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WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - --ETC(U)
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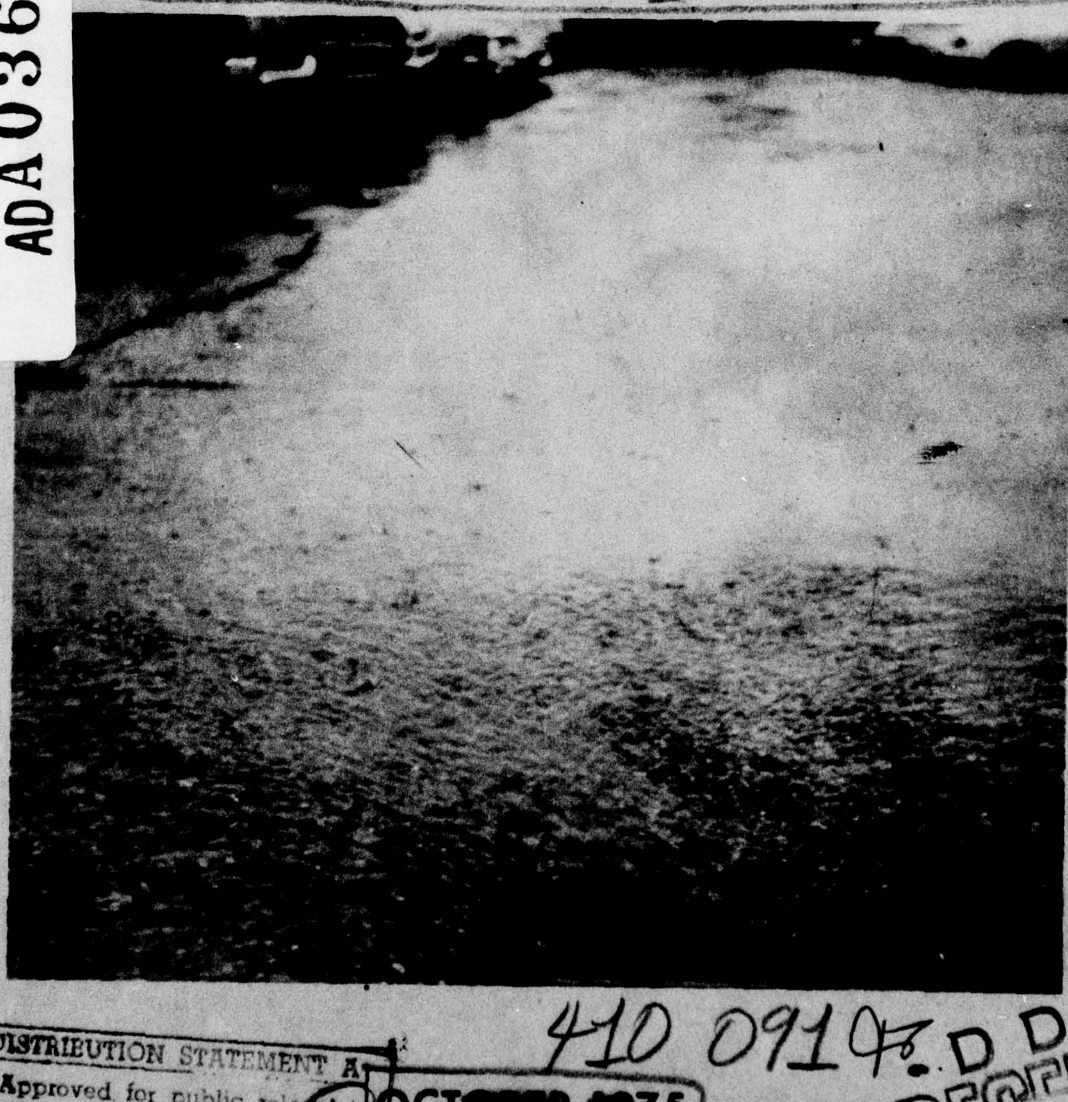
WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - EASTERN MASSACHUSETTS METROPOLITAN AREA EMMA STUDY.

TECHNICAL DATA [redacted] ume 8.
URBAN STORMWATER MANAGEMENT.



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WASTEWATER ENGINEERING
AND MANAGEMENT PLAN
FOR
Boston Harbor - Eastern Massachusetts Metropolitan Area
EMMA STUDY

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URBAN STORMWATER MANAGEMENT

FOR

EASTERN MASSACHUSETTS

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 Trapelo Road
Waltham, Mass.

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I. INTRODUCTION

Although urban stormwater runoff has been traditionally regarded as nonpolluting to receiving waters, recent studies(1,2,3) have shown that such flows may contribute a major portion of the pollution load to streams. Runoff has severe impacts on dissolved oxygen and may contribute considerably more pollution than a city's sanitary sewage during periods of moderate to heavy rain. Among the pollutants found in urban runoff are vehicle-wear particulates (like asbestos from brake linings), residues from engine emissions, drippings and assorted chemicals, including large amounts of heavy metals and pesticides. About 75% of the total weight of these materials are polychlorinated biphenyls (PCB's) a class of persistent chemicals similar in effects to DDT. In one city's runoff, Durham, N.C., it was determined that the runoff contributed 95% of the suspended solids, about 30% of the nutrients and about 80% of the heavy metals, to the receiving stream.

In addition to containing debris, clay, silt and organic matter from streets and gutters, stormwater contains soluble gases from industrial activities, particulate matter from industrial stacks, dust, and radioactive particles. Little is known about the long or short term toxic effects of urban runoff pollutants. It is apparent that receiving waters cannot be adequately protected unless either the runoff is controlled or treated. Because fine particulate matter remaining after street cleaning can contribute substantially to stream pollution, improved street cleaning methods and/or equipment should be considered.

The development of economical methods for the control and abatement of wet weather pollution ranks among the most challenging problems in the field of water pollution control today, particularly since water quality standards for receiving streams are becoming more stringent.

Purpose and Scope

The purpose of the urban stormwater management study reported herein is to prescribe cost-effective treatment measures for the river basins and drainage areas in the Eastern Massachusetts Metropolitan Area. The study considers treatment alternates of urban stormwater runoff and offers cost-effective methods for each town within the river basin or drainage area for treating its runoff. Wherever possible, the proposed methods of urban stormwater management are placed in perspective with respect to existing storm drainage facilities, future urban growth, and the receiving water body.

A basis of design for treatment facilities is provided. Facilities are designed to handle flows from urban areas in the year 2000. All treatment costs are projected to an Engineering News Record Cost Index of 2200.

