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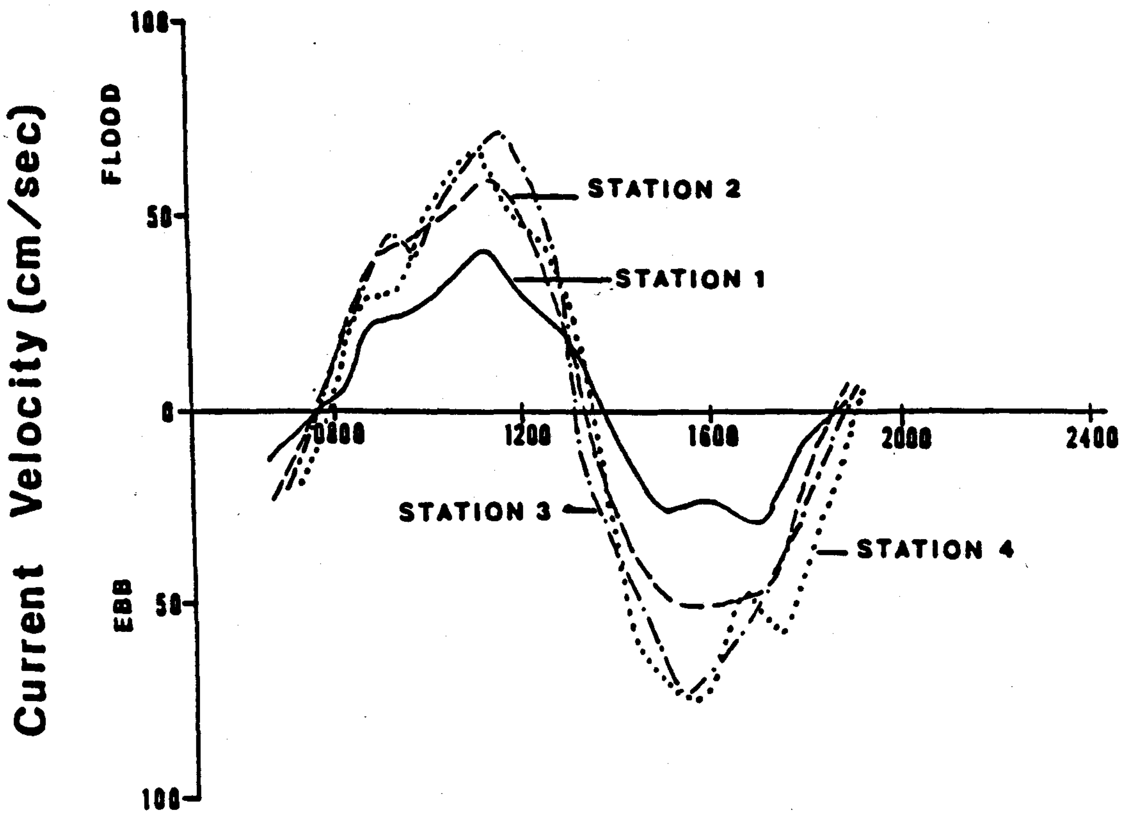
RELATIONSHIPS BETWEEN SUSPENDED SEDIMENT AND THE MOVEMENT OF BACTERIA IN THE EAST BRANCH OF THE WESTPORT RIVER



Fall 1986

Hydrogeology Research Group
Department of Geology
Boston University
Boston, Massachusetts

TECHNICAL REPORT #5

RELATIONSHIPS BETWEEN SUSPENDED SEDIMENT AND THE MOVEMENT OF BACTERIA IN THE EAST BRANCH OF THE WESTPORT RIVER

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Abstract

Shellfish beds of the East Branch of the Westport River, an estuary located in southeastern Massachusetts, are affected by bacterial contamination. The sources of bacteria are primarily agricultural with some occasional human input. Suspended sediment exacerbates bacterial pollution, resulting in continued closure of affected shellfish beds.

The sources, movement, and behavior of suspended sediment in the East Branch were studied to identify pollution sources in the Westport River system. Field work examined the tidal conditions in the estuary and the hydrology of the East Branch tributaries. Water samples taken to quantify the amounts of suspended sediment being transported in the estuary indicated that 4.5×10^6 Kg of suspended sediment was contributed from the marine environment annually. Long term USGS records used to estimate suspended sediment loads introduced by tributaries indicated that 0.59×10^6 Kg of suspended sediment was delivered to the estuary annually by tributary streams.

Sedimentation occurs throughout the estuary and is most pronounced in the upstream portion of the estuary. Suspended sediment concentrations of 2.4 mg/L to 3.4 mg/L and sedimentation rates of 0.40 mm/yr to 0.84 mm/yr in the East Branch are generally lower than the 4.0 mg/L to 36 mg/L concentrations and 0.7 mm/yr to 4 mm/yr of sedimentation in other estuaries along the East Coast. Suspended sediment concentrations and sedimentation rates are comparable to the larger Narragansett Bay estuary to the west.

Sedimentation and the transport into the estuary of suspended sediment associated with bacteria may contribute to the contamination problem in the East Branch. Continuing bacterial inputs and ineffective flushing by the tides and freshwater streams prolongs the contamination of the shellfish beds in the East Branch.

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INTRODUCTION

The East Branch of the Westport River in southeastern Massachusetts is a coastal plain estuary emptying into Rhode Island Sound. It is located in the Town of Westport, Massachusetts, situated midway between the cities of Fall River and New Bedford. The estuary has had a locally important shellfish harvest which in the last ten years has been progressively threatened by bacterial contamination. The shellfish beds have been closed in some areas of the estuary. In 1984, the Hydrogeology Research Group of the Geology Department at Boston University was asked by the Town of Westport Board of Health to conduct a study of the river and estuary to determine the sources, magnitudes, and significance of the pollution sources, and to recommend steps that might be taken to reduce the bacterial contamination that would lead to a cleaner river and a reopening of the shellfish beds.

The study was led by Professors Duncan FitzGerald and Dee Caldwell of the Geology Department, with the day to day operation of the project under the direction of Edward F. Kelly, Jr., a doctoral student in the Geology Department. The work presented here arose from this project, under the funding of the Town of Westport. It draws on the field work and lab work of the East Branch project, and on the analyses and conclusions reached as part of that project. It examines some areas in greater depth, covers additional areas, and presents some new analyses and conclusions.

Several aspects of the East Branch of the Westport River are examined in depth, including the hydrology of the watershed and the surrounding region, physical characteristics of the estuary, and the transport and behavior of suspended sediment in the river and estuary.

The Westport River drainage area (143.1 km^2) and place names are shown on Figures 1 and 2. Individual drainage areas in the study area are indicated in Figure 3. A conversion table for SI and English units is given in Table 1.

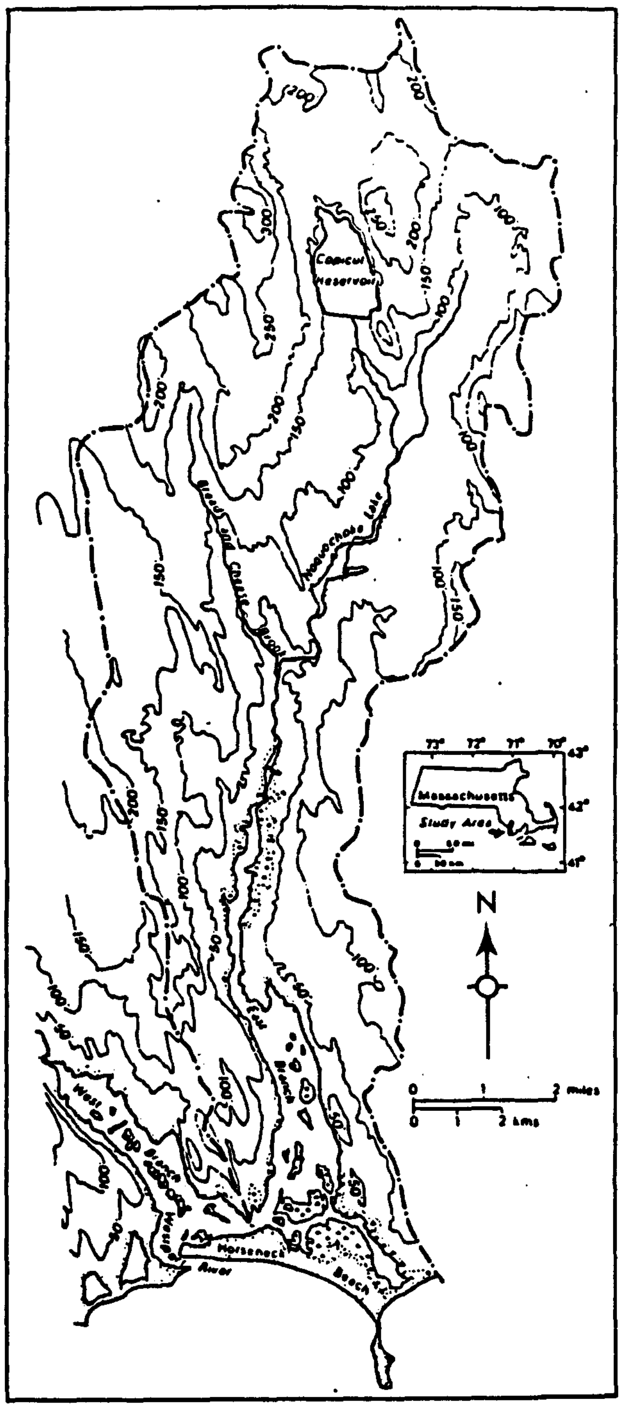


Figure 1. Map of the study area, indicating the East and West Branches of the Westport River; Bread and Cheese Brook, a major tributary to the East Branch; fifty foot topographic contours (solid lines); and the East Branch drainage area boundaries (dashed line).

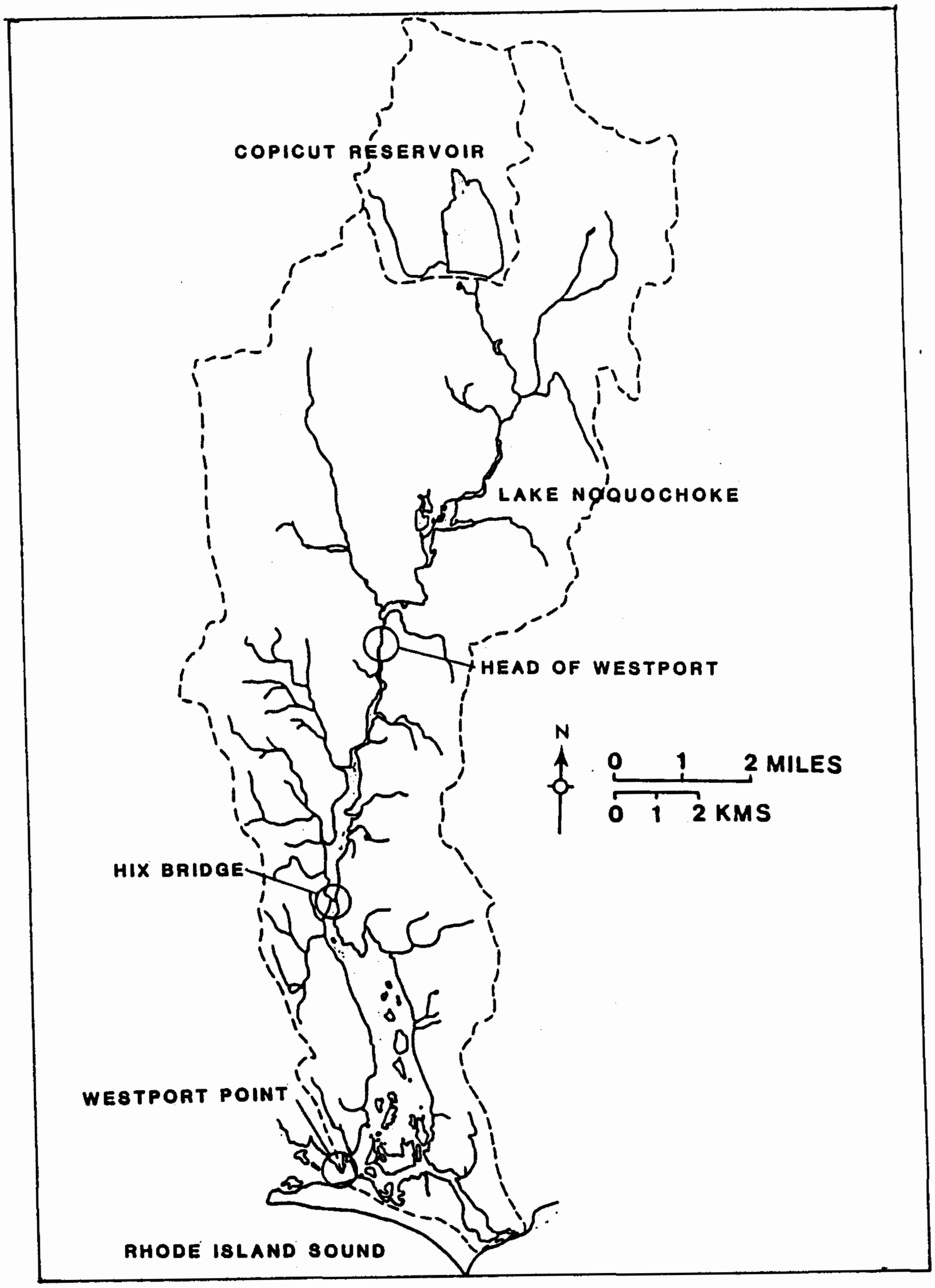


Figure 2. Map of the East Branch drainage area indicating names of major features frequently referred to in the text. Hix Bridge and Westport are the locations of much of the hydrographical and suspended sediment work mentioned in the text.

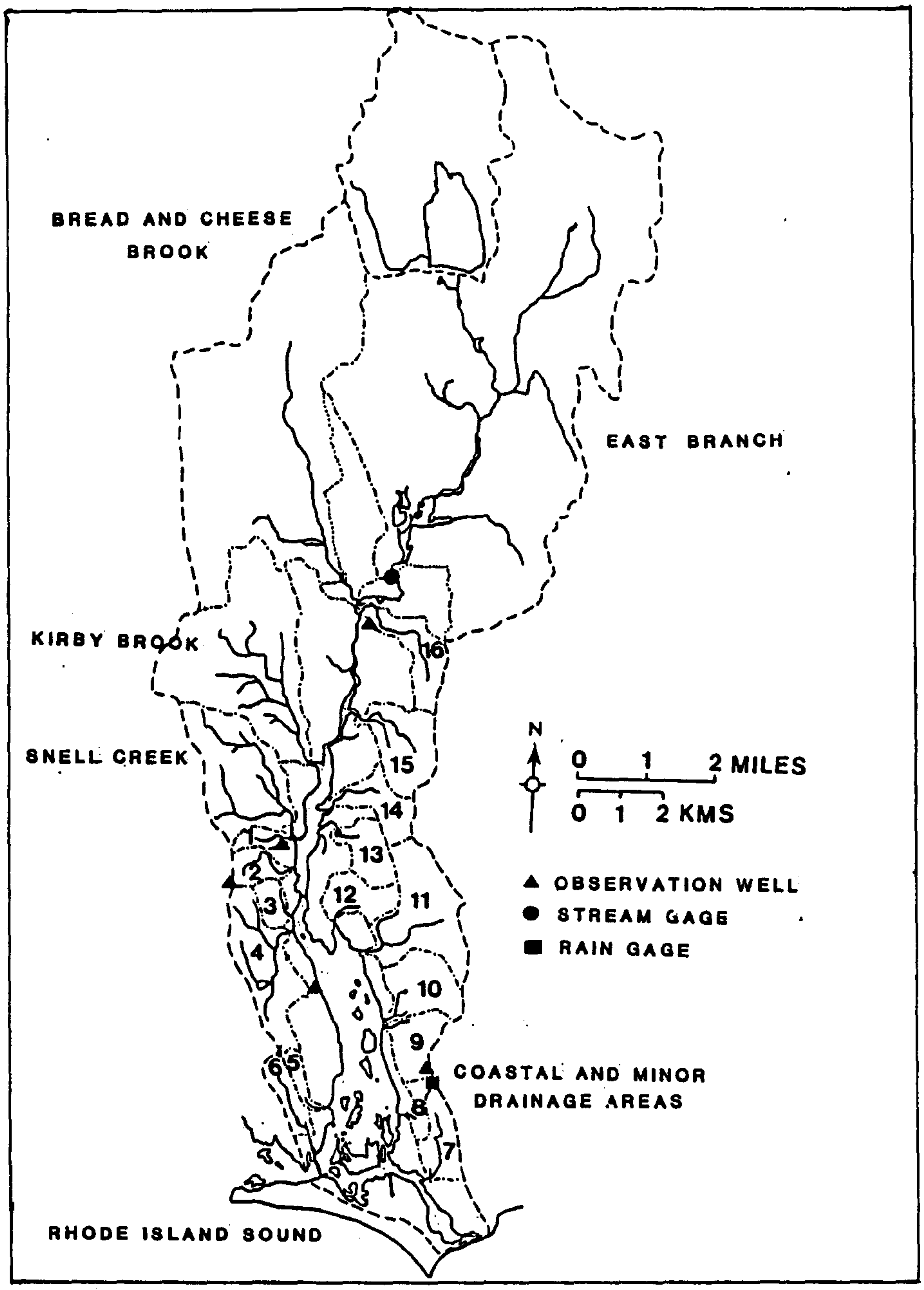


Figure 3. Map of the individual drainage areas in the East Branch watershed. The dashed line indicates the boundary of the East Branch watershed while dashed and dotted lines are boundaries of individual drainage areas. The major tributaries are named: the East Branch, Bread and Cheese Brook, Kirby Brook, and Snell Creek. The minor tributary drainage areas are assigned numbers from 1 to 16. The locations of the stream gage, rain gage, and observation wells used in the study are shown.

Table 1. SI-English Conversions
(after Dunne and Leopold, 1978)

Metric to English

Length

1 cm = 0.3941 inch
1 m = 39.37 inches
3.281 feet
1 km = 0.6214 mile

Volume

1 m^3 = 35.31 ft^3
1 L = 0.2642 gallon

Area

1 m^2 = 10.76 ft^2
1 km^2 = 0.3861 mi^2
247.1 acre
1 ha = 0.00386 mi^2
2.471 acre

1 km^2 = 100 ha

Weight

1 gm = 0.0353 oz
1 kg = 2.205 lbs
1 t = 2205 lbs

1 t = 1000 kg

Velocity

1 m/sec = 3.281 ft/sec

Discharge

1 m^3/sec = 35.32 cfs

English to Metric

Length

1 in = 2.54 cm
1 ft = 0.3048 m
1 mi = 1.609 km

Volume

1 ft^3 = 28.32 L

1 ft^3 = 7.480 gallon

Area

1 ft^2 = 0.0929 m^2
1 mi^2 = 2.590 km^2
1 mi^2 = 259 ha

1 mi = 640 acre

Weight

1 oz = 28.35 gm
1 lb = 0.4536 Kg
1 ton =907.2 Kg

Velocity

1 ft/sec = 0.3048 m/sec

Discharge

1 cfs = 0.0283 m^3/sec

PREVIOUS WORK

The Westport River has been the subject of previous research relating to hydrology, tidal processes, environmental assessment, and bacterial contamination.

Work related to the environmental health and the bacterial contamination of the river includes a study by Fiske (1968) of the marine resources of the river, work by Packard (1979) of the bacterial contamination and pollution sources in the river that led to the first closures of the shellfish beds, investigations by the Westport Shellfish Warden, Dave Roach, of bacterial levels and sources (Westport Shellfish Advisory Committee, 1983), and a plan for the management of the shellfish beds (Westport Shellfish Department). Additional testing has been completed by the FDA in 1982-1983, and the Massachusetts Department of Environmental Quality Engineering in 1983 (Dave Roach, pers. comm.). Related work includes studies by the Rural Clean Water Program (1984, 1985) of bacterial and other water quality parameter testing, and analyses of land use, erosion control, and manure management practices. An environmental assessment of the river was completed in 1985 (Westport Greenway Protection Plan, 1985). Geological mapping in the region includes the preparation of the Massachusetts Bedrock Map (Zen et al., 1983) and a USGS Hydrologic Atlas (Willey et al., 1978).

This thesis developed out of a study from 1984 to 1986 of the bacterial contamination and sources in the East Branch of the Westport River (Kelly et al., 1986). A companion study was started in the West Branch of the Westport River in 1985 (Kelly, pers. comm.). Work concurrent with the East Branch study included testing by a private environmental consulting firm, GHR, of Lakeville, Massachusetts, and bacterial analysis through the Westport High School (Kelly, pers. comm.). The Town of Westport and the surrounding area have been the site of a number of field research programs involving groundwater contamination, tidal inlet processes, beach development, and hydrographic studies (Caldwell, FitzGerald, pers. comm.).

GEOLOGY

Bedrock Geology

The study area is located in the Milford-Dedham Zone in the tectonic classification of Massachusetts (Zen et al., 1983). The bedrock geology consists of Upper Proterozoic quartzites, volcanic, and plutonic rocks that are intruded by Upper Proterozoic calc-alkalic granites of the Brittlely Deformed Terrane or that are metamorphosed to a gneiss of the Gneissic Terrane. The area of the estuary is divided into the Brittlely Deformed Terrane and the Gneissic Terrane. To the north and northwest is the Narragansett Basin (Zen et al., 1983).

Intrusive bedrock in the area includes diorite at East Horseneck Beach while the lower part of the estuary to near Gunning Island is underlain by porphyritic granite. Extending north from Gunning Island to Cadman Neck and to the northwest of the Westport River is a granite of the Fall River Pluton. To the northwest and west of the river, north to the Head of Westport is alaskite, a mafic-poor gneiss and granite. Metamorphic equivalents of sedimentary and volcanic rocks include gneiss and schist extending from Cadman Neck to the region around Snell Creek and along the East Branch to the northeast (Zen et al., 1983).

Metamorphism in the region is of Proterozoic age. The lower part of the estuary is underlain by rocks of a middle grade metamorphism zone, with mostly feldspathic gneiss and amphibolites. There are few indicators of metamorphic grade. The northern half of the study area lies in a low grade zone with primarily greenschist, greenstone, felsite, and quartzite, that is commonly enveloped in granite (Zen et al., 1983).

Structure in the region includes an interpreted fault trending northeasterly from the West Branch to the East Branch near Snell Creek, then past Lake Noquochoke (Zen et al., 1983).

Surficial Geology

The surficial geology of the study area has been mapped as part of the Hydrologic Investigations of the USGS (Willey et al., 1978, 1983). This published map was field checked as part of the East Branch study. The surficial geology is indicated in Figure 4.

The area was glaciated during the Pleistocene with a number of late-glacial ice margin positions occurring just to the south. Surficial deposits date from the Wisconsinan, from 18,000 years ago to 15,000 years ago. These deposits include both glacial outwash, generally in valleys, and till on higher elevations. These deposits mantle most of the area, and vary in thickness from 3.5 m to 27.5 m, as indicated by well logs and test boring records published by the USGS (Willey et al., 1983). The meltwater deposits range from fine to coarse sand to fine to coarse gravel. They are generally permeable but with high variability. The till is more compact and unsorted and is much less permeable (Willey et al., 1978; Caldwell, pers. comm.; Geraghty et al., 1973).

Bedrock crops out in a number of areas in the lower portion of the estuary, as islands. Scattered bedrock outcrops also occur near Hix Bridge, Kirby Brook, and southeast and east of Lake Noquochoke. Sand

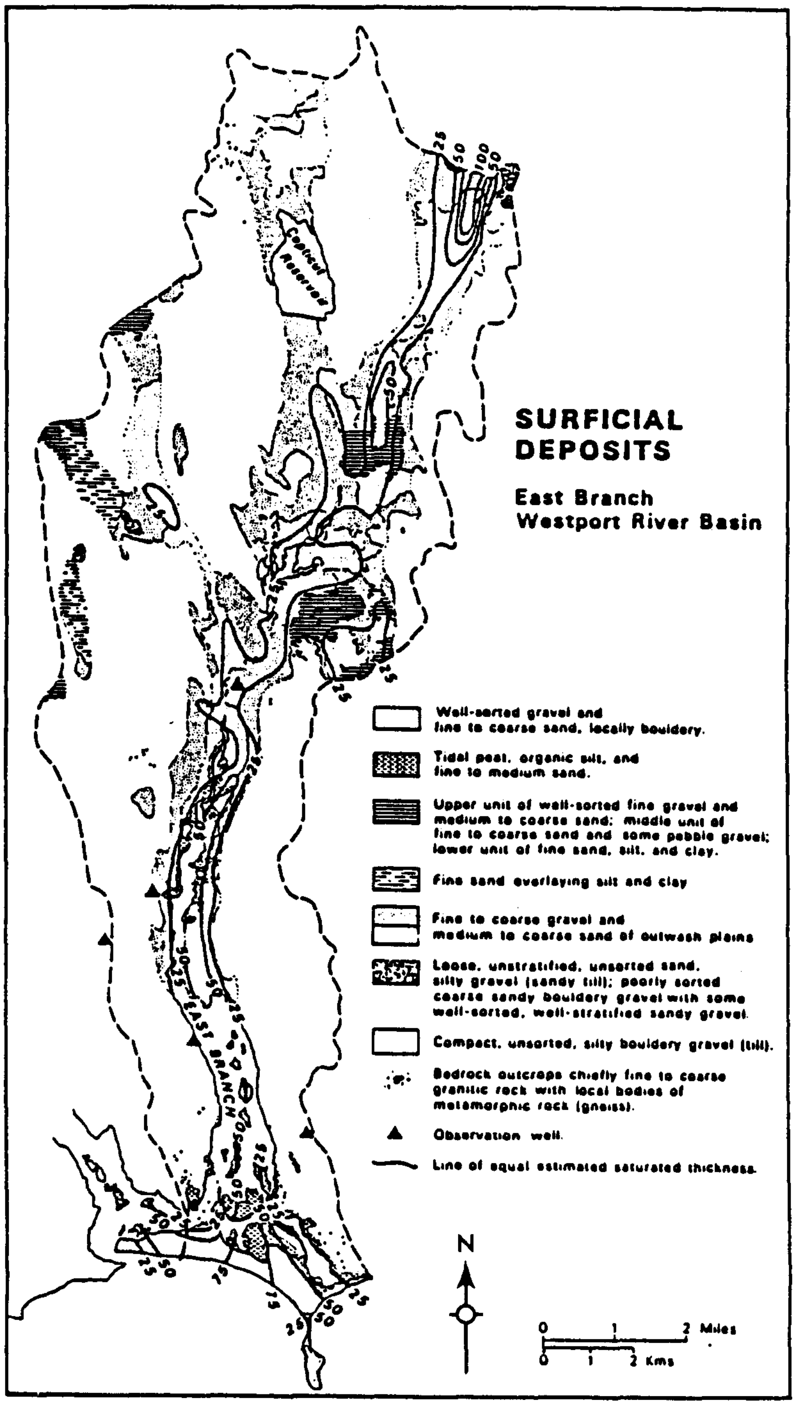


Figure 4. Map of the East Branch of the Westport River, showing the distribution of the surficial geologic deposits (Kelly et al., 1986).

and gravel beach deposits form most of the land surface south of the estuary, between the East Branch and Rhode Island Sound. Tidal peat, organic silt, and sand are found in the southernmost portion of the East Branch estuary, as well as along the shore between Hix Bridge and the Head of Westport. Glacial outwash sands and gravels are found extending along much of the shore of the East Branch from just south of Hix Bridge, past the Head of Westport and Lake Noquochoke, to the northern drainage divide of the main East Branch tributaries entering Lake Noquochoke. Sand and gravel with some silt and clay are found in areas southeast and northeast of Lake Noquochoke as kame delta deposits. Minor areas of sandy, silty, or bouldery gravels formed in glacial end moraines are found near the west-central and northeastern boundaries of the drainage area. Roughly one half of the study area consists of till overlying bedrock, forming ground moraine and drumlins. The till areas include most of the study area between Hix Bridge and Westport Point, the upland areas along the western and eastern edges of the central portion of the study area, and much of the northwestern portion and some of the northeastern portions of the East Branch drainage area (Willey et al., 1978).

Soils

Water quality in the estuarine environment of the East Branch may be adversely affected by soil that has been eroded and transported into the estuary. The Soil Conservation Service has mapped the soils in the area and classified them on the basis of slope as well as type. The entire East Branch watershed lies within the Paxton-Woodbridge-

Whitman association of soils, with well to very poorly drained soils on nearly level to moderately steep slopes (Soil Conservation Service, 1981).

The Paxton soils include a fine sandy loam, a very stony fine sandy loam, and an extremely stony fine sandy loam and are found on hills and ridges. They formed from compact glacial till and are deep and well drained. The Woodbridge soils are a fine sandy loam, a very stony fine sandy loam, and an extremely stony fine sandy loam on nearly level to gently sloping land. These are formed in a compact glacial till and are deep moderately well drained soils. The Whitman soils are a fine sandy loam and an extremely stony fine sandy loam formed from glacial till on uplands. They are deep and poorly drained. Other soils include the Gloucester-Hinckley complex, a fine sandy loam and gravelly fine sandy loam, and the Hinckley gravelly fine sandy loam. Numerous other minor soil types are also present (Soil Conservation Service, 1981).

LAND USE

Aerial photographs of the East Branch were obtained from the EROS Data Center of the United States Geological Survey, of the most recent aerial photograph mapping. The photographs were black and white images taken in 1980, at an approximate scale of 1:24,000.

The photographs were examined to determine land use practices and to observe circulation patterns and suspended sediment movement in the estuary. The analysis of land use provided information as to the location and extent of farmland and pasture. Farmland or open pastureland occupied much of the eastern shore of the estuary from below Gunning Island to Cadman Cove. This type of land use extends along the shore in a band ranging from approximately 300 to 450 meters from the shore landward. There is little photographic evidence of significant woodland vegetation between the shore and this open land. Significant non-cultivated land does not begin until half the distance from the shore to Horseneck Road near the eastern drainage divide. There are three clusters of housing along the eastern shore of the river. The western side of the estuary has much less open cultivated land bordering the water, with most of the land used for residential purposes. There is some cultivated land along Drift Road between Hix Bridge and Westport Point, however, from Drift Road west to the drainage divide is mostly undeveloped vegetated land.

Much of the land along the estuary from Cadman Cove to about 600 meters north of Hix Bridge is open cultivated land. Some trees are present in a very narrow band along the shore. The western shore in this same area is primarily residential. There is a significant amount of open cultivated land along the west shore from below Snell Creek to above Kirby Brook, between Drift Road and the water.

Land uses in the entire Town of Westport have been mapped by a town committee (Westport Master Plan Update Committee, 1983). Forests occupy the greatest percentage of the land (53.2%), agricultural land (18.5%), lakes and non-forested wetlands (15.9%), and developed land (10.2%) (Westport Master Plan Update Committee, 1983). Aerial photographs revealed that overall, most of the land used for farmland, cultivation, or residences appears to be along the shore of the river and estuary, extending in a band 150 to 900 meters wide. Most of the forested and undeveloped land is found farther from the estuary and nearer to the drainage divide.

These land use patterns indicate that there is a definite potential for soil erosion due to the location of the cultivated farmland, bare fields, or pastures next to the river. Rainsplash can more easily dislodge and subsequently transport soil particles through overland flow, either into tributaries or directly into the estuary, given the proximity of bare fields close to the estuary.

WATER QUALITY

The primary focus of the East Branch study was to assess the water quality in the estuary and to locate fecal bacteria pollution sources. Fecal coliform and fecal streptococci indicator bacteria counts in water can be used to assess the quality of the water due to extensive studies indicating the association of pathogenic species with the fecal indicator bacteria (Geldrich, 1969). A number of human diseases are transmitted by bacteria of animal origin with surface water serving as a mode of transportation (Kress and Gifford, 1984).

Fecal material from cattle has been shown experimentally to be a source of significant fecal coliform bacteria with runoff from fresh cow manure deposits having significantly higher bacteria counts than did old deposits. However, even fecal deposits 100 days old produced bacterial counts in surface runoff to nearby water bodies in excess of recreational water quality standards (Kress and Gifford, 1984). Contamination of shellfish beds by sewage can lead to infectious hepatitis in humans when raw shellfish are consumed (Metcalf and Stiles, 1968).

An extensive water sampling program for the fecal indicator bacteria fecal coliform and fecal streptococci was undertaken from August 1984 to September 1985 throughout the East Branch, Westport River watershed, with samplings at approximately one month intervals. Water samples were collected on foot or from a boat in sterile sampling bags and transported to the laboratory at Boston University for membrane filtration within 4 to 10 hours after collection.

Several initial samplings involved the collection of water samples from 100 sites located throughout the entire drainage area. The bacterial count results from these initial samplings were used to identify approximately 50 sites with higher bacteria counts as suspected pollution sources or localities. These critical areas were monitored during each of the subsequent samplings, as were other sites throughout the drainage area and estuary to establish background counts and to assess the movement of the bacteria. Additional sampling locations were continually added in order to pinpoint specific pollution sources by tracking the presence of higher than normal bacteria counts to an ever more limited area.

The membrane filtration method was used to provide data on the bacterial counts in the water samples due to its adaptibility to rapid and economical analysis of a large number of water samples. The general membrane filtration method as outlined by the USGS, EPA, and in "Standard Methods" was followed (Greeson et al., 1977; Bordner et al., 1977; American Public Health Association, 1980). Modifications of the method were made in order to increase the recovery of bacteria from the saline water. These included using a two stage incubation process and a buffered nutrient solution in filtering the samples.

Appropriate volumes of the water samples were filtered through sterile membrane filters using individual sterilized filter holder assemblies. The water for the determination of fecal coliform bacteria was filtered through 0.7 micron mean pore size filters and the water for fecal streptococci through 0.45 micron mean pore size filters. The filters were rinsed several times with a nutrient enriched buffered dilution water. The filters were then placed on a nutrient in 47 mm plastic petri dishes and incubated. The fecal coliform filters were placed on pads soaked with M-FC broth and incubated at 35 ^{o}C for 3 to 5 hours and then at 44.5 ^{o}C for the remainder of a 24 hour period. The fecal streptococci filters were placed on KF Agar in the petri dishes and incubated at 35 ^{o}C for 48 hours. At the end of each incubation period the filters were examined under low magnification and the bacteria colonies counted. The bacteria colony counts were then expressed as the number of colonies per 100 ml water. The bacteriological analysis data are listed in Appendix 1.

The fecal coliform to fecal streptococci ratio has been shown to be indicative of the source of fecal bacteria pollution, with a ratio of 4.4 or higher indicating a human origin and a ratio of 0.7 or less indicative of an animal or agricultural source. Ratios between 0.7 and 4.4 are indicative of mixed sources (Geldrich, 1970). In order to use this ratio, the sample collection and laboratory analysis must be completed within 24 hours of precipitation, due to differential bacterial die-off rates after this period. In most cases, the sampling and analysis in the East Branch was completed within 24 hours of a precipitation event.

The strength of this method for enumerating the bacteria counts and identifying the pollution sources in the East Branch was the ability to use the relative bacteria counts to assess the location and significance of the bacterial pollution sources. The method did not have to provide exact bacteria counts in order to determine the relative importance of the counts and sources at different locations.

A number of pollution sources were determined by the water sampling program and data analyses. The pollution sources were primarily agricultural. Three large farms, located at the confluence of the East Branch and Bread and Cheese Brook, along stream #15, and along stream #10, were found to be significant pollution sources. These streams are indicated in Figure 3. Bacteria sources at these farms consisted of manure deposited in fields close to the water, some of which had significant slopes, in manure piles, and of manure from cows wading in the water. Other farms, located on Kirby Brook and on Snell Creek, were also pollution sources. Significant domestic pollution sources were found to be present along Bread and Cheese Brook, at an amusement park located near the East Branch stream gage, along stream #15, and along Snell Creek. Other areas of periodic or potential pollution included clusters of homes along the estuary, homes along the East Branch between Lake Noquochoke and the Head of Westport, cottages at Lake Noquochoke and the Let, and homes and boats at Westport Harbor (Kelly et al., 1986).

Pollution sources existed along the length of the estuary, with the sources having the greatest impact located between the confluence of Bread and Cheese Brook and the East Branch, and Hix Bridge. Bacterial counts and loads were high in this region and were able to impact directly on the shellfish beds. The shellfish beds between the Head of Westport and Hix Bridge were those first affected by the pollution and are the most severly affected. Closure of the shellfish beds from Hix Bridge south to Gunning Island occurred later. Water quality generally becomes progressively better southward along the estuary.

HYDROLOGY

Introduction

The hydrological conditions in the East Branch were examined in a two part study. The actual hydrological conditions were monitored throughout the period of the study, which encompassed Water Year 1985, by means of a stream stage recorder on the East Branch, periodic discharge measurements at this gage and at other staff gages, measurement of groundwater levels at a number of observation wells, and continuous measurement of precipitation. The locations of the instruments used and measurement points for the hydrologic and climatic monitoring are indicated in Figure 3. In addition to the monitoring program, mapping of all of the tributary streams and drainage areas in the watershed of the East Branch was done. The second part of this study involved an analysis of USGS stream gage records for the region, in an attempt to gain a long-term regional perspective of the hydrology of the area.

In determining the hydrologic characteristics such as flood frequency and mean annual discharge of the region surrounding the East Branch USGS discharge records from a total of 10 gaging stations were used. These USGS gaging stations were on nine rivers in a region encompassing southeastern Massachusetts to the west of Cape Cod, and northern Rhode Island. The total drainage area of these rivers and other rivers lying within the study area is approximately 3900 km^2 (1500 mi^2). The maximum east-west dimension of the irregularly shaped study area is about 90 km (55 miles) and the maximum north-south dimension about 70 km (45 miles). Rivers in the region are south-trending, draining into Rhode Island Sound and with an average drainage area of 179 km^2 (69 mi^2). The area studied in this analysis includes the drainage basins of the Pawtuxet River to the west and the Taunton River to the east, and all the land between these rivers. The rivers are in long, narrow, shallow valleys that are occupied by glacial outwash, with glacial till on surrounding higher elevations. The topography is of gently rolling hills with north-south trending valleys.

Graphical analysis and regression analysis were done to develop explanative and predictive equations and curves for important aspects of the surface water hydrology of the region.

The mean annual discharge of rivers in the region is described by:

$$Q_{MA}=1.94A_d^{0.98} \qquad (1)$$

where Q_{MA} is the mean annual discharge and A_d is the drainage area. This corresponds to an average annual rainfall of 24 inches (610 mm) and a 1.78 cfsm value. The groundwater contribution to streamflow accounts for about 46.2% of the total flow. There is little variation in the discharge of flows during the year, which when combined with the high percentage of groundwater contribution, indicates that the surficial deposits through which the rivers flow are likely to be porous permeable glacial sands and gravels. There have been alternating periods of greater and lesser precipitation and discharge, with a slight trend toward more humid conditions during the last 50 years. The frequency of floods of various recurrence intervals may be described by:

$$Q_{2.33}=77.9A_d^{0.59} \qquad (2)$$

$$Q_5=137.8A_d^{0.53} \qquad (3)$$

$$Q_{10}=180.5A_d^{0.52} \qquad (4)$$

$$Q_{25}=220.7A_d^{0.54} \qquad (5)$$

$$Q_{50}=225.9A_d^{0.58} \qquad (6)$$

Urbanization does not appear to have been greatly significant in increasing flooding. The lowest daily flow during a ten year period can be expressed by:

$$Q_{low}=0.0006A_d^{1.98} \qquad (7)$$

This low flow is critical for water quality, although most of the rivers in the area generally appear to be clean.

Climate

The climate is generally humid, with an average rainfall of about 43 inches (1092 mm). Annual snowfall ranges from 32 to 40 inches (810 to 1020 mm). Precipitation is relatively constant throughout the year. The area is subject to occasional more intense rainfall during late summer or fall hurricanes, although generally rainfall is not very intense (Caldwell, 1984). Average annual evapotranspiration has been estimated at 19 inches (483 mm) and streamflow as the equivalent of 24 inches (610 mm) of precipitation. The normal air temperatures to be expected are -3 to -5^{o}C (mid 20's^{o}F) for the winter and 24 to 27^{o}C (upper 70's ^{o}F) during the summer. Water temperatures drop to 0^{o}C (32^{o}F) in January and February and rise to 25^{o}C (77^{o}F) in July (Geraghty et al., 1973; Willey et al., 1978).

Temperature and precipitation data for the Westport River region are given in Table 2. These averages are representative of a 22 year period between 1951-1973 at Fall River, Massachusetts.

Table 2. Temperature and Precipitation Data, from US Weather Service (Kelly et al., 1986).

Temperature (^oC)

				2 years in 10 will have:	
Month	Average daily maximum	Average daily minimum	Average daily	Maximum temperature higher than	Minumum temperature lower than
January	2.4	-5.8	-1.7	13.9	-18.3
February	3.6	-5.2	-0.8	15.0	-18.9
March	7.3	-1.3	3.0	18.9	-11.7
April	13.8	3.6	8.7	26.7	-3.9
May	19.6	8.7	14.2	30.6	1.7
June	24.8	14.2	19.5	33.9	6.7
July	27.6	17.7	22.7	34.4	11.7
August	26.8	16.9	21.8	33.3	9.4
September	23.0	12.9	17.9	32.2	3.3
October	17.4	7.6	12.5	27.2	-2.2
November	10.6	2.4	6.5	20.5	-7.8
December	4.6	-3.4	0.6	17.2	-15.6
Yearly	15.1	5.7	10.4	35.6	-20.6

Precipitation (cm)

		2 years in 10 will have			
Month	Average	Less than	More than	Average number of days with 0.25 cm or more	Average snowfall
January	8.81	4.72	12.14	7	22.4
February	10.62	7.32	13.64	7	26.9
March	11.40	6.88	15.44	8	21.3
April	10.01	6.55	13.11	7	1.8
May	9.14	5.03	12.47	7	0
June	7.06	3.33	10.06	6	0
July	8.03	3.73	11.48	5	0
August	9.91	4.34	14.40	6	0
September	8.31	4.14	11.73	5	0
October	8.03	4.57	10.82	5	0.3
November	11.73	7.62	15.27	8	0.8
December	12.14	6.55	16.66	8	6.7
Yearly	115.09	94.26	134.82	79	90.4

The amount of precipitation in the region of the East Branch of the Westport River was monitored throughout the period of the study. Records were obtained from the US Weather Service and a continuous record of precipitation was obtained from the recording rain gauge installed in the East Branch drainage basin. These precipitation records are given in Table 3.

Table 3. Precipitation data, 1984-1985 (mm)

Month	Westport	Newport	Fall River	New Bedford	Middleboro	Mean (mm)	Mean (in)
July 84	--	150	108	136	111	127	4.98
Aug 84	--	17	11	23	23	18	0.72
Sept 84	--	56	55	57	46	54	2.11
Oct 84	76	120	156	100	129	116	4.57
Nov 84	33	34	49	58	46	45	1.73
Dec 84	85	94	99	115	79	94	3.71
Jan 85	21	30	32	36	34	30	1.20
Feb 85	28	41	68	67	54	52	2.03
Mar 85	75	90	91	90	36	76	3.01
Apr 85	32	30	37	45	42	37	1.46
May 85	123	146	127	146	121	133	5.22
June 85	142	105	143	119	128	127	5.01
July 85	87	63	121	96	111	111	4.36
Aug 85	307	328	212	374	213	287	11.29
Sept 85	25	45	49	38	55	42	1.67
Total	1075	1349	1356	1534	1226	1347	53.04
Mean	90	90	90	102	82	90	3.54

The mean monthly precipitation is indicated in Figure 5, a histogram of the mean precipitation from the locations listed in Table 3 for the period of study.

Hydrological Analysis

The basic concepts of surface water hydrology, as explained below, are used in an analysis of USGS stream discharge records to determine

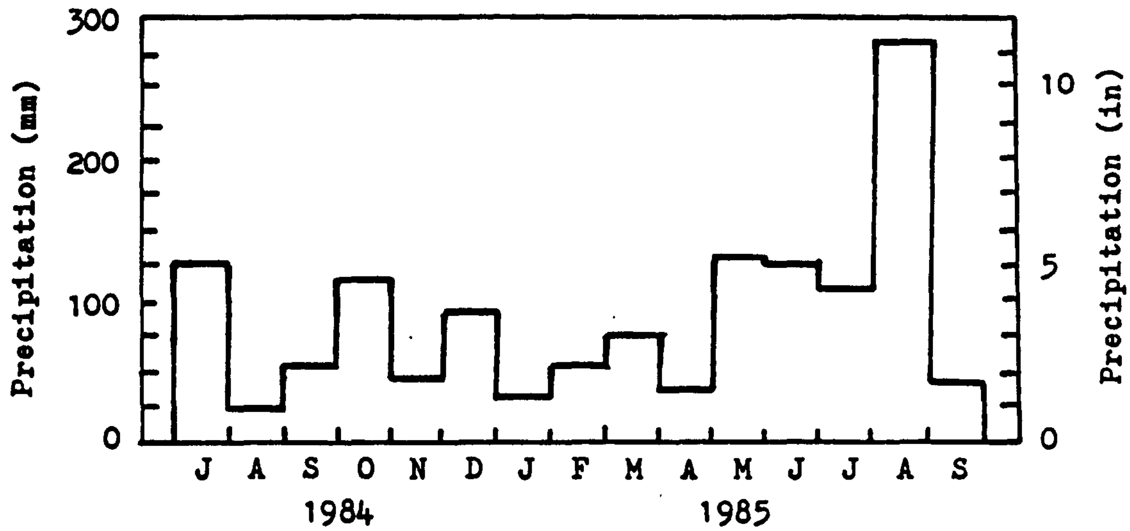


Figure 5. Histogram of the monthly precipitation totals in the region of the East Branch during 1984 to 1985, from four U.S. Weather Service gages in surrounding towns and from the rain gage in the East Branch watershed (Kelly et al., 1986).

the hydrologic characteristics of the East Branch watershed. The hydrologic cycle and the water budget provide a basic framework for understanding what happens to water in a watershed. The hydrologic cycle is the path that water takes on the surface of the earth and in the atmosphere. The water budget is described by:

$$P=ET + R \tag{8}$$

which states that the precipitation, P, is equal to the evapotranspiration, ET, and the runoff, R. Water used by plants or evaporated is evapotranspiration, while runoff is the streamflow in the rivers. In this analysis, the subcycle of groundwater is neglected, under the assumption that all groundwater resulting from rainfall infiltrating into the ground eventually becomes streamflow. The water budget can be used by measuring two of the parameters to solve for the third (Dunne and Leopold, 1978).

The basic measure of streamflow is discharge, the volume of water passing through a cross section of a river or stream. The most commonly used unit of discharge, also used here in the original analysis of the USGS records, is cfs, the cubic feet of water passing through a cross section in a second. This discharge can be calculated by using:

$$Q=wdv \tag{9}$$

where Q is discharge, w is width, d is depth, and v is volume.

In practice, discharge is determined by measuring the width, depth and velocity at many points across a stream or river. A current meter, similar in idea to a wind speed gage, is used in the water, with cups revolving around an axis due to the velocity of the water flowing past the cups. The revolutions around the cup are converted to velocity either electronically or by reference to a table of established values for that current meter. The current meter gives the current measurements of the water at that point in the stream. For accurate discharge measurements the current is measured at intervals across the stream at a depth of 0.6 feet (0.18 m) of the distance from the surface to the bottom for water less than 1.5 feet (0.46 m) deep, and at 0.2 and 0.8 of this distance for water greater than 1.5 feet (0.46 m) deep. An average velocity is then determined for that point. The result of this procedure is a series of measurements of current velocity at points of differing depth across the stream. The cross sectional area of the stream is then divided into compartments using the width intervals of the current measurement stations. The discharge is then calculated for each compartment by Equation 9 and summed over the width of the stream to provide a total discharge for the stream at that point in time.

The US Geological Survey routinely makes such discharge measurements at many locations at gaging stations established on rivers and streams of various sizes. At each gaging station a continuous record of stage, or water level, is constantly measured by a device that is essentially a float attached to a chart recorder. The gaging station established for this study on the East Branch was of this basic type. It consisted of a culvert pipe fixed vertically in the stream to decrease water turbulence, into which a float attached to a pulley on a chart recorder was placed on the water surface.

The data obtained by the stream gage consists of a record of stage,

or water level over time. A relationship exists between the stage and discharge at each point in a river. The relationship is determined through regression analysis of a large number of discharge measurements at many different stages and discharges. The regression curve (ie. rating curve) for the stream gage on the East Branch is given in Figure 6.

Ideally, the stream gage should be monitoring the flow of water under totally natural conditions. However, in many areas, especially urban areas, the flow of water is controlled by flood control projects or by hydroelectric projects. This regulation of streamflow lends an artificial component to the record of streamflow and discharge, as the water in the river may be held back by a dam and released at a later time. With artificial regulation, the discharge will not reflect the actual amount of water that would be flowing in a stream under natural conditions. Diversion of water for munincipal or industrial purposes will also affect the record of discharge derived from the stream gage, with lower amounts of discharge indicated.

The Geological Survey makes periodic discharge measurements and calculates daily discharges from stage records at gaging stations. These discharges are tabulated for each gage and published annually. Since 1961, records of all stream gages have been published annually, with a volume for each state. Records prior to 1961 were published as Water Supply Papers. The records list the river basin, stream gage number, name and location, drainage area, and period of record, as well as notes on regulation of the water upstream of the stream gage and on the quality of the records. Tables published in the annual

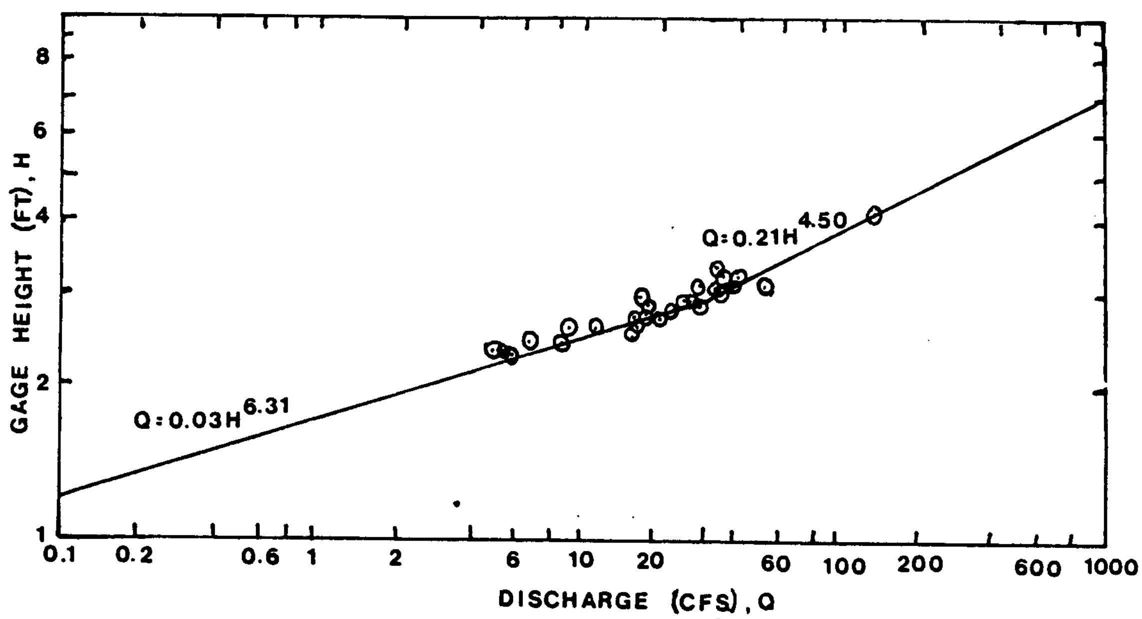


Figure 6. Rating curve for the East Branch stream gage, derived from measurements of stream discharge and stage. The lower portion of the curve represents stream stage at less than bankfull stage and the upper portion of the curve stream stage at greater than bankfull stage. Once the relationships have been established, stream discharge for any gage height may be estimated from the curve or from the regression equations (Kelly et al., 1986).

USGS publications for each state list the calculated average daily discharge, and the total, maximum, minimum, and mean discharge for each month and year. The Water Year, from October 1 to September 30 of the numbered year, is used as the time period. The records also include extremes of discharge for the Water Year and for the period of record, as well as the long term average discharge, the mean annual discharge, Q_{MA}.

These published records form the basis of the analysis of the surface water hydrology of the streams and rivers in the region of the East Branch. The ten gaging stations selected are listed in Table 4, including the drainage area, period of record, and amount of regulation.

Table 4. USGS gaging station data.

River Basin	Gaging Station, Location	A_d (mi^2)	Q_{MA} (cfs)	Length of Record (yrs)	Regulation
West Branch, Westport River	01106000, Adamsville Brook, Adamsville, RI	7.91	14.3	38 1941-1978	No
Taunton	01108000, Taunton River at State Farm, near Bridgewater, MA	260	464	46 1930-1975	Yes
	01108500, Wading River, West Mansfield, MA	19.2	32.3	29 1954-1982	Yes
	01109000 Wading River, Norton, MA	42.4	72.8	57 1926-1982	Yes
	01109060 Threemile River, N. Dighton, MA	83.8	170	16 1967-1982	Yes

Table 4.(continued)

River Basin	Gaging Station, Location	A_d (mi^2)	Q_{MA} (cfs)	Length of Record (yrs)		Regulation
	01109070 Segreganset River, Dighton, MA	10.6	22.3	16	1967-1982	Yes
Palmer	01109200 W. Branch Palmer R., Rehobeth, MA	4.96	8.29	11	1964-1974	No
Mohassuck	01114000 Mohassuck River, Providence, RI	23.1	40.5	19	1964-1982	Yes
Woonasquatucket	01114500 Woonasquatucket R., Centerdale, RI	38.3	72.0	41	1942-1982	Yes
Pawtuxet	01116500 Pawtuxet River, Cranston, RI	200	341	42	1941-1982	Yes
	Average	69	123.7	31		

The analysis of the records provides an understanding of the behavior of the streams in the region of the East Branch with respect to amount and pattern of streamflow, size and frequency of floods and period of low flow, water quality, and response to climatic and geologic conditions. The accuracy of the records increases with an increased period of record, as this decreases the effects of short term climatic fluctuations. Four of the gages analyzed have periods of less than 20 years but are included in order to broaden the data base. The overall average length of record is only 31 years, since no records over 57 years old exist for this region.

