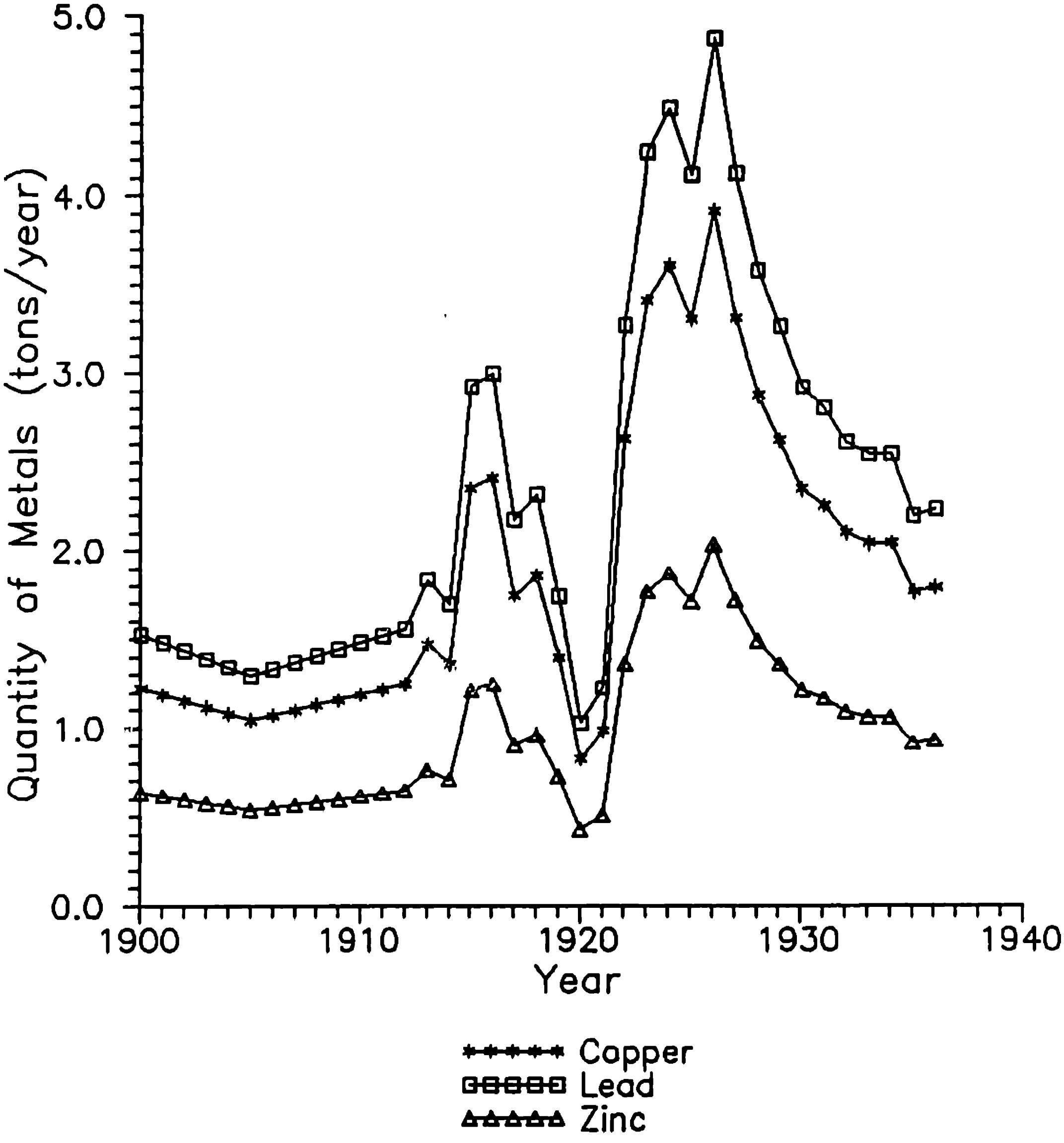

Figure 2.6 Quantity of Metals in Tannery Wastes Based on Gross Value of Finished Leather

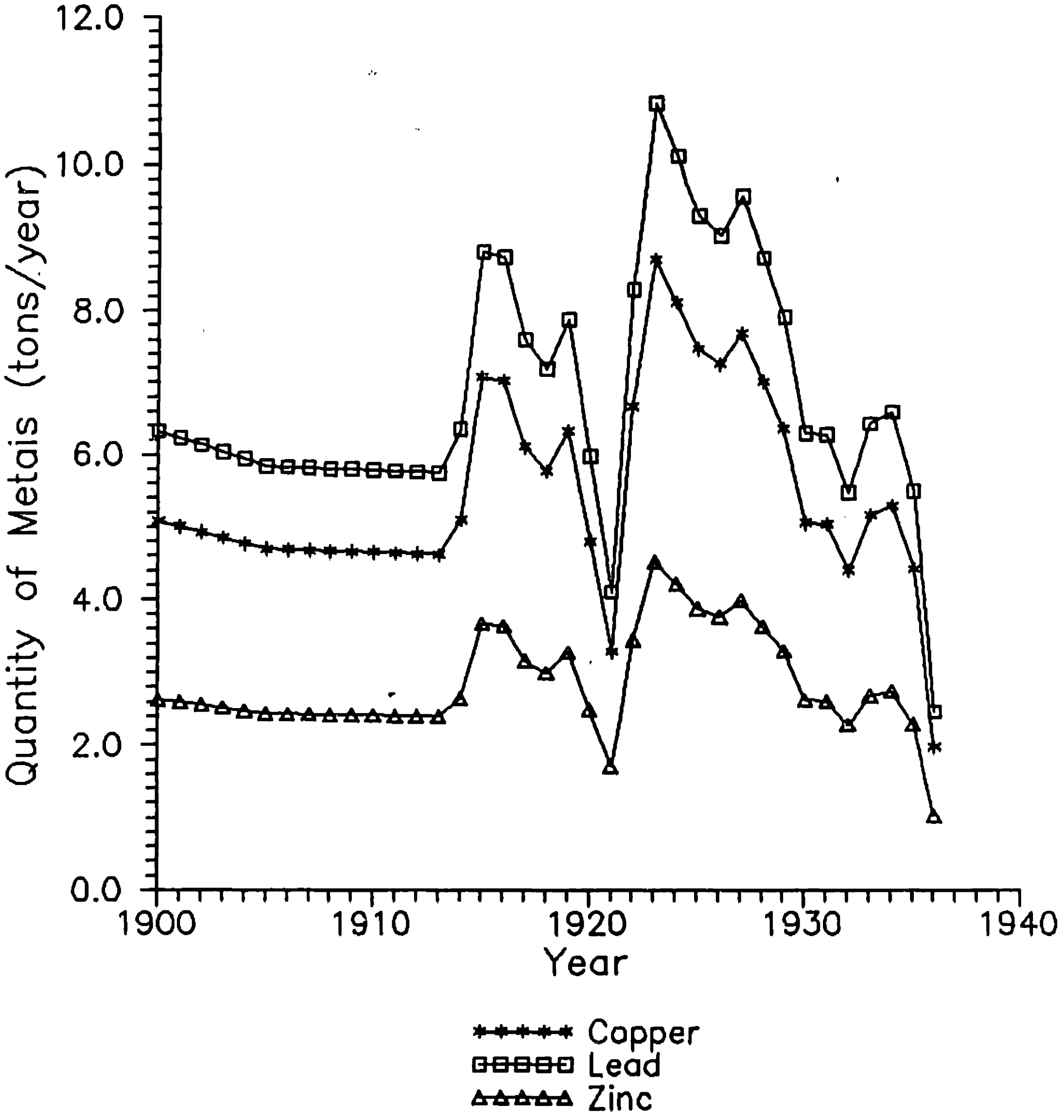

Figure 2.7 Quantity of Metals in Tannery Wastes Based on Finished Leather Produced Per Manhour

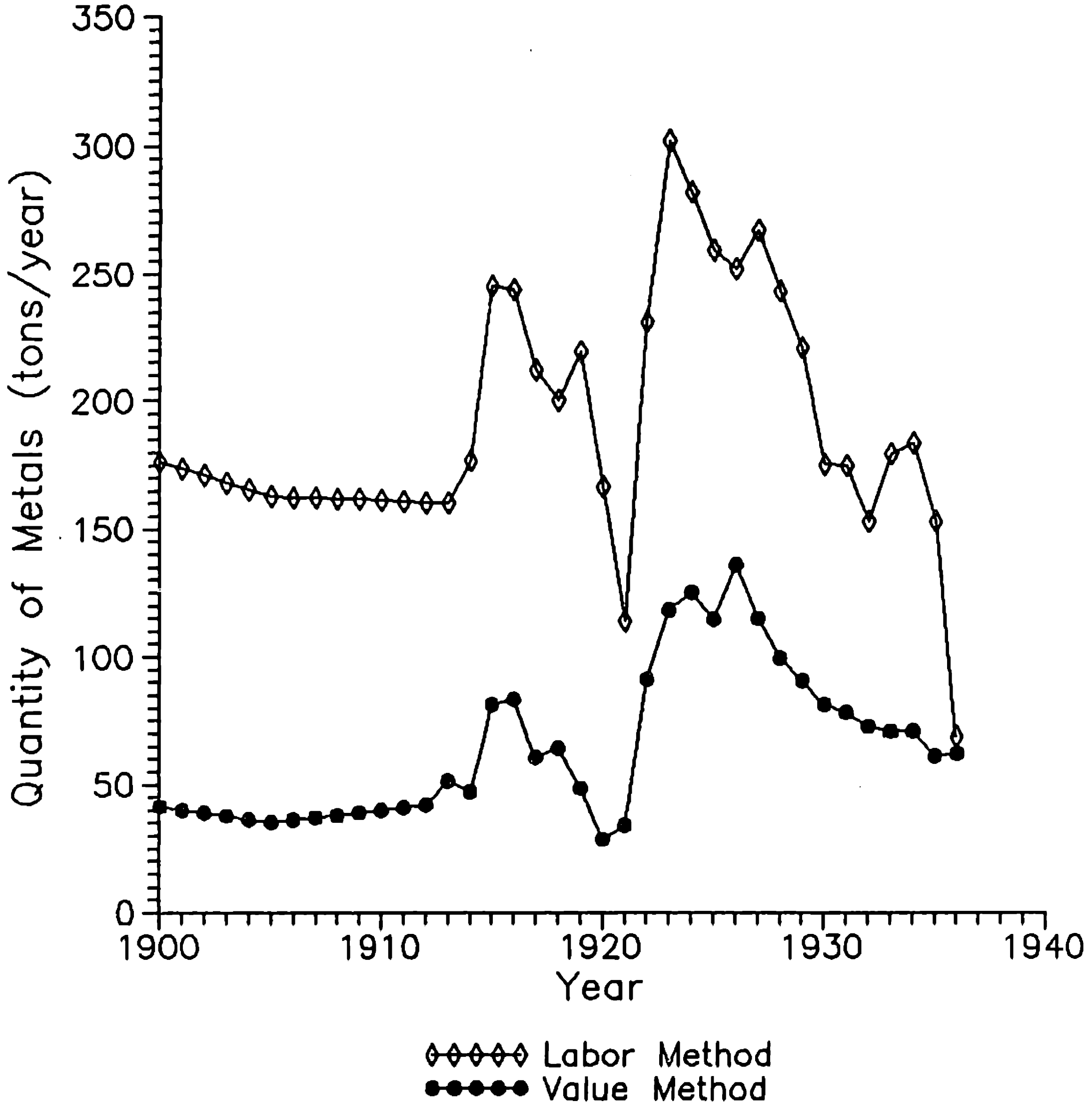

Figure 2.8 Comparison of the Total Quantities of Metals in Tannery Wastes Predicted by Two Mass Balance Methods

Three assumptions were used in applying the mass balance methods. First, it was assumed that the chemical characteristics of chrome-tanning and leather finishing wastes have not changed significantly since the introduction of chrome-tanning methods. Thus, chemical analyses of tanning and leather finishing wastes performed in the 1950s and 1970s can be used to characterize wastes generated between 1900 and 1936. This assumption is reasonable for chromium, which is still the most widely used tanning agent; however, because the history of copper, lead, and zinc use in tanning and leather finishing is not well documented, it is uncertain whether this assumption leads the mass balance models to overestimate or underestimate the amounts of these metals produced in leather industry wastes. Second, it was assumed that 85% of the leather produced in Woburn between 1900 and 1936 was chrome-tannned. This estimate is based on research conducted recently that indicates between 80 and 85% of leather produced in the U.S. is chrome-tanned (54,55). And third, in using the Value Method, it was assumed that the Census of Manufacturers value of product data (column 2, in Table 2.3) represent the value of finished leather. This assumption would result in an overestimation, using the Value Method, of the amount of leather produced if tanners and leather finishers reported profit on the same leather (that is, if tanners sold unfinished leather to finishers and both reported income on that leather).

2.5 Discussion

In the absence of complete historical records documenting the amount of leather produced and describing the chemical characteristics of wastes generated by the leather industry in the Aberjona watershed between 1900 and 1936, it is difficult to assess the accuracy of the waste metals estimates predicted in the mass balance analysis. Considering the limitations in the data available for the analysis and the uncertainty inherent in the assumptions used, it is possible that the mass balance estimates could be off by as much as a factor of two. Nonetheless, if the results are skewed, then it can be argued that the bias is in favor of underestimation rather than overestimation. Leather industry statistics could not be found in Census of Manufacturers data for Winchester and Stoneham, and therefore, tanning and leather finishing wastes generated in these two towns were not included in the analysis (rough estimates suggest that Winchester and Stoneham may have produced as much as one-tenth the amount of wastes generated by the leather industry in Woburn). Also, because there was not enough information to adequately characterize the rendering industry in Woburn, it too was excluded from the analysis. In light of recent investigations at former rendering sites in Woburn, the exclusion of rendering wastes from the analysis would result in the omission of significant amounts of chromium. At the Industriplex site, for example, glue manufacturing wastes are distributed over a 35 acre area, of which approximately half contains chromium at concentrations exceeding 1000 mg/kg or 0.1% by weight (68). Using conservative estimates of the depth (20 ft) and density (2 g/ml) of the rendering wastes, it is estimated that on the order of 1000 tons of chromium are present on the site. It follows, therefore, that if wastes from the other rendering companies that operated in the watershed were also included in the analysis, the amount of chromium predicted would be significantly larger.

An important question raised by the results of the analysis is: what has happened to the waste metals generated by the leather industry? It is likely that large amounts of metals discharged in leather industry wastewater are no longer present in the watershed. Wastewater discharged to sewer lines was carried out of the watershed and then either treated at Deer Island or dumped directly into Boston Harbor. Wastewater discharged to the Aberjona River and its tributaries ultimately flowed into the Mystic Lakes. Because leather industry wastewater contains large amounts of solid materials, it is likely that the binding of waste metals to settling solids was a significant transport process. In support of this hypothesis, there is mounting evidence that large quantities of waste metals were deposited in quiescent zones along the course of the Aberjona River and its tributaries, and in the Mystic Lakes (71,72). Rough estimates suggest that as much as 10% (200 tons) of the chromium predicted in leather industry wastewater is present in the sediments of the Mystic Lakes. Currently, researchers at MIT are trying to identify other surface water bodies where metals may have accumulated.

In addition to finding high concentrations of metals in river and lake sediments, large amounts of waste metals have also been discovered in abandoned lagoons and sludge dumping areas in the watershed. As was discussed in Section III, there are several former tanning and rendering sites in Woburn and Winchester that are currently being investigated for the presence of hazardous wastes. Though efforts have been made to identify the dumping areas that pose the most immediate environmental and human health risks, it is likely that other, less obvious leather industry waste disposal sites are scattered throughout the watershed.

2.6. Conclusions

Tanning, leather finishing, and hide and leather rendering were once an important part of the economy in the Aberjona watershed. Records indicate that between 1838 and 1988, approximately 100 tanneries, leather finishing companies, and rendering factories operated at over 67 sites in Woburn, Winchester, and Stoneham. For 50 years, between the 1870s and the late 1920s, the leather industry employed nearly 55% of all wage earners in the area, and accounted for more than half of the total annual value of goods produced in the watershed. Historical documents and records also indicate that the leather industry used considerable amounts of hazardous chemicals, and routinely discharged wastes to surface water bodies, lagoons, and dumps throughout the watershed. Mass balance models based on manufacturing statistics estimate that between 1900 and 1936 roughly 2000-4000 tons of chromium, 65-140 tons of copper, 85-175 tons of lead, and 40-75 tons of zinc were generated in leather industry wastes. Currently, officials from the EPA and Massachusetts DEP are investigating six sites in the watershed that are contaminated with leather industry wastes. On one former rendering site, it is estimated that over 1000 tons of chromium discharged in leather detanning effluent are distributed over a 35 acre area. Other locations where waste metals have been found in the watershed include sediment deposition areas in ponds, lakes, and tributaries.

For the past three years, researchers at MIT have been investigating pollution problems in the Aberjona watershed. Surface water, ground water, sediment, soil, and air samples have been collected and analyzed to determine the extent and approximate concentrations of anthropogenic chemicals at sites throughout the watershed. The ultimate goal of this research is to determine how hazardous wastes are distributed in and move through the watershed, and how humans may be exposed to and affected by particular waste chemicals. An important first step is to identify which hazardous chemicals were most widely used in the watershed, and which are most likely to be present in environmental samples. From the descriptive history of the leather industry, its chemical usage, and its waste disposal practices, it is evident that wastes containing hazardous metals - in particular chromium, copper, lead, and zinc - were routinely discharged to surface waters and dumps throughout the watershed. The mass balance analyses indicate that considerable quantities of these metals were present in the wastes. Based on these conclusions, it is hypothesized that a significant fraction of the total amount of metals discharged in the leather industry wastes is still present in the watershed. In testing this hypothesis, researchers have used the historical information to direct sampling and analytical programs toward identifying metals in samples collected in sediment deposition areas, and in parts of the watershed where the most active leather industry sites were located.

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Appendix 2.1: Approximate Addresses of Leather Industry Sites in the Aberjona Watershed

Site	Last Company to Operate at the Site	Approximate Address
1	Woburn Hide & Leather Co.	Main St., near North Maple St.
2	Stauffer Chemical Co.	Atlantic Ave.
3	Algonquin Leather Co.	North of Merrimac St., intersection with Milan St
4	Foucar Leather Co.	North side of Webster St., west of Site 5
5	Rathburn Leather	North side of Webster St., at east end
6	Eaton, Winn & Co.	Near intersection of Poole St. and Nichols St.
7	North Star Japanning Co.	Merrimac St.
8	Porter Japanning Factory 2	Webster St., west of Site 9
9	Porter Japanning Factory 1	Webster Ave. near Webster St.
10	Linscott Heel Manufacturers	Pearl St.
11	Bond & Tidd	East of Pearl St.
12	Bond Leather Specialists	Near intersection of Ward St. and Traverse St.
13	H.W. Clark Patent Leather	Mishawum Rd., on east bank of Aberjona River
14	Woburn Degreasing Co.	S. Bedford St., at intersection with Willow St.
15	Bacon's Patent Leather Co.	Northwest corner of intersection of Willow St. and Bedford Rd.
16	Colgate & Son Tannery	?
17	E.G. Place Split Leather	North of Kilby St., west of railroad tracks
18	W.P. Fox Grain & Split	Kilby St., east of railroad tracks
19	Kinney & Murphy	Manning St., near Main St.
20	Paterson Patent Leather	South of Salem St., near Woburn High School
21	Murray Leather Co.	West of railroad tracks, south of Salem St.
22	J.J. Riley Co.	228 Salem St.
23	Crescent Tanning Co.	Southeast of Cedar St., near intersection with Washington St.
24	Morocco Manufactory	Willow St., south of S. Bedford St.
25	Stephen Dow & Co.	Water St.
26	Prime Tanning Co.	Munroe St.
27	Bay State Japanning Co.	Park St., east of railroad tracks
28	Amer. Hide & Leather Fact. H	Between Chestnut St. and Scott St.
29	Winn Tannery	Between High St. and Jefferson St.
30	J.H. Connolly	?
31	Murray Leather Co.	Intersection of Union St. and Campbell St.
32	Woburn Japanning Co.	Eastern Ave., north of Jefferson St.
33	Griffin Place Curry Shop	Present site of Shamrock School
34	Tanners Degreasing Co.	South of Montvale Ave., between Washington St. and Aberjona River
35	Atlantic Gelatin	Hill St. near Route 93S.

Appendix 2.1: Continued

Site	Last Company to Operate at the Site	Approximate Address
36	A. Buckman Co.	South side of Maple St., at intersection with Atwood Ave.
37	J.H. Murphy Curriers	East side of Cottage St., at intersection with Montvale Ave.
38	Blank Brothers Curry Shop	Near intersection of Elm St. and Main St.
39	Best Leather Nut Co.	North side of Bow St., across from Eustis St., east of Green St.
40	W.H. Tidd	?
41	Van Tassel Co.	East side of Spencer St.,corner of Hancock St.
42	Ballard Japanning Co.	North of Jefferson St.
43	J. Kendall Chrome Tannery	Eastern Ave., south of Jefferson Ave.
44	Prime Tanning Co.	Near 8 Green St.
45	Tolman-Fox Corp.	South of Green St., next to railroad tracks
46	W.P. Fox Leather	North of Fowle St., east of railroad tracks
47	Dorrington Leather Co.	South of Porter St., north of John St.
48	Amer. Hide & Leather Fact. D	East of Site 47
49	E. Cummings Leather Co.	East of railroad tracks, south of Fowle St.
50	E.C. Cottle	West of railroad tracks, next to John St.
51	Watauga Tanning Co.	East of railroad tracks, north of Connecticut St.
52	Middlesex Leather Co.	West of railroad tracks, north of Connecticut St
53	Cottle Leather Co.	East of railroad tracks, south of Conn St.
54	American Hide & Leather	Bryant St., north of site 57
55	B.H. Nichols Grease Factory	South of Conn St., east of railroad tracks
56	Beggs & Cobb Factory 1	Middle lot between Conn St. and Cross St.
57	Beggs & Cobb Factory 2	Southeast of Conn St., west of railroad tracks
58	Kean Brothers & Bedell	South side of Conn St., west of railroad tracks
59	Amer. Hide & Leather Fact. E	Cross St., east of railroad tracks
60	Amer. Hide & Leather Fact. S	West of Main St., near Cross St., west of railroad tracks
61	J.O. Whitten Co.	East of railroad tracks, west of Aberjona River, south of Cross St.
62	A.H. McLatchy Co.	Same area as Site 61
63	Pantasote Leather Co.	Along east bank of Horn Pond Brook
64	Haley Patent Leather Co.	Same area as Site 64
65	Beggs & Cobb	Between Main St. and Swanton St., east of railroad tracks
66	Blank Brothers Tannery	Present site of Winchester DPW
67	Waldmyer Tannery	Manchester Field

3. FORWARD MUTATION IN *Salmonella typhimurium* BY EXTRACTS OF WATER SAMPLES FROM THE ABERJONA WATERSHED

3.1 Introduction

Considerable attention has been focussed recently on assessing the human health risks posed by exposure to anthropogenic chemicals present in aquatic systems. Studies in which the mutagenic activity of water samples has been measured using in vitro assays have shown that mutagens are abundant and widely distributed in natural waters (1-12). The discovery of industrial pollutants in drinking water supplies and the subsequent discovery of widespread surface and ground water contamination in the Aberjona watershed (13-21) has raised concern that residents of the watershed may have been and perhaps still are being exposed to hazardous, water-borne chemicals. In order to better assess the health risks posed by exposure to Aberjona watershed water, a study was conducted in which 53 surface water, ground water, and sediment pore water samples were tested for mutagenicity in a bacterial mutation assay (Figure 3.1). The assay was used as a screening tool to determine whether chemicals present in water to which humans could be exposed are capable of causing measurable, detrimental biological effects. Although no mutagenicity was detected in any of the filtered, 1 L water samples tested, there is evidence that extracts of suspended particles and concentrates of 60 L water samples may be mutagenic.

A *Salmonella typhimurium* forward mutation assay developed by Skopek et al. (22,23) was used in the study. The assay is designed to detect point and frameshift mutations at the xanthine-guanine-phosphoribosyltransferase (gpt) gene locus. Mutagenicity testing is performed by exposing a mutagen-treated population to the selective agent 8-azaguanine, which is toxic to wild-type organisms. Mutants that lack the ability to synthesize xanthine-guanine-phosphoribosyltransferase, an enzyme which transports and phosphoribosylates 8-azaguanine at the cell membrane, survive and can be detected. The assays were performed in both the presence (+PMS) and absence (-PMS) of an exogenous metabolizing enzyme system - made from rat-liver enzymes - to detect both promutagens and direct-acting mutagens. Toxicity was measured independently of mutagenicity by treating cultures with water sample extracts in the absence of 8-azaguanine. Further details of the assay as well as a description of the water extraction procedure and results are presented in the following sections.

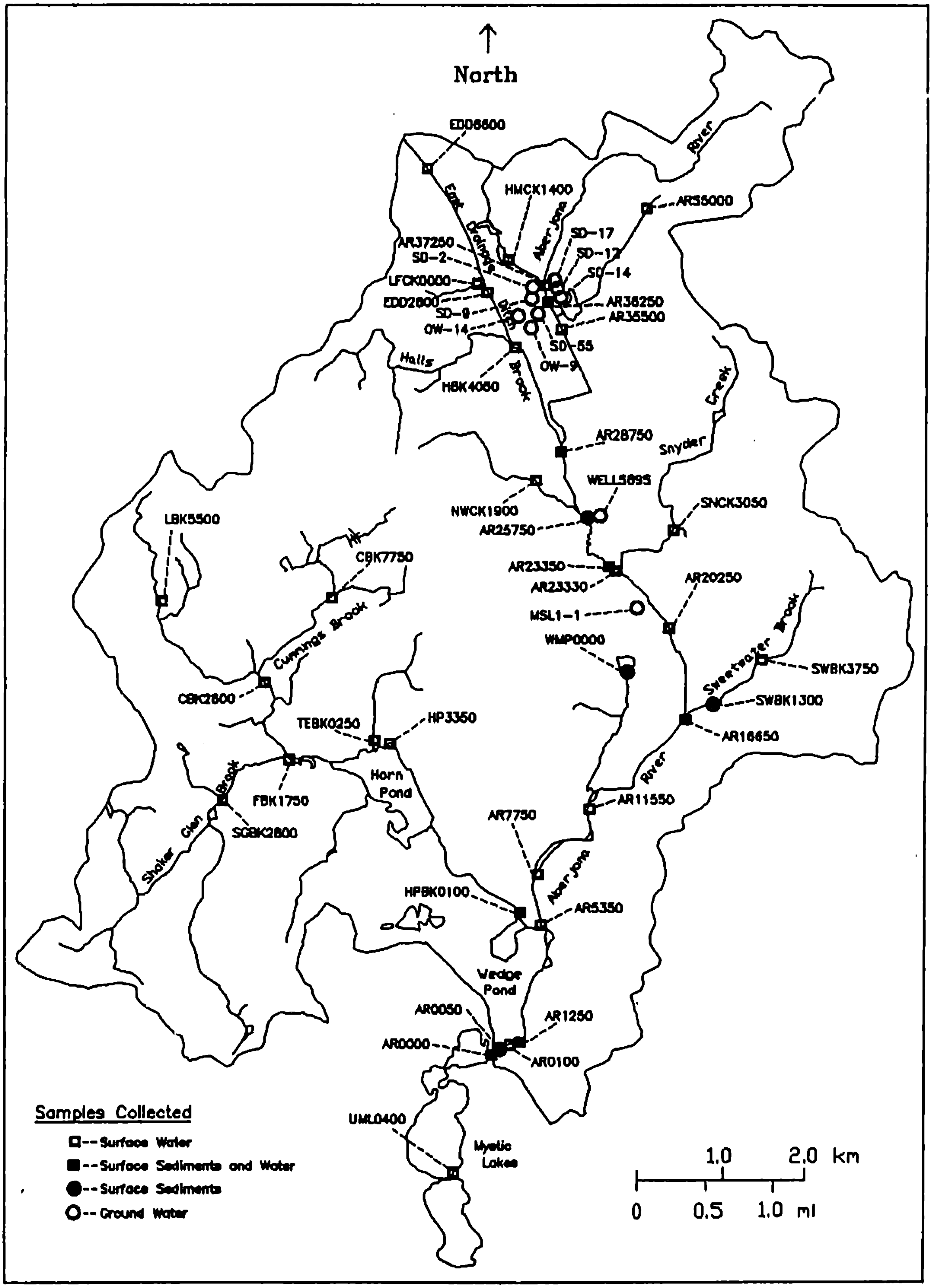

Figure 3.1 Sites in the Aberjona River from which Samples have been Collected for Mutagenicity Testing

3.2 Methods & Materials

3.2.1 Water Sampling Procedure

Three different types of water samples were collected for mutagenicity testing: surface water, ground water, and sediment pore water. In all, 32 surface water samples, 10 ground water samples, and 11 sediment pore water samples were collected from 46 sites in the watershed. Surface water samples were collected at confluences and in reaches where contamination was suspected; sediment pore water was sampled in areas where organic-rich sediments had accumulated; and ground water samples were collected from wells that were easily accessible. Surface water and sediment sampling stations are labelled on Figure 3.1 to reflect the position of the site with respect to the terminus of the waterbody (e.g. AR11500 = Aberjona River at 11,500 feet upstream of Upper Mystic Lake); ground water sampling sites are labelled according to the identification given the wells by the drillers or investigators that installed them.

Surface water sampling was typically done between precipitation events in order to collect baseflow samples. Samples were collected by placing 1 L glass bottles 6-12 inches below the water surface and filling them such that all headspace was eliminated. The bottles were then sealed with Teflon$^{®}$-lined screw caps, and placed on ice. Bottles and caps were sonnicated in an ultrasonic cleaner (Branson Ultrasonics Corp.), washed, and rinsed in the lab, and then rinsed three times with sample water just prior to sample collection. Samples were stored at 6-9 ^{o}C prior to sample preparation.

Sediment pore water samples were obtained by filling 250 mL polypropylene bottles (two bottles from each site) with surface sediments, and then centrifuging the sediments to separate the pore water from the sediment matrix. The polypropylene bottles were sonnicated and washed in methanol in the lab, and rinsed three times with river water prior to sampling. Sampling was performed such that organic-rich sediments were selectively collected. Sampling was done in shallow water with a large (2.5 inch dia.), stainless steel spoon, and with a 0.125 ft^3 Ekman sediment dredge in deeper water. Sediment samples were stored in an ice chest immediately after collection, and then refrigerated prior to centrifuging and sample preparation. Centrifuging was done with an International Equipment Company Universal Model UV centrifuge at 3,000 rpm. After 30 minutes, the sediment pore water was decanted, yielding approximately 200-250 mL per 500 mL sediment sample.

Ground water samples were obtained with either a 1 L or a 300 mL stainless steel bailer (with teflon check valves), depending on the diameter of the well being sampled. Prior to sample collection, each well was purged of five well-volumes to ensure that the samples were obtained from fresh ground water (24). Samples were collected in 1 L glass bottles with teflon-lined screw caps as were described for surface water sampling. After each well was sampled, the bailers were cleaned with both methanol and laboratory-grade detergent solution to prevent cross-contamination of well water.

3.2.2 Preconcentration Procedures

Mutagenicity testing is typically performed by exposing bacteria populations to uL (microliter) aliquots of concentrated samples. The majority of pollutants in surface waters and ground water in the watershed are present in dilute concentrations - on the order of parts per billion (14,15,17-21), thus, in order to increase the concentration of samples tested in the bacteria assay, sample preconcentration was required. A number of concentration and isolation procedures have been developed for preparing water samples for chemical and biological analysis. In selecting a preconcentration procedure that would be appropriate for preparing water samples for mutagenicity testing, the following alternatives were considered: liquid-liquid extraction, rotary evaporation, freeze concentration, and solid-phase extraction using XAD resins and bonded-phase sorbents.

Liquid-liquid extraction (or solvent extraction) is the process by which dissolved organic compounds partition from water into a contacting immiscible solvent. Liquid-liquid extraction is particularly useful for recovering nonpolar, volatile compounds, and it has the advantage of excluding aqueous salts. Studies have shown that liquid-liquid extraction is suitable for small volumes of water (e.g < 10 L), but that continuous extractors may be required for larger samples (25). Some of the disadvantages in using liquid-liquid extraction include solvent contamination, extraction specificity (i.e. the solvent and extraction parameters such as pH, ionic strength, and temperature must be adjusted to accommodate the chemistry of the compounds being extracted), and problems associated with the storage and subsequent concentration of the extraction solvent (25-27).

Rotary evaporation is a vacuum distillation process in which water samples are boiled at reduced pressure and at ambient or somewhat above ambient temperature. In rotary evaporation, the vessel containing the sample is continuously rotated in a heating-mantle or hot water bath to ensure uniform heating of the sample. Vacuum distillation procedures such as this have been used in several studies to concentrate water samples for both chemical analysis and testing in biological assays (28,29). Rotary evaporation can be used to achieve high concentration efficiency, however, laboratory-scale equipment is generally limited to sample volumes on the order of several liters per day. Additional drawbacks to rotary evaporation include loss of volatile compounds from solution, and formation of large amounts of inorganic precipitates (26).

In the freeze concentration process, the formation of ice in a water sample is controlled such that solutes are concentrated in the unfrozen portion. Differential freezing is typically achieved by either rotating the sample vessel in an ice bath or placing the sample vessel on top of a stirring plate in a freezer, thus allowing ice to form at the outside of the vessel while maintaining a liquid center. It has been demonstrated that freeze concentration techniques are particularly useful for recovering volatile and reactive compounds which are either chemically altered or selectively separated by thermal or solvent concentration procedures (30-35). Baker (30), for example, achieved recoveries of phenolic compounds in excess of 75% for 20-fold volume reductions in distilled water. A limitation to using freeze concentration techniques is that recoveries of dissolved organic constituents decrease significantly with increasing volume reduction. Islam and Hemond (36), for instance, found that for greater than 10-fold volume reductions, actual recoveries of total organic carbon from tap water were over a factor of 2 smaller than predicted recoveries. Also, Baker (30) showed that acetophenone recoveries decreased considerably for concentrations factors exceeding 9 and 6 in water with initial chloride concentrations of 10 mg/L and 100 mg/L respectively. It has been suggested that as volume reduction proceeds, increasing concentrations of dissolved salts induce morphological alterations in the ice matrix, thus leading to the entrapment of solute-rich water.

Solid-phase extraction methods in which dissolved hydrophobic organic compounds partition onto contacting sorptive surfaces have been widely used in water quality analysis. The most commonly used sorbents for preparing water samples for chemical analysis and biological testing are XAD resins (37). Five different types of XAD are commercially available: XAD made from styrene divinylbenzene copolymers, which is available in three surface area / pore size combinations (XAD-1, XAD-2, and XAD-4); and XAD made from methyl methacrylate polymer, which is available in two surface area / pore size combinations (XAD-7 and XAD-8). Not only do these resins possess favorable macroreticular characteristics and high sorptive capacity, but they are also relatively inexpensive and easy to use. A major drawback to using XAD resins, however, is that they tend to be contaminated with impurites such as residual monomers, manufacturing artifacts, and chemical preservatives (38). As a result, prior to using XAD resins in preparing water samples for biological assays, the resins must be exhaustively cleaned and tested to ensure that biologically active artifacts are eliminated.

Another group of solid-phase extraction materials frequently used in preparing water samples for chemical analysis and biological testing are bonded-phase silica sorbents. Bonded-phase silica sorbents are formed by reacting organosilanes with activated silica. Many different organosilanes can be used in synthesizing bonded-phase sorbents - including those with nonpolar, polar, and ion exchange functional groups - and, as a result, sorbents can be tailored to possess specific extraction properties. Bonded-phase sorbents (notably octyl and octadecyl bonded-phases) have been used in many recent studies to selectively isolate hydrophobic organic compounds from natural waters (39-52). The principal advantage in using bonded-phase sorbents over other sorbents, in particular XAD resins, is that bonded-phase sorbents have been found to produce fewer artifacts, and they therefore require less cleaning prior to use. In addition, because they are rigid and do not shrink and swell when wetted (as do many polystyrene resins), bonded-phase sorbents equilibrate quickly in changing solvent conditions, thus allowing extraction procedures involving several different solvents to be performed more rapidly.

In deciding which preconcentration procedure would be most appropriate for preparing water samples for bacterial mutagenicity testing, the following criteria were considered: 1) effectiveness in recovering a wide range of organic compounds (i.e. molecular weight, polarity, etc.); 2) ease with which the procedure is executed; 3) whether the procedure produced artifact problems; and 4) whether the procedure could be scaled to process considerably larger samples volumes (e.g. > 50 L). The procedure that best satisfied all four criteria was solid-phase extraction using bonded-phase sorbents. Liquid-liquid extraction and rotary evaporation procedures give high recoveries of several classes of organic compounds, are relatively simple to perform, and are relatively free of artifact problems; however, neither procedure could be feasibly scaled to process large sample volumes. Freeze concentration generates few artifacts (if any) and is relatively easy to execute, but was to give poor recoveries of organic compounds from water, especially from natural waters with high ionic strength. Finally, XAD resin procedures give high recoveries of a wide range of dissolved organic compounds, are easily performed, and could be readily scaled to accommodate larger sample volumes; however, due to well-documented artifact problems, XAD resins were deemed inappropriate for use in mutagenicity testing. As a result, it was concluded that a solid-phase extraction procedure using bonded-phase sorbents should be used. The procedure that was developed is described in the following section.

3.2.2.1 One-Liter Water Sample Preparation Procedure

The general procedure used for preparing water samples for mutagenicity testing consisted of solid-phase extraction on bonded-phase sorbents followed by solvent elution. The sorbents used were Analytichem International octadecyl (OD) and cyanopropyl (CN) bonded-phase sorbents; high purity methanol (MEOH) and dichloromethane (DCM) manufactured by Caledon Laboratories were used as the eluting solvents. Water samples were first passed sequentially through disposable 6 mL OD and CN cartridges, each containing 1 g of sorbent. The cartridges were then eluted with MEOH and DCM thus creating four eluate fractions of different polarity - the OD-DCM fraction being the most nonpolar, and the CN-MEOH fraction being the least.

Prior to extraction, the sorbents were cleaned with the eluting solvents to remove potentially toxic and/or mutagenic artifacts. Each new cartridge was sequentially washed with 15 mL of DCM, MEOH, and reverse osmosis deionized water. In order to remove suspended particles that would otherwise clog the sorbent beds, the water samples were first filtered on 0.45 uM Nalgene cellulose nitrate membranes. Following cleaning, the wetted sorbent cartridges were attached to a 2 L separatory funnel into which the filtered water samples were poured. The samples were then gravity fed through the cartridges at a flow rate of 2 mL/min. Once all the water had passed through the cartridges, residual sample water in the sorbent beds was pushed out with nitrogen gas. The cartridges were then sequentially eluted with 5 mL of MEOH and DCM.

The final step in the preparation procedure involved concentrating the eluate fractions, and then exchanging the concentrates into a bio-compatible solvent. Eluate fractions were concentrated in a mini Kudema-Danish concentrator with a 3-ball Snyder Column to a final volume of 1 mL. Next, 0.5 mL aliquots were removed and exchanged into 0.25 mL of dimethyl sulfoxide (DMSO) under a gentle stream of nitrogen gas. The DMSO fractions were then submitted for mutagenicity testing, while the remainder of each sample fraction was frozen for subsequent chemical analysis.

3.2.2.2 Sixty-Liter Water Sample Preparation Procedure

In order to test higher concentrations of aqueous solutes in the bacterial mutation assay, a 60 L water sample preparation procedure was also developed (Figure 3.2). The sample preparation steps in the 60 L procedure were essentially identical to those developed for the 1 L procedure, however, the materials used were scaled to accommodate larger sample volumes.

In the 60 L procedure, 24 g of OD and CN bonded-phase sorbents were put in separate 1" (i.d.) x 6" HPLC columns equipped with compression fittings. The columns were connected in series - the CN column downstream of the OD column - by 0.25" stainless steel tubing to a Liquid Metronics metering pump (D101-97). A 5.0 uM polytetrafluoroethylene membrane filter (Millipore) and a 0.45 uM polyvinylidene difluoride membrane filter (Millipore) were placed between the pump and the columns to remove particles from the water that would otherwise accumulate on and reduce the conductivity of the sorbent beds.

Prior to extraction, the sorbents were cleaned by sequentially pumping 2 L of reagent grade DCM and MEOH (Mallinckrodt) through each column. Extraction was then performed by pumping 60 L water samples from polypropylene carboys through the particle filters and over the sorbent beds. The pumping rate was set at 50 mL/min; the particle filters were replaced approximately every 6 liters depending on the turbidity of the water sample. Following extraction, the columns were centrifuged at 3,000 rpm for 30 minutes to remove residual pore water. The sorbents were then eluted by sequentially pumping 250 mL of high purity MEOH and DCM (Caledon Laboratories) through the columns at a flow rate of 20 mL/min. In order to recover organic compounds sorbed to the entrained particles, the used membrane filters were also extracted. The 5.0 uM and the 0.45 uM membrane filters were extracted separately in a Soxhlet extractor in 300 mL of DCM and MEOH (DCM:MEOH = 9:1) for 24 hours. The six eluate fractions were then concentrated and 5/6 of each concentrate (i.e. the equivalent of 50 L of water) was exchanged into DMSO by the procedure described in the previous section (NB: In addition to environmental samples, 60 L samples of reverse osmosis deionized water were prepared as system blanks).