II. STUDY AREA

Description

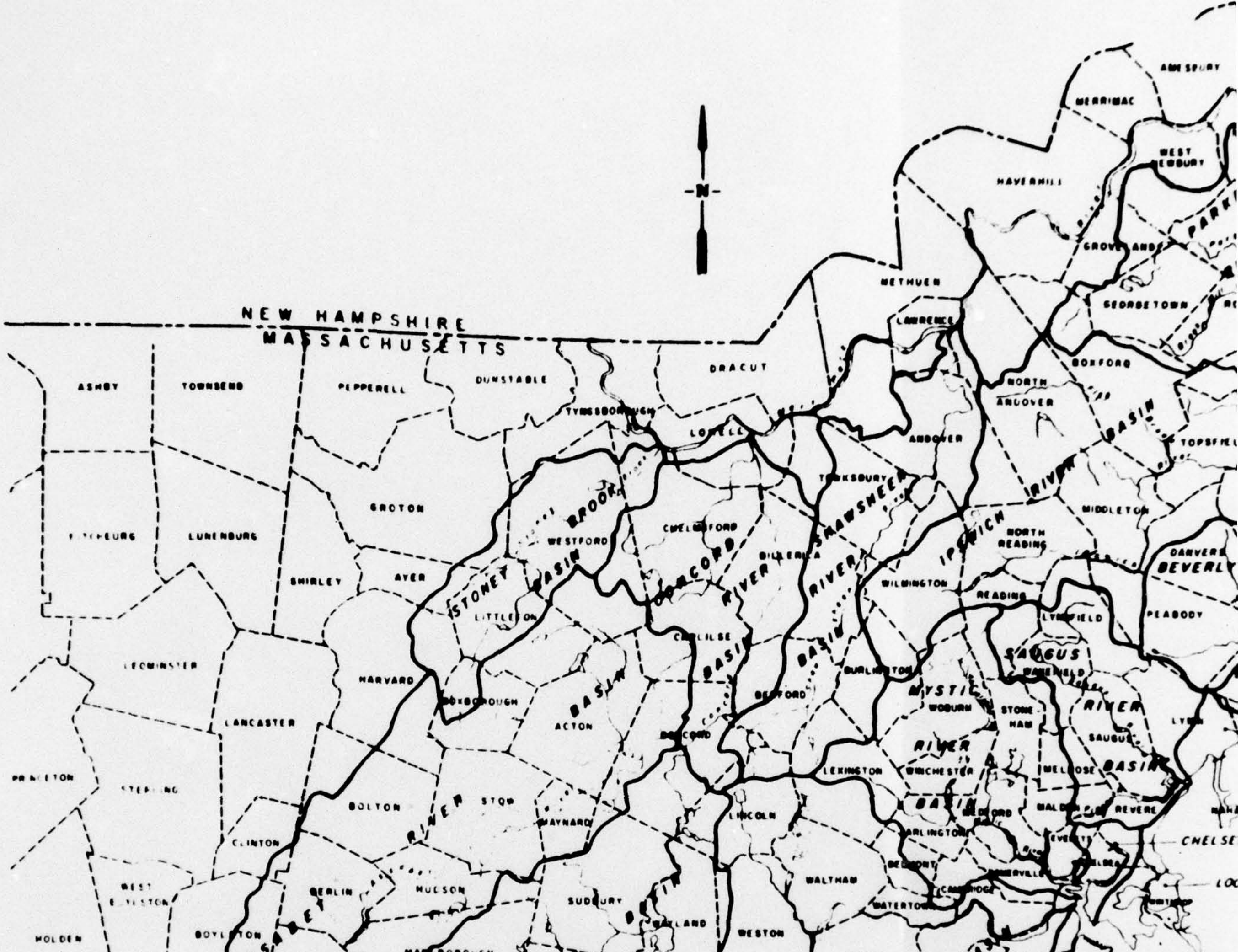
The river basins and drainage areas receiving consideration for urban stormwater management are shown in Figure 1. The overall area of all the basins and drainage areas generally includes the 109 cities and towns in the Boston Harbor-Eastern Massachusetts Metropolitan Area plus portions of 17 additional communities which border the area and drain into the watersheds encompassed by the study. A list of the study area communities is given in Table 1. The fringe towns included in the study are listed in Table 2. Table 3 lists the drainage areas with their respective communities and data regarding the community's total area and the portion of the area in the drainage area. Some communities, whose areas are given in Table 3, are not included in the study because they have combined sewers and are being studied under a separate effort.

The study area comprises about 1,600 square miles and had a 1970 population exceeding 3,100,000. While it encompasses only 20% of the total area of the State, *it is inhabited by over half the entire popularion of* the State. As a whole, the area may be considered to be urbanized although individually, the communities vary from extremely rural to suburban to highly urbanized.

There are 9 principal waterways within the study area including the Charles River, the Sudbury River, the Assabet River, the Concord River, the Ipswich River, the Mystic River, the Neponset River, the Shawsheen River, and the South Coastal Streams. Further hydrologic division reveals that there are 24 additional watersheds either wholly or partly within the area. The areal extent of these watersheds ranges from 2 to over 300 square miles, the largest being the Charles River Watershed.

Climatology

Eastern Massachusetts is a humid area with annual precipitation averaging greater than 43 inches, and has



N
NEW HAMPSHIRE
MASSACHUSETTS
RHODE ISLAND
AMESBURY
MERRIMAC
WEST NEWBURY
HAVERHILL
METHUEN
LAWRENCE
GEORGETOWN
BOXFORD
NORTH ANDOVER
ANDOVER
DRACUT
ASHBY
TOWNSEND
PEPPERELL
DUNSTABLE
TYNGSBOROUGH
LOWELL
GROTON
WESTFORD
CHELMSFORD
TEWKSBURY
FITCHBURG
LUNENBURG
SHIRLEY
AYER
BILLERICA
WILMINGTON
NORTH READING
MIDDLETON
DANVERS
BEVERLY
PEABODY
LITTLETON
READING
LYNNFIELD
LEOMINSTER
HARVARD
BOXBOROUGH
ACTON
CARLISLE
BEDFORD
BURLINGTON
WOBURN
STONEHAM
WAKEFIELD
SAUGUS
LANCASTER
CONCORD
LEXINGTON
WINCHESTER
MELROSE
PRINCETON
STERLING
BOLTON
STOW
MAYNARD
LINCOLN
MEDFORD
MALDEN
REVERE
ARLINGTON
CHELSEA
CLINTON
BERLIN
HUDSON
SUDBURY
WALTHAM
BELMONT
CAMBRIDGE
SOMERVILLE
WATERTOWN
WEST BOYLSTON
BOYLSTON
HOLDEN
WAYLAND
WESTON
NEWTON
MARLBOROUGH
NORTHBOROUGH
BROOKLINE
BOSTON
FRAMINGHAM
SOUTHBOROUGH
WELLESLEY
NATICK
NEEDHAM
WORCESTER
SHREWSBURY
WESTBOROUGH
ASHLAND
DEDHAM
MILTON
QUINCY
HOPKINTON
SHERBORN
DOVER
WESTWOOD
WEYMOUTH
GRAFTON
AUBURN
MILLBURY
HOLLISTON
MEDFIELD
NORWOOD
CANTON
BRAINTREE
RANDOLPH
UPTON
MILFORD
MEDWAY
MILLIS
WALPOLE
SHARON
STOUGHTON
AVON
HOLBROOK
ABINGTON
OXFORD
SUTTON
NORTHBRIDGE
HOPEDALE
NORFOLK
MENDON
FRANKLIN
BELLINGHAM
BROCKTON
WEBSTER
DOUGLAS
UXBRIDGE
MILLVILLE
BLACKSTONE
WRENTHAM
FOXBOROUGH
EASTON
WEST BRIDGEWATER
EAST BRIDGEWATER
PLAINVILLE
MANSFIELD
STONEY BROOK BASIN
CONCORD RIVER BASIN
SHAWSHEEN RIVER BASIN
IPSWICH RIVER BASIN
SAUGUS RIVER BASIN
MYSTIC RIVER BASIN
ASSABET RIVER
SUDBURY RIVER BASIN
CHARLES RIVER BASIN
NEPONSET RIVER BASIN
FORE RIVER BASIN
LOCAL No 5
LOCAL No 6

FIGURE 1

RIVER AND DRAINAGE BASINS
E M M A STORMWATER
MANAGEMENT STUDY

0 5 10
Scale in Miles

TABLE 1

STUDY AREA COMMUNITIES

Acton	Duxbury	Medford	Sharon
Arlington	Essex	Medway	Sherborn
Ashland	Everett	Melrose	Somerville
Avon	Framingham	Middleton	Southborough
Bedford	Franklin	Milford	Stoneham
Bellingham	Gloucester	Millis	Stoughton
Belmont	Hamilton	Milton	Stow
Berlin	Hanover	Nahant	Sudbury
Beverly	Hingham	Natick	Swampscott
Billerica	Holbrook	Needham	Tewksbury
Bolton	Holliston	Newton	Topsfield
Boston	Hopkinton	Norfolk	Wakefield
Boxborough	Hudson	Northborough	Walpole
Boxford	Hull	North Reading	Waltham
Braintree	Ipswich	Norwell	Watertown
Brookline	Lexington	Norwood	Wayland
Burlington	Lincoln	Peabody	Wellesley
Cambridge	Littleton	Pembroke	Wenham
Canton	Lynn	Quincy	Westborough
Carlisle	Lynnfield	Randolph	Westford
Chelmsford	Malden	Reading	Weston
Chelsea	Manchester	Revere	Westwood
Cohasset	Marblehead	Rockland	Weymouth
Concord	Marlborough	Rockport	Wilmington
Danvers	Marshfield	Salem	Winchester
Dedham	Maynard	Saugus	Winthrop
Dover	Medfield	Scituate	Woburn
			Wrentham