Most of the gages are subject to some degree of regulation with the exceptions of those gages in smaller drainage basins. This situation is difficult to avoid, as many gages in Massachusetts are subject to regulation. A variety of drainage areas has been selected, from 4.96 mi^2 (12.85 km^2) to 260 mi^2 (673 km^2), with an average drainage area of 69 mi^2 (179 km^2).

A few basic analytical techniques were used on the USGS data to derive relationships for watersheds in this region for the various aspects of surface water hydrology in order to predict the behavior of ungaged streams and rivers on the basis of what has happened in the past on similar rivers nearby. Data are plotted on the x and y axes of various types of graph paper. A line is determined by regression analysis that describes the relationship among the data. The line is expressed on arithmetic paper by:

$$y=mx + b \tag{10}$$

and for logarithmic paper by:

$$y=bx^m \tag{11}$$

where m is the slope of the line and b is the y-intercept.

These equations can then be used to calculate any x or y value, given a corresponding y or x value.

The technique of regression analysis is used to derive the equation of a line for any series of data sets. A calculator or computer may be used to calculate the values of the slope and y-intercept for Equations 10 or 11 for a set of x and y values. This technique can be used for either linear regression, for Equation 10, or for power function regression, for Equation 11. Also calculated is a correlation coefficient, a value between 0 and 1 which is a measure of the data with 1 being a perfect correspondence.

Regression analysis is always used to determine the mathematical relationship between sets of data. Occasionally, the data may not be represented by a linear or power function equation, but by a line having a different equation. In some cases, a curve may be divided into segments having different slopes if the physical conditions being described change, such as with a drastic change in cross-sectional area in a stream. Data may be plotted and regression analysis used to derive an equation for a line which is then drawn on the graph. The basic purpose of these methods is predictive, to analyze the data in order to find a relationship that may be used to predict what will happen in a stream in a region based on the data showing what has happened in the past in gaged rivers nearby.

Regional Surface Water Hydrology

The USGS stream discharge records for southeastern Massachusetts and northeastern Rhode Island were used in regression analysis to derive relationships for the mean annual discharge of rivers and streams in the region of the East Branch, the size and frequency of floods, and the level and frequency of periods of low flow , that may be used to predict these hydrologic characteristics for the East Branch. Additional analyses illustrate the effects of climate and geology on the rivers in the region, and provide an overview of water quality in the region.

Table 4 lists a value, Q_{MA}, for each of the gaging stations. This is the long-term mean annual flow which is the average discharge flowing past the gaging station for the entire period of operation for the stream gage. An analysis of the long-term mean annual discharge for all of the drainage areas is done in order to find a relationship between the drainage area size and the mean annual discharge. This relationship is expressed by a power function equation of the form:

$$y=bx^m \tag{12}$$

where x is drainage area and y is mean annual discharge.

The data sets for all of the stream gages have been plotted in Figure 7, and the regression analysis line drawn. The line is represented by Equation 13, in English units, with a correlation coefficient of .99:

$$Q_{MA}=1.94A_d^{0.98} \tag{13}$$

A conversion to metric units resulted in:

$$Q_{MA}=0.022A_d^{0.98} \tag{14}$$

The correlation coefficient is very close to 1.0, indicating that the equation is an accurate representation of the relationship. Equation 13 or 14 can be used to find the mean annual discharge for a river or stream of any size drainage area in the region. The value of 1.94 means that for each square mile the mean annual discharge will be 1.94 cfs. The exponent 0.98 means that as the drainage area increases in size, the mean annual discharge increases at a slower rate than does the drainage area since proportionally less water is coming from larger areas of land. The mean annual discharge will be 18.5 cfs for a 10 mi^2 drainage area and 176.9 cfs for a 100 mi^2 drainage area. This is due to a climatic effect, that in smaller drainage areas rainfall tends to be more evenly distributed over the entire drainage

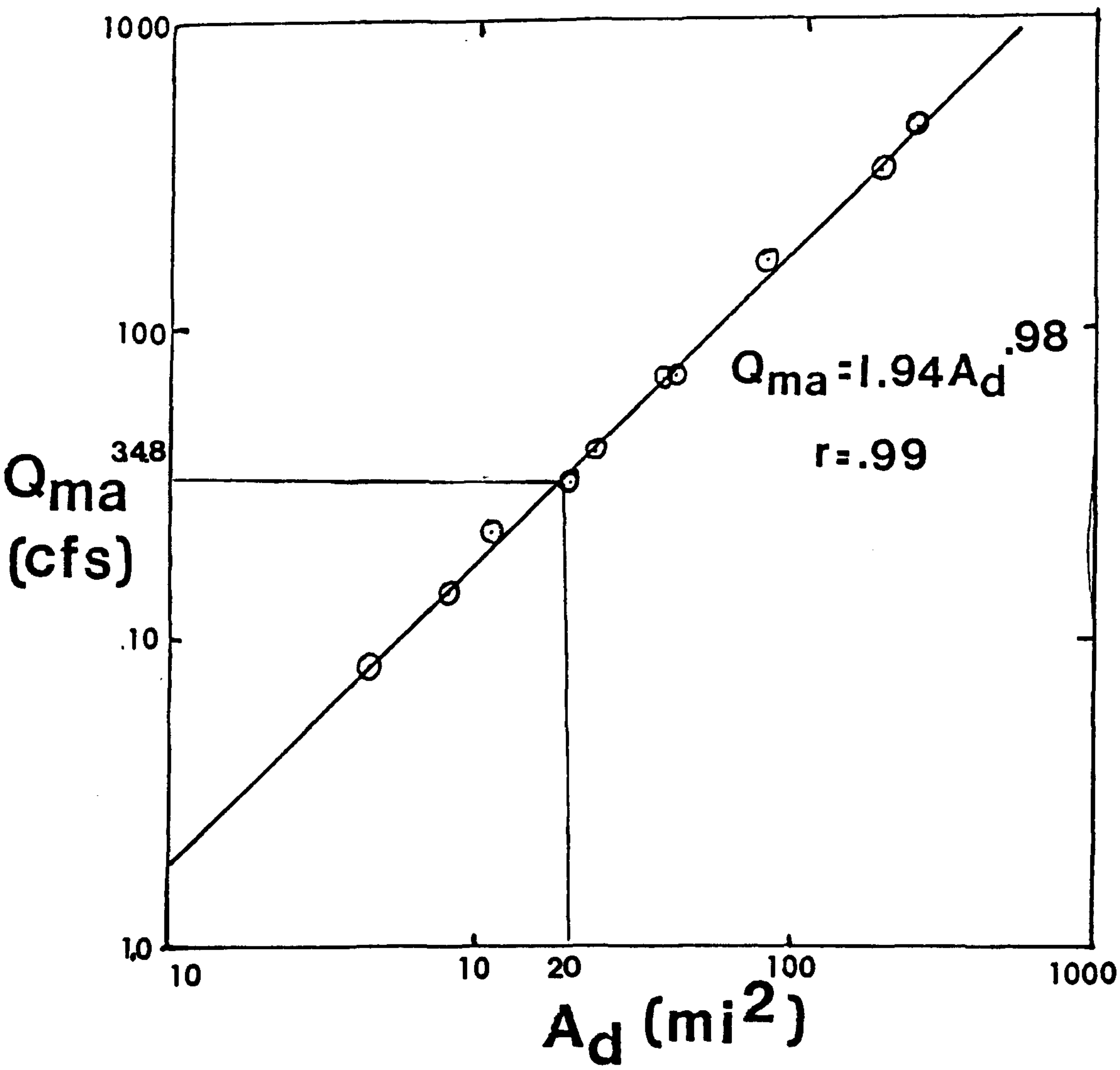


Figure 7. Drainage area-mean annual discharge relationship for southeastern Massachusetts and northeastern Rhode Island, derived from long-term USGS records of mean annual discharge for ten stream gages. The mean annual discharge for any size drainage area in the region may be estimated from the curve, for example, a drainage area of 20 square miles will have a mean annual discharge of 34.8 cfs.

area. Thus rainfall contributes to streamflow from the entire drainage area. In larger drainage basins rainstorms will occur over a smaller percent of the total land as it may be raining in one area but not in another. Thus the water contributed to the stream or river from the rain will be a smaller percentage of the total flow in the river than in a small drainage area so the discharge will not increase as rapidly during rainstorms.

A cfsm value may be calculated for the drainage basin. This is the cubic feet per second of discharge from each square mile of drainage area. It may be calculated for individual drainage areas by dividing the mean annual discharge by the drainage area. An average value may be found by using Equation 13. For drainage basins greater than 1.0 mi^2, the cfsm value is found by substituting the desired drainage area in Equation 13 and then dividing the result by the drainage area. Thus the 10 mi^2 drainage area has a cfsm value of 1.85 and the 100 mi^2 drainage area a cfsm value of 1.77. The average drainage area in the region is 69 mi^2, with a cfsm value of 1.78. This indicates that on the average, each mi^2 in the region contributed 1.78 cfs to the rivers.

This cfsm value of 1.78 may be used to calculate the amount of rainfall that becomes streamflow in this region during an average year. The cfsm value is multiplied by the number of seconds in a year to give the cubic feet of water per square mile that becomes streamflow. It is then divided by the number of square feet in a square mile and multiplied by 12 inches per foot to give the equivalent depth of water over the land surface, in inches. This represents the number of inches of water in the region that becomes streamflow in an average year. For a value of 1 cfsm the conversion factor obtained from this calculation is 13.57 inches of water per cfsm. For the average drainage area in the region of 69 mi^2 and the average value of 1.78 cfsm, the amount of rainfall contributing to streamflow is 24 inches. This value and the value for the average amount of rainfall each year can be used in the water budget to calculate the amount of evapotranspiration in the region:

$$P = ET + R \tag{15}$$

If P is 43 inches and R is 24 inches, then ET is 19 inches.

A long term water budget for the study area has been prepared using precipitation and temperature data from Fall River and USGS discharge records for Adamsville Brook (Kelly et al., 1986). This long term water budget is given graphically in Figure 8. A water budget has also been prepared for the study area for Water Year 1985 using the mean precipitation data from the rain gauge network, temperature records from NOAA records for Newport, Middleboro, and New Bedford, and stream discharge data from the stream gage on the East Branch of the Westport River. The water budget is given graphically in Figure 9.

Annual Hydrograph

A hydrograph is a graphical record of the discharge of a stream during a specific period. The hydrograph is constructed by calculating the amount of discharge for each day or other time period using the continuous stage record obtained from a stage recorder and

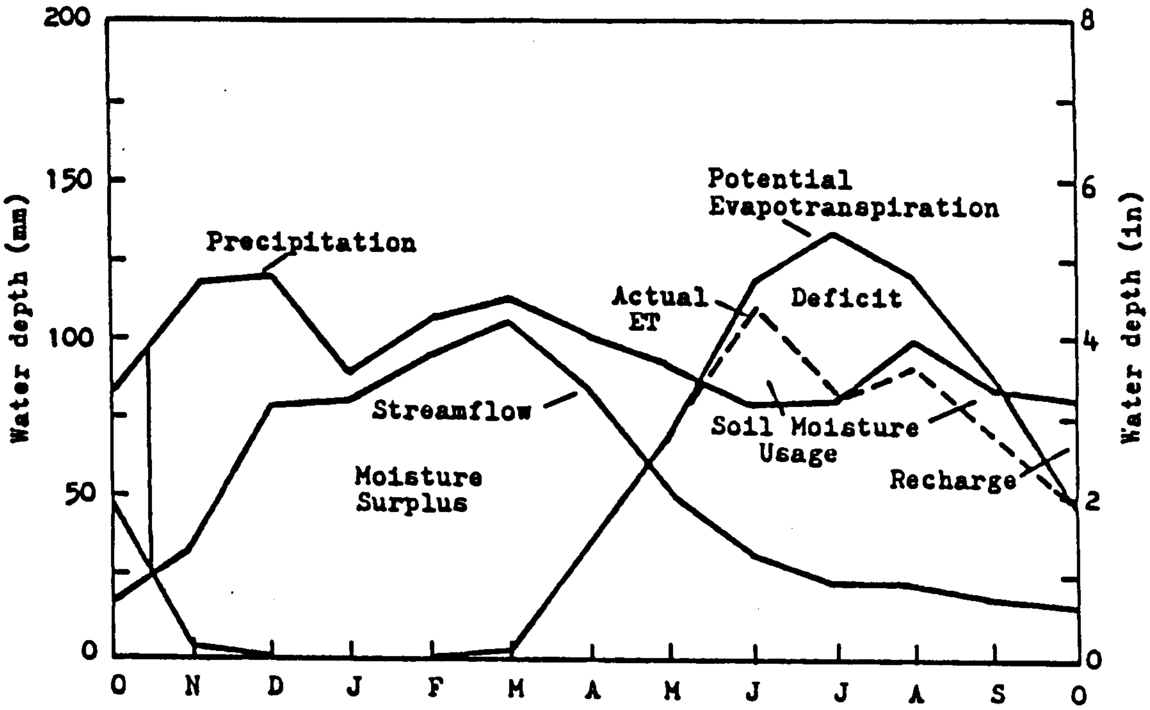


Figure 8. Long-term water budget for the region of the East Branch, derived from precipitation and temperature data from Fall River, MA, and stream discharge information from Adamsville, RI, showing the long-term average changes in precipitation, streamflow, evapotranspiration, and soil moisture (Kelly et al., 1986).

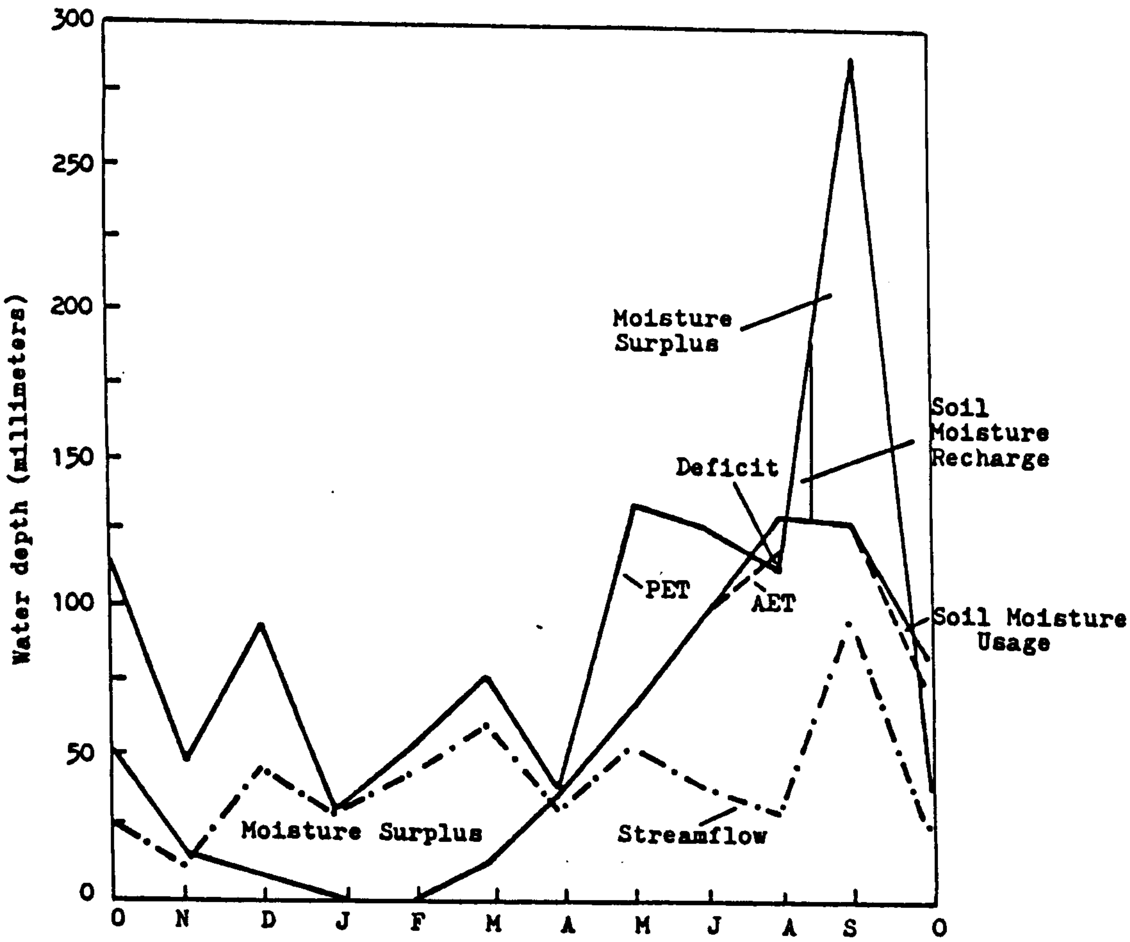


Figure 9. Water budget for 1985 for the East Branch, derived from precipitation and temperature data from several towns in the region, and stream discharge information from Adamsville, RI, showing the actual fluctuations in precipitation, streamflow, evapotranspiration, and soil moisture (Kelly et al., 1986).

the stage-discharge rating curve described earlier. Two annual hydrographs are presented in Figures 10 and 11. Figure 10 is a hydrograph of the discharge of Adamsville Brook, Adamsville, Rhode Island for Water Year 1965 and Figure 11 is an annual hydrograph for Water Year 1973. Adamsville Brook is just outside the western drainage divide of the East Branch drainage basin, and its hydrograph was selected as there is no regulation of the streamflow. These two examples were selected because 1965 was a relatively dry year and 1973 a relatively wet year. The hydrographs show the fluctuations in discharge over the course of the Water Year.

The solid line of the hydrographs represents the amount of discharge on each day of the year. The individual spikes on the hydrograph represent stormflow, the water from precipitation events that produces temporary increases in stream discharge. However, the overall shape of the hydrograph is due to the contribution of baseflow. The baseflow is the groundwater component of the streamflow. Groundwater contributes to the stream discharge by the relatively slow movement of water in the water table through the soil, sand, gravel, or bedrock into the stream. The source of the groundwater is rainfall that has infiltrated into the ground and moved more slowly into the stream than the water running off from the ground surface. The relative amounts of stormflow and baseflow may be separated out from the hydrograph by drawing a line, dotted in Figures 10 and 11, that connects the major troughs of the hydrograph. The amounts of stormflow and baseflow may be found by calculating the areas under each of the curves. The baseflow is the amount under the lower line on the hydrograph while

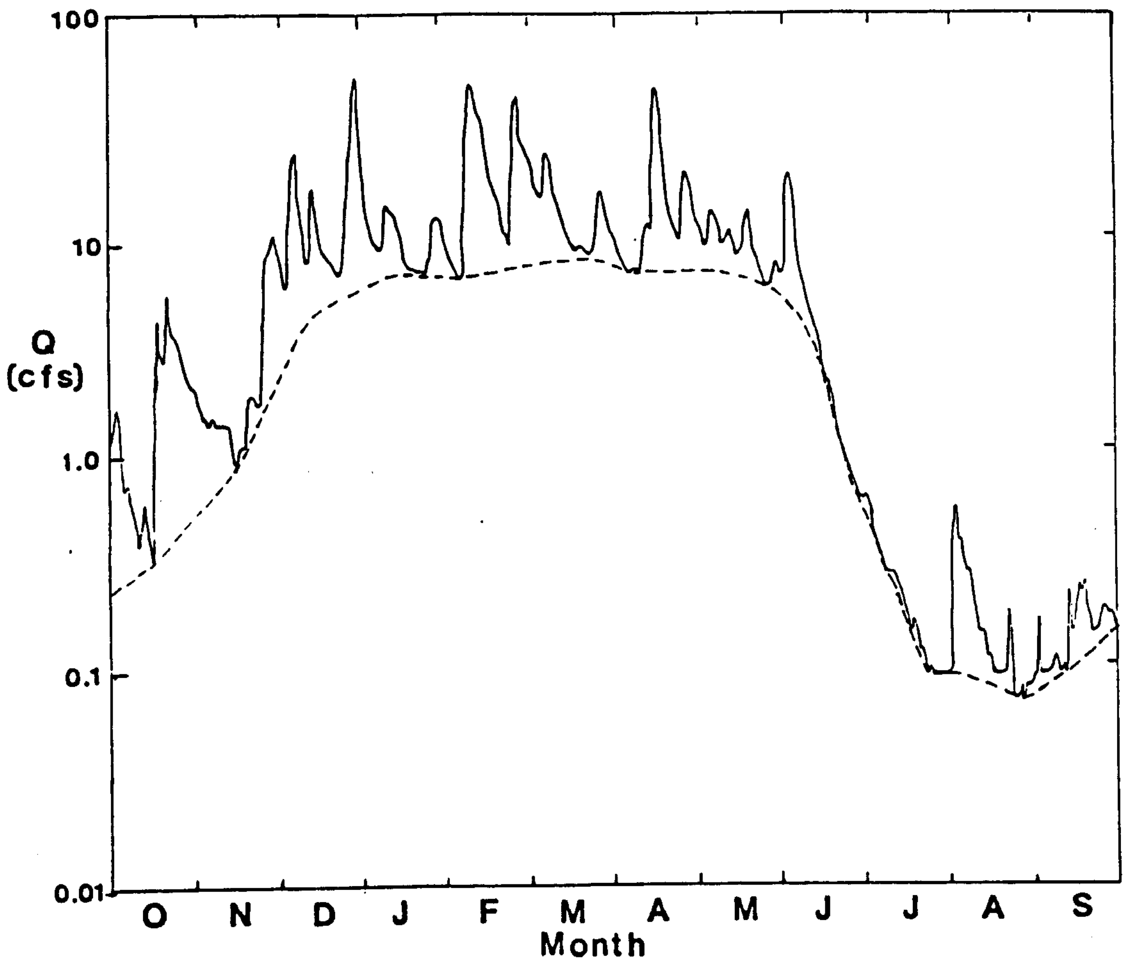


Figure 10. Annual hydrograph for Adamsville Brook, RI, for Water Year 1965, showing the yearly fluctuation in stream discharge (solid line) and in groundwater baseflow (dotted line). This Water Year was a particularly dry year.

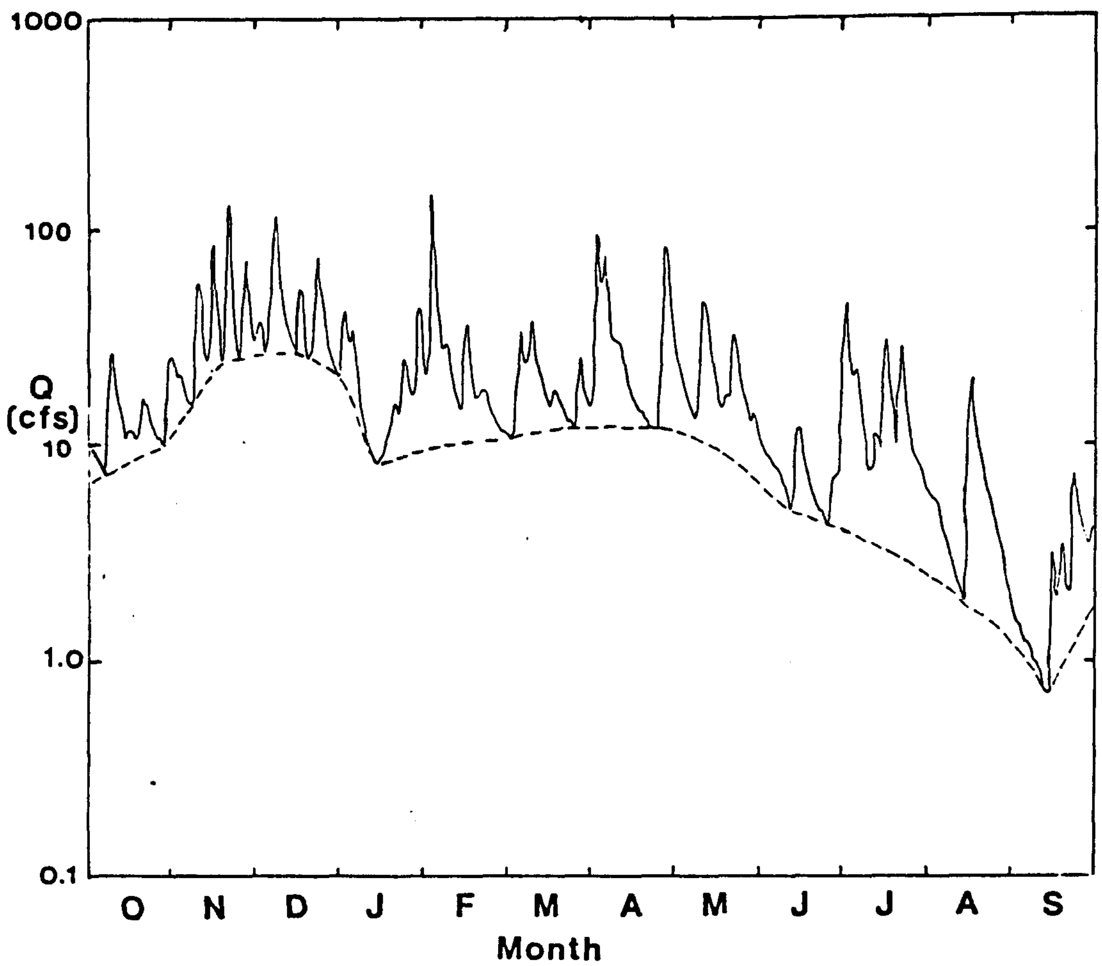


Figure 11. Annual hydrograph for Adamsville Brook, RI, for Water Year 1973, showing the yearly fluctuation in stream discharge (solid line) and in groundwater baseflow (dotted line). This Water Year was a particularly wet year.

the stormflow is the amount between the two lines. The results of this hydrograph separation are given in Table 5.

Table 5. Hydrograph Separation, Adamsville Brook, Water Years 1965 and 1973

Year	Q_{Total}(cfs)	$Q_{Baseflow}$	% Streamflow due to baseflow
1965	3009	1375	45.7
1973	7848	3663	46.7

The amount of streamflow due to baseflow is relatively constant in Adamsville Brook despite changes in climatic conditions. This happens since the baseflow depends in large part on the geology of the region. The deposits through which the groundwater travels to the stream do not change with the climate. The groundwater will travel through them at a relatively constant rate, with only minor variation in the velocity and thus discharge of the groundwater due to differing water levels. This explains the slight increase in the percentage of contribution due to baseflow during 1973. The water table was higher during this wet year so that the water table gradient and groundwater velocity were slightly greater than during the dry year. The relative amount of groundwater entering the stream was therefore slightly greater.

The percent of baseflow also indicates some measure of the geology of the drainage basin and Adamsville Brook. The surficial materials in the drainage basin must be sufficiently porous and permeable to allow substantial groundwater movement, since close to 50% of the streamflow is due to the groundwater component. This corresponds with the mapped surficial deposits of glacially deposited sand and gravel, A cumulative frequency plot of discharge in the Moshassuck River with discharge versus frequency is given in Figure 13. The discharge values for Water Year 1979 in the Moshassuck River range from 8.7 to 800 cfs, with a median discharge of 37 cfs. The median discharge is the level of discharge that is exceeded 50% of the time during the year. This discharge value may be read directly from Figure 13 at the intersection of the 50% frequency line with the plotted curve.

The curve shows relatively little variation in discharge, as about 60% of the discharges occur in a narrow range of 20 to 80 cfs. The river may be considered to have a regular flow without wide variations in discharge. This is typical of streams and rivers with a large groundwater contribution. As discussed previously, groundwater discharge to a river is relatively constant, without significant variation over short periods of time. The cumulative frequency curve of the flow duration plot reveals the contribution of groundwater to the river. The geology of the surficial deposits may be inferred from the contribution of groundwater to the streamflow. In the study area, the groundwater contribution indicates that the surficial deposits are porous and permeable, likely to be glacial outwash sands and gravels. A similar situation is found in the Herring River to the east of the study area. This river has a similar cumulative frequency curve and is in an area consisting almost entirely of permeable glacial sand deposits (Caldwell, 1984). Thus the surficial deposits in the vicinity of the Moshassuck River may be inferred to be similar.

Annual Discharge

Discharge records may provide information about the climatic conditions in an area, in addition to geological information. An analysis of annual average discharge over a long period of time will reflect the changing amounts and patterns of precipitation. The amount of discharge in a river reflects the amount of precipitation since a relatively constant percentage of rainfall will become streamflow over time. The average annual discharge of a river is the average of all discharge measurements made over a yearly period. The average annual discharges for the Wading River at Norton, Massachusetts for the period 1926 to 1980 are listed in Table 7. This table also lists the 5-year average discharge, obtaining by calculating a moving average for 5 year periods. This is done by averaging years 1 to 5 of the record, then 2 to 6, 3 to 7, and so forth.

Figure 14 is a histogram of the annual discharges for the period 1926 to 1980. This may be used to compare discharges over time and to easily determine if any cyclic patterns have occurred. Longer-term cyclic patterns may be more easily revealed by plotting the 5-year averages given in Table 7. This smooths out any temporary yearly fluctuations in discharge and thus in the climate. Figure 15 is a plot of the 5-year average for the Wading River at Norton, Massachusetts for the period 1926 to 1980, showing the 5-year average discharge versus each 5 year period. The plot clearly reveals periods of lower discharge and drier climate, during the periods 1928-1930, 1939-1941, 1946-1949, and 1962-1965. Periods of higher discharge reflecting a wetter climate occur during the periods 1931-1936, 1943-1945, 1950-1960, and 1965-1976. It is difficult to determine if there is any regular spacing between alternating periods of wetter and drier climate, although there does appear to be a very slight increase in levels of precipitation and discharge over the 55 year period of record.

Table 7. Annual Discharge, Wading River at Norton, MA, 1926 to 1980.
A_d=42.4 mi_2

Year	Q_A (cfs)	5-year Average	Year	Q_A (cfs)	5-year Average
1926	69.1		1954	90.6	71.8
1927	70.1		1955	90.3	82.7
1928	84.4		1956	98.6	88.7
1929	73.7		1957	54.2	83.1
1930	39.5	67.4	1958	84.5	83.6
1931	73.1	68.2	1959	69.4	79.4
1932	46.2	63.4	1960	74.6	76.3
1933	91.3	64.8	1961	85.9	73.7
1934	72.2	64.5	1962	68.9	76.7
1935	73.2	71.2	1963	74.1	74.6
1936	78.3	72.2	1964	68.3	74.4
1937	77.6	78.5	1965	35.2	66.5
1938	105	81.3	1966	28.8	55.1
1939	74.4	81.7	1967	74.0	56.1
1940	68.7	80.8	1968	78.9	57.0
1941	46.1	74.4	1969	69.1	57.2
1942	50.2	68.9	1970	87.1	67.6
1943	66.0	61.1	1971	57.1	73.2
1944	36.7	53.5	1972	83.1	75.1
1945	86.5	57.1	1973	107	80.7
1946	92.5	66.4	1974	78.2	82.5
1947	52.1	66.8	1975	70.4	79.2
1948	92.1	72.0	1976	92.6	86.3
1949	57.9	76.2	1977	73.4	84.3
1950	35.8	66.1	1978	115	85.9
1951	68.4	61.3	1979	103	90.9
1952	82.5	67.3	1980	71.1	91.0
1953	81.7	65.3			

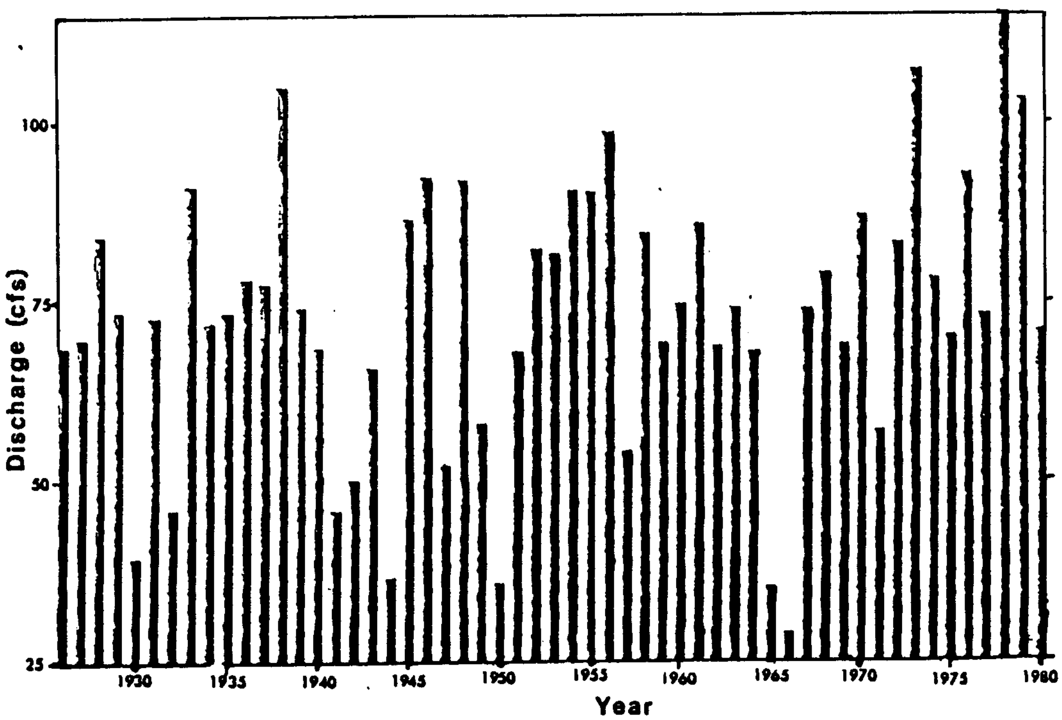


Figure 14. Histogram of annual discharges for the Wading River at Norton, MA for the period 1926 to 1980.

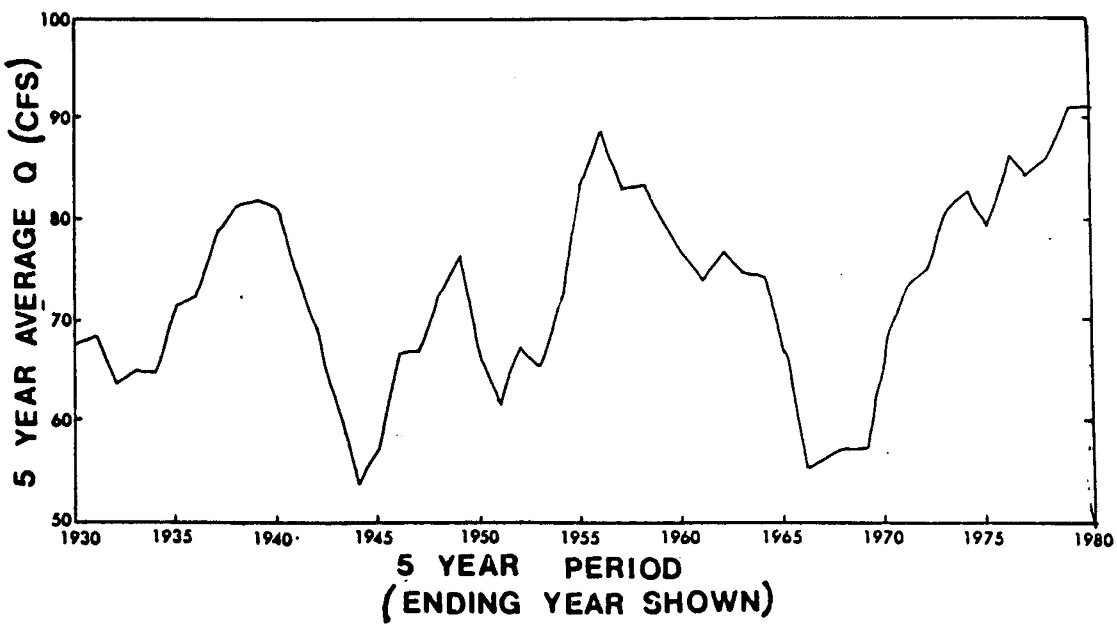


Figure 15. Plot of 5-year running average of annual discharges for the Wading River at Norton, MA, for the period 1930 to 1980. The plot indicates the average of the annual discharges for consecutive 5 year periods, revealing longer term climatic patterns. The curve indicates that the period after 1965 was a particularly dry period.

Flood Frequency

One of the most important predictions for a river is the size and frequency of possible floods on the river. Flood frequency analysis uses past flood records from a number of rivers in a region to estimate the frequency of floods of various sizes. The analysis uses the annual flood record from a stream gage for each year that records have been kept. The annual flood is the highest discharge occurring anytime during the year. When all of the years of record have been examined the relative sizes or magnitudes of each flood can be determined by comparing all of the annual floods. A magnitude 1 flood is the greatest flood occurring on the river during the period of record.

The recurrence interval concept is used in flood frequency analysis. The recurrence interval is the period of time within which, on average, one event (or flood) of a certain size is likely to occur. A ten year recurrence interval flood is the flood that is likely to occur once in a ten year period. The size of a flood is directly related to recurrence interval in that larger floods are less common and have a longer recurrence interval. The recurrence interval can be expressed by:

$$RI = \frac{n+1}{m} \tag{16}$$

where RI is the recurrence interval, n is the number of years of record, and m is the relative magnitude of the flood.

In the flood frequency analysis all of the annual floods for a stream are ranked in order of magnitude and the recurrence interval of each computed. An example of this ranking is given in Table 8 in which all of the annual floods for Adamsville Brook, Adamsville, Rhode Island, are listed.

Table 8. Annual floods, Adamsville Brook, Adamsville, Rhode Island 1941-1978, A_d=7.91 mi^2

Magnitude	Discharge (cfs)	Recurrence Interval (yrs)	Year
1	316	39.0	1970
2	273	19.5	1960
3	269	13.0	1954
4	241	9.8	1946
5	239	7.8	1953
6	231	6.5	1972
7	231	5.6	1978
8	221	4.9	1968
9	217	4.3	1958
10	213	3.90	1974
11	207	3.54	1962
12	202	3.25	1975
13	201	3.00	1945
14	198	2.79	1964
15	184	2.60	1963
16	182	2.44	1957
17	179	2.29	1969
18	176	2.17	1973
19	175	2.05	1976
20	173	1.95	1967
21	173	1.86	1971
22	157	1.77	1952
23	154	1.70	1941
24	154	1.63	1961
25	149	1.56	1977
26	146	1.50	1948
27	132	1.44	1956
28	130	1.39	1947
29	121	1.34	1944
30	119	1.30	1943
31	119	1.26	1959
32	117	1.22	1942
33	103	1.18	1950
34	90	1.15	1951
35	87	1.11	1955
36	85	1.08	1949
37	74	1.05	1966
38	66	1.03	1965

The annual floods are then plotted on a special type of logarithmic paper, Gumbel paper, with recurrence interval on the x-axis and discharge on the y-axis. A curve determined by regression analysis is then drawn through the points. Figure 16 is a flood frequency curve for Adamsville Brook, Adamsville, Rhode Island. The discharge of a flood of any recurrence interval may be determined from this flood frequency curve by reading the corresponding discharge on the y-axis at any recurrence interval on the x-axis.

Flood frequency curves were prepared for each of the ten stream gages examined for the region of southeastern Massachusetts and northeastern Rhode Island. The discharge for floods of recurrence intervals of 2.33, 5, 10, 25, and 50 years were determined for each of the stream gages from the flood frequency curves. The 2.33 year recurrence interval flood is the mean annual flood, the average of all of the annual floods in a period of record. Table 9 indicates the flood discharges for each of the ten stream gages examined, along with drainage area.

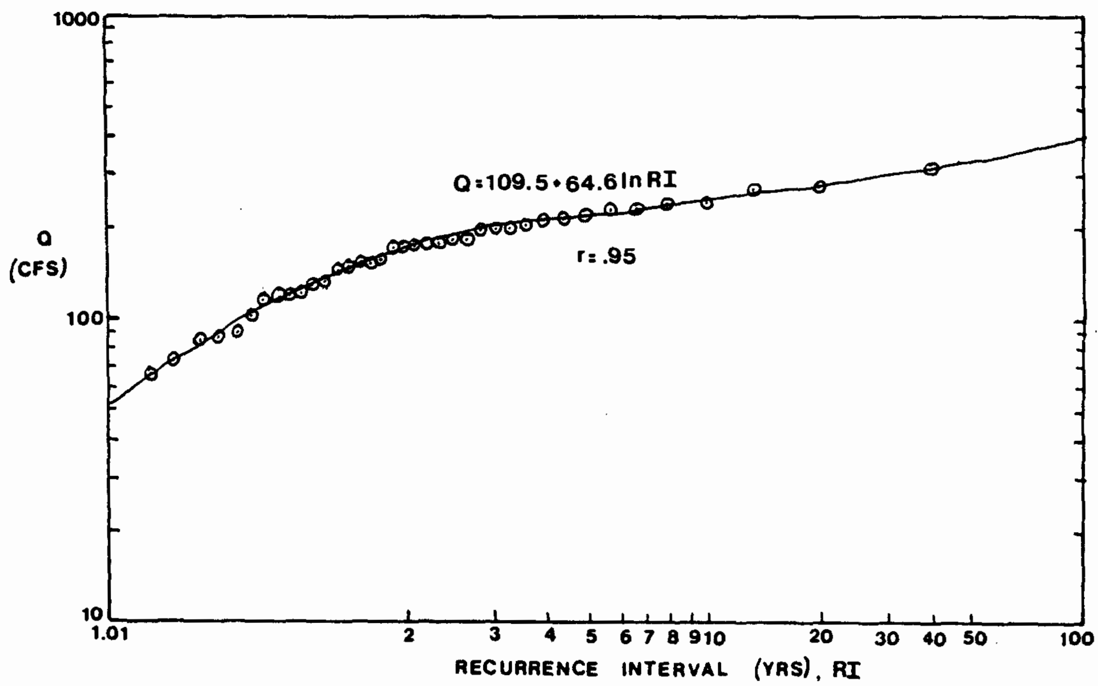


Figure 16. Flood frequency curve for Adamsville Brook, RI, for 1941-1978. The discharge of the annual floods during this period are plotted versus recurrence interval. The discharge of a flood of any recurrence interval may be estimated from the curve or from the regression equation.

Table 9. Flood discharges for rivers in southeastern Massachusetts and northeastern Rhode Island.

River/Stream Gage	Drainage Area (mi^2)	Flood Discharge (cfs) $Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}
Adamsville Brook, Adamsville, RI	7.91	192	222	250	290	330
Taunton River, Bridgewater, MA	260	2550	3000	3400	4200	5050
Wading River, West Mansfield, MA	19.2	170	260	395	570	630
Wading River, Norton, MA	42.4	480	650	830	1130	1440
Threemile River, N. Dighton, MA	83.8	1300	1770	2180	2670	2980
Segreganset River, Dighton, MA	10.6	470	660	800	960	1070
W. Branch Palmer River, Rehobeth, MA	4.96	200	325	415	540	620
Moshassuck River, Providence, RI	23.1	1050	1520	1930	2460	2870
Woonsquatucket River, Centerdale, RI	38.3	640	930	1100	1300	1500
Pawtuxet River, Cranston, RI	200	1900	2320	2980	4300	5900

Before further analysis of this data can be done a homogenity test is performed on the data. The purpose of this test is to determine if all of the rivers are in a homogeneous hydrologic region, with similar hydrologic and climatic conditions. For this test, the values of the mean annual flood and the ten year flood are determined from the flood frequency curves, and the ratio calculated. The average ratio is found and the mean annual flood multiplied by this value for each stream gage. The recurrence interval for this calculated discharge is read from the appropriate curve. This information is given in Table 10.

Table 10. Homogeneity test for flood frequency analysis.

Gaging Station	$Q_{2.33}$ (cfs)	Q_{10} (cfs)	$\frac{Q_{10}}{Q_{2.33}}$	$Q_{2.33}$x Mean ratio	RI of preceeding value	Period of record	Homogeneous
01106000	192	250	1.30	332	50	38	No
01108000	2550	3400	1.33	4412	31.8	46	No
01108500	170	395	2.32	294	6.3	29	Yes
01109000	480	830	1.73	830	10.0	57	Yes
01109060	1300	2180	1.68	2249	17.2	16	Yes
01109070	470	800	1.70	813	11.0	16	Yes
01109200	200	415	2.08	346	5.7	11	Yes
01114000	1050	1930	1.84	1817	8.5	19	Yes
01114500	640	1100	1.72	1107	10.1	41	Yes
01116500	1900	2980	1.57	3287	13.0	42	Yes
		Average	1.73				

The recurrence interval for the calculated discharge value is plotted versus the length of record for each gage on a special plot, given in Figure 17. Gages having data points that fall within the curve belong to a homogeneous hydrologic region. In this homogeneity analysis the gages at Adamsville Brook and at the Taunton River do not belong to the same hydrologic region as do the others. This may be explained by realizing that these two gages lie at the eastern edge of this study area and may be affected by a slightly different, possibly more maritime climate, or that the glacial deposits may tend to be thicker and more prevalent, as on Cape Cod to the east. Although the data from these gages will be excluded from a further flood frequency analysis as they do not meet the homogeneity test criteria, these stream gage records can still be used with the others in developing an overall hydrologic view of the region, as the dissimilarities are not

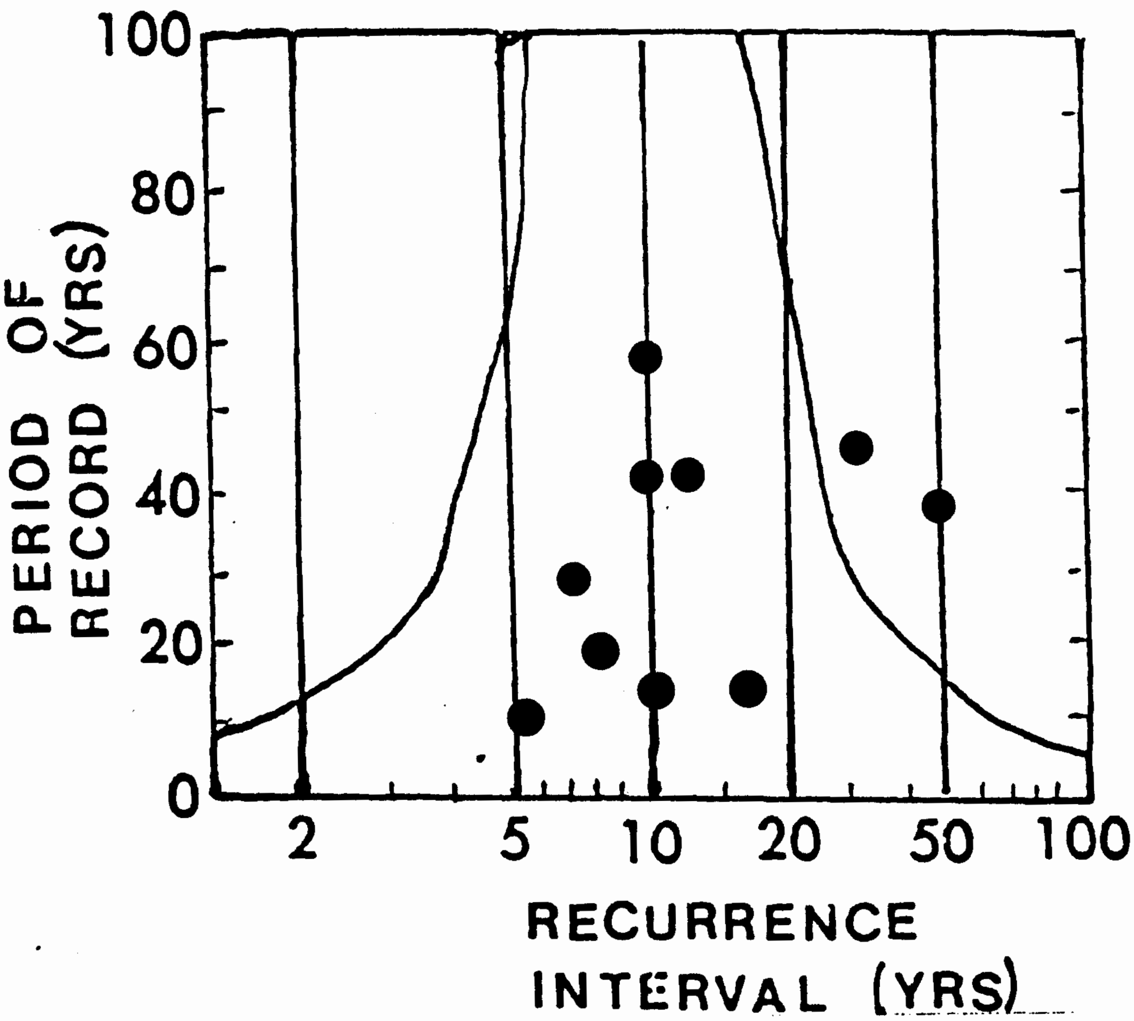


Figure 17. Homogeneity test plot for rivers in southeastern Massachusetts and northeastern Rhode Island. Data points of recurrence interval versus period of record falling within the test plot curves indicate rivers in a homogeneous hydrologic region.

too significant, and due to the lack of other stream discharge records from the region.

Regression analysis on the flood discharge and drainage area data from each stream gage was then done and results in equations describing the relationship of drainage area to flood discharge for floods of different recurrence intervals. These equations are given in Table 11. The first equation given in Table 11 for each flood is the equation as calculated using English units. The second equation is the equation as converted to metric units.

Table 11. Flood discharge relationships for floods of selected selected recurrence interval for rivers in southeastern Massachusetts and northeastern Rhode Island.

Flood	Correlation Coefficient (r)	Slope	Y-intercept	Equation	
$Q_{2.33}$	.80	.59	77.9	$Q_{2.33}=77.9A_d^{.59}$	(17a)
				$Q_{2.33}=1.26A_d^{.59}$	(17b)
Q_5	.77	.53	137.8	$Q_5=137.8A_d^{.53}$	(18a)
				$Q_5=2.35A_d^{.53}$	(18b)
Q_{10}	.80	.52	180.5	$Q_{10}=180.5A_d^{.52}$	(19a)
				$Q_{10}=3.11A_d^{.52}$	(19b)
Q_{25}	.84	.54	220.7	$Q_{25}=220.7A_d^{.54}$	(20a)
				$Q_{25}=3.74A_d^{.54}$	(20b)
Q_{50}	.85	.58	225.9	$Q_{50}=225.9A_d^{.58}$	(21a)
				$Q_{50}=3.68A_d^{.58}$	(21b)

where, for the first equation of each set, Q is in cfs and A_d is in mi^2, and for the second equation of each set, Q is in m^3/sec and A_d is in km^2.

These equations were plotted with drainage area versus flood discharge, in Figure 18. The equations or lines on the plot can be used to predict the size or discharge of a flood of recurrence interval 2.33, 5, 10, 25, or 50 years in any size drainage area in the region.

An analysis of the equations reveals that the rate of increase of flood size with increasing drainage area is approximately the same for any of the recurrence intervals. The exponents in the equations are alll less than one, indicating that the rate of increase in flood discharge is less than the rate of increase in drainage area. A flood in a smaller drainage area will appear to be proportionally larger than a flood of the same recurrence interval in a larger drainage area. The flood frequency curves are useful in predicting what size flood discharge may be expected in ungaged streams in the region for different recurrence intervals.