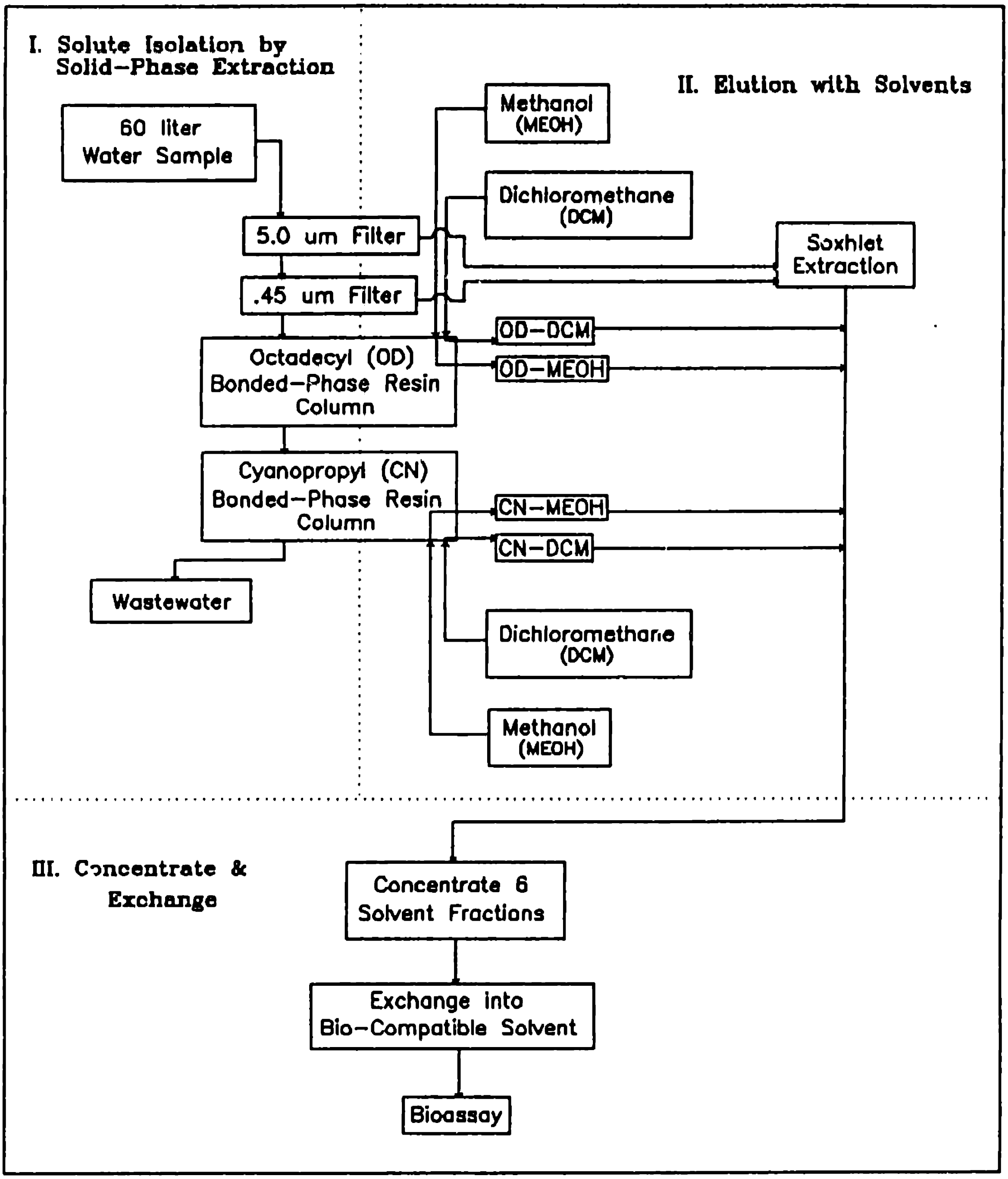

Figure 3.2 Large-Volume Water Sample Solute Isolation Procedure

3.2.3 Bacterial Mutation Assay

The mutation assays were performed by exposing exponentially growing populations of *S. typhimurium* (strain TM677) to uL concentrations of the water sample extracts. In each mutation experiment, two independent cultures were incubated in minimal E medium (a solution of $MgSO_4$, citric acid, K_2HPO_4, $NaNH_4HPO_4$, glucose, and biotin at pH=7.0) to a cell concentration of approximately 1 x 10^7/mL. Water sample extract aliquots of 10, 3, and 1 uL were then added to the cultures in both the absence and presence of Arochlor (i.e. a mixture of polychlorinated biphenyls) induced postmitochondrial supernatant (PMS). In -PMS experiments, samples of the culture and water sample extracts were combined in 20 mL vials to a total volume of 5.0 mL; in +PMS experiments, samples of the culture, water sample extracts, sterile PMS, and cofactors to enhance the enzyme activity of the PMS were combined in tissue culture flasks such that the volume of PMS was 5% of the total. Both -PMS and +PMS cultures were then incubated for approximately 2 hours. After treatment, the cultures were diluted with phosphate buffered saline solution (PBS) - thus terminating mutagenesis - to a viable cell concentration of 1 x 10^7/mL.

To determine the number of mutated cells in each experiment, aliquots of the treated cultures were plated (in triplicate) in the presence and absence of the selective agent 8-AG (about 1 x 10^6 mutagen treated cells were plated in petri dishes with an 8-AG concentration of 50 ug/mL). Toxicity caused by the water samples extracts was measured by plating (in triplicate) PBS-diluted aliquots of the treated cultures in the absence of 8-AG. Colonies on the mutation and toxicity plates were counted after a 48-hour incubation period. The fraction of 8-AG resistant mutants after treatment was calculated as the number of colonies on the 8-AG plates divided by the number of colonies on the plates without 8-AG multiplied by the dilution factor.

The statistical significance of the calculated mutant fractions was determined by comparison to negative controls and the cumulative historical control for the assay. Untreated control cultures (negative controls) were prepared in parallel with the treated cultures, and thus a background or spontaneous mutant fraction was determined for each experiment. The difference between the 8-AG resistant mutant fraction and the background mutant fraction is the induced mutant fraction (IMF). If the IMF was positive with greater than 99% confidence, and it exceeded the 95% upper confidence limit for the cumulative historical control (approximately 14 x 10^{-5}), then the outcome of an experiment was considered to be positive. The 99% confidence interval for each experiment was calculated by multiplying the standard deviation by the appropriate t value for one-sided student's t-distribution; the 95% upper confidence limit for the historical control was determined by observations from a series of independent untreated controls.

3.3 Results

3.3.1 One-Liter Surface Water, Sediment Pore Water, and Ground Water Samples

The results of mutagenicity testing of extracts from 1 L surface water, sediment pore water, and ground water samples are presented in Tables 3.1, 3.2, and 3.3, respectively. The tables show the mutagenic and toxic response of S. *typhimurium* to increasing concentrations of water sample extracts. Dose is expressed as a percentage of the highest concentration of sample extract to which the cells were exposed (e.g. 100% = 10 uL of sample extract in DMSO per mL of cell culture). Testing was done at three doses (i.e. 11%, 33%, and 100%) for each eluate fraction (i.e. ODMEOH, ODDCM, CNMEOH, and CNDCM) in only seven surface water samples. For the other surface water samples as well as the sediment pore water and ground water samples, the four eluate fractions were combined to make two "sorbent" fractions (i.e. ODMEOH/ODDCM and CNMEOH/CNDCM), and testing was done at only the highest dose to save time and laboratory resources.

Overall, the results indicate that none of the water sample extracts tested caused a statistically significant mutagenic response in the *S. typhimurium* forward mutation assay. All of the 120 eluate fractions tested in the absence of PMS were clearly negative, and 118 of the 122 eluate fractions tested in the presence of PMS produced low mutant fractions. Of the four extracts that produced high mutant fractions (ARW0000-871030, CNDCM; ARW1250-871103, ODDCM; ARW23330-871103, ODMEOH and ODDCM), none were considered mutagenic because either they were also highly toxic or their highest mutant fraction only marginally exceeded the 95% historical upper confidence limit of the assay. The results of the toxicity experiments - as measured by the relative survival of treated colonies in the absence of the selective agent - indicate that in six surface water eluate fractions (ARW0000-871030, CNDCM; ARW1250-871103, ODDCM; ARW16650-890120, ODMEOH/ODDCM; ARW28750-890125, ODMEOH/ODDCM; ARW36250-880531, ODDCM; and EDDW2800-880531, CNDCM)

Table 3.1 One-Liter Surface Water Samples Tested for Mutagenicity in *S.typhimurium*

		-PMS[1]			+PMS[2]		
Sample Label[3]		Mutant[4] Fraction (mean ± s.d.)	Relative[5] Survival	Statistical[6] Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
ARW0000-871030							
ODMEOH	C	13.8 ± 1.7	1.00	-	7.3 ± 1.2	1.00	-
	11%	16.1 ± 2.1	0.85	-	9.1 ± 1.6	0.80	-
	33%	16.0 ± 2.3	0.70	-	8.2 ± 1.5	0.75	-
	100%	17.6 ± 3.9	0.26	-	8.5 ± 2.1	0.41	-
ODDCM	C	13.8 ± 1.7	1.00	-	7.3 ± 1.2	1.00	-
	11%	18.3 ± 2.2	0.88	-	7.0 ± 1.2	1.03	-
	33%	16.4 ± 1.9	1.03	-	7.4 ± 1.2	1.01	-
	100%	18.1 ± 2.3	0.80	-	8.2 ± 1.4	0.87	-
CNMEOH	C	14.2 ± 2.3	1.00	-	13.7 ± 1.7	1.00	-
	11%	12.9 ± 1.8	1.42	-	14.4 ± 1.9	0.85	-
	33%	13.3 ± 1.9	1.36	-	12.8 ± 1.8	0.78	-
	100%	12.7 ± 1.9	1.29	-	12.2 ± 1.8	0.78	-
CNDCM	C	14.2 ± 2.3	1.00	-	13.7 ± 1.7	1.00	-
	11%	12.7 ± 1.8	1.44	-	10.2 ± 1.8	0.62	-
	33%	14.7 ± 3.7	0.42	-	19.8 ± 4.7	0.21	-
	100%	28.4 ± 15.3	0.05	-	40.7 ± 10.6	0.11	-
ARW0100-890218							
ODMEOH/ODDCM							
	C	6.9 ± 1.5	1.00	-	2.5 ± 0.4	1.00	-
	100%	6.9 ± 1.4	1.18	-	2.4 ± 0.4	0.97	-
CNMEOH/CNDCM							
	C	6.9 ± 1.5	1.00	-	2.5 ± 0.4	1.00	-
	100%	7.1 ± 1.5	0.99	-	2.0 ± 0.4	0.97	-
ARW1250-871103							
ODMEOH	C	7.5 ± 1.0	1.00	-	8.6 ± 1.6	1.00	-
	11%	9.6 ± 1.3	0.78	-	13.4 ± 2.2	0.83	-
	33%	9.0 ± 1.2	0.83	-	15.1 ± 2.6	0.73	-
	100%	9.7 ± 1.2	0.84	-	16.7 ± 2.8	0.69	-
ODDCM	C	7.5 ± 1.0	1.00	-	8.6 ± 1.6	1.00	-
	11%	11.9 ± 1.6	0.65	-	17.1 ± 3.0	0.62	?
	33%	12.9 ± 1.6	0.71	-	18.4 ± 3.6	0.48	?
	100%	12.6 ± 1.6	0.66	-	10.8 ± 4.4	0.16	-
CNMEOH	C	7.5 ± 1.0	1.00	-	8.6 ± 1.6	1.00	-
	11%	8.1 ± 0.9	1.18	-	9.4 ± 1.8	0.85	-
	33%	8.9 ± 1.0	1.10	-	6.6 ± 1.3	1.09	-
	100%	9.3 ± 1.0	1.19	-	9.8 ± 1.8	0.85	-
CNDCM	C	7.5 ± 1.0	1.00	-	8.6 ± 1.6	1.00	-
	11%	8.2 ± 1.0	1.04	-	13.7 ± 2.3	0.82	-

Table 3.1 Continued

	-PMS			+PMS		
Sample Label	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
33%	11.9 ± 1.3	0.92	-	11.9 ± 2.2	0.76	-
100%	16.0 ± 2.3	0.46	-	12.0 ± 2.0	0.93	-
ARW5350-890131						
ODMEOH/ODDCM						
C	10.0 ± 1.5	1.00	-	7.0 ± 1.1	1.00	-
100%	9.8 ± 1.8	0.68	-	7.4 ± 1.8	0.43	-
CNMEOH/CNDCM						
C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
100%	8.6 ± 1.4	0.88	-	6.6 ± 1.4	0.74	-
ARW7750-890130						
ODMEOH/ODDCM						
C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
100%	8.7 ± 1.5	0.85	-	7.7 ± 1.5	0.68	-
CNMEOH/CNDCM						
C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
100%	9.1 ± 1.6	0.79	-	6.3 ± 1.2	0.86	-
ARW11550-890125						
ODMEOH/ODDCM						
C	10.0 ± 1.5	1.00	-	7.0 ± 1.1	1.00	-
100%	6.4 ± 1.3	0.72	-	8.1 ± 2.0	0.35	-
CNMEOH/CNDCM						
C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
100%	8.5 ± 1.5	0.78	-	6.7 ± 1.4	0.68	-
ARW16650-890120						
ODMEOH/ODDCM						
C	10.0 ± 1.5	1.00	-	7.0 ± 1.1	1.00	-
100%	6.7 ± 1.2	0.97	-	12.3 ± 4.5	0.11	-
CNMEOH/CNDCM						
C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
100%	8.8 ± 1.5	0.86	-	7.6 ± 1.3	0.97	-
ARW20250-890125						
ODMEOH/ODDCM						
C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
100%	7.3 ± 1.3	0.81	-	6.9 ± 1.5	0.62	-
CNMEOH/CNDCM						
C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
100%	7.0 ± 1.1	1.03	-	9.2 ± 1.5	0.83	-

Table 3.1 Continued

Sample Label		-PMS			+PMS		
		Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
ARW23330-871103							
ODMEOH	C	9.3 ± 1.0	1.00	-	10.3 ± 2.2	1.00	-
	11%	6.1 ± 1.6	0.73	-	21.2 ± 4.4	0.69	?
	33%	5.3 ± 1.3	0.90	-	19.0 ± 3.9	0.67	?
	100%	7.2 ± 3.9	0.63	-	14.9 ± 3.1	0.61	-
ODDCM	C	9.3 ± 1.8	1.00	-	10.3 ± 2.2	1.00	-
	11%	6.7 ± 1.5	0.95	-	11.6 ± 2.7	0.80	-
	33%	6.8 ± 2.1	0.70	-	18.1 ± 3.9	0.62	?
	100%	8.8 ± 2.3	0.63	-	17.8 ± 3.8	0.64	-
CNMEOH	C	9.3 ± 1.8	1.00	-	10.3 ± 2.2	1.00	-
	11%	9.5 ± 1.6	1.23	-	10.4 ± 2.2	0.98	-
	33%	8.3 ± 1.6	1.12	-	12.6 ± 2.6	0.89	-
	100%	6.2 ± 1.6	0.73	-	13.8 ± 2.7	0.93	-
CNDCM	C	9.3 ± 1.8	1.00	-	10.3 ± 2.2	1.00	-
	11%	8.8 ± 1.9	1.33	-	12.7 ± 2.6	0.93	-
	33%	6.4 ± 1.3	1.12	-	15.0 ± 3.3	0.68	-
	100%	6.9 ± 1.4	1.10	-	12.0 ± 3.0	0.64	-
ARW23350-890120[7]							
ODMEOH/ODDCM							
	C				7.7 ± 1.3	1.00	-
	11%				4.4 ± 0.9	1.16	-
	33%				5.7 ± 1.2	0.96	-
CNMEOH/CNDCM							
	C				7.7 ± 1.3	1.00	-
	11%				6.7 ± 1.2	1.08	-
	33%				6.6 ± 1.3	0.96	-
ARW28750-890125							
ODMEOH/ODDCM							
	C	7.3 ± 1.5	1.00	-	7.7 ± 1.3	1.00	-
	11%				7.4 ± 1.3	1.04	-
	33%				6.1 ± 1.2	0.98	-
	100%	3.3 ± 1.3	0.56	-	57.6 ± 43.3	0.04	-
CNMEOH/CNDCM							
	C	7.5 ± 1.2	1.00	-	5.7 ± 2.0	1.00	-
	100%	5.6 ± 1.0	0.98	-	3.1 ± 1.6	0.86	-
ARW35500-890120							
ODMEOH/ODDCM							
	C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
	100%	6.3 ± 1.3	0.72	-	6.5 ± 1.3	0.78	-
CNMEOH/CNDCM							
	C	10.0 ± 1.5	1.00	-	6.7 ± 1.2	1.00	-
	100%	7.5 ± 1.3	0.95	-	6.2 ± 1.3	0.76	-

Table 3.1 Continued

		-PMS			+PMS		
Sample Label		Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
ARW36250-880531							
ODMEOH	C	7.3 ± 1.7	1.00	-	5.5 ± 1.3	1.00	-
	11%	6.8 ± 1.6	1.04	-	3.6 ± 1.0	0.97	-
	33%	5.6 ± 1.4	0.93	-	4.7 ± 1.2	0.89	-
	100%	8.6 ± 1.8	1.06	-	7.7 ± 1.6	0.94	-
ODDCM	C	7.3 ± 1.7	1.00	-	5.5 ± 1.3	1.00	-
	33%	5.3 ± 1.3	1.06	-	6.4 ± 1.7	0.67	-
	100%	5.4 ± 1.4	0.94	-	2.9 ± 3.2	0.09	-
CNMEOH	C	7.3 ± 1.7	1.00	-	5.5 ± 1.3	1.00	-
	33%	3.4 ± 1.0	1.05	-	5.3 ± 1.4	0.81	-
	100%	4.6 ± 1.2	1.04	-	4.9 ± 1.5	0.68	-
CNDCM	C	7.3 ± 1.7	1.00	-	5.5 ± 1.3	1.00	-
	33%	3.0 ± 1.2	0.70	-	6.1 ± 1.6	0.69	-
	100%	5.4 ± 1.7	0.65	-	5.8 ± 1.6	0.64	-
ARW37250-890218							
ODMEOH/ODDCM							
	C	3.8 ± 0.6	1.00	-	6.3 ± 1.9	1.00	-
	100%	4.8 ± 0.8	0.68	-	7.3 ± 2.4	0.77	-
CNMEOH/CNDCM							
	C	3.8 ± 0.6	1.00	-	6.3 ± 1.9	1.00	-
	100%	5.1 ± 0.8	0.72	-	7.2 ± 2.2	0.87	-
ARSW5000-871103							
ODMEOH	C	10.6 ± 1.9	1.00	-	12.3 ± 1.7	1.00	-
	11%	15.9 ± 2.2	1.15	-			
	33%	15.4 ± 2.3	1.07	-	11.9 ± 1.7	0.97	-
	100%	8.6 ± 2.1	0.59	-	9.2 ± 1.9	0.58	-
ODDCM	C	10.6 ± 1.9	1.00	-	12.3 ± 1.7	1.00	-
	11%	15.7 ± 2.2	1.11	-	14.7 ± 2.0	0.93	-
	33%	18.7 ± 2.7	0.92	-	10.3 ± 1.7	0.80	-
	100%	12.3 ± 2.6	0.60	-	13.6 ± 2.5	0.51	-
CNMEOH	C	12.7 ± 1.3	1.00	-	11.1 ± 1.5	1.00	-
	11%	10.7 ± 1.3	0.79	-	9.1 ± 1.4	0.91	-
	33%	13.1 ± 1.5	0.73	-	7.6 ± 1.3	0.91	-
	100%	13.5 ± 2.1	0.40	-	9.1 ± 1.7	0.66	-
CNDCM	C	12.7 ± 1.3	1.00	-	11.1 ± 1.5	1.00	-
	11%	11.5 ± 1.3	0.85	-			
	100%	14.2 ± 2.8	0.25	-	14.9 ± 2.0	0.86	-

Table 3.1 Continued

		-PMS			+PMS		
Sample Label		Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
CBKW2800-890215							
ODMEOH/ODDCM							
	C	8.5 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
	100%	6.7 ± 1.2	1.01	-	7.3 ± 1.3	0.72	-
CNMEOH/CNDCM							
	C	8.5 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
	100%	6.9 ± 1.2	1.01	-	6.3 ± 1.1	0.90	-
CBKW7750-890211							
ODMEOH/ODDCM							
	C	3.8 ± 0.6	1.00	-	3.2 ± 0.9	1.00	-
	100%	5.8 ± 1.0	0.58	-	4.1 ± 1.2	0.77	-
CNMEOH/CNDCM							
	C	3.8 ± 0.6	1.00	-	3.2 ± 0.9	1.00	-
	100%	4.1 ± 0.7	0.72	-	2.3 ± 1.0	0.60	-
EDDW2800-880531							
ODMEOH	C	2.1 ± 0.7	1.00	-	9.8 ± 2.1	1.00	-
	11%	3.3 ± 1.1	0.75	-	15.6 ± 3.4	0.70	-
	33%	3.6 ± 1.2	0.72	-	11.0 ± 3.0	0.59	-
	100%	4.9 ± 1.4	0.67	-	14.4 ± 3.0	0.49	-
ODDCM	C	2.1 ± 0.7	1.00	-	9.8 ± 2.1	1.00	-
	11%	7.4 ± 1.9	0.59	-	8.3 ± 2.7	0.51	-
	33%	3.2 ± 1.3	0.52	-	17.3 ± 5.1	0.35	-
	100%	0.7 ± 0.6	0.52	-	10.4 ± 3.9	0.33	-
CNMEOH	C	2.1 ± 0.7	1.00	-	9.8 ± 2.1	1.00	-
	11%	4.7 ± 1.2	0.80	-	13.0 ± 2.5	0.98	-
	33%	6.2 ± 1.6	0.69	-	12.3 ± 2.5	0.91	-
	100%	1.4 ± 0.7	0.68	-	13.4 ± 3.0	0.70	-
CNDCM	C	2.1 ± 0.7	1.00	-	9.8 ± 2.1	1.00	-
	11%	4.3 ± 1.2	0.70	-	10.9 ± 3.0	0.57	-
	33%	5.4 ± 1.7	0.52	-	23.1 ± 9.1	0.16	-
	100%	2.3 ± 0.9	0.70	-	6.2 ± 6.0	0.07	-
EDDW6600-890206							
ODMEOH/ODDCM							
	C	8.5 ± 1.4	1.00	-	4.3 ± 1.1	1.00	-
	100%	5.3 ± 1.1	0.95	-	4.6 ± 1.2	1.06	-
CNMEOH/CNDCM							
	C	8.5 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
	100%	5.1 ± 1.0	1.13	-	10.2 ± 1.9	0.54	-

Table 3.1 Continued

Sample Label	-PMS			+PMS		
	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
FBKW1750-890206						
ODMEOH/ODDCM						
C	8.5 ± 1.4	1.00	-	4.3 ± 1.1	1.00	-
100%	6.0 ± 1.1	1.03	-	2.8 ± 1.0	0.85	-
CNMEOH/CNDCM						
C	8.5 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
100%	5.3 ± 1.0	1.09	-	7.1 ± 1.3	0.75	-
HBKW4050-890131						
ODMEOH/ODDCM						
C	9.7 ± 1.4	1.00	-	3.9 ± 1.4	1.00	-
100%	8.0 ± 1.4	0.78	-	0.3 ± 0.3	0.59	-
CNMEOH/CNDCM						
C	9.7 ± 1.4	1.00	-	3.9 ± 1.4	1.00	-
100%	8.1 ± 1.2	1.07	-	2.1 ± 1.0	1.13	-
HMCKW1400-890221						
ODMEOH/ODDCM						
C	10.2 ± 1.5	1.00	-	3.9 ± 2.4	1.00	-
100%	8.4 ± 1.6	0.58	-	2.4 ± 1.1	0.98	-
CNMEOH/CNDCM						
C	10.5 ± 1.5	1.00	-	3.9 ± 2.4	1.00	-
100%	8.4 ± 1.6	0.71	-	4.6 ± 1.2	1.02	-
HPBKW0100-890206						
ODMEOH/ODDCM						
C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
100%	9.3 ± 1.4	0.92	-	6.5 ± 1.4	0.60	-
CNMEOH/CNDCM						
C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
100%	7.1 ± 1.1	1.05	-	5.9 ± 1.1	0.91	-
HPW3350-890218						
ODMEOH/ODDCM						
C	6.9 ± 1.5	1.00	-	2.5 ± 0.4	1.00	-
100%	6.4 ± 1.4	1.06	-	1.3 ± 0.3	0.91	-
CNMEOH/CNDCM						
C	6.9 ± 1.5	1.00	-	2.5 ± 0.4	1.00	-
100%	6.2 ± 1.3	1.08	-	1.5 ± 0.3	0.96	-
LFCKW0000-890131						
ODMEOH/ODDCM						
C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
100%	7.4 ± 1.2	0.92	-	7.7 ± 1.3	0.89	-

Table 3.1 Continued

Sample Label		-PMS			+PMS		
		Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
CNMEOH/CNDCM							
	C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
	100%	7.5 ± 1.2	1.01	-	7.4 ± 1.3	0.78	-
LBKW5500-890221							
ODMEOH/ODDCM							
	C	10.2 ± 1.5	1.00	-	3.2 ± 0.9	1.00	-
	100%	7.0 ± 1.4	0.72	-	3.3 ± 1.0	0.92	-
CNMEOH/CNDCM							
	C	10.2 ± 1.5	1.00	-	3.2 ± 0.9	1.00	-
	100%	9.1 ± 1.5	0.85	-	3.5 ± 1.0	0.96	-
NMCKW1900-871103							
ODMEOH	C	13.2 ± 1.7	1.00	-	15.1 ± 1.9	1.00	-
	11%	16.4 ± 2.6	0.57	-	15.3 ± 2.1	0.83	-
	33%	9.0 ± 1.6	0.69	-	14.3 ± 1.9	0.91	-
	100%	17.0 ± 3.3	0.37	-	14.0 ± 1.9	0.91	-
ODDCM	C	13.2 ± 1.7	1.00	-	15.1 ± 1.9	1.00	-
	11%	17.5 ± 2.6	0.61	-	12.4 ± 1.8	0.85	-
	33%	15.7 ± 2.5	0.59	-	15.0± 2.1	0.80	-
	100%	12.8 ± 2.4	0.49	-	20.0 ± 2.9	0.72	-
CNMEOH	C	13.2 ± 1.7	1.00	-	15.1 ± 1.9	1.00	-
	11%	11.1 ± 1.5	1.07	-	15.2 ± 1.9	1.00	-
	33%	12.1 ± 1.7	0.94	-	15.6 ± 2.0	0.93	-
	100%	9.8 ± 1.7	0.88	-	17.2 ± 2.1	0.90	-
CNDCM	C	13.2 ± 1.7	1.00	-	15.1 ± 1.9	1.00	-
	11%	13.6 ± 1.8	0.91	-	16.9 ± 2.0	0.97	-
	33%	19.4 ± 2.8	0.60	-	14.9 ± 1.8	0.96	-
	100%	15.4 ± 2.3	0.65	-	16.1 ± 2.1	0.90	-
SGBKW2800-890206							
ODMEOH/ODDCM							
	C	8.5 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
	100%	6.1 ± 1.1	1.04	-	6.2 ± 1.4	0.56	-
CNMEOH/CNDCM							
	C	8.5 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
	100%	5.8 ± 1.1	1.11	-	7.4 ± 1.2	0.88	-
SNBKW3050-890211							
ODMEOH/ODDCM							
	C	10.2 ± 1.5	1.00	-	3.2 ± 0.9	1.00	-
	100%	8.4 ± 1.8	0.78	-	2.8 ± 0.9	0.85	-

Table 3.1 Continued

	-PMS			+PMS		
Sample Label	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
CNMEOH/CNDCM						
C	10.2 ± 1.5	1.00	-	3.9 ± 2.4	1.00	-
100%	7.0 ± 1.2	1.01	-	2.8 ± 0.9	0.98	-
SWBKW3750-890211						
ODMEOH/ODDCM						
C	10.2 ± 1.5	1.00	-	3.9 ± 2.4	1.00	-
100%	8.4 ± 1.3	0.99	-	3.1 ± 1.0	0.99	-
CNMEOH/CNDCM						
C	10.2 ± 1.5	1.00	-	3.2 ± 0.9	1.00	-
100%	9.4 ± 1.5	0.92	-	2.7 ± 0.9	0.97	-
TEBKW0250-890211						
ODMEOH/ODDCM						
C	3.8 ± 0.6	1.00	-	6.3 ± 1.9	1.00	-
100%	5.2 ± 0.8	0.75	-	11.8 ± 3.2	0.72	-
CNMEOH/CNDCM						
C	3.8 ± 0.6	1.00	-	6.3 ± 1.9	1.00	-
100%	5.3 ± 0.9	0.67	-	6.2 ± 1.8	1.12	-
UMLW0400-890206						
ODMEOH/ODDCM						
C	9.7 ± 1.4	1.00	-	7.0 ± 1.1	1.00	-
100%	8.2 ± 1.3	0.88	-	9.5 ± 1.7	0.57	-
CNMEOH/CNDCM						
C	9.7 ± 1.4	1.00	-	6.0 ± 1.1	1.00	-
100%	6.6 ± 1.1	1.02	-	5.9 ± 1.4	0.59	-

[1] Extracts tested in the absence of postmitochondrial supernatant (PMS).

[2] Extracts tested in the presence of postmitochondrial supernatant (PMS).

[3] Sample Label indicates sampling location and date.

[4] Mutant fraction = 8-AG resistant fraction (x 10^5).

[5] Survival is measured relative to the negative control.

[6] A result is positive if the mutant fraction is larger than the background (C) with greater than 99% confidence, and it exceeds the 95% historical confidence limit (~14).

[7] -PMS experiments were not performed.

Table 3.2 Sediment Pore Water Samples Tested for Mutagenicity in *S. typhimurium*

	-PMS[1]			+PMS[2]		
Sample Label[3]	Mutant[4] Fraction (mean ± s.d.)	Relative[5] Survival	Statistical[6] Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
ARS0000-890313						
ODMEOH/ODDCM						
C	4.4 ± 1.0	1.00	-	3.9 ± 2.4	1.00	-
100%	2.1 ± 0.6	1.45	-	3.1 ± 1.1	0.86	-
CNMEOH/CNDCM						
C	4.4 ± 1.0	1.00	-	3.9 ± 2.4	1.00	-
100%	4.2 ± 1.1	0.89	-	3.4 ± 1.1	0.96	-
ARS0050-890313						
ODMEOH/ODDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
100%	5.1 ± 0.9	1.14	-	6.4 ± 1.8	0.73	-
CNMEOH/CNDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
100%	6.8 ± 1.0	1.22	-	5.6 ± 1.7	0.71	-
ARS1250-890313						
ODMEOH/ODDCM						
C	5.7 ± 1.4	1.00	-	6.6 ± 1.5	1.00	-
100%	10.7 ± 2.0	1.01	-	2.6 ± 1.1	0.63	-
CNMEOH/CNDCM						
C	5.7 ± 1.4	1.00	-	6.6 ± 1.5	1.00	-
100%	5.7 ± 1.5	0.89	-	2.2 ± 0.8	0.96	-
ARS16650-890315						
ODMEOH/ODDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	5.6 ± 2.2	0.63	-	13.6 ± 3.4	0.71	-
CNMEOH/CNDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	3.7 ± 1.5	0.84	-	11.6 ± 2.6	0.98	-
ARS23350-890315						
ODMEOH/ODDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
33%				5.3 ± 1.3	0.75	-
100%	5.4 ± 1.1	0.88	-	4.3 ± 3.1	0.17	-
CNMEOH/CNDCM						
C	7.5 ± 1.2	1.00		5.6 ± 1.5	1.00	-
100%	5.6 ± 1.0	0.98		5.8 ± 1.6	0.85	-

Table 3.2 Continued

Sample Label	-PMS			+PMS		
	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
ARS25750-890313						
ODMEOH/ODDCM						
C	7.5 ± 1.2	1.00	-	5.0 ± 1.1	1.00	-
100%	6.9 ± 1.1	1.06	-	5.3 ± 1.3	0.75	-
CNMEOH/CNDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
100%	7.0 ± 1.0	1.11	-	8.6 ± 2.0	0.85	-
ARS28750-890315						
ODMEOH/ODDCM						
C	6.9 ± 1.9	1.00	-	8.7 ± 1.6	1.00	-
100%	9.6 ± 2.6	0.77	-	7.7 ± 1.5	0.89	-
CNMEOH/CNDCM						
C	6.9 ± 1.9	1.00	-	8.7 ± 1.6	1.00	-
100%	7.2 ± 2.1	0.90		10.5 ± 1.9	0.87	-
ARS36250-890115						
ODMEOH/ODDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
100%	5.7 ± 0.9	1.23	-	6.2 ± 1.9	0.68	-
CNMEOH/CNDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
100%	7.2 ± 1.1	1.11	-	5.8 ± 1.5	0.96	-
HPBKS0100-890314						
ODMEOH/ODDCM						
C	7.5 ± 1.2	1.00	-	5.0 ± 1.1	1.00	-
100%	6.9 ± 1.2	0.91	-	5.7 ± 1.3	0.83	-
CNMEOH/CNDCM						
C	7.5 ± 1.2	1.00	-	5.6 ± 1.5	1.00	-
100%	5.8 ± 1.1	0.90	-	6.1 ± 1.7	0.80	-
SWBKS1300-890315						
ODMEOH/ODDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	7.1 ± 2.2	0.79	-	15.7 ± 3.5	0.78	-
CNMEOH/CNDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	4.4 ± 1.7	0.73	-	13.3 ± 2.8	0.99	-
WMPS0000-890315						
ODMEOH/ODDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	4.9 ± 1.8	0.75	-	15.5 ± 3.9	0.62	-

Table 3.2 Continued

Sample Label	-PMS			+PMS		
	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
CNMEOH/CNDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	3.7 ± 1.6	0.76	-	12.8 ± 2.9	0.93	-

[1] Extracts tested in the absence of postmitochondrial supernatant (PMS).
[2] Extracts tested in the presence of postmitochondrial supernatant (PMS).
[3] Sample Label indicates sampling location and date.
[4] Mutant fraction = 8-AG resistant fraction (x 10^5).
[5] Survival is measured relative to the negative control.
[6] A result is positive if the mutant fraction is larger than the background (C) with greater than 99% confidence, and it exceeds the 95% historical confidence limit (~14).

and one sediment pore water eluate fraction (ARS23350-890315, ODMEOH/ODDCM) tested in the presence of PMS, and in one surface water eluate fraction (ARW0000-871030, CNDCM) tested in the absence of PMS, cell survival decreased below 20% at the highest concentration tested.

3.3.2 Sixty-Liter Water Samples

The results of mutagenicity testing of extracts from two, 60 L system blanks and a 60 L surface water sample are presented in Table 3.4. The system blanks (SB) were prepared by extracting samples of reverse osmosis deionized water (from a Millipore water purification system), and then tested in the assay to determine whether toxic and/or mutagenic artifacts could be recovered from the extraction system. The surface water sample was taken from the East Drainage Ditch, a tributary to the Aberjona River in which high concentrations of industrial chemicals have been found (20,21,Chapter 1). The 60 L water samples were concentrated by a factor of 60,000, thus, 10 uL aliquots of the 60 L sample extracts (in DMSO) contained the equivalent of 2 L of extractable aqueous constituents.

The results indicate that toxic and potentially mutagenic compounds were present in both the system blanks and the East Drainage Ditch water. In testing extracts from SB-891001, extremely high toxicity (i.e. < 2% survival) was measured in *S. typhimurium* by

Table 3.3 Ground Water Samples Tested for Mutagenicity in *S. typhimurium*

	-PMS[1]			+PMS[2]		
Sample Label[3]	Mutant[4] Fraction (mean ± s.d.)	Relative[5] Survival	Statistical[6] Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
WELLS89S-890314						
ODMEOH/ODDCM						
C	5.7 ± 1.4	1.00	-	6.6 ± 1.5	1.00	-
100%	6.6 ± 1.6	0.82	-	2.5 ± 0.9	0.87	-
CNMEOH/CNDCM						
C	5.7 ± 1.4	1.00	-	6.6 ± 1.5	1.00	-
100%	4.3 ± 1.1	1.03	-	0.7 ± 0.5	0.75	-
SD-2-890319[7]						
ODMEOH/ODDCM						
C	5.7 ± 1.4	1.00	-	6.6 ± 1.5	1.00	-
100%	1.9 ± 0.7	1.09	-	7.6 ± 1.8	0.83	-
CNMEOH/CNDCM						
C	5.7 ± 1.4	1.00	-	6.6 ± 1.5	1.00	-
100%	4.4 ± 1.1	1.06	-	7.0 ± 1.6	0.90	-
SD-14-890315						
ODMEOH/ODDCM						
C	8.1 ± 1.9	1.00	-	7.6 ± 2.2	1.00	-
100%	5.9 ± 1.5	1.11	-	13.2 ± 3.3	0.89	-
CNMEOH/CNDCM						
C	8.1 ± 1.9	1.00	-	7.6 ± 2.2	1.00	-
100%	6.9 ± 1.6	1.13	-	11.7 ± 2.8	1.08	-
SD-12-890319						
ODMEOH/ODDCM						
C	6.9 ± 1.9	1.00	-	8.7 ± 1.6	1.00	-
100%	15.7 ± 2.6	1.41	-	10.5 ± 1.7	1.01	-
CNMEOH/CNDCM						
C	6.9 ± 1.9	1.00	-	11.1 ± 2.5	1.00	-
100%	8.9 ± 2.1	1.16	-	14.8 ± 3.1	0.92	-
SD-17-890319						
ODMEOH/ODDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	8.2 ± 2.1	0.85	-	4.8 ± 1.6	0.92	-
CNMEOH/CNDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	10.5 ± 2.2	1.03	-	12.4 ± 2.4	0.88	-

Table 3.3 Continued

Sample Label	-PMS			+PMS		
	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
OW-14-890409						
ODMEOH/ODDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	13.6 ± 2.6	1.01	-	7.5 ± 1.8	0.91	-
CNMEOH/CNDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	10.6 ± 2.6	1.02	-	6.9 ± 1.7	0.92	-
OW-9-890409						
ODMEOH/ODDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	12.7 ± 2.5	0.99	-	7.2 ± 1.8	0.86	-
CNMEOH/CNDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	11.3 ± 2.3	0.99	-	5.3 ± 1.5	0.82	-
SD-55-890409						
ODMEOH/ODDCM						
C	11.8 ± 2.4	1.00	-	12.8 ± 2.6	1.00	-
100%	16.4 ± 4.1	0.51	-	15.2 ± 3.3	0.77	-
CNMEOH/CNDCM						
C	11.8 ± 2.4	1.00	-	6.4 ± 1.5	1.00	-
100%	14.5 ± 2.5	1.16	-	8.7 ± 2.0	0.85	-
SD-9-890409						
ODMEOH						
C	7.8 ± 1.2	1.00	-	14.5 ± 1.9	1.00	-
100%	7.5 ± 1.2	0.96	-	17.1 ± 2.3	0.82	-
ODDCM						
C	7.8 ± 1.2	1.00	-	14.5 ± 1.9	1.00	-
100%	8.3 ± 1.4	0.76	-	17.9 ± 2.4	0.79	-
CNMEOH						
C	7.8 ± 1.2	1.00	-	14.5 ± 1.9	1.00	-
100%	8.8 ± 1.3	1.01	-	16.4 ± 2.2	0.89	-
CNDCM						
C	7.8 ± 1.2	1.00	-	14.5 ± 1.9	1.00	-
100%	9.5 ± 1.4	0.93	-	18.5 ± 2.7	0.79	-
MLS1-1-890619						
ODMEOH/ODDCM						
C	7.8 ± 1.2	1.00	-	14.5 ± 1.9	1.00	-
100%	7.2 ± 1.0	1.01	-	16.8 ± 2.1	0.94	-

Table 3.3 Continued

Sample Label	-PMS Mutant Fraction (mean ± s.d.)	-PMS Relative Survival	-PMS Statistical Significance	+PMS Mutant Fraction (mean ± s.d.)	+PMS Relative Survival	+PMS Statistical Significance
CNMEOH/CNDCM						
C	7.8 ± 1.2	1.00	-	14.5 ± 1.9	1.00	-
100%	8.2 ± 1.1	1.18	-	16.7 ± 2.2	0.88	-

[1] Extracts tested in the absence of postmitochondrial supernatant (PMS).
[2] Extracts tested in the presence of postmitochondrial supernatant (PMS).
[3] Sample Label indicates sampling location and date.
[4] Mutant fraction = 8-AG resistant fraction (x 10^5).
[5] Survival is measured relative to the negative control.
[6] A result is positive if the mutant fraction is larger than the background (C) with greater than 99% confidence, and it exceeds the 95% historical confidence limit (~14).
[7] SD = "Source Determination" sampling point (53,54).

exposure to the ODDCM and CNDCM eluate fractions in the presence of PMS. Retests of the fractions confirmed the initial results. The second system blank, SB-900225, was prepared by repacking the columns with fresh bonded-phase sorbents, and then cleaning the sorbents with larger volumes (i.e. 4 L) of the eluting solvents. In testing the SB-900225 extracts, high toxicity was measured in the presence of PMS in the ODDCM eluate fraction, and in the Soxhlet extracts of both particle filters. High toxicity was not observed in the CNDCM eluate fraction. High mutant fractions were also observed in the ODDCM eluate fraction and the 5.0 uM filter extracts when tested in the presence of PMS. In testing the East Drainage Ditch water sample, 2 sorbent eluate fractions (ODDCM and CNDCM) and both particle filter extracts were extremely toxic in the presence of PMS. High mutant fractions were also observed for these samples when tested in the presence of PMS, and for the 0.45 uM filter extract sample in the absence of PMS (NB: the same columns were used for SB-900225 and EDDW2800-900308).