TABLE 2

FRINGE TOWNS INCLUDED IN STUDY

Abington	Harvard
Andover	Hopedale
Boylston	Lawrence
Brockton	Lowell
Clinton	Mendon
Foxborough	North Andover
Grafton	Shrewsbury
Hanson	Upton
Whitman	

TABLE 3

EASTERN MASSACHUSETTS

WATERSHED AREA DATA

BY COMMUNITIES

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
		ASSABET RIVER	
Acton	20.31	20.31	100
Berlin	13.18	13.18	100
Bolton	19.99	15.43	77.2
Boxborough	10.40	7.75	74.5
Boylston	19.77	6.48	32.8
Carlisle	15.44	4.43	28.7
Clinton	7.21	0.72	10.0
Concord	25.77	8.81	34.2
Grafton	23.32	1.42	6.1
Harvard	26.98	5.94	22.0
Hudson	11.81	9.72	82.3
Littleton	17.34	7.49	43.2
Marlborough	22.04	8.62	39.1
Maynard	5.35	5.35	100
Northborough	18.72	17.33	z2.6
Shrewsbury	21.83	8.34	38.2
Stow	17.94	17.87	99.6
Sudbury	24.50	2.08	8.5
Westborough	21.51	8.30	38.6
Westford	31.00	6.60	21.3
		176.17	

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
BEVERLY HARBOR			
Beverly	15.36	8.62	56.1
Danvers	13.84	10.14	73.3
Lynn	11.21	0.07	0.6
Lynnfield	10.49	0.26	2.5
Peabody	16.81	11.90	70.8
Salem	8.81	3.14	38.4
Wenham	8.21	0.02	0.2
		34.15	
BLACKSTONE RIVER*			
Bellingham	18.86	10.92	57.9
Franklin	27.00	2.51	9.3
Hopkinton	27.92	5.50	19.7
Milford	14.99	2.04	13.6
Westborough	21.51	0.26	1.2
Wrentham	22.68	6.85	30.2
		28.08	
CHARLES RIVER			
Arlington	5.58	0.35	6.3
Ashland	12.96	0.56	4.3
Bellingham	18.86	7.94	6.3
Belmont	4.66	1.87	40.2
+Boston	45.40	25.97	57.2

*Communities outside of study area are not included
+Not included in Study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
CHARLES RIVER (Cont.)			
+Brookline	6.82	6.82	100
+Cambridge	7.14	4.44	62.2
Dedham	10.79	7.22	66.9
Dover	15.31	13.11	85.6
+Foxborough	20.80	0.02	0.1
Franklin	27.00	24.49	90.7
Holliston	19.10	19.08	99.9
Hopedale	5.27	0.99	18.8
Hopkinton	27.92	2.85	10.2
Lexington	16.63	4.91	29.5
Lincoln	14.92	9.51	61.3
Medfield	14.52	11.35	78.2
Medway	11.66	11.66	100
Mendon	17.94	0.29	1.6
Milford	14.99	12.95	86.4
Millis	12.26	12.26	100
Natick	15.99	8.35	52.2
Needham	12.75	12.75	100
Newton	18.33	18.33	100
Norfolk	15.35	15.32	99.8
Sherborn	17.12	13.99	81.7
Somerville	4.12	1.40	34.0
Walpole	21.09	2.07	9.8
Waltham	13.52	13.52	100
Watertown	4.17	3.60	86.3

+Not included in Study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
CHARLES RIVER (Cont.)			
Wayland	15.88	0.43	2.7
Wellesley	10.51	10.51	100
Weston	17.36	15.80	91.0
Westwood	11.24	3.86	34.3
Wrentham	22.68	9.82	43.3
		308.03	
CHELSEA RIVER			
+Boston	45.40	0.68	1.5
+Chelsea	2.17	1.17	53.9
Everett	3.75	0.48	12.7
Revere	6.32	0.87	13.7
		3.20	
CONCORD RIVER			
Bedford	13.85	4.76	34.4
Billerica	25.96	15.16	58.4
Carlisle	15.44	11.01	71.3
Chelmsford	22.96	17.93	78.1
Concord	25.77	8.07	31.3
Lincoln	14.92	0.51	3.4
Lowell	14.27	3.81	26.7
Tewksbury	20.91	1.57	7.5
Westford	31.00	3.53	11.4
		66.35	

+Not included in Study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
ESSEX BAY			
Beverly	15.36	0.15	1.0
Essex	14.38	13.19	91.7
Gloucester	26.45	4.97	18.8
Hamilton	14.99	2.50	16.7
Ipswich	33.35	3.20	9.6
+Manchester	7.72	1.15	14.9
Wenham	8.21	0.53	6.5
		25.69	
GLOUCESTER HARBOR-ANNISQUAM RIVER			
Gloucester	26.45	13.65	51.6
Rockport	7.08	0.57	8.1
		14.22	
IPSWICH RIVER			
Andover	31.99	5.12	16.0
Beverly	15.36	3.50	22.8
Billerica	25.96	0.60	2.3
Boxford	24.39	14.85	60.9
Burlington	11.88	3.63	30.6

+Not included in Study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
	IPSWICH RIVER (Cont.)		
Danvers	13.84	3.70	26.7
Hamilton	14.99	12.49	83.3
Ipswich	33.35	17.54	52.6
Lynnfield	10.49	2.84	27.1
Middleton	14.46	14.46	100
North Andover	27.83	16.84	60.5
North Reading	13.53	13.53	100
Peabody	16.81	4.61	27.4
Reading	9.85	4.95	50.2
Tewksbury	20.91	0.34	1.6
Topsfield	12.86	12.86	100
Wenham	8.21	7.46	90.9
Wilmington	17.12	14.84	86.7
+Woburn	13.11	0.10	0.8
	LOCAL NO. 1 CAPE ANN		
Gloucester	26.45	4.47	16.9
Rockport	7.08	6.51	91.9
		10.98	

+Not included in Study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
LOCAL NO. 2 MANCHESTER HARBOR AREA			
Beverly	15.36	3.09	20.1
+Essex	14.38	1.19	8.3
Gloucester	26.45	3.36	12.7
Manchester	7.72	6.57	85.1
Wenham	8.21	0.20	2.4
		14.41	
LOCAL NO. 3 MARBLEHEAD HARBOR-LYNN HARBOR AREA			
Lynn	11.21	3.61	32.2
Marblehead	4.42	2.94	66.5
Nahant	1.06	1.06	100
+Salem	8.18	0.23	2.8
Swampscott	3.10	2.67	86.1
		10.51	
LOCAL NO. 4 BOSTON HARBOR			
+Boston	45.40	3.90	8.6
Revere	6.32	1.18	18.7
Winthrop	1.63	1.63	100
		6.71	

+Not included in Study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
LOCAL NO. 5 BOSTON LOCAL			
+Boston	45.50	1.86	4.1
		1.86	
LOCAL NO. 6 QUINCY BAY			
Milton	13.20	0.66	5.0
Quincy	16.64	4.94	29.7
		5.60	
LOCAL NO. 7 HINGHAM HARBOR-HULL BAY			
Cohasset	10.06	2.64	26.2
Hingham	22.59	16.99	75.2
Hull	2.53	2.53	100
Norwell	21.33	1.19	5.6
Rockland	10.11	0.18	1.8
Weymouth	17.72	0.89	5.0
		24.42	
LOCAL NO. 8 COHASSET HARBOR-SCITUATE HARBOR			
Cohasset	10.06	7.42	73.8
+Hingham	22.59	1.22	5.4
Norwell	21.33	2.50	11.7
Scituate	17.07	9.66	56.6
		20.80	