Partial Duration

A technique similar to that for flood frequency analysis was used for a partial duration analysis. This analysis examined all floods occurring within a ten year period that were equal to or greater than a certain discharge level. These floods were then ranked by magnitude and the recurrence interval calculated. Each flood was then plotted on semi-logarithmic paper with recurrence interval on the x-axis and discharge on the y-axis. A partial duration flood frequency curve determined by regression analysis was drawn. This analysis was done

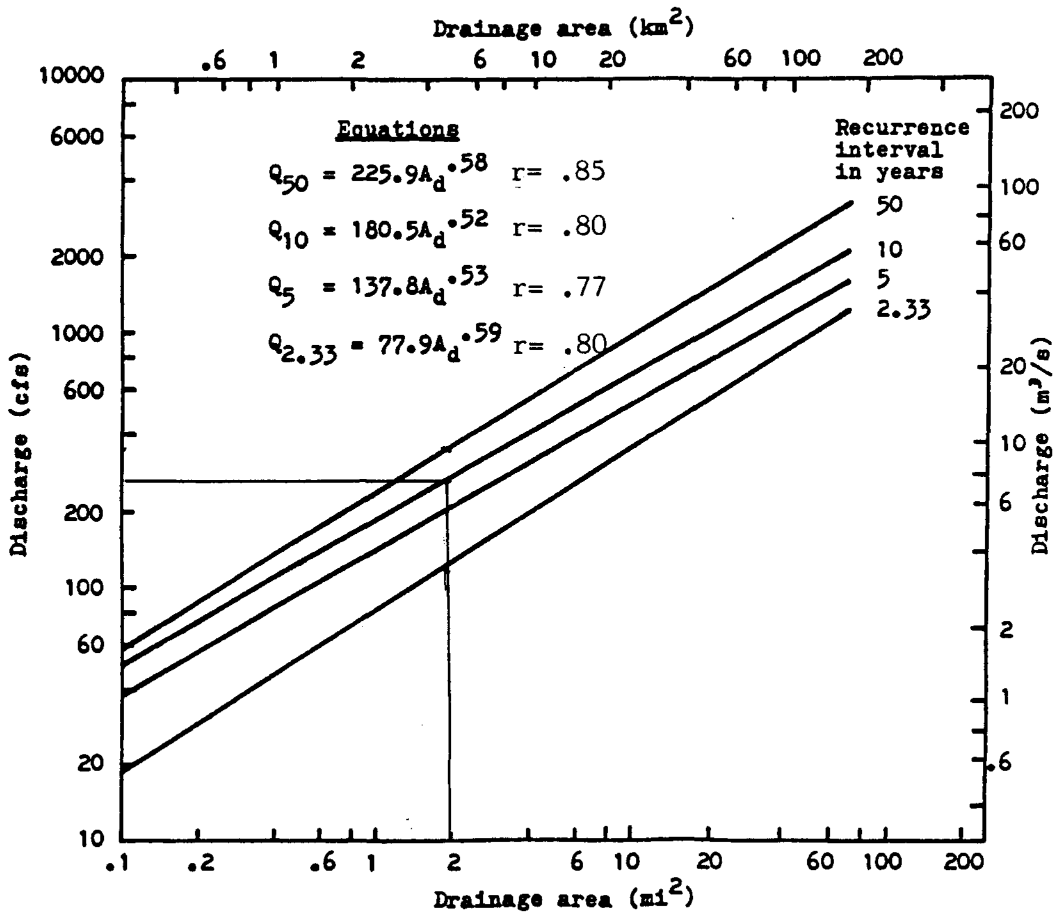


Figure 18. Drainage area and flood discharge relationships for rivers in southeastern Massachusetts and northeastern Rhode Island, from long-term USGS stream gage data. The example indicates that a 10 year recurrence interval flood in a drainage basin of 2 square miles will have a discharge of approximately 260 cfs.

on data from the Wading River at Norton, Massachusetts, for the periods 1961 to 1970 and 1971 to 1980. The data used is given in Table 12.

Table 12. Partial Duration Analysis
Wading River, Norton, MA
A_d=42.4 mi^2
base level= 280 cfs

1961-1970

Magnitude	Discharge (cfs)	Recurrence Interval	Magnitude	Discharge (cfs)	Recurrence Interval
1	1460	11.0	13	401	.85
2	819	5.5	14	378	.79
3	779	3.67	15	364	.73
4	622	2.75	16	361	.69
5	574	2.20	17	355	.65
6	541	1.83	18	346	.61
7	492	1.57	19	335	.58
8	470	1.38	20	312	.55
9	467	1.22	21	308	.52
10	464	1.10	22	295	.50
11	462	1.00	23	290	.48
12	453	.92	24	287	.46

1971-1980

Magnitude	Discharge (cfs)	Recurrence Interval	Magnitude	Discharge (cfs)	Recurrence Interval
1	951	11.0	26	356	.42
2	915	5.5	27	354	.41
3	780	3.67	28	340	.39
4	615	2.75	29	339	.38
5	590	2.20	30	336	.37
6	527	1.83	31	327	.35
7	517	1.57	32	326	.34
8	510	1.38	33	322	.33
9	478	1.22	34	314	.32
10	471	1.10	35	314	.31
11	462	1.00	36	306	.31
12	447	.92	37	304	.30
13	440	.85	38	303	.29
14	431	.79	39	303	.28
15	431	.73	40	301	.28
16	409	.69	41	299	.27
17	406	.65	42	299	.26
18	400	.61	43	294	.26
19	400	.58	44	293	.25
20	398	.55	45	291	.24
21	390	.52	46	291	.24
22	379	.50	47	287	.23
23	378	.48	48	281	.23
24	365	.46	49	280	.22
25	363	.44	50	280	.22

The partial duration analysis is used to examine the changes in behavior of floods over time. A number of ten year periods can be plotted to compare the flood behavior in different decades. A major cause of changing flood behavior is urbanization. An increase in urbanization increases the area of land in a drainage basin that is impermeable as a result of being paved over or built upon. As a result, runoff will be transmitted more rapidly to streams and floods of a certain size will occur more frequently, as there is less opportunity for the storm water to be infiltrated into the ground and stored as groundwater. The frequency of floods increases and the size of a certain frequency flood also increases (Leopold, 1968).

The data from Table 12 can be plotted on semi-logarithmic paper with recurrence interval on the logarithmic axis and discharge on the arithmetic axis. Figure 19 is a plot of the occurrence of floods above a base level of 280 cfs for the Wading River at Norton, Massachusetts, for the periods 1961-1970 and 1971-1980. It is evident that more floods above the base level occurred during the latter period and that the recurrence interval of the smaller floods (those 280-460 cfs) decreased. Thus, smaller floods occurred more frequently. The reason for this increase is difficult to determine. Without knowledge of the climatic conditions, it would appear that the increase is due to urbanization leading to increased storm runoff. However, reference to the annual discharge analysis reveals that the 1970's were wetter than the 1960's. This climatic change would affect the number of floods. It is likely, that in this case, the increase in floods is due to both increased urbanization and to climatic changes. If urbanization had not increased the total area of impermeable land the increased rainfall would be more likely to be infiltrated into the ground and released into the streams as baseflow at a slower rate, thus not causing an increase in floods. The total discharge would still increase but the water would be released to the streams in a sufficiently slow manner so as to not cause increased flooding. Further analysis to assess the impact of urbanization would involve partial duration analysis for earlier decades, and to attempt to equalize the data to remove any climatic variability.

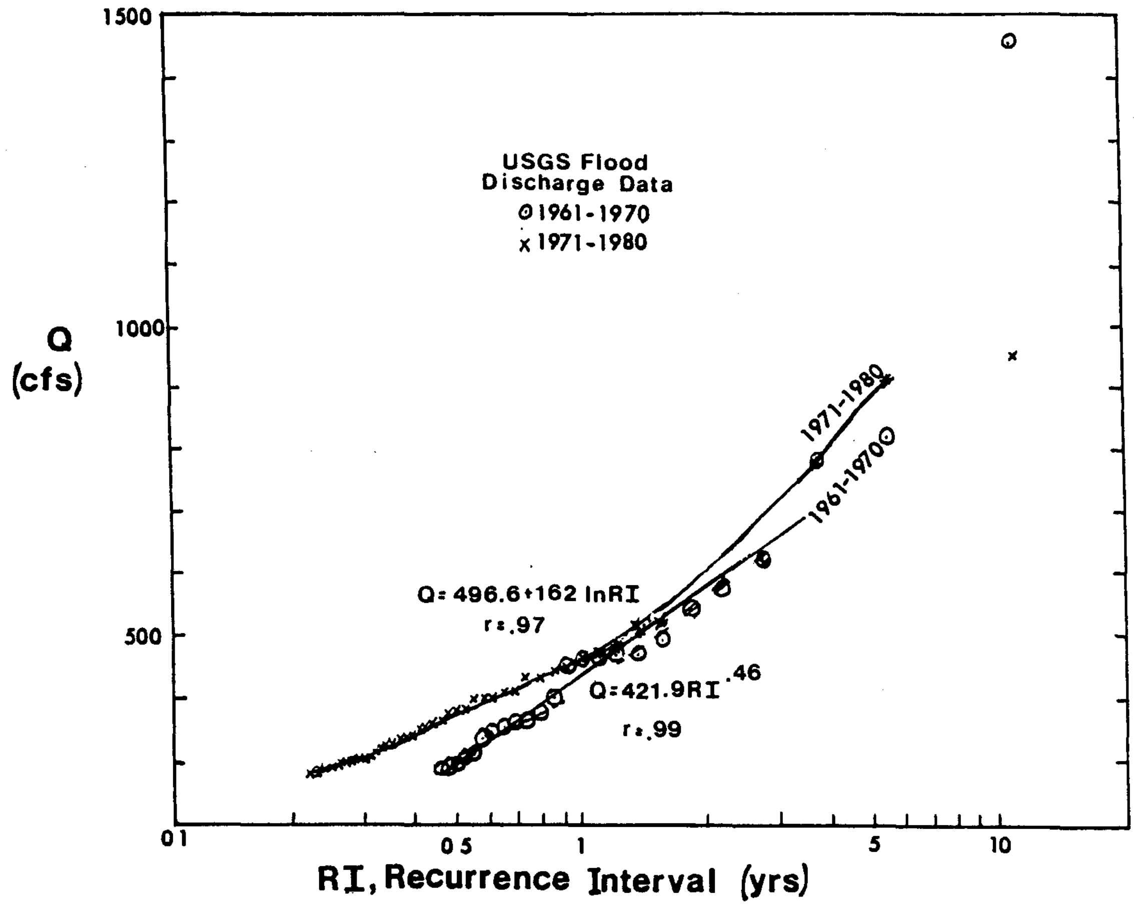


Figure 19. Partial duration curve for the Wading River at Norton, MA, of all floods above a base level of 280 cfs occurring during the two periods of 1961-1970 and 1971-1980 indicating the recurrence intervals and discharges of these floods. The curve for the 1971-1980 floods (upper curve) indicates that a flood of a given recurrence interval had a greater discharge for this time period than for the period 1961-1970, possibly indicating increased urbanization leading to more floods, or climatic changes leading to greater rainfall.

Low Flow

The last type of analysis of the USGS records in examining the overall hydrologic conditions in the region is to examine the low flow conditions in the rivers. Low flow is the period during which the discharge is at a minimum. Table 13 gives the data for a regression analysis of the 10 year recurrence interval daily low flow. This low flow is the lowest flow on any one day in a nine year period (by Equation 17 an event in a nine year period will have a recurrence interval of ten years). For this analysis, the dry period of 1963-1971 was selected as the period of record in which to determine the 10-year low flow. However, only 6 of the gages were in operation during this period so the data from only these 6 gages was used in a regression analysis of the data.

Table 13. Low Flow Analysis
10-year recurrence interval low flow
1963-1971

Gaging Station	A_d (mi^2)	Daily Low Flow (cfs)
Adamsville Brook	7.91	0.03
Taunton River	260	17
Wading River, W. Mansfield	19.2	0.12
Wading River, Norton	42.4	0.9
Woonsquatucket River	38.3	2.1
Pawtuxet River	200	34

Power function regression analysis was done to analyze the relationship between drainage area and low flow discharge for the region, resulting in:

$$Q_{low}=0.0006A_d^{1.98} \qquad (22)$$

where Q_{low} is the low flow and A_d is the drainage area. The slope of the line is 1.98, the y-intercept is 0.0006, and the correlation coeffficient is .97.

Equation 22 is plotted in Figure 20. Equation 22 and the plotted line can be used to estimate the 10-year daily low flow for any size drainage area in the region. The exponent 1.98 indicates that as drainage area increase, the low flow increases at a greater rate. Larger drainage areas will have proportionally greater discharge during low flow than will smaller drainage areas. This indicates that low flow conditions will be more critical in smaller drainage areas. This low flow discharge is important as it has a strong effect on water quality.

Water Quality

The amount of water flowing in a river affects the amount of oxygen in the water, thus the health of fish and aquatic vegetation. The amount of water is also important in the dilution of pollutants such as sewage. With low flow, there is less dilution of pollutants and less oxygen. In addition, more of the streamflow will consist of more mineralized groundwater. This affects usage of the stream for both drinking water and industrial purposes. Thus it is critical to be able to estimate the low flow conditions so that any diversion of water from the river may be halted, release of stored water initiated, or use of the possibly more polluted water curtailed (Caldwell, 1984).

Water quality is also affected by the chemical constituents present in the water. The USGS makes detailed measurements of the chemical and biological parameters of surface water at selected stream gages at

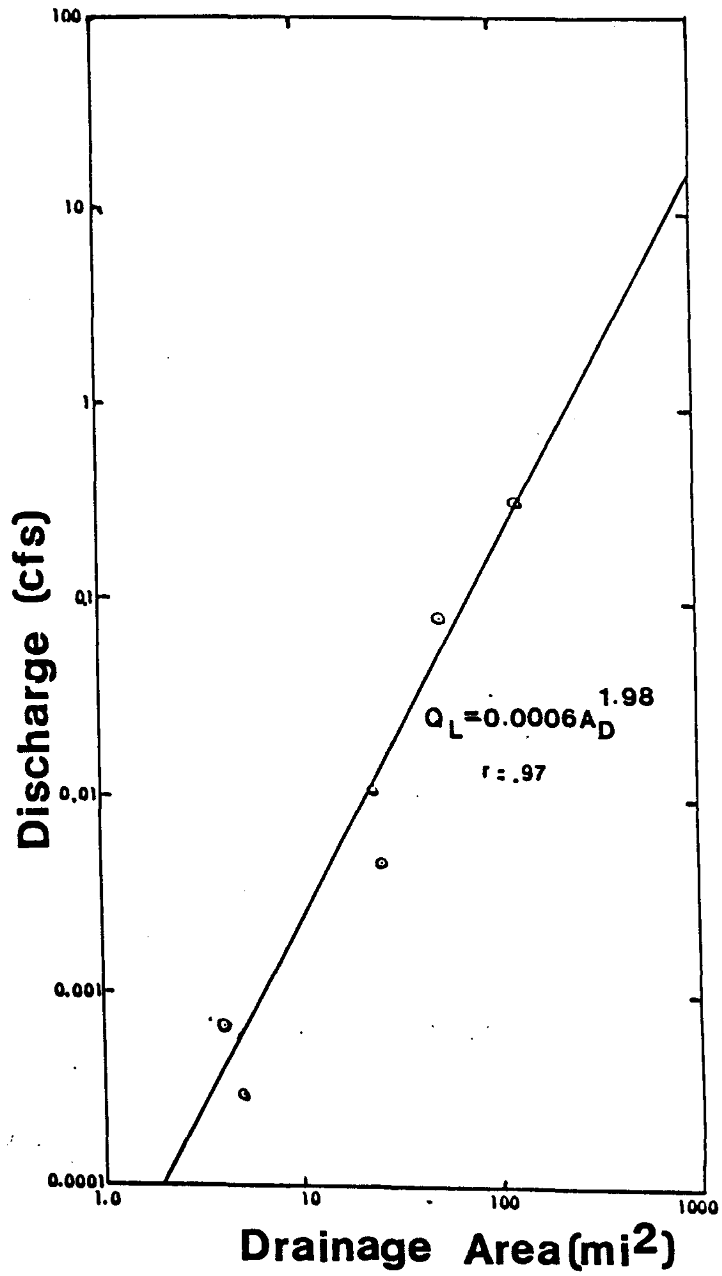


Figure 20. Ten-year low flow analysis of rivers in southeastern Massachusetts and northeastern Rhode Island, from long-term USGS stream discharge data. The line indicates the lowest stream discharge that will occur in a ten year recurrence interval, for any size drainage area in the region. The equation is derived from a regression analysis of the low flow data.

various time intervals. A large number of parameters can be measured, including hardness, bacterial levels, dissolved chemicals, organic chemicals, and metals. This data may be used to assess the overall quality of the water (USGS).

Interpretation of the data may be difficult, as safe standards for some of the parameters may not have been established or may be subject to uncertainty. In addition, the safe amount of a constituent may depend on the intended use of the water.

Overall, data for the Pawtuxet River, selected as an example for a regional view of water quality, indicate a relatively clean condition, with permissible levels of nitrogen and phosphorus, and very low levels of organic chemicals. In the region, overall averages for some water quality parameters include a $CaCO_3$ hardness of less than 60 ppm for both surface water and groundwater, less than 120 ppm dissolved solids in surface water, and less than 270 ppm sediment (Geraghty et al., 1973). The region has relatively clean water, based on this example, although as it is in the densely populated Northeast, the water is subject to manmade pollution problems, from industrial, munincipal, or agricultural sources. It is this last source that has strongly contributed to the pollution problem in the East Branch of the Westport River.

The analytical techniques described above are relatively simple, using only basic data including discharge and drainage area. However, the analyses provide useful information relating to the surface water hydrology of the region and can serve as predictive tools for understanding future behavior of rivers in the study region. The equations derived serve as a framework for describing the behavior of the rivers. Flood frequency, flow duration, hydrograph separation, average and annual discharges, partial duration, and low flow are all important aspects of the surface water hydrology that can be examined using these techniques and data.

Surface Water Hydrology of the East Branch, Westport River

The analyses presented above outline the general surface water hydrology of the region of the East Branch, and are useful in examining the East Branch, especially as very little data has been available for this particular river prior to the current study. No USGS stream discharge records are available for the East Branch.

Drainage Area Measurements

The entire drainage area of the East Branch was delineated on the available 1:24,000 and 1:25,000 USGS topographic quadrangles covering the area. The downstream boundary of the study area was defined to be at the estuary at Westport Point. The drainage area of Copicut Reservoir was excluded from all calculations throughout the study, as no discharges from the reservoir occurred throughout the period of study, and as very little discharge has occurred from the reservoir since the dam was built.

The drainage areas of individual tributary streams entering the East Branch estuary that were identifiable on the topographic maps were delineated. A total of four major tributaries: the East Branch, Bread and Cheese Brook, Snell Creek, and Kirby Brook, and 16 smaller tributaries were identified. The smaller unnamed tributaries have been designated by number. The remaining land area in the East Branch watershed consisted of land along the estuary with runoff directly to the estuary. The tributaries and other land areas are indicated in Figure 3.

The entire watershed was divided into three areas for ease in understanding stream discharge and sediment discharge data and in developing models for the watershed. These three areas are 1) all the land above the Head of Westport, 2) the land between the Head of Westport and Hix Bridge, and 3) land between Hix Bridge and Westport Point. These areas represent segments or compartments in developing the models for the East Branch, and also represent easily identified geographic units.

The drainage area of each of the identified tributaries was delineated on the topographic map. The drainage area was measured using a point counting technique on the topographic map. The first step in this technique involved the preparation from the topographic map of a base map at a known scale. A transparent grid with a known spacing interval between the grid lines was placed randomly over the area to be measured. The number of intersections of grid lines that occurred with the area to be measured was recorded. A total of five random placings of the grid and of the intersection countings were done, and the mean number of intersections calculated. The actual area was then calculated by knowing the base map scale and the grid line interval, in the following manner.

With a grid spacing of one line per centimeter, two lines intersect in every square centimeter. This was verified by drawing a square of known dimensions and counting the number of intersections that occurred when the grid was placed over the square. The inverse of this indicates that there is one square centimeter per intersection. The actual area on the base map was determined using:

$$(1\ cm^2/\text{intersection})(1\ km/1000\ m)^2(1\ m/100\ cm)^2(25{,}000\ cm/cm)^2 \quad (23)$$

$$= 0.0625\ km^2/\text{intersection}$$

This point counting technique was used throughout the study to determine all surface area measurements. The method is easily adapted to other grid line spacings and to other base map scales by simply inserting the appropriate values in Equation 23. The measurements obtained using this method compared favorably with measurements made by other researchers using other methods, such as a planimeter. For example, the point counting technique calculated a drainage area of 9.54 km^2 for the Kirby Brook watershed, comparing to values of 9.58 km^2 (Rural Clean Water Program, 1984) or 9.56 km^2 (Wandle and Keezen, 1984).

The land area of each of the tributaries to the East Branch estuary is given in Table 14. The tributaries are listed in Table 14 as they appear in a downstream direction.

Table 14. East Branch tributary drainage areas.

Tributary		Drainage Area (km^2)
To Head of Westport		
East Branch		55.77
Bread & Cheese Brook		27.06
#16		1.72
	Subtotal	84.55
Head of Westport to Hix Bridge		
#15		2.31
Kirby Brook		9.54
#14		1.35
#13		1.25
Snell Creek		4.42
#1		.46
#2		.74
Coastal Areas		9.42
	Subtotal	29.49
Hix Bridge to Westport Point		
#3		.59
#4		3.09
#12		1.25
#11		3.79
#10		1.95
#9		1.39
#5		.40
#8		.50
#7		1.28
#6		.84
Coastal Areas		9.42
	Subtotal	24.50
	Total	138.54

Stream Discharge

The total freshwater discharge to the estuary from tributary steams is important in estimating the amount and rate of flushing of the estuary and in estimating the sediment input into the estuary from erosion.

The statistical analysis of the USGS stream gage discharge records was done partly to obtain a method by which the stream discharges could be estimated, as sufficient records for the East Branch do not exist.

The regression analysis for mean annual discharge resulted in:

$$Q_{MA} = 1.94A_d^{.98} \qquad (13)$$

where A_d is in mi^2 and Q_{MA} is in cfs. The conversion resulted in:

$$Q_{MA} = 0.022A_d^{.98} \qquad (14)$$

where A_d is in km^2 and Q_{MA} is in m^3/sec. The correlation coefficient was .99.

Equation 14 was used to determine the mean annual stream discharges in the East Branch watershed, due to the high correlation coefficient.

The flood frequency analysis of the USGS records outlined above was used in the East Branch watershed to estimate the flood discharge for floods of various recurrence intervals for each of the mapped tributary drainage areas. The equations given in Table 11 were used for this purpose.

The mean annual discharges and flood discharges calculated for each of the tributaries to the East Branch estuary are given in Table 15.

Table 15. Stream Discharges, East Branch Tributaries

	Discharge (m^3/sec)						
Head Of Westport	Q_{MA}	Q_{A1985}	$Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}
East Branch	1.13	.92	13.5	19.8	25.2	32.8	37.9
Bread and Cheese	.56	.45	8.8	13.5	17.3	22.2	24.9
#16	.04	.03	1.7	3.1	4.1	5.0	5.1
	1.73	1.40	24.0	36.4	46.6	60.0	67.9
Head of Westport to Hix Bridge							
#15	.05	.04	2.1	3.7	4.8	5.9	6.0
Kirby Brook	.20	.16	4.8	7.8	10.0	12.6	13.6
#14	.03	.02	1.5	2.8	3.6	4.4	4.4
#13	.03	.02	1.4	2.6	3.5	4.2	4.2
Snell Creek	.09	.08	3.0	5.2	6.7	8.3	8.7
#1	.01	.01	.8	1.6	2.1	2.5	2.5
#2	.02	.01	1.0	2.0	2.7	3.2	3.2
Coastal Areas	.20	.16	4.7	7.7	10.0	12.6	13.5
	0.63	0.50	19.3	33.4	43.4	53.7	56.1
Hix Bridge to Westport Point							
#3	.01	.01	.9	1.8	2.4	2.8	2.8
#4	.07	.05	2.4	4.3	5.6	6.9	7.1
#12	.03	.02	1.4	2.6	3.5	4.2	4.2
#11	.08	.07	2.8	4.8	6.3	7.7	8.0
#10	.04	.03	1.9	3.4	4.4	5.4	5.4
#9	.03	.02	1.5	2.8	3.7	4.5	4.5
#5	.01	.01	.7	1.4	1.9	2.3	2.3
#8	.01	.01	.8	1.6	2.2	2.6	2.6
#7	.03	.02	1.5	2.7	3.5	4.3	4.3
#6	.02	.02	1.1	2.1	2.8	3.4	3.4
Coastal Areas	.20	.16	4.7	7.7	10.0	12.6	13.5
	0.53	0.42	19.7	35.2	46.3	56.7	58.1
Total	2.89	2.32	63.0	105.0	136.3	170.4	182.1

The stream discharges presented in Table 15 are useful in estimating the total amount of sediment discharge into the estuary, as will be done in a later section of this paper. The discharges are also useful in estimating the amount of flushing of the water contained in the estuary. The hydrological analysis of the available USGS records for the region and of the specific records obtained during the period of study is valuable in gaining an idea of the hydrological conditions in the watershed of the East Branch, and is useful in developing models of estuarine flushing and sediment movement and deposition in the East Branch.

ESTUARINE CIRCULATION

Introduction

A widely accepted definition of an estuary is that of "a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measureably diluted with freshwater from land drainage" (Pritchard, 1967). The East Branch of the Westport River may be considered geomorphologically a coastal plain estuary, formed by a drowned river valley (Pritchard, 1967). Hydrographically, it can be classified as a vertically well mixed estuary, in which there is little stratification of water of different salinities and densities (Beer, 1983).

Physically, the East Branch estuary is oriented generally northwest-southeast. It has a drainage area of 143.1 km^2 with a maximum relief of 117 m. The estuary has a mean depth of 1.2 m, a surface area of 7.2 km^2, and a volume of approximately 8.9×10^6 m^3. The coastal chart of the East Branch is given in Figure 21.

The mean tidal range at Westport Harbor is 0.91 m (1.5 ft) and at Hix Bridge 0.82 m (1.3 ft). The spring tides at Westport Harbor are 1.13 m (3.7 ft) and at Hix Bridge 1.04 m (3.4 ft).

Hydrographies

Tidal current velocities and tide level fluctuations were measured during hydrographies in the East Branch in 1984 and 1985. Each of the five hydrographies during 1985 involved measuring the tidal current velocities through the water column over a complete tidal cycle at several stations along cross sections of the estuary. The

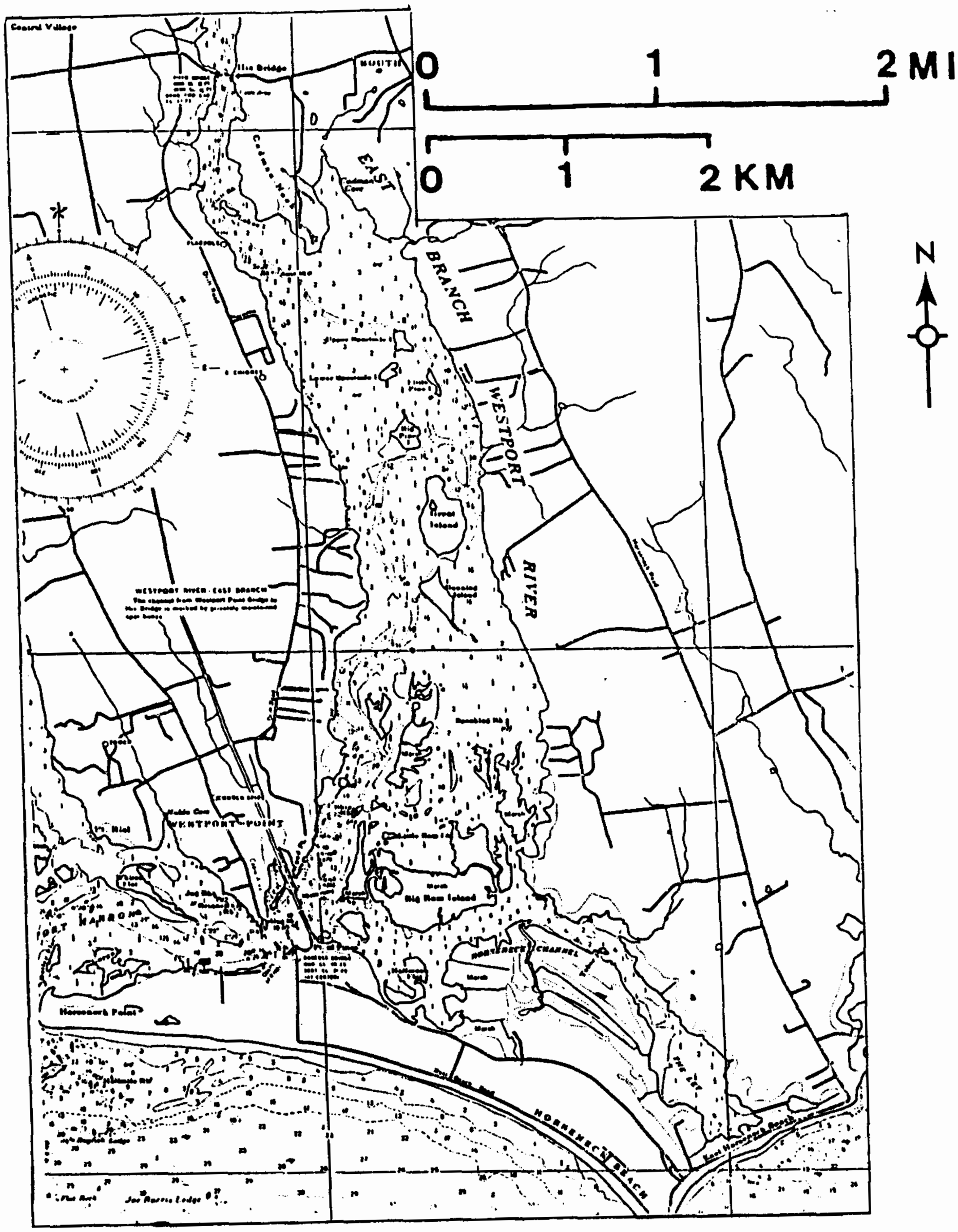


Figure 21. National Oceanographic and Atmospheric Administration coastal chart of the East Branch of the Westport River, of the region between Hix Bridge and Westport Point. Depths in the estuary are indicated in feet.

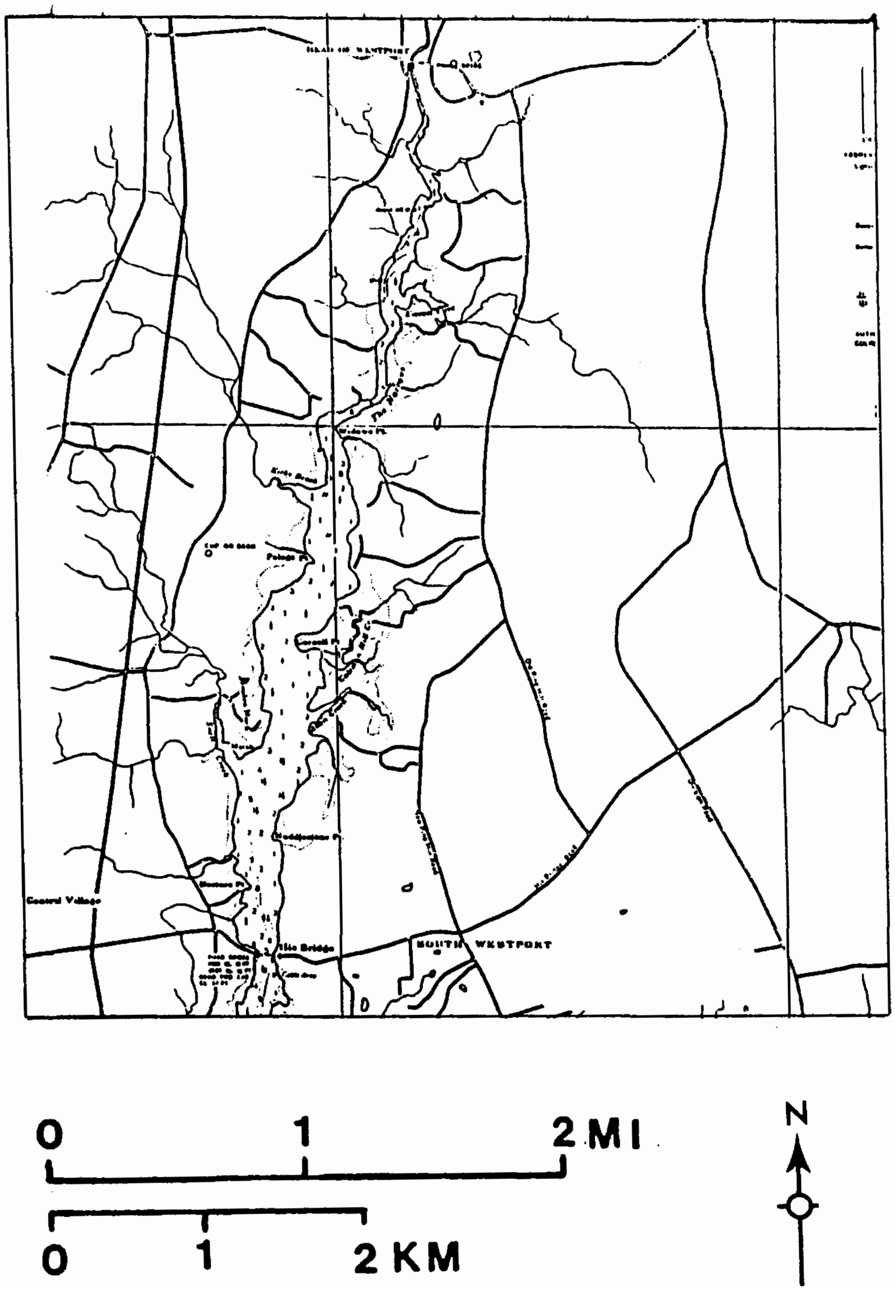


Figure 21 (continued). National Oceanographic and Atmospheric Administration coastal chart of the East Branch of the Westport River, of the region between the Head of Westport and Hix Bridge. Depths in the estuary are indicated in feet.

hydrographies in 1984 used the same techniques and measurements were taken at eight stations located longitudinally in the estuary, from above Hix Bridge to Westport Point. Three current measurements were made at different depths at each station at approximately one to one and a half hour intervals with an electromagnetic current velocity meter. In addition to the current measurements, salinity, conductivity, dissolved oxygen, and temperature were recorded at each sampling point. Surface readings of pH were also made. During 1985 water samples were obtained at the same depths using a one liter capacity modified Kemmerer type sampling bottle. Tide levels were measured during the hydrography periods using a fixed measuring staff. These data were used to construct tide fluctuation curves.

Three hydrographies were completed off Westport Point, during spring, mean, and neap tide conditions, as predicted calculated by the NOAA tide tables. Four stations were established along a north-south traverse across the estuary (Figure 22). A total of 475 current measurements and 444 water samples were taken during the hydrographies.

Two hydrographies were also completed at Hix Bridge, during neap and mean tide conditions. Three stations were set up along an east-west traverse by the boat landing at Hix Bridge (Figure 22). A total of 183 current measurements and 185 water samples were taken at this site.

Table 16 lists the dates of the hydrographies, number of current velocity measurements, number of water samples, and rainfall during preceeding intervals.

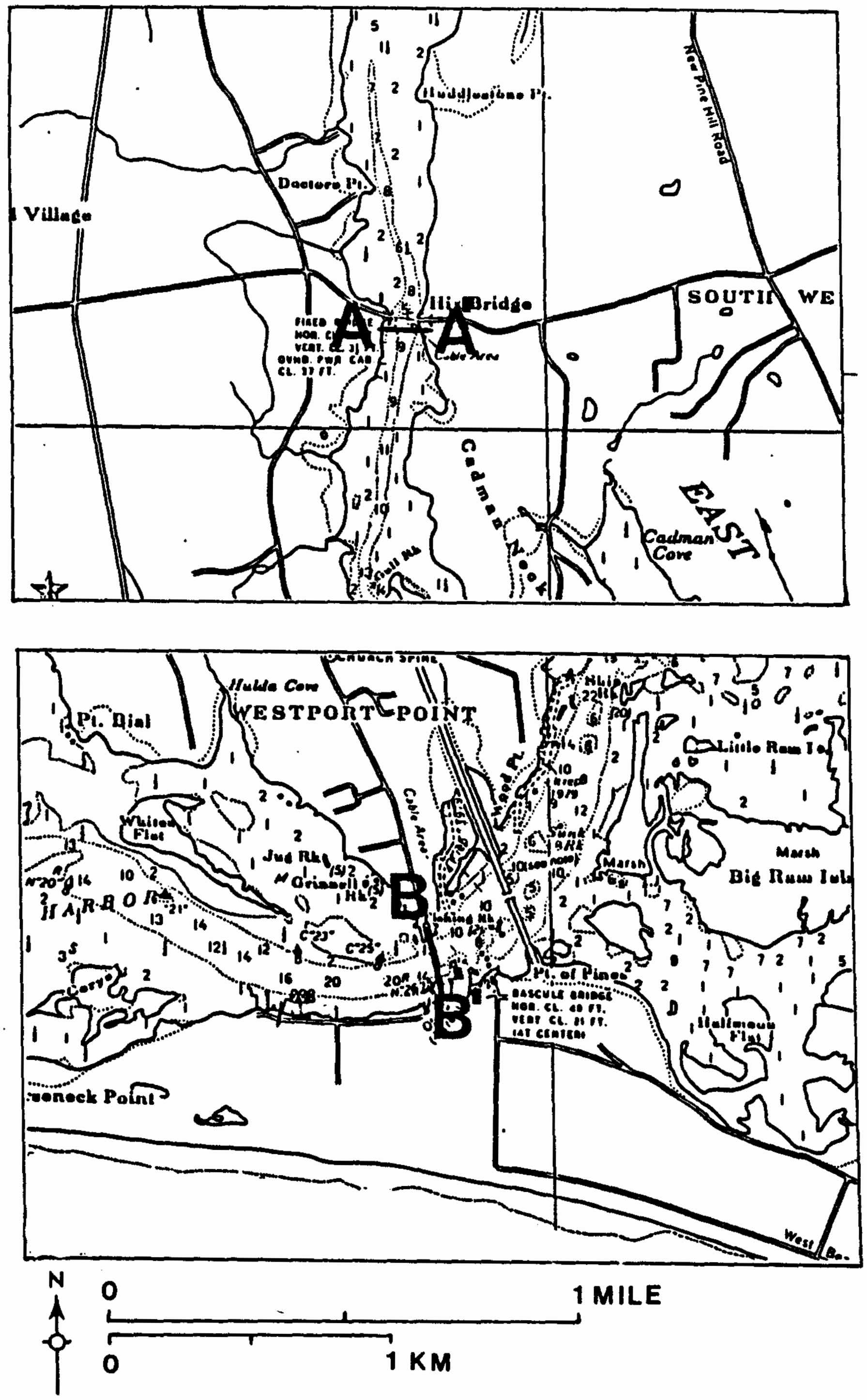


Figure 22. Location of the hydrographies and bathymetries at Hix Bridge (top) and at Westport Point (bottom).

Table 16. Hydrographies

Location	Date	Tide	Current Measurements	Water Samples	Rainfall during or preceeding hours (inches) During	12	24	48
East Branch	8/31/84	Spring	312	--	0	0	0	0
Westport Point	5/9/85	Mean	142	120	0	0	0	0
Hix Bridge	5/16/85	Mean	84	87	0	0	0	0
Westport Point	5/25/85	Neap	178	183	0	0	0	0
Hix Bridge	6/12/85	Neap	99	98	.02	0	.02	.0
Westport Point	6/30/85	Spring	155	141	0	0	.35	.35
		Totals	970	629				

Precipitation levels were taken from a recording rain gauge in operation during most of the study, or from the offical weather records. Rainfall data show that there was generally little, if any, precipitation preceeding the hydrographies. During storms, it can be assumed that there would be surface water runoff and increased stream discharge, resulting in greater erosion and transport of sediment into the estuary.

The data from each hydrography were used to construct current velocity curves for each station and each location. The three measurements were averaged and plotted versus time. A curve was drawn through the data points to indicate the variation with time of the current velocity over a complete tidal cycle.

The periodic measurements of the tide level were used to construct a tide fluctuation curve, indicating the rise and fall of the tide over the tidal cycle. The relative tide levels were compared with the predicted tide levels as given in the NOAA tide tables in order to establish the position of mean sea level.

The tidal current velocity curves and the tide curve obtained from the hydrography at Westport Point on May 25, 1985 are given in Figures 23 and 24. The tidal velocity curves and tide curves for the other hydrographies are given in Appendix 3. The important data from all of the hydrographies are presented in Table 17.

Table 17. Hydrography Data Summary

	Westport Point			Hix Bridge	
	Mean 5/9/85	Neap 5/25/85	Spring 6/30/85	Mean 5/16/85	Neap 6/12/85
Flood Tide Range (cm)	76	70	116	84	73
Ebb Tide Range (cm)	70	64	97	66	52
Flood Tide Duration (min)	345	370	385	415	385
Ebb Tide Duration (min)	320	300	390	525	370
Maximum Flood Velocity (cm/sec)	68	73	132	59	19
Maximum Ebb Velocity (cm/sec)	67	75	88	11	16
Mean Flood Velocity (cm/sec)	35	37	56	7	9
Mean Ebb Velocity (cm/sec)	26	36	34	6	5
Flood Discharge ($m^3 \times 10^6$)	4.8	5.0	9.7	0.5	0.6
Ebb Discharge ($m^3 \times 10^6$)	3.5	4.5	4.6	0.3	0.3

The hydrographies at Westport Point indicate an overall flood dominated situation. The measured mean flood velocities were greater than the mean ebb velocities. The flood discharges were greater than the ebb discharges, mostly due to the coincidental selection of tides having a strong inequality between ebb and flood tidal ranges. The strongest velocities and the greatest tidal ranges occurred during spring tide conditions.

The tidal current data at Hix Bridge indicate a situation similar to

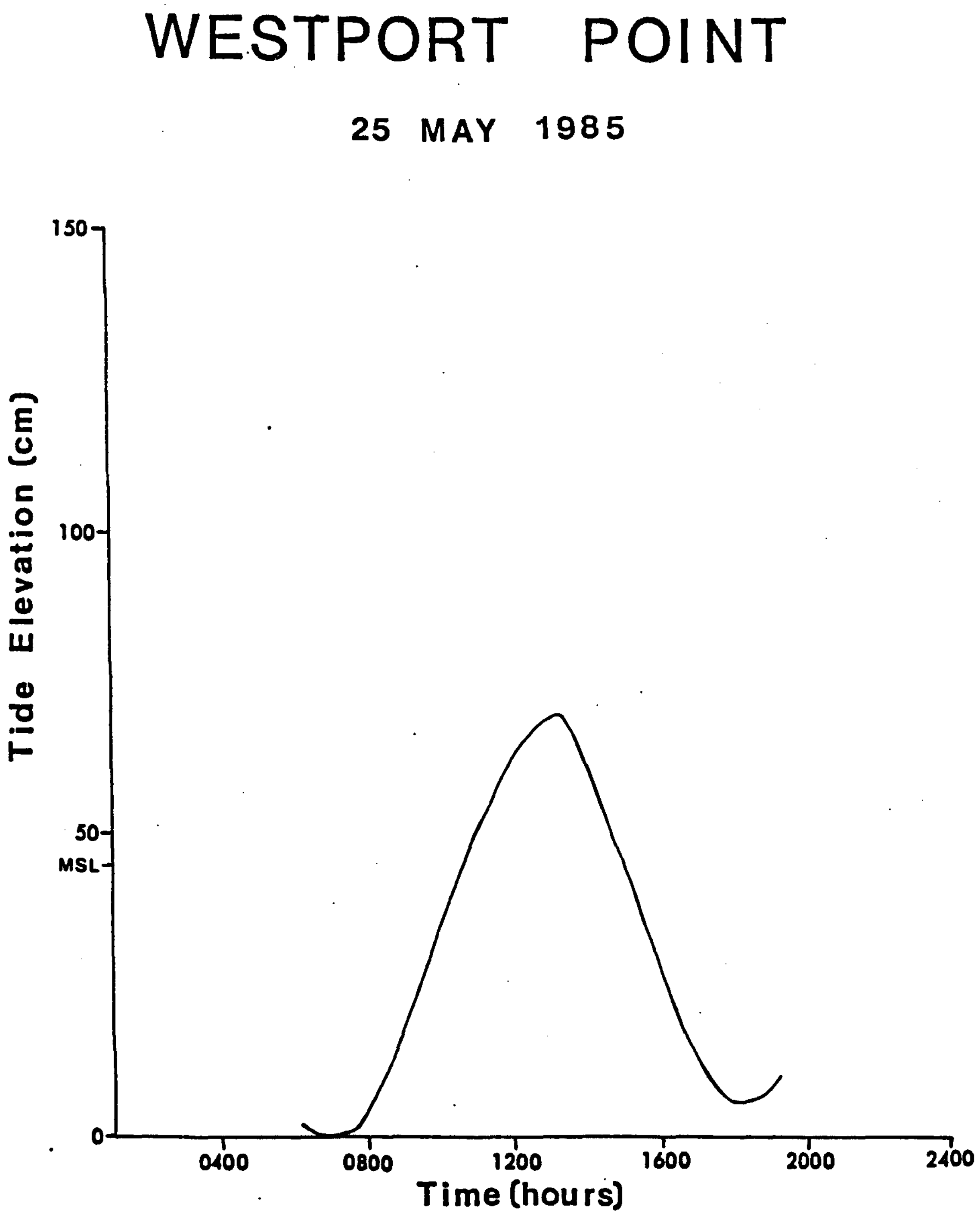


Figure 23. Tide curve for Westport Point on May 25, 1985. The curve indicates the relative rise and fall of the tide during the time period indicated and the total range of the tide for this date (68 cm). Mean sea level for Westport Point relative to this tide occured at 46 cm above the lowest tide.

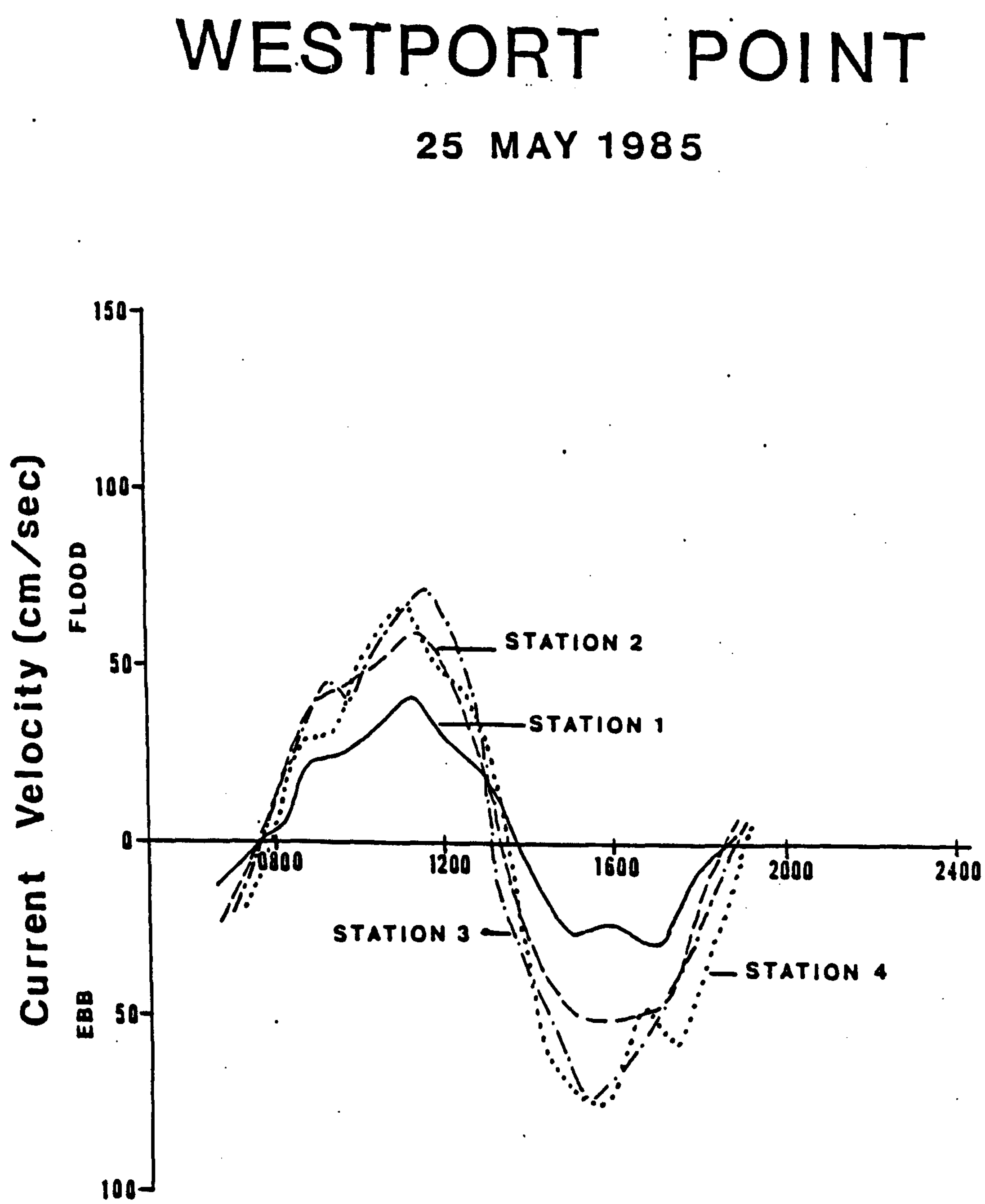


Figure 24. Current velocity curves for four stations at Westport Point on May 25, 1985. The curves indicate the current velocity during the ebb and flood tides for each of the stations. Stations 3 and 4 had the greatest velocities.

that at Westport Point. Generally, flood tide discharges were greater than ebb tidal discharges, due to the inequality of the tidal ranges measured. Flood velocities were greater than ebb velocities.

At Westport Harbor the high tide generally occurs two to three hours after the peak flood velocities, and does not vary significantly with the tidal conditions. The length of time from the peak ebb flood velocity to low tide is more erratic than with the high tide. The length of time to low tide after the peak ebb velocity also varies across the width of the estuary.

At Hix Bridge there is a greater variation in the timing of high tide with respect to peak flood velocity. A range of one to five hours after peak flood velocity was found, depending on position across the estuary. The hydrographies indicated a flood dominance at this location, as well.

Bathymetry

Detailed channel cross sections were made in November 1985 of the two locations where the hydrographies were done (Westport Point and Hix Bridge). A continuous recording Raytheon fathometer was used to measure the bottom contours. The position of mean sea level was plotted onto the cross section by examination of the tide curve predicted for the day of the bathymetry. The cross sections obtained are given in Figure 25, also showing the area in each cross section of each measurement station. The cross sections combined with the measured current velocities were used to calculate the volumes of water passing through each cross section during the hydrographies, the

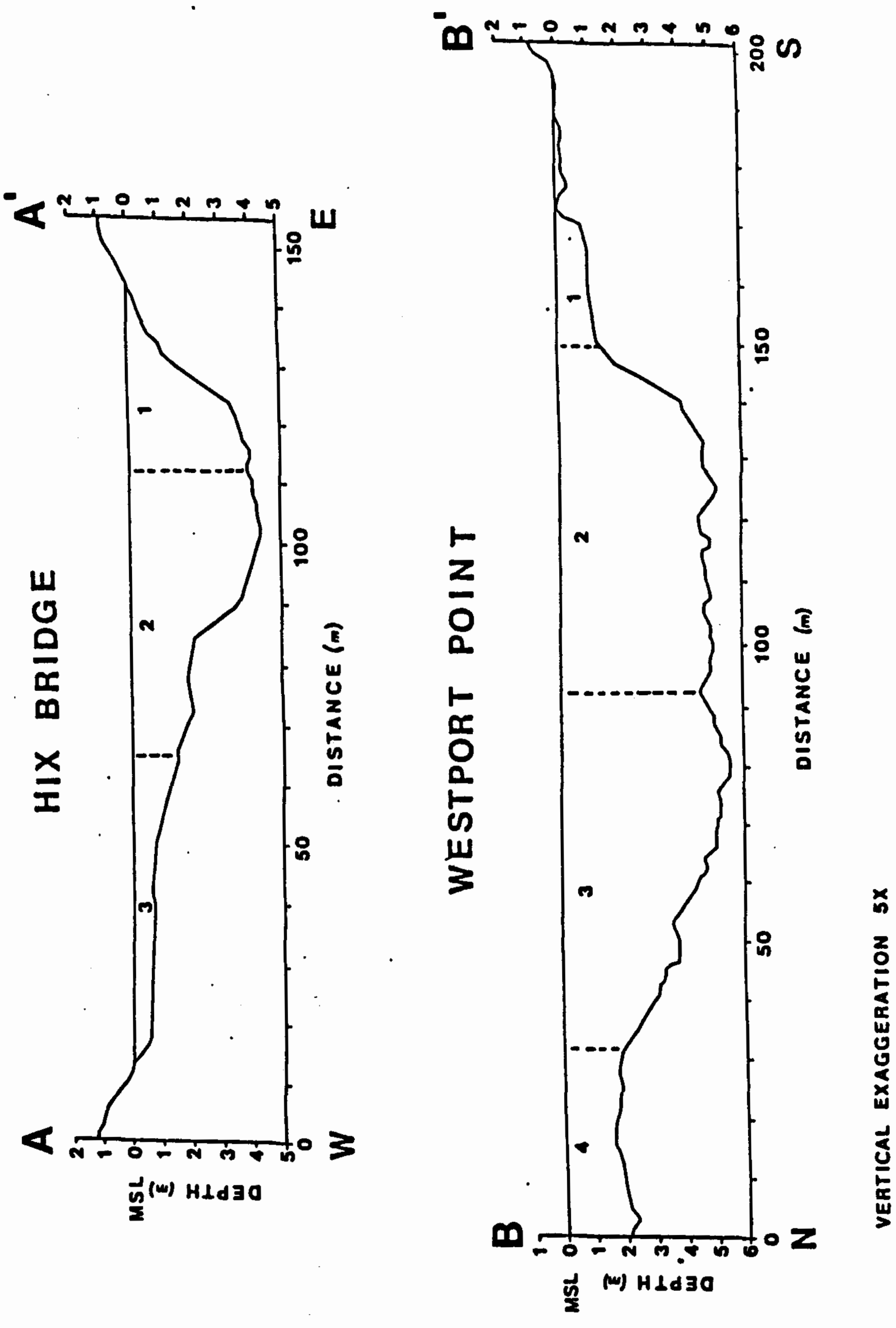


Figure 25. Cross sections of the East Branch at Hix Bridge (top) and at Westport Point (bottom), indicating the contours of the river bottom. The hydrography measurement stations are indicated by the numbers on the cross section.

tidal prism.