3.4 Discussion

3.4.1 Toxicity

The results of testing extracts of water samples from the Aberjona watershed in an *S. typhimurium* forward mutation assay indicate that substances present in several of the extracts ranged from being highly toxic (i.e. < 20% survival) to extremely toxic (i.e. < 2%

Table 3.4 Sixty-Liter Water Samples Tested for Mutagenicity in *S. typhimurium*

Sample Label		-PMS[1]			+PMS[2]		
		Mutant[3] Fraction (mean ± s.d.)	Relative[4] Survival	Statistical[5] Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
SB-891001[6]							
ODMEOH	C	7.1 ± 1.4	1.00	-	10.7 ± 1.8	1.00	-
	11%	11.4 ± 1.8	1.03	-	10.4 ± 1.9	0.88	-
	33%	10.3 ± 1.7	1.02	-	10.1 ± 1.8	0.96	-
	100%	11.5 ± 1.8	1.03	-	10.8 ± 1.9	0.85	-
ODDCM	C	4.3 ± 0.9	1.00	-	3.5 ± 0.9	1.00	-
(891128)	100%	4.0 ± 0.9	1.01	-	112.6 ± 125.7	0.01	-
ODDCM	C				3.8 ± 1.0	1.00	-
(891205)	11%				7.8 ± 2.1	0.52	-
	33%				14.3 ± 6.8	0.10	-
	100%				24.4 ± 22.2	0.01	-
CNMEOH	C	4.3 ± 0.9	1.00	-	3.5 ± 0.9	1.00	-
	100%	5.0 ± 1.0	1.00	-	4.2 ± 1.0	1.04	-
CNDCM	C	4.3 ± 0.9	1.00	-	3.5 ± 0.9	1.00	-
(891128)	100%	4.2 ± 0.8	1.00	-	18.2 ± 17.4	0.01	-
CNDCM	C				3.8 ± 1.0	1.00	-
(891205)	11%				4.0 ± 1.1	0.87	-
	33%				9.3 ± 3.7	0.21	-
	100%				27.5 ± 24.5	0.01	-
SB-900225							
ODMEOH	C	11.6 ± 1.6	1.00	-	11.4 ± 1.5	1.00	-
	11%	10.3 ± 1.6	0.89	-	10.5 ± 1.4	1.09	-
	33%	10.7 ± 1.8	0.85	-	11.2 ± 1.5	1.04	-
	100%	11.5 ± 1.8	0.77	-	12.4 ± 1.6	1.01	-
ODDCM	C	11.6 ± 1.6	1.00	-	11.4 ± 1.5	1.00	-
(900405)	11%	10.7 ± 1.6	0.94	-	11.7 ± 1.7	0.86	-
	33%	8.0 ± 1.3	1.06	-	39.4 ± 7.2	0.23	?
	100%	8.1 ± 1.3	1.01	-	27.4 ± 6.3	0.19	?
ODDCM	C				8.4 ± 1.7	1.00	-
(900515)	11%				9.8 ± 2.2	0.74	-
	33%				29.3 ± 7.3	0.27	?
	100%				143.2 ± 42.0	0.09	?
CNMEOH	C	14.6 ± 1.7	1.00	-	8.2 ± 1.1	1.00	-
	11%	14.9 ± 1.8	1.00	-	8.8 ± 1.2	0.97	-
	33%	14.6 ± 1.8	0.98	-	8.4 ± 1.1	0.96	-
	100%	15.6 ± 1.9	0.94	-	9.0 ± 1.2	0.95	-
CNDCM	C	4.9 ± 1.0	1.00	-	8.2 ± 1.1	1.00	-
	11%	5.8 ± 1.1	1.01	-	9.2 ± 1.2	0.99	-
	33%	6.2 ± 1.1	1.03	-	8.8 ± 1.2	0.96	-

Table 3.4 Continued

Sample Label		-PMS			+PMS		
		Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
	100%	7.2 ± 1.2	1.03	-	8.8 ± 1.2	0.96	-
PF-0.45 - DCM/MEOH							
	C	11.0 ± 1.8	1.00	-	4.4 ± 1.1	1.00	-
	11%	10.1 ± 1.6	1.10	-	3.9 ± 1.2	0.77	-
	33%	12.6 ± 1.8	1.18	-	6.8 ± 2.3	0.38	-
	100%	13.6 ± 2.1	0.99	-	13.8 ± 8.6	0.06	-
PF-5.0 - DCM/MEOH							
	C	4.9 ± 1.2	1.00	-	9.9 ± 2.5	1.00	-
	11%	5.4 ± 1.2	1.11	-	19.8 ± 6.0	0.39	-
	33%	7.1 ± 1.3	1.14	-	71.3 ± 48.0	0.03	?
	100%	8.9 ± 1.4	1.11	-	42.4 ± 52.3	0.01	?
EDDW2800-900308[7]							
ODMEOH	C	10.1 ± 1.8	1.00	-	13.4 ± 1.9	1.00	-
	11%	10.3 ± 1.9	0.96	-	13.1 ± 1.9	0.99	-
	33%	10.2 ± 1.9	0.90	-	14.5 ± 2.0	0.96	-
	100%	15.9 ± 2.8	0.76	-	14.8 ± 2.0	1.04	-
ODDCM	C	10.1 ± 1.8	1.00	-	13.4 ± 1.9	1.00	-
(900426)	11%	7.6 ± 1.5	1.13	-	23.1 ± 3.8	0.49	?
	33%	10.0 ± 1.8	0.98	-	36.3 ± 9.4	0.15	?
	100%	8.4 ± 1.6	1.05	-	182.0 ± 79.4	0.02	?
ODDCM	C				6.5 ± 1.7	1.00	-
(900516)	11%				10.6 ± 3.2	0.50	-
	33%				19.7 ± 5.8	0.33	-
	100%				66.0 ± 25.6	0.09	?
ODDCM	C				10.6 ± 1.8	1.00	-
(900523)	11%				11.8 ± 2.2	0.73	-
	33%				11.7 ± 2.2	0.77	-
	100%				206.1 ± 66.4	0.06	?
CNMEOH	C	6.2 ± 1.2	1.00	-	10.8 ± 1.5	1.00	-
	11%	6.4 ± 1.1	1.12	-	9.6 ± 1.4	0.97	-
	33%	5.8 ± 1.0	1.22	-	11.4 ± 1.6	0.90	-
	100%	6.0 ± 1.0	1.28	-	8.8 ± 1.3	1.00	-
CNDCM	C	6.2 ± 1.2	1.00	-	10.8 ± 1.5	1.00	-
(900419)	11%	5.8 ± 1.1	1.06	-	46.8 ± 8.0	0.24	?
	33%	5.7 ± 1.0	1.13	-	151.4 ± 37.6	0.07	?
	100%	5.5 ± 1.0	1.25	-	342.7 ± 123.7	0.03	?
CNDCM	C				6.5 ± 1.7	1.00	-
(900516)	11%				38.0 ± 11.7	0.20	?
	33%				63.4 ± 26.5	0.08	?
	100%				90.6 ± 44.3	0.05	?

Table 3.4 Continued

		-PMS			+PMS		
Sample Label		Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance	Mutant Fraction (mean ± s.d.)	Relative Survival	Statistical Significance
CNDCM	C				10.6 ± 1.8	1.00	-
(900523)	11%				62.0 ± 11.7	0.26	?
	33%				227.6 ± 64.2	0.07	?
	100%				317.1 ± 112.1	0.04	?
PF-0.45 - DCM/MEOH							
	C	12.3 ± 1.5	1.00	-	9.9 ± 1.9	1.00	-
	11%	11.9 ± 1.5	1.01	-	22.2 ± 4.4	0.48	?
	33%	13.1 ± 1.6	1.02	-	113.2 ± 26.3	0.15	?
	100%	17.7 ± 2.3	0.74	?	148.6 ± 45.7	0.08	?
PF-5.0 - DCM/MEOH							
	C	12.3 ± 1.5	1.00	-	9.9 ± 1.9	1.00	-
	11%	13.0 ± 1.6	0.97	-	29.6 ± 5.5	0.46	?
	33%	14.7 ± 1.8	0.86	-	115.1 ± 30.7	0.11	?
	100%	14.9 ± 2.0	0.74	-	186.8 ± 56.5	0.08	?

[1] Extracts tested in the absence of postmitochondrial supernatant (PMS).
[2] Extracts tested in the presence of postmitochondrial supernatant (PMS).
[3] Mutant fraction = 8-AG resistant fraction (x 10^5).
[4] Survival is measured relative to the negative control.
[5] A result is positive if the mutant fraction is larger than the background (C) with greater than 99% confidence, and it exceeds the 95% historical confidence limit (~14).
6 SB = System blank.
7 EDD = East Drainage Ditch.

suvival) in the presence of PMS. The majority of the water samples in which toxicity was measured (7 of 8 - excluding system blanks) were surface water samples. High toxicity was found in only one sediment pore water sample and in none of the ground water samples. Of the toxic surface water samples, five were from the Aberjona River and two were from the East Drainage Ditch. The toxic sediment pore water sample was also from the Aberjona River. Including the 60 L sample from the East Drainage Ditch, toxicity was observed in 12 eluate fractions. Of these, 11 required metabolic activation (PMS) for toxicity to be exhibited. Toxicity was observed in both OD and CN extracts, but only in fractions in which DCM or a DCM/MEOH solution was used as the eluting solvent. These results suggest that nonpolar or relatively nonpolar precursors of toxic agents are present in the East Drainage Ditch, and are both present and widely distributed in the Aberjona River.

The fact that extremely high toxicity was observed in the 60 L water sample system blank raises questions about the results from the 60 L East Drainage Ditch sample. Because high toxicity was observed in the ODDCM eluate fraction in the presence of PMS from both system blanks, the toxicity observed in the East Drainage Ditch ODDCM fraction cannot be attributed solely to chemicals present in the water. On the contrary, the results strongly suggest that the toxic substances were artifacts that originated from the ODDCM column (NB: in making this conclusion, it is assumed that the toxic substances did not originate from the reverse osmosis deionized water used for the system blank; also, solvent blanks were found to be both non-toxic and non-mutagenic in the assay). A similar conclusion must also be made from the particle filter extract results: because high toxicity was observed in both the system blank and the water sample 5.0 uM and 0.45 uM extracts (in the presence of PMS), the origin of the toxic substances is still in question.

For the CNDCM eluate fraction, on the other hand, a more definitive conclusion can be drawn. Whereas high toxicity was observed in testing the CNDCM fraction from SB-891001 in the presence of PMS, the CNDCM fraction from SB-900225 tested in the presence of PMS resulted in greater than 90% survival in the assay at all concentrations. This result strongly suggests that the toxicity observed by testing the EDDW2800-900308, CNDCM eluate fraction in the presence of PMS, derived from substances in the water sample and not from artifacts produced by the extraction system. This result is particularly interesting because it confirms the results from testing EDDW2800-880531 (1- L), CNDCM eluate fraction in the presence of PMS, and, hence, supports the conclusion that precursors to toxic substances are present in the East Drainage Ditch.

3.4.2 Mutagenicity

By definition, a sample is considered mutagenic in the *S. typhimurium* forward mutation assay if the 8-AG resistant fraction both exceeds the spontaneous mutant fraction with 99% confidence and is greater than the 95% historical upper confidence limit for the assay (~ 14×10^{-5}). Exceptions to this rule include samples that are weakly mutagenic (i.e. samples which exhibit mutant fractions that only marginally exceed the historical upper confidence limit for the assay), and samples which exhibit both high mutant fractions and high toxicity. Samples which are weakly mutagenic are generally retested to verify the initial result. If the retest result contradicts the initial result, a third test is performed. For samples that exhibit both high mutant fractions and high toxicity, the interpretation of whether or not the sample is mutagenic can no longer be made solely on the basis of statistical significance. The rationale for this caveat derives from the fact that dead cells cannot mutate, and, therefore, a mutant fraction which is high because the denominator (i.e. the number of treated colonies that survive in the absence of the selective agent) is low cannot necessarily be used to predict the outcome of experiments in which survival has increased. A method commonly used to determine the mutant fraction with increased cell survival is to improve plating efficiency by allowing the treated plates to incubate until the number of cells that were treated in the absence of the selective agent is equivalent to the control (i.e. relative survival = 1.00). This allows for a less biased determination of mutant fraction to be made. After incubation, the mutant fraction is again determined and mutagenicity can be assessed using the statistical significance criteria previously described.

High mutant fractions were observed in nine extracts from four surface water samples and in two extracts from SB-900225. Four of the extracts (ARW1250-871103, ODDCM: ARW23330-891103, ODMEOH and ODDCM; and EDDW2800-900308, PF-0.45(-PMS)) were only weakly mutagenic in the initial test, but because none of the samples has been retested, a conclusion regarding their mutagenic potential cannot yet be made. The other seven fractions (ARW0000-871030, CNDCM; EDDW2800-900308, ODDCM, CNDCM, PF-0.45(+PMS), and PF-5.0; and SB-900225 ODDCM and PF-5.0) exhibited high to extremely high toxicity. Plating efficiency enhancement experiments were not performed for any of these extracts, and, thus, the results of the mutagenicity tests are presently inconclusive.

3.5 Conclusions

Several conclusions can be drawn from the toxicity and "preliminary" mutagenicity results. First, precursors to substances that are toxic to *S. typhimurium* are present in extracts of 1 L water samples from the Aberjona River and the East Drainage Ditch. The majority of the toxic extracts were octadecyl bonded-phase sorbent eluates, thus suggesting that the toxin precursors possessed nonpolar characteristics. Second, none of the 1 L water sample extracts tested in the assay was mutagenic. This suggests that either no mutagens or promutagens were present in the water samples, that mutagens and promutagens were present but at concentrations that could not be detected, or that mutagens and promutagens were present but were insufficiently recovered in the extraction process. Third, when larger sample volumes (i.e. 60 L) were extracted, both and toxic and potentially mutagenic artifacts were formed. Both the ODDCM and the PF-

5.0 extracts from SB-900225 exhibited high mutant fractions and high toxicity when tested in the presence of PMS. This indicates that either more thorough cleaning techniques should be employed or substitute materials should be tested prior to extracting new water samples. The final, and perhaps most interesting conclusion, is that particles filtered from the East Drainage Ditch water sample on the 0.45 uM filter were potentially mutagenic when tested in both the presence and absence of PMS. This is particularly compelling because the PF-0.45 system blank was clearly not mutagenic in both the presence and absence of PMS, thus strongly suggesting that the potentially mutagenic and promutagenic agents derived only from the filtered particles. If substantiated by retests, this result would indicate that suspended particles play a role in transporting biologically active chemicals in surface waters in the watershed.

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4. MEASURING STREAMFLOW AT FOUR GAUGING SITES ON THE ABERJONA WATERSHED

4.1 Introduction

Hazardous chemical wastes have been discharged to the environment at dozens of sites in the Aberjona watershed (1-5). Large quantities of these chemicals have been introduced into aquatic systems, and some chemicals have been transported considerable distances as dissolved and particle-bound constituents in surface water (5-8). In order to determine the extent to which surface waters influence the distribution and transport of hazardous chemicals in the watershed, streamflow measurements have been made at four gauging sites. Recording streamflow gauges have been deployed on the Aberjona River at Route 128 (Streamgauge Site 2) and Montvale Avenue (Streamgauge Site 3), on Fowle Brook under the wooden foot-bridge at Well F (Streamgauge Site 4), and on the outlet of Wedge Pond at the Main Street bridge (Streamgauge Site 1) (Figure 4.1). The gauges record point readings of depth and velocity; flows are determined as the product of the flow area and the average velocity in the cross-section.

In the following sections, streamgauging methods are described, results are presented, and calibration and erroneous measurements are discussed. The immediate goal of the streamflow monitoring is to measure present-day pollutant fluxes, and to help identify areas ("hotspots") in the watershed that contribute pollutants to surface waters. The longterm goal is to generate a data set from which the spatial and temporal variability of the surface hydrology of the watershed can be inferred and from which estimates of historical pollutant fluxes can be made.

4.2 Streamgauging Sites

Streamflow gauging stations were established to measure surface drainage in four major subbasins of the watershed. Criteria used in selecting the gauging sites included proximity of the sites to industrial areas and/or hazardous waste sites, accessibility (i.e. distance from roads, sources of electricity, telephone lines, etc.), and feasibility (i.e. whether the gauges could be properly installed, proximity to flow control structures, likelihood of vandalism, etc.). The gauge sites are spaced with respect to one another so as to provide flow information on a useful spatial scale.

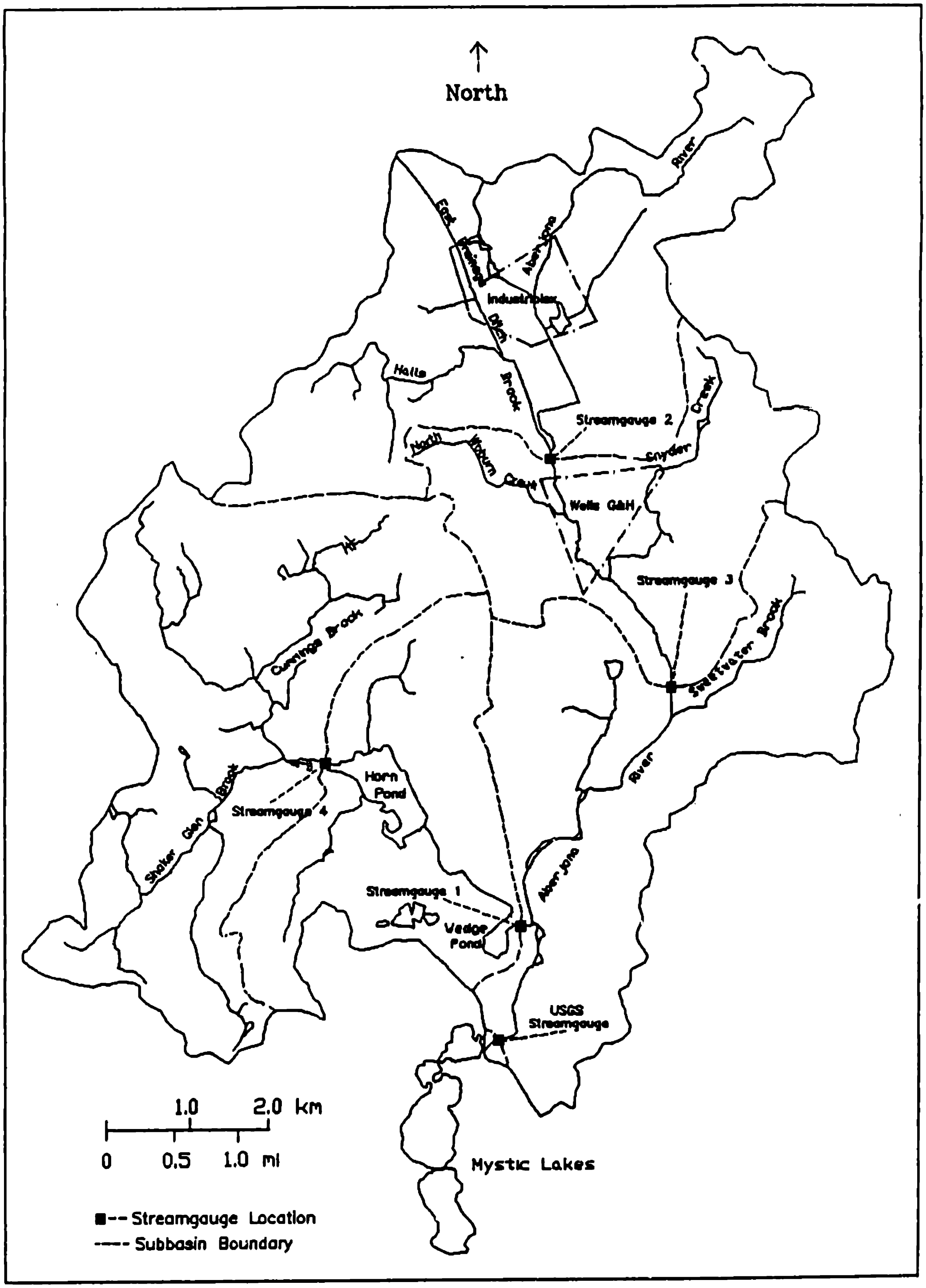

Figure 4.1. Location of Streamgauging Sites in the Aberjona Watershed

4.2.1 Streamgauge Site 1

Streamgauge Site 1, which is located at the Main Street bridge in Winchester center, measures discharge from Wedge Pond. The gauge was first installed in January, 1989, but was removed from May to December, 1989 due to bridge construction. It was redeployed in January, 1990 and has been operating since then - except during periods of routine maintenance and repair. Due to flow controls maintained at Horn Pond (to allow ground water to be withdrawn for municipal supply from wells near the pond), discharge to Horn Pond Brook is moderated during periods of low flow. As a result, inflows to and discharges from Wedge Pond are typically small (the average over the period of record = 8.1 cfs).

The Wedge Pond drainage basin has been extensively developed. It is characterized by a mix of suburban-residential areas and pockets of commercial establishments. Relatively few hazardous waste sites have been identified in the catchment; however, contaminants in storm water runoff and sewer overflows may impact the quality of surface waters.

4.2.2 Streamgauge Site 2

Streamgauge Site 2 is located on the Aberjona River at the Route 128/I95 bridge in north Woburn, immediately downstream of the confluence with Halls Brook. The gauge was deployed in May, 1989 and has remained in operation since then - except during periods of routine maintenance and repair. The drainage basin upstream of the gauge is well developed and is used predominantly for transportation and as a commercial and industrial area. There are several hazardous waste sites in the catchment - including the Industriplex "Superfund" site - which have contributed significant quantities of pollutants to surface water bodies (Figure 4.1).

4.2.3 Streamgauge Site 3

Streamgauge Site 3 is located on the Aberjona River at the Montvale Avenue bridge in east Woburn. The gauge was first installed in May, 1989 and has remained in place since then - except for short periods for routine maintenance and repair, and when the river froze over in December, 1989. The drainage area immediately upstream of the gauging station can be characterized as predominantly suburban-residential neighborhoods mixed with commercial and manufacturing establishments. Wetlands border the river from its confluence with North Woburn Creek approximately one mile south to the terminus of the old cranberry bogs. A potential contributor of surface water pollutants (e.g. volatile and semi-volatile organic compounds, and toxic metals) in the catchment is the Wells G & H "Superfund" site (3), located one and a half miles north of Montvale Avenue (Figure 4.1).

4.2.4 Streamgauge Site 4

Streamgauge Site 4 is located on Fowle Brook, immediately upstream of Horn Pond. The gauge was installed in July, 1989, and has been operating since then - except during periods of routine maintenance and repair, and during a power failure which lasted from January 13 to March 16, 1989. The drainage basin upstream of the gauge can be characterized as being a mix of rural and suburban areas with patches of commercial activity. Parts of the catchment are used for agriculture, and there are several commercial greenhouses operating north of Horn Pond. Much of the land to the west and northwest of Horn Pond is maintained as forest in order to protect the quality of the water in the pond and in the aquifers beneath.

4.2.5 USGS Streamgauge

The United States Geological Survey (USGS) operates a gauging station (Station No. 01102500) on the Aberjona River, approximately one-half mile upstream of Upper Mystic Lake (Figure 4.1). The gauging station consists of a weir, for which a stage - discharge curve has been developed. Water level changes are measured at 15 minute intervals using a float-controlled digital tape recorder. Data is available at the USGS in Boston from 1939 to present.

4.3 Equipment & Methods

The gauges deployed at each of the four sites are Marsh-McBirney Model 265 Open Channel Flow Meters equipped with Coastal Leasing microprocessors. Each gauge consists of a six gallon stainless steel canister which houses hardware, electronics, and the microprocessor (Figure 4.2). A pair of probe lines extending from the bottom of the canister is attached to the sensor assembly, which is anchored to the bottom of the channel. The gauges measure water velocity and depth at the point where the sensor assembly is fixed to the channel bottom (NB: the assembly is positioned such that the

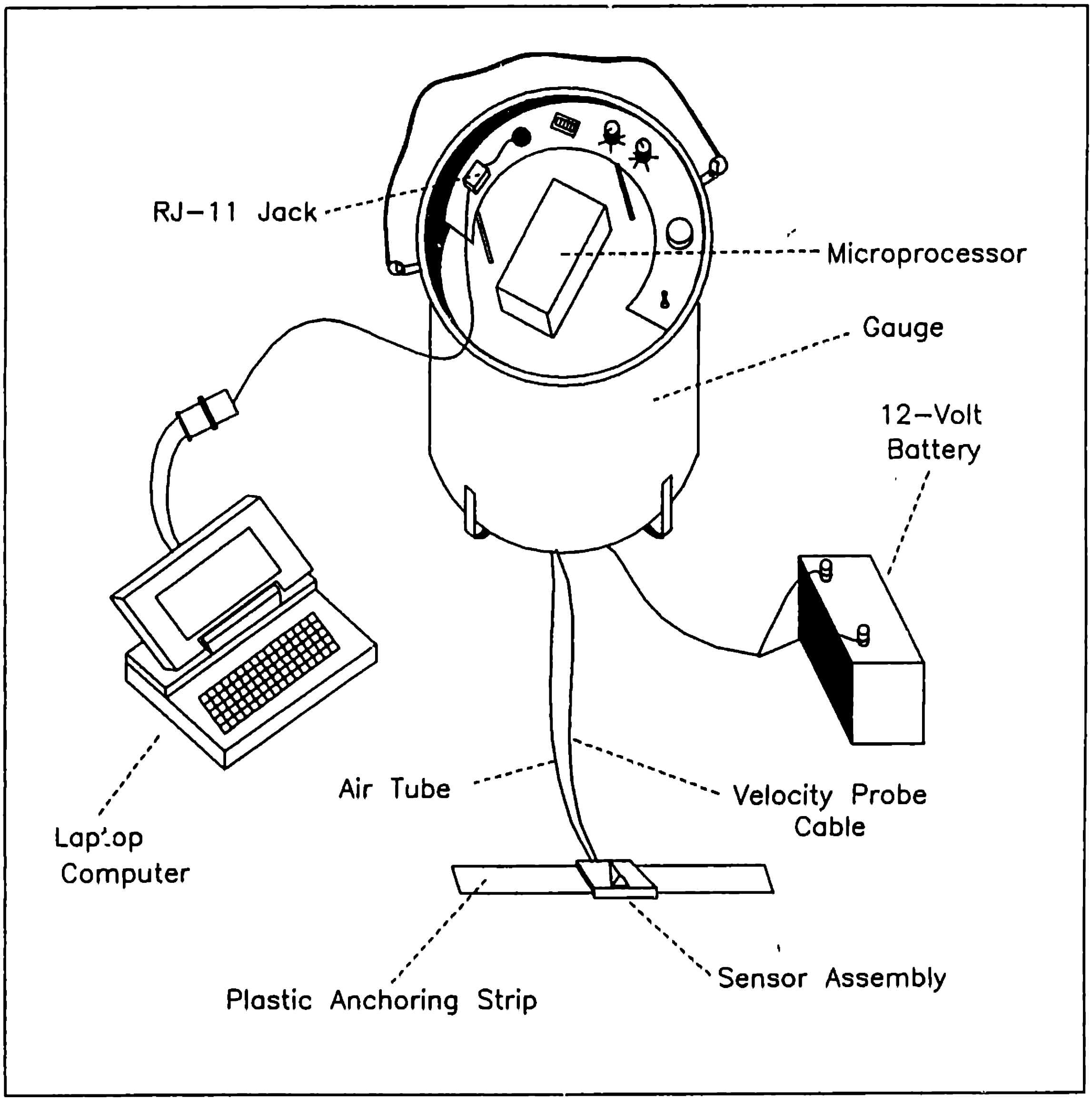

Figure 4.2 Major Components of the Streamgauge and Data-Retrieval System

(from Reference 9)

average velocity in the cross-section is measured). Velocity is measured by an electromagnetic sensor, which produces an electromagnetic field perpendicular to the direction of flow. Dissolved ions moving through the field generate a current, which is detected by electrodes fixed 180 degrees apart on the sides of the sensor. The electronic signal measured by the sensor is then sent to the gauge where it is amplified, demodulated, and filtered. Depth is measured with an air bubbler, which is connected in parallel to a pressure transducer. The depth of water at the free end of the air tube (i.e. at the sensor assembly) is directly proportional to the pressure required to bubble air from the tube. Water depth and velocity measurements are stored in solid-state memory in the microprocessor. The sampling interval and period are user-defined parameters used by the microprocessor to control when and how long the gauge samples. Power is supplied to the gauges by either 12-volt batteries (Streamgauge Sites 2 and 3) or 12-volt DC power-supplies operated from 120-volt AC power (Streamgauge Sites 1 and 4).

Data-retrieval and programming are facilitated by software written by Coastal Leasing. A Toshiba T1000 portable laptop computer is used to operate the software and to store data downloaded from the gauges. Sampling interval and duration have been set so as to maximize sampling accuracy, minimize battery drain, and to generate a data set that is resolved over a useful temporal scale. At Streamgauge Sites 1 and 4, which are powered by 12-volt power-supplies, measurements are made every 15 minutes; at streamgauge sites 2 and 3 the sampling interval is set at 30 minutes to preserve battery life. All measurements are averaged over a five minute sampling period.

The gauges are monitored every week in order to ensure their proper working condition. During monitoring the sensors are cleaned, the batteries are checked, depth measurements made by the gauge are compared in real time to the actual stream depth, and the overall condition of each gauge is assessed. The accuracy of velocity measurements made by the gauges is periodically checked by using a Marsh-McBirney 201 Portable Water Current Meter. The portable current meter is also used to measure velocity profiles and to calculate flows for instrument calibration curves (Section 4.4.2).

Depth and velocity measurements recorded by the gauges are downloaded monthly. Although the microprocessors have sufficient memory capacity to hold up to six months of data, downloading is performed more frequently so as to reduce the size of the data set that would be affected in the event of a gauge malfunction. Once the raw data has been retrieved, flows are calculated using established point velocity discharge measurement (PVDM) approximations. The basis for the PVDM methods and the results are presented in the following section.

4.4 Flow Calculations

4.4.1 Development of Flow Equations

Point velocity discharge measurement (PVDM) methods were developed to provide an inexpensive and accurate alternative to more widely used discharge measurement methods. Traditional techniques such as the use of in-line weirs and flumes are often expensive, cumbersome, and impractical for measuring open channel flow; commonly used slope-area methods frequently yield unreliable results in nonuniform flows. In the PVDM method introduced by Parr et al. (10) and later modified by Marsh-McBirney (11), discharge under both uniform and nonuniform open channel flow conditions can be calculated from measurements of depth and velocity made at a single point in a flow cross-section.

The PVDM method developed by Parr et al. is based on Manning's equation, which describes flow in open channels. Manning's equation is expressed by

$$Q = \frac{1.49}{n} AR^{2/3}S^{1/2} \tag{1}$$

where: Q = discharge in cubic feet per second (cfs)
n = Manning's roughness coefficient
A = cross-sectional area of flow in square feet (ft^2)
R = hydraulic radius in feet (ft) = A/P, where
P = wetted perimeter in feet (ft) and
S = slope of the energy grade line (ft/ft).

Under uniform flow conditions, S, by definition, is equal to the channel slope. Under nonuniform flow conditions, however, S can either be greater than or less than the channel slope, and thus, the slope of the energy grade line must be used in Manning's equation. Because the slope of the energy grade line constantly varies in unsteady, nonuniform flows, changes in S are not typically measured, but are predicted from fluid dynamics principles. Using the Prandtl - von Karman Universal Velocity Distribution Law for turbulent flow in an open channel, an expression for S can be derived:

$$u/u_f = 2.5 \ln y/y_o \tag{2}$$

where: u = point velocity at position y (ft/s)

u_f = friction velocity or shear velocity and
y_o = integration factor.

The Prandtl - von Karman Universal Velocity Distribution Law states that the point velocity of flow is a logarithmic function of the distance from the channel wall, y. Since shear velocity can be expressed by

$$u_f = (gRS)^{1/2} \tag{3}$$

substituting equation (3) into (2) and rearranging yields:

$$S^{1/2} = \frac{u}{(gR)^{1/2}(2.5 \ln y/y_o)} \tag{4}$$

The integration constant is dependent on the roughness of the channel bottom. From data presented by Nikuradse (12), the relationship between y_o and sand roughness, E, was shown to be:

$$y_o = E/m \tag{5}$$

where: m = proportionality constant (approximately = 30).

Henderson (13) has shown that the sand roughness, E, can be determined by using Manning's roughness coefficient, n, in the expression

$$E = (n/0.031)^6 \tag{6}$$

By combining equations (6) and (5) and substituting the resulting expression into equation (4), the energy slope equation becomes:

$$S^{1/2} = \frac{u}{(gR)^{1/2}(2.5 \ln(30y(0.031/n)^6))} \tag{7}$$

Equation (7) can be used to estimate the energy slope of turbulent flow in an infinitely wide, open channel. For flows in pipes, channels and, in particular, natural river and stream beds, where boundary shear can cause flows to be attenuated, the assumption of an infinitely wide, open channel is not valid. To compensate for boundary effects, equation (7) can be rewritten in a more general form, replacing the constant coefficients with the variables K and M:

$$S^{1/2} = \frac{u}{(gR)^{1/2}(K \ln(My(0.031/n)^6))} \tag{8}$$

Values for K and M have been estimated from experimental results and theoretical data. Marsh-McBirney has suggested that values for K and M of 1.3 and 3300, respectively, are appropriate for rectangular channels (11).

4.4.2 Results

Depth and velocity measurements recorded at the streamgauging sites were used in equations (8) and (1) to determine energy slopes and flows. Values for wetted perimeter, P, and cross-sectional area, A, were obtained from wetted perimeter - depth and cross-sectional area - depth curves developed for each of the gauging sites (Figures 4.3 - 4.6)(NB: depths on curves represent invert depths). A literature value of n = 0.027 - corresponding to a natural stream channel with a sandy bottom - was used for the Manning's roughness coefficient (13). The cross-sections at all four sites were modelled as being rectangular in shape (Figures 4.7 - 4.10).

The depth and velocity measurements made at each streamgauging site during the period of record are shown in Tables 4.1 - 4.4. Also shown in the tables are calculated values of energy slope, average velocity, and flow. The data points presented in the tables are daily averages - the raw data can be found on Disk 4.1.

In order to assess the accuracy of the PVDM flow calculations, flow measurements were periodically made with a portable current meter. The current meter was used to generate depth - velocity profiles at evenly spaced intervals across the cross-section; measurements were typically made at 5-6 inch depth increments at stations spaced 3-4 feet apart. The measured flow in the channel was computed as the sum of the flows in the individual control areas. Plots of flows calculated from the PVDM method versus flows measured in the field are shown for each gauging site in Figure 4.11.

4.5 Discussion

4.5.1 Calibration

Although only three calibration points comparing calculated to measured flows were generated at each station, a preliminary conclusion is that the PVDM method more

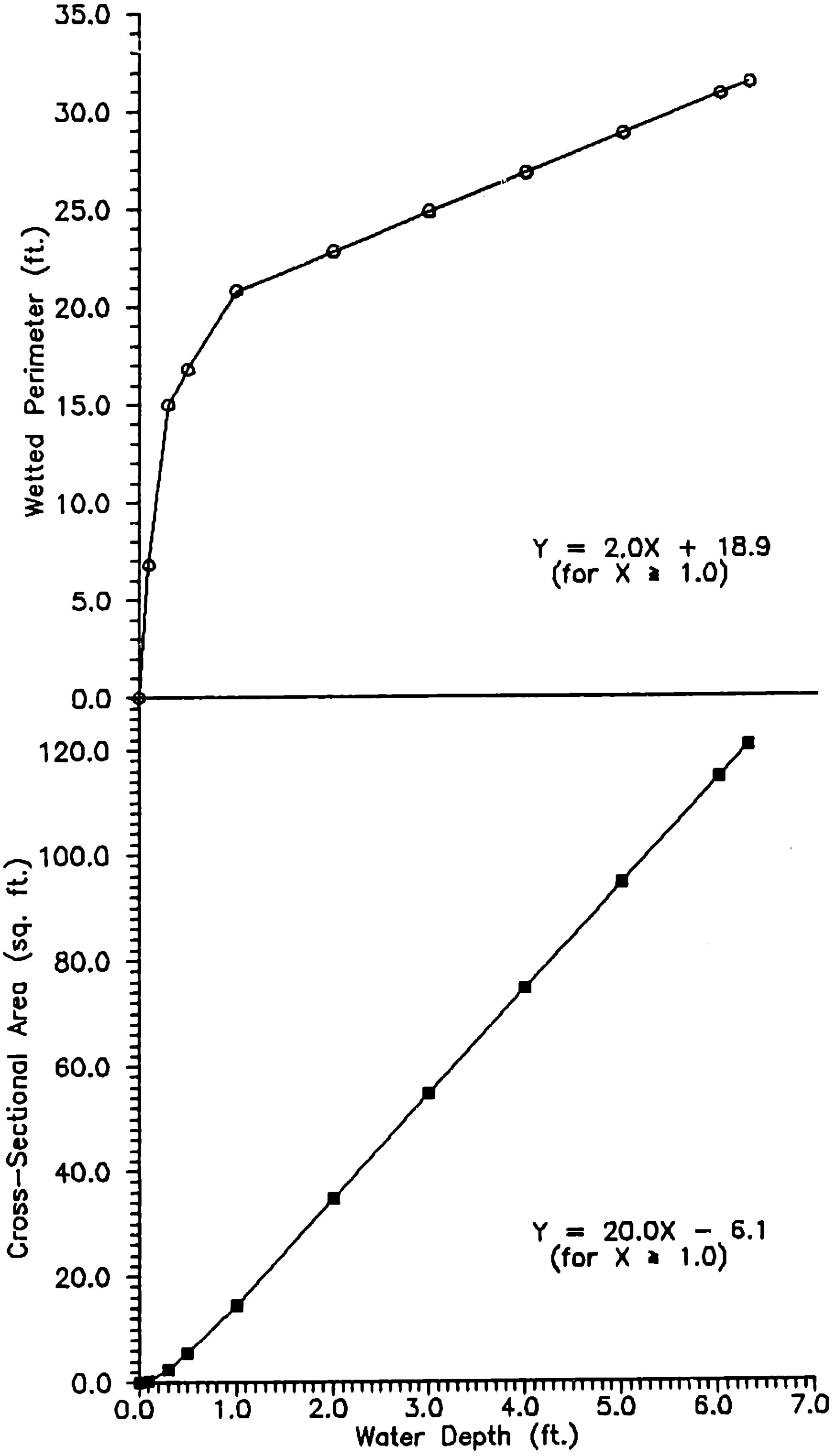

Figure 4.3. Wetted Perimeter - Depth and Area - Depth Curves for Wedge Pond Outlet at Streamgauge Site 1

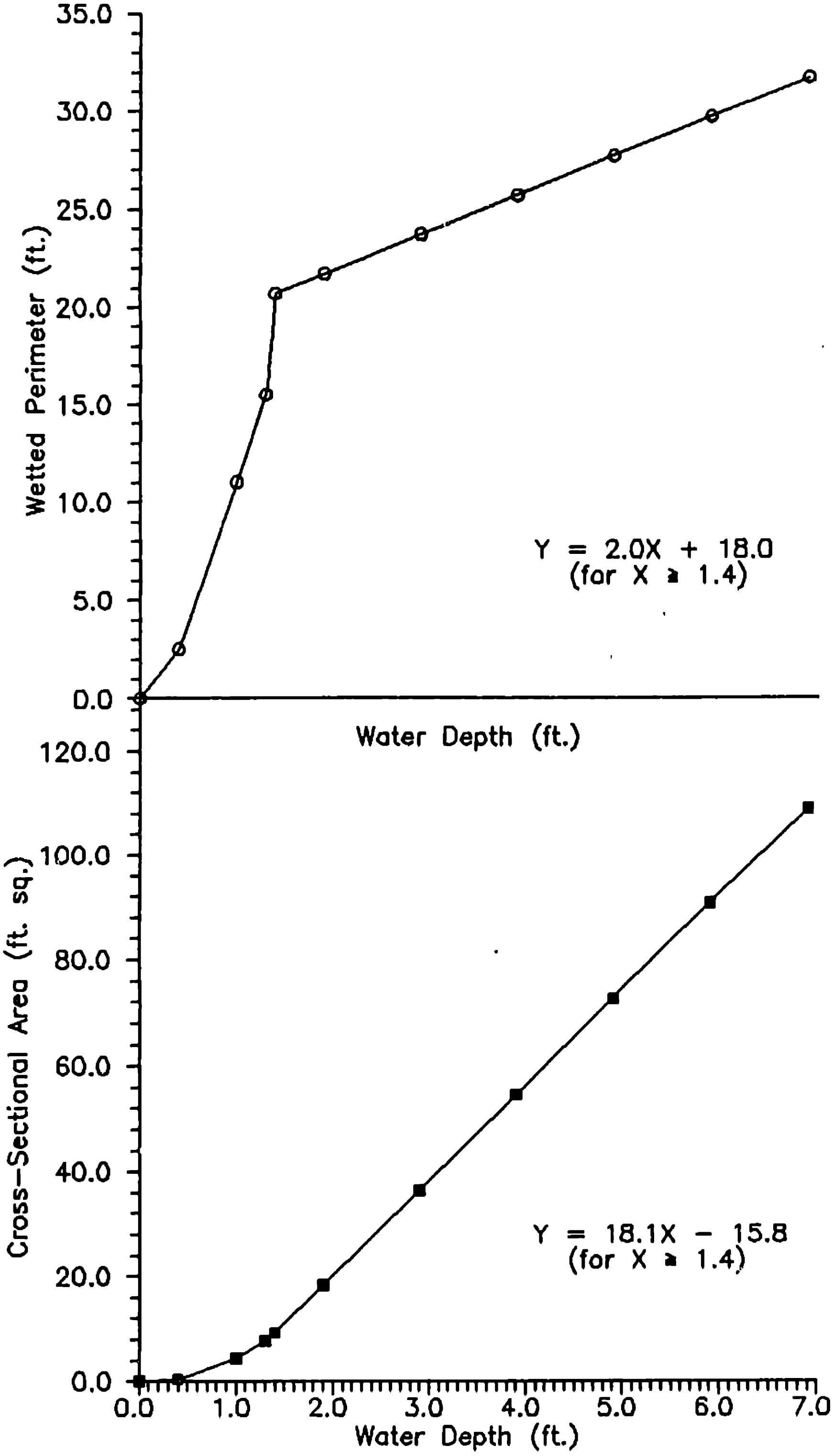

Figure 4.4. Wetted Perimeter - Depth and Area - Depth Curves for the Aberjona River at Streamgauge Site 2

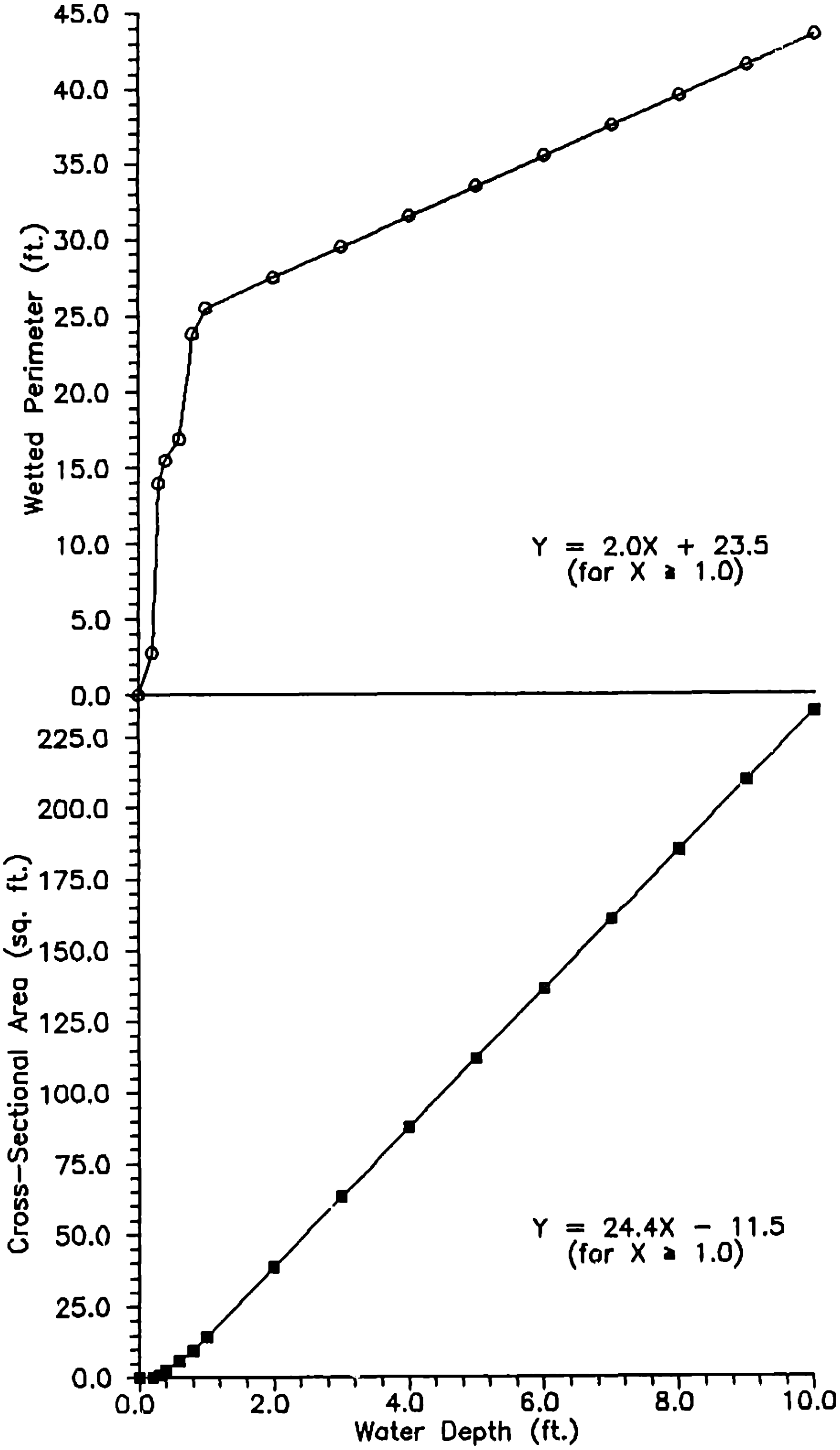

Figure 4.5. Wetted Perimeter - Depth and Area - Depth Curves for the Aberjona River at Streamgauge Site 3