+Not included in study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
LOCAL NO. 9 GREEN HARBOR-DUXBURY BAY			
Duxbury	24.51	15.71	64.1
Marshfield	28.52	6.70	23.5
Pembroke	23.25	4.95	21.3
		27.36	
MERRIMACK RIVER*			
Boxford	24.39	3.51	14.4
Chelmsford	22.96	1.70	7.4
Tewksbury	20.91	4.91	23.5
Westford	31.00	1.92	6.2
		12.04	
MYSTIC RIVER			
Arlington	5.58	5.23	93.7
Belmont	4.66	2.79	59.8
+Boston	45.40	0.59	1.3
Burlington	11.88	2.00	16.8
+Cambridge	7.14	2.70	37.8

+Not included in Study
*Communities outside of study area not included

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
MYSTIC RIVER (Cont.)			
+Chelsea	2.17	1.00	46.1
Everett	3.75	2.60	69.3
Lexington	16.63	4.99	30.0
Malden	5.13	2.80	54.6
Medford	8.76	8.76	100
Melrose	4.80	2.51	52.3
Reading	9.85	2.40	24.4
Somerville	4.12	2.72	66.0
Stoneham	6.66	6.65	99.9
Wakefield	7.89	1.82	23.1
Watertown	4.17	0.57	13.7
Wilmington	17.12	0.29	1.7
Winchester	6.28	6.28	100
Woburn	13.11	12.52	95.5
		69.22	
NEPONSET RIVER			
+Boston	45.40	12.39	27.3
Canton	19.38	18.88	97.4
Dedham	10.79	3.57	33.1
Dover	15.31	2.20	14.4
Foxborough	20.80	4.37	21.0

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
NEPONSET RIVER (Cont.)			
Medfield	14.52	3.17	21.8
Milton	13.20	11.34	85.9
Norwood	10.59	10.59	100
Quincy	16.64	2.50	15.0
Randolph	10.32	1.40	13.6
Sharon	24.31	16.09	66.2
Stoughton	16.39	7.90	48.2
Walpole	21.09	18.98	90.0
Westwood	11.24	7.38	65.7
		120.76	
NORTH RIVER			
Abington	10.14	1.54	15.2
Duxbury	24.51	1.20	4.9
Hanover	15.63	15.63	100
Hanson	15.82	6.55	41.4
+Hingham	22.59	0.16	0.7
Marshfield	28.52	8.61	30.2
Norwell	21.33	17.64	82.7
Pembroke	23.26	16.91	72.7
Rockland	10.11	8.68	85.8
Scituate	17.07	6.71	39.3
Weymouth	17.72	0.37	2.1
+Whitman	6.99	0.05	1.9
		84.05	

+Not included in study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
PARKER RIVER*			
Boxford	24.39	6.03	24.7
Ipswich	33.35	1.30	3.9
		7.33	
ROWLEY RIVER*			
Ipswich	33.35	11.31	33.9
		11.31	
SALEM HARBOR			
Lynn	11.21	0.10	0.9
Marblehead	4.42	1.48	33.5
Salem	8.18	4.81	58.8
Swampscott	3.10	0.43	13.9
		6.82	
SAUGUS RIVER			
Everett	3.75	0.67	18.0
Lynn	11.21	7.43	66.3
Lynnfield	10.49	7.39	70.4
Malden	5.13	2.33	45.4

*Communities outside of study area not included

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
	SAUGUS RIVER (Cont.)		
Melrose	4.80	2.29	47.7
+Peabody	16.81	0.30	1.8
Reading	9.85	2.50	25.4
Revere	6.32	4.27	67.6
Saugus	11.58	11.58	100
+Stoneham	6.66	0.01	0.1
Wakefield	7.89	6.07	76.9
		44.84	
	SHAWSHEEN RIVER		
+Andover	31.99	17.11	53.5
Bedford	13.85	9.09	65.6
Billerica	25.96	10.20	39.3
Burlington	11.88	6.25	52.6
Concord	25.77	1.34	5.2
Lawrence	7.24	0.87	12.0
Lexington	16.63	6.73	40.5
Lincoln	14.92	1.77	11.9
North Andover	27.83	1.73	6.2
Tewksbury	20.91	14.09	67.4
Wilmington	17.12	1.99	11.6
Woburn	13.11	0.49	3.7
		71.66	

+Not included in study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
SOUTH RIVER			
Duxbury	24.41	7.60	31.0
Marshfield	28.52	13.21	46.3
+Pembroke	23.26	0.10	0.4
Scituate	17.07	0.70	4.1
		21.61	
STONY BROOK*			
Boxborough	10.40	2.65	25.5
Chelmsford	22.96	3.33	14.5
Harvard	26.98	4.21	15.6
Littleton	17.34	9.85	56.8
Westford	31.00	18.57	59.9
		38.61	
SUDBURY RIVER			
Ashland	12.96	12.40	95.7
Concord	25.77	7.55	29.3
Framingham	25.54	25.54	100
+Holliston	19.10	0.02	0.1
Hopkinton	27.92	19.57	70.1

*Communities outside of study area not included
+Not included in study

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
	SUDBURY RIVER (Cont.)		
Hudson	11.81	2.09	17.7
Lincoln	14.92	3.49	23.4
Marlborough	22.04	13.42	60.9
Natick	15.99	7.64	47.8
Northborough	18.72	1.39	7.4
Sherborn	17.12	3.13	18.3
Southborough	15.42	15.42	100
+Stow	17.94	0.07	0.4
Sudbury	24.50	22.42	91.5
+Upton	21.81	0.68	3.1
Wayland	15.88	15.45	97.3
Westborough	21.51	12.95	60.2
Weston	17.36	1.56	9.0
		164.79	
	TAUNTON RIVER*		
Avon	4.50	3.50	77.8
Holbrook	7.32	1.68	23.0
+Norfolk	15.35	0.03	0.2
Pembroke	23.26	1.30	5.6
Rockland	10.11	0.07	0.7
Sharon	24.31	8.22	33.8
Stoughton	16.39	7.59	46.3
+Walpole	21.09	0.04	0.2
+Weymouth	17.72	0.12	0.7
Wrentham	22.68	5.51	24.3
		28.06	

+Not included in study
*Communities outside of study area not included

TABLE 3 (Cont.)

Town	Total Area (sq. mi.)	Area in Basin (sq. mi.)	% Area in Basin
WEYMOUTH BACK RIVER			
Abington	10.14	0.15	1.5
Braintree	14.41	0.71	4.9
Hingham	22.59	4.22	18.7
Holbrook	7.32	0.90	12.3
Rockland	10.11	1.18	11.7
Weymouth	17.72	12.81	72.3
		19.97	
WEYMOUTH FORE RIVER			
+Abington	10.14	0.14	1.4
Avon	4.50	1.00	22.2
Braintree	14.41	13.70	95.1
Brockton	21.48	0.32	1.5
Canton	19.38	0.50	2.6
Holbrook	7.32	4.74	64.7
Milton	13.20	1.20	9.1
Quincy	16.64	9.20	55.3
Randolph	10.32	8.92	86.4
Stoughton	16.39	0.90	5.5
Weymouth	17.72	3.53	19.9
		44.15	

+Not included in study

a variable climate that is characterized by frequent but generally short periods of heavy precipitation. The area lies in the path of the prevailing westerlies and is exposed to cyclonic disturbances that cross the country from the west or southwest. The area is also subject to coastal storms that travel up the Atlantic seaboard in the form of hurricanes of tropical origin as well as storms of extratropical nature which are called "nor'-easters." The latter are noted for unusually high snowfalls that they cause in the New England area.

Precipitation is generally uniform throughout the year with much occurring as snow during the winter. Melting of the snow cover generally occurs in March and early April although intermittent warming periods during the winter months often cause much of the snow to melt. Temperatures within the area range from summertime highs in the 90's to subzero for short periods during winter.

Hydrologically, the study area is characterized by unusually flat, swampy watersheds containing numerous man-made storages. These conditions are inclined to attenuate and delay the hydrologic response to intense rainfall. Conversely, these retention characteristics of the watersheds serve to augment streamflow during periods of little rain. The most rapid concentration of runoff during periods of intense rainfall occurs in the highly urbanized portions of the study area which are sewered. Urban development is virtually complete in the core city of Boston with saturation radiating outward into the surrounding towns and cities.