Tidal Prism

The tidal prism is the amount of water entering the estuary between low and high tides. An estimation of the tidal prism can be made by multiplying the tidal range in the bay by the surface area of the estuary (Beer, 1983). This method is problematic in the East Branch because the tidal range varies with position in the estuary. An estimate would have to model the change in tidal range at different locations. However, the calculation of the tidal prism is important in determining the amount of flushing of the estuary, and of the relative significance of tidal versus stream discharges in the estuary.

The data recorded during the hydrographies were used to calculate the tidal prism, using:

$$Q = AV \qquad (24)$$

where Q is discharge, A is area, and V is velocity.

Tidal current velocities were made at traverse stations at three depths at approximately 1 to 1-1/2 hour intervals. The current readings were averaged over depth at each station. The averages were plotted versus time over the tidal cycle (Figure 24 and Appendix 3). Mean velocities were calculated from the curves by dividing the curve into time segments. The time segments had boundaries that were set at the mid-point between actual measurement times, instead of at regular intervals. Mean velocities were given by the mean value of all the current readings from the curve at 10 minute intervals during the time segment. The time intervals used and the mean velocities obtained are listed in Appendix 2.

The depth of each cross sectional compartment continually changed with changing tide level. The tide curve obtained during the hydrography was used to determine the mean change in sea level during each of the time segments described above. The position of mean sea level was located on each of the tide curves. The mean change (rise or fall) of sea level from mean sea level during the time segment was determined by dividing the tide curve into identical time segments and finding the mean tide level relative to mean sea level for that time segment. The mean of all the tide level readings at five minute intervals was calculated from the plotted curve. This resulted in a mean tide level above or below the mean sea level for that particular time segment. This change in sea level was then added to the mean depth found at each station to obtain a depth for multiplication with the compartment width to obtain a compartment cross sectional area for the term A in Equation 24.

The width of each station compartment was obtained from the plotted cross section. Widths for mid-channel compartments were constant, and read directly from the cross section. The compartment cross sectional area was obtained by multiplication of the width and depth. The widths for the compartments at the channel edges changed as sea level rose or fell. The cross sectional areas for incremental sea level changes of 5 cm were calculated for the edge compartments, allowing the cross sectional area to be known for a particular sea level.

Flood and ebb discharges for each compartment or station were calculated for each measurement period. The discharges for each measurement period for each station were then summed, to give a total ebb or flood discharge for that station. The total cross sectional flood and ebb discharges were calculated by summing the appropriate discharges for all stations. Table 17 shows the measured and calculated flood and ebb discharges for the hydrographies at Westport Point and Hix Bridge. The flood and ebb discharges differ, in some cases significantly, as the flood and ebb tidal ranges varied during the tidal cycles chosen for the hydrographies. The flood and ebb discharges would be approximately equal if the ebb and flood tidal ranges were similar, except for the addition of a volume of fresh water from stream discharges into the estuary during the ebb flow.

The mean tidal prism at Westport Point, taken as the average of the tidal prisms for the three hydrographies at this location, was 6.5 x 10^6 m^3. A mean tidal prism of 9.28 x 10^6 m^3 for the Westport River as a whole, including both the East Branch and the West Branch, was calculated by Magee on the basis of two hydrographies at the Westport River inlet (Magee, 1981). Magee calculated that the Spring tidal prism would be 11.5 x 10^6 m^3 at the inlet. The tidal prism measured at Westport Point during Spring tidal conditions in 1985 was 9.7 x 10^6 m^3.

Salinity

Salinity measurements were made during each of the hydrographies at Westport Point and Hix Bridge during 1985 and during the hydrographies in 1984 between Hix Bridge and Westport Point. The maximum, minimum, and mean salinity values for each hydrography are given in Table 18. The salinity measurements were made at the three depths at each station throughout the tidal cycle.

Table 18. Salinity Data.

Date	Location	Salinity (o/oo) Max	Min	Mean
8/31/84	Station 4: Lakes Island	33.2	26.8	30.7
	Station 5: Big Pine/Great Islands	33.9	30.7	32.6
	Station 6: Gunning Island	33.9	29.4	32.1
	Station 7: West of Speaking Rock	33.5	29.8	32.0
	Station 8: Westport Point	33.3	31.0	32.0
5/16/85	Hix Bridge- Neap Tide	22.5	13.7	17.3
6/12/85	Hix Bridge- Mean Tide	23.8	17.0	20.5
5/9/85	Westport Point- Mean Tide	33.3	27.5	30.9
5/25/85	Westport Point- Neap Tide	32.3	27.3	30.0
6/30/85	Westport Point- Spring Tide	32.7	27.0	29.8

The salinity data show that the estuary is vertically well mixed, with almost no stratification. The salinity generally decreased gradually in an upstream direction. On occasion there was more of a range of salinity at one or two stations but this was the exception rather than the rule. Vertically well mixed estuaries are generally shallow with little freshwater influx (Beer, 1983). These traits characterize the East Branch of the Westport River.

Estuarine Circulation

The hydrographies completed during the spring and summer of 1985 were done to obtain the critical information of flood and ebb velocities and discharges, and the tidal prism. They reveal a similar circulation pattern at each of the two traverse locations, Westport Point and Hix Bridge. The main channel, and the left bank (in a seaward direction) have stronger mean flood than ebb velocities. An ebb channel, or ebb dominated area, is present in the shallower areas along the north bank at Westport Point and along the west bank at Hix Bridge. The mean ebb velocites are greater than the mean flood velocities in this area. This is to be expected, because the ebb flow is directed towards the northern bank at Westport Point and the western bank at Hix Bridge, or towards the cut bank of the channel. This may indicate that there is greater flushing of pollutants out of the estuary along these banks and less upstream travel of the sediment which assists in bacterial survival. It is difficult to identify a definite correlation of bacteria with position of the bank, given variations in freshwater inputs, waste inputs, and soils on each of the banks. However, it may suggest that the area towards the western bank at Hix Bridge and the northern bank at Westport Point may be an area where lower bacterial counts would be expected.

The hydrographies completed on August 31, 1984 were primarily designed to determine the relative differences in current velocity and direction throughout the estuary. The map in Figure 26 indicates the direction and relative magnitudes of the tidal currents at each of the measuring stations during the measured interval for the August 31, 1984 hydrographies. The subsequent measurement periods during the tidal cycle are indicated on the maps given in Appendix 4. Each location, except for the Westport Harbor location, had stronger flood currents. At Westport Harbor the currents were slightly ebb

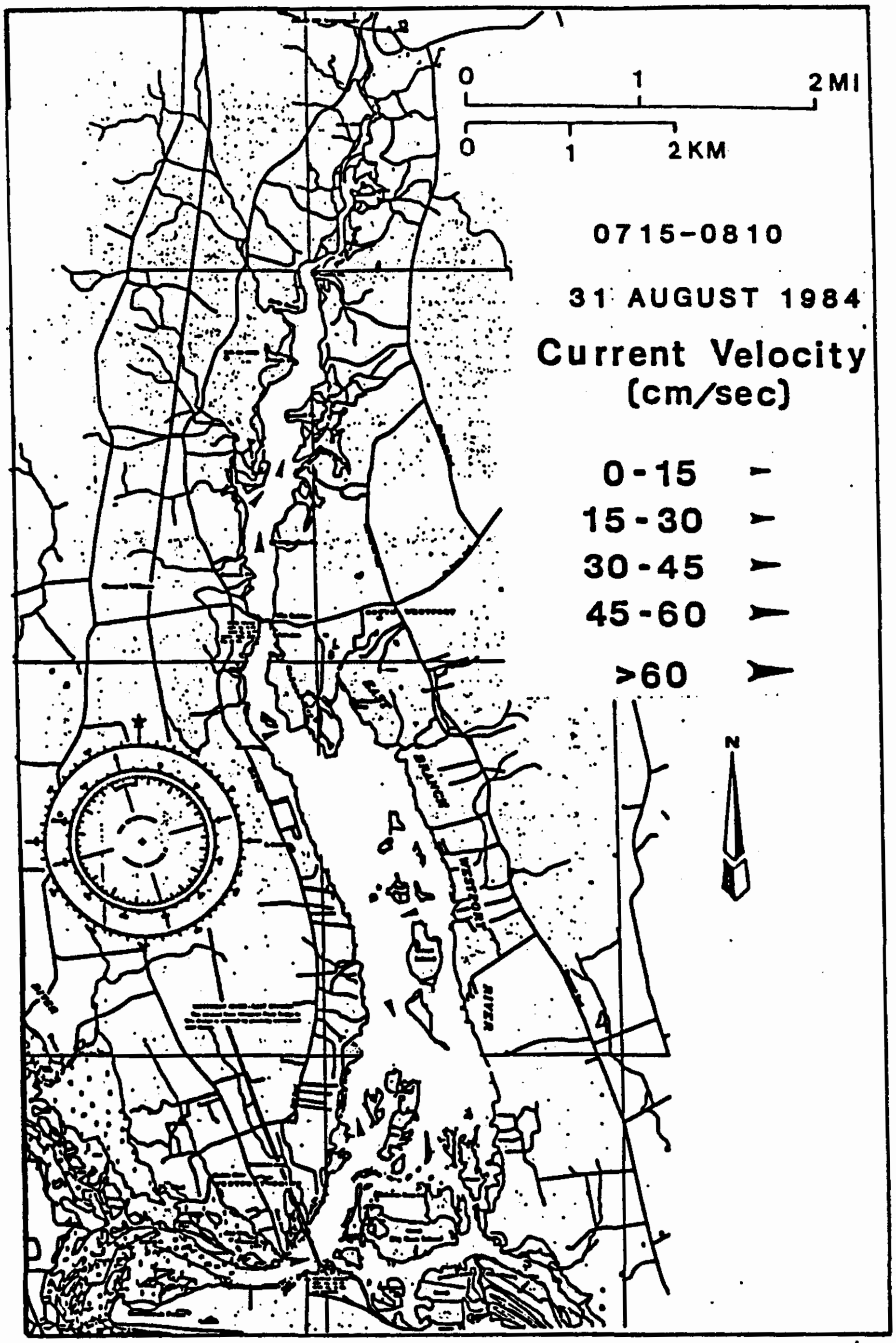


Figure 26. Current velocity magnitudes and directions for eight stations in the East Branch during the period 0715 to 0810 on August 31, 1984, indicated by the arrows shown in the channel. The lack of a uniform direction for the currents indicates the contorted circulation pattern throughout the East Branch.

dominated. Current directions are generally parallel to the thalweg. The magnitude of the current velocities decreased upstream.

The circulation patterns in the estuary have been determined from the velocity and salinity data, the bathymetry, and from an analysis of aerial photographs. Tonal variations on the air photos reveal trends of sediment plume and water movement. The aerial photographs are useful to determine the circulation patterns in the estuary. The position of the thalweg can be clearly seen in aerial photographs of the lower part of the estuary. Subsidiary channels are also evident in The Let, and among the islands in the lower part of the East Branch. The thalweg is the deeper portion of the estuary in which the tidal currents are stronger and where a greater volume of water flows. The route of the thalweg is circuitous, twisting around the islands in the lower part of the estuary, and becoming less discernible north of Upper Spectacle Island.

The configuration of the estuary and constriction of the inlet decreases the ease of water exchange between the ocean and estuarine environments. The twisting nature of the thalweg, or main channel, thoughout the estuary results in the incoming water being subjected to more turbulence and to a greater path length. The incoming water is not able to move into the upstream areas of the estuary during flood tide as easily as if the estuary were straight and uninterrupted by islands. Because of this pattern the flood waters are not able to displace as much of the polluted water in the estuary though mixing and removal on the ebb tide than if the estuary was straight, deep, and had an open access to the marine environment. The amount of flushing and efficiency of mixing decreases with distance into the estuary. In addition, the tidal range is decreased northwards in the estuary, due to the tortuousity of the tidal propagation. This is evident in the 0.09 m difference in the mean tidal range between Westport Harbor and Hix Bridge.

The prevailing northwest winds of the region generate currents moving downstream in the estuary. These currents enhance the ebb flow and retard the flood currents. The waves generated by these winds increase mixing in the estuary, particularly in the area below Hix Bridge.

Estuarine Flushing

Flushing of an estuary is accomplished by the influx of freshwater and is dependent on the replacement of estuarine waters by an equal volume of freshwater. The flushing time of an estuary is the time necessary to replace the estuarine waters and is most simply defined by: (Beer, 1983)

$$tf = V/Q \qquad (25)$$

where tf is the flushing time (sec), V is the estuarine volume (m^3), and Q is the river flow (m^3/sec).

Examination of Equation 26 reveals that flushing time decreases as river flow (freshwater) increases and the volume of water in the estuary decreases. A moderate sized estuary with very little freshwater discharge will have a greater flushing time than a small estuary with a significant freshwater riverine influx. The greater the flushing time the longer it takes for contaminants to be removed from the estuary.

The flushing time for the East Branch can be calculated using the information collected during the hydrographies, hydrological studies, and review of the literature. The pertinent information is summarized in Table 19. The estuarine volume was calculated from the coastal chart by constructing numerous cross sections across the estuary and calculating a mean depth. The volume was determined by multiplying the mean depth by the surface area of the estuary.

Table 19. Flushing data, East Branch,, Westport River

Mean Tidal Discharge:		
Westport Point	Flood	306 m^3/sec
	Ebb	129 m^3/sec
Hix Bridge	Flood	22 m^3/sec
	Ebb	16 m^3/sec
Freshwater Mean Annual Discharge:		
River at Head of Westport		1.80 m^3/sec
Total freshwater at Hix Bridge		2.46 m^3/sec
Total freshwater at Westport Point		3.00 m^3/sec
Total freshwater at Hix Bridge including Copicut Reservoir		2.80 m^3/sec
Total freshwater at Westport Point including Copicut Reservoir		3.35 m^3 /sec
Estuarine Volume:		
Head of Westport to Hix Bridge		1.1×10^6 m^3
Head of Westport to Westport Point		8.9×10^6 m^3

An examination of these data reveals that the flood tidal discharge at Westport Point is approximately 100 times the freshwater influx. At Hix Bridge the flood tidal discharge is almost 10 times the freshwater influx. The freshwater discharge at Westport Point is equivalent to about 1/130 of the ebb tidal discharge. At Hix Bridge the freshwater discharge is equivalent to about 1/2.5 of the ebb tidal discharge. Clearly, the volume of river flow and freshwater input into the estuary is significantly less than the volume of water brought in on the flood tide. Thus, the flushing by river flow may be assumed to be not very efficient, and slow.

The flushing times calculated using this equation are:

At Hix Bridge	5.2 days
At Westport Point	34.3 days

These figures are the times needed for the mean annual flow of the river to completely flush the volume of water from the area of the estuary to the indicated location, based on stream discharge alone. During storms, when there is a much greater stream discharge, the flushing times will be considerably less.

The diversion of water from approximately 26 km^2 of the drainage area of the East Branch by the construction of the Copicut Dam in 1964 may have exacerbated existing bacterial pollution. Approximately 10% of the total freshwater input to the estuary was lost when the dam was constructed. This decreased the already low relative volume of freshwater input and lengthened the flushing time. North of Hix Bridge, where the diversion represented a slightly greater porportional loss, 12%, the effect would be even more strongly felt. In addition this water from a relatively unpopulated and unused area would presumably have had less of a bacterial load than the other waters now entering the estuary north of Hix Bridge. Less water, and a greater proportion of more polluted water is now entering the East Branch due to the diversion. There is less dilution of polluted water by cleaner waters. The proportion of freshwater to estuarine water is greater north of Hix Bridge than it is lower in the estuary, and thus the loss of 12% of this freshwater is more significant and felt more north of Hix Bridge than it is near Westport flushing times for the mean annual flow of the streams entering the estuary are reduced to:

At Hix Bridge	4.5 days
At Westport Point	30.7 days

The decrease in the freshwater discharge into the East Branch, brought about by the construction of the Copicut Dam may also have had an additional effect. The salinity throughout the estuary would have increased slightly, affecting diffusion rates. The survival time of bacteria, the decomposition of waste, and the circulation of wastes may have been influenced by this change in diffusion rates and salinity (Ippen, 1966).

Mixing and dilution of the polluted water in the estuary by the flood tide might have been expected to decrease the bacterial counts. The flushing volume can be expressed as the ratio of water entering on the flood tide (the tidal prism) to the volume of water in the estuary (Ippen, 1966).

At Westport Point, the mean tidal prism, as measured during the hydrographies, was 6.5 x 10^6 m^3. This represents 73% of the volume of the estuary, for a flushing volume of 0.73. This indicates that if the waters in the estuary were completely mixed each tidal cycle then after 2 tidal cycles, 95% of the original estuarine water would have been replaced. After 4 tidal cycles, 99% of the estuarine waters would be replaced if the estuary was completely mixed.

At Hix Bridge, the mean tidal prism was determined to be 0.55×10^6 m^3. The estuarine volume from the Head of Westport to Hix Bridge is 1.1×10^6 m^3. The flushing volume is 0.5. Assuming complete mixing of new sea water with the estuarine water from the Head of Westport to Hix Bridge, after 4 tidal cycles 95% of the original water would have been replaced and after 8 tidal cycles 99% of the water would be replaced. However, this complete mixing situation is impossible due to the extent of the estuary below Hix Bridge. This indicates that mixing and flushing do decrease significantly above Hix Bridge, due to both lack of complete mixing and the smaller flushing volume in this portion of the estuary.

In the ideal case of the tidal prism the water that enters on the flood tide is completely mixed with the water in the estuary. The ebb tide removes the same volume of water plus an amount equal to the freshwater discharged into the estuary during the tidal cycle. This water would carry with it a percentage of the pollutants in the estuary (Ippen, 1966).

This concept is likely to be even less correct than usual, in the case of the East Branch. Much of the water is not able to mix freely and replace an equivalent volume of water from the estuary. Thus, the effect of the flood tide, in terms of actually mixing with and displacing a volume of water containing pollutants, is small. The consequences of this are even more severe when it is taken into account that some of the major sources of pollution are also those farthest from the influx of ocean water and the least likely to be directly mixed and removed. The relatively low freshwater discharge increases the time that it takes for pollutants to be flushed out into the estuary by the action of stream flow alone.

SUSPENDED SEDIMENT

Introduction

The investigation of suspended sediment transport in the estuary of the East Branch was based upon a large-scale water sampling program, discharge measurements in the estuary and of tributary streams, statistical analysis of available USGS records, and field observations in order to construct models of the inputs and outputs of suspended sediment in the estuary, of the transport, behavior, and deposition of suspended sediment in the estuary, and for a possible correlation with water quality bacterial data.

Suspended sediment may be significant in the East Branch not only in terms of filling the estuary but also as a factor in the bacterial contamination of the estuary. Thus, one possibility for reducing the bacterial levels in the East Branch may be to control and decrease the amount of sediment entering the estuary, especially sediment that may also be associated with land based sources of bacteria. To reduce erosion and contribution of sediment into the estuary may require techniques such as slope terracing in some areas or the development of a "green belt" along eroding banks. Bank erosion might still occur, but hopefully those areas would not be associated with bacteria sources.

The possible significance of suspended sediment in the bacterial water quality of the East Branch revealed the need for a better understanding of the sources, transport, behavior, and deposition of sediment in the East Branch, as well as a review of the literature for correlations of sediment with bacteria and an application of this correlation to the results in the East Branch.

Sediment-Bacterial Relationships

Sediment affects water bodies by increasing the turbidity and decreasing the biological productivity of the water. Fine grained sediments may also adsorb trace metals, nutrients, insecticides, and herbicides, leading to health concerns as well as eutrophication. In addition, sediment decreases oyster harvests and reproduction (Duda, 1985). Sediment density, volume, and movement may also be correlated with bacteria and virus levels. Evidence exists that shows that suspended sediment can be correlated with bacterial levels in estuarine waters.

Fecal coliform densities in bottom muds have been seen to be greatly increased relative to the fecal coliform densities in the overlying water by a factor of 10 to 20,000, with salmonella occurring in 23.5% to 68.2% of samples examined (Journal of American Water Works, 1970). Bacterial densities in sediment were several orders of magnitude greater than in the overlying water in a study of the Lower Chesapeake Bay (Erkenbrecher, 1981). The bacteria were thought to be contributed to the sediment by attachment to suspended sediment that results from surface runoff on the adjacent land. The sediment may provide a protective environment and nutrients for indicator bacteria, and serve as a reservoir for a high number of bacteria that have been transported along with the suspended material that has then settled (Erkenbrecher, 1981).

A significant proportion of total viable bacteria and fecal indicator bacteria were found to be closely associated with suspended sediment in the Chesapeake Bay, although a correlation between bacterial counts and suspended sediment concentration was not established (Sayler et al., 1975). In addition, the survival of fecal streptococci in the suspended sediment samples was enhanced, with less seasonal fluctuation of bacterial counts for bacteria associated with sediment than with overlying water. The study of sediment and bacteria in the Chesapeake Bay indicated that suspended sediment may provide a transport mechanism for the fecal indicator bacteria. (Sayler et al., 1975).

Experimental work in the Rhode River Estuary was undertaken to determine the effect of physical parameters on bacterial survival. The addition of montmorillonite at 50 mg/L increased the half-life of the viable bacterial cell population by 40% over the half-life in water alone (Faust et al., 1975). A possible solution for this effect is that montmorillonite can protect E. coli from attack by other organisms and that clay may provide a protective physical envelope around the bacterial cells (Faust et al., 1975).

An examination of enteroviruses in Galveston Bay indicated that suspended sediments enhance viral survival. The occurrence or attachment of viruses to sediment was indicated in 72% of suspended sediment samples, in 47% of "fluffy mud" samples, and in 5% of compact mud samples, but in only 14% of water samples free of suspended material. Experimental data showed that poliovirus and retrovirus remained infectious for 19 days when associated with solids but only for 9 days when not associated with solids. In addition, the accumulation of viruses by shellfish is cited to be greater when the viruses are associated with particulate matter (Rao et al., 1984). The circulation of water containing viruses associated with sediment can represent a health threat to areas of cleaner water (Johnson, 1984).

Thus, sediment, both suspended in water and deposited, can increase the severity and persistence of bacterial contamination. To establish a definite correlation between bacterial counts and suspended sediment concentrations in the East Branch would have required an overwhelming amount of work to obtain the necessary data, in view of the other goals of the East Branch study. Thus, only conjectural correlations may be drawn from the existing data. The areas of the East Branch that had significant amounts of deposition of fine-grained materials did consistently have high bacterial counts. Also, the water in the vicinity of Hix Bridge had higher bacterial counts and suspended sediment concentrations than did the water in the vicinity of Westport Point. This is suggestive of a possible correlation between suspended sediment and bacteria, although due to the multiplicity of factors a causal relationship between the two may not be established, and is beyond the scope of the present study. However, the importance of suspended sediment in bacterial transport and survival as indicated in the literature must be noted. Therefore, the study of suspended sediment sources, transport, and fate in the estuarine environment of the East Branch may prove to be of use in further work in the area.

The examination and development of a model for suspended sediment transport in the East Branch involved field sampling of water and lab analysis for suspended sediment, field observation of sediment sources and deposition, and examination of published work and data on sediment and soils in the region of the East Branch.

Suspended sediment sampling and analysis

Methodolgy. Water samples for suspended sediment analysis were collected during the hydrographies at Westport Point and Hix Bridge during the summer of 1985. Measurements of current velocity, salinity, temperature, conductivity, and dissolved oxygen were made along with the water sample collection at the same stations and depths.

A 1.3 liter Kemmerer style water sampler, as illustrated on page 645 of Standard Methods for the Examination of Water and Wastewater, (American Public Health Association, 1976), was used to obtain water samples. This sampler consisted of a 40 cm long 6 cm diameter brass tube open at both ends, that was lowered on a marked cable to a specified depth, at which point a brass messenger was dropped along the line onto the sampler, activating rubber stoppers at both ends of the sample tube. During the lowering of the sampler the water passed freely through the sampler, allowing a depth specific sample to be obtained at the point that the messenger was dropped. The sampler thus obtained a water sample representing a 40 cm vertical at the desired depth. The water samples were then placed into 1 liter sample bottles and treated with 5 ml of hydrogen peroxide to kill any bacteria or algae that might multiply and cause an increase in mass of suspended matter in the sample.

Water samples were collected at three depths at roughly equal increments of depth at four stations at the cross section at Westport Point and at three stations at Hix Bridge. The sample volumes were approximately one liter. The frequency and volume of the water samples was judged to be sufficient after a review of the literature for similar studies.

A total of four point samples per station were judged sufficient for a study of suspended matter, salinity, and temperature in the Gulf of St. Lawrence, although station depths there ranged from 232 to 453 meters. Sample volumes were 12 liters (Sundby, 1974). A study in Narragansett Bay was undertaken with samples from one meter below the surface and one meter above the bottom, while samples from Rhode Island Sound were taken only from mid-depth only. The sample volumes were 270 liters (Morton, 1972). Less than 50 mg of suspended material has been found to be sufficient to obtain suspended sediment concentrations, and a volume of one liter is adequate (McCave, 1979). Water volumes of of 400 to 500 ml were filtered to obtain suspended sediment concentrations for Chesapeake Bay (Sayler et al., 1975). Samples of 100 to 400 ml were filtered for a study of a subestuary of the Lower Chesapeake Bay (Erkenbrecher, 1981). Anderson (1970) determined sediment concentrations by filtering 2 liters of sea water through 0.45 micron filters.

The materials referred to as suspended sediment throughout this study of the East Branch of the Westport River is defined here as the total nonfiltrable residue, all the material retained on a filter after filtration of the water (American Public Health Association, 1976). This residue is what is commonly referred to as suspended materials, suspended sediment, suspended matter, suspensate, or seston (McCave, 1979).

The common method for determining the concentration of suspended sediment is to filter a known volume of water and to weigh the material retained on the filter. The general method of determining suspended sediment concentrations as outlined by Banse and others (1963), was used throughout this study of the East Branch. This method is a modification of earlier methods.

The filters used in this study were 47 mm diameter Millipore HA filters with a pore diameter of 0.45 micron. These filters were marked and preweighed prior to filtration. The water samples were then filtered through the filters, using a vacuum pump to draw the water through the filter held in place by a plastic filter holder. The average water volume filtered was 0.9 to 1.0 liter. Any visible organic matter that was retained along with the water sample was carefully removed by forceps during the filtration. After the sample filtration was complete the sides of the filter holder were rinsed several times with small volumes of distilled water from a wash bottle to rinse down any suspended sediment adhering to the filter holder walls. The top of the filter holder was then removed and the filter exposed. The filters were then rinsed four more times with small volumes of distilled water while under vacuum, for a total volume of approximately 25 ml. The filters were then placed on foil trays and placed in a drying oven for a period of approximately 24 hours. After this time, the filters were removed and weighed on a Mettler Type H6T digital analytical balance.

The procedure followed eliminated possible sources of error that might be present in a filtering and weighing process such as this, as identified by Eatons and others (1969). These sources of error include the weight change of membrane filters due to electrostatic charge, the absorption of atmospheric moisture, and the loss of leachable material from the filter during filtration. Modifications of the method and additional steps were taken to minimize the effects of these possible sources of error. A control filter was weighed along with every set of ten sample filters after the first five sample filters were weighed. These control filters accompanied the sample filters through every step of the procedure, except that they were not used for sample filtration. After filtration, the control filters were then reweighed, in the same order as previously. The change in weight of these filters was assumed to be due to the changes in atmospheric moisture content between the two weighing periods, the changes in electrostatic charge, and any dessication occurring during the drying period. The weight change of each control filter was then added to the post-filtration weight of the appropriate set of sample filters. This procedure had the effect of negating the effect of the atmospheric moisture and electrostatic charge and provided a way to relate the pre- and post-filtering weights of the sample filters even though the filters may have been weighed under different atmospheric conditions. The control filter essentially revealed what effect the atmosphere had on the sample filter weights and provided a common relative base measurement so that the absolute change in weight of the sample filters due to the sediment could be determined.

The weight changes of the filters due to leaching of material during filtration was compensated for by using one filter as a leaching filter blank for every set of five sample filters. The leaching blank filter was preweighed and treated as were all the other sample and control filters. One leaching filter was placed beneath every fifth sample filter during filtration of the water sample. The remainder of the filtration, drying, and weighing procedure was identical to the other filters. After making the same correction on the leaching blank filter using the control filters the weight loss of the leaching blank filter was calculated. The average weight loss of the leaching blank filters for each lot of filters was calculated and added to the post-filtering weight of the sample filters.

This procedure of using multiple control filters is generally followed in determining suspended sediment concentrations (Banse et al., 1963; McCave, 1979; Eaton et al., 1969). It proved to be the most feasible method for this study, as alternate methods of reducing possible sources of error, such as using an alpha-emitter under the weighing pan to remove electrostatic charge, were not possible.

An additional source of error in determining suspended sediment concentrations in sea water is the presence of sea salt, as a 47 mm diameter filter may hold up to 5 mg of salt with the filter holder in place (Banse, 1963). The recommended procedure, followed here, is to remove the filter holder and rinse the filter while under vacuum with several applications of small volumes of distilled water from a wash bottle. A filtration through 0.4 um filters, followed by a rinsing with 50 ml of distilled water, was used for a study in the Gulf of St. Lawrence (Sundby, 1974).

Once the corrections for compensating for atmospheric moisture, electrostatic charge, dessication, and leached material were made, the weight change of the each of the sample filters could then be calculated. This weight represented the weight of suspended sediment.

Precision and Accuracy. The weighing procedure was the step that might introduce the greatest amount of error in calculating the suspended sediment concentrations, due to the factors mentioned above. The precision of the measurement can be thought of as how precise the measurement is or to what level of detail can be obtained and reproduced. In the case of the weighing, the analytical balance would weigh to 0.1 mg, so that defines the level of detail obtainable.

The precision can be though of as how correct the measurements are, or how much variance there will be in individual measurements in a set of measurements. Occasionally, throughout the weighing process, specific filters would be reweighed more than once, or by two different people. Once the corrections had been made to the filter weights, in virtually all the reweighings the weights fell within a 0.1 mg range. Thus the precision was 0.1 mg. The filter weights encountered ranged from 74.2 to 101.3 mg, and the sediment weights from 0.2 to 6.9 mg, with the majority of actual sediment weights in the range 2.0 to 3.0 mg. Thus the error introduced into the calculation of the sediment weights was approximately 3.3% to 5%. Errors introduced into the calculations during the volume measurement can be due to improper reading of the sample volumes. The volumes could be read to a precision of 10 ml, out of a sample volume of 1000 ml, for a 1% error.

The types of error affecting the accuracy of suspended sediment measurements include sampling error, spatial error, temporal error, and sediment discharge error, all errors in obtaining the true suspended sediment concentrations based on a certain number of water samples (Burkham, 1985). Equations for determining the amount of error have been developed by Burkham. The amount of error and the accuracy of the suspended sediment data for the East Branch has not been calculated. The accuracy of any suspended sediment data is almost impossible to obtain, as the true values may not ever be known. Thus the figures are to be regarded as useful approximations, as may be all suspended sediment load data (Linsley, 1982). An additional source of error pointed out by Burkham is that most suspended sediment sampling programs exclude the bottom 0.1 to 0.3 meter of depth of each vertical, due to interference with the bottom. This omits the area of the highest suspended sediment concentrations and the coarsest sediment, although the omission is less critical in examinations of fine suspended sediment (Burkham, 1985). Error is also associated with the fact that sand will settle out of conventional water bottles in estuaries with high current velocities and a high proportion of sand (McCave, 1979). These last two sources of error are less critical with the East Branch, as finer grained materials than sand were observed to be more predominant.

Suspended Sediment Flux

Methodology. An analysis of sediment circulation and sediment budgets can be made by calculating the sediment flux over a tidal cycle. The flux for a given cross section can be given in terms of weight per unit width per unit time by integrating the current velocity and suspended sediment concentrations over depth (McCave, 1979).

To determine the suspended sediment discharges at Westport Point and at Hix Bridge the fluxes were calculated using the measured current velocities and suspended sediment concentrations. At Westport Point a total of 12 sets of measurements (three depths at four stations) were used for each traverse over a cross section of 592 m^2, and at Hix Bridge a total of 9 sets of measurement (three depths at three stations) over a cross section of 253 m^2.

Prior to determining the suspended sediment fluxes it was necessary to insure that the current velocities and suspended sediment concentrations generally correlated so that the two measurements could be paired. It was necessary to determine that there were no unusual patterns such as abnormally high currents associated with low suspended sediment concentrations, or low currents associated with high suspended sediment concentrations. Otherwise, the calculations might be skewed. In addition, the applicability of averaging or integrating of the suspended sediment concentrations over depth was examined.

In order to determine the correlations between the current velocity measurements and the suspended sediment concentrations, the data for each of the measurements was ranked according to at what depth or position the highest reading occurred. The number of maximum readings occurring at the shallowest depth, the middle depth, and the bottommost depth was determined for the flood and ebb tides at each location for each of the hydrographies. The numbers for the current measurements were compared to the numbers for the suspended sediment concentrations. For example, if 30 sets of current velocity and suspended sediment measurements were made, and the greatest number of maximum readings for both current velocity and suspended sediment for each vertical occurred at the same depth, there would be a correlation. In eight of the ten tides (flood and ebb tide during 5 hydrographies) there was a correlation between the position of the greatest number of the maximum readings of both current velocity and suspended sediment concentration measurements. At Westport Point, the maximum velocity and highest suspended sediment concentration occurred at the surface more times than at either of the other two vertical locations. At Hix Bridge there was no predominant depth where maximum measurements occurred. The finding that the two sets of measurements generally correlated allowed the use of the averaging over depth, without the possibility that this might skew the results.

The suspended sediment loads calculated for each of the hydrographies were determined by using the average of the three suspended sediment concentration values determined at three different depths, once the above correlation was verified. The average of the three measurements was verified to be representative of the suspended sediment concentration distribution throughout the water column. In order to make this verification, an additional series of water samples was collected during the hydrography at Westport Point on May 25, 1985. Replacing the normal series of three samples taken at equal increments of depth at one station was a series of six samples taken at 0.5 meter increments of depth from 1.0 meter depth to 3.5 meter depth during the flood tide, and at 0.6 meter increments of depth from 1.1 meter depth to 4.1 meter depth during the ebb tide. The six measured concentrations were then graphed for the flood tide and for the ebb tide, to represent the suspended sediment variation over depth. The mean suspended sediment concentration was then determined for the vertical by measuring the area under the curve. This mean concentration for the curve constructed from the six sample measurements was then compared to the average of the three normal sample measurements, as summarized in Table 20.

Table 20. Suspended sediment concentration comparisons.

	Mean from curve	Average of three readings	Error	% Error
Flood	1.60 mg/L	1.67 mg/L	0.07 mg/l	4%
Ebb	1.52 mg/L	1.50 mg/L	0.02 mg/L	1%

In each case, the amount of error introduced by averaging three suspended sediment measurements instead of using a more complete set of six measurements was less than 0.1 mg/L. The level of precision in weighing the sample filters was 0.1 mg/L, thus the amount of error introduced by the averaging technique is below the obtainable level of precision possible in the laboratory analysis. The averaging technique is thus valid, given the level of precision obtainable.

Sediment Flux Calculations. The suspended sediment discharge or flux at Westport Point and at Hix Bridge was calculated by averaging the suspended sediment concentrations over depth for each station and time and multipying by the water discharge for that station and time. The water discharge was calculated by multiplying the mean current velocity for each station and time as determined from the current velocity curve obtained from plotting the current measurements from the hydrographies by the cross section measured during the bathymeytry and modified by the change in sea level as indicated by the tide pole maintained during the hydrographies. The individual suspended sediment discharge values for each station and time were summed over each tide for each hydrography.

The mean suspended sediment concentrations for Westport Point and for Hix Bridge are summarized in Table 21.

Table 21. Suspended Sediment Concentrations (mg/L).

		Mean Concentration Station				
		1	2	3	4	Mean
Westport Point						
Mean Tide	Flood	2.1	1.8	1.9	2.1	2.0
5/9/85	Ebb	1.5	2.2	2.6	2.4	2.2
Neap Tide	Flood	2.3	2.4	1.8	2.0	2.1
5/25/85	Ebb	2.1	2.2	1.7	2.3	2.1
Spring Tide	Flood	2.8	2.8	3.3	3.6	3.1
6/30/85	Ebb	3.8	3.7	4.6	4.0	4.0
					Flood	2.4
					Ebb	2.8

Table 21 (continued)

		Mean Concentration Station 1	2	3	4	Mean
Hix Bridge						
Mean Tide 5/16/85	Flood	3.6	3.2	4.1	--	3.6
	Ebb	2.6	3.1	2.8	--	2.8
Neap Tide 6/12/85	Flood	2.9	3.1	3.8	--	3.3
	Ebb	3.4	3.6	3.7	--	3.6
					Flood	3.4
					Ebb	3.2

These results show that at Westport Point the mean concentration during ebb tide is greater than or equal to the mean concentration during flood tide. This indicates that there are upstream sources of sediment and that the ebb tide is transporting this sediment down the estuary. The flood tide from the ocean has a lower concentration of sediment. The flood tidal currents carry some sediment into the estuary from the marine environment and possibly some sediment that has been previously transported out of the estuary by the ebb currents. The relative concentrations indicate that sediment is possibly being contributed into the estuary from the surrounding land surface at a greater rate than sediment is being moved into the inlet from offshore. The stronger flood currents are able to carry a larger particle size, evident from the presence of sand in the water samples taken at Westport Point and the lack of comparable grain sizes at Hix Bridge. At Hix Bridge the results were varied. The mean suspended sediment concentration values are greater for the flood tide during mean tidal conditions, but during neap tidal conditions the reverse was true.

The sediment calculations for the flood tide and for the ebb tide at Westport Point indicate that a greater overall load of sediment is carried by the flood tide. The suspended sediment discharges are summarized in Table 22.

Table 22. Suspended Sediment Discharge (Kg)

		Flood	Ebb
Westport Point			
5/9/85	Mean	9,000	8,400
5/25/85	Neap	9,100	8,100
6/30/85	Spring	29,700	19,200
Hix Bridge			
5/16/85	Neap	1,640	870
6/12/85	Mean	1,770	1,150

Estuarine Sediment Transport

A review of the literature was undertaken to determine sediment loads and circulation patterns in other estuaries.

Suspended sediment concentrations in the Gulf of St. Lawrence were found to be highest closest to the estuarine outflow into the Gulf. The 50 meter surface layer had concentrations of 0.1 mg/L to 2.9 mg/L, the intermediate layer to 50 meters above the bottom concentrations of 0.05 mg/L to 0.1 mg/L, and the bottom layer concentrations of 0.1 mg/L to 0.4 mg/L (Sundby, 1974). Suspended sediment concentrations in a number of estuaries, such as the Long Island Sound, Upper Chesapeake Bay, York River, and James River, were found to range from 4 mg/L to 36 mg/L (Meade, 1972). In the James River estuary, suspended sediment concentrations at the mouth were 12 mg/L, with significantly higher concentrations in the James River. The predominant sediment in the James River estuary was silty clay (Nichols, 1972). Average suspended sediment concentrations in Narragansett Bay were 3.17 mg/L and in Rhode Island Sound 1.83 mg/L (Morton, 1972).

Sediment movement in moderately stratified or vertically homogeneous estuaries is landward along the bottom, with accumulation near the net landward flow limit (Meade, 1972). The net suspended sediment movement in the well mixed estuary of Delaware Bay was landward, near the bottom. Fine grained material from tributary streams predominated in the upper part of the estuary, and sand from the continental shelf and Atlantic shores at the mouth of the bay (Oostdam and Jordan, 1972). Well mixed estuaries in Great Britain have been extensively studied. These estuaries have a very large tidal exchange of water relative to the fresh water inflow from rivers, a situation similar to that of the East Branch. Bottom sediment has a strong net landward movement, during spring tide (Meade, 1972). A situation of sediment entrapment by estuaries and of net landward sediment movement for East Coast estuaries has been cited by McCave (1979). Sediment transport and deposition is affected by the processes circulating and mixing estuarine water and by the flocculation processes that increase the settling of sediment particles (Meade, 1972). Clams and oysters are also agents of deposition, capable of agglomerating and depositing significant amounts of sediment (Meade, 1972).

Sediment sources are rivers, shorelines, offshore, and littoral areas, with much of the offshore material likely to be sand. The greatest percentage of the sediment load of tributary rivers is carried during relatively infrequent floods, which may have sufficient discharge to transport the sediment out of the estuary (Meade, 1972). Virtually all suspended sediment particles in estuarine waters at low velocities are less than 100 microns in size, with most much finer (Meade, 1972). The settling velocity of the particles increases with increasing salinity, with only 2 to 3 parts per thousand causing maximum settling in experimental suspensions of greater than 120 mg/L (Meade, 1972). This is the electrochemical process of flocculation, another factor that contributes to the presence of suspended sediment and bottom muds in estuaries. In this process, when clay particles are exposed to salt water, which acts as an electrolyte, they are attracted and bound together, forming floccules. Floccules settle to the bottom and layers of a "fluffy mud" are formed. The increase in particle size and weight, as the clay particles group together, increases the current velocity necessary to transport the floccules. However, the actual processes of salt flocculation of fine grained sediments as a control of deposition in estuaries has been difficult to study in the field (Meade, 1972). Moderately stratified estuaries commonly do have a feature of maximum suspended sediment concentration at the landward limit of sea salt (Meade, 1972). Deposition of sediments was found to be greatest in a region with salinity of 5 to 14 ppt in the James River estuary, a coastal plain estuary (Nichols, 1972).

The process of flocculation may occur throughout the East Branch. In stratified estuaries, flocculation generally occurs at the end of the salt wedge, where the gradient between saltwater and fresh water is the most pronounced. In the East Branch, however, the influx of freshwater is not limited to one dominant river but rather from a number of streams, most significantly the Westport River, Snell Creek, Kirby Brook, and a number of places south of Hix Bridge so that a salt wedge is not formed. Flocculation may occur in a number of areas where freshwater enters the estuary and flows directly into water of relatively high salinity. The flocculation may be occurring at a rapid rate. The weaker ebb tidal currents in the East Branch will be less able to carry the flocculated clays than the flood tide due to the greater velocities necessary to transport the larger particles, resulting in landward movement and sedimentation. This upstream transport and filling in of the East Branch is common to many estuaries (Ippen, 1966).

Estuaries with a large width to depth ratio were noted by Anderson (1970) to be susceptible to resuspension of sediments by wind waves. Resuspension of sediment by wind waves was important during rough seas in the Upper Chesapeake Bay, with a mean depth of 4.8 meters (Schubel, 1972). The James River estuary is shallow, with a mean depth of 3.7 meters, and also subject to sediment resuspension by wind waves. Resuspension of sediment by wind waves is likely to play an important role in the East Branch, given the very shallow mean depth of 1.2 meters.

An examination of suspended sediment concentrations in Narragansett Bay and Rhode Island Sound revealed an average of 3.17 mg/L for the Bay and an average of 1.83 mg/L for the Sound. Deposition of sediments contributed from tributaries occurred near the head of the

Bay with an additional area of deposition in areas with weak or variable currents. The average sedimentation rate over the entire Bay was 0.092 gm/cm^2/year with only 10% of the tributary sediment load being transported through the estuary into the ocean (Morton, 1972).

The Narragansett Bay is a typical drowned river valley estuary of New England. It differs from the Westport River in that it has major tributaries, the Taunton River and the Seekonk and Providence Rivers combination. It is also deeper, with a mean depth of 7.5 meters for two parts and a mean depth of 17.8 for a third part. Tidal currents of generally less than 50 cm/sec are somewhat higher than those of the East Branch at Westport Point, and with a maximum of 140 cm/sec, slightly higher than the East Branch (Morton, 1972). A four hour slack water period was found to allow a good amount of sediment to settle.

All of the samples taken in the study of Narragansett Bay, except for those from one station in the Providence River, had suspended sediment concentrations of less than 10 mg/L. In a distance of 8 km downstream in the Providence River, the concentrations decreased to 5% of the original value. Higher suspended sediment concentrations near Buzzards Bay in Rhode Island Sound than those in Narragansett Bay indicated a sediment source in the vicinity of Buzzards Bay (Morton, 1972). This sediment source is likely to be contributing to the flood tide sediment load in the East Branch. One conclusion reached in the Narragansett Bay study was that the suspended sediment concentration decreased rapidly in a downstream direction, possible due to salinity effects. The salinity of Narragansett Bay was noted to be much higher than that of the Chesapeake coastal plain estuary (Morton, 1972).

The Susquehanna River has been found to be the major source of sediment to the Upper Chesapeake Bay, especially during spring discharges. During other seasons, a sediment trap is formed in the upper parts of the estuary. The significant sediment load of the Susquehanna River is not surprising, given its mean annual discharge of 985 m^3/sec, over 300 times that of the East Branch of the Westport River (Schubel, 1972).

The Rural Clean Water Project in Westport has undertaken suspended sediment sampling throughout the estuary and drainage basin. Suspended sediment concentrations were measured at stations on tributaries and at two locations in the estuary, from July 1973 to August 1985. The mean suspended sediment concentrations, excluding Hix Bridge, were generally below 10 mg/L. Measurements at Hix Bridge for different periods, had mean values of 10.4 mg/L to 28.5 mg/L. The lower figure is from data collected between September 1984 and August 1985, and encompasses the period of this study. Maximum suspended sediment concentrations reached 20 to 55 mg/L in several tributaries, including Snell Creek, and 150 mg/L at Hix Bridge (Rural Clean Water Program, 1984, 1985).

A study by Helsel (1985) summarizes a number of previous studies of suspended sediment loads in rivers. An estimate of the suspended sediment load delivered to the ocean by rivers in the U.S. yields an average of 65,000 kg/km^2/yr (185 tons/mi^2/year). Estimates of the suspended sediment yield from cropland range from 145,000 to 1,100,000 kg/km^2/yr (416 to 3200 tons/mi^2/year), from rural land from 70,000 to

175,000 $kg/km^2/yr$ (200 to 500 $tons/mi^2/year$), and from forested land from 5,300 to 39,000 $kg/km^2/yr$ (15 to 110 $tons/mi^2/year$) (Helsel, 1985).

A five year interdisciplinary study of the Potomac River estuary summarized the important points of sediment transport in estuaries, indicating that due to the decrease in water velocity from the river to the estuarine environment, the estuary will be a sediment trap. In addition, the sediment loads carried by streams are said to be the most important source of sediment to estuaries (Callender et al., 1984). Urbanization and farming in the basin of the Potomac River have led to an increase in sedimentation in the estuary. The sediment yield from a rural watershed draining into the Potomac River estuary was calculated to be 72,000 $kg/km^2/yr$, as compared to sediment yields from two other estuaries in Maryland of 11,000-31,000 $kg/km^2/yr$ and 9,000 $kg/km^2/year$ (Hickman).

Sediment Circulation

Black and white aerial photographs at a scale of approximately 1:24,000 were used to examine circulation patterns and suspended sediment movement in the estuary by observing the variations in tone in the waters shown in the black and white photos. Water having a higher concentration of suspended material than clear water in the same area will appear lighter in tone, as it has a higher visible reflectance. This difference in tone can be used to determine areas where sediment due to soil erosion or other sources has resulted in more turbid water (Lillesand and Kiefer, 1979). Shallow water, perhaps where sand bars are present, will also appear lighter in tone. However, in the East Branch lighter areas are more likely to be due to turbid water since sediment is mostly finer than sand.

The photographs show that the areas in the lower portion of the estuary that appear lighter in tone are shallower than the darker areas and have had more sediment deposition. These areas are lighter in tone than the surrounding water due to the high load of suspended sediment in the water. These are also likely areas of active deposition into which sediment is being transported by the water movement and then deposited. These areas are shallow and possibly subject to resuspension of the sediment. Suspended sediment concentrations are most likely greater than elsewhere due to the presence of more sediment in these shallower calmer waters than in the adjacent deeper more disturbed water.

The region from the midpoint between Westport Point and Hix Bridge north to Cadman Cove, below Hix Bridge, appears to be generally uniform in tone on the photographs. The upper limit of the lighter area is an east to west line extending across the estuary in the vicinity of Cadman Neck, by Cadman Cove. This line may represent an upstream limit of incoming sediment derived from offshore and from erosion in the lower part of the estuary.

North of Hix Bridge, suspended sediment is revealed by lighter toned areas around the mouth of Kirby Brook, along the west bank between Kirby Brook and Snell Creek, and to a lesser extent at the mouth of Snell Creek. Kirby Brook appears in the photos to be the most prominant source of suspended sediment north of Hix Bridge. A plume of more turbid water extends in a fan shape north and south of the mouth of this stream. This is evidence that sediment is being delivered by Kirby Brook into the estuary where it is transported both upstream and downstream or deposited as a deltaic feature. The mouth of Snell Creek is also lighter in tone, although this feature does not extend far into the estuary.

The analysis of the aerial photographs is particularly useful in indicating the areas of greater turbidity and shallower water. These are areas where the suspended sediment is greater and likely to be deposited, possibly temporarily before being reworked and transported.

Sediment Sources

Sediment is contributed to an estuary by a number of different porcesses and from a variety of sources. These include 1) erosion from the land with sediment carried by streams and by overland flow, 2) bank erosion, 3) littoral drift, 4) erosion of the near shore continental shelf, 5) wind erosion of dunes, 6) disposal of wastes into the estuary, 7) decomposition and excretions of organisms, and 8) redistribution of dredged spoil (Beer, 1983). This variety of sources of sediment to an estuary includes the offshore environment. However, Schubel concludes that the sea is an important sediment source in relatively few estuaries (Biggs, 1978). This situation may be reversed in extreme events such as hurricanes or other extreme storms that wash significant amounts of sediment, including sand, into the estuary from offshore. These extreme events may be most important in supplying the volumetrically significant amounts of sediment to the estuary (Biggs, 1978). However, another consideration in determining the most significant sediment source is that while these extreme events may lead to a significant amount of sediment transport from offshore, the high rainfall associated with such storms will lead to accelerated erosion and greatly increased stream discharge that also can contribute significant amounts of sediment to the estuary.

The suspended sediment in water is affected by not only the stream discharge but also on the the amount of erosion of the adjacent land, which, in turn, depends partly on the soil and vegetative cover of an area. A general conclusion drawn by Schubel and Meade is that 100 to 1000 times more sediment is carried by storm runoff from bare soil than from vegetated soil (Callender et al., 1985). Also, the suspended sediment concentration in stormflow may be 100 to 1000 times greater than the concentration in normal streamflow (Guy, 1965). A study of small forested and pastureland drainage areas in Pennsylvania revealed that cattle standing in a stream increased the base suspended sediment concentration from 4 mg/L to 10 mg/L (Reed, 1976). This is of particular significance to the East Branch, as there are areas where this practice occurs, thus, where cattle are contributing both suspended sediment and bacteria to the downstream direction.

An assessment can be made of the relative significance of the possible sediment sources in the East Branch. Redistribution of dredged spoil is not possible in the East Branch because dredging has not been done for at least 25 years. There is likely to be excretion and decomposition of organisms in the estuary, although the amount of solid matter contributed in this way is very difficult to assess.

Direct disposal of wastes into the estuary through sewage discharge will contribute particulate matter. The relatively low percentage of land occupied by dunes and dune vegetation suggests that dune erosion is not a significant source of sediment in the East Branch. However, in the southernmost areas, especially around the Let and Horseneck Channel, wind transported sediment may be locally important. Bank erosion was not seen to be present to any significant extent in the East Branch. The major sources of sediment are likely to be 1) land erosion, with the significant contribution of sediment occurring from the major streams, and 2) the movement of sediment into the estuary from the marine environment.

The study in Narragansett Bay mentioned previously, found a likely sediment source for Rhode Island Sound to be in the vicinity of Buzzards Bay (Morton, 1972). Suspended sediment may be contributed from this direction to the East Branch. The glacial deposits at Gooseberry Neck, offshore to the southeast of the East Branch estuary, were found to be a source of sediment for the beaches on the east side of the Westport River Inlet (Magee, 1981). Sediment may also be transported into the East Branch from these deposits.

Soils

Streams entering the East Branch contribute the major portion of the suspended material into the estuary. This sediment is derived from the erosion of the surrounding land in each stream's drainage area and from erosion of the stream channels. This sediment can lead to lower water quality for a number of uses (Soil Conservation Service, 1981).

An examination of the soils in the watershed of the East Branch is useful in order to determine possible source areas of sediment, from the areas most likely to undergo erosion. Easily erodible soils will be more likely to contribute sediment to the estuary during precipitation events and increased stream discharge. The factors affecting the amount of erosion of the soil include the type of soil, the slope, the vegetative cover, land use, and other human practices.

The Soil Conservation Service has mapped soil types in the drainage area of the East Branch, resulting in a detailed soil type map of the area. The Soil Conservation Service has determined that soil erosion is of major concern in cropland and pastureland in the region (Soil Conservation Service, 1981). The possibility of erosions increase with slopes above 3%, a situation found in many of the Paxton soils in the area (Soil Conservation Service, 1981). The SCS mapped approximately 67,200 hectares (166,000 acres) of which 8100 hectares (20,000 acres) is cropland. Approximately 40,500 hectares (100,000 acres) of the total land area surveyed was woodland in 1968. However, since 1968 deforestation of portions of the East Branch watershed has occurred as additional homes were built. The erosion hazard for all of the woodland area was rated as slight, defined as a small expected soil loss (Soil Conservation Service, 1981).