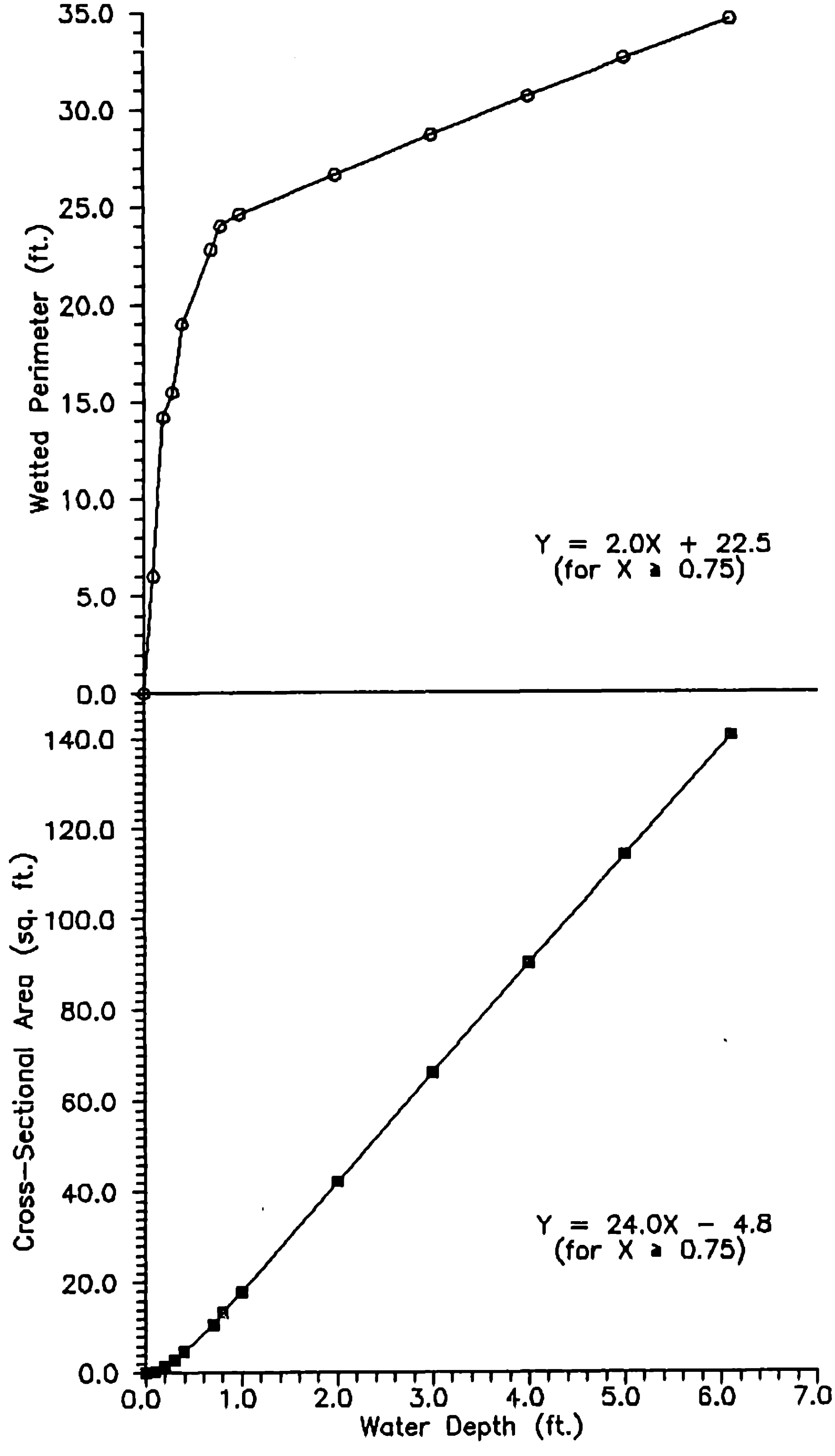

Figure 4.6. Wetted Perimeter - Depth and Area - Depth Curves for Fowle Brook at Streamgauge Site 4

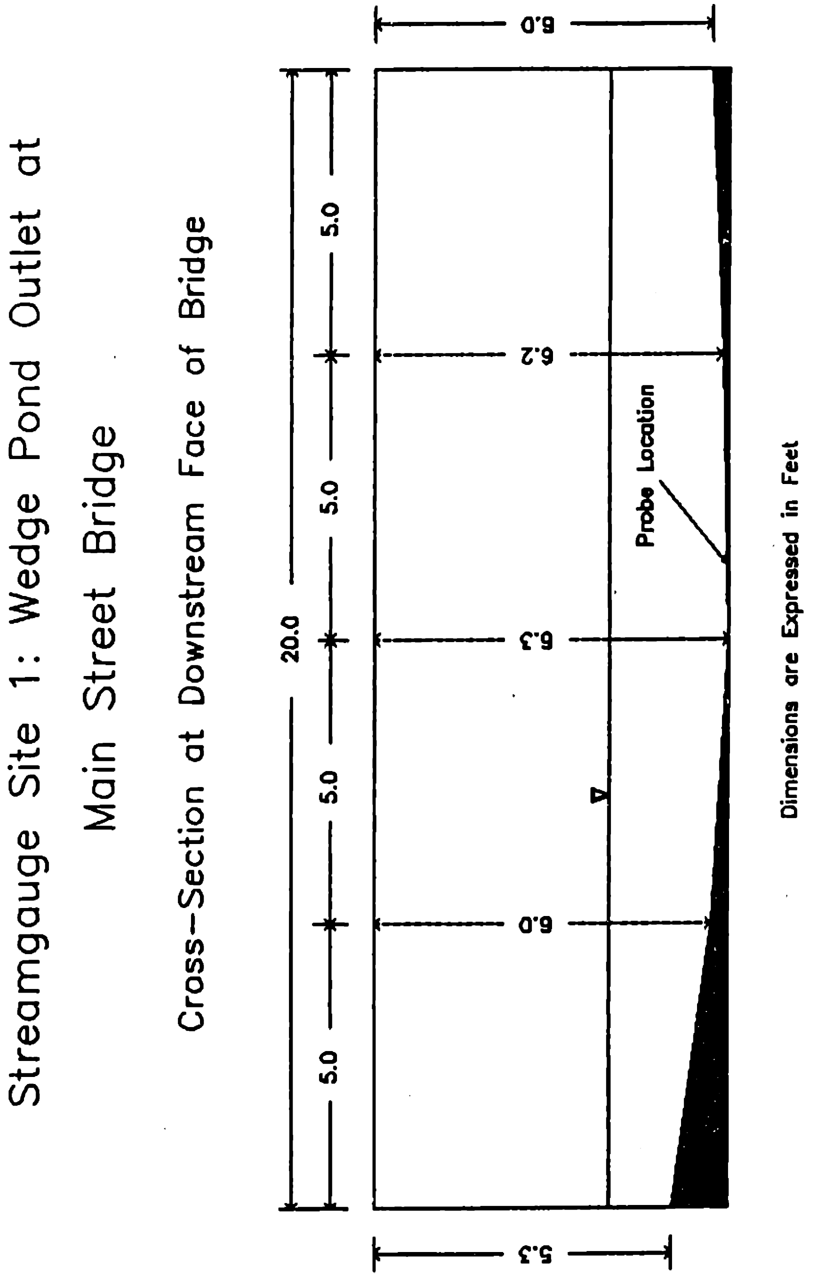

Figure 4.7. Cross-Section of Wedge Pond Outlet at the Downstream Face of the Main Street Bridge at Streamgauge Site 1.

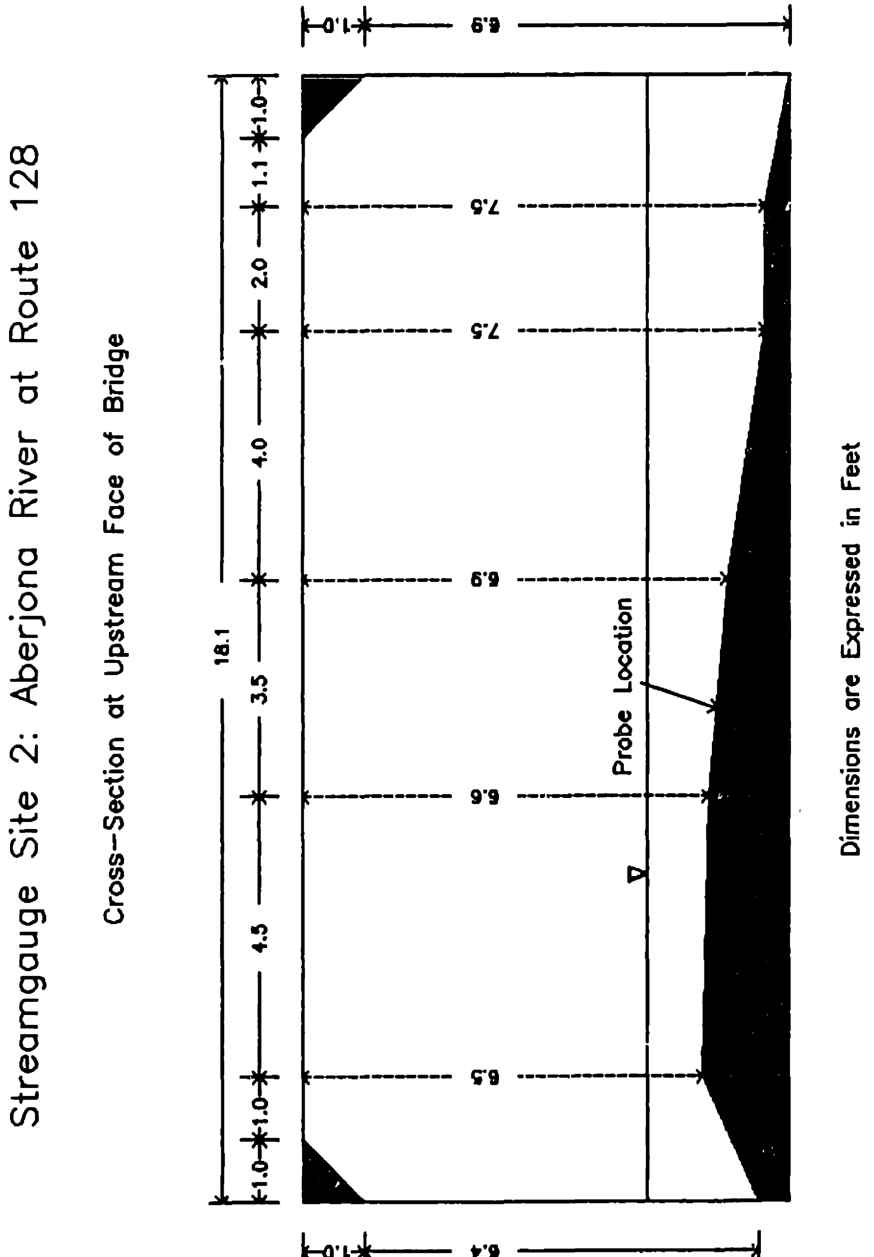

Figure 4.8. Cross-Section of the Aberjona River at the Upstream Face of the Route 128 Bridge at Streamgauge Site 2.

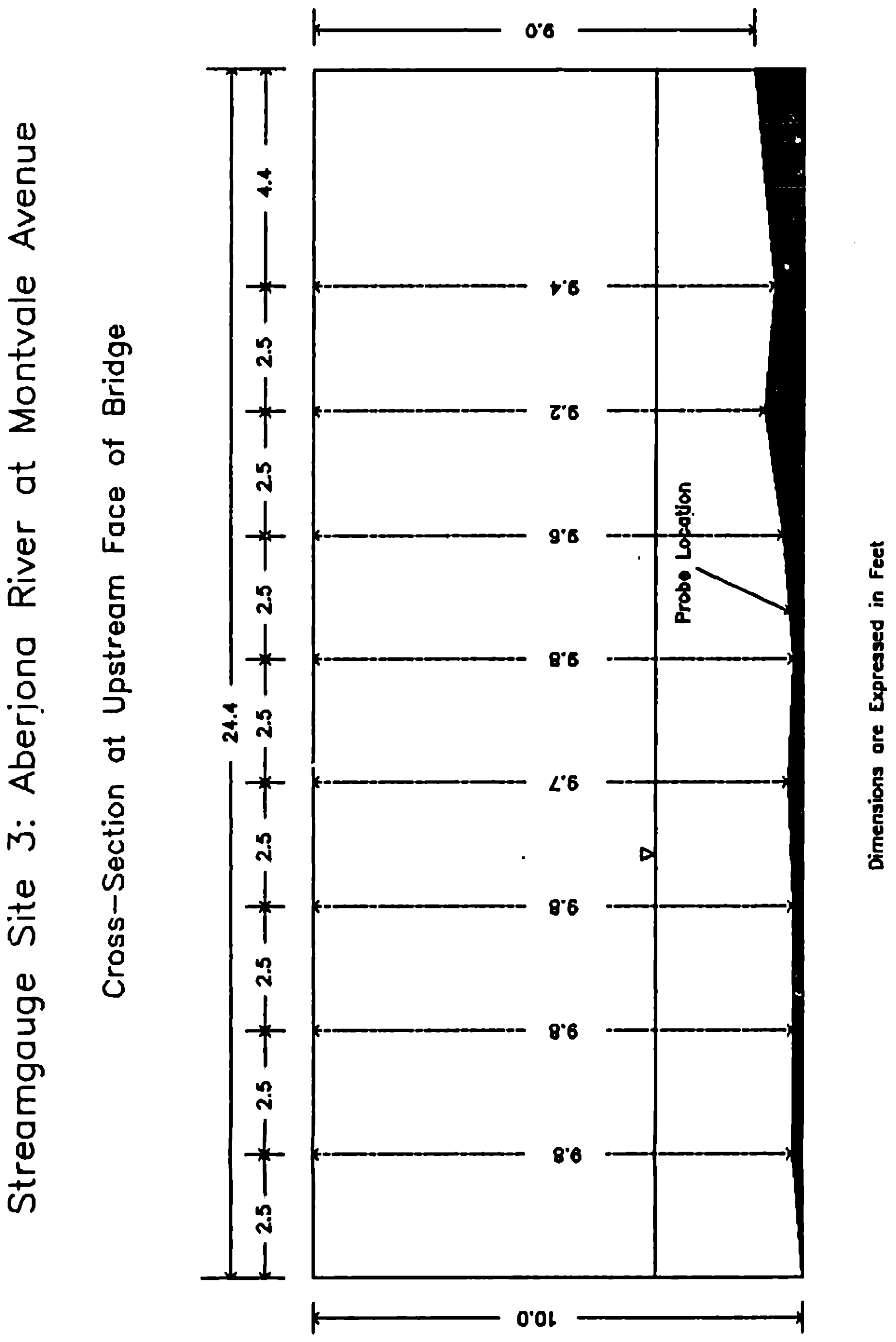

Figure 4.9. Cross-Section of the Aberjona River at the Upstream Face of the Montvale Avenue Bridge at Streamgauge Site 3.

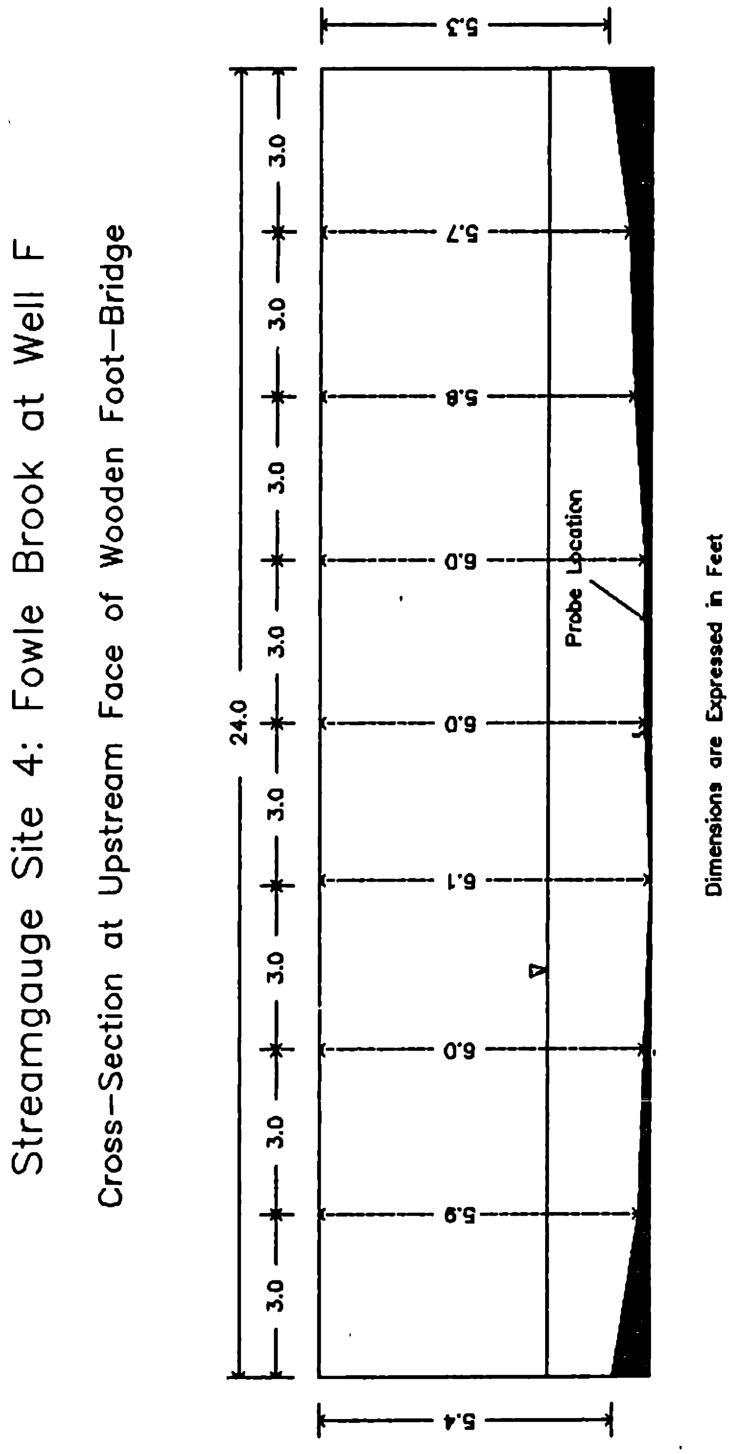

Figure 4.10. Cross-Section of Fowle Brook at the Upstream Face of the Wooden Footbridge at Streamgauge Site 4.

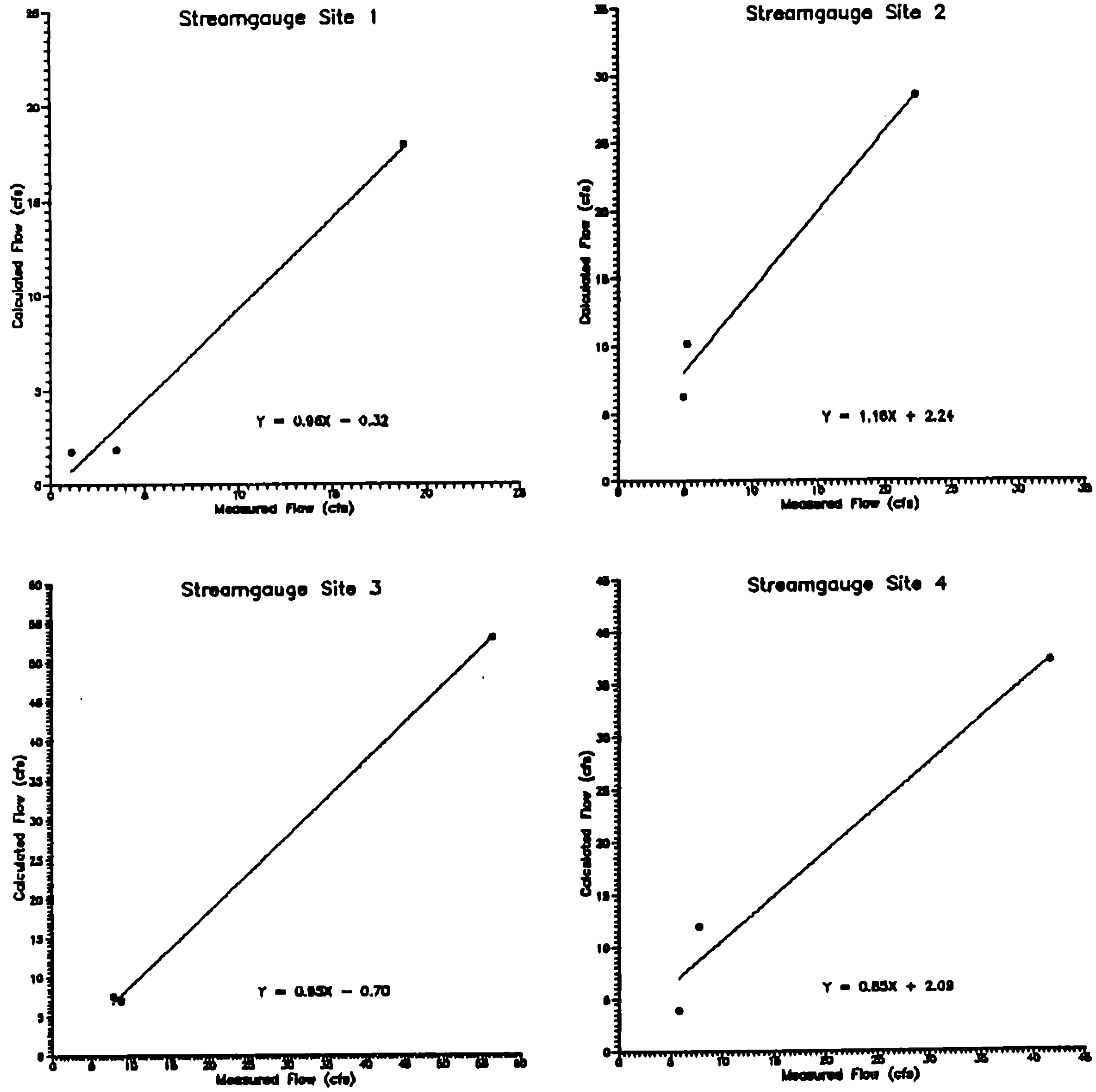

Figure 4.11. Plots of Calculated Versus Measured Flow for Streamgauging Sites in the Aberjona Watershed.

accurately predicts flows when discharges are high. Whereas the average of the ratio of calculated flows to measured flows under high flow conditions (i.e. > 15 cfs) at all four gauging sites was 1.1 ± 0.14, the same ratio for low flow conditions was 1.2 ± 0.52. One possible explanation for this result is suggested from the field observation that the temporal distribution of velocity fluctuations is higher with respect to the mean in low flows than in high flows. Consequently, under low flow conditions, it is more difficult to accurately determine the average velocity in the cross-section. Velocity profiles measured in the water column directly above the probe assembly and calculated average velocities are compared in both low and high flows for each gauging site in Figures 4.12 - 4.15. Another explanation could be that as the depth of water in the channel decreases, the flow cross-section becomes less rectangular, thus altering the spatial distribution of velocities throughout the cross-section. As a result, the location at which the average velocity occurs in the cross-section in high flows is likely to be different in low flows.. A third explanation derives from the fact that the effect of boundary resistance increases as flow decreases, thereby implying that the effective cross-sectional flow area should be smaller under low flow conditions than in higher flows. This line of reasoning is confirmed by field observation. In late summer and winter, for instance, when flows are typically at their lowest, stagnant water has been observed near the bridge abutments and as far into the channel as 8-12 inches. These observations and the results of the calibration calculations suggest that flow estimation techniques that rely on a single velocity measurement are likely to be poor predictors of low flows .

4.5.2 Measurement Error and Gauge Malfunction

The data gaps in Tables 4.1 - 4.4 are the result of either erroneous measurements made by the gauge (EMR), or gauge malfunction (NMR) (total missing data ≈ 30%). Erroneous measurements - measurements made by the gauges that are interpreted to be unrealistic - are typically induced by high flow conditions, ice formation, and sensor impairment. During gauge malfunctions, no measurements are recorded. Gauge malfunctions usually result from loss of power or from very high flow conditions.

High flow conditions are the cause of the majority of erroneous measurements and gauge malfunctions. During storms, floating debris such as sticks, branches, grass, and uprooted plants, and the flowing water itself apply considerable pressure on the sensor assembly and the sensor cables. When the pressure is high enough, the sensor assembly becomes detached from its mooring. Also, under very high flow conditions (such as

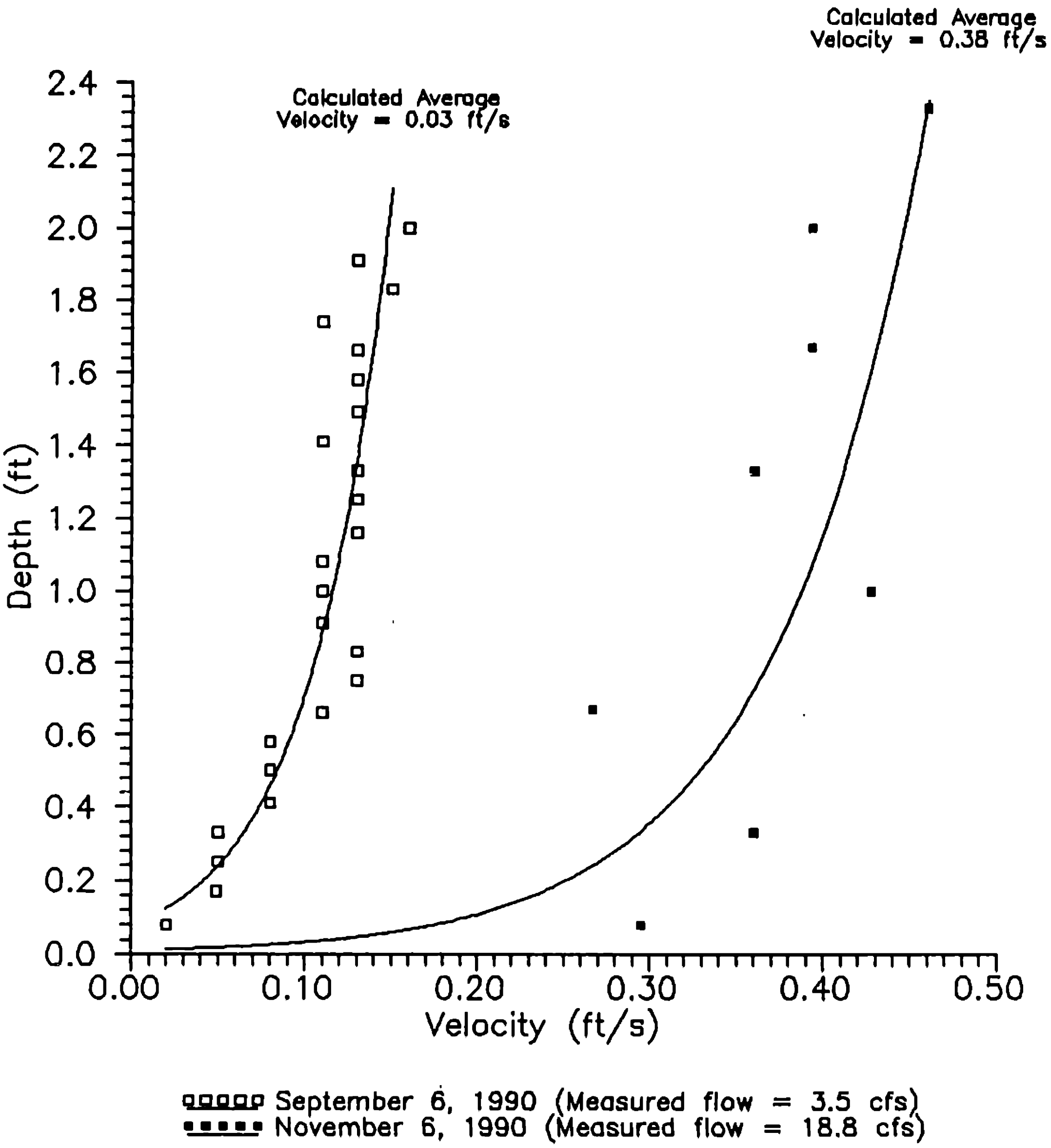

Figure 4.12 Depth - Velocity Profiles for Wedge Pond Outlet at Streamgauge Site 1

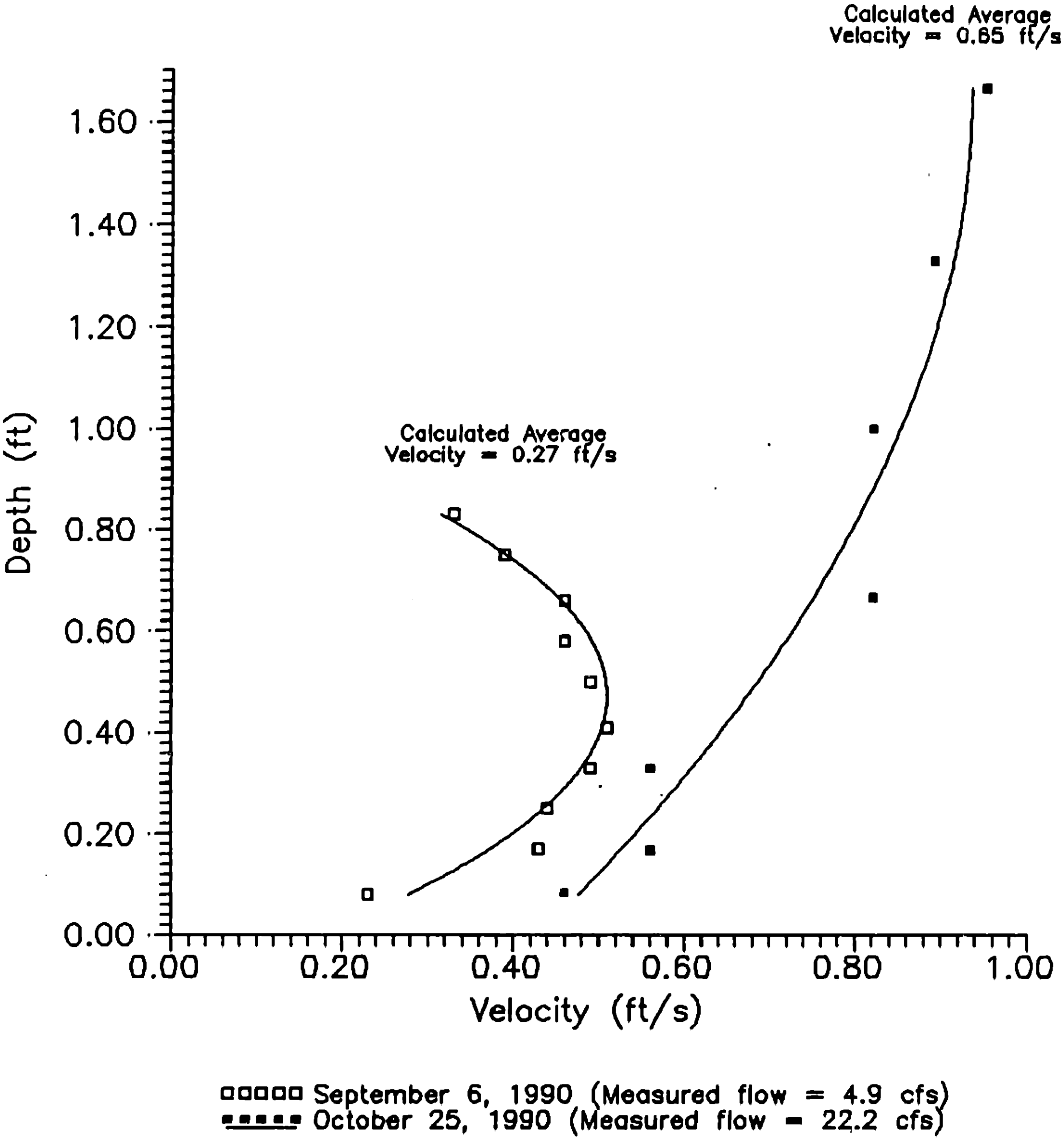

Figure 4.13 Depth - Velocity Profiles for the Aberjona River at Streamgauge Site 2

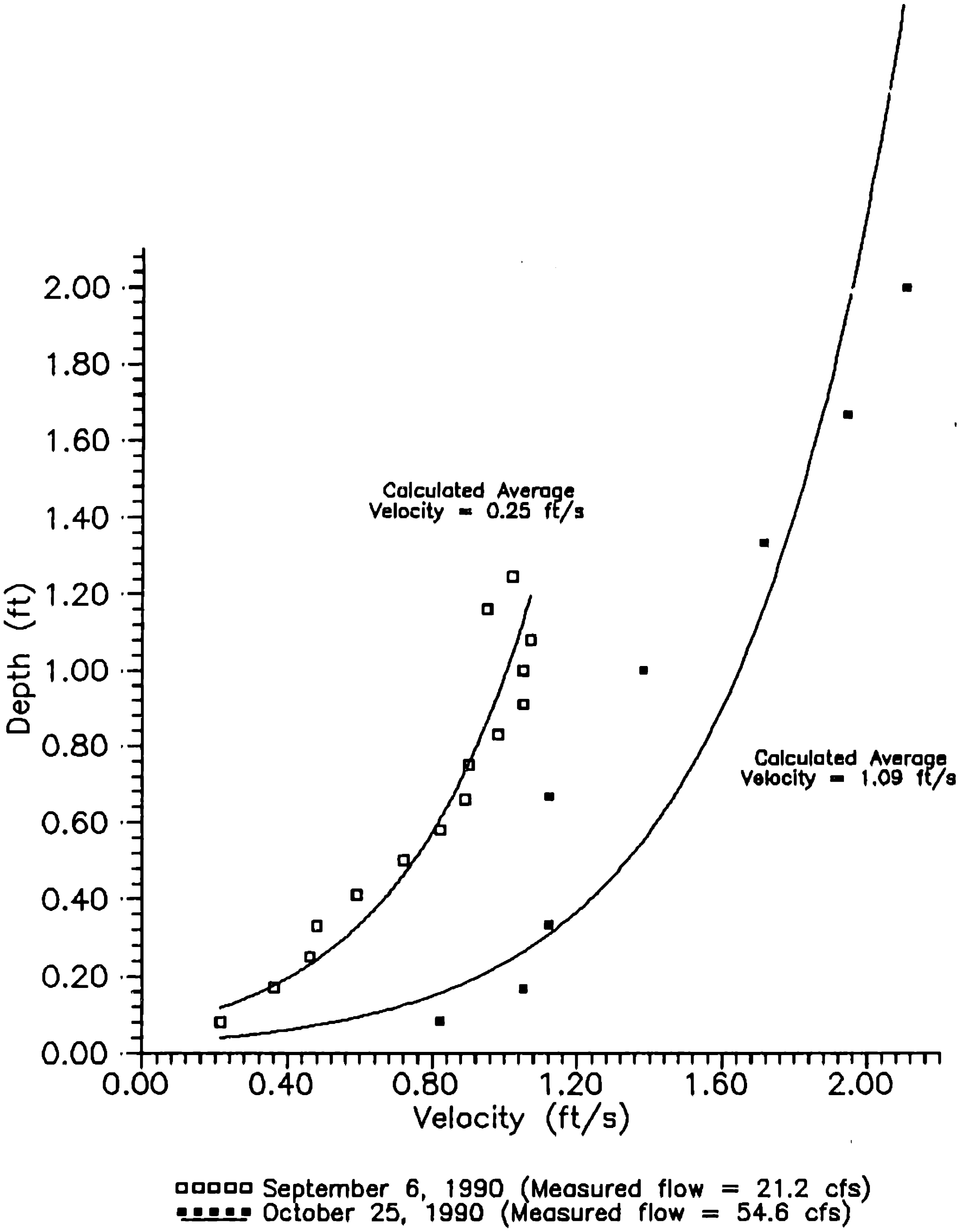

Figure 4.14 Depth - Velocity Profiles for the Aberjona River at Streamgauge Site 3

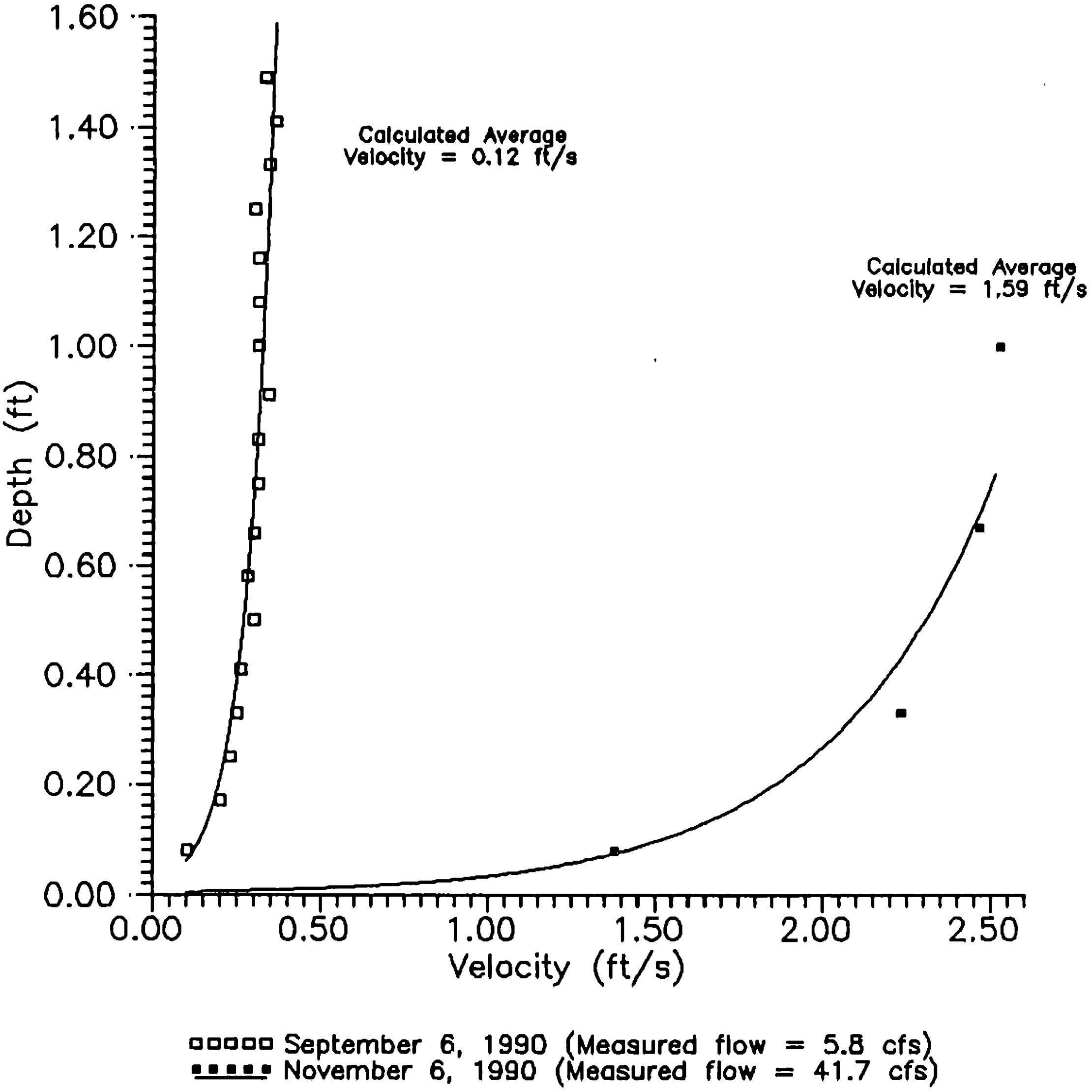

Figure 4.15 Depth - Velocity Profiles for Fowle Brook at Streamgauge Site 4

occurred in August and October, 1990) the gauges at Streamgauge Sites 1, 2, and 3 are prone to become partially submerged. When this occurs, water is sucked in through the air intake and clogs the air tubes. Once the air pump becomes wet, the valves no longer seat properly, air pressure decreases, and, as a result, bubbling stops.

Another common, seasonal variable which influences the accuracy of the streamflow measurements is the formation of ice. Ice tends to pinch the air tube, thus causing the air pressure in the tube to increase considerably. A second problem caused by ice occurs when large ice sheets that break free during warm weather are borne downstream. Sensor cables imbedded in or situated in the way of moving ice can be pulled by the ice, thus causing the sensor assembly to lose its mooring and risk being stretched and damaged (which is what happened at Streamgauge Site 3 in December, 1989).

The accumulation of particles settling from the water column and the shifting of bottom sediments on top of the sensor assembly are the chief causes of sensor impairment. As the electrodes on the velocity probe become buried, their capacity to detect the electric current generated by dissolved ions moving through the magnetic field is diminished, and as the end of the air tube fills with sediments and sand, the air pressure in the tube increases.

Many malfunctions have been caused by either a decrease or a complete loss of power to gauges. At Streamgauge Sites 2 and 3, where power is supplied by 12-volt marine deep cycle batteries, malfunctions have occurred when batteries have become discharged. As a battery loses its charge, the gauge cycles on for shorter measurement intervals thus reducing the sampling time over which each measurement is averaged. The gauges will cease to operate if the voltage in the battery drops below 10.8 volts. At Streamgauge Sites 1 and 4, where power is supplied from 12-volt DC power-supplies, disconnections have occurred several times. Vandalism, trees falling on power lines, and electricians have all been culprits. An additional cause of gauge malfunction at Streamgauge Sites 1 and 4 is power surges. A power surge causes the microprocessor to electrically seize, thus incapacitating it. The only way to treat a seized microprocessor is to disconnect its internal battery, which causes all the data stored in memory to be lost. Power surges caused gauge malfunctions at Streamgauge Site 4 in April, 1990 and at Streamgauge Site 1 in October, 1990.