The mean annual temperature in the area varies from slightly above 50° Fahrenheit (F) along the coast to just below 50°F in the higher elevations of the interior with average monthly temperatures varying from about 72°F in July to 26°F in January. Temperature data from the National Weather Service stations at Boston and Framingham, Massachsuetts were selected as representative of the coastal and interior portions of the study area, repsectively. A summary of these data is presented in Table 4.

The mean annual precipitation at Boston is 43 inches, with recorded annual maximum and minimum values of 67.7 and 23.7 inches, respectively. At Framingham, the average annual precipitation is 43.8 inches, with extremes of 60 and 29 inches, respectively.

Table 5 summarizes precipitation data recorded at the two selected Weather Service stations in the study area. Values of the mean monthly precipitation at these stations indicate a rather uniform distribution throughout the year. During the winter months, precipitation over the study area is characterized by alternate periods of rain and snow. Average annual snowfall varies from 43 inches at Boston to over 51 inches at Framingham.

TABLE 4

MONTHLY TEMPERATURE RECORD
(In Degrees Fahrenheit)

Month	Boston, Mass. Elevation 15 feet msl 101 Years of Record Through 1972			Framingham, Mass. Elevation 170 feet msl 87 Years of Record Through 1971		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	29.0	72	-13	26.3	72	-24
February	29.2	68	-18	26.8	66	-21
March	37.6	86	- 8	36.2	85	- 3
April	47.2	91	11	47.3	93	10
May	57.9	97	31	58.3	96	25
June	67.3	100	41	67.2	100	35
July	72.3	104	50	72.3	102	42
August	71.5	101	46	69.9	104	34
September	64.4	102	34	62.9	95	27
October	55.0	90	25	52.4	91	16
November	44.5	83	- 2	41.0	83	6
December	32.7	69	-17	29.9	71	-16
Annual	50.7	104	-18	49.2	104	-24

TABLE 5

MONTHLY PRECIPITATION RECORD
(In Inches)

Month	Boston, Mass. Elevation 15 feet msl 155 Years of Record Through 1972			Framingham, Mass. Elevation 170 feet msl 96 Years of Record Through 1971		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	3.62	9.54	0.89	3.86	9.67	0.75
February	3.47	7.08	0.45	3.77	8.82	0.26
March	3.96	11.00	T	4.16	9.61	0.04
April	3.73	9.14	0.93	3.65	8.78	0.85
May	3.45	13.38	0.25	3.24	7.01	0.72
June	3.19	9.13	0.27	3.28	9.33	0.38
July	3.32	11.69	0.52	3.47	11.80	0.73
August	3.78	17.09	0.39	3.62	15.69	0.54
September	3.34	10.94	0.21	3.53	10.65	0.18
October	3.35	8.84	0.06	3.29	10.26	0.10
November	4.02	11.03	0.59	4.04	7.94	0.89
December	3.77	9.74	0.66	3.91	10.87	0.92
Annual	43.01	67.7	23.7	43.82	59.94	28.96

T - Trace

Stormwater Treatment

At the present time there is one facility in the study area which treats combined sewage overflows, the Cottage Farm Stormwater Treatment Station located on the Cambridge side of the Charles River Basin near the mouth of the river. The station is a demonstration project funded in part by the EPA and has been operated by the Metropolitan District Commission since May 1971.

Combined sewage, in excess of the dry weather flow to be treated, overflows through the facility where it receives screening and detention following hypochlorite disinfection. All screenings are flushed to the interceptor which conducts flows to the MSD treatment facilities. At the maximum design flow rate of 233 MGD, disinfection contact time is 10 minutes, however, it is estimated that the contact time will be in excess of 30 minutes for 80% of the overflows.

In its first 2-year period of operation, the automated facility was activated 81 times which is considerably above the design estimate of 22 anticipated events per year. Performance data indicates that settleable solids were reduced on an average of 85%; suspended solids, 40%; and total coliforms, 99%. BOD removals were erratic and showed little or no improvement.

STUDY AREA DRAINAGE

The study area is furnished with a variety of drainage systems, sanitary, storm, and combined. While it is difficult and often undesirable to generalize, certain facts regarding the drainage systems become apparent from the standpoint of an overview. High density communities within or near the core of the metropolitan area, are generally served by combined sewage systems, an outgrowth from early times when emphasis was placed on storm drainage and was followed by sanitary accretions to the storm sewers well in advance of waste treatment practice and planning. Many suburban communities in their early growth stages utilized on-site treatment for disposal of sanitary wastes but most of these have now adopted separate collection. Many rural communities still employ on-site treatment measures and because of slow community growth brought about by adverse industrial and economic conditions, may continue to do so for some time in the future.

The following discussion essentially presents qualitative information regarding drainage systems throughout the study area. The information is presented by watershed, however, it actually represents an overall concensus of the communities making up the respective watersheds or river basins after a survey of each town's drainage had been made.

Assabet River Basin

Approximately 50 percent of the urban area in the basin is provided with storm drainage while 15 percent of the population is served by sanitary sewers. There are no combined sewers within the basin. The predominant means of sanitary waste disposal is by individual on-site septic tanks and leaching systems. Although there are a few exceptions, flooding of urban areas by stormwater does not appear to pose a serious problem. The Town of Maynard reports that a storm having a duration of 12 hours and a total rainfall of 2-inches has caused severe flooding. In 1955, Hudson experienced serious flooding however improvements to the storm sewerage system have been made to prevent a repetition of this problem. Westborough is now in the process of studying storm sewer additions to alleviate flooding of the town's commercial area.

Beverly Harbor Area

Approximately 99 percent of the Beverly Harbor drainage basin belongs to the South Essex Sewerage District (SESD). The SESD communities are provided with separate sanitary sewers and storm drainage systems, however, there are no combined sewers. The city of Lynn comprises only 0.07 square miles of this watershed and has only combined sewers.

The survey revealed no major flooding problems due to storm water in the area.

Blackstone River Basin

Only a small number of the communities in the entire basin are part of the study area. In these communities, approximately 5% of the population is served by sanitary sewers and 50 percent of the urban area is provided with storm drainage. There are no combined sewers. Wrentham reported no stormwater flooding problems and Bellingham corrected stormwater flooding problems which occurred in certain areas. Hopkinton reports its flooding to be due to backed-up or overloaded streams.

Charles River Basin

The Charles River watershed is the largest drainage basin in the study area making up about 20 percent of the total study area. About 60 percent of the watershed is served by sanitary sewers, 75 percent by storm sewers, and 12 percent by combined sewers. Nearly all of the combined sewers are located in Boston, Brookline, Cambridge, and Somerville. The discharge from these combined sewers contribute heavily to the gross pollution of the Charles River Basin near the mouth of the river. The basin is an impoundment of the lower Charles River created by the Charles River Dam. Approximately 50% of the watershed's communities belong to the Metropolitan Sewerage District (MSD), a legal jurisdiction administered by the Metropolitan District Commission (MDC).

The Charles River itself creates certain flooding problems along its course through the watershed. Attempts have been made to correct these problems through the installation of dams. Various communities experience flooding problems of a localized nature, which may result from inadequate storm drainage or lack of flow capacity in the small tributary streams and the river. Among the towns reporting flooding due to stormwater were: Bellingham, Franklin, Hopkinton, Medfield, Medway, Mendon, Milford, Millis, and Sherborn.

Chelsea River Basin

This basin consists of 4 cities which are members of the MDC. About 90 percent of the watershed area is served by sewers, 60% of which are combined. Unusually high water levels in the river, probably accentuated by incoming tides, cause flooding in the communities.

Concord River Basin

Approximately one-third of the drainage basin is served by sanitary and storm sewers. The City of Lowell is the only community having combined sewers in the basin. However, these serve only 6% of the drainage area. Only Tewksbury and Lowell report any serious flooding problems.

Essex Bay Basin

About 5% of this drainage basin is served by sanitary sewers while 65% is provided with storm drainage. The City of Essex reports some flooding to be caused by salt water intrusion in storm drains.