The SCS has also classified the soil by a land capability classification system, a rating of the soils' suitability for field crops, including the limitations for crops and the degree of damage if the soils are used. Table 23 defines the land capability classes used by the Soil Conservation Service, indicating the severity of limitation for the use of crops.

Table 23. Soil capability classes.

Soil Class	Limitations
Class I	Slight limitations restricting use.
Class II	Moderate restrictions reducing plant choice or that require moderate conservation practices.
Class III	Severe limitations reducing plant choice or that require special conservation practices or both.
Class IV	Very severe limitations reducing plant choice or that require very careful management or both.
Class V	Erosion not likely but have other restrictions limiting use.
Class VI	Severe limitations; unsuitable for cultivation.
Class VII	Very severe limitations; unsuitable for cultivation.
Class VIII	Limitations that nearly preclude use of soil for commercial crop production.

Classes II, III, IV, VI, and VII have some degree of limitation and potential for increased erosion and sediment production with agricultural use. An erosion land capability subclass, denoted by "e" following the Class, is used to denote those soils where the main limitation of the use of the soils for crops is the risk of erosion with cropping resulting in increased erosion (Soil Conservation Service, 1981).

The Soil Conservation Service land capability classification system has been used here to delineate areas with soils that are more likely to erode. The areas examined include not only commercial cropland but also pastureland for the many dairy farms in the region of the East Branch since erosion is likely to be greater with use of the land and disturbance of the soil by cows. The Soil Conservation Service has mapped soil types, with their limitations, rather than mapping land uses. However, field investigation of the land use in the East Branch drainage area revealed that there was a significant amount of land that was used for dairy farms that would be subject to the use limitations outlined above.

The East Branch drainage basin from the Head of Westport to Westport Point was examined using the published soil map to determine the amount of land that was subject to an increased risk of erosion. Each soil type described as having an erosion hazard was grouped into its appropriate land capability class and subclass. All areas of the soil types in each class and subclass were located on the soil map and the total land area of each class and subclass determined using the point counting method. Figure 27 indicates the locations and mapped units having a noted increased risk of erosion in the land capability class IIe, showing the proximity of these soils to the estuary. The maps indicating the locations of all the soil classes subject to erosion are given in Appendix 5.

Table 24 lists the total area of land with soils in each land capability class and subclass. The total land area examined was 5000 hectares, of which 18% had soils with an increased threat of erosion. Land classified as having soil in the erosion subclass comprised 9% of the total land area examined.

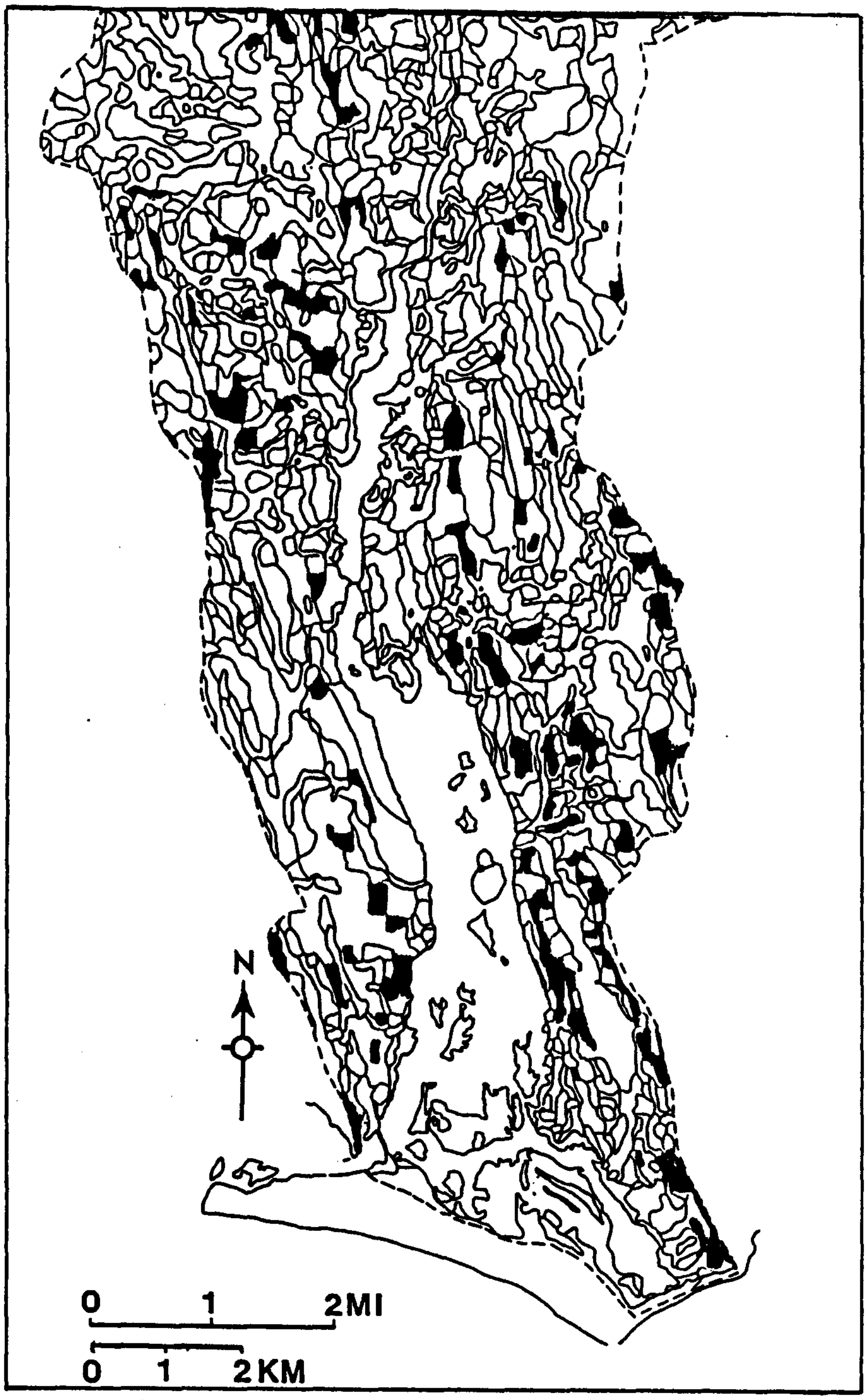


Figure 27. Map of the lower portion of the East Branch watershed, indicating fields (in black) that are subject to above average erosion in the Soil Conservation Service soil capability class 2e, soils with an increased risk of erosion requiring moderate conservation practices.

Table 24 Soil capability class land areas.

Class	Area (hectares)	% of Land Area
II	70	1.4
IIe	410	8.2
III	140	2.8
IIIe	40	0.8
IV	110	2.2
VI	130	2.6
VII	2	0.04
	902	18.0

These figures are significant as they indicate that a sizeable land area has soils with an increased threat of erosion. The figures become more significant when the slope of this land, position of the mapped areas relative to the estuary, and the land use are examined. Many of the areas mapped as having an increased degree of erosion hazard are indeed on increased slopes, and are among the closer areas to the estuary and to the shellfish beds in the estuary. In addition, a number of farms are located in these areas of soils having the higher erosion risk, such as the farms near Snell Creek and along the east bank of the estuary between Hix Bridge and Westport Point.

A measure of the scope of the erosion problem in the area of the East Branch is provided by the research undertaken by the Rural Clean Water Program. This progam in Westport has been active in analyzing agricultural problems that might be contributing to the bacterial contamination of the East Branch and to the sediment loads in the river. Two annual reports provide data regarding these matters. The program has examined 10 sub-basins in the East Branch drainage area, concentrating on cropland in agricultural areas, from the headwaters of the East Branch south to Gunning Island. The Program has considered only agricultural land to be subject to significant erosion, of all the land uses in the East Branch area. The Program has evaluated the agricultural land for potential effect on water quality, through runoff containing wastes or through erosion, placing the land examined into three categories reflecting potential for adverse effects, high, medium, and low potential. Some remedial work of treating acreage for decreased pollution or erosion has arisen from this project, through arrangements for seeding or by avoiding manure spreading on critical land. A summary of the Rural Clean Water Progam data for 1984 is given in Table 25.

Table 25. Rural Clean Water Program data, 1984

Priority	Cropland (Hectares)	Acres Treated	Percent Treated
High	320	272	85
Medium	245	108	44
Low	1076	4	0.4
Total	1641	384	

Of the total area treated to decrease possible contribution of pollution, only 8 hectares has been treated with structural work to decrease erosion. Most of the work has concentrated on decreasing bacterial inputs to the river (Rural Clean Water Program, 1984).

Field Observations

Areas of sedimentation of clay-sized particles were observed during the field sampling. The areas of significant accumulation included the mouth of Snell Creek and Hix Bridge. Areas of mud were also observed along the shores of the estuary above Hix Bridge, as well as in the lowermost part of the estuary near Horseneck Channel and the Let. A short length of Bread and Cheese Brook above the confluence of this stream with the East Branch had areas of significant sedimentation, as did a stretch of the East Branch below this point. The tributary creeks to the East Branch from the Head of Westport to Hix Bridge also contained areas of easily suspended bottom muds.

Evidence of the bottom materials at Hix Bridge was evident numerous times when the boat anchor was brought to the surface. The anchor was coated with, and often brought up clumps of a thick mud. A sample of this bottom sediment revealed the presence of silt and clay, with very little sand. Visual examination of the sediment on the sample filters revealed that the sediment at Hix Bridge was almost entirely composed of silt and clay while sediment at Westport Point also included some sand.

Suspended Sediment Discharges

Estimates of the suspended sediment carried into the East Branch by its tributary streams were necessary in order to understand the suspended sediment transport in the estuary. Given the nature of the project on the East Branch, extensive suspended sediment sampling throughout the estuary was not possible. Rather, estimates of the possible suspended sediment concentrations and loads were made using available USGS data for the region and other available data.

Suspended sediment and stream discharge data were available from four USGS water quality stream stations in southeastern Massachusetts and Rhode Island from Water Years 1979 to 1983. These four stations were the only available USGS sources of periodically measured suspended sediment concentrations in the region of the East Branch. Data from the region of the East Branch were selected in order to apply the results of the data analysis to the East Branch, which would not have been possible if the data were from an area of dissimilar geologic, topographic, climatic, or vegetative conditions. The suspended sediment concentration measurements were made under a variety of stream discharge conditions, from 63 to 3560 cfs.

A power function regression analysis was done using the suspended sediment concentration and stream discharge data. The initial data used in the analysis was the stream discharge and the corresponding suspended sediment concentration. The concentrations were then converted into daily suspended sediment loads using: (USGS, 1983)

$$L = QC(0.0027) \qquad (26)$$

where L is the suspended sediment load in tons/day, Q is the stream discharge in cfs, and C is the suspended sediment concentration in mg/L. A power function regression was then done using the stream discharge data and the corresponding suspended sediment load data using an equation defining suspended sediment load as given by Bloom (1978):

$$L = pQ^{j} \qquad (27)$$

where L is the suspended sediment load in tons/day, Q the stream discharge in cfs, and where p and j are terms arising from the regression analysis.

An equation of this form is also cited by Linsley and others (1982) as a means to calculate the mean annual suspended sediment load as a function of mean annual discharge, for various types of vegetation, and is given by:

$$Q_s=aQ^n \tag{28}$$

where Q_s is the suspended sediment load in tons/yr and Q is Q_{ma} in cfs. Linsley and others pointed out that calculations of this sort may result in errors of +/-50%. The use of sediment rating curves relating stream discharge and suspended sediment concentrations also results in approximations, with longer periods of record yielding better results. In addition, their use is thought to be more useful in examining small and homogeneous basins (Linsley et al., 1982).

The regression analysis of 78 sets of published USGS data for the region of the East Branch had a correlation coefficient of .80 and resulted in:

$$L=0.016Q^{1.04} \tag{29}$$

where L is the suspended sediment load in tons/day and Q the stream discharge in cfs. Equation 29 was then directly converted to the SI system, resulting in:

$$L=591.2Q^{1.04} \tag{30}$$

where Q is in m^3/sec and L is in Kg/day. Equation 30 was then used to calculate the annual load of suspended sediment contributed from each of the tributaries of the East Branch into the estuary for the mean annual discharge calculated previously and for the measured discharge for Water Year 1985. The daily suspended sediment load for each of the tributaries was calculated separately and then summed to obtain a suspended sediment load for the entire estuary. This was then summed over the entire year to provide an annual sediment load for the watershed. Equation 30 was also used to calculate a daily suspended sediment load for the 2.33, 5, 10, 25, and 50 year floods. These suspended sediment loads are given in Table 26.

Table 26. Suspended sediment loads

	L (kg/day)						
Head of Westport	Qma	Q1985	Q2.33	Q5	Q10	Q25	Q50
East Branch	670	540	8,860	13,190	16,950	22,300	25,900
Bread and Cheese	320	260	5,680	8,860	11,460	14,900	16,700
#16	20	15	1,030	1,920	2,560	3,200	3,200
	1010	815	15,570	23,970	30,970	40,400	45,800
Head of Westport to Hix Bridge							
#15	25	20	1,280	2,300	3,020	3,700	3,800
Kirby Brook	110	90	3,020	5.010	6,480	8,200	8,900
#14	15	10	900	1,720	2,240	2,800	2,800
#13	15	10	840	1,600	2,180	2,600	2,600
Snell Creek	50	40	1,850	3,280	4,270	5,300	5,600
#1	5	5	470	960	1,280	1,500	1,500
#2	10	5	590	1,220	1,660	2,000	2,000
Coastal Areas	110	90	2,960	4,940	6,480	8,200	8,900
	340	270	11,910	21,030	27,610	34,300	36,100
Hix Bridge to Westport Point							
#3	5	5	530	1.090	1,470	1,700	1,700
#4	35	25	1,470	2,690	3,550	4,400	4,500
#12	15	10	840	1,600	2,180	2,600	2,600
#11	40	35	1,720	3,020	4,010	4,900	5,100
#10	20	15	1,150	2,110	2,760	3,400	3,400
#9	15	10	900	1,720	2,300	2,800	2,800
#5	5	5	410	840	1,150	1,400	1,400
#8	5	5	470	960	1,340	1,600	1,600
#7	15	10	900	1,660	2,180	2,700	2,700
#6	10	10	650	1,280	1,720	2,100	2,100
Coastal Areas	110	90	2,960	4,940	6,480	8,200	8,900
	275	220	12,000	21,910	29,140	35,800	36,800
Total Daily Load	1,625	1,305	39,480	66,910	87,720	110,500	118,700

Annual Load: 590,000 Kg
590 t
650 tons

Water Year 1985 Load: 480,000 Kg
480 t
530 tons

Daily Flood Sediment Loads:

Flood	Kg	t	tons
$Q_{2.33}$	39,500	39.5	43.5
Q_5	66,900	66.9	73.7
Q_{10}	87,700	87.7	96.7
Q_{25}	110,500	110.5	121.8
Q_{50}	118,700	118.7	130.8

The suspended sediment concentrations may then be determined by "backing out" the concentration using Equation 26:

$$L=QC(0.0027) \tag{26}$$

for each of the calculated discharges.

Although these calculations of suspended sediment loads in the East Branch can really only be thought of as approximations, they are of great use in gaining an understanding of the quantities of suspended sediment in the East Branch.

These calculated suspended sediment loads can be examined in relation to the only other available data concerning suspended sediment and sedimentation in the East Branch, from the Rural Clean Water Project. The loads calculated here are substantially less than those presented by the Rural Clean Water Program. The sediment load as calculated by the Program for Kirby Brook was 144 tonnes per year (159 tons per year), compared to 40 tonnes (44 tons per year) presented here. The former figure is questionable when the suspended sediment concentrations are calculated by Equation 26. With a mean annual discharge of 6.5 cfs and an annual sediment load of 144 tonnes (159 tons), or 0.39 tonnes per day (0.44 tons per day), the calculated sediment concentration is 25 mg/L. However, the mean suspended sediment concentration given by the RCWP for Kirby Brook is 7.7 mg/L. The 25 mg/L value is abnormally high, given the published suspended sediment concentration values for similar streams in the region. In addition, the annual erosion rate for Kirby Brook, as calculated by the RCWP, results in an erosion load of 730 tonnes per year (805 tons per year) for Kirby Brook, much higher than other figures would suggest.

Similar problems arise when the other sediment load figures calculated by the RCWP are examined. A possible explanation for the discrepencies may be that the RCWP apparently calculated erosion rates and sediment loads by examining individual sample fields using the Universal Soil Loss Equation. The error may have been in the assumption that these rates and loads could be extrapolated to too many other areas. However, this does indicate that the problem of erosion and high sediment loading is severe, especially when individual fields, farms, and land use practices are examined. Sediment loads and erosion are likely to be significant especially in critical areas of farms.

The sediment yield from the East Branch watershed can be calculated by dividing the annual sediment load, as determined from the statistical analysis, by the drainage area. The result is a sediment yield of 4,250 kg/km^2/yr. This can be compared to the sediment yields given in a summary of a number of previous studies of suspended sediment loads in rivers. An estimate of the suspended sediment load delivered to the ocean by rivers in the U.S. yields an average of 65,000 $kg/km^2/yr$ (185 $tons/mi^2/year$). Estimates of the suspended sediment yield from cropland range from 145,000 to 1,100,000 $kg/km^2/yr$ (416 to 3200 $tons/mi^2/year$), from rural land from 70,000 to 175,000 $kg/km^2/yr$ (200 to 500 $tons/mi^2/year$), and from forested land from 5,300 to 39,000 $kg/km^2/yr$ (15 to 110 $tons/mi^2/year$) (Helsel, 1985). The sediment yields from a rural watershed draining into the Potomac River estuary was calculated to be 72,000 $kg/km^2/yr$, as compared to sediment yields from two other estuaries in Maryland of 11,000-31,000 $kg/km^2/yr$ and 9,000 $kg/km^2/year$ (Hickman). The sediment yields from the East Branch are lower, as would be expected given the lower measured suspended sediment concentrations than in the other estuaries mentioned. This also indicates that land-based sources of sediment are less important in the East Branch than in other estuaries.

The suspended sediment loads calculated here may be used in a model of sediment transport and sedimentation in the East Branch, along with the suspended sediment concentration and load data collected through the water sampling program.

Sedimentation

Estuarine sedimentation rates have been estimated to range from 4 mm/yr to less than 0.7 mm/yr for estuaries along the East Coast of the United States. The sedimentation rate for Narragansett Bay was calculated to be 0.65 mm/yr. This is at the lower end of the range of values for the estuaries studied (Biggs, 1978). One conclusion for estuarine sedimentation is that estuaries will tend to trap sediment (Biggs, 1978).

Sedimentation in the Potomac River estuary has been estimated to be, on the average, approximately 2.1 mm/yr. However, the amount of sedimentation has been found to be greatest in the upper reaches of the tidal river and estuary (Callender et al., 1985). Delaware Bay had an estimated sedimentation rate of 1.5 mm/year (Oostdam and Jordan, 1972). A generallized sedimentation rate for humid estuaries was estimated to be 2 mm/yr (Rusnak, 1967). The average sedimentation rate over the entire Narragansett Bay was 0.092 gm/cm^2/year.

SEDIMENT TRANSPORT AND SEDIMENTATION MODEL

The data collected throughout the study in the East Branch may be used to construct a model of sediment transport and sediment deposition in the estuary. Simple mass transport models have been developed to examine sediment movement in Narragansett Bay by Morton and in Delaware Bay by Oostdam and Jordan (Morton, 1972; Oostdam and Jordan, 1972). Morton defined the mass transport through a cross section of the estuary as the product of the cross sectional area, the mean current velocity, and the suspended sediment concentration. Possible sediment inputs were identified and set equal to the sediment outputs. The difference was the amount of sediment remaining in the estuary, that is, being deposited. The sediment deposition rate was given by Morton in terms of grams per unit area per year, calculated by dividing the excess mass of sediment by the area of the estuary. Oostdam and Jordan used a simpler model, determining sediment inputs and outputs at a cross section of the Delaware Bay by multiplying the flood and ebb discharges by the appropriate average turbidity. The riverine sediment input was added to the flood sediment input. The difference between the flood and ebb sediment discharges was the excess inward suspended sediment. This excess suspended sediment was then divided by the area of the Bay to determine an average sedimentation rate in terms of centimeters of sediment per year.

These sediment transport models indicated that in each case, sediment was being retained in the estuary. The sedimentation rate calculated for Narragansett Bay in the Fall months, was 0.092 $gm/cm^2/yr$ (Morton, 1972). The sedimentation rate in Delaware Bay was

1.4 mm/yr (Oostdam and Jordan, 1972).

A similar type of mass transport model may be developed for the East Branch estuary. The inputs of suspended sediment can be defined to be the sediment transported in through the tidal inlet from the marine environment and the sediment transported by the tributaries to the East Branch and by overland flow. The model developed here neglects two additional possible sources of sediment, bank erosion and aeolian transport. Bank erosion was not seen in the field to be a significant source of sediment (FitzGerald, pers. comm.). Aeolian transport is also not significant, as there are not significant areas of dunes or other bare land subject to wind erosion. The outputs of sediment are defined to be the sediment moving oceanward out through the tidal inlet and the sediment being deposited.

The influx of suspended sediment from the tributaries to the East Branch has been calculated above for various discharge conditions. The movement of suspended sediment through the downstream edge of the study area, at Westport Point, was calculated from the suspended sediment water sampling program and hydrographies as outlined above. In order to obtain a useable value for the model of sediment movement, a rate of suspended sediment transport was calculated. This was done by dividing the total mass of suspended sediment transported during an ebb or flood tide by the respective length of the tide. This resulted in a suspended sediment movement rate for each of the tidal period observed, in terms of kilograms per minute of suspended sediment transported. The mean value for each of the locations was then obtained. These values are listed in Table 27.

Table 27. Suspended Sediment Transport Rates (kg/min).

	Flood	Ebb
Westport Point		
Mean Tide	26.0	26.25
Neap Tide	24.5	27.0
Spring Tide	77.0	49.0
Mean Rate	42.5	34.0
Hix Bridge		
Mean Tide	4.25	2.25
Neap Tide	4.25	2.35
Mean Rate	4.25	2.3

The total amount of suspended sediment transported during a year was then calculated by first determining the excess rate of inward sediment movement. At both Westport Point and at Hix Bridge the rate of inward sediment movement was greater than that of outward sedimnet movement. The difference between the two values, in kg/min, was then multiplied by the number of minutes in a year to determine the mass of suspended sediment tranported in a landward direction in the estuary. These values are given in Table 28.

Table 28. Landward Suspended Sediment Movement

Westport Point	4.5×10^6 kg/yr
Hix Bridge	1.0×10^6 kg/yr

These values were then combined with the appropriate figures for riverine suspended sediment transport to determine the total inputs of suspended sediment into the estuary. The values used for riverine suspended sediment are those calculated above. The model developed examined the estuary as a whole, and the two easily defined geographic regions in the estuary, from Westport Point to Hix Bridge and from Hix Bridge to the Head of Westport. The total input of suspended sediment into the appropriate section of the estuary was calculated. A sedimentation rate was calculated under the assumption that the suspended sediment in the estuary would be or was in the process of being deposited, and that the suspended sediment load in the estuary would remain at an approximately constant level over time, with the inputs leading to deposition. The annual sedimentation rate in terms of $gm/cm^2/yr$ was then determined by dividing the mass of suspended sediment by the surface area of the estuary. A sedimentation rate in terms of mm/yr was obtained by dividing the mass of the sediment by an appropriate density for the sediment. The models developed and the sedimentation rates obtained are detailed below in Figure 28.

Figure 28. Sedimentation Rate Models

East Branch Estuary

Suspended Sediment Inputs

Tidal influx	$+4.5 \times 10^6$ kg/yr
Riverine influx	$+0.6 \times 10^6$ kg/yr
Total influx	5.1×10^6 kg/yr

Sediment Outputs (Sedimentation)

$$\frac{\text{Sediment Influx}}{\text{Estuarine Area}} = \frac{5.1 \times 10^6 \text{ kg/yr}}{7.2 \text{ km}^2}$$

$$= 0.07 \text{ gm/cm}^2\text{/yr}$$

Westport Point to Hix Bridge

Suspended Sediment Inputs

Tidal influx	$+4.5 \times 10^6$ kg/yr
Tidal outflow (to north of Hix Bridge)	-1.0×10^6 kg/yr
Riverine influx	$+0.1 \times 10^6$ kg/yr
Total influx	3.6×10^6 kg/yr

Sediment Outputs (Sedimentation)

$$\frac{\text{Sediment Influx}}{\text{Estuarine Area}} = \frac{3.6 \times 10^6 \text{ kg/yr}}{6.0 \text{ km}^2}$$

$$= 0.06 \text{ gm/cm}^2\text{/yr}$$

Hix Bridge to Head of Westport

Suspended Sediment Inputs

Tidal influx	$+1.0 \times 10^6$ kg/yr
Riverine influx	$+0.5 \times 10^6$ kg/yr
Total influx	1.5×10^6 kg/yr

Sediment Outputs (Sedimentation)

$$\frac{\text{Sediment Influx}}{\text{Estuarine Area}} = \frac{1.5 \times 10^6 \text{ kg/yr}}{1.2 \text{ km}^2}$$

$$= 0.125 \text{ gm/cm}^2\text{/yr}$$

The sedimentation rates calculated above are in terms of mass per unit area per time. To determine a sedimentation rate in terms of length per time, the mass of the sediment was divided by the density of the material. A density for a clayey silt (7.3% sand, 60.0% silt, and 32.7% clay) of 1.488 gm/cm^3, obtained from published data for recent marine sediments, was used to approximate the density of the sediments being deposited in the East Branch (Dietrich et al., 1982).

The sedimentation rates calculated using these terms are given in

Table 29, along with the mass rates.

Table 29. Sedimentation Rates

East Branch Estuary	0.47 mm/yr	0.07 $gm/cm^2/yr$
Westport Point to Hix Bridge	0.40 mm/yr	0.06 $gm/cm^2/yr$
Hix Bridge to Head of Westport	0.84 mm/yr	0.125 $gm/cm^2/yr$

The sedimentation rate calculated for the East Branch may be compared to those established for Narragansett Bay, at 0.092 $gm/cm^2/yr$ (Morton, 1972) and for Delaware Bay at 1.4 mm/yr (Oostdam and Jordan, 1972). The East Branch sedimentation rates are on the same order of magnitude as those of Narragansett Bay, as might be expected given the proximity of the two areas, in the same region of similar geology, topography, and climate. The East Branch sedimentation rates are approximately 1/3 to 1/2 those of Delaware Bay, which may be attributed to greater erosion and greater discharge in the region around Delaware Bay. The sedimentation rates in the East Branch are also at the lower end of the range of values in the literature, that were mentioned previously.

The calculations of annual sediment discharge and sedimentation rates were based on the mean annual discharge data. As indicated in a previous section, floods will increase the sediment discharge from the tributaries of the East Branch and lead to a greater sedimentation rate, as the floods can carry a greater amount of sediment. A measure of the significance of this can be indicated by adding approximate flood sediment loads to the annual sediment load of the tributaries under mean annual discharge conditions. The annual suspended sediment load of 0.6×10^6 kg will be increased by the amounts given in Table

30, calculated as the daily flood sediment discharge for certain frequency floods.

Table 30. Flood sediment loads.

Annual sediment load	Flood	Daily flood load	% increase due to daily load
0.06×10^6 kg	$Q_{2.33}$	0.04×10^6 kg	7
0.06×10^6 kg	Q_5	0.07×10^6 kg	12
0.06×10^6 kg	Q_{10}	0.09×10^6 kg	15
0.06×10^6 kg	Q_{25}	0.11×10^6 kg	18
0.06×10^6 kg	Q_{50}	0.12×10^6 kg	20

The figures in Table 30 indicate the significance of floods in contributing to the sediment delivery to the estuary. The amount of sediment delivered in one day by a flood may range up to 20% of the mean annual sediment load contributed under mean annual discharge conditions. However, although occasional floods may deliver a significant suspended sediment load, this is a short term phenomenon.

An examination of the suspended sediment transport into the estuary by riverine discharge over a more geologically realistic time period, 100 years, reveals that the overall effect of flood transport of suspended sediment is less than that of transport by the mean annual discharge. Table 31 lists the mass of suspended sediment that will be transported in a 100 year period.

Table 31. Suspended sediment discharge during a 100 year period.

Discharge	Number of discharges	100-year sediment load
Q_{MA}	100	59×10^6 kg
$Q_{2.33}$	43	1.7×10^6 kg
Q_5	20	1.4×10^6 kg
Q_{10}	10	0.9×10^6 kg
Q_{25}	4	0.44×10^6 kg
Q_{50}	2	0.24×10^6 kg

This analysis leads to the conclusion that, although floods may bring a temporary surge of suspended sediment, the geologically significant transport of suspended sediment is done under the mean annual discharge conditions and by smaller, more frequent discharge events.

The model of sediment transport and sedimentation in the estuary also reveals that the influx of sediment from the marine environment, in through the tidal inlet, predominates over the riverine influx. This was also indicated by the lower sediment yields of the East Branch estuary watershed, as compared to other estuarine watersheds along the East Coast. The land supplies a lower sediment yield than in other areas, reducing the significance of riverine input of suspended sediment.

The relative significance of the riverine and marine suspended sediment inputs can be seen in an examination of the calculated suspended sediment loads. The annual suspended sediment load from the ocean was calculated to be 4.5×10^6 kg while the annual suspended sediment load from tributaries to the East Branch was calculated to be 0.6×10^6 kg. With the addition of several days of flood suspended sediment loads, the riverine load would still not exceed 1.0×10^6 kg. Thus the contribution of suspended sediment by the tributaries is less than 20% of the total suspended sediment load entering the estuary. There is less of an imbalance at Hix Bridge, where the contribution of suspended sediment from the tributaries accounts for about 30% of the total suspended sediment discharge.

The sedimentation rates calculated by the mass transport balance model indicate that sedimentation is likely to be more pronounced and proceeding at a greater rate north of Hix Bridge than in the lower portion of the estuary. The calculated rate for the northern section is over twice that of the southern section, south of Hix Bridge. As outlined earlier, it was not possible, given the scope of this study, to establish a definitive correlation between suspended sediment and bacterial levels. However, this imbalance of sedimentation rates may have some bearing on the greater impact of the bacterial pollution in the region north of Hix Bridge, and the decreasing impact downstream in the estuary.

The models of suspended sediment transport and calculations of suspended sediment loads in the East Branch, based on the measured suspended sediment concentrations in the estuary, the calculated tributary suspended sediment loads, and the field observations in the East Branch, lead to several fundamental conclusions of suspended sediment in the estuary. The East Branch is gradually filling with sediment, which although due to both riverine and marine transport mechanisms, is primarily due to suspended sediment movement from the marine environment. A greater amount of suspended sediment is transported into the estuary from the ocean than from the tributaries. However, due to the configuration of the estuary and of the major tributaries, the rate of sedimentation is greater in the northern portion of the estuary, between the Head of Westport and Hix Bridge. The suspended sediment loads and sedimentation in this area may have a greater impact on the shellfish beds than that in the lower portion of the estuary, given the relationship outlined in the literature of suspended sediment and bacteria.

CONCLUSIONS

The study of the East Branch of the Westport River, in southeastern Massachusetts, led to a number of conclusions regarding the bacteriological contamination, hydrology, estuarine hydrography and circulation patterns, and suspended sediment sources, transport, and deposition of the East Branch.

1. The sources of bacteria affecting the shellfish resources of the East Branch are primarily agricultural in origin, from several large farms located along the estuary or along tributaries to the estuary. Human pollution, from septic systems improperly placed or maintained, is an occasional source of contamination.

2. The mean annual discharge of rivers in the region is described by:

$$Q_{MA}=1.94A_d^{0.98} \qquad (1)$$

where Q_{MA} is the mean annual discharge and A_d is the drainage area, in English units, or by:

$$Q_{MA}=0.022A_d^{0.98} \qquad (14)$$

in metric units.

3. The mean annual discharge has a 1.78 cfsm value, corresponding to an average annual rainfall of 43 inches (1092 mm), with annual evapotranspiration of 19 inches (482 mm) and runoff of 24 inches (610 mm).

4. The groundwater contribution to streamflow in the region accounts for about 46.2% of the total flow, with little variation in the discharge of flows during the year, indicating that the surficial deposits through which the rivers flow are likely to be porous permeable glacial sands and gravels.

5. There have been alternating periods of greater and lesser precipitation and discharge, with a slight trend toward more humid conditions during the last 50 years.

6. The frequency of floods of various recurrence intervals may be described by:

$$Q_{2.33}=77.9A_d^{0.59} \quad (2)$$

$$Q_5=137.8A_d^{0.53} \quad (3)$$

$$Q_{10}=180.5A_d^{0.52} \quad (4)$$

$$Q_{25}=220.7A_d^{0.54} \quad (5)$$

$$Q_{50}=225.9A_d^{0.58} \quad (6)$$

7. The lowest daily flow during a ten year period can be expressed by:

$$Q_{low}=0.0006A_d^{1.98} \quad (7)$$

8. The East Branch has a drainage area of 143.1 km^2. The estuary has a mean depth of 1.2 m, a surface area of 7.2 km, and a volume of about 8.9×10^6 m^3.

9. The calculated mean annual discharge of the East Branch is 2.89 m^3/sec.

10. The estuary is flood dominated, with stronger flood tidal currents at both Westport Point and Hix Bridge.

11. The mean tidal prism at Westport Point is 6.5×10^6 m^3.

12. The estuary is vertically well mixed, with saline water extending to the Head of Westport.

13. The flushing times for freshwater flushing of the estuary are 5.2 days for the portion extending to Hix Bridge and 34.3 days for the entire estuary.

14. Flushing by the tides is slow and inefficient, with greatly decreased flushing occurring north of Hix Bridge.

15. Higher bacterial counts generally occurred in areas of the East Branch having higher suspended sediment concentrations.

16. The mean suspended sediment concentration at Westport Point was 2.4 mg/L for the flood tide and 2.8 mg/L for the ebb tide. At Hix Bridge, the mean suspended sediment concentration was 3.4 mg/L for the flood tide and 3.2 mg/L for the ebb tide.

17. Suspended sediment loads for rivers in the region of the East Branch may be expressed by:

$$L=591.2Q^{1.04} \qquad (30)$$

where L is in Kg/day and Q is in m^3/sec.

18. The annual suspended sediment load of the East Branch tributaries is 0.59×10^6 Kg. Floods will have a significant short term suspended sediment load, however, the mean annual disharges are the most significant riverine transport mechanism for suspended sediment into the estuary.

19. The annual suspended sediment load into the estuary from the marine environment is 4.5×10^6 Kg. The marine environment is the significant source of suspended sediment to the estuary.

20. The East Branch estuary is gradually filling with sediment, and is most affected in the area from the Head of Westport to Hix Bridge. The sedimentation rates in the estuary are:

East Branch Estuary	0.47 mm/yr	0.07 $gm/cm^2/yr$
Westport Point to Hix Bridge	0.40 mm/yr	0.06 $gm/cm^2/yr$
Hix Bridge to Head of Westport	0.84 mm/yr	0.125 $gm/cm^2/yr$

CONCLUDING NOTE

The relationship between suspended sediment and bacteria would be interesting and informative to establish for the East Branch, and would perhaps lend weight to efforts to reduce the bacterial contamination of the shellfish beds in the East Branch through erosion control measures. Although it was beyond the scope of this project to definitively establish the relationship, it is hoped that the study of the East Branch with the data generated, the models developed, and the conclusions reached, will provide a framework for better understanding the movement and behavior of suspended sediment in the estuarine environment, and will be of benefit to others working in the field. It is hoped that the ideas presented here will be used, tested, and modified in similar studies, perhaps in the West Branch of the Westport River, and will result in decreasing the bacterial contamination of shellfish resources.

REFERENCES

American Public Health Association, 1976, Standard methods for the examination of water and wastewater, Fourteenth Edition: The American Public Health Association.

American Public Health Association, 1980, Standard methods for the examination of water and wastewater, Fifteenth Edition: The American Public Health Association.

Anderson, Franz E., 1970, The periodic cycling of particulate matter in a shallow, temperate estuary: Journal of Sedimentary Petrology, Vol. 40, No. 4, pp. 1128-1135.

Banse, K., C.P. Falls, and L.A. Hobson, 1963, A gravimetric method for determining suspended matter in sea water using Millipore Filters: Deep Sea Research, Vol. 10, pp. 639-642.

Beer, Thomas, 1983, Environmental Oceanography: An Introduction to the Behaviour of Coastal Waters: Pergamon Press, Oxford, 262 pp.

Biggs, Robert, 1978, Coastal Bays, in Davis, Richard A., Jr., (ed.), 1978, Coastal Sedimentary Environments: Springer-Verlag, NY, NY 420 pp., pp. 69-99.

Bordner, R.H., P.V. Scarpino and J.A. Winter, 1977, Microbiological Methods for monitoring the environment. Part I-Water and Wastes: Environmental Monitoring and Support Laboratory, US EPA, Cincinatti, Ohio.

Buller, A.T. and J. McManus, 1979, Sediment sampling and analysis: in Dyer, Keith R. (ed.). 1979, Estuarine Hydrography and Sedimentation: Cambridge University Press, Cambridge, England, 230 pp.

Burkham, D.E., 1985, An approach for appraising the accuracy of suspended sediment data: U.S. Geological Survey Professional Paper 1333, U.S. Geological Survey, 18 pp.

Caldwell, D.W., 1983, 1984, class notes: Glacial and Pleistocene Geology; Surface Water Hydrology: Boston University Department of Geology.

Callender, Edward, Virginia Carter, D.C. Hahl, Kerie Hitt, and Barbara I. Schultz, 1984, A Water Quality Study of the Tidal Potomac River and Estuary- An Overview: US Geological Survey Professional Paper 2233, 46 pp.

Davis, Richard A., Jr., (ed.), 1978, Coastal Sedimentary Environments: Springer-Verlag, NY, NY 420 pp.

Dietrich, R.V., J.T. Dutro, Jr., and R.M. Foose, 1982, AGI data sheets for geology in the field, laboratory, and office: American Geological Institute.

Doran, J.W. and D.M. Linn, 1978, Bacteriological quality of runoff from pastureland: Applied and Environmental Microbiology, Vol. 37, No. 5, pp. 985-991.

Duda, Alfred M., 1985, Environmental and economic damage caused by sediment from agricultural nonpoint sources: Water Resources Bulletin, Vol 21, No. 2, American Water Resources Association, pp. 225-234.

Dunne, Thomas and Luna B. Leopold, 1978, Water in Environmental Quality: W.H. Freeman Company, NY, NY, 818 pp.

Dyer, Keith R., 1973, Estuaries: A Physical Introduction: John Wiley and Sons, London, England, 140 pp.

Dyer, Keith R. (ed.), 1979, Estuarine Hydrography and Sedimentation: Cambridge University Press, Cambridge, England, 230 pp.

Eaton, John S., Gene E. Likens, and F.H. Bormann, 1969, Use of membrane filters in gravimetric analyses of particulate matter in natural waters: Water Resources Research, Vol. 5, No. 5, pp. 1151-1156.

Erkenbrecher, Carl W., Jr., 1981, Sediment bacterial indicators in an urban shellfishing subestuary of the Lower Chesapeake Bay: Applied and Environmental Microbiology, Vol. 42, No. 3, pp. 484-492.

Faust, Maria A., A.E. Aotaky, and M.T. Hargadon, 1975, Effect of physical parameters on the in situ survival of Escherichia coli MC-6 in an estuarine environment: Applied and Environmental Microbiology, Vol. 30, pp. 800-806.

Faust, Maria A., 1976, Coliform bacteria from diffuse sources as a factor in estuarine pollution: Water Research, Vol. 10, pp. 619-627.

Fiske, J.D., J.R. Curley, and R.P. Lawton, 1968, A study of the marine resources of the Westport River: Monograph No. 7, Massachusetts Division of Marine Fisheries.

Geldrich, Edwin E., 1970, Applying bacteriological parameters to recreational water quality: Journal of the American Water Works Association, Vol. 62, No. 2, pp.113-120.

Geraghty, J.J., D.W. Miller, F. van der Leeden, and F.L. Troise, 1973, Water Atlas of the United States: Water Information Center, Port Washington, NY.

Gibbs, R.J., (ed.), 1974, Suspended Solids in Water: Plenum Press, NY, NY, 320 pp.

Greeson, D.E., T.A. Ehlke, G.A. Irwin, B.V. Lium, and K.U. Slack (eds.), 1977, Techniques of Water Resources Investigations of the United States Geological Survey, Book 5 Chapter A4, Laboratory Analysis: Methods for Collection and Analysis of Aquatic, Biological, and Microbiological Samples: U.S. Geological Survey, 332 pp.

Helsel, Dennis R., 1985, Contributions of suspended sediment from highway construction and other land uses to the Olegantangy River, Columbus, Ohio: US Geological Survey Water-Resources Investigations Report 84-4336.

Hickman, R.E., Loads of suspended sediment and nutrients from local nonpoint sources to the tidal Potomac River and Estuary, Maryland and Virginia, 1979-1981 Water Years: A water quality study of the tidal Potomac River and Estuary: US Geological Survey Open-File Report 84-860, 82 pp.

Ippen, Arthur T., 1966, Estuary and Coastline Hydrodynamics: McGraw Hill Book Co., Inc., N.Y., 744 pp.

Johnson, Richard A., Rudolph D. Ellender and Shiow-Chuan Tsai, 1984, Elution of enteric viruses from Mississippi estuarine sediments with lecithin-supplemented eluents: Applied and Environmental Microbiology, Vol. 48, No. 3, pp. 581-585.

Journal of the American Water Works Association, 1970, Vol 62, No.2, p.113.

Kelly, Edward F., Jr., Bruce E. Pivetz, D.W. Caldwell, and Duncan M. FitzGerald, 1986, A study to determine the causes, types, and locations of pollutants contaminating the Westport River Estuary, Westport, Massachusetts: Hydrogeology Research Group, Department of Geology, Boston University, 190 pp..

Kennedy, V.S., (ed.), 1982, Estuarine Comparisons: Academic Press NY, NY, 709 pp.

Kjerve, Bjorn (ed.), 1978, Estuarine Transport Processes: University of South Carolina Press, Columbia, South Carolina, 331 pp.

Kress, M. and G.F. Gifford, 1984, Fecal coliform release from cattle fecal deposits: Water Resources Bulletin, Vol. 20, No. 1, American Water Resources Association, pp. 61-66.

Lauff, George. H., (ed.) 1967, Estuaries: American Association for the Advancement of Science Publication No. 83, Washington, D.C., 757 pp.

Leopold, Luna B., 1968, Hydrology for Urban Land Planning: US Geological Survey Circular 554, US Geological Survey.

Lillesand, Thomas M. and Ralph W. Kiefer, 1979, Remote Sensing and Image and Interpretation: John Wiley and Sons, N.Y., N.Y., 612 pp.

Linsley, Ray K., Jr., Max A. Kohler and Joseph L.H. Paulhus, 1982 Hydrology for Engineers, Third Edition: McGraw Hill Book Company NY, NY 508 pp.

Magee, Andrew Davies, 1981, Investigation of Shoaling Problems at Westport River Inlet and Sedimentation Processes at Horseneck and East Horseneck Beaches: Boston University MA Thesis, 137 pp.

McCave, I.N., 1979, Suspended sediment, in Dyer, Keith R. (ed.). 1979, Estuarine Hydrography and Sedimentation: Cambridge University Press, Cambridge, England, 230 pp.

Meade, Robert H., 1972, Transport and deposition of sediments in estuaries, in Nelson, Bruce W. (ed), 1972, Environmental Framework of Coastal Plain Estuaries: The Geological Society of America, Inc., Memoir No. 133, 619 pp., pp. 91-120.

Metcalf, T.G. and W.C. Stiles, 1968, Viral pollution of shellfish in estuary waters: Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 94, No. SA4, pp. 595-609.

Morton, Robert W., 1972, Spatial and temporal distribution of suspended sediment in Narragansett Bay and Rhode Island Sound, in Nelson, Bruce W. (ed), 1972, Environmental Framework of Coastal Plain Estuaries: The Geological Society of America, Inc. Memoir No. 133, 619 pp.

National Oceanic and Atmospheric Administration, 1985, Tide Tables 1985: High and low water predictions, East Coast of North and South America.

National Research Council, 1977, Estuaries, Geophysics and the Environment: National Academy of Sciences, Washington, D.C., 127 pp.

Nelson, Bruce W. (ed), 1972, Environmental Framework of Coastal Plain Estuaries: The Geological Society of America, Inc., Memoir No. 133 619 pp.

Nichols, Maynard M., 1972, Sediments of the James River Estuary, Virginia, in Nelson, Bruce W. (ed), 1972, Environmental Framework of Coastal Plain Estuaries: The Geological Society of America, Inc., Memoir No. 133, 619 pp., pp. 169-212.

Oostdam. B.L. and Robert R. Jordan, 1972, Suspended sediment transport in Delaware Bay, in Nelson, Bruce W. (ed), 1972, Environmental Framework of Coastal Plain Estuaries: The Geological Society of America, Inc., Memoir No. 133, 619 pp.

Packard, R., 1979, Westport Shellfish- "A sanitary re-survey of Westport River": Massachusetts Department of Environmental Quality Engineering.

Pritchard, Donald W., 1967, What is an estuary: physical viewpoint, in Lauff, George. H., (ed.) 1967, Estuaries: American Association for the Advancement of Science Publication No. 83, Washington, D.C., 757 pp., pp. 3-5.

Rao, V. Chalapati, Karsten M. Seidel, S.M. Goyal, Theodore G. Metcalf, and Joseph L. Melnick, 1984, Isolation of enteroviruses from water, suspended solids, and sediments from Galveston Bay: survival of Poliovirus and Rotavirus adsorbed to sediments: Applied and Environmental Microbiology, Vol. 48, pp. 404-409.

Reed, Lloyd A., 1976, Sediment characteristics of five streams near Harrisburg, Pennsylvania, before highway construction: Water Supply Paper 1798-M United States Geological Survey, 29 pp.

Rural Clean Water Program, 1984, Annual Rural Clean Water Program Progress Report, Westport River, Massachusetts Rural Clean Water Program.

Rural Clean Water Program, 1985, Draft Water Quality Monitoring and Analysis Program.

Rusnak, Gene A., 1967, Rates of Sediment Accumulation in Modern Estuaries. in Lauff, George. H., (ed.) 1967, Estuaries: American Association for the Advancement of Science Publication No. 83, Washington, D.C., 757 pp. pp. 180-184.

Sayler, G.S., J.D. Nelson, Jr., A. Justice, and R.R. Colwell, 1975, Distribution and significance of fecal indicator bacteria in the Upper Chesapeake Bay: Applied and Environmental Microbiology, Vol. 30, pp. 625-638.

Schubel, J.R., 1972, Distribution and transportation of suspended sediment in Upper Chesapeake Bay., in Nelson, Bruce W. (ed), 1972, Environmental Framework of Coastal Plain Estuaries: The Geological Society of America, Inc. Memoir No. 133, 619 pp., pp. 151-167.

Soil Conservation Service, 1981, Soil Survey of Bristol County, Massachusetts, Southern Part, 124 pp.

Sundby, Bjorn, 1974, Distribution and transport of suspended particulate matter in the Gulf of St. Lawrence: Canadian Journal of Earth Science, Vol. 11, pp. 1517-1533.

Thomas, Kathyrn E., 1985, Westport River Greenway Protection Plan: Westport River Defense Fund, Inc., 32 pp.

US Geological Survey, 1954, Compilations of records of surface waters of the United States through September 1950: Part 1-A North Atlantic Slope Basins, Maine to Connecticut: USGS Water Supply Paper 1301, US Geological Survey, 380 pp.

US Geological Survey, 1964, Compilations of records of surface waters of the United States October 1950-September 1960: Part 1-A North Atlantic Slope Basins, Maine to Connecticut: USGS Water Supply Paper 1721, US Geological Survey, 317 pp.

US Geological Survey, 1969, Surface Water Supply of the United States Part 1- North Atlantic Slope Basins, Volume 1-Basins from Maine to Connecticut: USGS Water Supply Paper 2107, US Geological Survey, 1027 pp.

US Geological Survey, 1975, Surface Water Supply of the United States 1966-1970, Part 1- North Atlantic Slope Basins, Volume 1-Basins from Maine to Connecticut: USGS Water Supply Paper 2101, US Geological Survey, 1123 pp.

US Geological Survey, Water Resources Data for Massachusetts and Rhode Island: Part 1: Surface Water Records, Volumes 1961-1983.

Van Donsel, D.J. and E.E. Geldrich, 1971, Relationships of salmonellae to fecal coliforms in bottom sediments: Water Research, Vol. 5, Pergamon Press, Great Britain, pp. 1079-1087.

Wandle, S. William, Jr. and Gordon R. Keezer, 1984, Gazetteer of hydrologic characteristics of streams in Massachusetts- Taunton and Ten Mile River basins and coastal river basins of Mount Hope Bay, Narragansett Bay, and Rhode Island Sound: US Geological Survey Water Resources Investigations Report 84-4283, 38 pp.

Westport Master Plan Update Committee, 1983, Westport Land Use Plan- An addendum to the Westport Master Plan of February, 1972.

Westport Shellfish Advisory Committee and the Westport Shellfish Department, 1983, Shellfish advisory committee report on: Pollution in the East Branch of the Westport River.

Westport Shellfish Department, 1983, Management Plan for Utilization of moderately contaminated shellfish resource.

Hydrologic data of the coastal drainage basins of southeastern Massachusetts, Narragansett Bay, and Rhode Island Sound: Massachusetts Hydrologic-Data Report No. 25, United States Department of the Interior, Geological Survey, Open-File Report 83-145.

Zen, E-an, Richard Goldsmith, Nicholas M. Ratcliffe, Peter Robinson, Rolfe S. Stanley, Norman L. Hatch, Jr., Andrew F. Shride, Elaine G. A. Weed, and David R. Wones, 1983, Bedrock geologic map of Massachusetts, US Geological Survey, Department of the Interior, in cooperation with the Commonwealth of Massachusetts Department of Public Works and Joseph A. Sinnott, State Geologist.

APPENDIX 1

Bacterial Data:

Fecal coliform and fecal streptococci analysis results, by region of the East Branch of the Westport River, listing sample collection sites, number of samples collected, and median, mean, minimum, maximum, and log mean of bacterial counts.

Summary of analyses for fecal bacteria, East Branch, Westport River, 7 August 1984 - 10 September 1985. All results reported as the number of colonies per 100 ml water. The top line for each site gives the test results for fecal coliform bacteria and the bottom line lists the data for fecal streptococci. Analyses by Geology Department, Boston University.