4.5.3 Recommendations

In order to ensure the proper working condition of the streamgauges, the following recommendations are made. First, monitoring should be done at least once a week and especially after large storms or when ice formation is suspected. Monitoring activities should include making sure the sensor assembly is properly anchored and free of obstructions such as leaves, branches, sediments, etc., checking the battery or power-supply voltage, and using the "Monitor" utility in the Coastal Leasing software. The "Monitor" utility is used to check real time instrument measurements of depth and velocity. The record of measurements made since data was last downloaded can also be assessed using the "Monitor" routine.

Second, it is recommended that the batteries at Streamgauge Sites 2 and 3 be changed every three to four weeks. Recharging should be done with a 10 amp battery charger, and the specific gravity of the electrolyte should be checked with a hydrometer after recharging. This recharging schedule is prescribed to preserve battery life when five minute samples are made at 30 minute sampling intervals. The batteries may require more frequent replacement in cold weather.

Finally, it is recommended that the data stored in the gauge microprocessors be downloaded at least once a month. Although the microprocessors can hold considerably more data, this downloading period is suggested so as to minimize the size of the data set that would be lost due to gauge malfunction. In addition to frequently downloading the data, it is further recommended that new data be examined in a timely manner so as to detect erroneous measurements and to quickly diagnose measurement problems.

Recommendations for improvements to the existing streamgauging sites include raising the gauges at least 12 inches and securing the sensor cables in PVC pipe anchored to the channel bottom at all four gauging sites, and installing surge protectors at Sites 1 and 4. Raising the gauges by a foot would provide a greater margin of clearance between the gauges and rising storm waters; burying the cables or placing them in PVC pipe which is anchored to the streambed would significantly reduce the likelihood of the sensor assembly being dislodged during high flows; and placing surge protectors between the AC power source and the stepdown transformers at Streamgauge Sites 1 and 4 would be an inexpensive and effective means of preventing power surges.

4.6 References

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Table 4.1

Daily Average Flow Measurements at the Outlet of Wedge Pond, Winchester, Massachusetts

Streamgauge Site 1

January, 1989 - May, 1989
January, 1990 - October, 1990

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): January, 1989

Day	Probe Depth (ft)	Invert Depth (ft) [1]	Wetted Perimeter (ft)	Flow Area (sq ft)	R (ft) [2]	Bottom Velocity (ft/s)	Energy Slope (ft/ft) [3]	Average Velocity (ft/s) [4]	Flow (cfs) [5]
(Streamgauge deployed 1/13/90)									
13	1.52	1.62	22.14	26.30	1.19	0.028	2.92E-07	0.033	0.88
14	1.47	1.57	22.04	25.30	1.15	0.026	2.60E-07	0.031	0.78
15	1.55	1.65	22.20	26.90	1.21	0.009	2.96E-08	0.011	0.29
16	1.52	1.62	22.14	26.30	1.19	0.014	7.30E-08	0.017	0.44
17	1.42	1.52	21.94	24.30	1.11	0.024	2.30E-07	0.028	0.69
18	1.33	1.43	21.76	22.50	1.03	0.017	1.24E-07	0.020	0.45
19	1.53	1.63	22.16	26.50	1.20	0.003	3.33E-09	0.004	0.10
20	1.56	1.66	22.22	27.10	1.22	0.002	1.45E-09	0.002	0.07
21	1.52	1.62	22.14	26.30	1.19	0.002	1.49E-09	0.002	0.06
22	1.56	1.66	22.22	27.10	1.22	0.012	5.22E-08	0.014	0.39
23	1.58	1.68	22.26	27.50	1.24	0.008	2.29E-08	0.010	0.26
24	1.59	1.69	22.28	27.70	1.24	0.000	0.00E+00	0.000	0.00
25	1.59	1.69	22.28	27.70	1.24	0.000	0.00E+00	0.000	0.00
26	1.57	1.67	22.24	27.30	1.23	0.004	5.76E-09	0.005	0.13
27	1.57	1.67	22.24	27.30	1.23	0.001	3.60E-10	0.001	0.03
28	1.57	1.67	22.24	27.30	1.23	0.002	1.44E-09	0.002	0.07
29	1.54	1.64	22.18	26.70	1.20	0.001	3.67E-10	0.001	0.03
30	1.52	1.62	22.14	26.30	1.19	0.002	1.49E-09	0.002	0.06
31	1.00	1.10	21.10	15.90	0.75	0.041	9.87E-07	0.045	0.72

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): February, 1989

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	1.03	1.13	21.16	16.50	0.78	0.0240	3.27E-07	0.027	0.44
2	2.19	2.29	23.48	39.70	1.69	0.0004	4.19E-11	0.001	0.02
3	2.81	2.91	24.72	52.10	2.11	0.0000	0.00E+00	0.000	0.00
4	2.45	2.55	24.00	44.90	1.87	0.0000	0.00E+00	0.000	0.00
5	1.02	1.12	21.14	16.30	0.77	0.0240	3.30E-07	0.034	0.56
6	1.25	1.35	21.60	20.90	0.97	0.0100	4.57E-08	0.014	0.30
7	2.44	2.54	23.98	44.70	1.86	0.0060	8.54E-09	0.009	0.42
8	2.95	3.05	25.00	54.90	2.20	0.0010	2.01E-10	0.002	0.09
9	2.79	2.89	24.68	51.70	2.09	0.0090	1.71E-08	0.015	0.76
10	1.73	1.83	22.56	30.50	1.35	0.0010	3.27E-10	0.001	0.05
11	1.63	1.73	22.36	28.50	1.27	0.0190	1.25E-07	0.028	0.80
12	1.58	1.68	22.26	27.50	1.24	0.0110	4.33E-08	0.016	0.45
13	1.08	1.18	21.26	17.50	0.82	0.0260	3.63E-07	0.037	0.65
14	1.30	1.40	21.70	21.90	1.01	0.0300	3.94E-07	0.043	0.95
15	1.53	1.63	22.16	26.50	1.20	0.0020	1.48E-09	0.003	0.08
16	1.55	1.65	22.20	26.90	1.21	0.0020	1.46E-09	0.003	0.08
17	1.90	2.00	22.90	33.90	1.48	0.1280	4.90E-06	0.194	6.57
18	1.89	1.99	22.88	33.70	1.47	0.0690	1.43E-06	0.104	3.52
19	1.72	1.82	22.54	30.30	1.34	0.0410	5.53E-07	0.061	1.85
20	1.47	1.57	22.04	25.30	1.15	0.0200	1.54E-07	0.029	0.74
21	1.45	1.55	22.00	24.90	1.13	0.0160	1.00E-07	0.023	0.58
22	2.00	2.10	23.10	35.90	1.55	0.0290	2.39E-07	0.044	1.59
23	1.57	1.67	22.24	27.30	1.23	0.0030	3.24E-09	0.004	0.12
24	1.55	1.65	22.20	26.90	1.21	0.0040	5.84E-09	0.006	0.16
25	1.57	1.67	22.24	27.30	1.23	0.0008	2.31E-10	0.001	0.03
26	1.55	1.65	22.20	26.90	1.21	0.0004	5.84E-11	0.001	0.02
27	1.56	1.66	22.22	27.10	1.22	0.0004	5.80E-11	0.001	0.02
28	1.57	1.67	22.24	27.30	1.23	0.0004	5.76E-11	0.001	0.02

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): March, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.57	1.67	22.24	27.30	1.23	0.0004	5.76E-11	0.0005	0.01
2	1.57	1.67	22.24	27.30	1.23	0.0000	0.00E+00	0.0000	0.00
3	1.49	1.59	22.08	25.70	1.16	0.0010	3.80E-10	0.0012	0.03
4	0.95	1.05	21.00	14.90	0.71	0.0160	1.60E-07	0.0175	0.26
5	1.63	1.73	22.36	28.50	1.27	0.0120	5.00E-08	0.0145	0.41
6	1.76	1.86	22.62	31.10	1.37	0.0070	1.58E-08	0.0086	0.27
7	1.55	1.65	22.20	26.90	1.21	0.0030	3.29E-09	0.0036	0.10
8	1.58	1.68	22.26	27.50	1.24	0.0008	2.29E-10	0.0010	0.03
9	1.58	1.68	22.26	27.50	1.24	0.0000	0.00E+00	0.0000	0.00
10	1.55	1.65	22.20	26.90	1.21	0.0000	0.00E+00	0.0000	0.00
11	1.57	1.67	22.24	27.30	1.23	0.0010	3.60E-10	0.0012	0.03
12	1.57	1.67	22.24	27.30	1.23	0.0010	3.60E-10	0.0012	0.03
13	1.57	1.67	22.24	27.30	1.23	0.0010	3.60E-10	0.0012	0.03
14	1.66	1.76	22.42	29.10	1.30	0.0000	0.00E+00	0.0000	0.00
15	1.66	1.76	22.42	29.10	1.30	0.0090	2.76E-08	0.0109	0.32
16	1.65	1.75	22.40	28.90	1.29	0.0020	1.37E-09	0.0024	0.07
17	1.65	1.75	22.40	28.90	1.29	0.0040	5.48E-09	0.0048	0.14
18	1.64	1.74	22.38	28.70	1.28	0.0060	1.24E-08	0.0073	0.21
19	1.65	1.75	22.40	28.90	1.29	0.0180	1.11E-07	0.0218	0.63
20	1.63	1.73	22.36	28.50	1.27	0.0020	1.39E-09	0.0024	0.07
21	1.72	1.82	22.54	30.30	1.34	0.0240	1.90E-07	0.0293	0.89
22	1.68	1.78	22.46	29.50	1.31	0.0040	5.39E-09	0.0049	0.14
23	1.67	1.77	22.44	29.30	1.31	0.0060	1.22E-08	0.0073	0.21
24	1.67	1.77	22.44	29.30	1.31	0.0120	4.88E-08	0.0146	0.43
25	1.88	1.98	22.86	33.50	1.47	0.0940	2.67E-06	0.1162	3.89
26	1.84	1.94	22.78	32.70	1.44	0.1330	5.45E-06	0.1639	5.36
27	1.81	1.91	22.72	32.10	1.41	0.1410	6.22E-06	0.1733	5.56
28	1.80	1.90	22.70	31.90	1.41	0.1240	4.84E-06	0.1523	4.86
29	1.78	1.88	22.66	31.50	1.39	0.1200	4.58E-06	0.1471	4.63
30	1.90	2.00	22.90	33.90	1.48	0.2120	1.34E-05	0.2626	8.90
31	2.09	2.19	23.28	37.70	1.62	0.5620	8.63E-05	0.7066	26.64

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): April, 1989

Day	Probe Depth (ft)	Invert Depth (ft) [1]	Wetted Perimeter (ft)	Flow Area (sq ft)	R (ft) [2]	Bottom Velocity (ft/s)	Energy Slope (ft/ft) [3]	Average Velocity (ft/s) [4]	Flow (cfs) [5]
1	1.96	2.06	23.02	35.10	1.52	0.47	6.33E-05	0.58	20.40
2	1.87	1.97	22.84	33.30	1.46	0.32	3.15E-05	0.40	13.25
3	1.83	1.93	22.76	32.50	1.43	0.25	1.92E-05	0.31	9.96
4	1.82	1.92	22.74	32.30	1.42	0.23	1.69E-05	0.29	9.26
5	1.78	1.88	22.66	31.50	1.39	0.20	1.32E-05	0.25	7.88
6	2.02	2.12	23.14	36.30	1.57	0.39	4.20E-05	0.48	17.52
7	2.08	2.18	23.26	37.50	1.61	0.53	7.62E-05	0.66	24.83
8	2.13	2.23	23.36	38.50	1.65	0.60	9.66E-05	0.76	29.13
9	2.07	2.17	23.24	37.30	1.60	0.57	8.83E-05	0.71	26.50
10	1.95	2.05	23.00	34.90	1.52	0.43	5.34E-05	0.53	18.58
11	1.89	1.99	22.88	33.70	1.47	0.33	3.25E-05	0.41	13.72
12	1.84	1.94	22.78	32.70	1.44	0.27	2.28E-05	0.34	10.96
13	1.84	1.94	22.78	32.70	1.44	0.22	1.48E-05	0.27	8.83
14	1.81	1.91	22.72	32.10	1.41	0.18	1.05E-05	0.22	7.22
15	1.80	1.90	22.70	31.90	1.41	0.16	8.16E-06	0.20	6.31
16	2.45	2.55	24.00	44.90	1.87	0.60	8.57E-05	0.78	34.81
17	2.46	2.56	24.02	45.10	1.88	0.85	1.69E-04	1.09	49.28
18	2.22	2.32	23.54	40.30	1.71	0.71	1.29E-04	0.90	36.10
19	2.10	2.20	23.30	37.90	1.63	0.55	8.23E-05	0.69	26.23
20	2.03	2.13	23.16	36.50	1.58	0.45	5.58E-05	0.56	20.37
21	1.97	2.07	23.04	35.30	1.53	0.35	3.52E-05	0.43	15.35
22	1.89	1.99	22.88	33.70	1.47	0.30	2.65E-05	0.37	12.39
23	1.84	1.94	22.78	32.70	1.44	0.23	1.64E-05	0.28	9.31
24	1.84	1.94	22.78	32.70	1.44	0.19	1.14E-05	0.24	7.74
25	1.86	1.96	22.82	33.10	1.45	0.17	8.50E-06	0.21	6.82
26	1.79	1.89	22.68	31.70	1.40	0.14	6.47E-06	0.18	5.56
27	1.78	1.88	22.66	31.50	1.39	0.13	5.21E-06	0.16	4.94
28	1.77	1.87	22.64	31.30	1.38	0.11	3.80E-06	0.13	4.18
29	1.76	1.86	22.62	31.10	1.37	0.09	2.49E-06	0.11	3.35
30	1.95	2.05	23.00	34.90	1.52	0.19	1.10E-05	0.24	8.42

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): May, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.88	1.98	22.86	33.50	1.47	0.21	1.37E-05	0.26	8.82
2	2.06	2.16	23.22	37.10	1.60	0.34	3.14E-05	0.42	15.68
3	2.06	2.16	23.22	37.10	1.60	0.39	4.25E-05	0.49	18.24
4	1.94	2.04	22.98	34.70	1.51	0.30	2.57E-05	0.37	12.76
5	1.86	1.96	22.82	33.10	1.45	0.22	1.48E-05	0.27	8.99
6	1.95	2.05	23.00	34.90	1.52	0.25	1.76E-05	0.31	10.68
7	1.89	1.99	22.88	33.70	1.47	0.23	1.52E-05	0.28	9.38
8	1.82	1.92	22.74	32.30	1.42	0.18	9.65E-06	0.22	6.99
9	1.78	1.88	22.66	31.50	1.39	0.14	5.88E-06	0.17	5.25
10	1.80	1.90	22.70	31.90	1.41	0.12	4.68E-06	0.15	4.78
11	2.12	2.22	23.34	38.30	1.64	0.33	2.90E-05	0.41	15.83
12	2.35	2.45	23.80	42.90	1.80	0.59	8.60E-05	0.76	32.50
13	2.11	2.21	23.32	38.10	1.63	0.49	6.55E-05	0.62	23.60
14	1.99	2.09	23.08	35.70	1.55	0.35	3.58E-05	0.44	15.77
15	1.93	2.03	22.96	34.50	1.50	0.27	2.10E-05	0.33	11.44
16	1.86	1.96	22.82	33.10	1.45	0.21	1.32E-05	0.26	8.50
17	1.84	1.94	22.78	32.70	1.44	0.19	1.11E-05	0.23	7.66

(Streamgauge removed 5/17/90 due to bridge construction)

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): January, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
(Streamgauge redeployed 1/5/90)									
5	1.89	1.99	22.88	33.70	1.47	0.039	4.57E-07	0.048	1.63
6	1.89	1.99	22.88	33.70	1.47	0.022	1.45E-07	0.027	0.92
7	1.89	1.99	22.88	33.70	1.47	0.036	3.89E-07	0.045	1.50
8	1.88	1.98	22.86	33.50	1.47	0.030	2.72E-07	0.037	1.24
9	1.84	1.94	22.78	32.70	1.44	0.033	3.36E-07	0.041	1.33
10	1.91	2.01	22.92	34.10	1.49	0.018	9.63E-08	0.022	0.76
11	1.87	1.97	22.84	33.30	1.46	0.029	2.55E-07	0.036	1.19
12	1.85	1.95	22.80	32.90	1.44	0.010	2.91E-08	0.012	0.40
13	1.88	1.98	22.87	33.58	1.47	0.002	1.18E-09	0.002	0.08
14	1.84	1.94	22.79	32.75	1.44	0.003	3.14E-09	0.004	0.13
15	1.84	1.94	22.78	32.68	1.43	0.001	6.43E-10	0.002	0.06
16	1.84	1.94	22.78	32.68	1.43	0.003	2.57E-09	0.004	0.12
17	1.84	1.94	22.78	32.68	1.43	0.012	4.22E-08	0.014	0.47
18	1.86	1.96	22.83	33.18	1.45	0.022	1.46E-07	0.027	0.90
19	1.86	1.96	22.82	33.10	1.45	0.000	0.00E+00	0.000	0.00
20	1.84	1.94	22.77	32.60	1.43	0.006	1.21E-08	0.008	0.25
21	1.86	1.96	22.83	33.18	1.45	0.015	6.51E-08	0.018	0.60
22	1.89	1.99	22.89	33.76	1.48	0.001	1.51E-10	0.001	0.03
23	1.88	1.98	22.87	33.55	1.47	0.002	6.78E-10	0.002	0.06
24	1.88	1.98	22.87	33.59	1.47	0.009	2.30E-08	0.011	0.36
25	1.96	2.06	23.03	35.18	1.53	0.011	3.42E-08	0.014	0.48
26	2.32	2.42	23.74	42.31	1.78	0.158	6.17E-06	0.201	8.52
27	2.41	2.51	23.92	44.09	1.84	0.336	2.71E-05	0.432	19.05
28	2.23	2.33	23.56	40.45	1.72	0.172	7.62E-06	0.218	8.83
29	2.16	2.26	23.43	39.16	1.67	0.124	4.04E-06	0.156	6.11
30	2.93	3.03	24.95	54.40	2.18	0.645	8.44E-05	0.852	46.36
31	2.75	2.85	24.59	50.85	2.07	0.789	1.33E-04	1.033	52.5

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): February, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	2.48	2.58	24.06	45.46	1.89	0.68	1.09E-04	0.88	39.98
2	2.41	2.51	23.93	44.16	1.85	0.56	7.51E-05	0.72	31.76
3	2.45	2.55	24.00	44.95	1.87	0.57	7.69E-05	0.74	33.04
4	2.30	2.40	23.69	41.81	1.76	0.51	6.53E-05	0.65	27.21
5	2.27	2.37	23.64	41.34	1.75	0.42	4.37E-05	0.53	21.89
6	2.22	2.32	23.54	40.32	1.71	0.30	2.31E-05	0.38	15.29
7	2.16	2.26	23.43	39.18	1.67	0.24	1.49E-05	0.30	11.74
8	2.15	2.25	23.40	38.87	1.66	0.20	1.02E-05	0.25	9.61
9	2.17	2.27	23.44	39.34	1.68	0.22	1.23E-05	0.27	10.73
10	2.25	2.35	23.60	40.95	1.73	0.35	3.06E-05	0.44	18.05
11	2.22	2.32	23.53	40.23	1.71	0.28	2.02E-05	0.35	14.27
12	2.26	2.36	23.62	41.10	1.74	0.22	1.25E-05	0.28	11.59
13	2.22	2.32	23.54	40.26	1.71	0.20	1.04E-05	0.25	10.24
14	2.11	2.21	23.32	38.08	1.63	0.14	5.37E-06	0.18	6.75
15	2.16	2.26	23.43	39.18	1.67	0.13	4.66E-06	0.17	6.57
16	2.21	2.31	23.52	40.11	1.71	0.19	8.96E-06	0.24	9.45
17	2.24	2.34	23.58	40.74	1.73	0.16	6.62E-06	0.20	8.32
18	2.17	2.27	23.45	39.37	1.68	0.15	5.76E-06	0.19	7.36
19	2.16	2.26	23.43	39.18	1.67	0.14	5.18E-06	0.18	6.93
20	2.13	2.23	23.36	38.53	1.65	0.09	2.01E-06	0.11	4.20
21	2.10	2.20	23.30	37.90	1.63	0.10	2.57E-06	0.12	4.63
22	2.10	2.20	23.30	37.87	1.63	0.14	4.96E-06	0.17	6.43
23	2.21	2.31	23.51	40.04	1.70	0.26	1.79E-05	0.33	13.32
24	2.30	2.40	23.69	41.81	1.76	0.35	3.03E-05	0.44	18.54
25	2.30	2.40	23.70	41.87	1.77	0.40	3.93E-05	0.51	21.16
26	2.02	2.12	23.14	36.32	1.57	0.30	2.53E-05	0.37	13.62
27	2.09	2.19	23.29	37.79	1.62	0.21	1.25E-05	0.27	10.19
28	2.16	2.26	23.42	39.13	1.67	0.13	4.36E-06	0.16	6.34

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): March, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.08	2.18	23.26	37.46	1.61	0.10	2.78E-06	0.13	4.73
2	2.11	2.21	23.32	38.10	1.63	0.13	4.91E-06	0.17	6.46
3	2.11	2.21	23.32	38.14	1.64	0.15	6.26E-06	0.19	7.31
4	2.11	2.21	23.32	38.10	1.63	0.09	2.35E-06	0.12	4.47
5	2.06	2.16	23.21	37.04	1.60	0.08	1.98E-06	0.11	3.92
6	2.06	2.16	23.21	37.04	1.60	0.09	2.02E-06	0.11	3.97
7	2.04	2.14	23.19	36.78	1.59	0.08	1.67E-06	0.10	3.57
8	2.02	2.12	23.14	36.35	1.57	0.07	1.34E-06	0.09	3.14
9	2.06	2.16	23.21	37.02	1.59	0.09	2.09E-06	0.11	4.03
10	2.05	2.15	23.21	36.95	1.59	0.09	2.47E-06	0.12	4.37
11	2.02	2.12	23.13	36.22	1.57	0.11	3.72E-06	0.14	5.20
12	2.03	2.13	23.15	36.40	1.57	0.11	3.44E-06	0.14	5.04
13	2.06	2.16	23.22	37.13	1.60	0.10	2.50E-06	0.12	4.43
14	2.06	2.16	23.22	37.14	1.60	0.09	2.01E-06	0.11	3.97
15	2.06	2.16	23.22	37.06	1.60	0.10	2.61E-06	0.12	4.51
16	2.06	2.16	23.22	37.09	1.60	0.10	2.88E-06	0.13	4.75
17	2.10	2.20	23.29	37.82	1.62	0.13	4.67E-06	0.16	6.23
18	2.16	2.26	23.41	39.04	1.67	0.13	4.14E-06	0.16	6.17
19	2.12	2.22	23.35	38.36	1.64	0.14	5.05E-06	0.17	6.62
20	2.17	2.27	23.43	39.22	1.67	0.13	4.33E-06	0.16	6.35
21	2.18	2.28	23.46	39.52	1.68	0.14	5.44E-06	0.18	7.20
22	2.15	2.25	23.40	38.92	1.66	0.17	7.69E-06	0.21	8.36
23	2.12	2.22	23.34	38.32	1.64	0.14	5.59E-06	0.18	6.95
24	2.06	2.16	23.21	37.02	1.59	0.10	2.83E-06	0.13	4.69
25	2.06	2.16	23.21	37.02	1.59	0.12	3.86E-06	0.15	5.48
26	2.02	2.12	23.15	36.36	1.57	0.10	2.70E-06	0.12	4.46
27	2.00	2.10	23.10	35.92	1.55	0.06	1.17E-06	0.08	2.87
28	2.02	2.12	23.14	36.28	1.57	0.09	2.28E-06	0.11	4.08
29	1.99	2.09	23.07	35.60	1.54	0.08	1.83E-06	0.10	3.55
30	1.96	2.06	23.03	35.18	1.53	0.08	1.63E-06	0.09	3.29
31	2.06	2.16	23.21	37.02	1.59	0.08	1.56E-06	0.09	3.48

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): April, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.02	2.12	23.15	36.38	1.57	0.08	1.67E-06	0.10	3.50
2	2.00	2.10	23.10	35.94	1.56	0.08	1.96E-06	0.10	3.73
3	2.19	2.29	23.48	39.66	1.69	0.13	4.16E-06	0.16	6.33
4	3.11	3.21	25.32	58.14	2.30	0.66	8.42E-05	0.88	51.20
5	2.81	2.91	24.73	52.16	2.11	0.82	1.42E-04	1.08	56.39
6	2.54	2.64	24.17	46.62	1.93	0.69	1.09E-04	0.89	41.51
7	2.45	2.55	24.01	44.96	1.87	0.60	8.62E-05	0.78	34.98
8	2.39	2.49	23.89	43.78	1.83	0.50	6.06E-05	0.64	28.15
9	2.32	2.42	23.75	42.36	1.78	0.42	4.31E-05	0.53	22.57
10	2.24	2.34	23.57	40.60	1.72	0.32	2.66E-05	0.41	16.61
11	2.27	2.37	23.64	41.34	1.75	0.34	2.92E-05	0.43	17.90
12	2.27	2.37	23.64	41.34	1.75	0.30	2.20E-05	0.38	15.53
13	2.17	2.27	23.43	39.20	1.67	0.19	9.15E-06	0.24	9.22
14	2.12	2.22	23.35	38.36	1.64	0.17	7.42E-06	0.21	8.03
15	2.34	2.44	23.78	42.68	1.79	0.30	2.17E-05	0.38	16.21
16	2.37	2.47	23.84	43.26	1.81	0.38	3.46E-05	0.48	20.90
17	2.27	2.37	23.64	41.30	1.75	0.33	2.76E-05	0.42	17.35
18	2.22	2.32	23.54	40.34	1.71	0.25	1.67E-05	0.32	13.00
19	2.16	2.26	23.42	39.14	1.67	0.21	1.20E-05	0.27	10.54
20	2.11	2.21	23.32	38.10	1.63	0.19	9.37E-06	0.23	8.92
21	2.18	2.28	23.47	39.56	1.69	0.20	1.01E-05	0.25	9.81
22	2.18	2.28	23.46	39.52	1.68	0.22	1.32E-05	0.28	11.20
23	2.14	2.24	23.37	38.62	1.65	0.17	8.10E-06	0.22	8.48
24	2.03	2.13	23.17	36.58	1.58	0.11	3.51E-06	0.14	5.13
25	1.95	2.05	23.00	34.86	1.52	0.09	2.21E-06	0.11	3.77
26	1.95	2.05	23.00	34.86	1.52	0.10	2.77E-06	0.12	4.23
27	1.98	2.08	23.06	35.48	1.54	0.15	6.30E-06	0.18	6.55
28	1.98	2.08	23.05	35.40	1.54	0.13	4.87E-06	0.16	5.74
29	1.95	2.05	23.00	34.86	1.52	0.09	2.42E-06	0.11	3.94
30	2.07	2.17	23.24	37.26	1.60	0.09	2.23E-06	0.11	4.21

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): May, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	2.14	2.24	23.38	38.66	1.65	0.12	3.85E-06	0.15	5.85
2	2.08	2.18	23.26	37.52	1.61	0.14	5.15E-06	0.17	6.46
3	2.02	2.12	23.13	36.24	1.57	0.14	5.38E-06	0.17	6.25
4	2.00	2.10	23.10	35.94	1.56	0.13	4.51E-06	0.16	5.66
5	2.17	2.27	23.44	39.26	1.68	0.13	4.60E-06	0.17	6.55
6	2.12	2.22	23.34	38.30	1.64	0.12	3.95E-06	0.15	5.84
7	2.06	2.16	23.21	37.02	1.59	0.10	2.83E-06	0.13	4.69
8	2.03	2.13	23.15	36.40	1.57	0.11	3.28E-06	0.14	4.92
9	2.03	2.13	23.15	36.44	1.57	0.11	3.22E-06	0.13	4.88
10	2.05	2.15	23.20	36.86	1.59	0.11	3.13E-06	0.13	4.90
11	2.36	2.46	23.82	43.08	1.81	0.28	1.94E-05	0.36	15.56
12	2.19	2.29	23.47	39.60	1.69	0.17	7.75E-06	0.22	8.62
13	2.21	2.31	23.51	40.00	1.70	0.19	9.09E-06	0.24	9.48
14	2.27	2.37	23.63	41.20	1.74	0.22	1.23E-05	0.28	11.54
15	2.18	2.28	23.45	39.40	1.68	0.16	6.91E-06	0.20	8.07
16	2.13	2.23	23.36	38.46	1.65	0.12	3.93E-06	0.15	5.87
17	2.39	2.49	23.88	43.72	1.83	0.32	2.54E-05	0.42	18.18
18	2.44	2.54	23.97	44.60	1.86	0.42	4.25E-05	0.54	24.27
19	2.31	2.41	23.72	42.06	1.77	0.30	2.17E-05	0.38	15.84
20	2.21	2.31	23.51	40.02	1.70	0.18	8.42E-06	0.23	9.13
21	2.28	2.38	23.67	41.56	1.76	0.22	1.16E-05	0.27	11.39
22	2.24	2.34	23.59	40.78	1.73	0.20	1.05E-05	0.26	10.52
23	2.18	2.28	23.47	39.58	1.69	0.14	4.85E-06	0.17	6.81
24	2.16	2.26	23.43	39.18	1.67	0.11	3.44E-06	0.14	5.65
25	2.11	2.21	23.32	38.10	1.63	0.11	3.40E-06	0.14	5.37
26	2.10	2.20	23.30	37.90	1.63	0.11	3.29E-06	0.14	5.25
27	2.06	2.16	23.21	37.02	1.59	0.09	2.35E-06	0.12	4.27
28	2.05	2.15	23.20	36.86	1.59	0.11	3.13E-06	0.13	4.90
29	2.08	2.18	23.26	37.46	1.61	0.10	2.53E-06	0.12	4.52
30	2.78	2.88	24.66	51.48	2.09	0.59	7.40E-05	0.78	39.90
31	2.61	2.71	24.32	48.08	1.98	0.67	1.02E-04	0.88	42.12

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): June, 1990

Day	Probe Depth (ft)	Invert Depth (ft) 1	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.33	2.43	23.75	42.44	1.79	0.37	3.30E-05	0.47	19.80
2	2.19	2.29	23.47	39.60	1.69	0.17	7.31E-06	0.21	8.37
3	2.15	2.25	23.40	38.92	1.66	0.16	6.47E-06	0.20	7.67
4	2.11	2.21	23.32	38.14	1.64	0.12	3.77E-06	0.15	5.67
5	2.06	2.16	23.21	37.00	1.59	0.11	3.12E-06	0.13	4.92
6	1.99	2.09	23.08	35.72	1.55	0.08	1.83E-06	0.10	3.57
7	2.00	2.10	23.09	35.80	1.55	0.10	3.09E-06	0.13	4.65
8	2.00	2.10	23.10	35.94	1.56	0.14	5.26E-06	0.17	6.10
9	1.99	2.09	23.08	35.74	1.55	0.14	5.36E-06	0.17	6.11
10	2.00	2.10	23.10	35.92	1.55	0.13	4.96E-06	0.16	5.92
11	2.02	2.12	23.15	36.36	1.57	0.12	3.72E-06	0.14	5.23
12	2.03	2.13	23.16	36.50	1.58	0.10	3.04E-06	0.13	4.75
13	1.97	2.07	23.03	35.22	1.53	0.08	1.71E-06	0.10	3.38
14	1.95	2.05	23.00	34.86	1.52	0.08	2.01E-06	0.10	3.60
15	1.95	2.05	23.00	34.86	1.52	0.09	2.31E-06	0.11	3.86
16	1.94	2.04	22.99	34.78	1.51	0.10	3.04E-06	0.13	4.41
17	1.92	2.02	22.95	34.36	1.50	0.13	4.62E-06	0.16	5.33
18	1.92	2.02	22.94	34.34	1.50	0.18	9.05E-06	0.22	7.46
19	1.90	2.00	22.91	33.98	1.48	0.24	1.73E-05	0.30	10.15
20	1.90	2.00	22.91	33.96	1.48	0.15	6.98E-06	0.19	6.44
21	1.89	1.99	22.89	33.76	1.48	0.21	1.31E-05	0.26	8.73
22	1.91	2.01	22.92	34.12	1.49	0.21	1.30E-05	0.26	8.84
23	1.90	2.00	22.89	33.80	1.48	0.17	8.25E-06	0.21	6.95
24	1.90	2.00	22.90	33.94	1.48	0.14	5.93E-06	0.17	5.93
25	1.85	1.95	22.81	32.98	1.45	0.10	3.00E-06	0.12	4.03
26	1.88	1.98	22.87	33.58	1.47	0.13	5.41E-06	0.17	5.57
27	1.89	1.99	22.87	33.62	1.47	0.12	4.05E-06	0.14	4.83
28	1.99	2.09	23.08	35.70	1.55	0.09	2.26E-06	0.11	3.96
29	1.87	1.97	22.84	33.34	1.46	0.09	2.35E-06	0.11	3.63
30	1.89	1.99	22.88	33.68	1.47	0.09	2.27E-06	0.11	3.63

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): July, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.89	1.99	22.88	33.72	1.47	0.10	3.00E-06	0.12	4.17
2	1.91	2.01	22.92	34.14	1.49	0.08	2.05E-06	0.10	3.51
3	1.90	2.00	22.89	33.82	1.48	0.11	3.89E-06	0.14	4.77
4	1.90	2.00	22.91	33.96	1.48	0.13	5.28E-06	0.16	5.60
5	1.89	1.99	22.89	33.76	1.48	0.13	5.07E-06	0.16	5.43
6	1.88	1.98	22.85	33.40	1.46	0.12	4.58E-06	0.15	5.08
7	1.84	1.94	22.78	32.74	1.44	0.11	3.79E-06	0.14	4.48
8	1.85	1.95	22.80	32.90	1.44	0.11	3.84E-06	0.14	4.54
9	1.87	1.97	22.84	33.34	1.46	0.19	1.06E-05	0.23	7.70
10	1.89	1.99	22.89	33.73	1.48	0.25	1.83E-05	0.31	10.33
11	1.85	1.95	22.81	32.96	1.45	0.25	1.97E-05	0.31	10.33
12	1.87	1.97	22.83	33.22	1.45	0.13	5.46E-06	0.17	5.50
13	1.91	2.01	22.92	34.12	1.49	0.10	3.15E-06	0.13	4.36
14	1.89	1.99	22.89	33.78	1.48	0.18	9.60E-06	0.22	7.49
15	1.89	1.99	22.89	33.78	1.48	0.22	1.50E-05	0.28	9.37
16	1.89	1.99	22.89	33.78	1.48	0.21	1.31E-05	0.26	8.74
17	1.90	2.00	22.89	33.80	1.48	0.21	1.28E-05	0.26	8.66
18	1.89	1.99	22.89	33.78	1.48	0.24	1.74E-05	0.30	10.08
19	1.88	1.98	22.86	33.46	1.46	0.21	1.35E-05	0.26	8.73
20	1.89	1.99	22.88	33.74	1.47	0.19	1.07E-05	0.23	7.89
21	1.95	2.05	23.00	34.86	1.52	0.16	7.01E-06	0.19	6.72
22	1.93	2.03	22.95	34.40	1.50	0.26	2.03E-05	0.33	11.19
23	1.91	2.01	22.92	34.08	1.49	0.28	2.37E-05	0.35	11.91
24	1.94	2.04	22.97	34.60	1.51	0.26	2.00E-05	0.32	11.22
25	2.78	2.88	24.67	51.56	2.09	0.36	2.68E-05	0.47	24.08
26	2.55	2.65	24.21	46.96	1.94	0.31	2.16E-05	0.40	18.74
27	2.16	2.26	23.41	39.04	1.67	0.31	2.55E-05	0.39	15.29
28	1.93	2.03	22.96	34.52	1.50	0.26	1.91E-05	0.32	10.93
29	1.75	1.85	22.59	30.82	1.36	0.26	2.23E-05	0.32	9.87
30	1.73	1.83	22.57	30.56	1.35	0.26	2.14E-05	0.31	9.55
31	1.95	2.05	22.99	34.82	1.51	0.20	1.20E-05	0.25	8.79

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): August, 1990

Day	Probe Depth (ft)	Invert Depth 1 (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	Energy Slope 3 (ft/ft)	Average Velocity 4 (ft/s)	5 Flow (cfs)
1	1.93	2.03	22.97	34.56	1.50	0.08	1.70E-06	0.09	3.26
2	1.90	2.00	22.89	33.80	1.48	0.08	2.06E-06	0.10	3.47
3	1.90	2.00	22.90	33.88	1.48	0.17	8.74E-06	0.21	7.18
4	1.90	2.00	22.90	33.86	1.48	0.23	1.57E-05	0.28	9.60
5	1.89	1.99	22.89	33.78	1.48	0.25	1.81E-05	0.30	10.29
6	2.11	2.21	23.31	38.00	1.63	0.15	6.27E-06	0.19	7.27
7	2.15	2.25	23.41	38.96	1.66	0.12	4.02E-06	0.16	6.05
8	2.33	2.43	23.75	42.42	1.79	0.10	2.58E-06	0.13	5.53
9	2.21	2.31	23.51	40.04	1.70	0.10	2.55E-06	0.13	5.03
10	2.15	2.25	23.41	38.98	1.67	0.06	1.05E-06	0.08	3.10
11	2.88	2.98	24.87	53.56	2.15	0.47	4.56E-05	0.62	33.25
12	3.55	3.65	26.20	66.88	2.55	0.97	1.62E-04	1.31	87.69
13	3.40	3.50	25.90	63.86	2.47	0.49	4.24E-05	0.66	41.84
14	2.69	2.79	24.47	49.62	2.03	0.22	1.04E-05	0.28	14.12
15	2.56	2.66	24.21	47.04	1.94	0.19	8.31E-06	0.25	11.64
16	2.61	2.71	24.32	48.06	1.98	0.15	4.97E-06	0.19	9.31
17	2.71	2.81	24.53	50.16	2.05	0.11	2.52E-06	0.14	7.08
18	2.71	2.81	24.52	50.06	2.04	0.12	3.22E-06	0.16	7.98
19	2.65	2.75	24.41	48.96	2.01	0.08	1.38E-06	0.10	5.04
20	2.63	2.73	24.36	48.50	1.99	0.19	8.19E-06	0.25	12.12
21	2.67	2.77	24.45	49.38	2.02	0.25	1.36E-05	0.32	16.04
22	2.60	2.70	24.30	47.94	1.97	0.12	3.45E-06	0.16	7.72
23	2.44	2.54	23.97	44.64	1.86	0.10	2.42E-06	0.13	5.80
24	2.42	2.52	23.94	44.28	1.85	0.12	3.16E-06	0.15	6.55
25	2.99	3.09	25.08	55.70	2.22	0.48	4.63E-05	0.64	35.57
26	2.93	3.03	24.96	54.46	2.18	0.60	7.39E-05	0.80	43.46
27	2.76	2.86	24.62	51.14	2.08	0.36	2.82E-05	0.48	24.39
28	2.45	2.55	24.00	44.90	1.87	0.23	1.25E-05	0.30	13.30
29	2.22	2.32	23.55	40.36	1.71	0.12	3.90E-06	0.16	6.30
30	2.16	2.26	23.43	39.18	1.67	0.06	1.08E-06	0.08	3.17
31	2.13	2.23	23.35	38.42	1.65	0.06	1.00E-06	0.08	2.95

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): September, 1990

Day	Probe Depth (ft)	Invert Depth (ft)	Wetted Perimeter[1] (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	2.11	2.21	23.32	38.10	1.63	0.09	2.19E-06	0.11	4.32
2	2.11	2.21	23.32	38.10	1.63	0.09	1.96E-06	0.11	4.08
3	2.06	2.16	23.22	37.14	1.60	0.09	2.00E-06	0.11	3.96
4	2.06	2.16	23.21	37.02	1.59	0.08	1.56E-06	0.09	3.48
5	2.06	2.16	23.21	37.02	1.59	0.10	2.56E-06	0.12	4.46
6	2.04	2.14	23.18	36.70	1.58	0.08	1.88E-06	0.10	3.77
7	2.02	2.12	23.13	36.24	1.57	0.12	4.00E-06	0.15	5.39
8	2.01	2.11	23.11	36.02	1.56	0.09	2.20E-06	0.11	3.96
9	2.00	2.10	23.10	35.94	1.56	0.10	2.62E-06	0.12	4.31
10	2.02	2.12	23.14	36.34	1.57	0.06	1.15E-06	0.08	2.91
11	2.06	2.16	23.21	37.00	1.59	0.06	1.07E-06	0.08	2.88
12	2.01	2.11	23.12	36.08	1.56	0.04	4.31E-07	0.05	1.76
13	2.00	2.10	23.10	35.94	1.56	0.04	5.50E-07	0.05	1.97
14	2.05	2.15	23.21	36.96	1.59	0.08	1.69E-06	0.10	3.61
15	2.06	2.16	23.22	37.08	1.60	0.07	1.28E-06	0.09	3.16
16	2.18	2.28	23.45	39.44	1.68	0.10	2.84E-06	0.13	5.19
17	2.08	2.18	23.25	37.44	1.61	0.13	4.36E-06	0.16	5.93
18	2.06	2.16	23.22	37.06	1.60	0.08	1.91E-06	0.10	3.86
19	2.06	2.16	23.22	37.12	1.60	0.13	4.75E-06	0.16	6.10
20	2.07	2.17	23.25	37.36	1.61	0.15	6.53E-06	0.19	7.22
21	2.10	2.20	23.30	37.90	1.63	0.12	3.98E-06	0.15	5.77
22	2.06	2.16	23.21	37.04	1.60	0.13	4.98E-06	0.17	6.22
23	2.12	2.22	23.33	38.24	1.64	0.09	2.04E-06	0.11	4.19
24	2.13	2.23	23.36	38.52	1.65	0.10	2.63E-06	0.12	4.81
25	2.06	2.16	23.21	37.02	1.59	0.12	4.26E-06	0.16	5.76
26	2.06	2.16	23.21	37.02	1.59	0.13	4.47E-06	0.16	5.90
27	2.06	2.16	23.21	37.02	1.59	0.14	5.44E-06	0.18	6.50
28	2.06	2.16	23.21	37.02	1.59	0.07	1.28E-06	0.09	3.16
29	2.06	2.16	23.21	37.02	1.59	0.05	6.66E-07	0.06	2.27
30	2.06	2.16	23.21	37.02	1.59	0.07	1.17E-06	0.08	3.02