Gloucester Harbor-Annisquam River Area

About 50% of the area is served by sanitary sewers and 60% by storm drains. There are no combined sewers in this drainage area. Both Rockport and Gloucester report flooding problems accentuated by high tides.

Ipswich River Basin

About 15% of the area in this drainage basin is served by the MDC, while 17% belongs to the SESD. Approximately 30% of the drainage area is served by sanitary sewers while 60% is served by storm drainage. There are no combined sewers within the basin.

Ipswich reported that its last serious flooding problems occurred in 1967, however, it experiences some flooding problems with stormwater when rainfall intensities reach 0.5 inches per hour.

Both North Reading and Topsfield experience flooding in areas along the Ipswich River during high water stage.

Local No. 1 - Cape Ann

(The term "local" is applied to coastal areas that do not contribute drainage to any one well-defined hydrologic feature. Rather, the areas are characterized by a dispersed drainage pattern with runoff concentrating at many points within the area).

About 60% of the drainage area has sanitary sewers and 70% storm drainage. There are no combined sewers in the area.

Local No. 2 - Manchester Harbor Area

About 50% of the watershed area is served by sanitary sewers and 60% by storm drains. There are no combined sewers in the area. With the exception of some minor problems, stormwater flooding does not constitute a problem.

Local No. 3 - Marblehead Harbor - Lynn Harbor Area

Approximately 95% of the area is served by sanitary sewers and about 100% by storm drains. About one-third of the area has combined sewers which are located in Lynn and a few places in Nahant. Stormwater flooding, previously a problem in Nahant, has been corrected by drainage additions.

Local No. 4 - Boston Harbor

This drainage area is served by the MDC; 90% of the area has sanitary sewers and storm drains. About 50% of the area is served by combined sewers. While the area reports no major flooding problems, some stormwater flooding may occur when tides are high and from backup of streams.

Local No. 5 - Boston

Consisting of only 4% of the City of Boston, this area is almost completely sewered by combined sewers. There are no serious stormwater flooding problems in the area.

Local No. 6 - Quincy Bay Area

All of the Quincy Bay area is served by the MDC. About 90% of the area has sanitary and storm sewerage, however, there are no combined sewers. Flooding problems are minor in nature and usually arise from high frequency return storms accentuated by high tides.

Local No. 7 Hingham Harbor - Hull Bay Area

About 70% of the population is served by sanitary sewers and 90% by storm drains. Only 10% of the area has combined sewers which are located in Hull, however these combined sewers will be eliminated within a 3-year period. Cohasset experiences occassional minor flooding in its marshes.

Local No. 8 Cohasset Harbor - Scituate Harbor Area

About 15% of this area has sanitary sewers and 60% storm drains. There are no combined sewers. Cohasset reports some stormwater flooding. Scituate has experienced stormwater flooding from a storm estimated to have a 5-year return frequency.

Local No. 9 Green Harbor - Sudbury Bay Area

At the present time this area has some storm drains but neither sanitary nor combined sewers. No serious stormwater flooding in the area was reported.

Merrimack River Basin

Only a few of the communities in this watershed are within the study area and the information presented is related to only those communities. The part of the watershed area included in the study does not have sanitary sewers, however, 35% has storm drains. There are no combined sewers and no major flooding problems caused by stormwater.

Mystic River Basin

The Mystic River Basin is served entirely by the MSD. About 90% of the area has sanitary sewerage and about 90%, storm drainage. About 10% of the area has combined sewers or combinations of combined and sanitary sewerage. The cities in the watershed which have combined sewers are Cambridge, Chelsea, and Somerville. No major flooding problems were reported for the area although the river banks may overflow during very severe storms.

Neponset River Basin

Approximately 85% of this drainage area is served by sanitary sewers while close to 90% has storm drainage. Combined sewers, or a combination of combined and sanitary sewers, serve about 10% of the area with Boston having the largest portion.

Very high river stages may cause some low lying lands to flood but usually nothing very extensive. Foxborough experiences a minimum amount of flooding problems.

North River Basin

Approximately 10% of this river basin area has sanitary sewerage while 50% is served by storm drains. There are no combined sewers in the area.

Hanover reported severe flooding occurred during storms having return frequencies of 10 to 15 years. Scituate reported experiencing extensive flooding from storms having a return frequency of 5 years.

Parker River Basin

Only a very small portion of the Parker River Basin is within the study area. About 5% of this area has sanitary sewerage and about 15%, storm drainage. The area reports no combined sewers at present.

Aside from Ipswich, which reports flooding generally occurs when rainfall rates attain 0.5 inches per hours, there are no major flooding problems from stormwater.

Rowley River Basin

Only one community in the basin is included in the study area, Ipswich. About 30% of Ipswich has sanitary sewers but storm drainage is nearly 100% complete.

Salem Harbor Area

About 90% of this watershed has sanitary sewers, however, storm drainage is about 100% complete. Approximately 2% of the drainage area is in Lynn which has combined sewers.

There are no serious stormwater flooding problems in this drainage basin other than those accentuated by high tides.

Saugus River Basin

About 68% of the basin area has sanitary sewers and 90% storm sewers. About one-sixth of the watershed is in Lynn and consists of combined sewers. About 40% of the drainage basin is served by MSD.

The survey did not reveal any serious stormwater flooding problems in the basin.

Shawsheen River Basin

About 50% of the basin has sanitary sewers and 65% storm sewers. About one-third of the area is served by the MSD.

South Tewksbury reports stormwater flooding affects 75% of its area; Lawrence reports some flooding problems occur in the Saw Brook area.

South River Basin

This area has very little, if any, sanitary sewerage, while about 50% has storm drains. There are no combined sewers in the basin.

Stoney Brook Basin

There are no sanitary sewers in that portion of the Stoney Brook basin which is within the study area, however, about 40% of this area has storm sewers. There are no combined sewers and no reported flooding problems from stormwater.

Sudbury River

About 30% of the drainage area lies in towns affiliated with the M.D.C. On the whole, 40% of the watershed has sanitary sewers and 60%, storm drains. The basin does not have combined sewers.

Southborough reported some flooding occurring in the south end of the town. Wayland experiences some flooding along its Pelham Island Road and Westborough is studying the problem of stormwater flooding in its commercial district.

Taunton River Basin

That portion of the basin within the study area is reported to have sanitary sewers for 25% of the area and storm drainage for 45%. The area has no combined sewers. Almost 30% of the area is within the M.D.C. limits.

Weymouth Back River Basin

90% of the area is served by the MSD; sanitary sewers serve 80% of the area while storm drains are provided for 90%. The basin has no combined sewers or serious stormwater flooding problems.

Weymouth Fore River Basin

Almost 85% of the watershed lies in communities affiliated with the M.D.C. Sanitary sewers serve 80% of the basin area; storm drains, about 85%.

There are no combined sewers in the basin and only Holbrook experiences stormwater flooding.

III. URBAN STORMWATER RUNOFF

Quality Characteristics

Until the last decade, the quantitative or hydraulic aspects of stormwater runoff were the prime concern of the design engineers. The principal interest then was to develop systems which would remove the stormwater from the urban area and discharge it to the nearest watercourse as expeditiously as possible. The prevailing opinion held that stormwater runoff was virtually pollution free because it was simply rainwater whose only demerit was the potential to cause flooding.

Although mention of the qualitative aspects of storm runoff has appeared at random in the literature since the 1940's, it was not until passage of Federal water pollution control legislation that more serious attention began to be given to stormwater and its effects on the receiving stream. The increasing emphasis on water quality standards brought about the Federal Water Pollution Control Act Amendments of 1972 requires that every effort be taken to minimize all pollution to the receiving stream.

The quality and quantity of stormwater depends on several factors. Intensity, duration, and areal extent of storms, as well as the time intervals between successive storms, will have significant effects on the runoff. In addition, land contours, land uses, population densities, incidence and nature of industries, size and layout of sewer systems, and other factors will also exert an influence. Studies on stormwater runoff qualities may differ widely in pattern and background conditions, consequently, they should not be simply consolidated and treated as being representative of conditions throughout the United States.