Site	n[1]	Median	Mean	Minimum	Maximum	Log Mean
		BREAD AND CHEESE BROOK				
1	3	60	43	0	70	16
		300	311	296	336	309
2	5	342	1,890	174	4,808	800
		360	496	200	1,280	383
3	3	130	76	0	314	29
		230	591	208	1,336	400
4	14	224	1,126	0	11,088	93
		320	752	30	3,810	325
13A	12	130	2,460	0	23,000	64
		400	1,100	50	5,200	493
13E	5	550	1,762	0	6,720	809
		760	1,060	350	2,700	820
13D	9	1,450	5,347	0	22,850	520
		850	1,983	50	7,600	761
		EAST BRANCH UPSTREAM OF ROUTE 6				
5	3	—	125	94	156	121
		248	231	84	360	196
6	3	12	13	0	38	8
		84	128	50	124	80
7	3	30	557	4	1,536	57
		0	104	0	312	7
8	3	16	13	8	16	13
		40	47	36	64	45
9	9	4	7	0	24	4
		10	69	0	356	15
9A	2	—	139	10	268	52
		—	368	30	706	146

Site	n	Median	Mean	Minimum	Maximum	Log Mean
EAST BRANCH - ROUTE 6 TO HEAD OF WESTPORT						
10	13	80	1,134	0	6,970	39
		60	311	0	1,600	69
11	13	70	930	0	5,100	110
		140	299	0	1,380	105
11A	9	560	529	0	4,900	81
		850	5,859	0	40,250	630
12	11	188	937	0	3,840	247
		590	372	20	1,580	317
13	12	200	2,065	20	17,388	362
		620	1,059	0	5,750	266
13B	12	280	822	0	3,290	152
		435	482	100	1,360	328
13C	2	---	9,690	580	18,800	3,302
		---	525	450	600	520
14	11	420	1,096	0	4,500	100
		300	718	0	2,400	257
14A	9	400	1,122	0	4,350	258
		350	572	0	1,750	218
15	9	600	783	0	4,186	61
		304	622	25	1,840	350
16	4	800	698	520	800	697
		168	207	120	400	183
16A	8	190	230	0	1,032	28
		280	427	0	1,260	127
17	14	550	1,502	0	10,948	131
		700	1,468	0	5,350	519
18	5	2,000	10,533	162	47,120	2,055
		1,400	3,838	336	10,730	1,830
19	11	0	10,896	0	115,000	20
		748	5,211	40	25,120	1,111

Site	n	Median	Mean	Minimum	Maximum	Log Mean
			EAST BRANCH - HEAD OF WESTPORT TO HIX BRIDGE			
19A	10	0 2,600	1,662 3,621	0 200	11,808 9,750	54 1,656
19B	3	880 3,050	2,763 3,483	0 2,750	5,910 4,650	2,698 3,391
20	12	27 4,250	14,221 6,949	0 0	>100,000 19,675	104 1,785
21	4	1,224 770	736 2,779	0 304	1,710 7,264	66 1,757
22	11	0 1,950	3,998 6,133	0 200	39,200 32,900	26 2,454
25	6	25 1,720	1,475 2,204	0 72	6,016 8,000	127 895
30	2	--- ---	10,950 3,670	5,900 3,540	16,000 3,800	9,716 3,668
31	7	4,120 5,750	20,946 6,275	0 690	>100,000 14,000	911 4,019
32	4	1,916 1,972	4,117 1,521	0 540	13,848 2,860	370 911
35	3	0 670	308 889	0 397	923 1,600	10 752
36	11	60 665	769 2,220	0 80	6,000 9,080	22 843
38	4	2,300 532	3,345 1,732	2,000 304	9,081 5,760	452 746
39	3	560 716	1,285 642	362 260	2,932 950	841 561
40	3	1,200 276	4,088 252	800 110	10,263 364	2,144 222
44	13	80 160	2,598 3,342	0 0	21,600 16,800	67 372

Site	n	Median	Mean	Minimum	Maximum	Log Mean
45	3	0 690	175 527	0 140	526 750	8 417
46	3	1,100 960	8,711 1,055	77 572	24,956 1,633	1,283 964
47	3	5 60	76 63	0 44	224 86	10 61
48A	10	0 3,060	3,936 2,642	0 40	19,400 7,700	33 1,003
48B	3	780 1,120	2,097 1,480	760 940	4,750 2,380	1,412 1,358
48C	2	--- ---	2,130 2,030	1,300 940	2,960 3,120	1,962 1,712
49	3	4 72	11 67	0 44	29 84	5 64
50	3	500 452	14,100 574	100 150	41,700 452	1,278 423
51	3	86 96	97 81	18 20	186 128	66 63
52	3	270 516	329 617	144 266	574 1,068	282 527
53	3	186 46	145 47	39 30	211 64	115 45
54	13	0 80	27 740	0 2	126 2,710	7 162
			STREAM AT EVERETT COVE			
23	10	16,000 11,050	28,801 10,738	0 550	174,000 33,450	1,064 6,537
23A	10	400 350	889 930	0 0	2,800 2,850	190 264
23B	4	1,610 4,000	2,940 3,017	0 259	9,600 5,808	304 1,863
24	14	6,500 4,075	15,071 9,932	0 140	84,000 41,500	299 3,226

Site	n	Median	Mean	Minimum	Maximum	Log Mean
			KIRBY BROOK			
26	10	68 160	520 625	0 0	4,672 2,700	38 104
26A	8	326 2,510	994 2,026	0 20	6,268 6,060	48 714
27	10	2 810	145 764	0 0	1,212 1,800	6 309
28	3	32 340	37 577	4 108	74 1,284	21 361
29	12	2 896	690 1,038	0 10	4,988 2,960	19 485
33A	7	100 200	1,277 2,054	0 35	7,350 6,000	23 535
33	12	0 1,260	406 1,907	0 40	2,140 TNTC[2]	6 1,400
			SNELL CREEK			
34B	9	272 490	997 821	0 30	7,032 2,640	474 490
34	11	112 680	242 1,001	0 10	778 3,170	38 561
41	11	420 1,650	2,669 2,581	0 0	15,000 4,550	194 908
41A	11	20 2,800	875 2,813	0 150	6,170 6,250	46 1,724
41B	2	--- ---	574 1,644	490 1,280	658 2,008	556 1,603
42	11	350 500	3,250 1,871	0 0	16,950 8,000	350 464
42A	2	--- ---	1,160 2,280	0 2,100	2,320 3,660	48 2,772
43	14	500 3,650	3,245 4,487	0 400	17,388 10,200	312 2,505

Site	n	Median	Mean	Minimum	Maximum	Log Mean
			EAST BRANCH - HIX BRIDGE TO GUNNING ISLAND			
55	3	0 22	25 68	0 16	74 166	17 39
56	3	104 800	179 582	16 110	417 836	92 419
57	2	--- ---	289 451	38 290	540 612	143 421
61	3	15 32	12 35	0 20	20 54	7 33
63	3	9 16	11 29	8 6	16 64	10 18
64	11	0 32	6 368	0 0	44 2,870	3 45
65	3	8 16	49 20	1 12	138 32	10 18
66	3	3 72	5 69	0 6	11 128	8 38
67	3	134 76	243 66	0 30	596 92	43 59
68	4	116 228	4,030 631	2 0	>16,000 2,270	64 106
69	3	4 8	19 19	1 8	52 42	6 14
71	3	0 12	1 71	0 8	1 193	0 26
72	3	7 40	32 40	6 4	84 76	27 23
73	4	4 8	7 71	0 2	20 266	7 14
74	12	0 116	8 609	0 4	84 3,136	2 128

Site	n	Median	Mean	Minimum	Maximum	Log Mean
			CADMAN COVE			
58	3	1,100 97	8,953 831	0 40	25,760 2,360	305 206
59	12	0 284	16 992	0 0	90 5,800	5 112
60	5	14 24	37 64	0 0	130 240	9 19
62	10	100 374	412 313	0 0	1,650 640	51 106
62A	6	0 240	38 1,897	0 20	180 10,600	4 233
62B	5	12 100	80 432	0 0	120 1,760	33 251
62C	5	40 180	195 1,504	0 0	720 7,060	28 51
62D	2	--- ---	150 150	0 60	300 240	17 120
			UNNAMED STREAM AT SITE 70			
70F	2	--- ---	1,375 1,275	1,150 550	1,600 2,000	1,356 1,049
70E	6	2,150 2,650	2,175 2,200	150 700	5,100 3,000	1,155 1,977
70D	8	4,950 1,600	4,345 4,331	0 0	11,970 24,600	861 782
70C	9	300 1,700	4,363 9,778	0 0	24,150 77,750	47 917
70B	8	1,050 1,800	1,250 1,144	300 50	2,900 2,450	871 516
70A	9	0 26,900	11,192 23,733	0 5,950	88,228 39,700	28 20,997
70	11	0 12,900	1,116 19,669	0 2,405	7,084 56,250	28 11,796

Site	n	Median	Mean	Minimum	Maximum	Log Mean
EAST BRANCH - GUNNING ISLAND TO ROUTE 88 BRIDGE						
75	3	1 36	7 73	1 0	20 182	3 19
76	3	4 14	23 27	4 2	60 64	12 12
77	3	2 0	2 47	0 0	3 142	2 5
78	3	6 192	50 195	3 10	140 384	14 90
79	3	8 40	41 430	0 0	116 1,250	10 37
80	4	3,950 1,500	7,136 1,118	0 280	24,496 1,810	314 904
81	3	3 4	11 25	2 4	28 68	10 10
82	4	3 204	3 181	0 0	10 506	2 33
HORSENECK CHANNEL AND THE LET						
87	3	7 16	7 15	0 4	14 24	5 12
91	3	1 12	2 37	0 2	4 98	2 13
92	3	1 36	4 131	0 4	10 352	2 37
93	3	0 20	10 787	0 20	30 2,320	3 98
94	3	5 52	6 58	1 8	12 114	4 36
95	3	0 160	422 143	0 0	1,267 270	11 35

Site	n	Median	Mean	Minimum	Maximum	Log Mean
97	4	3 882	211 549	0 10	840 1,034	7 222
98	3	40 ——	53 191	0 80	120 494	17 199
99	3	0 36	110 362	0 14	330 1,036	7 81
100	3	5 40	32 39	0 0	90 78	8 15
			WESTPORT HARBOR			
83	3	1,400 1,576	4,693 2,015	0 50	12,679 4,420	261 704
84	3	16 178	110 30	0 27	314 476	17 73
85	3	76 84	66 189	45 70	78 414	64 135
86	3	2 12	1 218	0 0	2 642	2 20
88	3	50 460	66 502	29 220	120 826	56 437
89	3	1 100	10 181	0 8	28 431	3 70
90	3	16 60	42 258	0 32	109 682	12 109

Notes: [1]Number of samplings.

[2]Colonies were too numerous to count.

APPENDIX 2

Hydrography Data:

Current velocity and discharge data from each station during each hydrography at Westport Point and Hix Bridge, including measurement periods, tide direction, sea level changes, station cross-sectional areas, mean velocities, mean discharges, discharges, mean suspended sediment concentrations, and suspended sediment discharges.

Date 25 May 1985 Location Westport Point Cross-sectional Area $25.9 m^2$

Tide Neap Station 1 Width 45.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0635-0700	25	Ebb	-.45	12.8	.10	1.28	1,920		3.2	6.1
0700-0735	35		-.45	12.8	.04	.51	1,075		3.5	3.8
0735-0830	55	Flood	-.40	13.8	.06	.83	2,732		3.0	8.2
0830-0910	40		-.32	15.6	.21	3.28	7,862		2.6	20.4
0910-1000	50		-.20	18.4	.26	4.78	14,352		3.4	48.8
1000-1050	50		-.05	23.7	.33	7.82	23,463		2.5	58.7
1050-1140	50		+.08	29.3	.40	11.72	35,160		1.4	49.2
1140-1235	55		+.18	34.1	.30	10.23	33,759		1.7	57.4
1235-1350	75		+.23	36.5	.15	5.48	24,638		1.6	39.4
							141,966			282.1
1350-1435	45	Ebb	+.15	32.6	.10	3.26	8,802		1.7	15.0
1435-1535	60		+.01	26.3	.24	6.31	22,723		1.4	31.8
1535-1635	60		-.17	19.4	.24	4.66	16,762		2.2	36.9
1635-1730	55		-.32	15.6	.27	4.21	13,900		2.5	34.8
1730-1840	70		-.38	14.3	.09	1.29	5,405		2.5	13.5
							67,592			132.0

Date 25 May 1985 Location Westport Point Cross-sectional Area $249.6 m^2$

Tide Neap Station 2 Width 57.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	(L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0650-0715	25	Ebb	-.45	223.7	.18	40.27	60,399		3.7	223.5
0715-0740	25		-.45	223.7	.05	11.18	16,778		4.5	75.5
0740-0840	60	Flood	-.39	227.2	.17	38.62	139,046		3.8	528.4
0840-0920	40		-.30	232.4	.39	90.64	217,526		3.6	783.1
0920-1010	50		-.17	239.8	.45	107.91	323,730		2.7	874.1
1010-1100	50		-.02	248.4	.52	129.17	387,504		2.6	1007.5
1100-1150	50		+.10	255.4	.58	148.13	444,396		1.1	488.8
1150-1245	55		+.19	260.5	.46	119.83	395,439		1.1	435.0
1245-1325	40		+.24	263.4	.19	50.05	120,110		1.2	144.1
							2,027,751			4,261.0
1325-1445	80	Ebb	+.16	258.8	.25	64.7	310,560		1.7	528.0
1445-1545	60		-.02	248.4	.49	121.72	438,178		1.2	525.8
1545-1645	60		-.20	238.1	.50	119.05	428,580		2.0	857.2
1645-1740	55		-.33	230.6	.45	103.77	342,441		2.8	958.8
1740-1845	65		-.38	227.8	.18	41.00	159,916		3.2	511.7
							1,679,675			3,381.5

Date 25 May 1985 Location Westport Point Cross-sectional Area $257.7 m^2$

Tide Neap Station 3 Width 61.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	(L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0700-0740	40	Ebb	-.45	230.0	.12	27.6	66,240		3.4	225.2
0740-0810	30	Flood	-.42	231.9	.09	20.9	37,568		4.0	150.3
0810-0850	40		-.35	236.2	.27	63.8	153,058		2.9	443.9
0850-0930	40		-.28	240.5	.43	103.4	248,196		2.7	670.1
0930-1020	50		-.14	249.1	.47	117.1	351,231		2.2	772.7
1020-1110	50		0.0	257.7	.63	162.4	487,053		1.7	828.0
1110-1150	40		+.11	264.5	.71	187.8	450,708		1.1	495.8
1150-1310	80		+.21	270.6	.46	124.5	597,485		0.5	298.7
							2,325,299			3,659.5
1310-1355	45	Ebb	+.23	271.8	.17	46.2	124,756		1.1	137.2
1355-1500	65		+.10	263.8	.47	124.0	483,545		1.4	677.0
1500-1605	65		-.06	254.0	.59	175.3	683,514		1.5	1,025.3
1605-1700	55		-.25	242.3	.59	143.0	471,758		1.8	849.2
1700-1750	50		-.35	236.2	.42	99.2	297,612		2.1	625.0
1750-1900	70		-.38	234.3	.16	37.5	157,450		2.3	362.1
							2,218,635			3,675.5

Date 25 May 1985 Location Westport Point Cross-sectional Area $58.9 m^2$

Tide Neap Station 4 Width 31.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0710-0755	45	Ebb	-.45	45.0	.13	5.85	15,795		3.5	55.3
0755-0820	25	Flood	-.39	46.8	.12	5.62	8,424		3.6	30.3
0820-0900	40		-.34	48.4	.27	13.07	31,363		3.0	94.1
0900-0940	40		-.25	51.2	.33	16.90	40,550		3.4	137.9
0940-1030	50		-.10	55.8	.52	29.02	87,048		2.3	200.2
1030-1125	55		+.03	59.8	.64	38.27	126,298		1.5	189.4
1125-1210	45		+.16	63.9	.52	33.23	89,716		1.0	89.7
1210-1333	83		+.23	66.0	.32	21.12	105,178		1.2	126.2
							488,577			867.8
1333-1405	32	Ebb	+.21	65.4	.18	11.77	22,802		1.6	36.2
1405-1510	65		+.07	61.1	.62	37.88	147,740		1.5	221.6
1510-1615			-.09	56:1	.72	40.39	157,529		2.1	330.8
1615-1710	55		-.28	50.2	.52	26.10	86,143		2.3	198.1
1710-1800	50		-.36	47.7	.53	25.28	75,843		2.5	198.6
1800-1910	70		-.38	47.1	.24	11.30	47,477		3.1	147.2
							537,334			923.5

Date 9 May 1985 | Location Westport Point | Cross-sectional Area 25.9m^2

Tide Mean | Station 1 | Width 45.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0730-0850	80	Flood	-.34	15.2	.12	1.82	8,755		2.6	22.8
0850-1020	90		-.14	20.3	.28	5.68	30,694		2.4	73.7
1020-1115	55		+.06	28.4	.32	9.09	29,990		3.3	99.0
1115-1220	65		+.24	36.9	.31	11.44	44,612		1.5	66.9
1220-1345	85		+.34	41.8	.21	8.78	44,768		1.1	49.2
							159,089			311.6
1345-1410	25	Ebb	+.26	37.9	.07	2.65	3,980		1.8	7.2
1410-1510	60		+.16	33.1	.15	4.96	17,874		1.2	21.4
1510-1610	60		-.02	25.0	.14	3.50	12,600		1.1	13.9
1610-1735	85		-.20	18.4	.17	3.13	15,953		0.8	12.8
1735-1940	125		-.31	15.8	.14	2.21	16,866		2.1	35.4
							67,273			90.7

Date 9 May 1985 Location Westport Point Cross-sectional Area $249.6 m^2$

Tide Mean Station 2 Width 57.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0805-0910	65	Flood	-.28	233.5	.17	39.70	154,810		2.0	309.6
0910-1035	85		-.10	243.8	.41	99.96	509,786		2.3	1,172.5
1035-1130	55		+.13	257.1	.53	136.26	449,668		2.0	899.3
1130-1235	65		+.27	265.1	.48	127.25	496,267		1.3	645.1
1235-1335	60		+.35	269.7	.24	64.73	233,021		1.1	256.3
							1,843,552			3,282.8
1335-1425	50	Ebb	+.26	264.5	.13	34.38	103,155		1.3	134.1
1425-1520	55		+.12	256.5	.32	82.08	270,864		1.8	487.6
1520-1620	60		-.05	246.7	.43	106.08	381,902		2.2	840.2
1620-1725	65		-.20	238.1	.33	78.57	306,435		1.8	551.6
1725-1835	70		-.32	231.2	.19	43.93	184,498		4.0	738.0
1835-1950	75		-.29	232.9	.12	27.95	125,766		1.9	239.0
							1,372,610			2,990.5

Date 9 May 1985 | Location Westport Point | Cross-sectional Area $257.7m^2$

Tide Mean | Station 3 | Width 61.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0815-0925	70	Flood	-.26	241.7	.24	58.01	243,634		2.3	560.4
0925-1050	85		-.04	255.2	.63	160.78	819,958		2.3	1,885.9
1050-1145	55		+.16	267.5	.64	171.20	564,960		1.6	903.9
1145-1250	65		+.31	276.8	.47	130.10	507,374		1.6	811.8
1250-1355	65		+.33	278.0	.19	52.82	205,998		1.3	267.8
							2,341,924			4,429.8
1355-1435	40	Ebb	+.23	271.8	.10	27.18	65,232		1.6	104.4
1435-1530	55		+.09	263.2	.34	89.49	295,310		2.3	679.2
1530-1635	65		-.08	252.8	.32	80.90	315,494		2.4	757.2
1635-1750	75		-.26	241.7	.34	82.18	369,801		3.6	1,331.3
1750-1855	65		-.32	238.0	.41	98.58	380,562		3.0	1,141.7
1855-1945	50		-.29	239.9	.14	33.59	100,758		2.2	221.7
							1,527,157			4,235.5

Date 9 May 1985 | Location Westport Point | Cross-sectional Area 58.9m[2]

Tide Mean | Station 4 | Width 31.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0750-0940	110	Flood	-.27	50.5	.24	12.12	79,992		2.0	160.0
0940-1100	80		-.01	58.6	.52	30.47	146,266		2.8	409.5
1100-1205	65		+.19	64.8	.50	32.40	126,360		2.3	290.6
1205-1320	75		+.34	69.4	.28	19.43	87,444		1.4	122.4
							440,062			982.5
1320-1400	40	Ebb	+.30	68.2	.14	9.55	22,915		1.5	34.4
1400-1450	50		+.20	65.1	.41	26.69	80,073		1.7	136.1
1450-1545	55		+.06	60.8	.64	38.91	128,410		2.0	256.8
1545-1645	60		-.12	55.2	.53	29.26	105,322		2.1	221.2
1645-1800	75		-.28	50.2	.43	21.59	97,137		2.5	242.8
1800-1910	70		-.32	49.0	.28	13.72	57,624		3.4	195.9
1910-1950	40		-.29	49.9	.10	4.99	11,976		2.8	33.5
							503,457			1,120.7

Date 30 June 1985 Location Westport Point Cross-sectional Area $25.9 m^2$

Tide Spring Station 1 Width 45.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	(L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0730-0830	60	Ebb	+.32	40.8	.02	0.82	2,938		3.1	9.1
0830-0930	60		+.13	31.7	.06	1.90	6,847		2.8	19.2
0930-1040	70		-.08	22.5	.10	2.25	9,450		4.2	39.7
1040-1140	60		-.27	16.8	.14	2.35	8,467		3.8	32.2
1140-1240	60		-.40	13.8	.11	1.52	5,465		4.1	22.4
1240-1340	60		-.46	12.6	.15	1.89	6,804		4.3	29.3
1340-1400	20		-.44	13.0	.05	0.65	780		4.5	3.5
							40,751			155.4
1400-1445	45	Flood	-.37	14.5	.11	1.60	4,306		4.4	18.9
1445-1545	60		-.23	17.7	.33	5.84	21,028		3.6	75.7
1545-1640	55		+.01	26.3	.44	11.57	38,188		3.3	126.0
1640-1745	65		+.25	37.4	.59	22.07	86,057		2.9	249.6
1745-1850	65		+.52	50.6	.62	31.37	122,351		2.3	281.4
1850-1950	60		+.67	58.0	.41	23.78	85,608		1.6	137.0
1950-2020	30		+.69	59.0	.12	7.08	12,744		1.5	19.1
							370,282			907.7

Date 30 June 1985 | Location Westport Point | Cross-sectional Area 249.6m²

Tide Spring | Station 2 | Width 57.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m²)	Mean Velocity (m/sec)	Mean Discharge (m³/sec)	Discharge (m³)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0800-0850	50	Ebb	+.25	264.0	.10	26.40	79,200		3.3	261.4
0850-0950	60		+.06	253.0	.27	68.31	245,916		3.7.	909.9
0950-1050	60		-.12	242.7	.38	92.23	332,014		3.4	1128.8
1050-1155	65		-.29	232.9	.48	111.79	435,989		3.3	1438.8
1155-1255	60		-.43	224.9	.45	101.20	364,338		4.5	1639.5
1255-1420	85		-.44	224.3	.21	47.10	240,225		4.1	984.9
							1,697,682			6,363.3
1420-1455	35	Flood	-.34	230.0	.09	20.70	43,470		4.4	191.3
1455-1555	60		-.20	238.1	.46	109.53	394,294		3.6	1419.5
1555-1655	60		+.05	252.5	.84	212.10	763,560		3.5	2673.5
1655-1800	65		+.34	269.2	.95	255.74	997,386		3.0	2992.2
1800-1905	65		+.56	281.8	.88	247.98	967,138		2.2	2127.7
1905-2000	55		+.69	289.3	.60	173.58	572,814		2.0	1145.6
2000-2025	25		+.68	288.7	.20	57.74	86,610		2.0	173.2
							3,825,272			10,723.0

Date 30 June 1985 Location Westport Point Cross-sectional Area 257.7m²

Tide Spring Station 3 Width 61.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0750-0900	70	Ebb	+.23	271.8	.33	89.69	376,715		2.7	1,017.1
0900-1000	60		+.03	259.5	.41	106.40	383,022		2.4	919.3
1000-1105	65		-.15	248.5	.47	116.80	455,500		5.6	2,550.8
1105-1205	60		-.34	236.8	.37	87.62	315,418		5.1	1,608.6
1205-1310	65		-.44	230.6	.47	108.38	422,690		6.4	2,705.2
1310-1420	70		-.43	231.2	.27	64.24	262,181		5.1	1,337.1
							2,215,526			10,138.1
1420-1505	45	Flood	-.33	237.4	.23	54.60	147,425		4.6	678.2
1505-1610	65		-.14	249.1	.67	166.90	650,898		3.9	2,538.5
1610-1705	55		+.10	263.8	1.09	287.54	948,889		4.5	4,170.0
1705-1840	95		+.43	284.1	1.19	338.08	1,927,050		2.8	5,395.7
1840-2010	90		+.67	298.9	.66	197.27	1,065,280		2.3	2,450.1
2010-2030	20		+.66	298.3	.13	38.78	46,535		2.2	102.4
							4,786,077			15,434.9

Date 30 June 1985 Location Westport Point Cross-sectional Area $58.9 m^2$

Tide Spring Station 4 Width 31.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0755-0915	80	Ebb	+.22	65.7	.42	27.59	132,451		2.5	331.1
0915-1015	60		-.02	58.3	.85	49.56	178,398		3.2	570.9
1015-1115	60		-.19	53.0	.76	40.28	145,008		3.9	565.5
1115-1215	60		-.36	47.7	.60	28.62	103,032		4.2	432.7
1215-1320	65		-.45	45.0	.49	22.05	85,995		5.8	498.8
1320-1400	40		-.45	45.0	.21	9.45	22,680		5.1	115.7
							667,564			2,514.7
1400-1515	75	Flood	-.34	49.6	.24	11.90	53,568		4.4	235.7
1515-1625	70		-.10	55.8	.52	29.02	121,867		3.6	438.7
1625-1725	60		+.19	64.8	.56	36.29	130,637		3.6	470.3
1725-1825	60		+.44	72.5	.65	47.12	169,650		4.9	831.3
1825-1930	65		+.63	78.4	.57	44.69	174,283		3.2	557.7
1930-2030	60		+.68	80.0	.21	16.80	60,480		2.1	127.0
							710,485			2,660.7

Date 12 June 1985 Location Hix Bridge Cross-sectional Area 85.7m²

Tide Neap Station 1 Width 35.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	(L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0520-0710	110	Ebb	+.20	93.0	.11	10.23	67,518		3.7	249.8
0710-0810	60		+.04	87.1	.13	11.32	40,763		2.8	114.1
0810-0920	70		-.09	82.5	.07	5.78	24,255		3.0	72.8
0920-1030	70		-.10	78.8	.04	3.15	13,238		3.1	41.0
1030-1130	60		-.24	77.5	.02	1.55	5,580		3.9	21.8
							151,354			499.5
1130-1245	75	Flood	-.16	80.1	.03	2.40	10,814		2.8	20.3
1245-1350	65		-.03	84.6	.08	6.77	26,395		2.3	60.7
1350-1450	60		+.10	89.3	.13	11.61	41,792		2.7	112.8
1450-1600	70		+.27	95.7	.11	10.53	44,213		2.9	128.2
1600-1720	80		+.43	102.0	.12	12.24	58,752		3.0	176.3
1720-1755	35		+.47	103.6	.04	4.14	8,702		4.2	36.5
							190,668			534.8

Date 12 June 1985 Location Hix Bridge Cross-sectional Area 125.8m^2

Tide Neap Station 2 Width 43.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0510-0735	145	Ebb	+.18	133.5	.05	8.01	69,687		4.0	278.7
0735-0835	60		-.01	125.4	.06	7.52	27,086		3.3	89.4
0835-0935	60		-.13	120.2	.05	6.01	21,636		3.4	73.6
09351045	70		-.22	116.3	.03	3.49	14,654		3.0	44.0
1045-1150	65		-.23	115.9	.02	2.32	9,040		3.8	34.4
							142,103			520.1
1150-1300	70	Flood	-.13	120.2	.07	8.41	35,339		3.7	130.8
1300-1400	60		-.01	125.4	.16	20.06	72,230		3.1	223.9
1400-1505	65		+.13	131.4	.15	19.71	76,869		3.0	230.6
1505-1620	75		+.32	139.6	.17	23.73	106,794		2.8	299.0
1620-1725	65		+.44	144.7	.09	13.02	50,790		3.0	152.4
							342,022			1,036.7

189

Date 12 June 1985 Location Hix Bridge Cross-sectional Area 41.2m^2

Tide Neap Station 3 Width 52.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0520-0750	150	Ebb	+.16	49.8	.03	1.49	13,446		3.9	52.5
0750-0850	60		-.04	39.1	.06	2.35	8,446		4.0	33.8
0850-0945	55		-.14	34.0	.03	1.02	3,366		3.4	11.4
0945-1055	70		-.23	29.4	.05	1.47	6,174		3.4	21.0
1055-1155	60		-.23	29.4	.03	.88	3,175		3.5	11.1
							34,607			129.7
1155-1315	80	Flood	-.11	35.5	.04	1.42	6,816		3.1	21.1
1315-1415	60		+.02	42.3	.12	5.08	18,274		3.2	58.5
1415-1520	65		+.18	50.8	.05	2.54	9,906		4.5	44.6
1520-1630	70		+.34	59.7	.06	3.58	15,044		3.9	58.7
1630-1710	40		+.44	65.3	.02	1.31	3,134		4.7	14.7
							53,174			197.6

Date 16 May 1985 Location Hix Bridge Cross-sectional Area 85.7m²

Tide Mean Station 1 Width 35.5m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0750-1020	150	Ebb	+.15	91.1	.05	4.56	40,995		2.2	90.2
1020-1125	65		-.07	83.2	.07	5.82	22,714		2.1	47.7
1125-1215	50		-.19	79.1	.06	4.75	14,238		3.7	52.7
1215-1315	60		-.31	75.2	.04	3.01	10,829		3.3	35.7
							88,776			226.3
1315-1425	70	Flood	-.34	74.2	.03	2.23	9,349		3.7	34.6
1425-1535	70		-.24	77.5	.04	3.10	13,020		2.9	37.8
1535-1635	60		-.10	82.2	.07	5.75	20,714		4.0	82.9
1635-1745	70		+.08	88.6	.13	11.52	48,376		3.9	188.7
1745-1840	55		+.28	96.1	.05	4.80	15,856		3.7	58.7
1840-2010	90		+.44	102.4	.02	2.05	11,059		3.7	40.9
							118,374			443.6

Date 16 May 1985 Location Hix Bridge Cross-sectional Area 125.8m^2

Tide Mean Station 2 Width 43.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	(L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0715-1040	205	Ebb	+.15	132.2	.06	7.93	97,564		3.0	292.7
1040-1135	55		-.10	121.5	.08	9.72	32,076		2.8	89.8
1135-1230	55		-.22	116.3	.07	8.14	26,865		3.4	91.3
1230-1330	60		-.33	111.6	.03	3.35	12,053		3.4	41.0
							168,558			514.8
1330-1450	80	Flood	-.31	112.5	.03	3.38	16,200		3.5	56.7
1450-1550	60		-.20	117.2	.08	9.38	33,754		2.5	84.4
1550-1700	70		-.05	123.6	.17	21.01	88,250		3.2	282.4
1700-1805	65		+.14	131.8	.21	27.68	107,944		3.2	345.4
1805-1855	50		+.33	140.0	.16	22.40	67,200		3.9	262.1
1855-1925	30		+.43	144.3	.04	5.77	10,390		2.8	29.1
							323,738			1,060.1

Date 16 May 1985 | Location Hix Bridge | Cross-sectional Area $41.2 m^2$

Tide Mean | Station 3 | Width 52.0m

Measurement Period	Minutes	Tide	Mean Change in Sea Level	Mean Cross-Sectional Area (m^2)	Mean Velocity (m/sec)	Mean Discharge (m^3/sec)	Discharge (m^3)	Discharge (L)	Mean Sediment Concentration (mg/L)	Suspended Sediment Discharge (kg)
0750-1055	185	Ebb	+.12	47.6	.05	2.38	26,418		2.4	63.4
1055-1220	85		-.17	32.4	.10	3.24	16,524		2.5	41.3
1220-1350	90		-.32	24.9	.04	1.00	5,378		3.8	20.4
							48,320			125.1
1350-1510	80	Flood	-.29	26.4	.04	1.06	5,069		4.7	23.8
1510-1610	60		-.16	33.0	.05	1.65	5,940		4.7	27.9
1610-1715	65		-.01	40.7	.02	.81	3,175		3.6	11.4
1715-1820	65		+.21	52.5	.02	1.05	4,095		3.9	16.0
1820-1915	55		+.37	61.3	.04	2.45	8,092		3.5	28.3
1915-2015	60		+.46	66.4	.03	1.99	7,171		4.0	28.7
							33,542			136.1

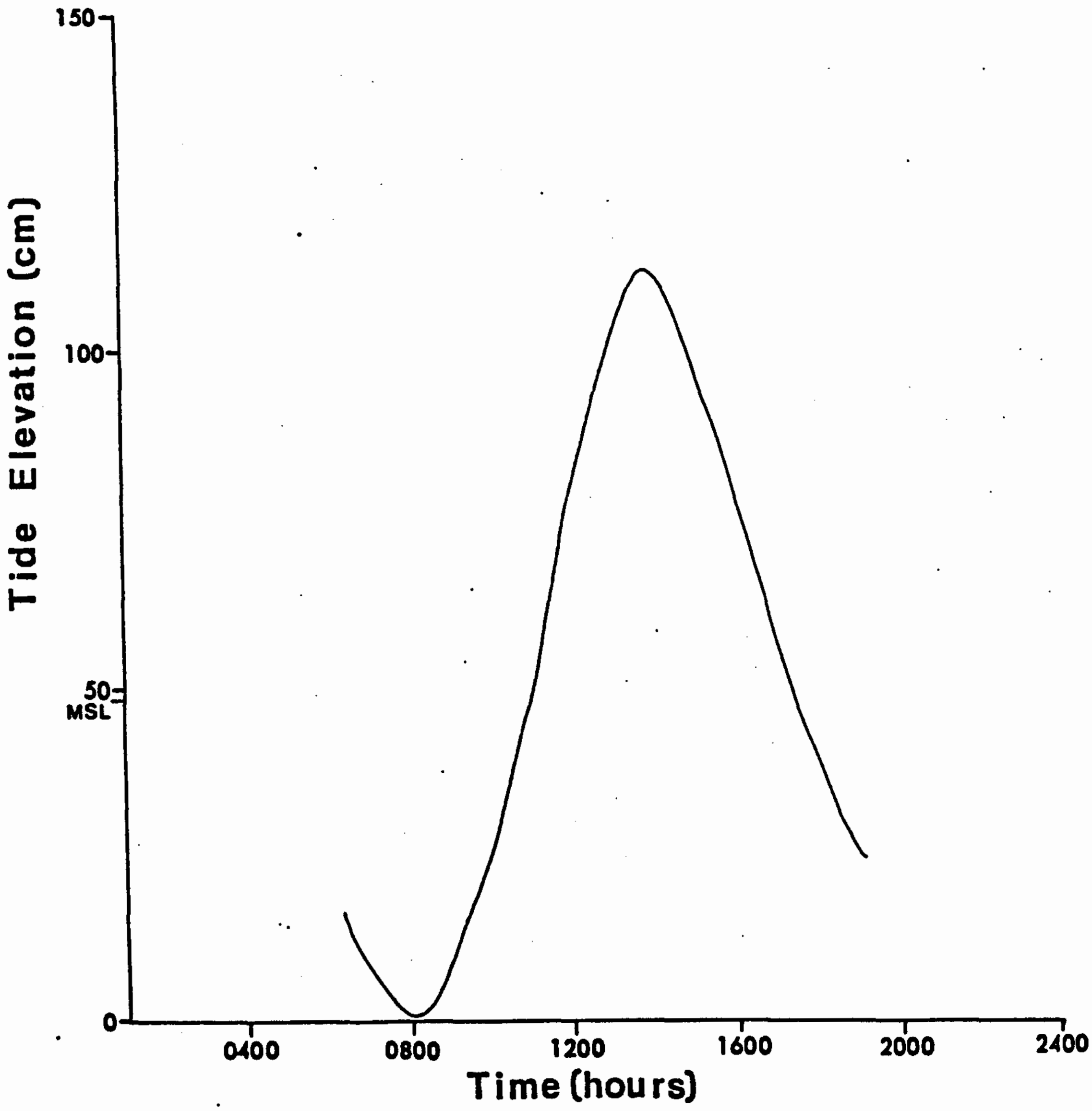
APPENDIX 3

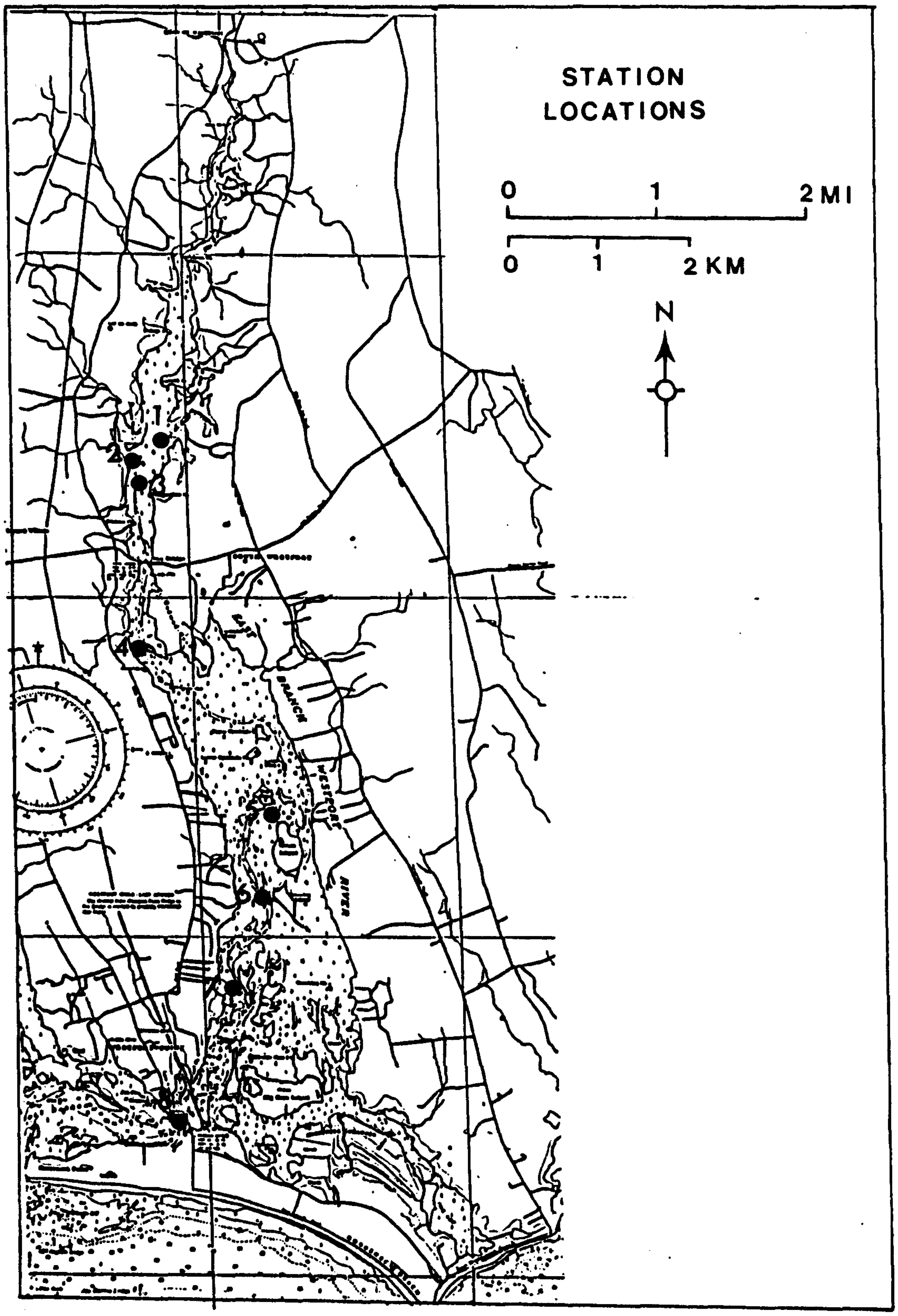
Hydrography Curves:

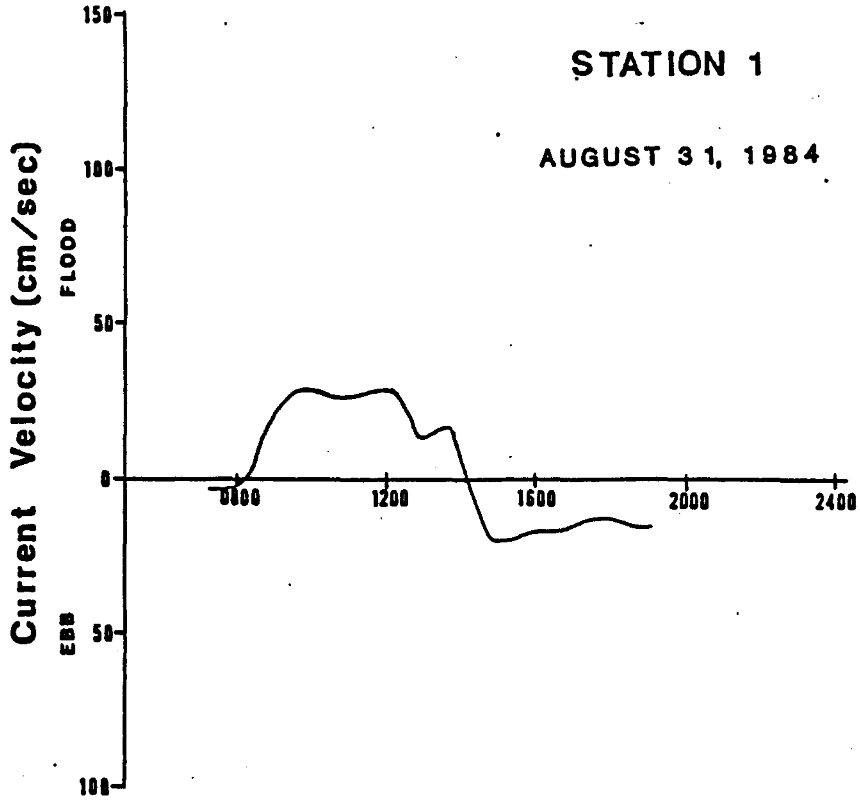
Tide and current velocity curves for each hydrography in the East Branch, at Westport Point, and at Hix Bridge, showing fluctuation of tide level over time and fluctuation of the tidal current velocity throughout a tidal cycle, with a comparison of tidal current velocities for each station at Westport Point and at Hix Bridge.