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured at Wedge Pond Outlet (Streamgauge Site 1): October, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.10	2.20	23.29	37.82	1.62	0.11	3.18E-06	0.14	5.14
2	2.06	2.16	23.21	37.04	1.60	0.12	3.67E-06	0.14	5.34
3	2.06	2.16	23.22	37.08	1.60	0.15	5.82E-06	0.18	6.74
4	2.06	2.16	23.21	37.04	1.60	0.08	1.77E-06	0.10	3.72
5	2.16	2.26	23.42	39.14	1.67	0.12	3.62E-06	0.15	5.79
6	2.11	2.21	23.32	38.10	1.63	0.11	3.04E-06	0.13	5.09
7	2.07	2.17	23.24	37.28	1.60	0.10	2.92E-06	0.13	4.82
8	2.06	2.16	23.21	37.02	1.59	0.07	1.40E-06	0.09	3.30
9	2.16	2.26	23.43	39.18	1.67	0.08	1.78E-06	0.10	4.06
10	2.21	2.31	23.53	40.16	1.71	0.11	3.31E-06	0.14	5.76
11	2.13	2.23	23.36	38.52	1.65	0.11	3.13E-06	0.14	5.25
12	2.16	2.26	23.42	39.08	1.67	0.10	2.87E-06	0.13	5.14
13	2.25	2.35	23.61	40.98	1.74	0.07	1.28E-06	0.09	3.70
14	2.92	3.02	24.95	54.38	2.18	0.32	2.05E-05	0.42	22.84
15	3.55	3.65	26.19	66.80	2.55	0.83	1.20E-04	1.13	75.35
16	2.88	2.98	24.86	53.46	2.15	0.65	8.56E-05	0.85	45.44
17	2.60	2.70	24.30	47.88	1.97	0.29	1.91E-05	0.38	18.16
18	2.44	2.54	23.98	44.70	1.86	0.18	7.95E-06	0.24	10.53
19	2.79	2.89	24.69	51.76	2.10	0.34	2.48E-05	0.45	23.30
20	2.62	2.72	24.34	48.28	1.98	0.34	2.58E-05	0.44	21.35
21	2.48	2.58	24.05	45.44	1.89	0.27	1.66E-05	0.34	15.59
22	2.43	2.53	23.96	44.52	1.86	0.18	7.29E-06	0.23	10.02
23	2.39	2.49	23.88	43.70	1.83	0.16	5.81E-06	0.20	8.69
24	2.87	2.97	24.84	53.28	2.15	0.39	3.09E-05	0.51	27.16
25	2.81	2.91	24.72	52.14	2.11	0.48	4.83E-05	0.63	32.88
26	NMR					NMR			
27	NMR					NMR			
28	NMR					NMR			
29	NMR					NMR			
30	NMR					NMR			
31	NMR					NMR			

NMR - No Measurements Recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Table 4.2

Daily Average Flow Measurements in the Aberjona River at the Route 128 Bridge, Woburn, Massachusetts

Streamgauge Site 2

May, 1989 - October, 1990

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: May, 1989

Day	Probe Depth (ft)	Invert Depth (ft)	1 Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
(Streamgauge deployed 5/24/89)									
24	1.84	3.24	24.48	42.83	1.75	0.16	6.23E-06	0.20	8.56
25	1.83	3.23	24.46	42.70	1.75	0.17	6.90E-06	0.21	8.97
26	1.79	3.19	24.37	41.85	1.72	0.14	4.69E-06	0.17	7.17
27	1.81	3.21	24.41	42.21	1.73	0.20	1.03E-05	0.26	10.78
28	1.79	3.19	24.39	41.99	1.72	0.13	4.61E-06	0.17	7.15
29	1.73	3.13	24.26	40.87	1.68	0.10	2.84E-06	0.13	5.38
30	1.68	3.08	24.15	39.89	1.65	0.10	2.42E-06	0.12	4.78
31	1.67	3.07	24.14	39.79	1.65	0.09	2.17E-06	0.11	4.51

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: June, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.66	3.06	24.12	39.55	1.64	0.04	4.76E-07	0.05	2.09
2	1.99	3.39	24.79	45.63	1.84	0.05	6.25E-07	0.07	2.99
3	2.15	3.55	25.09	48.38	1.93	EMR			
4	1.82	3.22	24.45	42.54	1.74	EMR			
5	1.72	3.12	24.24	40.64	1.68	EMR			
6	1.82	3.22	24.43	42.41	1.74	EMR			
7	2.02	3.42	24.83	46.03	1.85	EMR			
8	2.24	3.64	25.28	50.12	1.98	EMR			
9	2.04	3.44	24.89	46.52	1.87	EMR			
10	2.66	4.06	26.12	57.65	2.21	EMR			
11	2.16	3.56	25.11	48.56	1.93	EMR			
12	1.85	3.25	24.49	42.93	1.75	EMR			
13	1.91	3.31	24.61	44.02	1.79	EMR			
14	1.89	3.29	24.57	43.66	1.78	EMR			
15	1.95	3.35	24.70	44.84	1.82	EMR			
16	2.71	4.11	26.21	58.54	2.23	EMR			
17	2.15	3.55	25.10	48.44	1.93	EMR			
18	2.06	3.46	24.92	46.79	1.88	EMR			
19	1.88	3.28	24.55	43.48	1.77	EMR			
20	1.78	3.18	24.36	41.74	1.71	EMR			
21	1.73	3.13	24.26	40.87	1.68	EMR			
22	1.72	3.12	24.25	40.74	1.68	EMR			
23	1.68	3.08	24.15	39.89	1.65	EMR			
23	0.97	2.37	22.74	27.08	1.19	0.51	9.62E-05	0.61	16.47
24	1.01	2.41	22.81	27.75	1.22	0.39	5.39E-05	0.46	12.81
25	0.89	2.29	22.59	25.72	1.14	0.29	3.24E-05	0.34	8.82
26	0.86	2.26	22.52	25.14	1.12	0.25	2.44E-05	0.29	7.37
27	0.81	2.21	22.42	24.24	1.08	0.16	1.10E-05	0.19	4.67
28	0.77	2.17	22.34	23.50	1.05	0.23	2.22E-05	0.27	6.32
29	0.76	2.16	22.31	23.21	1.04	0.24	2.39E-05	0.28	6.42
30	0.70	2.10	22.21	22.26	1.00	0.25	2.80E-05	0.29	6.51

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: July, 1989

Day	Probe Depth (ft)	Invert Depth 1 (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R 2 (ft)	Bottom Velocity (ft/s)	Energy Slope 3 (ft/ft)	Average Velocity 4 (ft/s)	Flow 5 (cfs)
1	0.70	2.10	22.21	22.26	1.00	0.25	2.76E-05	0.29	6.46
2	0.70	2.10	22.21	22.26	1.00	0.22	2.17E-05	0.26	5.74
3	0.66	2.06	22.12	21.49	0.97	0.22	2.24E-05	0.26	5.51
4	0.65	2.05	22.10	21.29	0.96	0.20	1.82E-05	0.23	4.89
5	0.70	2.09	22.19	22.12	1.00	0.19	1.57E-05	0.22	4.82
6	1.12	2.52	23.03	29.74	1.29	0.46	7.15E-05	0.55	16.46
7	0.85	2.25	22.49	24.87	1.11	0.33	4.30E-05	0.39	9.63
8	0.74	2.14	22.28	22.92	1.03	0.31	4.00E-05	0.36	8.15
9	0.70	2.10	22.21	22.26	1.00	0.27	3.22E-05	0.31	6.98
10	0.97	2.37	22.75	27.17	1.19	0.43	6.75E-05	0.51	13.87
11	1.52	2.92	23.84	37.03	1.55	0.37	3.94E-05	0.46	17.20
12	0.77	2.17	22.35	23.55	1.05	0.33	4.63E-05	0.39	9.15
13	0.70	2.10	22.21	22.26	1.00	0.28	3.53E-05	0.33	7.32
14	0.65	2.05	22.11	21.36	0.97	0.19	1.64E-05	0.22	4.66
15	0.65	2.05	22.10	21.29	0.96	0.14	8.37E-06	0.16	3.31
16	0.65	2.05	22.10	21.29	0.96	0.12	6.29E-06	0.13	2.87
17	1.67	3.07	24.14	39.79	1.65	0.58	8.97E-05	0.73	29.00
18	1.35	2.75	23.50	33.99	1.45	0.50	7.64E-05	0.62	20.97
19	0.90	2.30	22.60	25.79	1.14	0.23	2.05E-05	0.27	7.04
20	0.81	2.21	22.42	24.24	1.08	0.24	2.44E-05	0.29	6.95
21	NMR					NMR			
22	NMR					NMR			
23	NMR					NMR			
24	NMR					NMR			
25	NMR					NMR			
25	EMR					0.10			
26	EMR					0.09			
27	EMR					0.10			
28	EMR					0.13			
29	EMR					0.06			
30	EMR					0.06			
31	EMR					0.08			

NMR - No measurements recorded

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: August, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	EMR					0.08			
2	EMR					0.07			
3	EMR					0.07			
4	EMR					0.08			
5	EMR					0.07			
6	EMR					0.18			
7	EMR					0.18			
8	EMR					0.34			
9	EMR					0.18			
10	EMR					0.12			
11	EMR					0.25			
12	EMR					0.59			
13	EMR					0.58			
14	EMR					0.27			
15	NMR					NMR			
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
21	0.49	1.89	21.77	18.35	0.84	0.20	2.04E-05	0.22	4.08
22	0.45	1.85	21.69	17.63	0.81	0.24	3.13E-05	0.27	4.74
23	0.43	1.83	21.67	17.38	0.80	0.24	3.15E-05	0.27	4.65
24	0.43	1.83	21.67	17.38	0.80	0.23	3.02E-05	0.26	4.55
25	0.41	1.81	21.62	17.00	0.79	0.23	3.08E-05	0.26	4.44
26	0.38	1.78	21.56	16.44	0.76	0.23	2.96E-05	0.25	4.12
27	0.38	1.78	21.56	16.40	0.76	0.20	2.23E-05	0.22	3.56
28	0.38	1.78	21.56	16.40	0.76	0.18	1.90E-05	0.20	3.29
29	0.38	1.78	21.56	16.40	0.76	0.16	1.56E-05	0.18	2.98
30	0.82	2.22	22.43	24.29	1.08	0.36	5.29E-05	0.42	10.28
31	0.55	1.95	21.90	19.48	0.89	0.20	1.97E-05	0.23	4.41

EMR - Erroneous measurements recorded
NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: September, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.45	1.85	21.69	17.61	0.81	0.28	4.21E-05	0.31	5.49
2	0.42	1.82	19.14	8.88	0.46	0.23	4.83E-05	0.23	2.04
3	0.38	1.78	17.06	8.25	0.48	0.18	2.80E-05	0.18	1.49
4	0.38	1.78	17.06	16.40	0.96	0.17	1.38E-05	0.20	3.27
5	0.38	1.78	17.06	16.40	0.96	0.16	1.22E-05	0.19	3.08
6	0.38	1.78	17.06	16.40	0.96	0.16	1.12E-05	0.18	2.95
7	0.38	1.78	17.06	16.40	0.96	0.16	1.15E-05	0.18	2.99
8	0.38	1.78	17.06	8.25	0.48	0.16	2.40E-05	0.17	1.37
9	0.36	1.76	16.02	7.94	0.50	0.16	2.23E-05	0.16	1.30
10	0.35	1.75	15.50	7.78	0.50	0.16	2.20E-05	0.16	1.27
11	0.33	1.72	14.60	7.55	0.52	0.16	2.08E-05	0.16	1.23
12	0.33	1.72	14.60	7.55	0.52	0.14	1.70E-05	0.15	1.11
13	0.33	1.72	14.60	7.55	0.52	0.12	1.17E-05	0.12	0.92
14	0.33	1.72	14.60	7.55	0.52	0.08	6.03E-06	0.09	0.66
15	NMR					NMR			
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
19	NMR					NMR			
20	NMR					NMR			
21	NMR					NMR			
22	0.72	2.12	22.24	22.57	1.01	0.19	1.57E-05	0.22	4.99
23	0.76	2.16	22.32	23.26	1.04	0.20	1.61E-05	0.23	5.30
24	0.71	2.11	22.22	22.35	1.01	0.15	9.24E-06	0.17	3.77
25	0.59	1.98	21.97	20.13	0.92	0.09	4.00E-06	0.10	2.10
26	0.94	2.34	22.69	26.63	1.17	0.43	6.84E-05	0.51	13.52
27	0.86	2.26	22.52	25.12	1.12	0.41	6.63E-05	0.48	12.14
28	0.65	2.05	22.10	21.34	0.97	0.06	1.82E-06	0.07	1.55
29	0.57	1.96	21.93	19.77	0.90	0.06	2.01E-06	0.07	1.44
30	0.51	1.91	21.83	18.83	0.86	0.09	4.34E-06	0.10	1.96

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: October, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.49	1.89	21.77	18.35	0.84	0.16	1.41E-05	0.19	3.40
2	0.75	2.15	22.31	23.17	1.04	0.30	3.86E-05	0.35	8.15
3	1.42	2.82	23.64	35.28	1.49	0.75	1.65E-04	0.93	32.69
4	1.02	2.42	22.84	27.98	1.23	NMR			
5	0.80	2.20	22.40	24.02	1.07	NMR			
6	0.73	2.13	22.26	22.73	1.02	NMR			
7	0.67	2.07	22.14	21.69	0.98	NMR			
8	0.65	2.05	22.10	21.27	0.96	NMR			
9	0.60	2.00	21.99	20.35	0.93	NMR			
10	0.60	1.99	21.99	20.31	0.92	NMR			
11	0.63	2.03	22.06	20.98	0.95	NMR			
12	0.34	1.74	15.35	7.67	0.50	NMR			
13	0.21	1.61	13.40	6.20	0.46	NMR			
14	0.32	1.72	15.05	7.44	0.49	0.45	1.80E-04	0.46	3.44
15	1.17	2.57	23.13	30.63	1.32	0.52	8.93E-05	0.63	19.25
16	0.81	2.21	22.42	24.16	1.08	0.46	8.80E-05	0.54	13.15
17	1.05	2.45	22.90	28.58	1.25	0.47	7.80E-05	0.56	16.14
18	1.35	2.75	23.49	33.88	1.44	0.62	1.18E-04	0.77	25.95
19	1.27	2.67	23.33	32.47	1.39	0.58	1.08E-04	0.71	23.21
20	1.41	2.81	23.61	34.99	1.48	0.64	1.21E-04	0.79	27.57
21	1.35	2.75	23.50	34.01	1.45	0.64	1.26E-04	0.79	26.90
22	1.35	2.75	23.50	33.94	1.44	0.55	9.23E-05	0.68	22.99
23	1.08	2.48	22.96	29.05	1.27	0.41	5.79E-05	0.49	14.27
24	0.94	2.34	22.67	26.50	1.17	0.35	4.50E-05	0.41	10.89
24	0.82	2.22	22.44	24.35	1.09	0.59	1.40E-04	0.69	16.78
25	0.74	2.14	22.27	22.88	1.03	0.56	1.35E-04	0.65	14.91
26	0.67	2.07	22.13	21.58	0.97	0.50	1.12E-04	0.57	12.39
27	0.61	2.01	22.03	20.65	0.94	0.49	1.12E-04	0.56	11.57
28	0.59	1.99	21.98	20.18	0.92	0.45	9.93E-05	0.52	10.49
29	0.54	1.94	21.88	19.33	0.88	0.48	1.14E-04	0.54	10.48
30	0.51	1.91	21.81	18.68	0.86	0.49	1.26E-04	0.56	10.42
31	0.68	2.08	22.16	21.87	0.99	0.46	9.28E-05	0.53	11.52

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: November, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.46	2.86	23.72	35.97	1.52	EMR			
2	1.17	2.57	23.14	30.72	1.33	EMR			
3	1.24	2.64	23.28	31.98	1.37	EMR			
4	1.34	2.74	23.47	33.70	1.44	EMR			
5	1.14	2.54	23.08	30.19	1.31	EMR			
6	0.90	2.30	22.60	25.79	1.14	EMR			
7	0.80	2.20	22.40	24.04	1.07	EMR			
8	0.74	2.14	22.29	23.01	1.03	0.58	1.42E-04	0.67	15.43
9	1.32	2.72	23.43	33.38	1.42	0.87	2.37E-04	1.08	35.90
10	1.32	2.72	23.44	33.47	1.43	0.84	2.19E-04	1.04	34.66
11	1.03	2.43	22.86	28.22	1.23	0.64	1.46E-04	0.77	21.67
12	0.86	2.26	22.53	25.18	1.12	0.47	8.85E-05	0.56	14.08
13	0.75	2.15	22.30	23.12	1.04	0.27	3.06E-05	0.31	7.23
14	0.70	2.10	22.21	22.26	1.00	0.30	4.00E-05	0.35	7.78
15	0.76	2.16	22.32	23.31	1.04	0.40	6.88E-05	0.47	10.98
16	1.07	2.47	22.93	28.83	1.26	0.57	1.16E-04	0.69	19.95
17	1.35	2.75	23.50	33.99	1.45	0.93	2.62E-04	1.14	38.84
18	1.16	2.56	23.12	30.52	1.32	0.71	1.68E-04	0.86	26.26
19	0.92	2.32	22.63	26.10	1.15	0.63	1.53E-04	0.75	19.60
20	0.91	2.31	22.62	26.05	1.15	0.62	1.48E-04	0.74	19.19
21	0.95	2.35	22.70	26.75	1.18	0.59	1.29E-04	0.70	18.73
22	0.81	2.21	22.41	24.15	1.08	0.48	9.58E-05	0.57	13.70
23	0.74	2.14	22.29	22.99	1.03	0.45	8.84E-05	0.53	12.18
24	0.75	2.15	22.29	23.02	1.03	0.47	9.30E-05	0.54	12.52
25	0.67	2.07	22.15	21.74	0.98	0.47	9.79E-05	0.54	11.72
26	0.78	2.18	22.36	23.66	1.06	0.45	8.46E-05	0.53	12.47
27	0.80	2.20	22.39	23.95	1.07	0.50	1.05E-04	0.59	14.14
28	0.88	2.28	22.55	25.40	1.13	0.50	9.94E-05	0.60	15.12
29	0.90	2.30	22.59	25.78	1.14	0.55	1.15E-04	0.65	16.66
30	0.78	2.18	22.36	23.64	1.06	0.50	1.05E-04	0.59	13.85

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: December, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.71	2.11	22.22	22.41	1.01	0.50	1.10E-04	0.58	13.05
2	0.64	2.04	22.08	21.14	0.96	0.50	1.13E-04	0.57	12.06
3	0.65	2.05	22.10	21.29	0.96	0.47	1.02E-04	0.54	11.56
4	0.64	2.04	22.07	21.07	0.95	0.49	1.09E-04	0.56	11.79
5	0.55	1.95	21.90	19.51	0.89	0.51	1.28E-04	0.58	11.29
6	0.56	1.96	21.91	19.60	0.89	0.50	1.26E-04	0.57	11.26
7	0.68	2.08	22.15	21.76	0.98	0.47	9.90E-05	0.54	11.81
8	0.56	1.96	21.92	19.71	0.90	0.50	1.21E-04	0.57	11.15
9	0.53	1.93	21.85	19.06	0.87	0.50	1.26E-04	0.57	10.79
10	0.49	1.89	21.77	18.35	0.84	0.15	1.24E-05	0.17	3.19
11	0.49	1.89	21.77	18.35	0.84	0.09	4.44E-06	0.10	1.90
12	0.49	1.89	21.77	18.32	0.84	0.28	4.15E-05	0.32	5.81
13	0.45	1.85	21.69	17.61	0.81	0.41	9.20E-05	0.46	8.12
14	0.43	1.83	19.66	9.04	0.46	0.43	1.76E-04	0.44	3.95
15	0.43	1.83	19.66	9.04	0.46	0.43	1.76E-04	0.44	3.95
16	0.43	1.83	19.66	9.04	0.46	0.43	1.80E-04	0.44	3.98
17	0.43	1.83	19.66	9.04	0.46	0.47	2.09E-04	0.48	4.30
18	0.43	1.83	19.66	9.04	0.46	0.49	2.30E-04	0.50	4.51
19	0.42	1.82	19.14	8.88	0.46	0.50	2.34E-04	0.51	4.49
20	0.43	1.83	19.66	9.04	0.46	0.46	2.06E-04	0.47	4.27
21	0.38	1.78	17.06	8.25	0.48	0.45	1.88E-04	0.47	3.84
22	0.40	1.80	18.10	8.57	0.47	0.50	2.36E-04	0.52	4.42
23	0.40	1.80	18.10	8.57	0.47	0.53	2.59E-04	0.54	4.63
24	0.40	1.80	18.10	8.57	0.47	0.58	3.11E-04	0.59	5.07
25	0.38	1.78	17.06	8.25	0.48	0.59	3.17E-04	0.61	5.00
26	0.39	1.79	17.58	8.41	0.48	0.55	2.79E-04	0.56	4.74
27	0.43	1.83	19.66	9.04	0.46	0.58	3.18E-04	0.59	5.30
28	0.63	2.03	22.06	20.94	0.95	0.56	1.44E-04	0.64	13.37
29	0.98	2.38	22.76	27.31	1.20	0.54	1.08E-04	0.65	17.71
30	1.00	2.40	22.81	27.69	1.21	0.56	1.16E-04	0.68	18.72
31	0.91	2.31	22.62	25.99	1.15	0.49	9.28E-05	0.58	15.16

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: January, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.29	2.69	23.38	32.89	1.41	0.67	1.41E-04	0.82	27.06
2	0.92	2.32	22.65	26.25	1.16	0.60	1.38E-04	0.71	18.76
3	0.66	2.06	22.13	21.56	0.97	0.58	1.50E-04	0.66	14.32
4	0.55	1.95	21.89	19.40	0.89	0.54	1.44E-04	0.61	11.85
5	0.54	1.94	21.88	19.33	0.88	0.52	1.33E-04	0.59	11.32
6	0.52	1.92	21.83	18.90	0.87	0.51	1.31E-04	0.57	10.83
7	0.49	1.89	21.77	18.35	0.84	0.46	1.12E-04	0.52	9.59
8	0.43	1.83	19.66	9.04	0.46	0.47	2.12E-04	0.48	4.33
9	0.43	1.83	19.66	9.04	0.46	0.45	1.94E-04	0.46	4.14
10	0.43	1.83	19.66	9.04	0.46	0.44	1.88E-04	0.45	4.08
11	0.43	1.83	19.66	9.04	0.46	0.44	1.82E-04	0.44	4.01
12	0.58	1.97	21.95	19.95	0.91	0.30	4.41E-05	0.34	6.86
13	0.76	2.16	22.31	23.24	1.04	0.20	1.72E-05	0.23	5.46
14	0.97	2.37	22.74	27.06	1.19	0.21	1.62E-05	0.25	6.76
15	1.07	2.47	22.93	28.82	1.26	0.18	1.18E-05	0.22	6.36
16	0.70	2.10	22.21	22.26	1.00	0.21	2.00E-05	0.25	5.51
17	0.70	2.10	22.21	22.26	1.00	0.23	2.35E-05	0.27	5.97
18	0.75	2.15	22.30	23.12	1.04	0.25	2.75E-05	0.30	6.85
19	0.78	2.18	22.36	23.62	1.06	0.21	1.92E-05	0.25	5.92
20	0.74	2.14	22.27	22.88	1.03	0.30	3.88E-05	0.35	8.00
21	0.73	2.13	22.25	22.70	1.02	0.25	2.80E-05	0.30	6.71
22	0.74	2.14	22.27	22.86	1.03	0.31	4.03E-05	0.36	8.15
23	0.77	2.17	22.34	23.44	1.05	0.23	2.21E-05	0.27	6.28
24	0.84	2.24	22.47	24.65	1.10	0.15	9.44E-06	0.18	4.45
25	1.26	2.66	23.31	32.26	1.38	0.29	2.76E-05	0.36	11.62
26	1.93	3.33	24.66	44.51	1.80	0.55	7.41E-05	0.70	31.34
27	NMR					NMR			
28	NMR					NMR			
29	NMR					NMR			
30	NMR					NMR			
31	NMR					NMR			

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: February, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	NMR					NMR			
2	NMR					NMR			
3	NMR					NMR			
4	NMR					NMR			
5	NMR					NMR			
6	1.37	2.77	23.53	34.26	1.46	0.44	5.80E-05	0.54	18.50
7	1.35	2.75	23.50	33.94	1.44	0.44	5.98E-05	0.55	18.51
8	1.37	2.77	23.54	34.34	1.46	0.44	5.98E-05	0.55	18.84
9	1.51	2.91	23.82	36.87	1.55	0.46	6.07E-05	0.58	21.21
10	1.86	3.26	24.52	43.17	1.76	0.45	5.06E-05	0.57	24.71
11	1.78	3.18	24.36	41.72	1.71	0.48	5.95E-05	0.61	25.41
12	1.50	2.90	23.80	36.67	1.54	0.47	6.26E-05	0.58	21.35
13	1.37	2.77	23.54	34.37	1.46	0.46	6.33E-05	0.56	19.41
14	1.33	2.73	23.47	33.69	1.44	0.43	5.80E-05	0.53	18.02
15	1.30	2.70	23.40	33.09	1.41	0.43	5.73E-05	0.53	17.41
16	1.46	2.86	23.71	35.91	1.51	0.47	6.48E-05	0.59	21.03
17	1.52	2.92	23.84	37.02	1.55	0.46	6.08E-05	0.58	21.35
18	1.40	2.80	23.59	34.79	1.47	0.47	6.51E-05	0.58	20.07
19	1.32	2.72	23.44	33.45	1.43	0.45	6.14E-05	0.55	18.33
20	1.26	2.66	23.33	32.42	1.39	0.45	6.36E-05	0.55	17.76
21	1.18	2.58	23.16	30.92	1.33	0.40	5.33E-05	0.49	15.09
22	1.28	2.68	23.36	32.73	1.40	0.41	5.28E-05	0.50	16.43
23	1.76	3.16	24.31	41.32	1.70	0.46	5.51E-05	0.58	24.09
24	2.04	3.44	24.89	46.52	1.87	0.50	5.84E-05	0.64	29.77
25	1.66	3.06	24.12	39.57	1.64	0.46	5.78E-05	0.58	23.08
26	2.35	3.75	25.50	52.04	2.04	0.47	4.79E-05	0.61	31.95
27	3.38	4.78	27.55	70.66	2.56	0.47	3.78E-05	0.64	44.88
28	3.90	5.30	28.59	80.08	2.80	0.44	3.02E-05	0.60	48.18

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: March, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	3.81	5.21	28.42	78.46	2.76	0.42	2.88E-05	0.58	45.70
2	2.68	4.08	26.16	58.01	2.22	0.42	3.53E-05	0.56	32.35
3	1.36	2.76	23.52	34.16	1.45	0.48	7.05E-05	0.59	20.29
4	1.30	2.70	23.39	32.98	1.41	0.49	7.62E-05	0.61	19.98
5	1.20	2.60	23.21	31.31	1.35	0.46	6.82E-05	0.56	17.42
6	1.18	2.58	23.17	30.95	1.34	0.46	7.04E-05	0.56	17.38
7	1.13	2.53	23.07	30.07	1.30	0.43	6.25E-05	0.52	15.64
8	1.09	2.49	22.98	29.31	1.28	0.40	5.61E-05	0.49	14.24
9	1.08	2.48	22.96	29.12	1.27	0.39	5.33E-05	0.47	13.75
10	1.08	2.48	22.96	29.12	1.27	0.39	5.33E-05	0.47	13.75
11	1.10	2.50	23.01	29.50	1.28	0.40	5.57E-05	0.49	14.35
12	1.26	2.66	23.31	32.27	1.38	0.48	7.27E-05	0.58	18.86
13	1.26	2.66	23.32	32.36	1.39	0.48	7.44E-05	0.59	19.16
14	1.20	2.60	23.21	31.33	1.35	0.47	7.21E-05	0.57	17.93
15	1.15	2.55	23.10	30.32	1.31	0.44	6.49E-05	0.53	16.16
16	1.14	2.54	23.07	30.10	1.30	0.43	6.24E-05	0.52	15.66
17	1.14	2.54	23.08	30.19	1.31	0.43	6.17E-05	0.52	15.64
18	1.46	2.86	23.72	35.97	1.52	0.49	6.95E-05	0.61	21.83
19	1.29	2.69	23.38	32.91	1.41	0.45	6.22E-05	0.55	17.99
20	1.47	2.87	23.75	36.22	1.53	0.46	6.14E-05	0.57	20.74
21	1.45	2.85	23.70	35.77	1.51	0.48	6.72E-05	0.60	21.29
22	1.29	2.69	23.38	32.85	1.41	0.44	6.18E-05	0.54	17.87
23	1.17	2.57	23.14	30.70	1.33	0.39	5.17E-05	0.48	14.71
24	1.09	2.49	22.98	29.25	1.27	0.38	4.99E-05	0.46	13.39
25	1.04	2.44	22.87	28.31	1.24	0.35	4.25E-05	0.41	11.74
26	1.03	2.43	22.85	28.09	1.23	0.32	3.68E-05	0.38	10.80
27	1.01	2.41	22.82	27.86	1.22	0.31	3.55E-05	0.38	10.46
28	1.08	2.48	22.97	29.16	1.27	0.32	3.59E-05	0.39	11.30
29	1.05	2.45	22.91	28.60	1.25	0.30	3.21E-05	0.36	10.37
30	0.99	2.39	22.77	27.40	1.20	0.28	2.82E-05	0.33	9.08
31	NMR					NMR			

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: April, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	NMR					NMR			
2	NMR					NMR			
3	NMR					NMR			
4	NMR					NMR			
5	2.35	3.75	25.50	52.09	2.04	0.37	3.00E-05	0.49	25.32
6	1.85	3.25	24.50	42.99	1.75	0.31	2.38E-05	0.39	16.82
7	1.61	3.01	24.02	38.72	1.61	0.27	1.96E-05	0.34	12.99
8	NMR					NMR			
9	NMR					NMR			
10	NMR					NMR			
11	NMR					NMR			
12	NMR					NMR			
13	NMR					NMR			
14	NMR					NMR			
15	NMR					NMR			
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
19	NMR					NMR			
20	NMR					NMR			
21	NMR					NMR			
22	NMR					NMR			
23	NMR					NMR			
24	NMR					NMR			
25	NMR					NMR			
26	NMR					NMR			
26	1.13	2.53	23.05	29.94	1.30	0.16	8.72E-06	0.19	5.81
27	1.07	2.47	22.94	28.89	1.26	0.13	5.84E-06	0.16	4.49
28	1.01	2.41	22.82	27.78	1.22	0.14	6.62E-06	0.16	4.50
29	0.97	2.37	22.75	27.17	1.19	0.08	2.61E-06	0.10	2.73
30	1.51	2.91	23.82	36.85	1.55	0.35	3.48E-05	0.44	16.05

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: May, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.61	3.01	24.02	38.72	1.61	0.46	5.73E-05	0.57	22.23
2	1.36	2.76	23.52	34.12	1.45	0.42	5.30E-05	0.51	17.57
3	1.16	2.56	23.11	30.48	1.32	0.29	2.84E-05	0.35	10.78
4	1.08	2.48	22.97	29.16	1.27	0.22	1.73E-05	0.27	7.85
5	1.75	3.15	24.29	41.14	1.69	0.46	5.57E-05	0.59	24.08
6	1.43	2.83	23.66	35.42	1.50	0.45	6.09E-05	0.56	19.96
7	1.22	2.62	23.23	31.57	1.36	0.34	3.83E-05	0.42	13.22
8	1.14	2.54	23.07	30.12	1.31	0.28	2.58E-05	0.33	10.08
9	1.08	2.48	22.96	29.12	1.27	0.24	1.99E-05	0.29	8.40
10	1.22	2.62	23.24	31.59	1.36	0.27	2.39E-05	0.33	10.45
11	2.13	3.53	25.06	48.06	1.92	0.52	6.26E-05	0.67	32.38
12	1.46	2.86	23.71	35.91	1.51	0.43	5.38E-05	0.53	19.16
13	1.66	3.06	24.12	39.60	1.64	0.43	5.07E-05	0.55	21.66
14	1.74	3.14	24.29	41.09	1.69	0.43	4.86E-05	0.55	22.43
15	1.46	2.86	23.73	36.02	1.52	0.31	2.76E-05	0.38	13.80
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
19	NMR					NMR			
20	NMR					NMR			
21	NMR					NMR			
22	NMR					NMR			
23	NMR					NMR			
24	1.28	2.68	23.36	32.69	1.40	0.42	5.55E-05	0.51	16.81
25	1.22	2.62	23.25	31.68	1.36	0.40	5.06E-05	0.48	15.29
26	1.22	2.62	23.24	31.60	1.36	0.39	4.90E-05	0.47	14.98
27	1.27	2.67	23.34	32.51	1.39	0.42	5.60E-05	0.52	16.74
28	1.16	2.56	23.11	30.45	1.32	0.33	3.70E-05	0.40	12.28
29	1.34	2.74	23.47	33.74	1.44	0.35	3.68E-05	0.43	14.39
30	2.80	4.20	26.39	60.13	2.28	0.81	1.27E-04	1.08	64.65
31	2.04	3.44	24.88	46.48	1.87	0.57	7.67E-05	0.73	34.05

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: June, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.51	2.91	23.82	36.87	1.55	0.49	6.97E-05	0.62	22.73
2	1.32	2.72	23.43	33.36	1.42	0.42	5.45E-05	0.52	17.20
3	1.24	2.64	23.29	32.06	1.38	0.35	3.91E-05	0.43	13.69
4	1.24	2.64	23.29	32.06	1.38	0.31	3.15E-05	0.38	12.28
5	1.14	2.54	23.09	30.25	1.31	0.25	2.08E-05	0.30	9.10
6	1.04	2.44	22.88	28.36	1.24	EMR			
7	0.98	2.38	22.76	27.31	1.20	EMR			
8	0.59	1.99	21.98	20.20	0.92	EMR			
9	1.03	2.43	22.86	28.22	1.23	0.20	1.42E-05	0.24	6.75
10	1.01	2.41	22.82	27.86	1.22	0.41	6.18E-05	0.50	13.80
11	1.16	2.56	23.12	30.57	1.32	0.28	2.64E-05	0.34	10.44
12	1.11	2.51	23.01	29.54	1.28	0.29	2.90E-05	0.35	10.36
13	0.99	2.39	22.77	27.40	1.20	0.64	1.52E-04	0.77	21.09
14	0.97	2.37	22.74	27.12	1.19	0.26	2.57E-05	0.31	8.52
15	0.90	2.30	22.61	25.88	1.15	0.48	8.72E-05	0.56	14.59
16	0.92	2.32	22.64	26.19	1.16	0.20	1.54E-05	0.24	6.26
17	0.90	2.30	22.60	25.81	1.14	0.20	1.50E-05	0.23	6.03
18	0.87	2.27	22.53	25.21	1.12	0.18	1.29E-05	0.21	5.40
19	0.85	2.25	22.50	24.91	1.11	0.37	5.53E-05	0.44	10.94
20	0.87	2.27	22.54	25.32	1.12	0.15	9.10E-06	0.18	4.55
21	0.87	2.27	22.54	25.31	1.12	0.16	1.03E-05	0.19	4.85
22	0.87	2.27	22.53	25.21	1.12	0.14	8.20E-06	0.17	4.29
23	0.87	2.27	22.53	25.21	1.12	0.10	3.80E-06	0.12	2.92
24	0.84	2.24	22.48	24.78	1.10	0.09	3.04E-06	0.10	2.54
25	0.81	2.21	22.42	24.24	1.08	0.05	9.43E-07	0.06	1.37
26	0.81	2.21	22.42	24.24	1.08	0.04	7.57E-07	0.05	1.23
27	0.99	2.39	22.77	27.39	1.20	0.13	6.31E-06	0.16	4.29
28	0.92	2.32	22.64	26.21	1.16	0.07	1.82E-06	0.08	2.15
29	0.88	2.28	22.56	25.45	1.13	0.06	1.23E-06	0.07	1.69
30	0.87	2.27	22.53	25.21	1.12	0.05	9.88E-07	0.06	1.49

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: July, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.89	2.29	22.57	25.58	1.13	0.06	1.22E-06	0.07	1.70
2	0.91	2.31	22.61	25.96	1.15	0.05	9.63E-07	0.06	1.54
3	0.85	2.25	22.50	24.93	1.11	0.04	6.39E-07	0.05	1.18
4	0.81	2.21	22.42	24.24	1.08	0.05	8.66E-07	0.05	1.31
5	0.78	2.18	22.37	23.71	1.06	0.04	7.01E-07	0.05	1.14
6	0.76	2.16	22.31	23.24	1.04	0.04	6.46E-07	0.05	1.06
7	EMR					EMR			
8	EMR					EMR			
9	NMR					NMR			
10	0.70	2.10	22.21	22.26	1.00	0.06	1.81E-06	0.07	1.65
11	0.70	2.10	22.21	22.26	1.00	0.04	8.54E-07	0.05	1.14
12	0.79	2.19	22.37	23.77	1.06	0.05	8.43E-07	0.05	1.25
13	0.85	2.25	22.50	24.94	1.11	0.05	1.16E-06	0.06	1.59
14	0.78	2.18	22.36	23.66	1.06	0.06	1.66E-06	0.07	1.75
15	0.74	2.14	22.29	22.99	1.03	0.06	1.44E-06	0.07	1.56
16	0.70	2.10	22.21	22.26	1.00	0.04	7.78E-07	0.05	1.09
17	0.70	2.10	22.21	22.26	1.00	0.04	7.06E-07	0.05	1.03
18	0.70	2.10	22.21	22.26	1.00	0.04	6.71E-07	0.05	1.01
19	0.70	2.10	22.19	22.14	1.00	0.04	6.74E-07	0.05	1.00
20	0.81	2.21	22.43	24.27	1.08	0.06	1.62E-06	0.07	1.80
21	0.88	2.28	22.57	25.54	1.13	0.00	0.00E+00	0.00	0.00
22	0.79	2.19	22.38	23.80	1.06	0.00	0.00E+00	0.00	0.00
23	0.76	2.16	22.32	23.28	1.04	0.00	0.00E+00	0.00	0.00
24	0.77	2.17	22.33	23.42	1.05	0.04	6.41E-07	0.05	1.07
25	2.68	4.08	26.15	57.98	2.22	0.66	8.69E-05	0.87	50.68
26	3.06	4.46	26.91	64.85	2.41	NMR			
27	2.08	3.48	24.96	47.22	1.89	NMR			
28	1.79	3.19	24.37	41.85	1.72	NMR			
29	1.72	3.12	24.25	40.73	1.68	NMR			
30	1.68	3.08	24.15	39.88	1.65	NMR			
31	1.63	3.03	24.05	38.95	1.62	NMR			

EMR - Erroneous measurements recorded

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: August, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.62	3.02	24.05	38.93	1.62	NMR			
2	1.61	3.01	24.01	38.63	1.61	NMR			
3	1.60	3.00	24.00	38.48	1.60	NMR			
4	1.58	2.98	23.96	38.10	1.59	NMR			
5	1.57	2.97	23.94	37.96	1.59	NMR			
6	1.56	2.96	23.93	37.85	1.58	NMR			
6	1.66	3.06	24.12	39.55	1.64	0.12	3.82E-06	0.15	5.93
7	1.64	3.04	24.09	39.30	1.63	0.19	9.68E-06	0.24	9.35
8	2.27	3.67	25.33	50.54	2.00	0.27	1.57E-05	0.35	17.50
9	2.00	3.40	24.80	45.78	1.85	0.14	4.43E-06	0.17	8.00
10	2.00	3.40	24.80	45.74	1.84	0.08	1.46E-06	0.10	4.58
11	3.22	4.62	27.23	67.77	2.49	0.23	9.08E-06	0.31	20.68
12	3.85	5.25	28.50	79.23	2.78	EMR			
13	3.57	4.97	27.95	74.21	2.66	EMR			
14	0.45	1.85	21.71	17.76	0.82	EMR			
15	0.60	1.99	21.99	20.31	0.92	EMR			
16	1.17	2.57	23.15	30.77	1.33	0.12	4.71E-06	0.14	4.46
17	1.06	2.46	22.92	28.69	1.25	0.09	3.12E-06	0.11	3.25
18	0.99	2.39	22.79	27.53	1.21	0.05	1.07E-06	0.06	1.78
19	1.31	2.71	23.42	33.29	1.42	0.24	1.75E-05	0.29	9.71
20	1.15	2.55	23.10	30.39	1.32	0.23	1.84E-05	0.28	8.64
21	1.05	2.45	22.89	28.49	1.24	0.09	2.57E-06	0.10	2.91
22	1.04	2.44	22.87	28.31	1.24	0.11	3.94E-06	0.13	3.57
23	1.19	2.59	23.19	31.15	1.34	0.24	1.90E-05	0.29	9.11
24	1.07	2.47	22.94	28.87	1.26	0.22	1.73E-05	0.27	7.73
25	2.58	3.98	25.96	56.20	2.17	0.77	1.20E-04	1.01	56.87
26	1.89	3.29	24.57	43.69	1.78	0.51	6.50E-05	0.65	28.51
27	2.40	3.80	25.59	52.89	2.07	0.39	3.17E-05	0.50	26.66
28	1.95	3.35	24.71	44.89	1.82	0.32	2.42E-05	0.40	18.12
29	1.61	3.01	24.02	38.66	1.61	0.27	2.03E-05	0.34	13.21
30	1.58	2.98	23.96	38.17	1.59	0.25	1.76E-05	0.32	12.06
31	1.51	2.91	23.82	36.89	1.55	0.24	1.62E-05	0.30	10.96