Table 6 presents a summary of the characteristics of combined and separate storm sewer discharges throughout the United States as compiled by Kothandaraman(1). These data amply justify the concern for protecting the water quality in streams from pollution by stormwater runoff.

Hedley and Kint(8), on the basis of their observations of storm runoffs from the Haunch Valley drainage area (steep, about 100 acres), estimated pollution loads on an effective impervious area basis. For combined sewer overflows they estimated the BOD load to be 6 lb/acre and the suspended solids load to be about 16/acre during the storm. Burm, Krawczyk, and Harlow(9) estimated the pollution loads for a Detroit area which is served by a combined sewer system and for Ann Arbor which is served by a separate sewer system. The results are shown in Table 7. Weibel et al(10) from their Cincinnati studies, have given a comparison of the strength of separate storm sewer discharges with that of domestic sewage. The results are shown in Table 8.

Bryan(11), on the basis of his studies on urban drainage in North Carolina, came to the conclusion that the total weight (presumably on an annual basis) contribution of BOD by stormwater was about equal to the sanitary wastewater effluent from secondary treatment at 85-95 percent efficiency. This compares favorably with the findings of Weibel et al(10). The contribution of total organic matter as measured by chemical oxygen demand in stormwater was greater than that attributable to the discharge of sanitary wastewater. The total solids contribution by urban stormwater was substantially larger than would be expected from average raw domestic wastewater. The contribution of phosphate was nominal for the stormwater in comparison with that of domestic wastewater.

Table 6. Summary of Characteristics of Combined and Separate Storm Sewer Discharges(1)

Location	pH	Suspended solids (mg/l)	Volatile suspended solids (mg/l)	COD (mg/l)	BOD (mg/l)	Total nitrogen (mg/l)	Total phosphorus (mg/l)	Total coliform (MPN/100 ml)
Combined Sewer Discharges								
Baltimore, Md.	-	396-2509	26.3-57.9**	-	-	-	-	-
Bucyrus, Ohio	-	306-675	96-390	-	31-177	0.5-16.9†	2.0-15.1	-
Cincinnati, Ohio *	-	450-1460	30-280	96-2000	130-700	-	-	-
Detroit, Mich.	-	250	50-200	-	50	-	-	4.3×10^6
Detroit, Mich.	-	260-510	92-310	-	92-410	6.0-9.9	10.1-34.0	-
Philadelphia, Pa.	-	1-15	-	-	36-148	-	-	$1 \times 10^7 - 1 \times 10^8$
Portland, Ore.	4.5-6.0	70-325	57-166	138-324	57-155	3.7-7.0	-	-
Sacramento, Calif.	6.5-7.5	30-500	30-311	59-431	75-328	-	-	$1.2 \times 10^5 - 8.6 \times 10^6$
Washington, D. C.	5.6-6.7	135-2000	10-1280	80-1760	10-470	1.0-16.5	0.8-9.4	$4.2 \times 10^5 - 5.8 \times 10^6$
Separate Storm Sewer Discharges								
Ann Arbor, Mich.	-	470-4400	31-530	-	24-49	-	1.2-9.4	-
Cincinnati, Ohio	5.3-8.7	5-1200	1-290	20-610	1-173	0.3-7.5	0.0-7.3	$2.9 \times 10^3 - 4.6 \times 10^5$
Detroit, Mich.	-	310-914	136-370	-	96-234	-	-	$25 \times 10^3 - 9.3 \times 10^5$
Sacramento, Calif.	-	19-211	3-211	21-176	24-283	-	-	$5.5 \times 10^3 - 1.0 \times 10^6$
Washington, D. C.	5.6-6.7	130-11,280	0-880	29-1514	3-90	0.5-6.5	0.2-4.5	$1.2 \times 10^3 - 3.2 \times 10^6$

*Data from May 12,1970 storm

**Volatile suspended solids in percent

†Nitrogen as NO_3

TABLE 7

POLLUTIONAL LOAD FACTORS

Constituents	Combined sewer, Detroit (lb/acre)	Separate storm sewer, Ann Arbor (lb/acre)
Phenols	0.042	0.002
BOD	90	31
NH_3-N	6.2	0.7
Organic N	1.6	0.4
Suspended solids	200	1010
Volatile suspended solids	93	185
Total PO_4	11.0	2.8
NO_3-N	0.15	0.8

TABLE 8

COMPARISON OF URBAN STORMWATER RUNOFFS

WITH DOMESTIC SEWAGE LOADS

Constituents	Domestic Sewage (lb/day/acre)	Domestic Sewage (lb/year/acre)	Urban runoff loads as percentage of sewage loads During runoff	Urban runoff loads as percentage of sewage loads Annually
Suspended Solids	1.5	540	2400	160
COD	2.6	960	520	33
BOD	1.5	540	110	7
Total PO_4	0.19	68	70	5
Total N	0.23	82	200	14

The American Public Works Association(12), on the basis of studies in the metropolitan Chicago area, reported that street refuse-litter creates a water pollution potential when it comes in contact with run-off waters resulting from precipitation of thaws in direct proportion to the amount and nature of these urban environment wastes. The pollution potential can be reduced and minimized by better municipal sanitation practices, the use of more sophisticated equipment, and improved public cooperation and participation. The significant component of street litter, in terms of producing water pollution potential by runoff, was found to be the dust and dirt fraction. This varied from 0.4 to 5.2 pounds per day per 100 feet of curb. The soluble dust and dirt contained appreciable amounts of water pollution contaminants. The weighted amounts of these constituents were: BOD, 5 mg/g; COD, 40 mg/g; coliforms, 1 million/g; and fecal enterococci, 5400/g. The BOD of street litter was found to be equivalent to 25 persons per day per mile.

Impact of Stormwater Runoff on Receiving Waters

Several studies have been made which indicate that stormwater runoff can and does have an impact on receiving waters. Gannon and Streck(13) reported on the influence of the discharge from separate stormwater sewers in Ann Arbor, Michigan, on the Huron River following a storm on the evening of July 20, 1964. They found that the DO level in the river was depressed from about 10 mg/l to 2 mg/l. The effect lasted about 24 hours after the storm ceased, and a river stretch of 2 miles below the outfall was found to be affected. Burm(14) studied the bacteriological effects of combined sewer overflows from Detroit, Michigan, on the Detroit River and concluded that the duration of adverse effects was proportional to the intensity of rains. Coliform densities exceeded 100,000 per 100 ml in the river after a moderate rain, and the effects of overflow discharges were felt for several days after the acutal overflows had ceased.

The results of a detailed water quality survey of the Sandusky River in Ohio before and after rainstorms have been reported by Burgess and Niple, Ltd.(15). They found that the BOD concentration of the Sandusky River, immediately downstream from Bucyrus, varied from an average of 6 mg/l during dry weather to a high of 51 mg/l during overflow discharges. The total coliforms (by the membrane filter technique) varied from an average of 400,000 per 100 ml during dry weather to a high of 8,800,000 per 100 ml during overflow discharges. The effects of combined sewer overflows on the Sandusky River in and below the city of Bucyrus were visually apparent. Median flows in the river at Bucyrus in June, July, and August of 1969 were 13, 6.9, and 4.8 cfs, respectively.

In assessing the effects of stormwater overflows from the Oakland and Berkeley, California, area on San Francisco Bay, Metcalf and Eddy, Inc.(16), reported that although dissolved oxygen was depressed by overflows, the average DO levels were well above the minimum objective of 5.0 mg/l during the rainy season. Only localized and short-lived DO levels below the minimum DO objective were noted during the rainy season. Coliform bacteria after an overflow event were found to produce a concentration above the selected objective (total coliform MPN not higher than 1000 per 100 ml more than 20 percent of the time in a 30-day period) for approximately 2.6 days after each overflow event.

These studies add emphasis to the argument that stormwater runoff can cause problems in receiving waters which can not be ignored.