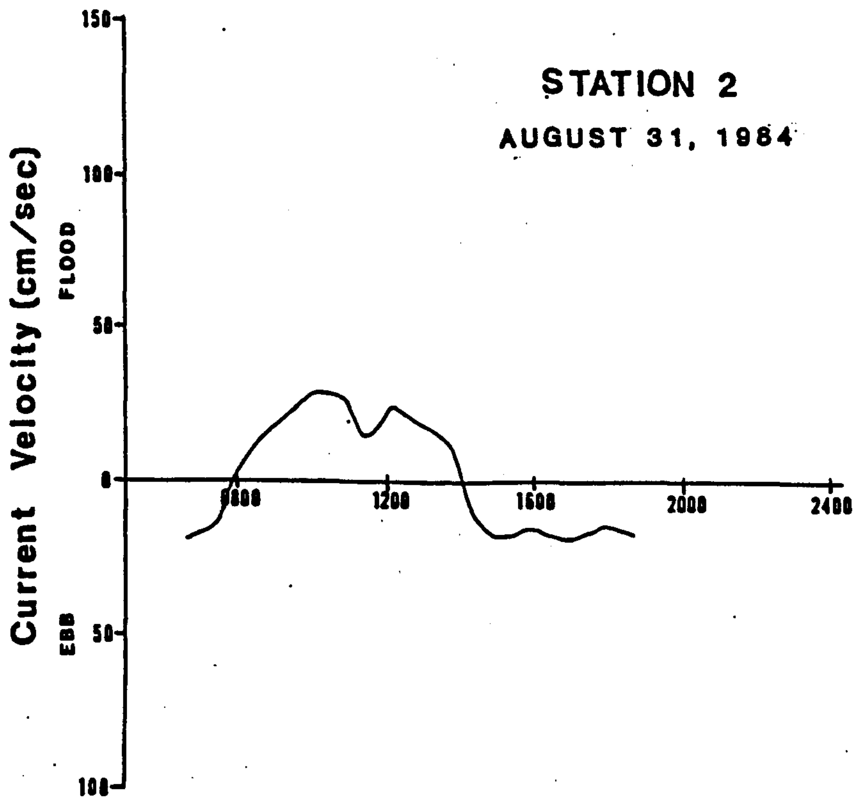
HIX BRIDGE

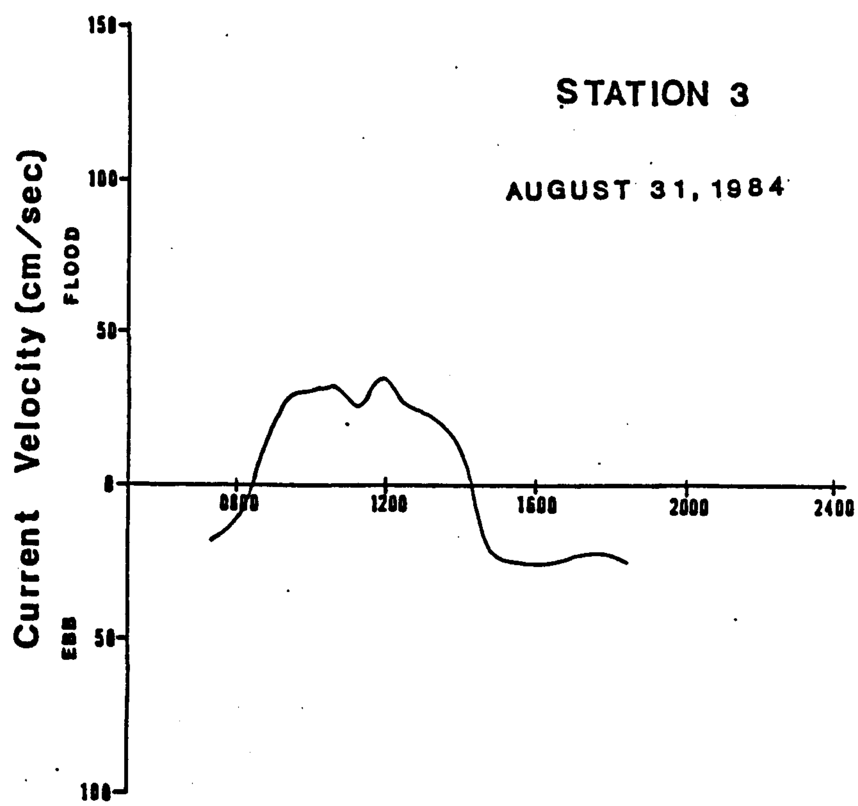
31 AUGUST 1984

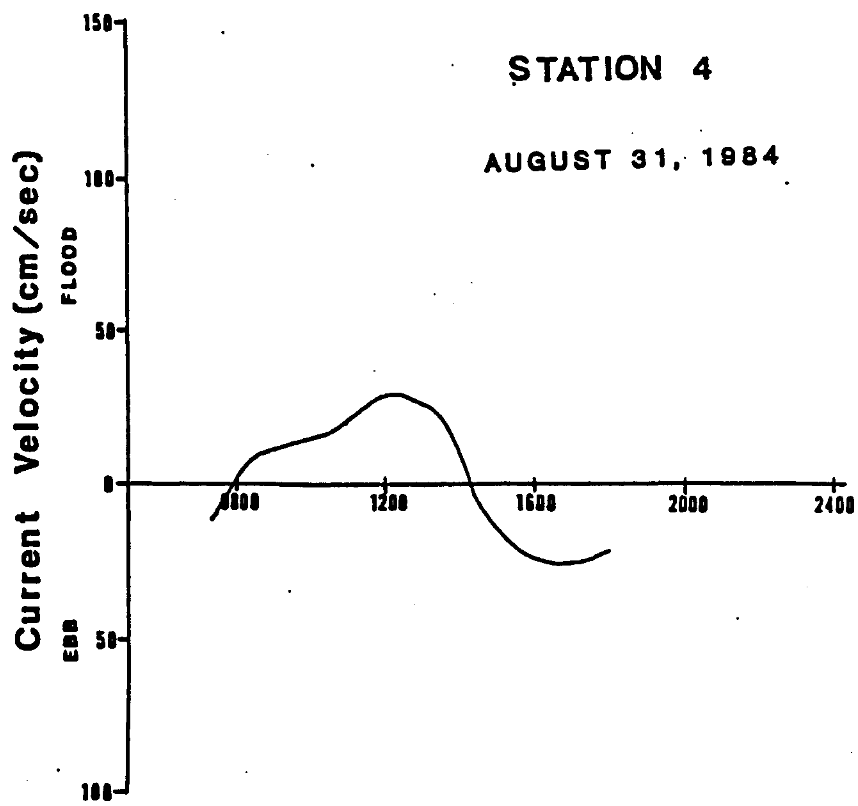


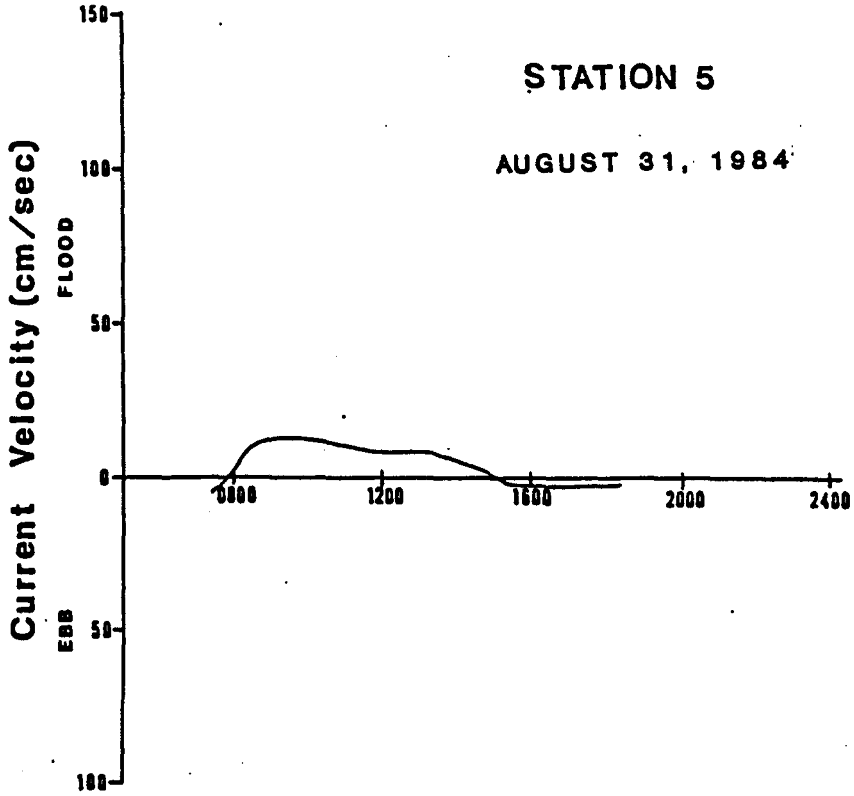

STATION
LOCATIONS
0
1
2 MI
0
1
2 KM
N
1
2
3
4
5
6
7
8
EAST
BRANCH
WESTPORT
RIVER

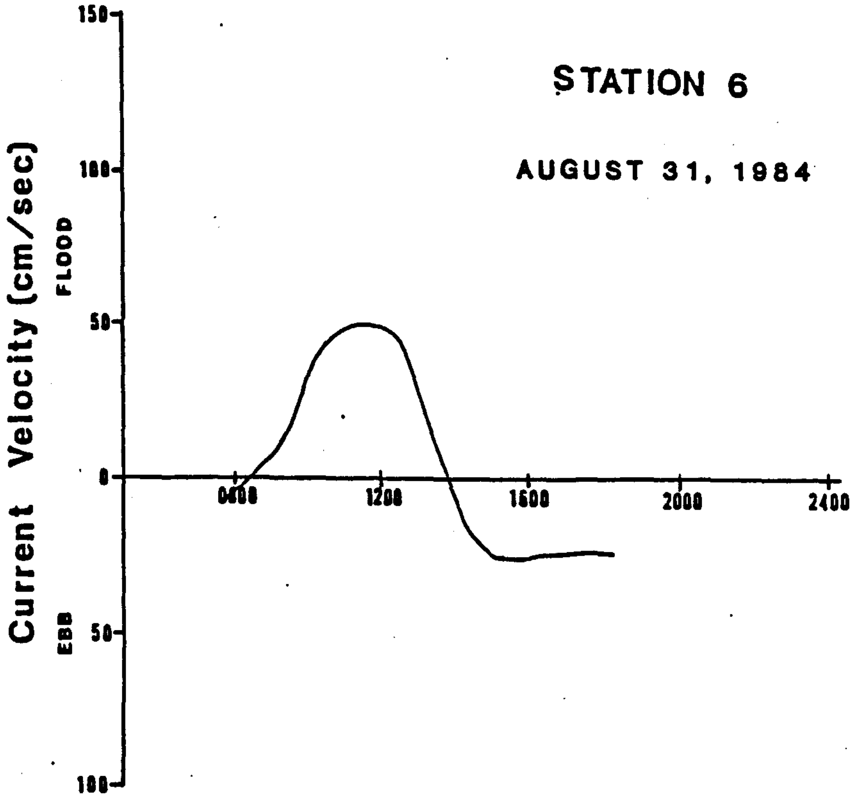

STATION 1
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400

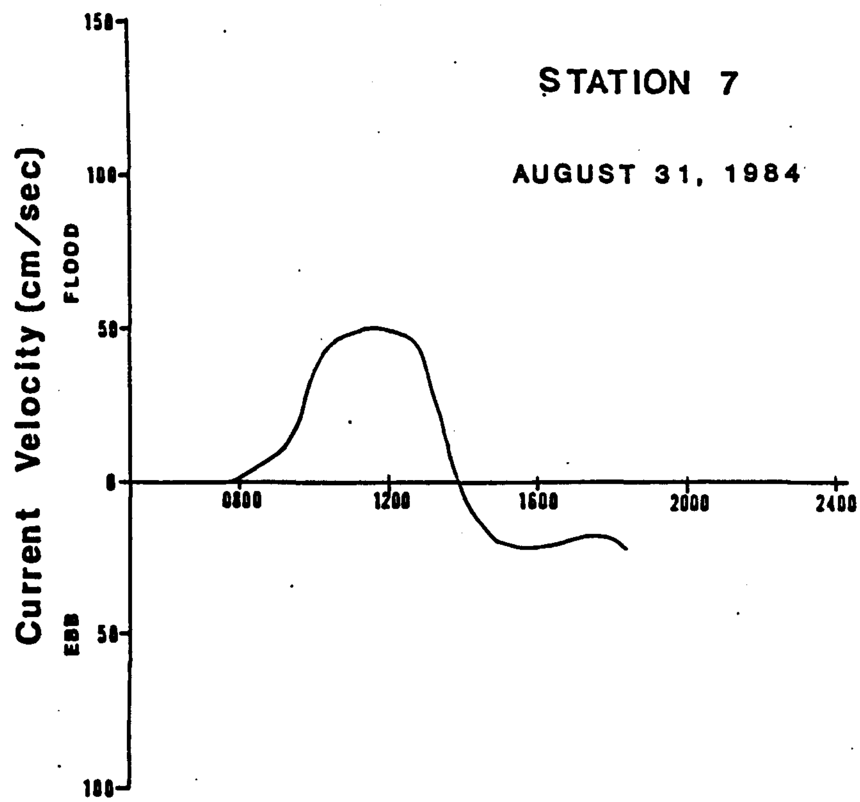

STATION 2
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400

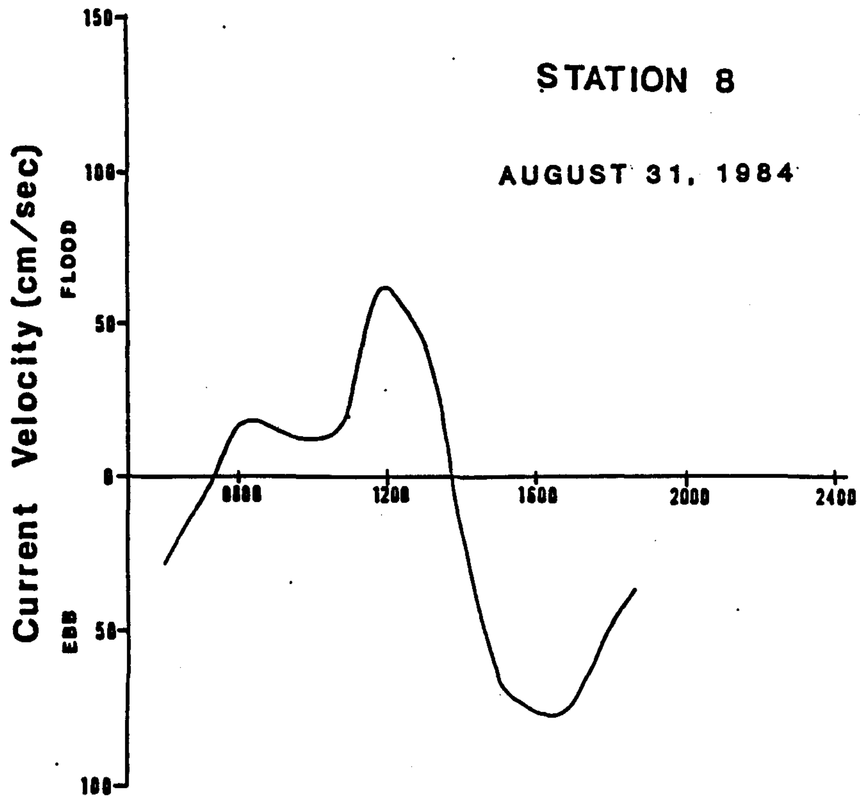

STATION 3
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400

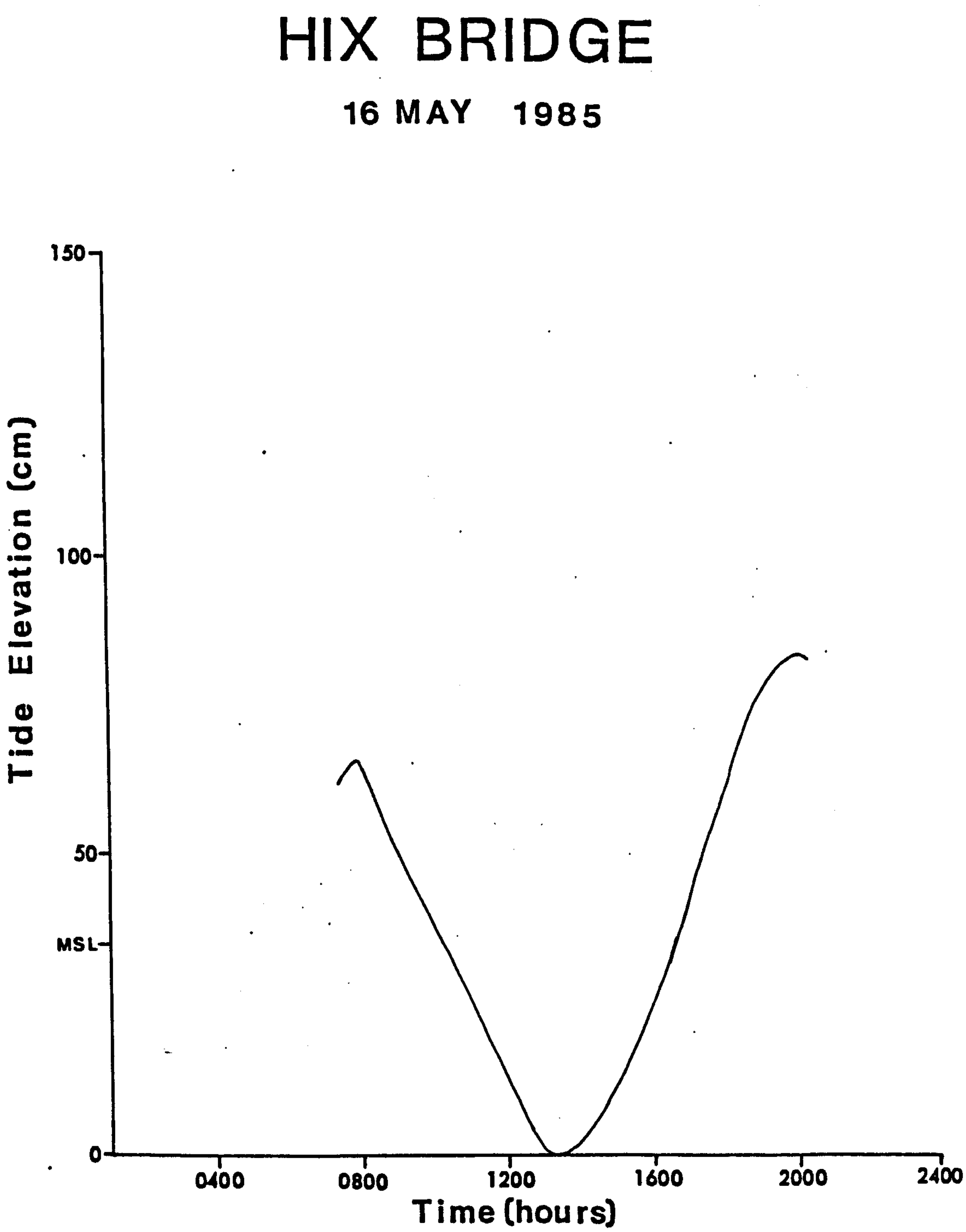

STATION 4
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400

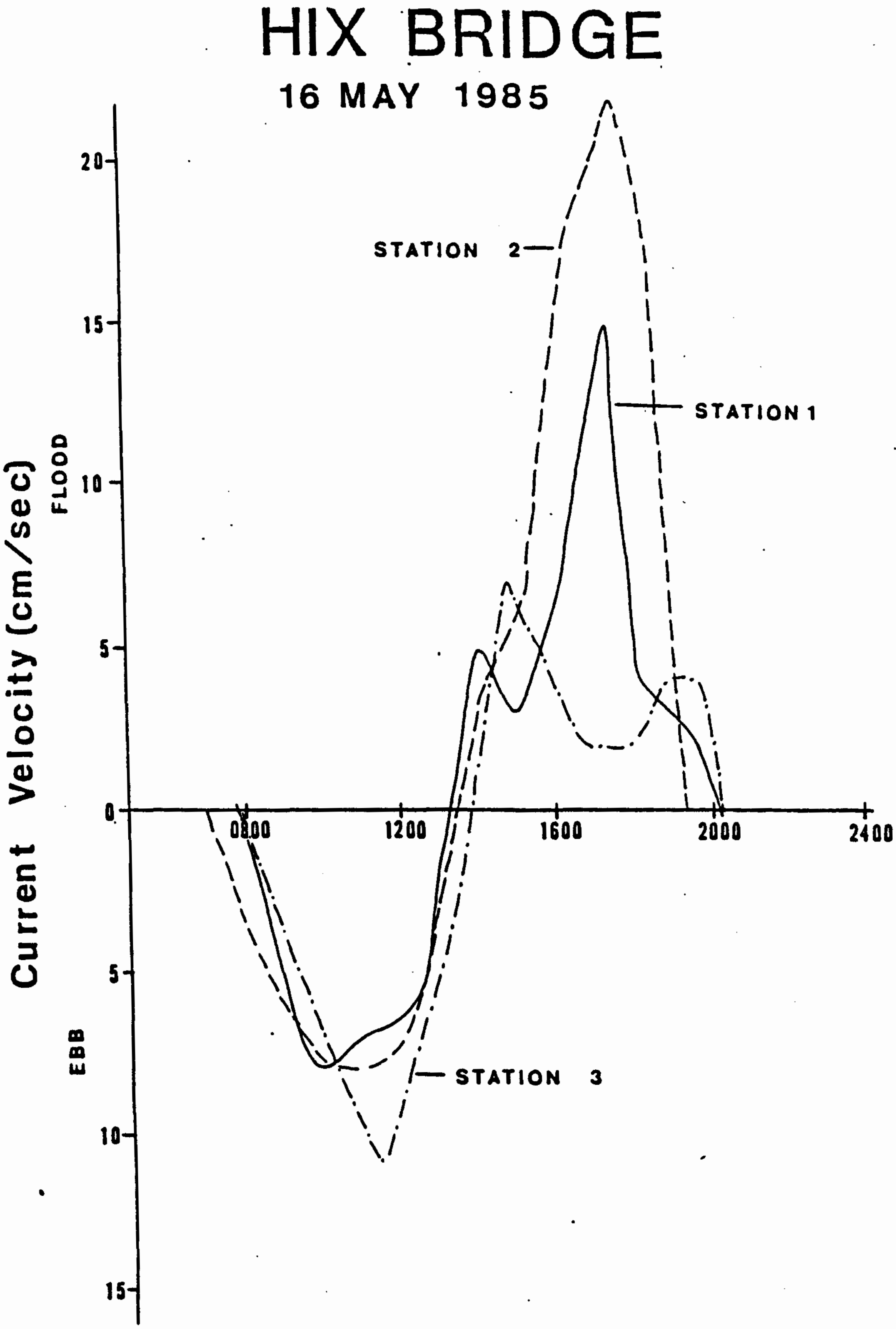

STATION 5
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400


STATION 6
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400


STATION 7
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400

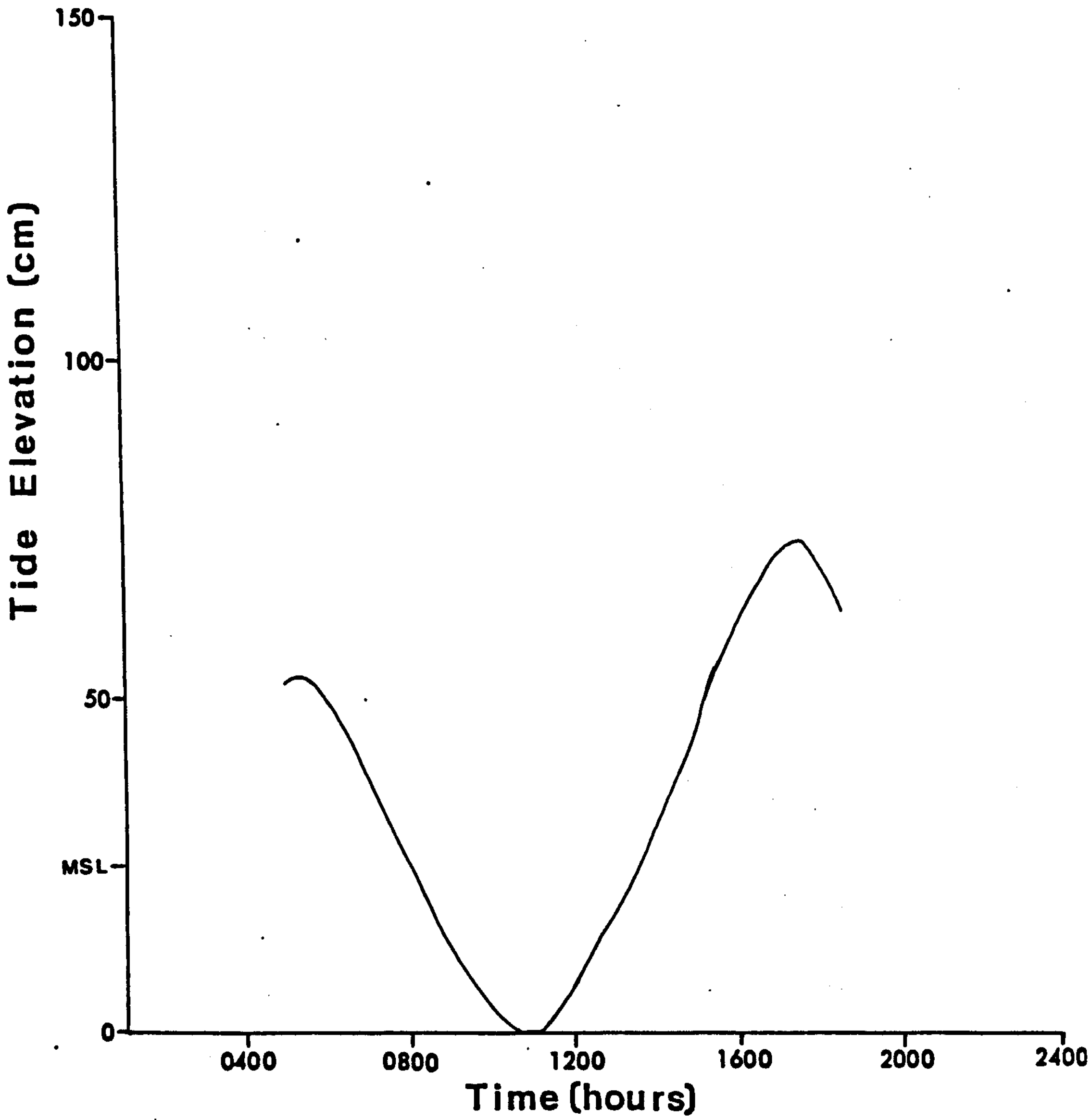

STATION 8
AUGUST 31, 1984
Current Velocity (cm/sec)
FLOOD
EBB
150
100
50
0
50
100
0800
1200
1600
2000
2400

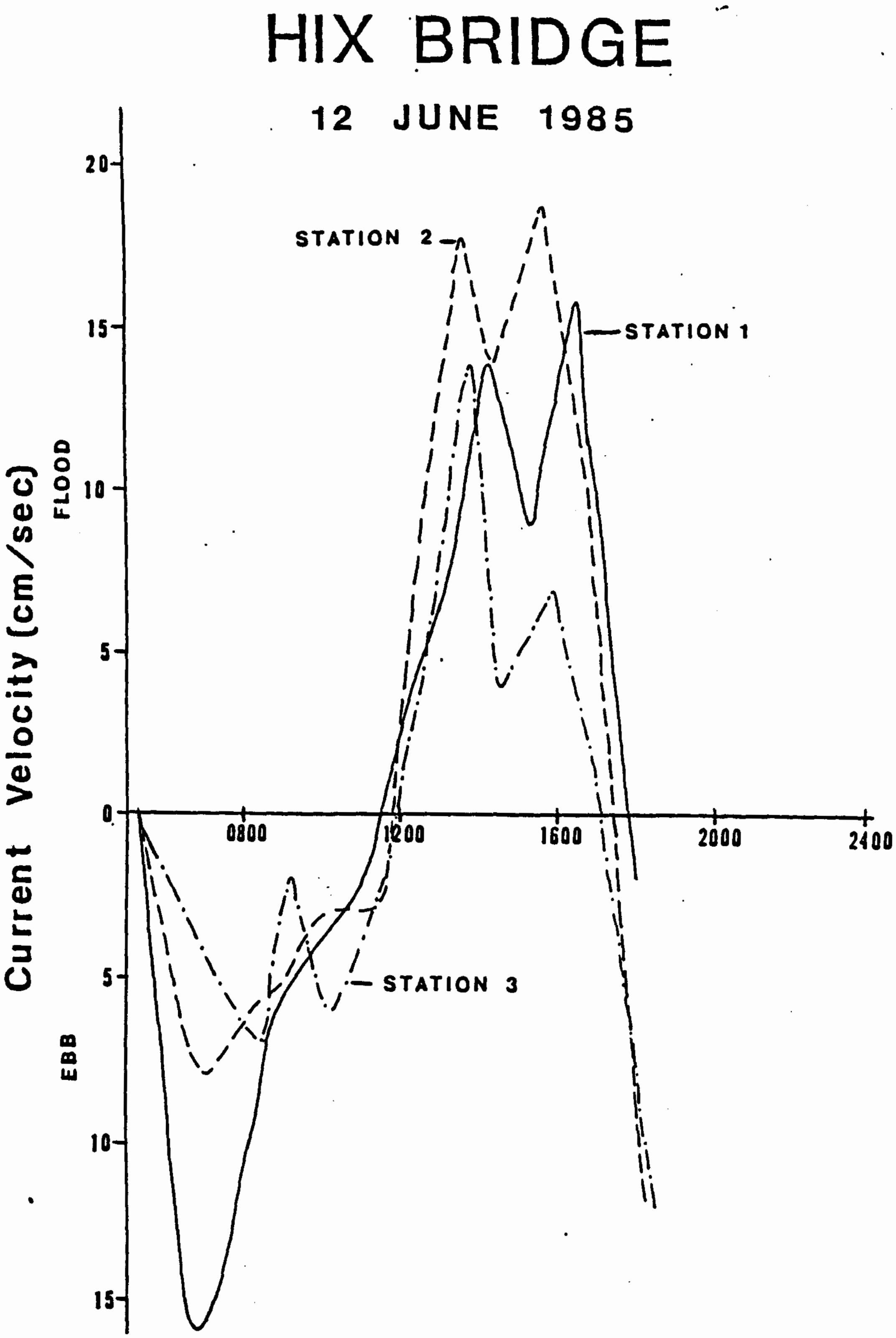

HIX BRIDGE
16 MAY 1985
150
100
50
MSL
0
Tide Elevation (cm)
0400
0800
1200
1600
2000
2400
Time (hours)


HIX BRIDGE
16 MAY 1985
STATION 2
STATION 1
STATION 3
Current Velocity (cm/sec)
FLOOD
EBB
20
15
10
5
0
5
10
15
0800
1200
1600
2000
2400

HIX BRIDGE

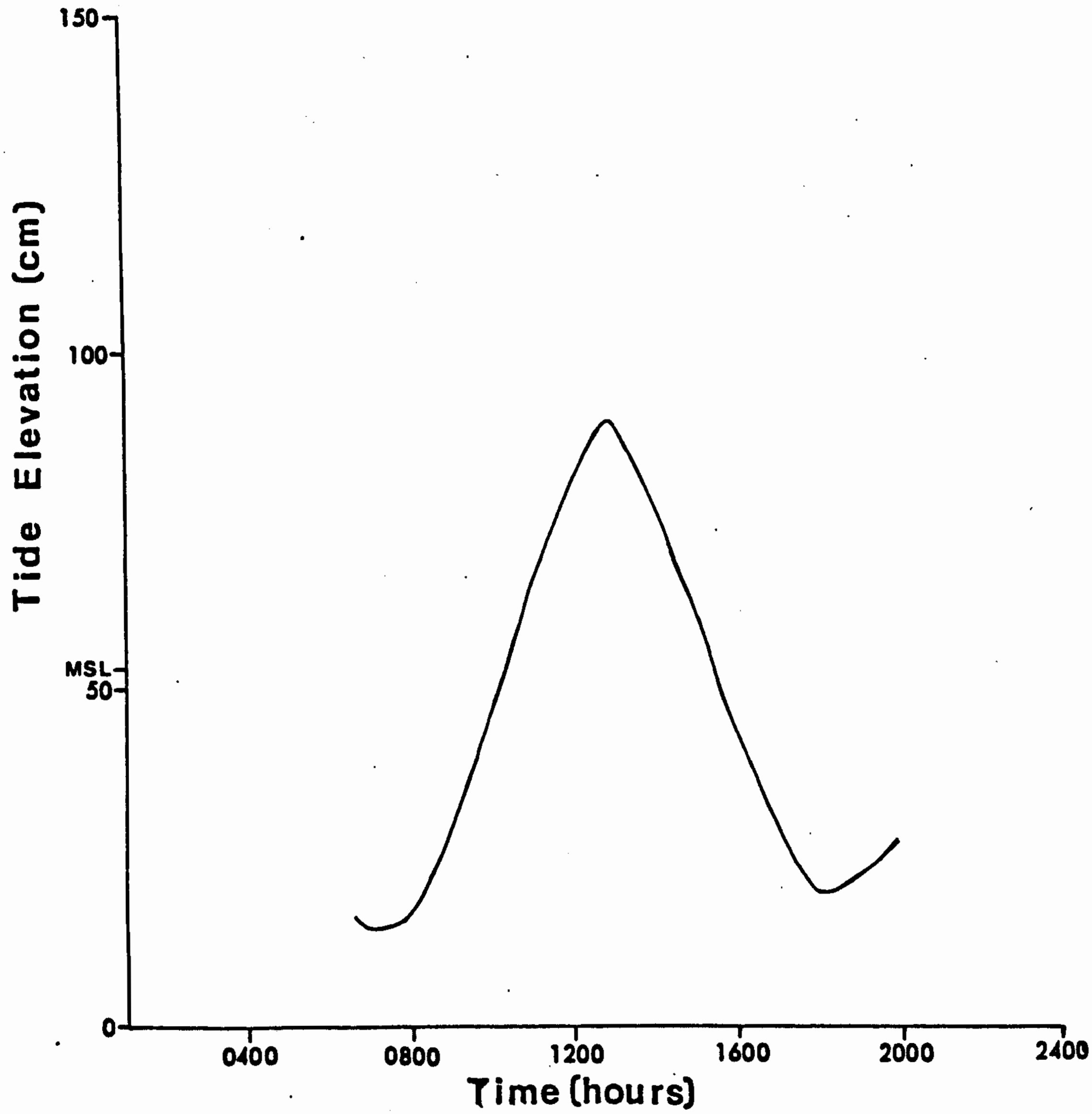
12 JUNE 1985




HIX BRIDGE
12 JUNE 1985
Current Velocity (cm/sec)
FLOOD
EBB
20
15
10
5
0
5
10
15
0800
1200
1600
2000
2400
STATION 2
STATION 1
STATION 3

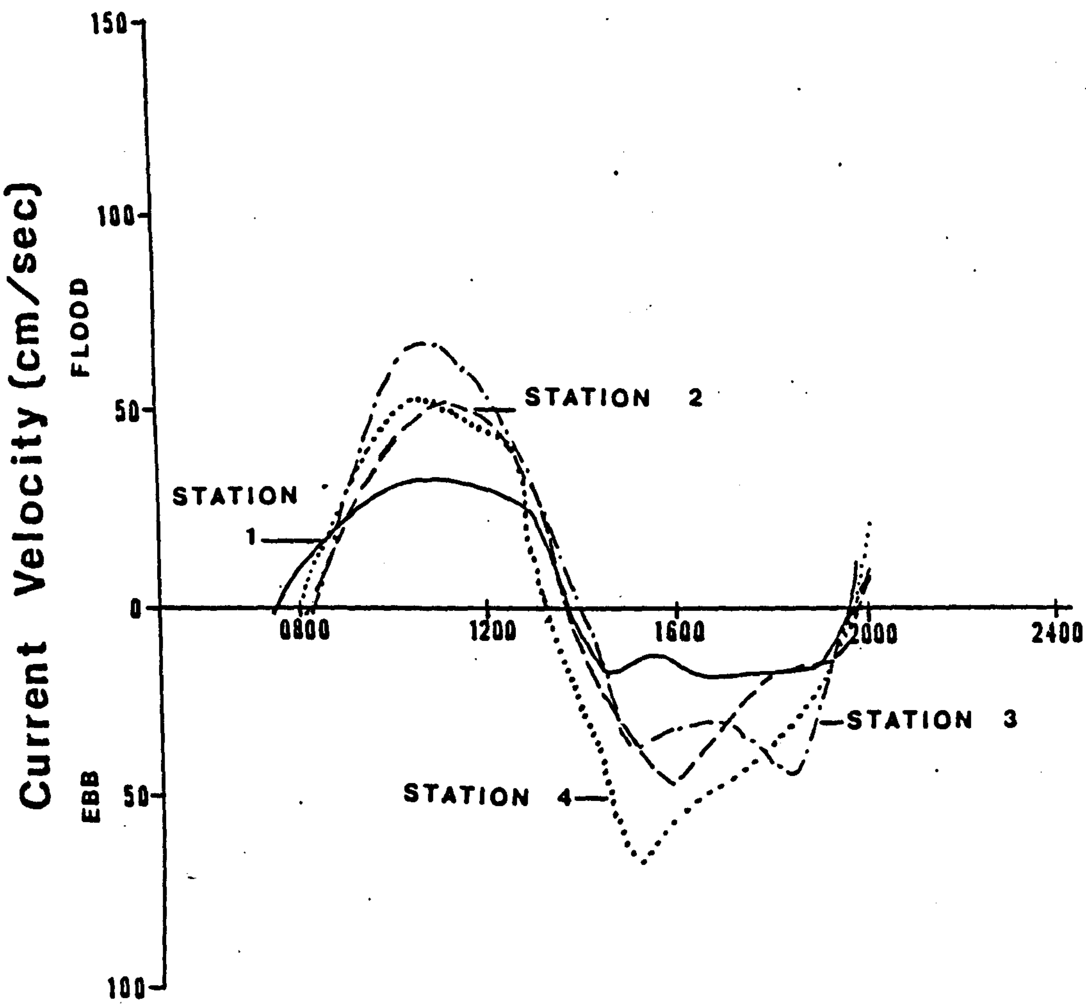
WESTPORT POINT

9 MAY 1985



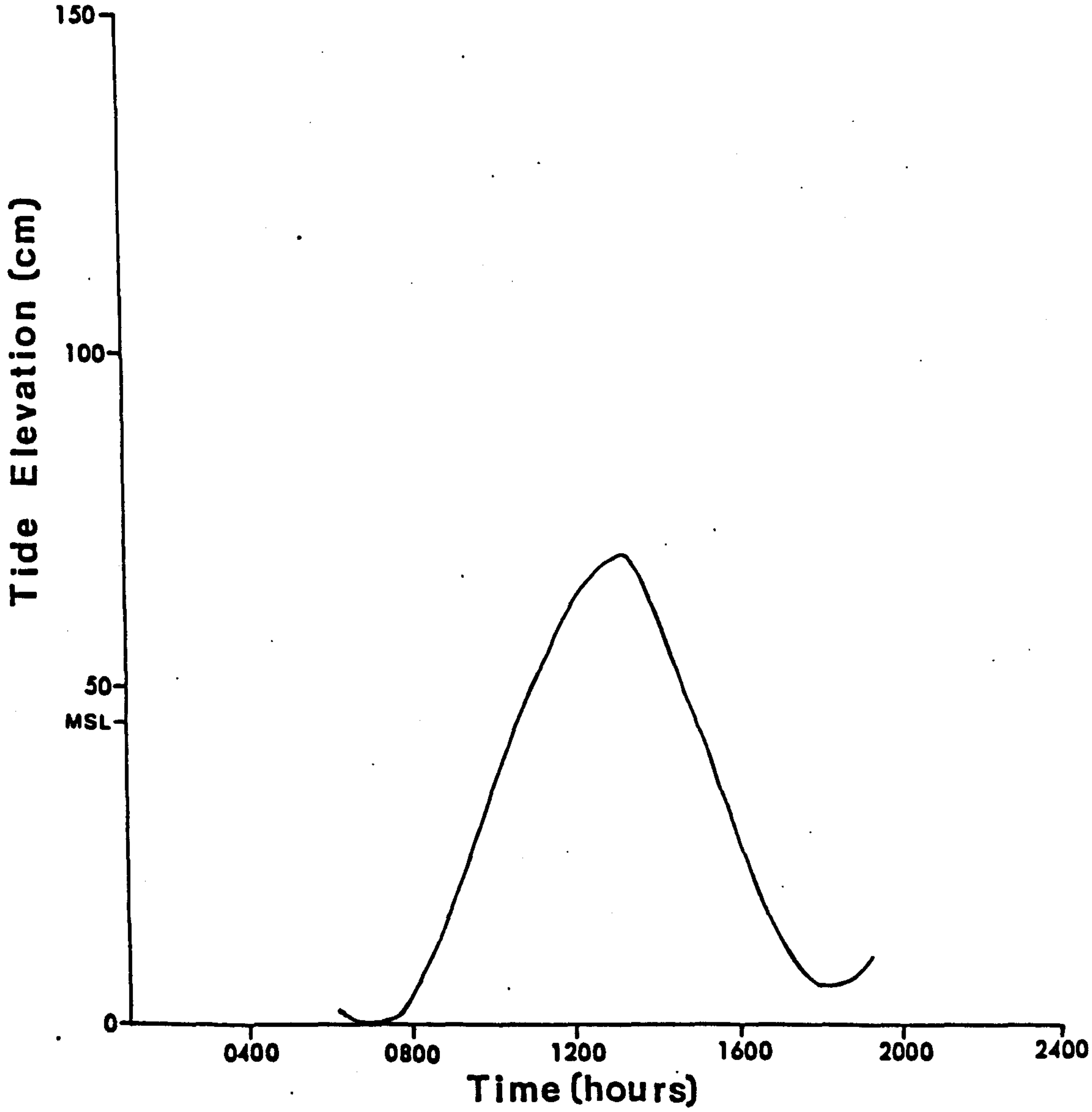
WESTPORT POINT

9 MAY 1985



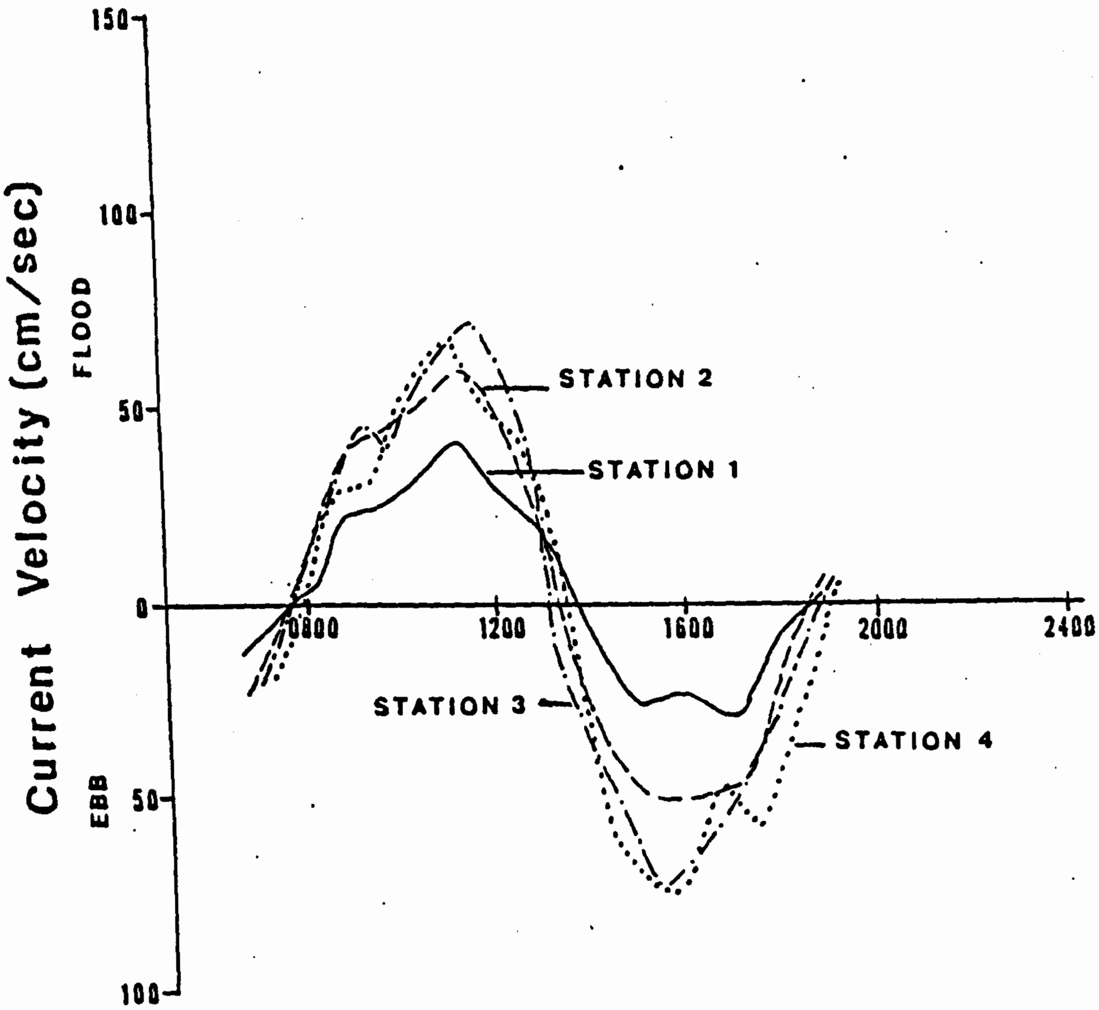
WESTPORT POINT

25 MAY 1985



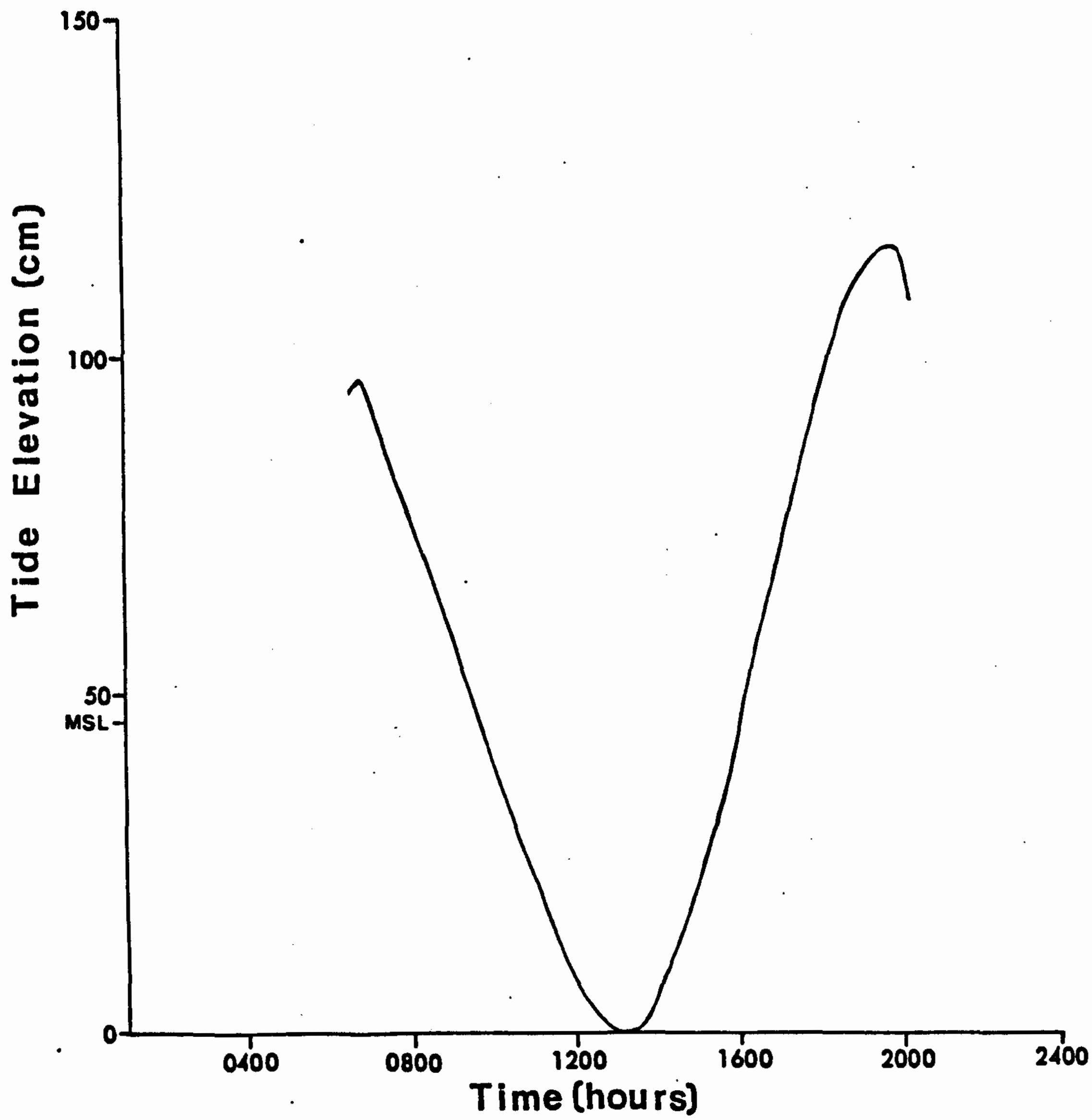
WESTPORT POINT

25 MAY 1985



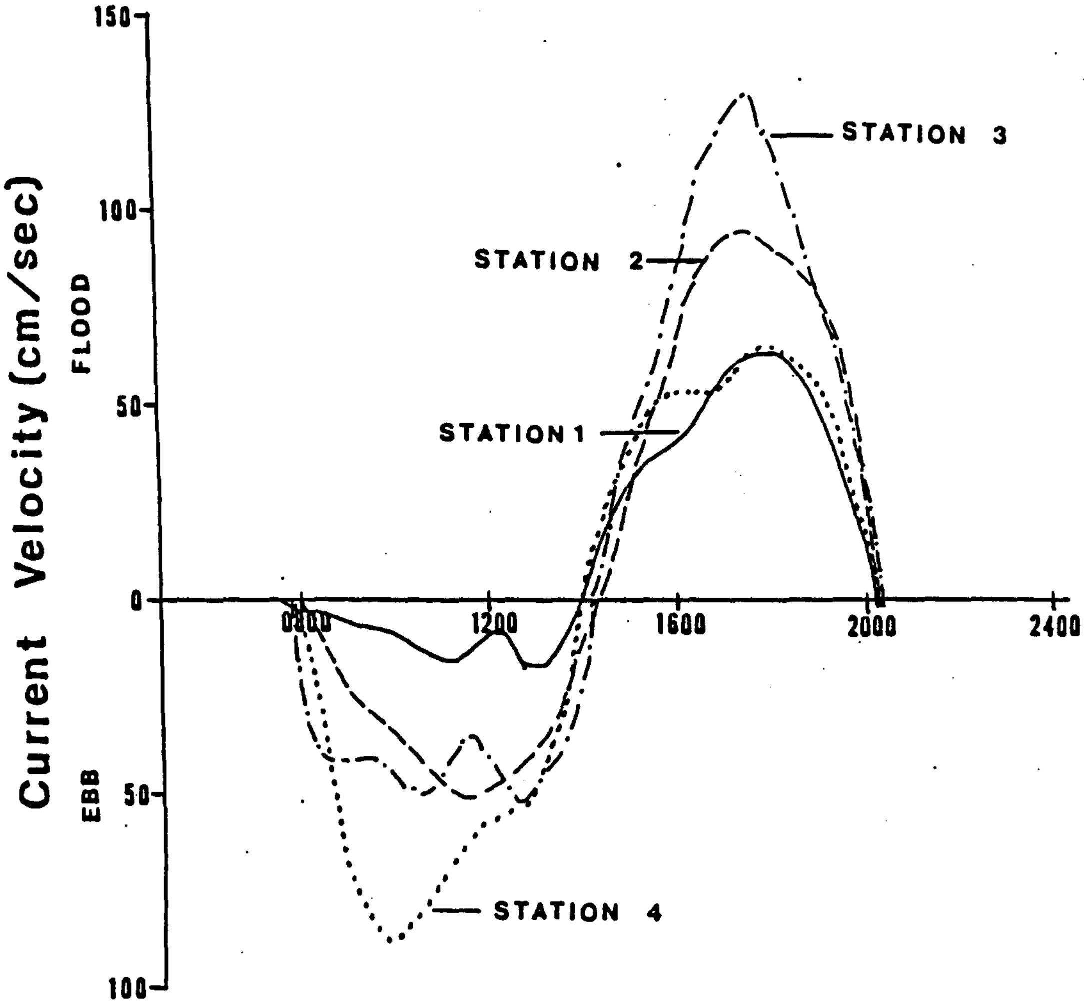
WESTPORT POINT

30 JUNE 1985



WESTPORT POINT

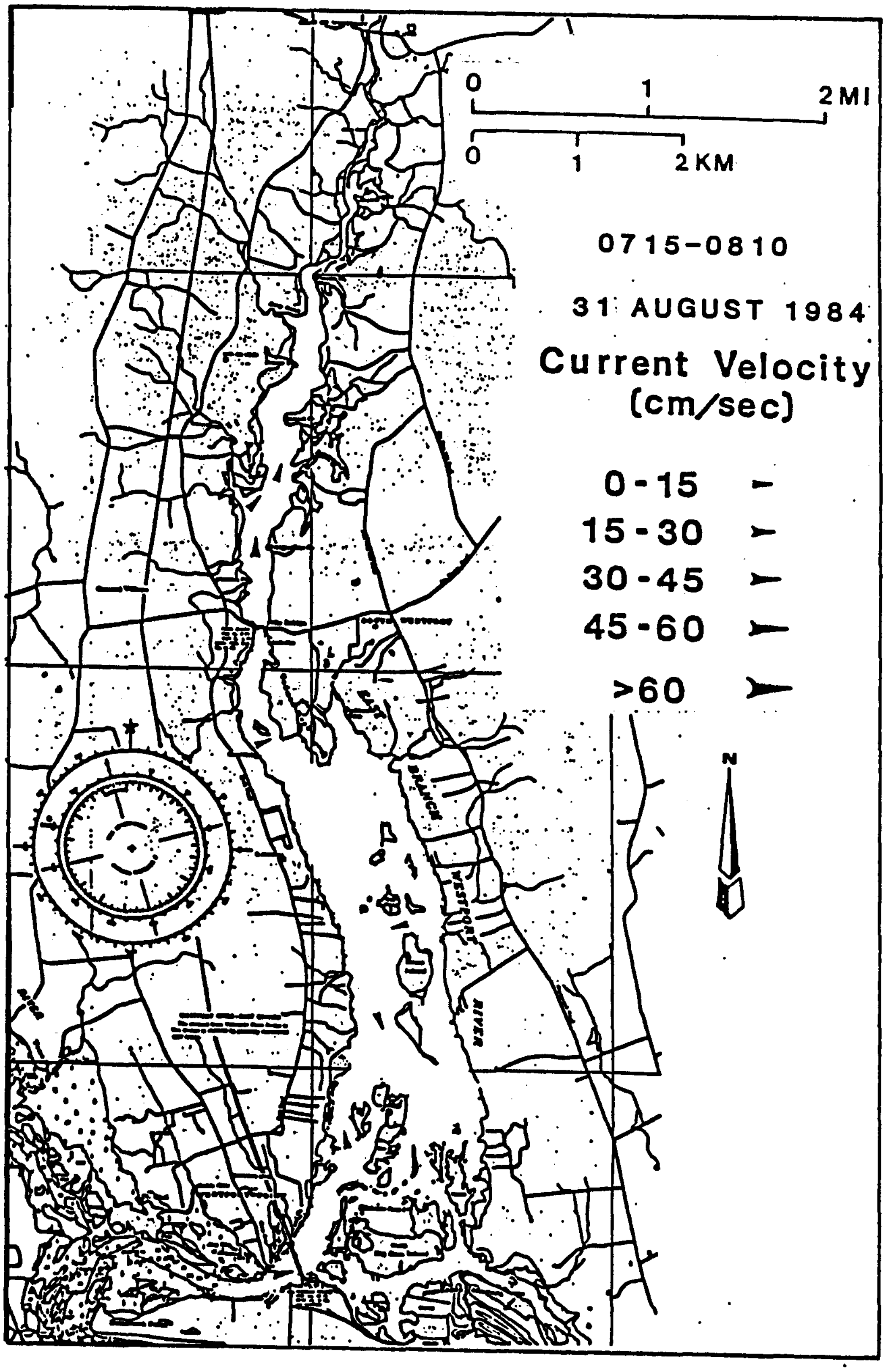
30 JUNE 1985

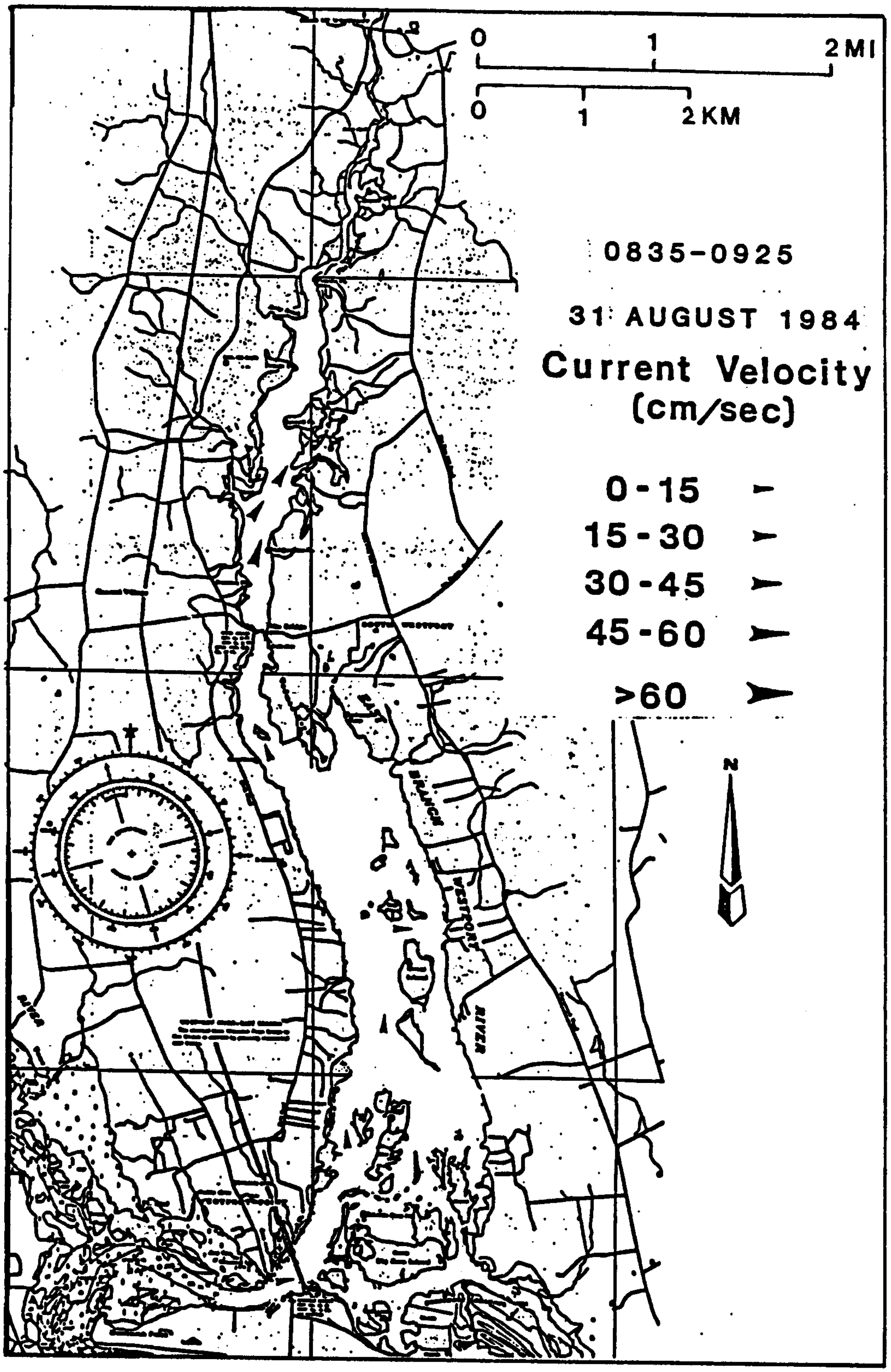


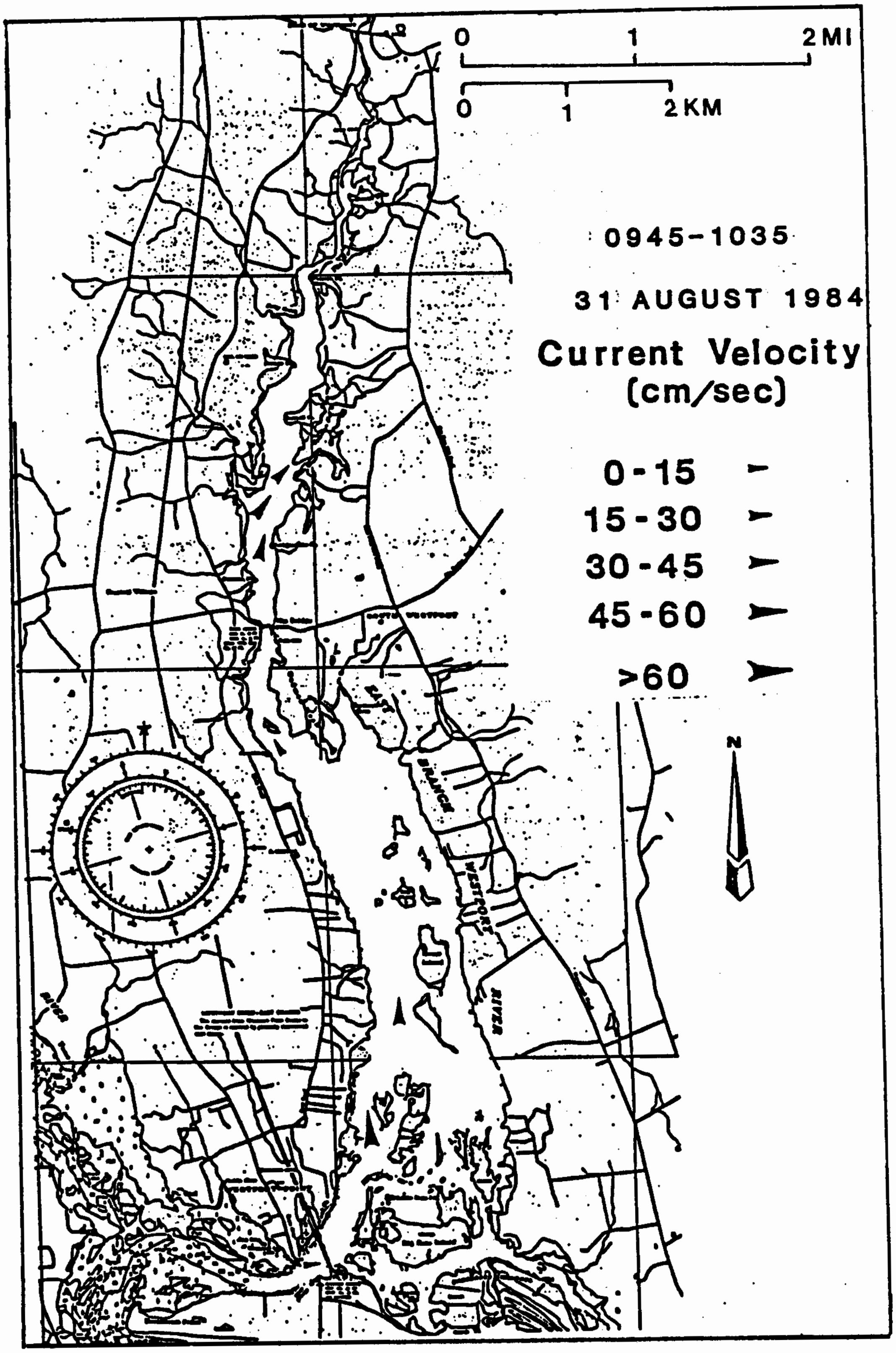
APPENDIX 4

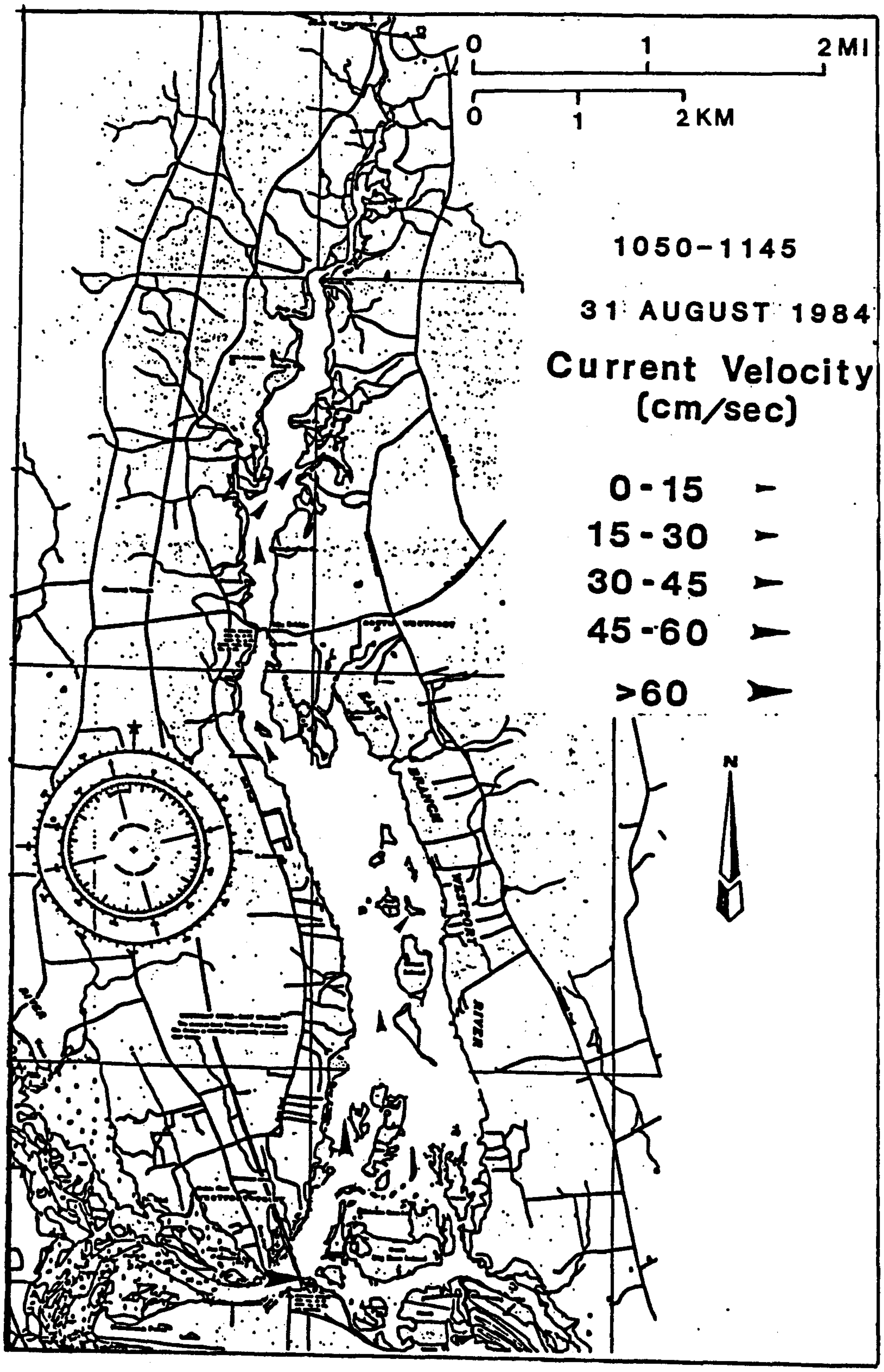
Current Magnitudes and Directions:

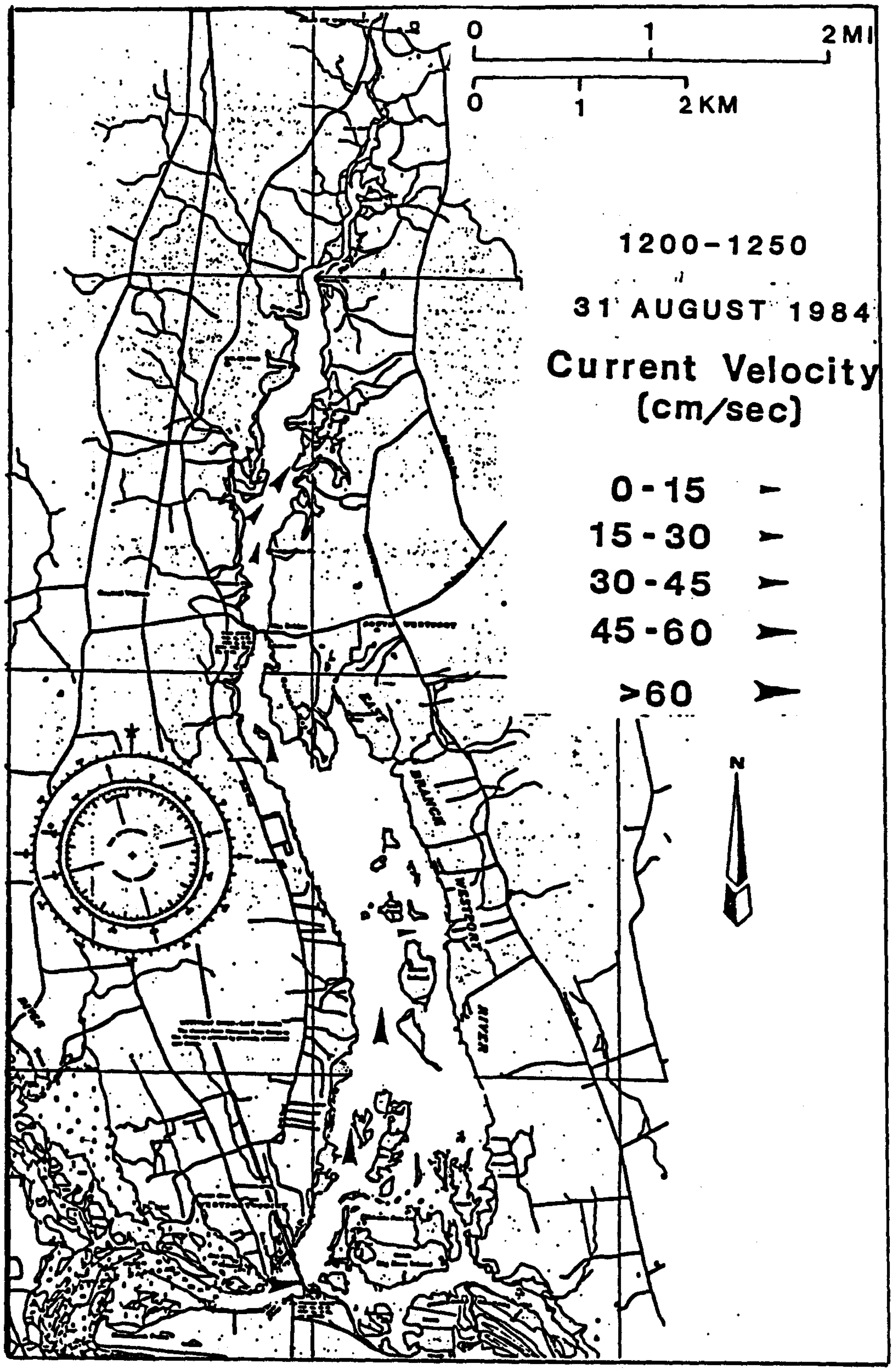
Current velocity magnitudes and directions on August 31, 1984, pictorially represented on a coastal chart of the East Branch.