NMR - No measurements recorded

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300z(.031/n)^6))^2)
4. Calculated from Manning's equation: V = (1.49/n)R^2/3*S1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: September, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.05	2.45	22.89	28.45	1.24	0.22	1.68E-05	0.26	7.43
2	1.02	2.42	22.85	28.06	1.23	0.20	1.40E-05	0.24	6.64
3	1.07	2.47	22.93	28.82	1.26	0.20	1.38E-05	0.24	6.88
4	1.06	2.46	22.91	28.67	1.25	0.19	1.29E-05	0.23	6.60
5	0.94	2.34	22.68	26.59	1.17	0.19	1.41E-05	0.23	6.12
6	0.95	2.35	22.69	26.68	1.18	0.19	1.34E-05	0.23	6.01
7	0.87	2.27	22.54	25.32	1.12	0.19	1.48E-05	0.23	5.81
8	0.82	2.22	22.44	24.42	1.09	0.18	1.26E-05	0.21	5.06
9	0.78	2.18	22.36	23.64	1.06	0.16	1.11E-05	0.19	4.51
10	0.86	2.26	22.53	25.18	1.12	0.17	1.14E-05	0.20	5.06
11	0.84	2.24	22.48	24.73	1.10	0.17	1.09E-05	0.19	4.81
12	0.85	2.25	22.49	24.87	1.11	0.19	1.46E-05	0.23	5.61
13	0.82	2.22	22.43	24.31	1.08	0.19	1.40E-05	0.22	5.29
14	0.82	2.22	22.45	24.45	1.09	0.18	1.33E-05	0.21	5.21
15	0.84	2.24	22.47	24.65	1.10	0.20	1.55E-05	0.23	5.70
16	0.00	1.40	20.80	9.54	0.46	0.00	0.00E+00	0.00	0.00
17	0.87	2.27	22.54	25.32	1.12	0.24	2.21E-05	0.28	7.10
18	0.81	2.21	22.43	24.27	1.08	0.23	2.14E-05	0.27	6.54
19	0.77	2.17	22.33	23.39	1.05	0.20	1.66E-05	0.23	5.42
20	0.91	2.31	22.62	25.97	1.15	0.30	3.49E-05	0.36	9.28
21	0.80	2.20	22.41	24.09	1.08	0.26	2.74E-05	0.30	7.30
22	0.74	2.14	22.27	22.88	1.03	0.23	2.34E-05	0.27	6.21
23	1.02	2.42	22.85	28.07	1.23	0.32	3.66E-05	0.38	10.76
24	0.83	2.23	22.47	24.62	1.10	0.30	3.73E-05	0.36	8.82
25	0.73	2.13	22.26	22.72	1.02	0.26	2.82E-05	0.30	6.75
26	0.74	2.14	22.29	22.99	1.03	0.23	2.27E-05	0.27	6.17
27	0.76	2.16	22.31	23.21	1.04	0.21	1.88E-05	0.25	5.69
28	0.76	2.16	22.32	23.26	1.04	0.19	1.53E-05	0.22	5.16
29	0.72	2.12	22.24	22.54	1.01	0.19	1.54E-05	0.22	4.93
30	0.69	2.09	22.18	22.07	0.99	0.17	1.27E-05	0.20	4.32

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 2: October, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.86	2.26	22.51	25.02	1.11	0.29	3.26E-05	0.34	8.45
2	0.74	2.14	22.28	22.90	1.03	0.26	2.93E-05	0.30	6.97
3	0.70	2.10	22.19	22.14	1.00	0.21	1.94E-05	0.24	5.37
4	0.82	2.22	22.44	24.38	1.09	0.20	1.63E-05	0.24	5.74
5	0.93	2.33	22.66	26.39	1.16	0.31	3.58E-05	0.37	9.64
6	0.84	2.24	22.48	24.74	1.10	0.29	3.26E-05	0.34	8.32
7	0.75	2.15	22.30	23.12	1.04	0.22	2.01E-05	0.25	5.86
8	0.75	2.15	22.29	23.02	1.03	0.18	1.36E-05	0.21	4.78
9	1.52	2.92	23.83	36.98	1.55	0.32	2.86E-05	0.40	14.63
10	1.13	2.53	23.07	30.05	1.30	0.31	3.28E-05	0.38	11.33
11	1.04	2.44	22.87	28.31	1.24	0.27	2.68E-05	0.33	9.33
12	1.06	2.46	22.93	28.78	1.26	0.29	2.88E-05	0.34	9.92
13	1.97	3.37	24.75	45.25	1.83	0.35	2.90E-05	0.44	20.09
14	EMR					EMR			
15	NMR					NMR			
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
19	NMR					NMR			
20	NMR					NMR			
21	NMR					NMR			
22	NMR					NMR			
23	NMR					NMR			
24	NMR					NMR			
25	1.71	3.11	24.22	40.45	1.67	0.48	6.10E-05	0.61	24.54
26	1.49	2.89	23.79	36.56	1.54	0.48	6.49E-05	0.59	21.65
27	1.34	2.74	23.47	33.70	1.44	0.50	7.76E-05	0.62	20.85
28	1.40	2.80	23.60	34.92	1.48	0.53	8.24E-05	0.65	22.70
29	1.65	3.05	24.09	39.33	1.63	0.43	4.99E-05	0.54	21.24
30	1.33	2.73	23.47	33.67	1.43	0.45	6.10E-05	0.55	18.46
31	1.24	2.64	23.27	31.89	1.37	0.46	6.74E-05	0.56	17.82

EMR - Erroneous measurements recorded

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Table 4.3

Daily Average Flow Measurements in the Aberjona River at the Montvale Avenue Bridge, Woburn, Massachusetts

Streamgauge Site 3

May, 1989 - October, 1990

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: May, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
(Streamgauge deployed 5/25/89)									
25	1.39	1.70	26.89	29.88	1.11	0.31	3.78E-05	0.36	10.87
26	1.35	1.66	26.82	29.00	1.08	0.25	2.58E-05	0.30	8.56
27	1.38	1.69	26.88	29.74	1.11	0.27	2.85E-05	0.32	9.37
28	1.38	1.69	26.87	29.64	1.10	0.29	3.47E-05	0.35	10.28
29	1.28	1.59	26.67	27.20	1.02	0.22	2.16E-05	0.26	7.06
30	1.32	1.63	26.76	28.25	1.06	0.16	1.03E-05	0.18	5.19
31	1.30	1.61	26.72	27.78	1.04	0.16	1.02E-05	0.18	5.03

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: June, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.30	1.61	26.72	29.50	1.10	0.14	7.74E-06	0.16	4.84
2	1.54	1.85	27.20	35.45	1.30	0.22	1.61E-05	0.26	9.37
3	1.85	2.16	27.81	42.89	1.54	0.43	5.28E-05	0.54	22.95
4	1.39	1.70	26.90	31.69	1.18	0.25	2.25E-05	0.29	9.26
5	1.28	1.59	26.69	29.13	1.09	0.16	1.05E-05	0.19	5.52
6	1.36	1.67	26.83	30.93	1.15	0.22	1.86E-05	0.26	8.09
7	1.52	1.83	27.17	34.99	1.29	0.31	3.26E-05	0.37	13.04
8	1.75	2.06	27.62	40.50	1.47	0.38	4.42E-05	0.47	19.18
9	1.62	1.93	27.36	37.30	1.36	0.35	3.93E-05	0.43	15.86
10	2.12	2.43	28.35	49.48	1.75	0.45	5.16E-05	0.57	28.41
11	1.80	2.11	27.71	41.67	1.50	0.42	5.24E-05	0.52	21.84
12	1.39	1.70	26.91	31.81	1.18	0.30	3.39E-05	0.36	11.43
13	1.31	1.62	26.75	29.89	1.12	0.34	4.44E-05	0.40	11.84
14	1.37	1.68	26.87	31.33	1.17	0.39	5.62E-05	0.46	14.36
15	1.32	1.63	26.77	30.11	1.12	0.34	4.44E-05	0.40	11.97
16	2.21	2.52	28.54	51.80	1.81	0.52	6.57E-05	0.66	34.44
17	1.74	2.05	27.59	40.16	1.46	0.48	7.03E-05	0.59	23.86
18	1.55	1.86	27.22	35.69	1.31	0.48	7.68E-05	0.58	20.67
19	1.37	1.68	26.86	31.30	1.17	0.39	5.80E-05	0.47	14.57
20	1.18	1.49	26.47	26.54	1.00	0.33	4.72E-05	0.38	10.08
21	1.13	1.44	26.38	25.40	0.96	0.31	4.33E-05	0.35	8.99
22	1.12	1.43	26.35	25.08	0.95	0.28	3.57E-05	0.32	8.00
23	1.14	1.45	26.40	25.62	0.97	0.20	1.77E-05	0.23	5.83
24	1.25	1.56	26.61	28.20	1.06	0.26	2.89E-05	0.31	8.69
25	1.22	1.53	26.56	27.54	1.04	0.18	1.41E-05	0.21	5.85
26	1.15	1.46	26.41	25.81	0.98	0.15	9.52E-06	0.17	4.33
27	1.06	1.37	26.24	23.69	0.90	0.12	6.94E-06	0.14	3.22
28	1.04	1.35	26.20	23.22	0.89	0.11	5.71E-06	0.12	2.83
29	1.01	1.32	26.15	22.54	0.86	0.09	3.71E-06	0.10	2.17
30	0.97	1.28	26.07	21.59	0.83	0.07	2.47E-06	0.08	1.65

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: July, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.97	1.28	26.07	21.59	0.83	0.07	2.47E-06	0.08	1.65
2	0.96	1.27	26.05	21.32	0.82	0.07	2.88E-06	0.08	1.75
3	0.97	1.28	26.07	21.57	0.83	0.09	4.43E-06	0.10	2.21
4	0.96	1.27	26.04	21.20	0.81	0.08	3.22E-06	0.09	1.83
5	0.99	1.30	26.10	21.98	0.84	0.08	3.71E-06	0.09	2.08
6	1.48	1.79	27.08	33.89	1.25	0.40	5.60E-05	0.48	16.25
7	1.15	1.46	26.42	25.84	0.98	0.10	4.17E-06	0.11	2.87
8	1.05	1.36	26.22	23.42	0.89	0.10	4.66E-06	0.11	2.59
9	0.98	1.29	26.08	21.76	0.83	0.08	3.23E-06	0.09	1.91
10	1.17	1.48	26.46	26.35	1.00	0.13	7.86E-06	0.15	4.06
11	1.32	1.63	26.76	30.03	1.12	0.22	1.84E-05	0.26	7.67
12	1.01	1.32	26.13	22.39	0.86	0.06	1.62E-06	0.06	1.42
13	0.98	1.29	26.07	21.66	0.83	0.04	8.10E-07	0.04	0.95
14	0.97	1.28	26.07	21.59	0.83	0.05	1.34E-06	0.06	1.21
15	0.97	1.28	26.07	21.59	0.83	0.04	8.54E-07	0.04	0.97
16	0.97	1.28	26.07	21.59	0.83	0.04	8.12E-07	0.04	0.95
17	0.97	1.28	26.07	21.59	0.83	0.50	1.36E-04	0.57	12.24
18	0.97	1.28	26.07	21.57	0.83	0.49	1.27E-04	0.55	11.84
19	0.96	1.27	26.03	21.13	0.81	0.19	1.87E-05	0.21	4.38
20	0.96	1.27	26.04	21.20	0.81	0.15	1.26E-05	0.17	3.61
21	0.97	1.28	26.06	21.54	0.83	0.17	1.55E-05	0.19	4.12
22	NMR					NMR			
23	NMR					NMR			
24	NMR					NMR			
25	0.87	1.18	25.85	18.95	0.73	0.10	5.68E-06	0.11	2.03
26	0.87	1.18	25.85	18.95	0.73	0.06	1.89E-06	0.06	1.17
27	0.87	1.18	25.85	18.95	0.73	0.04	9.18E-07	0.04	0.81
28	1.31	1.62	26.73	29.67	1.11	0.05	1.04E-06	0.06	1.79
29	1.04	1.35	26.20	23.20	0.89	0.00	0.00E+00	0.00	0.00
30	0.97	1.28	26.06	21.52	0.83	0.00	0.00E+00	0.00	0.00
31	1.04	1.35	26.19	23.10	0.88	0.00	0.00E+00	0.00	0.00

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: August, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.96	1.27	26.04	21.25	0.82	EMR			
2	0.92	1.23	25.95	20.15	0.78	EMR			
3	0.90	1.21	25.91	19.66	0.76	EMR			
4	0.87	1.18	25.85	18.95	0.73	EMR			
5	0.87	1.18	25.85	18.95	0.73	EMR			
6	1.09	1.40	26.30	24.42	0.93	EMR			
7	1.12	1.43	26.37	25.25	0.96	EMR			
8	1.65	1.96	27.42	38.11	1.39	EMR			
9	1.16	1.47	26.44	26.15	0.99	EMR			
10	0.98	1.29	26.08	21.74	0.83	EMR			
11	1.15	1.46	26.42	25.88	0.98	EMR			
12	1.85	2.16	27.83	43.04	1.55	EMR			
13	2.66	2.97	29.43	62.65	2.13	EMR			
14	2.63	2.94	29.37	61.92	2.11	EMR			
15	2.78	3.09	29.68	65.66	2.21	EMR			
16	2.65	2.96	29.42	62.53	2.13	EMR			
17	2.52	2.83	29.16	59.34	2.03	EMR			
18	2.45	2.76	29.01	57.51	1.98	EMR			
19	NMR					NMR			
20	NMR					NMR			
21	1.09	1.40	26.29	24.30	0.92	EMR			
22	1.07	1.38	26.26	23.88	0.91	EMR			
23	1.02	1.33	26.17	22.81	0.87	EMR			
24	0.99	1.30	26.09	21.86	0.84	EMR			
25	0.94	1.25	26.01	20.86	0.80	EMR			
26	0.92	1.23	25.97	20.35	0.78	EMR			
27	0.90	1.21	25.92	19.78	0.76	EMR			
28	0.92	1.23	25.96	20.27	0.78	EMR			
29	0.92	1.23	25.96	20.32	0.78	EMR			
30	1.36	1.67	26.84	31.03	1.16	EMR			
31	1.20	1.51	26.51	27.01	1.02	EMR			

EMR - Erroneous measurements recorded

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: September, 1989

Day	Probe Depth (ft)	Invert Depth (ft) 1	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.05	1.36	26.21	23.37	0.89	EMR			
2	0.99	1.30	26.10	22.00	0.84	EMR			
3	0.93	1.24	25.97	20.42	0.79	EMR			
4	0.89	1.20	25.90	19.56	0.76	EMR			
5	0.88	1.19	25.89	19.37	0.75	EMR			
6	0.89	1.20	25.89	19.47	0.75	EMR			
7	0.89	1.20	25.90	19.49	0.75	EMR			
8	0.89	1.20	25.89	19.42	0.75	EMR			
9	0.89	1.20	25.90	19.49	0.75	EMR			
10	0.89	1.20	25.90	19.59	0.76	EMR			
11	NMR					NMR			
12	NMR					NMR			
13	NMR					NMR			
14	NMR					NMR			
15	NMR					NMR			
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
19	NMR					NMR			
20	NMR					NMR			
21	NMR					NMR			
22	1.38	1.69	26.87	31.40	1.17	EMR			
23	1.30	1.61	26.71	29.42	1.10	EMR			
24	1.32	1.63	26.76	30.08	1.12	EMR			
25	1.15	1.46	26.41	25.76	0.98	EMR			
26	1.49	1.80	27.11	34.25	1.26	EMR			
27	1.49	1.80	27.10	34.20	1.26	EMR			
28	1.24	1.55	26.60	28.10	1.06	EMR			
29	1.13	1.44	26.38	25.44	0.96	EMR			
30	1.06	1.37	26.24	23.71	0.90	EMR			

EMR - Erroneous measurements recorded

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: October, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.01	1.32	26.15	22.54	0.86	NMR			
2	1.30	1.61	26.71	29.47	1.10	0.14	7.75E-06	0.16	4.83
3	2.28	2.59	28.68	53.43	1.86	0.24	1.38E-05	0.31	16.57
4	1.57	1.88	27.27	36.21	1.33	0.12	4.96E-06	0.15	5.37
5	1.25	1.56	26.62	28.37	1.07	0.06	1.26E-06	0.06	1.83
6	1.17	1.48	26.47	26.47	1.00	NMR			
7	1.12	1.43	26.36	25.15	0.95	NMR			
8	1.04	1.35	26.21	23.27	0.89	NMR			
9	1.02	1.33	26.16	22.71	0.87	NMR			
10	0.98	1.29	26.07	21.61	0.83	NMR			
11	1.45	1.76	27.03	33.30	1.23	0.11	4.26E-06	0.13	4.36
12	1.39	1.70	26.89	31.62	1.18	0.07	1.74E-06	0.08	2.56
13	1.22	1.53	26.56	27.62	1.04	0.04	6.47E-07	0.05	1.26
14	1.07	1.38	26.26	23.93	0.91	0.17	1.40E-05	0.19	4.65
15	1.87	2.18	27.86	43.45	1.56	0.49	6.73E-05	0.61	26.44
16	1.56	1.87	27.24	35.84	1.32	0.34	3.98E-05	0.42	14.98
17	1.69	2.00	27.50	39.11	1.42	0.34	3.68E-05	0.42	16.55
18	2.17	2.48	28.45	50.65	1.78	0.24	1.45E-05	0.31	15.65
19	1.81	2.12	27.74	42.04	1.52	0.08	1.73E-06	0.10	4.02
20	2.48	2.79	29.08	58.29	2.00	0.35	2.37E-05	0.43	24.90
21	2.90	3.21	29.92	68.61	2.29	0.48	4.48E-05	0.64	44.05
22	2.17	2.48	28.46	50.82	1.79	0.49	5.95E-05	0.63	31.82
23	1.73	2.04	27.59	40.11	1.45	0.49	7.18E-05	0.60	24.07
24	1.55	1.86	27.21	35.55	1.31	0.44	6.44E-05	0.53	18.80
25	1.48	1.79	27.08	33.96	1.25	0.37	4.70E-05	0.44	14.94
26	1.42	1.73	26.96	32.50	1.21	0.33	3.97E-05	0.39	12.80
27	1.38	1.69	26.89	31.59	1.18	0.29	3.14E-05	0.34	10.88
28	1.37	1.68	26.87	31.35	1.17	0.27	2.72E-05	0.32	10.00
29	1.35	1.66	26.82	30.79	1.15	0.24	2.20E-05	0.28	8.74
30	1.34	1.65	26.79	30.40	1.13	0.20	1.56E-05	0.24	7.21
31	1.46	1.77	27.04	33.40	1.24	0.21	1.52E-05	0.25	8.27

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: November, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.74	3.05	29.59	64.61	2.18	0.43	3.78E-05	0.57	36.87
2	1.90	2.21	27.93	44.28	1.59	0.35	3.40E-05	0.44	19.36
3	2.01	2.32	28.14	46.89	1.67	0.36	3.46E-05	0.46	21.38
4	2.34	2.65	28.80	54.90	1.91	0.40	3.75E-05	0.52	28.51
5	1.88	2.19	27.87	43.57	1.56	0.34	3.35E-05	0.43	18.74
6	1.61	1.92	27.34	37.16	1.36	0.31	3.15E-05	0.38	14.11
7	1.49	1.80	27.10	34.13	1.26	0.31	3.31E-05	0.37	12.64
8	1.44	1.75	27.01	33.03	1.22	0.31	3.52E-05	0.37	12.37
9	2.05	2.36	28.22	47.82	1.69	0.35	3.12E-05	0.44	20.96
10	2.16	2.47	28.43	50.45	1.77	0.42	4.46E-05	0.54	27.24
11	1.78	2.09	27.67	41.16	1.49	0.36	3.79E-05	0.44	18.21
12	1.58	1.89	27.27	36.30	1.33	0.33	3.51E-05	0.40	14.36
13	1.42	1.73	26.96	32.47	1.20	0.31	3.51E-05	0.37	12.01
14	1.41	1.72	26.94	32.25	1.20	0.32	3.83E-05	0.39	12.42
15	1.50	1.81	27.11	34.33	1.27	0.39	5.31E-05	0.47	16.16
16	1.77	2.08	27.66	41.01	1.48	0.42	5.26E-05	0.52	21.34
17	2.28	2.59	28.67	53.38	1.86	0.42	4.09E-05	0.53	28.51
18	1.82	2.13	27.77	42.33	1.52	0.34	3.37E-05	0.42	17.97
19	1.56	1.87	27.24	35.94	1.32	0.30	3.06E-05	0.37	13.19
20	1.51	1.82	27.15	34.77	1.28	0.32	3.49E-05	0.38	13.37
21	2.91	3.22	29.94	68.83	2.30	0.29	1.63E-05	0.39	26.69
22	EMR					0.26			
23	EMR					0.25			
24	EMR					0.19			
25	EMR					0.23			
26	1.30	1.61	26.72	29.50	1.10	0.27	3.01E-05	0.32	9.53
27	NMR					NMR			
28	NMR					NMR			
29	NMR					NMR			
30	1.35	1.66	26.82	30.81	1.15	0.15	8.55E-06	0.18	5.45

EMR - Erroneous measurements recorded

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: December, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	EMR					0.15			
2	EMR					0.19			
3	EMR					0.17			
4	EMR					0.15			
5	EMR					0.19			
6	EMR					0.17			
7	EMR					0.15			
8	EMR					0.17			
9	EMR					0.20			
10	EMR					0.19			
11	EMR					0.18			
12	EMR					0.16			
13	EMR					0.15			
14	EMR					0.24			
15	EMR					0.23			
16	EMR					0.20			
17	EMR					0.23			
18	EMR					0.22			
19	EMR					0.19			
20	EMR					0.16			

(No measurements recorded due to ice on river 12/21/89 - 1/3/90)

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: January, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
4	1.24	1.55	26.61	28.18	1.06	0.28	3.34E-05	0.33	9.34
5	1.24	1.55	26.59	28.01	1.05	0.25	2.52E-05	0.29	8.03
6	EMR					0.23			
7	EMR					0.20			
8	1.03	1.34	26.18	22.91	0.88	0.24	2.89E-05	0.27	6.21
9	1.03	1.34	26.18	22.91	0.88	0.20	2.00E-05	0.23	5.17
10	1.03	1.34	26.18	22.96	0.88	0.20	1.96E-05	0.22	5.14
11	1.03	1.34	26.18	22.91	0.88	0.20	2.00E-05	0.23	5.17
12	1.03	1.34	26.18	22.91	0.88	0.20	1.94E-05	0.22	5.10
13	EMR					0.10			
14	EMR					0.11			
15	EMR					0.13			
16	EMR					0.14			
17	0.96	1.27	26.04	21.27	0.82	0.09	4.00E-06	0.10	2.05
18	1.08	1.39	26.27	24.05	0.92	0.10	4.36E-06	0.11	2.61
19	1.03	1.34	26.18	22.98	0.88	0.09	4.36E-06	0.11	2.43
20	EMR					0.08			
21	EMR					0.13			
22	EMR					0.14			
23	NMR					NMR			
24	NMR					NMR			
25	NMR					NMR			
26	NMR					NMR			
27	NMR					NMR			
28	NMR					NMR			
29	1.83	2.14	27.77	42.38	1.53	0.22	1.38E-05	0.27	11.50
30	3.68	3.99	31.47	87.52	2.78	0.48	3.63E-05	0.66	57.54
31	2.81	3.12	29.73	66.27	2.23	0.33	2.17E-05	0.44	29.08

NMR - No measurements recorded

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: February, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.05	2.36	28.23	47.94	1.70	0.19	9.80E-06	0.25	11.79
2	2.10	2.41	28.31	48.99	1.73	0.20	1.04E-05	0.26	12.58
3	3.88	4.19	31.87	92.37	2.90	0.20	5.86E-06	0.27	25.07
4	EMR					0.13			
5	EMR					0.16			
6	EMR					0.20			
7	1.64	1.95	27.40	37.86	1.38	0.11	4.09E-06	0.14	5.24
8	1.66	1.97	27.43	38.23	1.39	0.21	1.39E-05	0.26	9.80
9	1.80	2.11	27.72	41.74	1.51	0.19	1.01E-05	0.23	9.59
10	2.05	2.36	28.23	47.94	1.70	0.17	7.44E-06	0.21	10.27
11	2.03	2.34	28.17	47.28	1.68	0.19	9.82E-06	0.24	11.54
12	1.75	2.06	27.61	40.40	1.46	EMR	9.82E-07	ERR	ERR
13	1.61	1.92	27.35	37.18	1.36	EMR	4.95E-07	ERR	ERR
14	1.60	1.91	27.32	36.86	1.35	EMR	0.00E+00	ERR	ERR
15	1.55	1.86	27.22	35.60	1.31	EMR	0.00E+00	ERR	ERR
16	1.81	2.12	27.75	42.09	1.52	EMR	4.44E-07	ERR	ERR
17	1.87	2.18	27.86	43.40	1.56	EMR	0.00E+00	ERR	ERR
18	1.96	2.27	28.04	45.65	1.63	EMR	0.00E+00	ERR	ERR
19	1.57	1.88	27.25	36.01	1.32	EMR	0.00E+00	ERR	ERR
20	1.53	1.84	27.18	35.11	1.29	EMR	0.00E+00	ERR	ERR
21	1.72	2.03	27.56	39.79	1.44	EMR	0.00E+00	ERR	ERR
22	1.49	1.80	27.09	34.06	1.26	EMR	0.00E+00	ERR	ERR
23	1.95	2.26	28.01	45.31	1.62	EMR	0.00E+00	ERR	ERR
24	2.21	2.52	28.54	51.72	1.81	EMR	3.34E-06	ERR	ERR
25	NMR					NMR			
26	NMR					NMR			
27	NMR					NMR			
28	NMR					NMR			

EMR - Erroneous measurements recorded
NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: March, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	NMR					NMR			
2	NMR					NMR			
3	1.62	1.93	27.35	37.28	1.36	0.33	3.53E-05	0.40	15.03
4	1.55	1.86	27.21	35.55	1.31	0.32	3.51E-05	0.39	13.89
5	1.43	1.74	26.97	32.59	1.21	0.31	3.52E-05	0.37	12.10
6	1.35	1.66	26.83	30.86	1.15	0.31	3.60E-05	0.36	11.22
7	1.59	1.90	27.30	36.57	1.34	0.26	2.21E-05	0.32	11.54
8	1.30	1.61	26.72	29.50	1.10	0.36	5.11E-05	0.42	12.42
9	NMR					NMR			
10	NMR					NMR			
11	NMR					NMR			
12	NMR					NMR			
13	NMR					NMR			
14	NMR					NMR			
15	NMR					NMR			
16	NMR					NMR			
17	1.41	1.72	26.93	32.15	1.19	0.31	3.47E-05	0.37	11.76
18	1.69	2.00	27.51	39.16	1.42	0.32	3.12E-05	0.39	15.28
19	1.53	1.84	27.19	35.23	1.30	0.15	7.99E-06	0.19	6.53
20	1.71	2.02	27.53	39.47	1.43	0.13	4.82E-06	0.15	6.08
21	1.75	2.06	27.62	40.48	1.47	0.04	4.59E-07	0.05	1.95
22	1.55	1.86	27.22	35.69	1.31	0.04	5.13E-07	0.05	1.69
23	1.44	1.75	27.00	32.98	1.22	0.04	6.09E-07	0.05	1.62
24	1.31	1.62	26.74	29.74	1.11	0.00	0.00E+00	0.00	0.00
25	1.24	1.55	26.60	28.13	1.06	0.29	3.52E-05	0.34	9.56
26	1.17	1.48	26.46	26.42	1.00	0.26	2.95E-05	0.30	7.91
27	1.12	1.43	26.36	25.18	0.96	0.28	3.60E-05	0.32	8.09
28	1.17	1.48	26.45	26.30	0.99	0.28	3.56E-05	0.33	8.63
29	1.16	1.47	26.45	26.23	0.99	0.32	4.65E-05	0.37	9.82
30	1.18	1.49	26.48	26.64	1.01	0.32	4.47E-05	0.37	9.87
31	1.58	1.89	27.27	36.28	1.33	0.37	4.63E-05	0.45	16.47

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: April, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.44	1.75	27.00	33.01	1.22	0.33	3.99E-05	0.40	13.15
2	1.30	1.61	26.73	29.62	1.11	0.32	3.96E-05	0.37	11.01
3	1.74	2.05	27.59	40.18	1.46	0.41	5.06E-05	0.50	20.25
4	EMR					0.30			
5	EMR					EMR			
6	1.75	2.06	27.62	40.50	1.47	0.86	2.22E-04	1.06	42.97
7	1.55	1.86	27.23	35.72	1.31	0.69	1.59E-04	0.83	29.79
8	1.43	1.74	26.99	32.81	1.22	0.62	1.40E-04	0.74	24.43
9	1.30	1.61	26.73	29.62	1.11	0.65	1.67E-04	0.76	22.59
10	1.27	1.58	26.66	28.86	1.08	0.61	1.50E-04	0.71	20.53
11	1.50	1.81	27.12	34.38	1.27	0.68	1.61E-04	0.82	28.22
12	1.36	1.67	26.84	30.98	1.15	0.66	1.66E-04	0.78	24.23
13	1.18	1.49	26.48	26.66	1.01	0.58	1.47E-04	0.67	17.91
14	1.11	1.42	26.34	24.96	0.95	0.59	1.60E-04	0.67	16.79
15	1.88	2.19	27.87	43.62	1.56	0.69	1.33E-04	0.86	37.36
16	1.99	2.30	28.09	46.26	1.65	EMR			
17	1.50	1.81	27.13	34.50	1.27	EMR			
18	1.33	1.64	26.77	30.18	1.13	EMR			
19	1.18	1.49	26.49	26.69	1.01	EMR			
20	1.14	1.45	26.41	25.74	0.97	EMR			
21	1.47	1.78	27.06	33.69	1.25	EMR			
22	1.52	1.83	27.15	34.81	1.28	EMR			
23	1.31	1.62	26.73	29.71	1.11	EMR			
24	NMR					NMR			
25	NMR					NMR			
26	NMR					NMR			
27	NMR					NMR			
28	NMR					NMR			
29	NMR					NMR			
30	NMR					NMR			

EMR - Erroneous measurements recorded
NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: May, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	NMR					NMR			
2	NMR					NMR			
3	NMR					NMR			
4	1.08	1.39	26.28	24.22	0.92	0.38	6.97E-05	0.44	10.57
5	1.67	1.98	27.46	38.52	1.40	0.49	7.51E-05	0.60	23.08
6	1.53	1.84	27.17	35.03	1.29	0.45	6.82E-05	0.54	18.92
7	1.25	1.56	26.62	28.30	1.06	0.33	4.50E-05	0.39	10.92
8	1.13	1.44	26.38	25.44	0.96	0.26	3.17E-05	0.30	7.72
9	1.10	1.41	26.33	24.74	0.94	0.20	1.90E-05	0.23	5.71
10	1.16	1.47	26.43	26.03	0.98	0.23	2.29E-05	0.26	6.81
11	2.20	2.51	28.52	51.48	1.81	0.40	3.82E-05	0.51	26.03
12	1.58	1.89	27.29	36.45	1.34	0.28	2.56E-05	0.34	12.34
13	1.62	1.93	27.36	37.35	1.37	0.26	2.11E-05	0.31	11.64
14	1.81	2.12	27.74	42.04	1.52	0.33	3.18E-05	0.41	17.25
15	1.49	1.80	27.10	34.16	1.26	0.34	4.03E-05	0.41	13.96
16	1.34	1.65	26.80	30.50	1.14	0.29	3.20E-05	0.34	10.38
17	1.99	2.30	28.09	46.28	1.65	0.47	5.83E-05	0.59	27.19
18	1.93	2.24	27.98	44.87	1.60	0.45	5.46E-05	0.56	25.06
19	1.74	2.05	27.60	40.26	1.46	0.40	4.80E-05	0.49	19.80
20	1.44	1.75	26.99	32.89	1.22	0.35	4.35E-05	0.41	13.65
21	1.76	2.07	27.64	40.72	1.47	0.39	4.59E-05	0.48	19.71
22	1.62	1.93	27.35	37.23	1.36	0.37	4.35E-05	0.45	16.64
23	1.39	1.70	26.91	31.84	1.18	0.32	3.90E-05	0.39	12.27
24	1.29	1.60	26.69	29.23	1.09	0.34	4.78E-05	0.41	11.85
25	1.21	1.52	26.55	27.42	1.03	0.37	5.80E-05	0.43	11.77
26	1.18	1.49	26.48	26.66	1.01	0.35	5.29E-05	0.40	10.75
27	1.26	1.57	26.65	28.67	1.08	0.39	6.22E-05	0.46	13.10
28	1.14	1.45	26.39	25.57	0.97	0.39	6.77E-05	0.44	11.36
29	1.24	1.55	26.61	28.15	1.06	0.35	5.06E-05	0.41	11.48
30	2.86	3.17	29.84	67.58	2.27	0.57	6.34E-05	0.76	51.21
31	2.11	2.42	28.35	49.38	1.74	0.28	2.02E-05	0.36	17.72

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: June, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.52	1.83	27.16	34.89	1.28	0.34	3.91E-05	0.41	14.22
2	1.30	1.61	26.71	29.47	1.10	0.56	1.26E-04	0.66	19.47
3	1.18	1.49	26.49	26.69	1.01	0.60	1.56E-04	0.69	18.48
4	1.17	1.48	26.46	26.37	1.00	0.59	1.56E-04	0.69	18.11
5	1.08	1.39	26.28	24.13	0.92	0.58	1.64E-04	0.67	16.10
6	1.02	1.33	26.16	22.71	0.87	0.57	1.66E-04	0.65	14.70
7	1.03	1.34	26.18	22.98	0.88	0.59	1.75E-04	0.67	15.40
8	0.97	1.28	26.07	21.59	0.83	0.58	1.82E-04	0.66	14.18
9	0.97	1.28	26.06	21.49	0.82	0.58	1.82E-04	0.65	14.06
10	0.97	1.28	26.06	21.47	0.82	0.58	1.78E-04	0.65	13.90
11	1.01	1.32	26.14	22.52	0.86	0.58	1.75E-04	0.66	14.86
12	1.07	1.38	26.27	24.01	0.91	0.58	1.60E-04	0.66	15.78
13	0.95	1.26	26.03	21.08	0.81	0.54	1.60E-04	0.61	12.80
14	0.90	1.21	25.91	19.69	0.76	0.47	1.31E-04	0.53	10.35
15	0.88	1.19	25.87	19.17	0.74	0.40	9.55E-05	0.44	8.47
16	0.87	1.18	25.85	18.95	0.73	0.37	8.44E-05	0.41	7.81
17	0.87	1.18	25.85	18.95	0.73	0.33	6.61E-05	0.36	6.92
18	0.87	1.18	25.85	18.95	0.73	0.14	1.15E-05	0.15	2.88
19	0.85	1.16	25.81	18.44	0.71	0.23	3.30E-05	0.25	4.68
20	0.85	1.16	25.82	18.56	0.72	0.30	5.57E-05	0.33	6.14
21	0.83	1.14	25.79	18.15	0.70	0.31	5.96E-05	0.34	6.12
22	0.85	1.16	25.81	18.47	0.72	0.31	5.90E-05	0.34	6.26
23	0.82	1.13	25.77	17.91	0.69	0.28	5.06E-05	0.31	5.52
24	0.82	1.13	25.76	17.83	0.69	0.25	3.84E-05	0.27	4.77
25	0.80	1.11	25.73	17.42	0.68	0.19	2.24E-05	0.20	3.51
26	0.78	1.09	25.68	16.88	0.66	0.17	1.90E-05	0.18	3.07
27	0.96	1.27	26.03	21.13	0.81	0.24	3.14E-05	0.27	5.68
28	1.16	1.47	26.43	26.03	0.98	0.46	9.30E-05	0.53	13.71
29	0.82	1.13	25.77	17.91	0.69	0.28	4.99E-05	0.31	5.48
30	0.81	1.12	25.74	17.64	0.69	0.24	3.57E-05	0.26	4.52

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = $(\text{bottom velocity})^2/(54.42R(\ln(3300Z(.031/n)^6))^2)$
4. Calculated from Manning's equation: $V = (1.49/n)R^{2/3}*S^{1/2}$
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: July, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	NMR					NMR			
2	NMR					NMR			
3	NMR					NMR			
4	NMR					NMR			
5	NMR					NMR			
6	NMR					NMR			
7	NMR					NMR			
8	NMR					NMR			
9	NMR					NMR			
10	0.73	1.04	25.57	15.54	0.61	0.12	9.79E-06	0.12	1.93
11	0.70	1.01	25.52	14.86	0.58	0.12	1.06E-05	0.13	1.86
12	0.74	1.05	25.60	15.88	0.62	0.17	1.94E-05	0.18	2.81
13	0.85	1.16	25.81	18.47	0.72	0.22	2.84E-05	0.24	4.36
14	0.76	1.07	25.63	16.29	0.64	0.18	2.25E-05	0.19	3.16
15	0.74	1.05	25.59	15.78	0.62	0.15	1.70E-05	0.16	2.60
16	0.72	1.03	25.56	15.44	0.60	0.14	1.41E-05	0.15	2.29
17	0.70	1.01	25.53	14.98	0.59	0.12	1.03E-05	0.12	1.86
18	0.68	0.99	25.49	14.49	0.57	0.12	1.05E-05	0.12	1.78
19	0.67	0.98	25.47	14.25	0.56	0.11	9.22E-06	0.11	1.62
20	0.69	1.00	25.50	14.71	0.58	0.11	9.11E-06	0.12	1.70
21	0.91	1.22	25.93	19.91	0.77	0.35	7.06E-05	0.39	7.74
22	0.77	1.08	25.65	16.51	0.64	0.21	2.92E-05	0.22	3.67
23	0.75	1.06	25.61	16.03	0.63	0.16	1.72E-05	0.17	2.68
24	0.74	1.05	25.61	15.98	0.62	0.16	1.75E-05	0.17	2.69
25	2.05	2.36	28.22	47.82	1.69	0.31	2.49E-05	0.39	18.72
26	4.33	4.64	32.79	103.5	3.16	NMR			
27	4.16	4.47	32.44	99.28	3.06	NMR			
28	2.72	3.03	29.56	64.17	2.17	NMR			
29	2.59	2.90	29.31	61.09	2.08	NMR			
30	2.58	2.89	29.29	60.85	2.08	NMR			
31	2.56	2.87	29.25	60.39	2.06	NMR			

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: August, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	2.59	2.90	29.30	61.00	2.08	NMR			
2	2.35	2.66	28.82	55.16	1.91	NMR			
3	2.37	2.68	28.87	55.73	1.93	NMR			
4	2.25	2.56	28.61	52.63	1.84	NMR			
5	2.03	2.34	28.19	47.43	1.68	NMR			
6	1.94	2.25	28.01	45.23	1.62	NMR			
7	NMR					NMR			
8	1.81	2.12	27.74	41.96	1.51	0.79	1.82E-04	0.98	41.21
9	1.33	1.64	26.78	30.32	1.13	0.52	1.07E-04	0.62	18.79
10	1.14	1.45	26.40	25.66	0.97	0.54	1.32E-04	0.62	15.98
11	3.49	3.80	31.11	83.05	2.67	0.65	6.98E-05	0.89	73.63
12	5.09	5.40	34.30	122.1	3.56	0.26	8.08E-06	0.37	44.60
13	2.76	3.07	29.64	65.17	2.20	0.59	7.07E-05	0.78	51.12
14	1.45	1.76	27.02	33.20	1.23	0.64	1.45E-04	0.76	25.32
15	1.16	1.47	26.45	26.23	0.99	0.34	5.13E-05	0.39	10.30
16	0.96	1.27	26.04	21.22	0.82	0.73	2.87E-04	0.82	17.31
17	1.03	1.34	26.18	22.93	0.88	1.34	9.03E-04	1.52	34.81
18	0.93	1.24	25.97	20.42	0.79	1.32	9.73E-04	1.47	29.94
19	1.22	1.53	26.56	27.54	1.04	1.12	5.32E-04	1.30	35.92
20	1.28	1.59	26.68	29.06	1.09	1.18	5.66E-04	1.39	40.39
21	1.02	1.33	26.16	22.71	0.87	1.04	5.52E-04	1.18	26.80
22	1.03	1.34	26.17	22.83	0.87	1.18	7.00E-04	1.33	30.44
23	1.11	1.42	26.34	24.88	0.94	1.09	5.52E-04	1.25	31.07
24	1.08	1.39	26.29	24.25	0.92	1.16	6.43E-04	1.33	32.16
25	2.12	2.43	28.37	49.65	1.75	0.96	2.34E-04	1.23	60.89
26	2.02	2.33	28.17	47.19	1.68	1.02	2.76E-04	1.29	61.03
27	1.55	1.86	27.22	35.67	1.31	0.90	2.70E-04	1.09	38.75
28	1.30	1.61	26.73	29.62	1.11	0.71	2.00E-04	0.84	24.75
29	1.12	1.43	26.36	25.15	0.95	0.65	1.97E-04	0.75	18.88
30	0.91	1.22	25.94	20.08	0.77	0.70	2.78E-04	0.78	15.59
31	1.05	1.36	26.22	23.44	0.89	0.56	1.55E-04	0.64	14.96

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: September, 1990

Day	Probe Depth (ft)	Invert Depth (ft)	[1] Wetted Perimeter (ft)	Flow Area (sq ft)	[2] R (ft)	Bottom Velocity (ft/s)	[3] Energy Slope (ft/ft)	[4] Average Velocity (ft/s)	[5] Flow (cfs)
1	1.26	1.57	26.63	28.47	1.07	0.45	8.45E-05	0.53	15.10
2	1.21	1.52	26.54	27.37	1.03	0.47	9.27E-05	0.54	14.85
3	1.19	1.50	26.50	26.91	1.02	0.46	9.26E-05	0.54	14.43
4	1.23	1.54	26.57	27.76	1.04	0.38	6.21E-05	0.45	12.43
5	1.23	1.54	26.58	27.79	1.05	0.22	1.99E-05	0.25	7.05
6	1.30	1.61	26.72	29.50	1.10	0.12	5.87E-06	0.14	4.21
7	1.23	1.54	26.58	27.88	1.05	0.20	1.67E-05	0.23	6.49
8	1.18	1.49	26.49	26.71	1.01	0.15	1.00E-05	0.18	4.69
9	1.26	1.57	26.64	28.59	1.07	0.25	2.58E-05	0.29	8.39
10	1.22	1.53	26.55	27.52	1.04	0.17	1.29E-05	0.20	5.59
11	1.19	1.50	26.50	26.86	1.01	0.12	6.49E-06	0.14	3.81
12	1.19	1.50	26.50	26.86	1.01	0.17	1.22E-05	0.19	5.22
13	1.19	1.50	26.50	26.86	1.01	0.15	9.17E-06	0.17	4.53
14	1.44	1.75	26.99	32.89	1.22	0.18	1.15E-05	0.21	7.02
15	1.40	1.71	26.91	31.91	1.19	0.35	4.47E-05	0.41	13.18
16	1.25	1.56	26.62	28.37	1.07	0.32	4.12E-05	0.37	10.48
17	1.18	1.49	26.48	26.62	1.01	0.23	2.35E-05	0.27	7.14
18	1.16	1.47	26.43	26.01	0.98	0.22	2.14E-05	0.25	6.56
19	1.35	1.66	26.82	30.74	1.15	0.32	3.90E-05	0.38	11.60
20	1.22	1.53	26.56	27.57	1.04	0.25	2.75E-05	0.30	8.18
21	1.20	1.51	26.52	27.15	1.02	0.19	1.58E-05	0.22	6.04
22	1.54	1.85	27.21	35.47	1.30	0.30	3.13E-05	0.37	13.08
23	1.27	1.58	26.66	28.81	1.08	0.24	2.32E-05	0.28	8.06
24	1.19	1.50	26.50	26.84	1.01	0.16	1.15E-05	0.19	5.06
25	1.16	1.47	26.44	26.18	0.99	0.15	1.01E-05	0.17	4.55
26	1.14	1.45	26.39	25.54	0.97	0.12	6.36E-06	0.14	3.48
27	1.17	1.48	26.45	26.30	0.99	0.20	1.71E-05	0.23	5.98
28	1.15	1.46	26.43	25.96	0.98	0.20	1.87E-05	0.24	6.13
29	1.15	1.46	26.42	25.93	0.98	0.20	1.78E-05	0.23	5.97
30	1.14	1.45	26.40	25.66	0.97	0.20	1.77E-05	0.23	5.84

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in the Aberjona River at Streamgauge Site 3: October, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	1.31	1.62	26.74	29.81	1.11	0.31	3.71E-05	0.36	10.78
2	1.18	1.49	26.48	26.62	1.01	0.22	2.03E-05	0.25	6.65
3	1.14	1.45	26.39	25.52	0.97	0.18	1.43E-05	0.20	5.21
4	1.17	1.48	26.47	26.45	1.00	0.18	1.36E-05	0.20	5.37
5	1.47	1.78	27.06	33.72	1.25	0.18	1.09E-05	0.21	7.10
6	1.27	1.58	26.66	28.76	1.08	NMR			
7	1.18	1.49	26.49	26.71	1.01	NMR			
8	1.14	1.45	26.39	25.54	0.97	NMR			
9	1.83	2.14	27.79	42.55	1.53	EMR			
10	1.60	1.91	27.33	36.94	1.35	EMR			
11	1.44	1.75	26.99	32.84	1.22	0.43	6.85E-05	0.52	17.09
12	1.37	1.68	26.86	31.23	1.16	0.38	5.41E-05	0.45	14.01
13	2.04	2.35	28.21	47.70	1.69	0.30	2.37E-05	0.38	18.18
14	1.95	2.26	28.02	45.36	1.62	0.14	5.20E-06	0.17	7.87
15	2.48	2.79	29.08	58.38	2.01	EMR			
16	1.83	2.14	27.79	42.55	1.53	EMR			
17	1.58	1.89	27.28	36.35	1.33	EMR			
18	1.32	1.63	26.76	30.06	1.12	0.94	3.44E-04	1.11	33.25
19	1.36	1.67	26.83	30.93	1.15	0.94	3.35E-04	1.11	34.37
20	1.34	1.65	26.80	30.54	1.14	0.82	2.62E-04	0.97	29.78
21	1.31	1.62	26.73	29.69	1.11	0.65	1.68E-04	0.77	22.76
22	1.35	1.66	26.82	30.81	1.15	0.70	1.88E-04	0.83	25.54
23	1.36	1.67	26.85	31.08	1.16	0.78	2.35E-04	0.93	28.98
24	1.39	1.70	26.90	31.72	1.18	1.03	3.99E-04	1.23	39.04
25	1.37	1.68	26.87	31.35	1.17	0.88	2.93E-04	1.05	32.81
26	1.33	1.64	26.77	30.15	1.13	0.80	2.50E-04	0.94	28.48
27	1.29	1.60	26.70	29.35	1.10	0.68	1.85E-04	0.80	23.46
28	1.34	1.65	26.81	30.62	1.14	0.60	1.39E-04	0.71	21.76
29	1.35	1.66	26.82	30.79	1.15	0.68	1.77E-04	0.81	24.79
30	1.30	1.61	26.72	29.52	1.10	0.54	1.16E-04	0.64	18.77
31	1.30	1.61	26.71	29.45	1.10	0.44	7.80E-05	0.52	15.32

NMR - No measurements recorded

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300z(.031/n)^6))^2)
4. Calculated from Manning's equation: V = (1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Table 4.4

Daily Average Flow Measurements in Fowle Brook at the Wooden Footbridge near Well F, Woburn, Massachusetts

Streamgauge Site 4

July, 1989 - January, 1990
March, 1990 - October, 1990

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: July, 1989

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
(Streamgauge deployed 7/6/89)									
6	1.05	1.15	24.80	22.80	0.92	0.12	6.59E-06	0.13	3.05
7	0.99	1.09	24.68	21.33	0.86	EMR			
8	NMR					NMR			
9	NMR					NMR			
10	NMR					NMR			
11	NMR					NMR			
12	NMR					NMR			
13	NMR					NMR			
14	0.60	0.70	23.90	11.93	0.50	0.07	4.22E-06	0.07	0.85
15	0.53	0.63	21.91	10.45	0.48	0.07	4.41E-06	0.07	0.74
16	0.49	0.59	21.40	9.58	0.45	0.07	4.84E-06	0.07	0.68
17	0.37	0.47	19.89	6.99	0.35	0.04	2.33E-06	0.04	0.29
18	EMR					EMR			
19	EMR					EMR			
20	EMR					EMR			
21	0.35	0.45	19.63	6.56	0.33	0.24	7.75E-05	0.23	1.54
22	0.48	0.58	21.28	9.37	0.44	0.04	1.53E-06	0.04	0.37
23	0.42	0.52	20.52	8.07	0.39	0.04	1.71E-06	0.04	0.31
24	0.38	0.48	20.01	7.21	0.36	0.04	1.87E-06	0.04	0.28
25	0.38	0.48	20.01	7.21	0.36	0.04	1.87E-06	0.04	0.28
26	0.40	0.50	20.27	7.64	0.38	0.04	1.78E-06	0.04	0.29
27	0.40	0.50	20.27	7.64	0.38	0.05	2.59E-06	0.05	0.35
28	0.64	0.74	23.76	12.92	0.54	0.07	3.54E-06	0.07	0.89
29	0.56	0.66	22.29	11.10	0.50	0.04	1.35E-06	0.04	0.45
30	0.47	0.57	21.15	9.15	0.43	0.04	1.89E-06	0.04	0.40
31	0.09	0.19	17.00	3.00	0.18	0.07	1.13E-05	0.06	0.17

NMR - No measurements recorded

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: August, 1989

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	EMR					EMR			
2	EMR					EMR			
3	EMR					EMR			
4	EMR					EMR			
5	NMR					NMR			
6	NMR					NMR			
7	NMR					NMR			
8	NMR					NMR			
9	NMR					NMR			
10	NMR					NMR			
11	NMR					NMR			
12	NMR					NMR			
13	NMR					NMR			
14	NMR					NMR			
15	NMR					NMR			
16	NMR					NMR			
17	NMR					NMR			
18	NMR					NMR			
19	NMR					NMR			
20	NMR					NMR			
21	NMR					NMR			
22	1.16	1.26	25.01	25.29	1.01	0.51	1.14E-04	0.59	15.03
23	1.05	1.15	24.80	22.73	0.92	0.29	4.00E-05	0.33	7.49
24	1.03	1.13	24.76	22.22	0.90	0.21	2.17E-05	0.24	5.32
25	1.08	1.18	24.86	23.42	0.94	0.27	3.40E-05	0.31	7.24
26	1.07	1.17	24.83	23.13	0.93	0.24	2.69E-05	0.27	6.32
27	1.04	1.14	24.77	22.44	0.91	0.17	1.36E-05	0.19	4.28
28	1.03	1.13	24.77	22.37	0.90	0.16	1.29E-05	0.18	4.13
29	1.06	1.16	24.81	22.92	0.92	0.13	7.72E-06	0.15	3.33
30	1.27	1.37	25.23	27.96	1.11	0.51	1.05E-04	0.61	16.96
31	1.11	1.21	24.91	24.07	0.97	0.40	7.36E-05	0.46	11.14

EMR - Erroneous measurements recorded

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: September, 1989

Day	Probe Depth (ft)	Invert Depth (ft) [1]	Wetted Perimeter (ft)	Flow Area (sq ft)	R (ft) [2]	Bottom Velocity (ft/s)	Energy Slope (ft/ft) [3]	Average Velocity (ft/s) [4]	Flow (cfs) [5]
1	1.08	1.18	24.86	23.42	0.94	0.29	3.84E-05	0.33	7.70
2	1.09	1.19	24.88	23.71	0.95	0.22	2.25E-05	0.25	6.01
3	1.09	1.19	24.87	23.59	0.95	0.19	1.67E-05	0.22	5.13
4	1.11	1.21	24.91	24.12	0.97	0.16	1.21E-05	0.19	4.54
5	1.12	1.22	24.94	24.38	0.98	0.13	7.30E-06	0.15	3.58
6	1.11	1.21	24.92	24.21	0.97	0.13	7.93E-06	0.15	3.69
7	1.10	1.20	24.89	23.88	0.96	0.13	7.32E-06	0.15	3.47
8	1.09	1.19	24.89	23.81	0.96	0.12	6.22E-06	0.13	3.18
9	1.08	1.18	24.87	23.57	0.95	0.11	5.75E-06	0.13	3.01
10	1.09	1.19	24.88	23.69	0.95	0.11	5.52E-06	0.13	2.97
11	1.10	1.20	24.91	24.05	0.97	0.10	4.67E-06	0.12	2.80
12	1.13	1.23	24.96	24.65	0.99	0.08	2.87E-06	0.09	2.28
13	1.19	1.29	25.08	26.11	1.04	0.04	6.46E-07	0.05	1.19
14	1.23	1.33	25.16	27.05	1.08	0.07	1.79E-06	0.08	2.10
15	1.71	1.81	26.11	38.49	1.47	0.28	2.35E-05	0.35	13.34
16	1.24	1.34	25.18	27.31	1.08	0.31	3.94E-05	0.37	9.99
17	1.31	1.41	25.31	28.87	1.14	0.21	1.74E-05	0.25	7.26
18	1.16	1.26	25.03	25.46	1.02	0.22	2.12E-05	0.26	6.55
19	1.25	1.35	25.19	27.45	1.09	0.15	9.50E-06	0.18	4.95
20	1.30	1.40	25.29	28.63	1.13	0.21	1.71E-05	0.25	7.09
21	1.38	1.48	25.46	30.72	1.21	0.15	8.14E-06	0.18	5.48
22	1.22	1.32	25.14	26.83	1.07	0.36	5.25E-05	0.42	11.21
23	1.26	1.36	25.22	27.84	1.10	0.37	5.61E-05	0.44	12.28
24	1.34	1.44	25.38	29.66	1.17	0.36	4.99E-05	0.43	12.82
25	1.13	1.23	24.97	24.74	0.99	0.37	6.24E-05	0.43	10.72
26	1.36	1.46	25.43	30.26	1.19	0.44	7.29E-05	0.53	16.02
27	1.27	1.37	25.24	28.08	1.11	0.74	2.18E-04	0.87	24.54
28	1.16	1.26	25.02	25.44	1.02	0.91	3.60E-04	1.06	26.94
29	1.10	1.20	24.91	24.02	0.96	1.26	7.28E-04	1.45	34.92
30	1.13	1.23	24.95	24.55	0.98	1.01	4.59E-04	1.17	28.70

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(56.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: October, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.11	1.21	24.91	24.09	0.97	1.11	5.63E-04	1.28	30.87
2	0.98	1.08	24.66	21.09	0.86	1.97	2.01E-03	2.23	46.99
3	1.19	1.29	25.08	26.11	1.04	1.27	6.85E-04	1.48	38.74
4	1.20	1.30	25.10	26.30	1.05	1.46	9.00E-04	1.71	44.92
5	1.11	1.21	24.92	24.17	0.97	1.10	5.52E-04	1.27	30.69
6	NMR					NMR			
7	1.00	1.10	24.70	21.50	0.87	1.44	1.05E-03	1.63	35.12
8	1.06	1.16	24.83	23.06	0.93	1.03	5.05E-04	1.18	27.23
9	1.03	1.13	24.75	22.17	0.90	1.80	1.60E-03	2.05	45.48
10	0.99	1.09	24.69	21.41	0.87	1.00	5.10E-04	1.13	24.26
11	1.14	1.24	24.97	24.81	0.99	1.87	1.56E-03	2.17	53.80
12	1.16	1.26	25.02	25.37	1.01	1.47	9.43E-04	1.71	43.38
13	1.07	1.17	24.84	23.23	0.94	1.61	1.23E-03	1.85	42.93
14	1.06	1.16	24.82	22.99	0.93	1.15	6.31E-04	1.32	30.30
15	NMR					NMR			
16	NMR					NMR			
17	0.96	1.06	24.61	20.52	0.83	1.75	1.62E-03	1.97	40.44
18	0.38	0.48	20.01	7.21	0.36	1.12	1.54E-03	1.10	7.91
19	0.38	0.48	20.01	7.21	0.36	1.07	1.41E-03	1.05	7.56
20	NMR					NMR			
21	0.34	0.44	19.51	6.34	0.32	2.13	6.17E-03	2.05	13.00
22	0.45	0.55	20.90	8.72	0.42	1.54	2.51E-03	1.55	13.48
23	0.64	0.74	23.76	12.92	0.54	1.61	2.11E-03	1.69	21.82
24	1.24	1.34	25.19	27.41	1.09	0.43	7.41E-05	0.50	13.77
25	1.26	1.36	25.23	27.86	1.10	0.38	5.69E-05	0.44	12.39
26	1.27	1.37	25.24	28.08	1.11	0.32	4.12E-05	0.38	10.68
27	1.30	1.40	25.29	28.68	1.13	0.29	3.35E-05	0.35	9.96
28	1.31	1.41	25.32	29.01	1.15	0.28	2.92E-05	0.33	9.47
29	1.31	1.41	25.32	28.94	1.14	0.26	2.70E-05	0.31	9.07
30	1.31	1.41	25.32	28.94	1.14	0.24	2.15E-05	0.28	8.11
31	1.32	1.42	25.33	29.11	1.15	0.30	3.49E-05	0.36	10.41

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: November, 1989

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	1.77	1.87	26.25	40.10	1.53	0.28	2.19E-05	0.34	13.73
2	1.73	1.83	26.15	38.97	1.49	0.04	4.51E-07	0.05	1.88
3	1.78	1.88	26.25	40.17	1.53	0.12	3.82E-06	0.14	5.75
4	1.90	2.00	26.50	43.20	1.63	0.07	1.25E-06	0.09	3.70
5	1.87	1.97	26.44	42.41	1.60	0.04	4.19E-07	0.05	2.08
6	1.84	1.94	26.38	41.66	1.58	0.04	4.26E-07	0.05	2.03
7	1.79	1.89	26.27	40.44	1.54	0.04	4.37E-07	0.05	1.97
8	1.73	1.83	26.15	38.97	1.49	0.13	4.71E-06	0.16	6.09
9	1.87	1.97	26.44	42.38	1.60	0.71	1.38E-04	0.89	37.61
10	1.97	2.07	26.63	44.71	1.68	0.51	6.74E-05	0.64	28.61
11	1.87	1.97	26.44	42.48	1.61	0.35	3.33E-05	0.44	18.56
12	1.78	1.88	26.26	40.29	1.53	0.31	2.79E-05	0.39	15.61
13	1.67	1.77	26.04	37.65	1.45	0.30	2.72E-05	0.37	13.84
14	1.65	1.75	25.99	37.03	1.42	0.28	2.50E-05	0.35	12.94
15	1.62	1.72	25.95	36.50	1.41	0.36	3.98E-05	0.44	15.96
16	1.69	1.79	26.08	38.13	1.46	0.58	1.00E-04	0.71	27.10
17	1.87	1.97	26.44	42.43	1.60	0.36	3.61E-05	0.45	19.28
18	1.77	1.87	26.25	40.13	1.53	0.28	2.32E-05	0.35	14.14
19	1.66	1.76	26.01	37.32	1.43	0.28	2.43E-05	0.35	12.92
20	1.62	1.72	25.94	36.43	1.40	0.32	3.18E-05	0.39	14.22
21	1.55	1.65	25.79	34.65	1.34	0.32	3.35E-05	0.39	13.47
22	1.41	1.51	25.51	31.32	1.23	0.28	2.87E-05	0.34	10.60
23	1.23	1.33	25.15	27.00	1.07	0.33	4.35E-05	0.38	10.30
24	1.78	1.88	26.27	40.34	1.54	0.34	3.31E-05	0.42	17.04
25	EMR					0.35			
26	1.03	1.13	24.76	22.22	0.90	0.37	6.86E-05	0.43	9.45
27	0.99	1.09	24.67	21.24	0.86	0.37	7.15E-05	0.42	8.97
28	1.00	1.10	24.69	21.43	0.87	0.43	9.29E-05	0.48	10.37
29	0.93	1.03	24.56	19.82	0.81	0.46	1.18E-04	0.52	10.30
30	0.88	0.98	24.45	18.60	0.76	0.47	1.29E-04	0.52	9.71

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: December, 1989

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.77	0.87	24.24	16.05	0.66	0.57	2.15E-04	0.61	9.87
2	0.87	0.97	24.44	18.48	0.76	0.55	1.78E-04	0.61	11.28
3	0.76	0.86	24.21	15.69	0.65	0.59	2.35E-04	0.63	9.95
4	0.62	0.72	23.94	12.45	0.52	0.54	2.45E-04	0.56	6.96
5	1.21	1.31	25.12	26.54	1.06	0.52	1.15E-04	0.61	16.29
6	1.19	1.29	25.07	25.99	1.04	0.55	1.29E-04	0.64	16.69
7	0.80	0.90	24.31	16.82	0.69	0.65	2.73E-04	0.71	12.01
8	0.58	0.68	22.54	11.53	0.51	0.56	2.69E-04	0.58	6.68
9	0.56	0.74	23.76	12.92	0.54	0.51	2.13E-04	0.54	6.94
10	0.73	0.83	24.16	15.02	0.62	0.50	1.80E-04	0.54	8.10
11	0.70	0.80	24.11	14.42	0.60	0.51	1.94E-04	0.55	7.87
12	0.71	0.81	24.12	14.64	0.61	0.51	1.87E-04	0.54	7.93
13	0.66	0.76	24.03	13.49	0.56	0.49	1.89E-04	0.52	6.97
14	0.65	0.75	24.00	13.13	0.55	0.42	1.41E-04	0.44	5.75
15	1.19	1.29	25.08	26.16	1.04	0.40	6.79E-05	0.47	12.23
16	1.53	1.63	25.76	34.22	1.33	0.40	5.35E-05	0.49	16.70
17	1.39	1.49	25.48	30.96	1.21	0.41	6.18E-05	0.49	15.29
18	1.19	1.29	25.07	26.01	1.04	0.41	7.20E-05	0.48	12.48
19	1.04	1.14	24.78	22.51	0.91	0.40	7.95E-05	0.46	10.39
20	1.45	1.55	25.59	32.23	1.26	0.42	6.08E-05	0.50	16.17
21	0.72	0.82	24.14	14.81	0.61	0.37	9.71E-05	0.39	5.81
22	0.28	0.38	19.00	5.59	0.29	0.40	2.44E-04	0.38	2.13
23	0.40	0.50	20.27	7.64	0.38	0.38	1.69E-04	0.38	2.87
24	0.64	0.74	23.76	12.92	0.54	0.57	2.63E-04	0.60	7.71
25	2.43	2.53	27.56	55.89	2.03	0.55	6.62E-05	0.72	40.19
26	2.83	2.93	28.36	65.45	2.31	0.44	3.69E-05	0.59	38.31
27	0.45	0.55	20.90	8.72	0.42	0.40	1.65E-04	0.40	3.46
28	0.97	1.07	24.65	20.90	0.85	0.35	6.35E-05	0.39	8.24
29	0.49	0.59	21.40	9.58	0.45	0.26	6.83E-05	0.27	2.56
30	0.60	0.70	22.80	11.96	0.52	0.24	4.82E-05	0.25	2.98
31	0.66	0.76	24.03	13.46	0.56	0.37	1.08E-04	0.39	5.25

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: January, 1990

Day	Probe Depth (ft)	Invert Depth (ft) 1	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.06	1.16	24.81	22.92	0.92	0.88	3.72E-04	1.01	23.13
2	0.80	0.90	24.31	16.82	0.69	0.53	1.80E-04	0.58	9.75
3	0.74	0.84	24.17	15.24	0.63	0.56	2.16E-04	0.60	9.09
4	0.72	0.82	24.13	14.76	0.61	0.71	3.63E-04	0.76	11.18
5	0.76	0.86	24.21	15.72	0.65	0.81	4.43E-04	0.87	13.69
6	0.73	0.83	24.15	14.95	0.62	0.61	2.63E-04	0.65	9.73
7	0.70	0.80	24.11	14.42	0.60	0.52	1.99E-04	0.55	7.98
8	0.70	0.80	24.11	14.42	0.60	0.47	1.60E-04	0.50	7.15
9	0.70	0.80	24.09	14.28	0.59	0.47	1.67E-04	0.50	7.19
10	0.70	0.80	24.11	14.42	0.60	0.49	1.80E-04	0.53	7.58
11	0.70	0.80	24.11	14.42	0.60	0.48	1.71E-04	0.51	7.39
12	0.70	0.80	24.11	14.42	0.60	0.46	1.58E-04	0.49	7.12

(Streamgauge removed for repair 1/13/90 - 3/16/90)

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: March, 1990

Day	Probe Depth (ft)	[1] Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	[2] R (ft)	Bottom Velocity (ft/s)	[3] Energy Slope (ft/ft)	[4] Average Velocity (ft/s)	[5] Flow (cfs)
17	0.70	0.80	24.11	14.42	0.60	0.99	7.19E-04	1.05	15.15
18	0.82	0.92	24.34	17.21	0.71	1.16	8.36E-04	1.27	21.79
19	0.74	0.84	24.18	15.31	0.63	0.99	6.90E-04	1.07	16.37
20	0.85	0.95	24.39	17.85	0.73	1.12	7.55E-04	1.23	22.00
21	0.85	0.95	24.40	18.00	0.74	1.09	7.18E-04	1.21	21.73
22	0.79	0.89	24.27	16.44	0.68	0.94	5.81E-04	1.03	16.86
23	0.75	0.85	24.19	15.48	0.64	0.82	4.64E-04	0.88	13.66
24	0.70	0.80	24.11	14.42	0.60	0.88	5.76E-04	0.94	13.57
25	0.69	0.79	24.07	14.04	0.58	0.89	5.99E-04	0.94	13.24
26	0.65	0.75	24.00	13.13	0.55	0.98	7.73E-04	1.03	13.48
27	0.65	0.75	24.00	13.13	0.55	0.96	7.51E-04	1.01	13.29
28	0.64	0.74	23.76	12.92	0.54	0.93	6.96E-04	0.97	12.54
29	0.60	0.70	22.80	11.96	0.52	0.92	7.07E-04	0.96	11.42
30	0.62	0.72	23.04	12.20	0.53	0.96	7.65E-04	1.00	12.19
31	0.76	0.86	24.21	15.72	0.65	1.25	1.07E-03	1.35	21.28

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: April, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	0.71	0.81	24.11	14.52	0.60	1.05	8.02E-04	1.11	16.19
2	0.65	0.75	24.00	13.20	0.55	0.90	6.47E-04	0.94	12.44
3	0.86	0.96	24.43	18.26	0.75	1.30	9.94E-04	1.43	26.17
4	1.95	2.05	26.60	44.37	1.67	1.45	5.57E-04	1.83	81.24
5	1.78	1.88	26.25	40.17	1.53	0.61	1.08E-04	0.76	30.62
6	1.59	1.69	25.87	35.61	1.38	0.60	1.16E-04	0.74	26.19
7	1.42	1.52	25.54	31.61	1.24	0.60	1.27E-04	0.72	22.65
8	1.29	1.39	25.29	28.61	1.13	0.62	1.49E-04	0.73	20.94
9	1.18	1.28	25.06	25.85	1.03	0.62	1.66E-04	0.73	18.75
10	1.10	1.20	24.90	23.90	0.96	0.68	2.11E-04	0.78	18.63
11	1.12	1.22	24.94	24.45	0.98	0.83	3.14E-04	0.96	23.59
12	1.06	1.16	24.82	23.01	0.93	0.73	2.57E-04	0.84	19.36
13	0.99	1.09	24.67	21.21	0.86	0.76	2.96E-04	0.86	18.22
14	0.93	1.03	24.55	19.75	0.80	0.81	3.57E-04	0.90	17.82
15	0.92	1.02	24.54	19.68	0.80	0.86	4.05E-04	0.96	18.87

(No measurements recorded due to power failure 4/16/90 - 5/4/90)

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: May, 1990

Day	Probe Depth (ft)	Invert Depth (ft) 1	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
4	1.69	1.79	26.09	38.18	1.46	0.20	1.17E-05	0.24	9.30
5	1.82	1.92	26.33	41.11	1.56	0.46	5.99E-05	0.57	23.63
6	1.84	1.94	26.38	41.69	1.58	0.25	1.81E-05	0.32	13.26
7	1.80	1.90	26.30	40.75	1.55	0.21	1.21E-05	0.26	10.48
8	1.78	1.88	26.26	40.25	1.53	0.20	1.11E-05	0.24	9.83
9	1.73	1.83	26.16	39.09	1.49	0.19	1.11E-05	0.24	9.41
10	1.69	1.79	26.09	38.21	1.46	0.23	1.61E-05	0.29	10.91
11	2.03	2.13	26.76	46.22	1.73	0.71	1.29E-04	0.90	41.71
12	1.94	2.04	26.58	44.11	1.66	0.25	1.60E-05	0.31	13.64
13	1.95	2.05	26.61	44.45	1.67	0.39	4.09E-05	0.50	22.07
14	2.04	2.14	26.77	46.44	1.73	0.38	3.68E-05	0.48	22.44
15	1.98	2.08	26.65	45.00	1.69	0.25	1.64E-05	0.32	14.24
16	1.90	2.00	26.51	43.22	1.63	0.26	1.83E-05	0.33	14.15
17	2.09	2.19	26.88	47.71	1.77	0.50	6.11E-05	0.63	30.15
18	2.03	2.13	26.76	46.29	1.73	0.43	4.66E-05	0.54	25.13
19	1.94	2.04	26.58	44.13	1.66	0.31	2.59E-05	0.39	17.38
20	1.83	1.93	26.36	41.52	1.57	0.28	2.15E-05	0.35	14.39
21	1.87	1.97	26.45	42.53	1.61	0.41	4.58E-05	0.51	21.79
22	1.86	1.96	26.42	42.14	1.60	0.29	2.38E-05	0.37	15.49
23	1.78	1.88	26.26	40.32	1.54	0.24	1.69E-05	0.30	12.16
24	1.73	1.83	26.16	39.12	1.50	0.21	1.30E-05	0.26	10.19
25	1.64	1.74	25.98	36.93	1.42	0.22	1.52E-05	0.27	10.04
26	1.58	1.68	25.86	35.49	1.37	0.24	1.83E-05	0.29	10.33
27	1.62	1.72	25.93	36.31	1.40	0.25	2.04E-05	0.31	11.32
28	1.63	1.73	25.96	36.65	1.41	0.18	1.06E-05	0.23	8.29
29	1.66	1.76	26.01	37.27	1.43	0.21	1.40E-05	0.26	9.78
30	2.27	2.37	27.24	52.08	1.91	0.80	1.49E-04	1.04	54.04
31	2.05	2.15	26.79	46.68	1.74	0.33	2.73E-05	0.42	19.48

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: June, 1990

Day	Probe Depth (ft)	Invert Depth (ft)	Wetted Perimeter (ft) [1]	Flow Area (sq ft)	R (ft) [2]	Bottom Velocity (ft/s)	Energy Slope (ft/ft) [3]	Average Velocity (ft/s) [4]	Flow (cfs) [5]
1	1.84	1.94	26.38	41.66	1.58	0.26	1.88E-05	0.32	13.51
2	1.78	1.88	26.26	40.22	1.53	0.21	1.26E-05	0.26	10.47
3	1.73	1.83	26.16	39.09	1.49	0.19	1.09E-05	0.24	9.31
4	1.71	1.81	26.11	38.47	1.47	0.18	1.01E-05	0.23	8.71
5	1.63	1.73	25.97	36.74	1.42	0.15	6.94E-06	0.18	6.73
6	1.66	1.76	26.02	37.41	1.44	0.12	4.21E-06	0.14	5.40
7	1.68	1.78	26.07	37.94	1.46	0.12	4.09E-06	0.14	5.44
8	1.70	1.80	26.10	38.37	1.47	0.09	2.33E-06	0.11	4.18
9	1.70	1.80	26.09	38.28	1.47	0.12	4.06E-06	0.14	5.49
10	1.73	1.83	26.16	39.09	1.49	0.09	2.62E-06	0.12	4.56
11	1.73	1.83	26.16	39.09	1.49	0.09	2.51E-06	0.11	4.46
12	1.73	1.83	26.16	39.09	1.49	0.09	2.14E-06	0.11	4.12
13	1.73	1.83	26.16	39.09	1.49	0.08	1.80E-06	0.10	3.78
14	1.68	1.78	26.06	37.87	1.45	0.08	2.05E-06	0.10	3.83
15	1.67	1.77	26.03	37.53	1.44	0.10	3.32E-06	0.13	4.81
16	1.62	1.72	25.95	36.50	1.41	0.12	4.76E-06	0.15	5.51
17	1.60	1.70	25.91	36.05	1.39	0.12	4.35E-06	0.14	5.17
18	1.56	1.66	25.82	35.04	1.36	0.12	4.46E-06	0.14	5.00
19	1.52	1.62	25.73	33.91	1.32	0.11	4.36E-06	0.14	4.70
20	1.51	1.61	25.71	33.72	1.31	0.12	4.62E-06	0.14	4.79
21	1.46	1.56	25.62	32.61	1.27	0.12	4.76E-06	0.14	4.61
22	1.46	1.56	25.62	32.61	1.27	0.11	4.20E-06	0.13	4.33
23	1.44	1.54	25.57	32.04	1.25	0.11	3.89E-06	0.13	4.05
24	1.39	1.49	25.49	31.01	1.22	0.11	4.24E-06	0.13	4.01
25	1.34	1.44	25.37	29.59	1.17	0.09	3.00E-06	0.11	3.14
26	1.29	1.39	25.28	28.46	1.13	0.10	4.01E-06	0.12	3.40
27	1.28	1.38	25.26	28.27	1.12	0.28	3.17E-05	0.33	9.46
28	1.41	1.51	25.51	31.32	1.23	0.24	2.04E-05	0.29	8.95
29	1.39	1.49	25.47	30.81	1.21	0.12	4.84E-06	0.14	4.24
30	1.35	1.45	25.40	30.00	1.18	0.10	3.97E-06	0.12	3.69

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: July, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.32	1.42	25.34	29.18	1.15	0.14	7.00E-06	0.16	4.68
2	1.34	1.44	25.38	29.73	1.17	0.14	7.40E-06	0.17	4.96
3	1.30	1.40	25.30	28.70	1.13	0.09	3.23E-06	0.11	3.10
4	1.26	1.36	25.21	27.69	1.10	0.11	4.44E-06	0.12	3.43
5	1.20	1.30	25.10	26.37	1.05	0.11	4.82E-06	0.13	3.30
6	1.14	1.24	24.97	24.79	0.99	0.11	5.69E-06	0.13	3.25
7	1.08	1.18	24.85	23.35	0.94	0.11	6.01E-06	0.13	3.03
8	1.01	1.11	24.72	21.77	0.88	0.10	5.33E-06	0.12	2.55
9	0.94	1.04	24.59	20.21	0.82	0.11	6.87E-06	0.13	2.56
10	0.89	0.99	24.47	18.79	0.77	0.12	7.88E-06	0.13	2.44
11	0.80	0.90	24.31	16.82	0.69	0.12	8.90E-06	0.13	2.17
12	0.76	0.86	24.21	15.72	0.65	0.23	3.45E-05	0.24	3.82
13	0.76	0.86	24.21	15.72	0.65	0.26	4.64E-05	0.28	4.43
14	0.72	0.82	24.15	14.90	0.62	0.20	2.87E-05	0.21	3.19
15	0.66	0.76	24.03	13.49	0.56	0.20	3.03E-05	0.21	2.79
16	0.62	0.72	23.28	12.44	0.53	0.21	3.48E-05	0.21	2.67
17	0.54	0.64	22.04	10.66	0.48	0.23	4.75E-05	0.23	2.50
18	0.47	0.57	21.15	9.15	0.43	0.31	9.51E-05	0.31	2.82
19	0.42	0.52	20.52	8.07	0.39	0.40	1.79E-04	0.40	3.20
20	0.39	0.49	20.14	7.42	0.37	0.60	4.25E-04	0.59	4.34
21	0.40	0.50	20.27	7.64	0.38	0.72	6.08E-04	0.71	5.43
22	0.36	0.46	19.76	6.78	0.34	0.69	6.08E-04	0.67	4.53
23	0.40	0.50	20.27	7.64	0.38	0.68	5.49E-04	0.68	5.16
24	0.37	0.47	19.89	6.99	0.35	0.75	7.08E-04	0.73	5.11
25	1.43	1.53	25.57	31.94	1.25	1.66	9.74E-04	2.00	63.82
26	1.92	2.02	26.53	43.53	1.64	EMR			
27	2.07	2.17	26.83	47.11	1.76	EMR			
28	1.98	2.08	26.65	45.00	1.69	EMR			
29	1.90	2.00	26.50	43.17	1.63	EMR			
30	1.83	1.93	26.36	41.49	1.57	EMR			
31	1.77	1.87	26.24	40.05	1.53	EMR			

EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: August, 1990

Day	Probe Depth (ft)	Invert Depth 1 (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.70	1.80	26.09	38.28	1.47	0.04	4.59E-07	0.05	1.85
2	1.61	1.71	25.92	36.17	1.40	0.04	4.82E-07	0.05	1.73
3	1.55	1.65	25.80	34.75	1.35	0.04	4.99E-07	0.05	1.65
4	1.48	1.58	25.66	33.02	1.29	0.04	5.23E-07	0.05	1.56
5	1.41	1.51	25.51	31.29	1.23	0.04	5.48E-07	0.05	1.47
6	1.20	1.30	25.10	26.35	1.05	0.10	4.21E-06	0.12	3.08
7	1.06	1.16	24.81	22.89	0.92	0.21	2.05E-05	0.24	5.43
8	1.15	1.25	25.00	25.13	1.01	0.50	1.09E-04	0.58	14.51
9	1.19	1.29	25.08	26.11	1.04	0.21	1.79E-05	0.24	6.25
10	1.19	1.29	25.08	26.13	1.04	0.21	1.89E-05	0.25	6.44
11	2.17	2.27	27.04	49.68	1.84	0.51	6.14E-05	0.65	32.21
12	2.42	2.52	27.54	55.68	2.02	NMR			
13	1.94	2.04	26.59	44.18	1.66	0.33	2.90E-05	0.42	18.41
14	1.90	2.00	26.51	43.22	1.63	0.26	1.83E-05	0.33	14.15
15	1.81	1.91	26.32	40.99	1.56	0.21	1.22E-05	0.26	10.60
16	1.74	1.84	26.18	39.33	1.50	0.18	9.54E-06	0.22	8.79
17	1.67	1.77	26.05	37.73	1.45	0.16	7.62E-06	0.20	7.36
18	1.60	1.70	25.91	36.05	1.39	0.16	7.74E-06	0.19	6.89
19	1.62	1.72	25.94	36.43	1.40	0.32	3.29E-05	0.40	14.45
20	1.65	1.75	26.00	37.20	1.43	0.20	1.18E-05	0.24	8.93
21	1.59	1.69	25.88	35.73	1.38	0.14	6.64E-06	0.18	6.30
22	1.55	1.65	25.81	34.85	1.35	0.12	4.80E-06	0.15	5.14
23	1.58	1.68	25.86	35.52	1.37	0.26	2.13E-05	0.31	11.17
24	1.61	1.71	25.92	36.17	1.40	0.16	8.01E-06	0.20	7.05
25	2.53	2.63	27.77	58.37	2.10	0.38	2.97E-05	0.49	28.81
26	2.37	2.47	27.43	54.31	1.98	0.11	2.85E-06	0.15	7.98
27	2.14	2.24	26.99	49.01	1.82	0.06	9.98E-07	0.08	4.02
28	2.00	2.10	26.70	45.50	1.70	0.05	6.23E-07	0.06	2.83
29	1.89	1.99	26.49	42.98	1.62	0.08	1.57E-06	0.10	4.11
30	1.81	1.91	26.32	40.97	1.56	0.08	1.73E-06	0.10	3.99
31	1.76	1.86	26.21	39.69	1.51	0.08	1.78E-06	0.10	3.85

NMR - No measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: September, 1990

Day	Probe Depth (ft)	1 Invert Depth (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	2 R (ft)	Bottom Velocity (ft/s)	3 Energy Slope (ft/ft)	4 Average Velocity (ft/s)	5 Flow (cfs)
1	1.72	1.82	26.14	38.81	1.48	0.08	1.81E-06	0.10	3.75
2	1.66	1.76	26.03	37.46	1.44	0.08	1.87E-06	0.10	3.60
3	1.61	1.71	25.92	36.14	1.39	0.08	1.93E-06	0.10	3.46
4	1.56	1.66	25.82	34.99	1.36	0.07	1.69E-06	0.09	3.08
5	1.52	1.62	25.73	33.91	1.32	0.08	1.94E-06	0.09	3.13
6	1.48	1.58	25.65	33.00	1.29	0.09	2.91E-06	0.11	3.67
7	1.44	1.54	25.57	32.01	1.25	0.12	4.84E-06	0.14	4.51
8	1.39	1.49	25.49	30.98	1.22	0.11	4.65E-06	0.14	4.20
9	1.35	1.45	25.40	30.00	1.18	0.10	3.90E-06	0.12	3.65
10	1.35	1.45	25.40	30.00	1.18	0.12	5.48E-06	0.14	4.33
11	1.35	1.45	25.40	30.00	1.18	0.11	4.70E-06	0.13	4.01
12	1.31	1.41	25.31	28.89	1.14	0.07	1.90E-06	0.08	2.40
13	1.30	1.40	25.30	28.70	1.13	0.09	2.88E-06	0.10	2.93
14	1.25	1.35	25.21	27.65	1.10	0.08	2.52E-06	0.09	2.57
15	1.30	1.40	25.30	28.75	1.14	0.25	2.45E-05	0.30	8.55
16	1.35	1.45	25.40	30.00	1.18	0.14	7.34E-06	0.17	5.01
17	1.34	1.44	25.37	29.64	1.17	0.11	4.17E-06	0.13	3.71
18	1.30	1.40	25.29	28.63	1.13	0.08	2.38E-06	0.09	2.65
19	1.24	1.34	25.19	27.41	1.09	0.08	2.47E-06	0.09	2.52
20	1.26	1.36	25.23	27.86	1.10	0.15	8.54E-06	0.17	4.80
21	1.24	1.34	25.19	27.41	1.09	0.08	2.54E-06	0.09	2.55
22	1.20	1.30	25.11	26.45	1.05	0.08	2.89E-06	0.10	2.57
23	1.29	1.39	25.29	28.58	1.13	0.22	1.84E-05	0.26	7.35
24	1.29	1.39	25.27	28.41	1.12	0.09	2.98E-06	0.10	2.93
25	1.24	1.34	25.19	27.41	1.09	0.08	2.47E-06	0.09	2.52
26	1.21	1.31	25.12	26.64	1.06	0.08	2.54E-06	0.09	2.43
27	1.19	1.29	25.08	26.11	1.04	0.08	2.58E-06	0.09	2.38
28	1.12	1.22	24.93	24.36	0.98	0.08	2.75E-06	0.09	2.20
29	1.07	1.17	24.85	23.33	0.94	0.08	2.87E-06	0.09	2.09
30	1.03	1.13	24.76	22.22	0.90	0.08	3.00E-06	0.09	1.98

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(33002(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Daily Average Flows Measured in Fowle Brook at Streamgauge Site 4: October, 1990

Day	Probe Depth (ft)	Invert Depth[1] (ft)	Wetted Perimeter (ft)	Flow Area (sq ft)	R[2] (ft)	Bottom Velocity (ft/s)	Energy Slope[3] (ft/ft)	Average Velocity[4] (ft/s)	Flow[5] (cfs)
1	1.07	1.17	24.84	23.25	0.94	0.18	1.46E-05	0.20	4.70
2	1.03	1.13	24.75	22.17	0.90	0.08	3.00E-06	0.09	1.97
3	0.98	1.08	24.65	20.95	0.85	0.08	3.17E-06	0.09	1.85
4	0.98	1.08	24.65	20.95	0.85	0.10	5.31E-06	0.11	2.39
5	1.03	1.13	24.76	22.22	0.90	0.17	1.41E-05	0.19	4.28
6	1.03	1.13	24.76	22.22	0.90	0.08	3.15E-06	0.09	2.03
7	0.99	1.09	24.67	21.19	0.86	0.08	3.13E-06	0.09	1.87
8	0.96	1.06	24.62	20.64	0.84	0.08	3.21E-06	0.09	1.81
9	1.12	1.22	24.94	24.45	0.98	0.43	8.19E-05	0.49	12.05
10	1.19	1.29	25.08	26.11	1.04	0.14	8.09E-06	0.16	4.21
11	1.19	1.29	25.08	26.11	1.04	0.11	5.23E-06	0.13	3.39
12	1.16	1.26	25.02	25.37	1.01	0.10	4.36E-06	0.12	2.95
13	1.29	1.39	25.29	28.61	1.13	0.34	4.49E-05	0.40	11.49
14	3.24	3.34	29.18	75.36	2.58	0.05	4.81E-07	0.07	5.43
15	2.53	2.63	27.76	58.25	2.10	NMR			
16	2.17	2.27	27.04	49.68	1.84	NMR			
17	1.96	2.06	26.61	44.47	1.67	0.04	4.03E-07	0.05	2.19
18	1.80	1.90	26.31	40.85	1.55	0.04	4.33E-07	0.05	1.99
19	2.09	2.19	26.87	47.64	1.77	0.04	3.80E-07	0.05	2.37
20	2.00	2.10	26.69	45.43	1.70	NMR			
21	1.87	1.97	26.43	42.36	1.60	NMR			
22	1.77	1.87	26.24	40.05	1.53	0.04	4.41E-07	0.05	1.94
23	1.73	1.83	26.16	39.05	1.49	0.04	4.51E-07	0.05	1.89
24	2.11	2.21	26.92	48.19	1.79	NMR			
25	2.06	2.16	26.83	47.06	1.75	EMR			
26	NMR					NMR			
27	NMR					NMR			
28	NMR					NMR			
29	NMR					NMR			
30	NMR					NMR			
31	NMR					NMR			

NMR - No measurements recorded
EMR - Erroneous measurements recorded

1. Depth of water at deepest point in cross-section.
2. R = Hydraulic radius; R = flow area / wetted perimeter.
3. Energy slope (S) = (bottom velocity)^2/(54.42R(ln(3300Z(.031/n)^6))^2)
4. Calculated from Manning's equation: V =(1.49/n)R^2/3*S^1/2
5. Flow = average velocity * flow area.

Disk 4.1

Complete Streamflow Records from Four Gauging Sites in the Aberjona Watershed

Raw data files compiled at monthly downloading intervals are presented for each streamgauging site. All data points collected over the period of record are contained in the files. The raw data can be accessed by creating "processed" data files using the Wizard Software (© Coastal Leasing, Inc.) provided. The Disk is a 1.4 megabyte high density floppy formatted for an IBM PC or IBM-compatible computer.