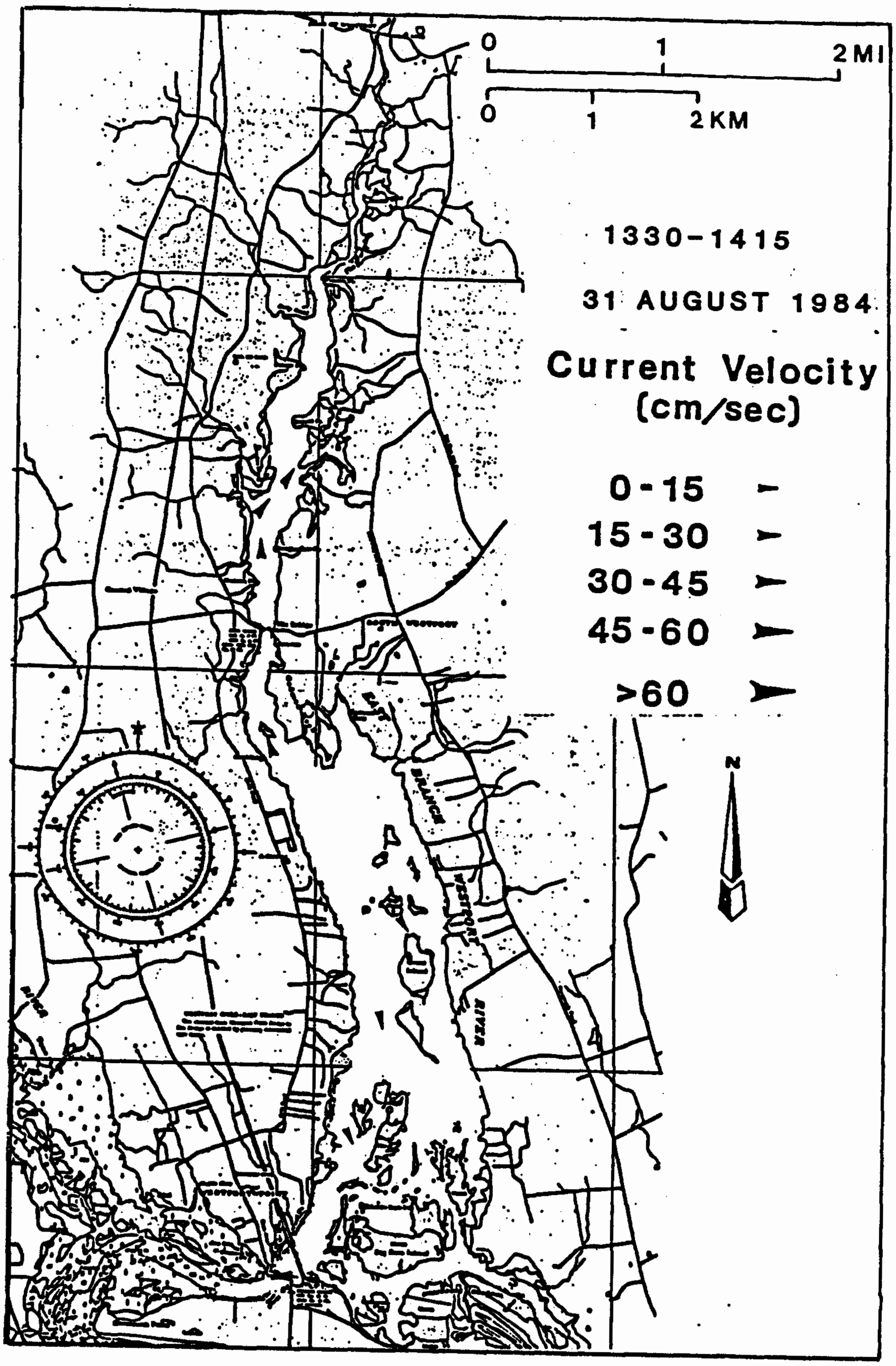

0
1
2 MI
0
1
2 KM
0715-0810
31 AUGUST 1984
Current Velocity
(cm/sec)
0-15
15-30
30-45
45-60
>60
N
WESTPORT
RIVER
BRANCH


0 1 2 MI
0 1 2 KM
0835-0925
31 AUGUST 1984
Current Velocity
(cm/sec)
0-15
15-30
30-45
45-60
>60
N

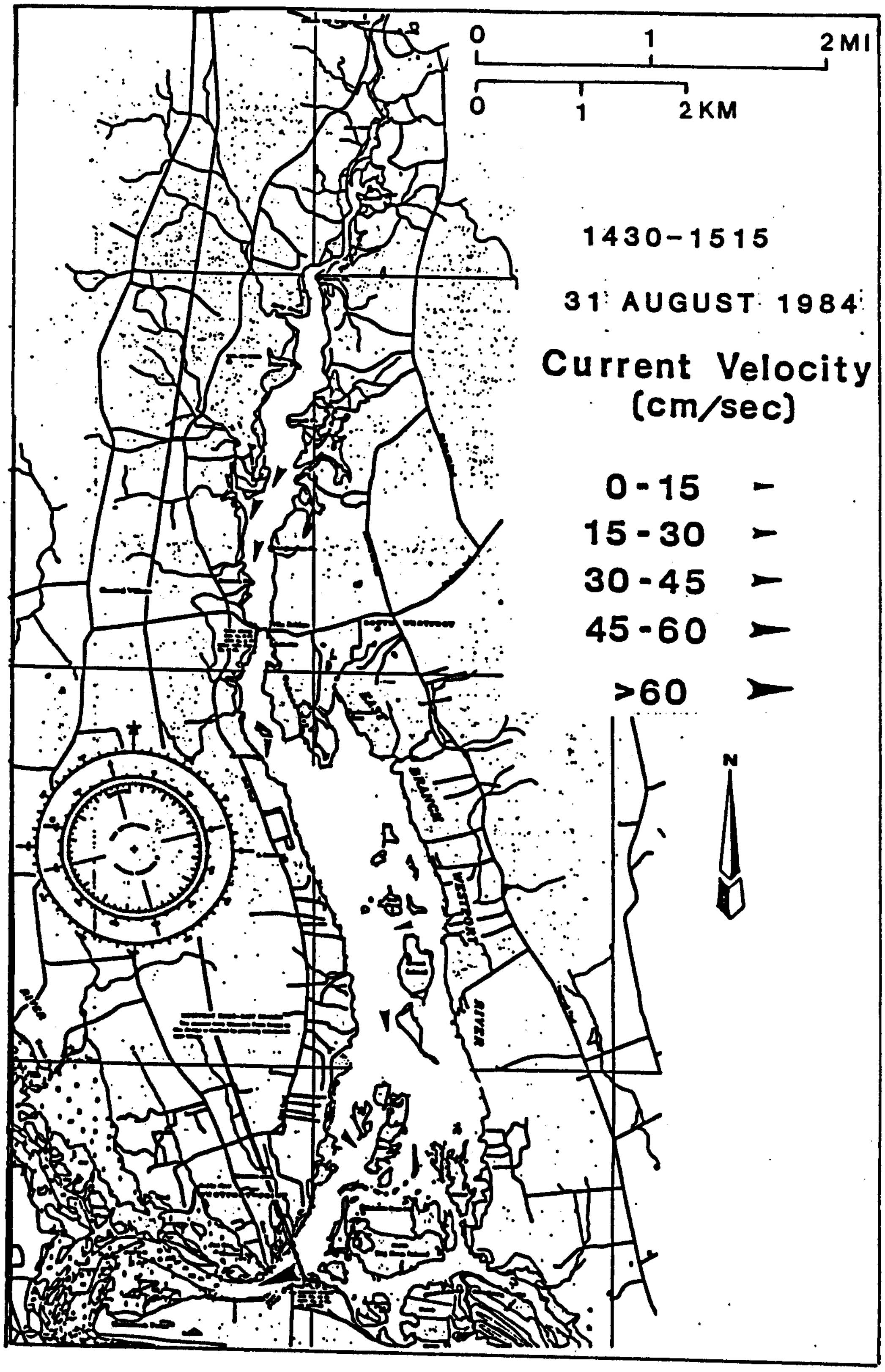

0 1 2 MI
0 1 2 KM
0945-1035
31 AUGUST 1984
Current Velocity
(cm/sec)
0-15
15-30
30-45
45-60
>60
N

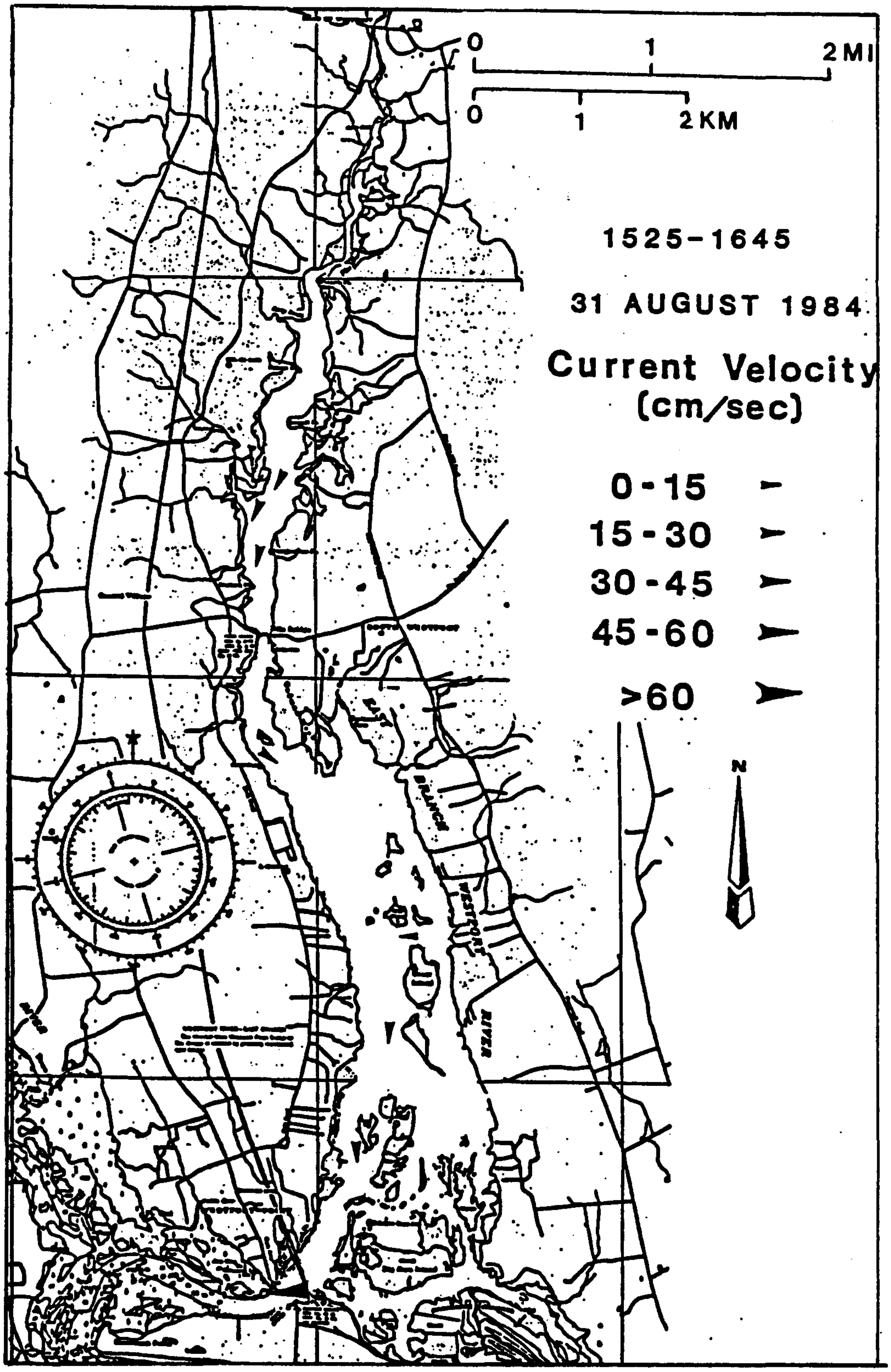

0 1 2 MI
0 1 2 KM
1050–1145
31 AUGUST 1984
Current Velocity
(cm/sec)
0 - 15
15 - 30
30 - 45
45 - 60
>60
N
BRANCH
WESTPORT
RIVER

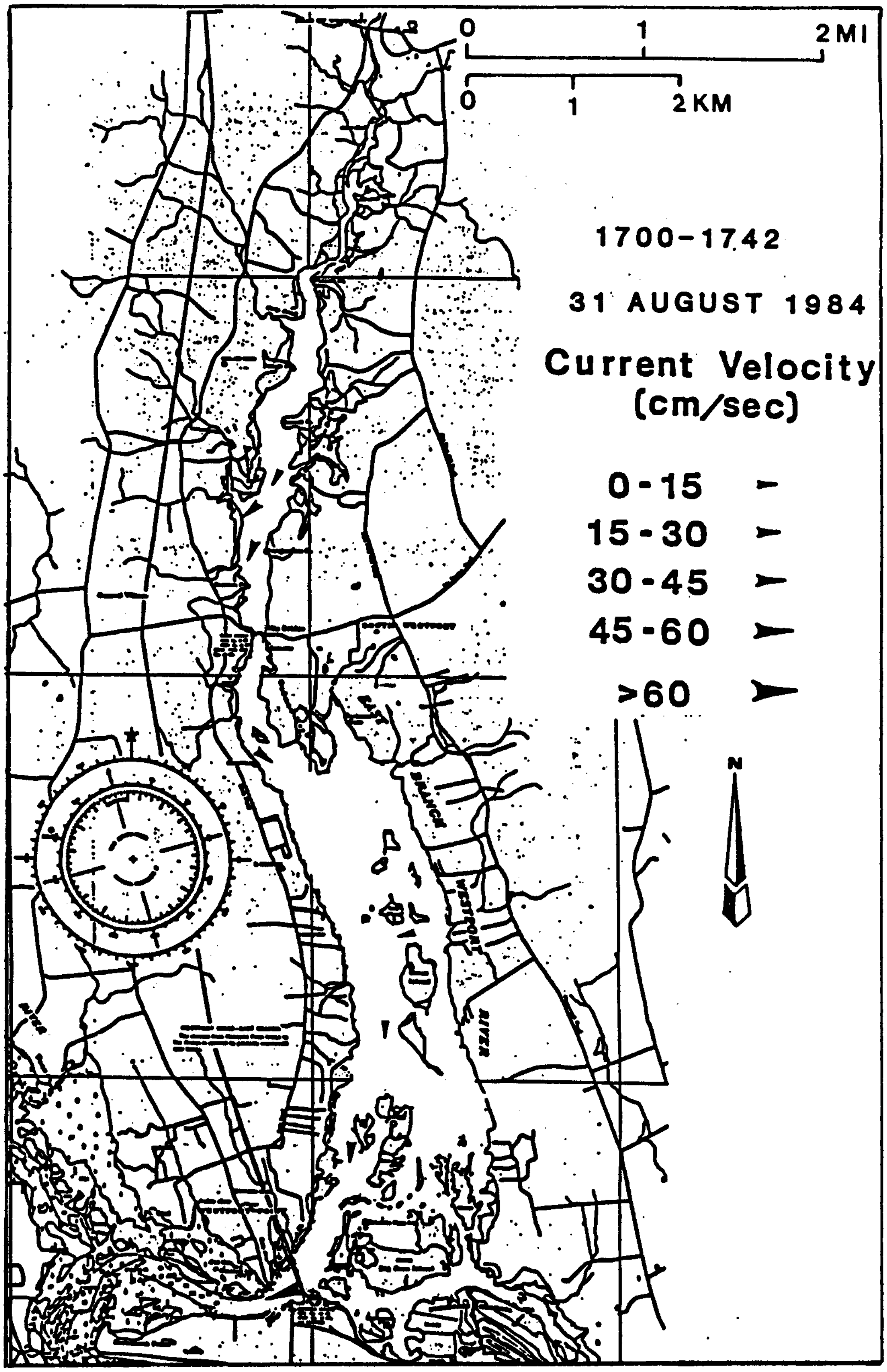

0
1
2 MI
0
1
2 KM
1200–1250
31 AUGUST 1984
Current Velocity
(cm/sec)
0-15
15-30
30-45
45-60
>60
N

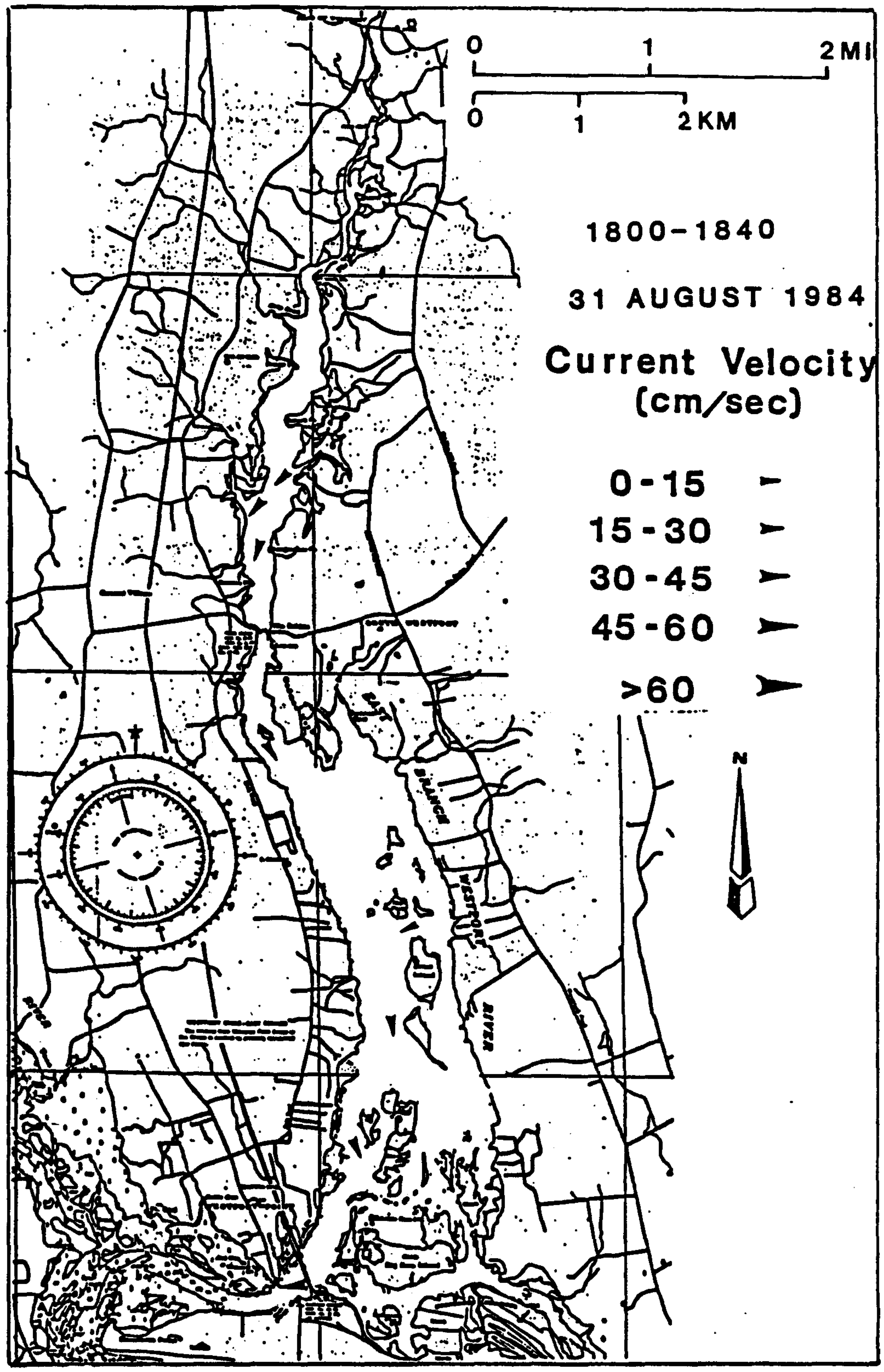


0 1 2 MI
0 1 2 KM
1330-1415
31 AUGUST 1984
Current Velocity
(cm/sec)
0-15
15-30
30-45
45-60
>60
N


0
1
2 MI
0
1
2 KM
1430-1515
31 AUGUST 1984
Current Velocity
(cm/sec)
0 - 15
15 - 30
30 - 45
45 - 60
>60
N


0
1
2 MI
0
1
2 KM
1525-1645
31 AUGUST 1984
Current Velocity
(cm/sec)
0-15
15-30
30-45
45-60
>60
N


0
1
2 MI
0
1
2 KM
1700-1742
31 AUGUST 1984
Current Velocity
(cm/sec)
0 - 15
15 - 30
30 - 45
45 - 60
>60
N


0 1 2 MI
0 1 2 KM
1800-1840
31 AUGUST 1984
Current Velocity (cm/sec)
0-15
15-30
30-45
45-60
>60
N

APPENDIX 5

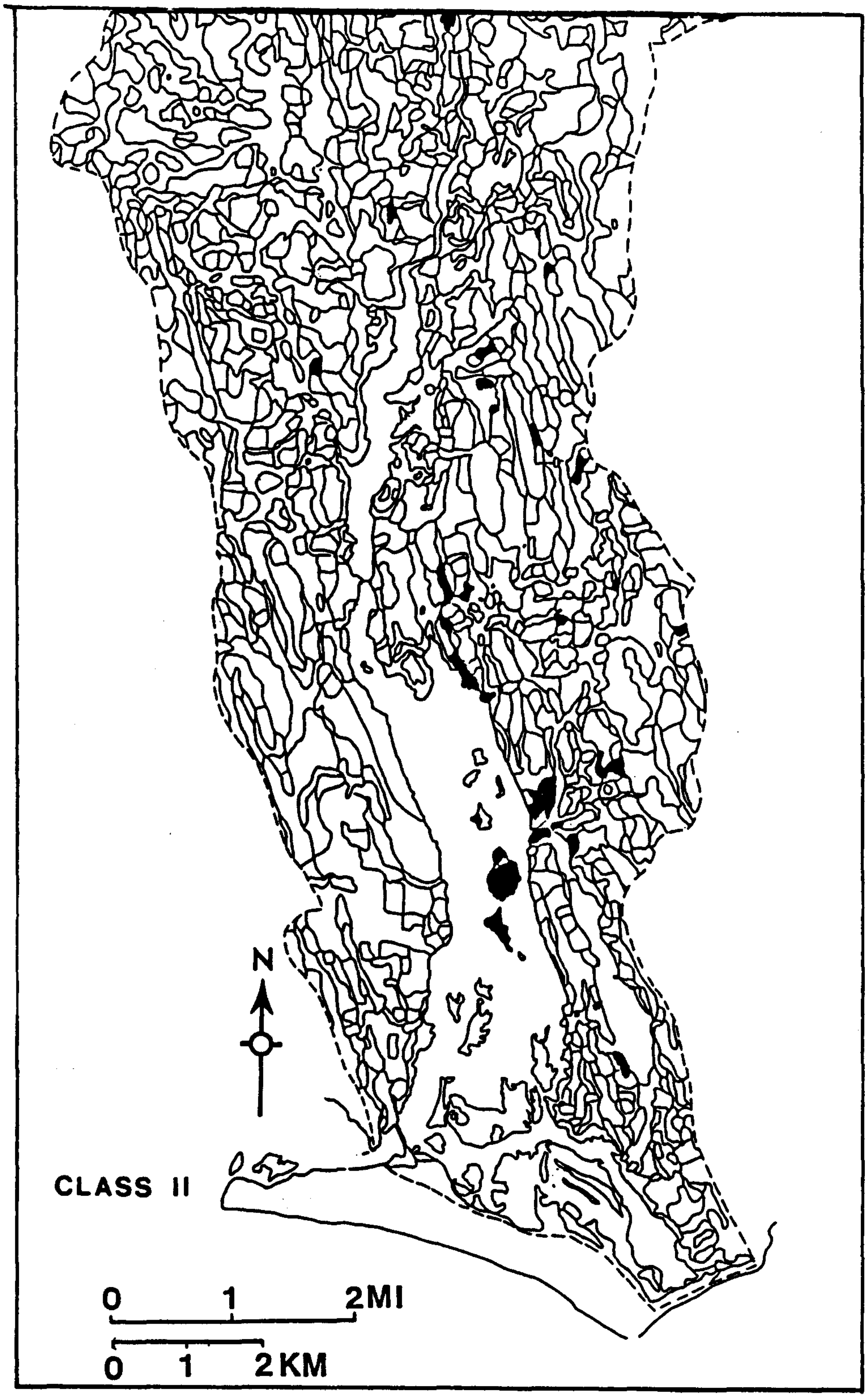
Soil Erosion Class Maps:

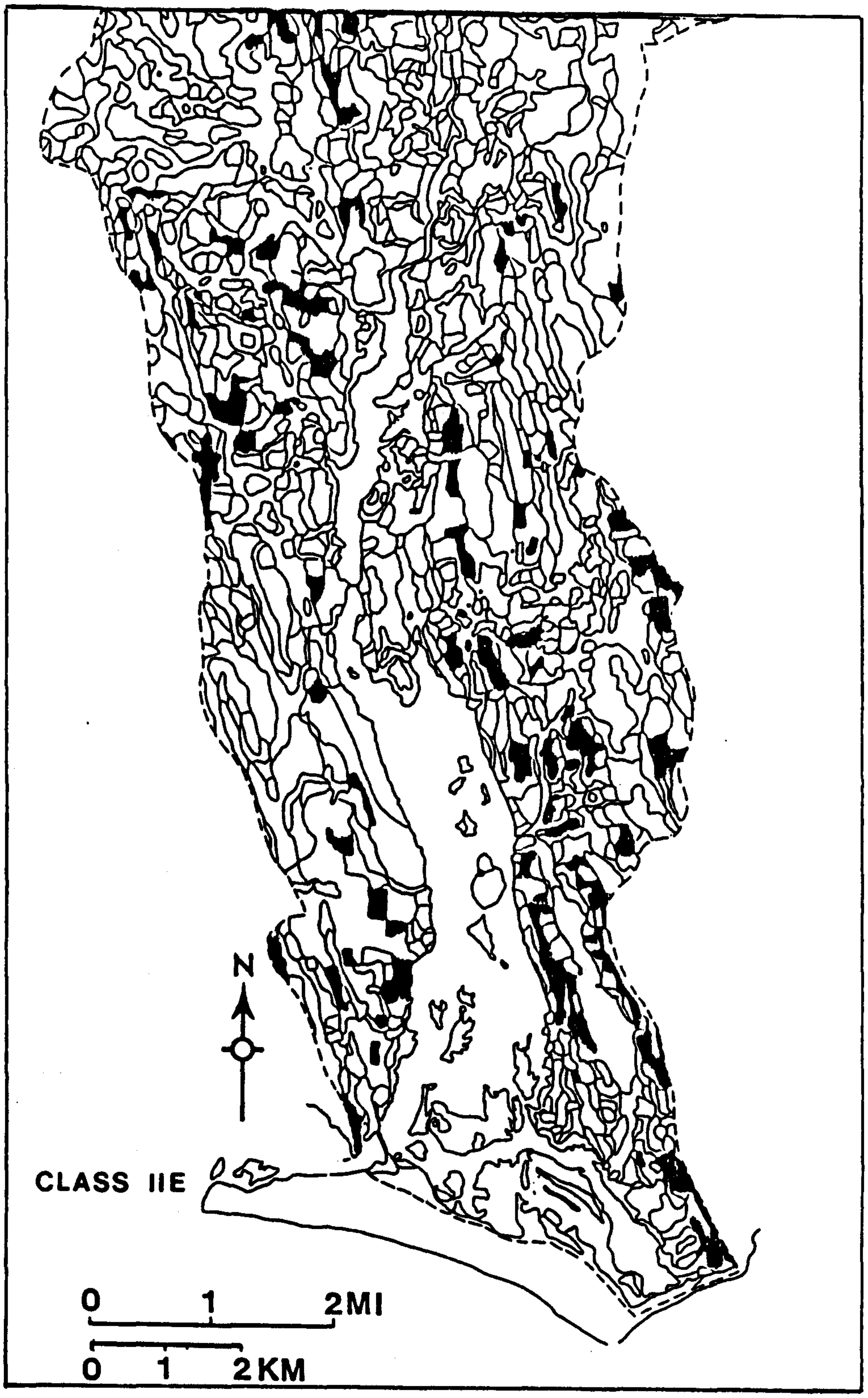
Maps of the lower part of the East Branch watershed, indicating fields classified under the Soil Conservation Service land capability classification, and the proximity to the East Branch. Shaded areas represent fields belonging to the indicated class of soils subject to erosion.

Soil capability classes.

Soil Class	Limitations
Class I	Slight limitations restricting use.
Class II	Moderate restrictions reducing plant choice or that require moderate conservation practices.
Class III	Severe limitations reducing plant choice or that require special conservation practices or both.
Class IV	Very severe limitations reducing plant choice or that require very careful management or both.
Class V	Erosion not likely but have other restrictions limiting use.
Class VI	Severe limitations; unsuitable for cultivation.
Class VII	Very severe limitations; unsuitable for cultivation.
Class VIII	Limitations that nearly preclude use of soil for commercial crop production.

Subclass e: erosion hazard.


N
CLASS II
0 1 2MI
0 1 2KM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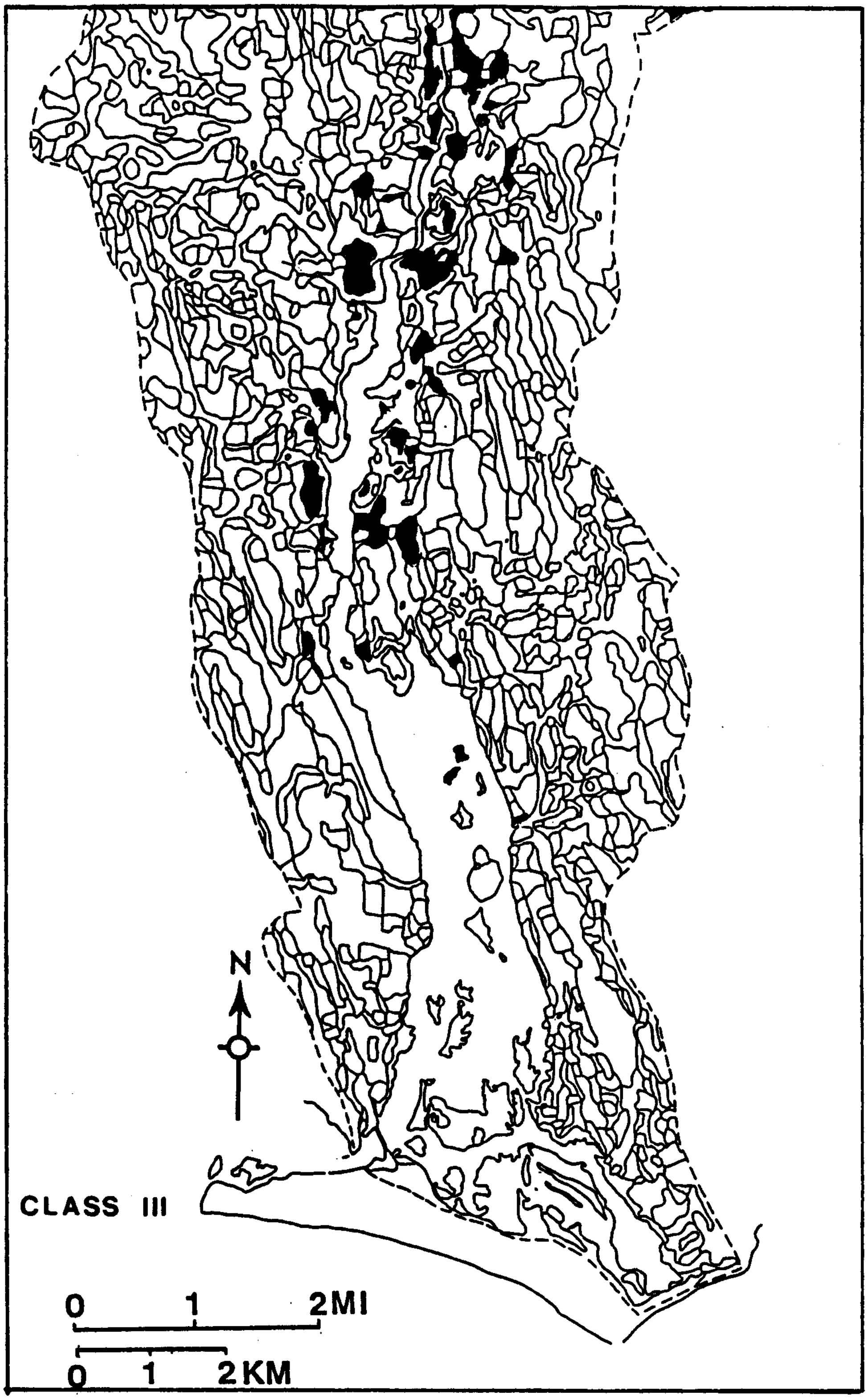
CLASS IIE
0 1 2MI
0 1 2KM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CLASS III
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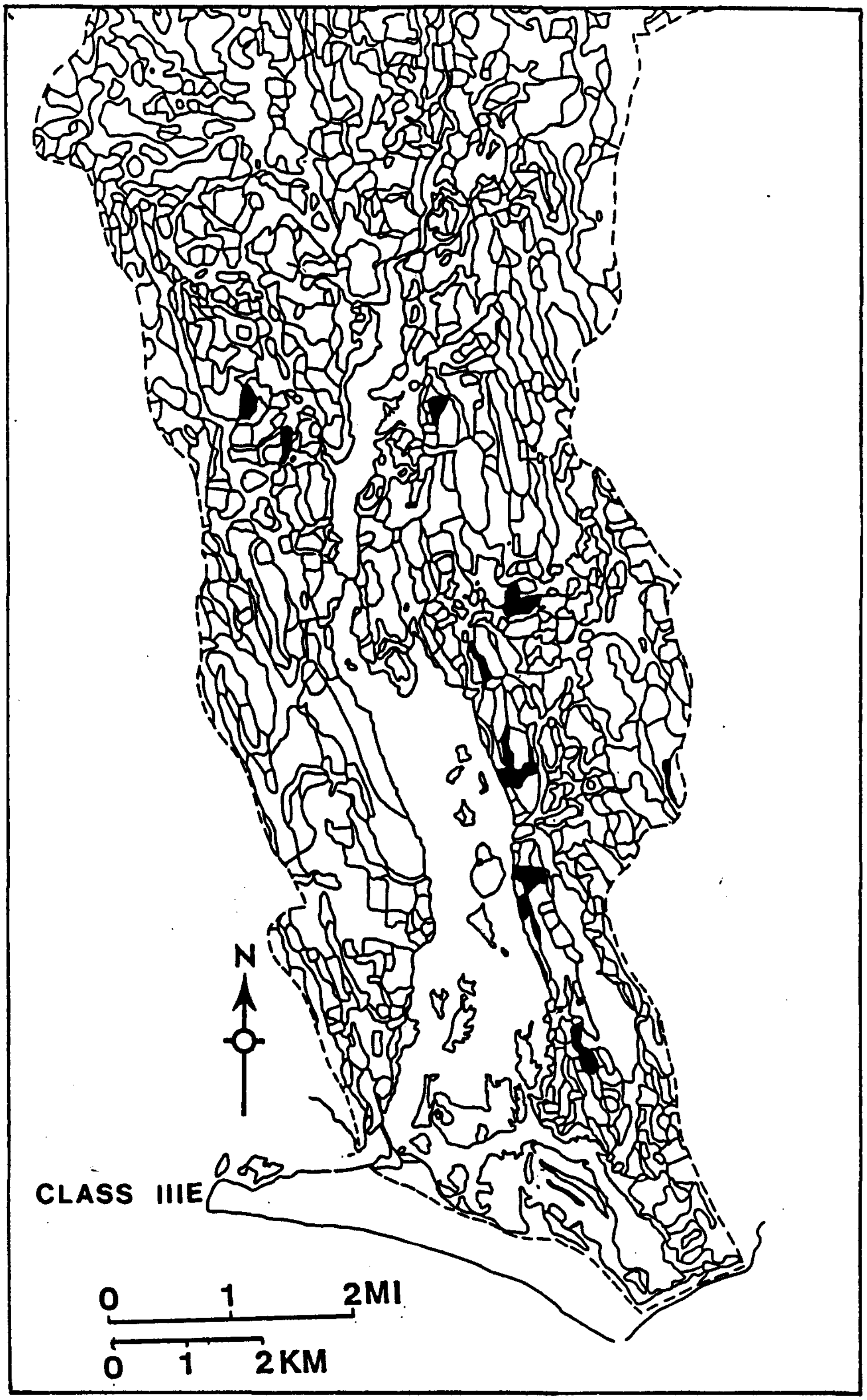
0 1 2KM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CLASS IIIE
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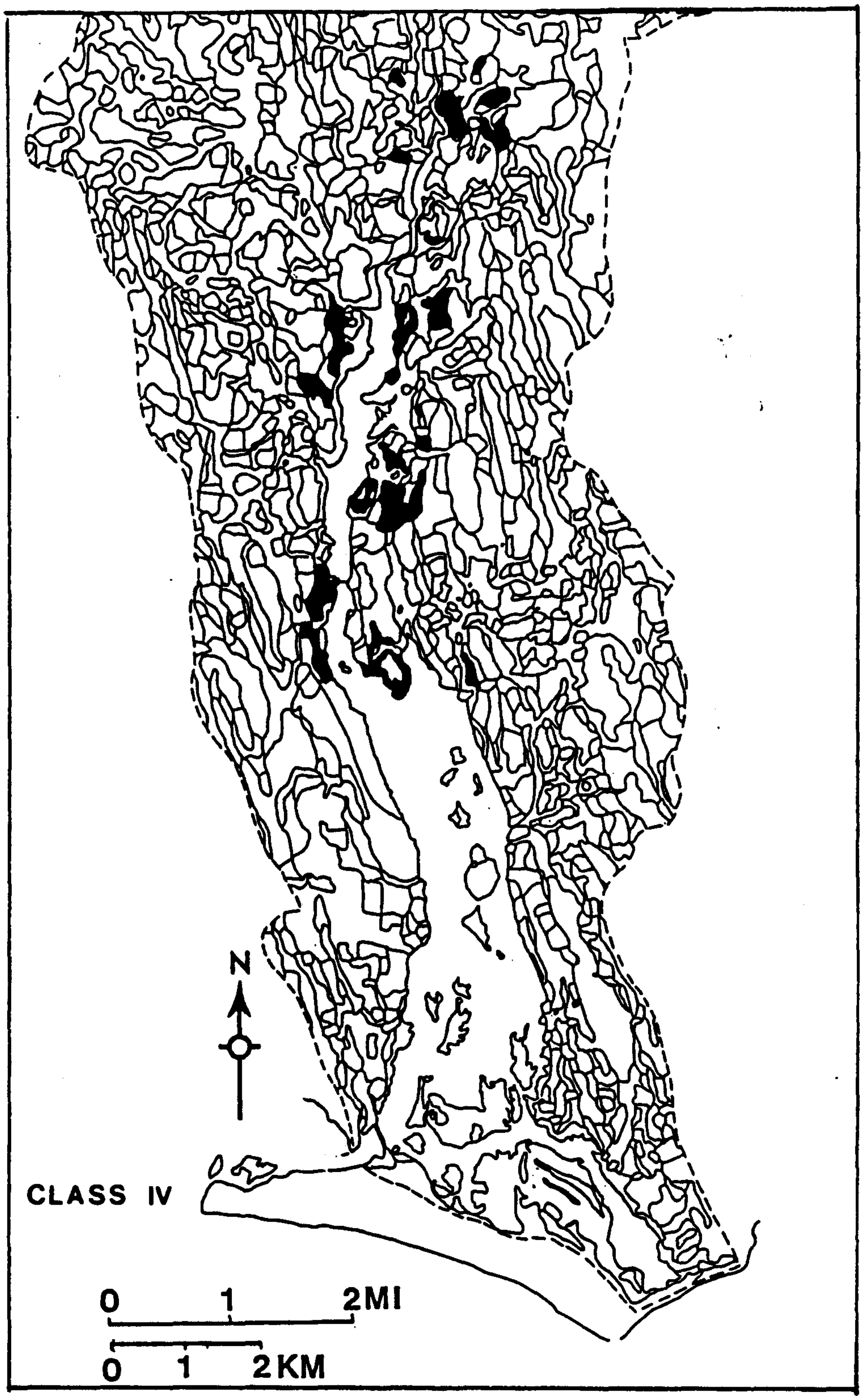
0 1 2KM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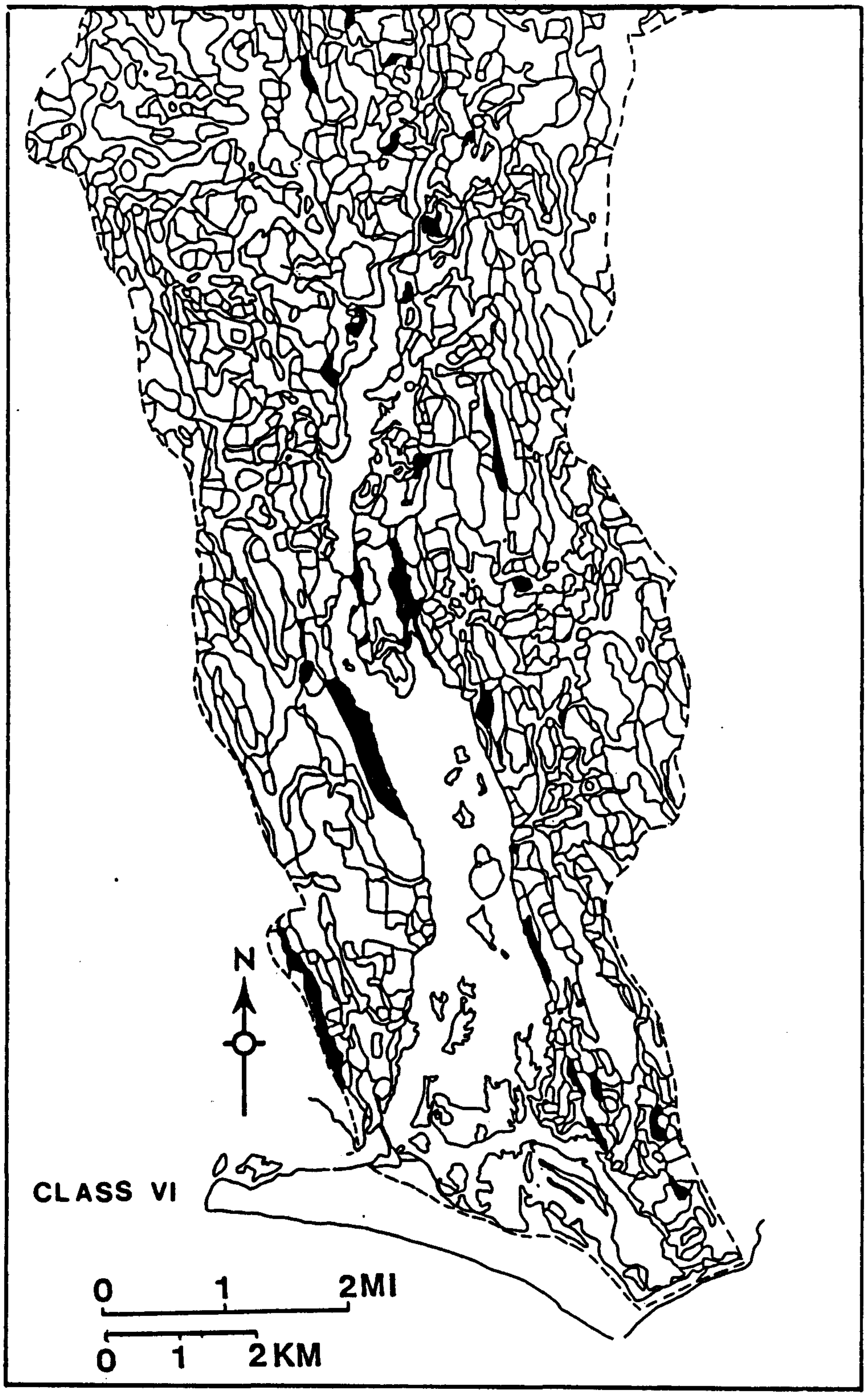
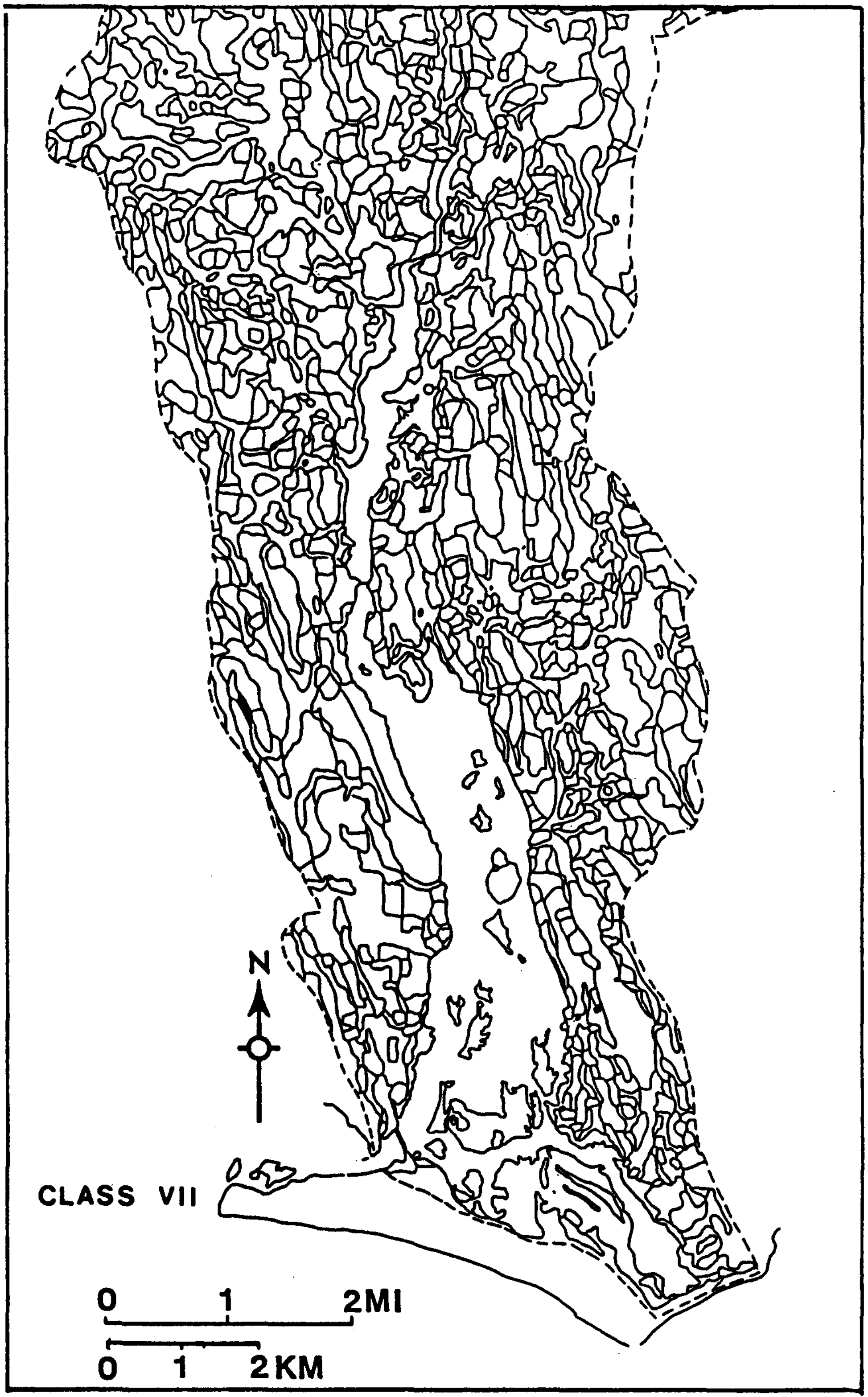
CLASS IV
0 1 2MI
0 1 2KM


N
CLASS VI
0 1 2MI
0 1 2KM


N
CLASS VII
0 1 2MI
0 1 2KM