Stormwater Collection and Treatment Problems

Whereas conventional wastewater treatment is based on comparatively steady state conditions, stormwater treatment must adapt to intermittent and random occurrences. Flow and quality characteristics are subject to high variability over short periods of time. Peak flow rates may equal or exceed 50-100 times dry weather flows from the same area. Thus, facilities must either be exorbitantly large or supported by equalization storage.

Many studies involving the hydraulic characteristics of urban storm runoff have shown the difficulty of collecting stormwater in sewers and the necessity of overflows. In Detroit, Michigan, Palmer(5) found that no satisfactory reduction in the number of storm overflow occurrences can be made by any reasonable increase in interceptor capacity. In Boston, Massachusetts, McKee(6) found that stormwater runoff was equal to the dry weather sanitary sewage flow when the rainfall intensity was about 0.01 inch/hour after impervious surfaces were wetted. He estimated that with combined sewer interceptors designed to collect flows as great as 9 times the dry weather flow, 82% of the incoming sewage would overflow from storms of 0.5 inch/hour.

Because of the high flow rates which can occur, transmission facilities costs can be very high, constraining options for centralization of treatment facilities. These conditions often necessitate the use of treatment sites in prime real estate areas. In many cases treatment facilities must be kept simple, compact, and attractive to the surroundings. In addition, because storm occurrences may occur with little advance warning and at any time, day or night, weekdays or weekends, automatic operational control is required. Treatment effectiveness is largely dependent upon facilities which will not be rendered inoperative by scum or debris, but can come on line instantly and self-adjust to changes in flow and concentration of pollutants.

The collection and treatment problems associated with combined as well as stormwater runoff flows as described above make treatment decision choices difficult. The complete separation of sanitary and storm sewers by itself, will not provide the solution for pollution control of surface runoff. It will be necessary to treat both sources of pollution in ways which are as cost-effective as possible.

TREATMENT OBJECTIVES AND METHODOLOGY

The necessity of stormwater or combined sewage treatment facilities to be able to treat and/or handle flow rates ranging from zero to rates far in excess of the treatment plant's capacity requires that treatment objectives be established. Lager(17) has developed a decision matrix system which acts as a guide to the design engineer and assists him in the selection of those processes which will attain the objective or goal desired. Figure 2 shows the treatment design matrix. The repeated "Bypass" notations on the figure indicate the option to end the treatment sequence at any level and/or skip intervening levels depending upon treatment objectives.

Level 1

The first-level decision sets constraints on the flow rate that is to be processed. The use of storage is the most cost-effective means available to the design engineer for reducing pollution resulting from combined sewer overflows and for improving the management of urban stormwater runoff. It is the best documented abatement measure in present practice. Concentration devices(18) typified by the swirl concentrator, split the runoff into a low volume concentrate stream and a high volume relatively clear stream.

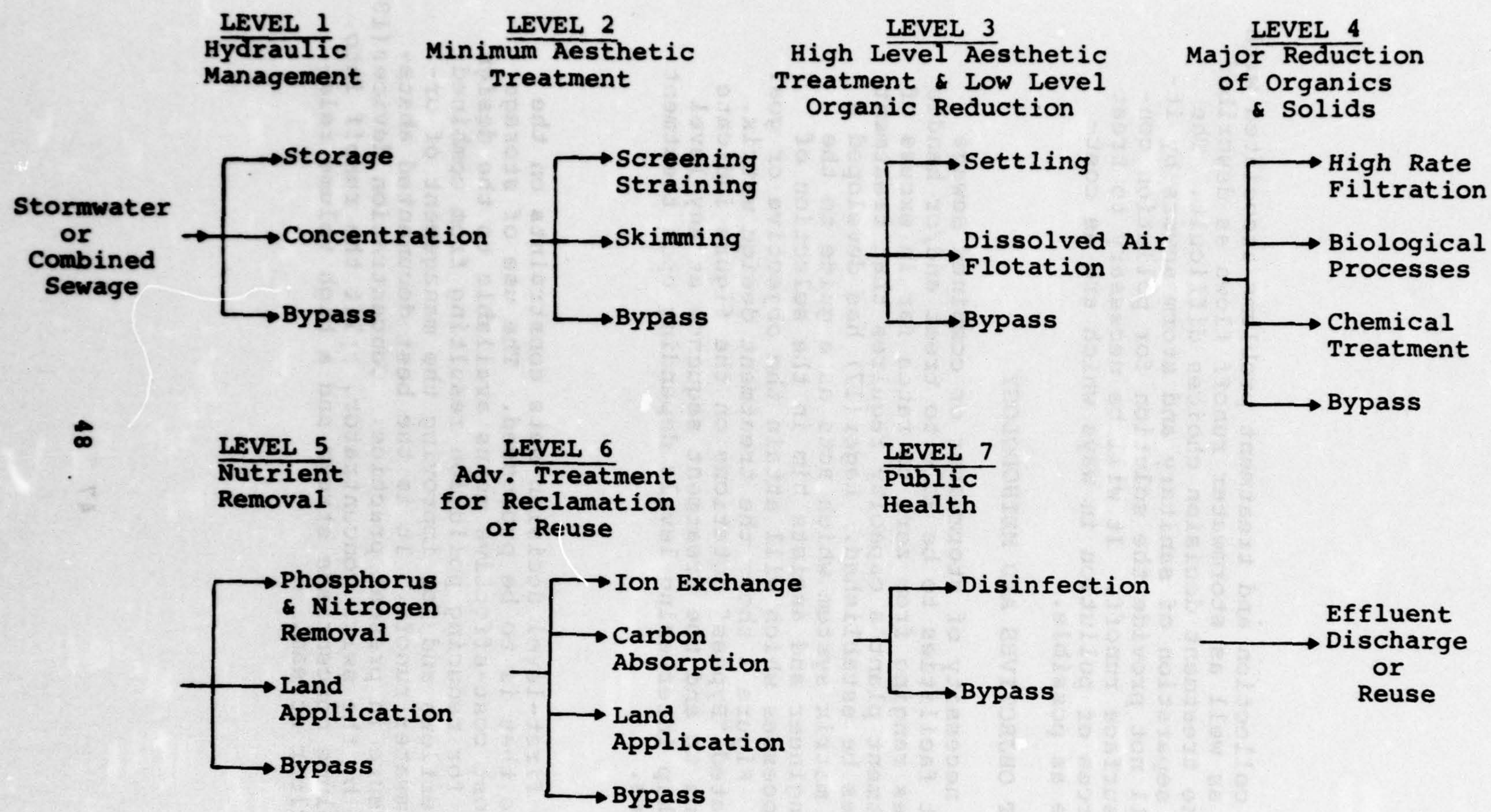


FIGURE 2. TREATMENT DECISION MATRIX

Level 2

The second-level decision offers a modest upgrading of the waste flow where screening/straining devices may vary from bar racks to drum screens to microstrainers. Table 9 lists the common screen/strainer sizes and typical removal efficiencies. Bar screens are used as protection devices for pumps and other equipment; fine screens have been used effectively as pretreatment devices; and microstrainers have been used as complete treatment units and as polishing devices(19,20). Skimming is accomplished by use of submerged outlets or elongated weirs protected by baffles.

Level 3

Sedimentation is the most commonly practiced treatment process in use for combined sewage(21,22). Because flow rates may vary widely throughout a storm, basin performances are difficult to evaluate. In practice, most basins have a primary function as storage and a secondary function as a disinfection contract detention basin. Treatment by sedimentation is practically incidental. Peak flow-through rates are generally governed by disinfection requirements, thus overflow rates at peak design may exceed 10,000 gal/sf/day, or approximately 10 times conventional treatment practice. Most storm flows will load basins at rates of 2,500 gpd/sf or less. Within this range, suspended solids removals can be expected to vary linearly from 70% at 300 gpd/sf to 30% at 2,300 gpd/sf.

The dissolved air flotation process(23) can operate effectively at high overflow rates on the order of 4,000 to 5,000 gpd/sf and can efficiently remove visible floating matter. At these rates, suspended solids removals are approximately 50% and BOD_5 removals are 45%. Chemical polymer additions can improve suspended solids removals by 15% but only 2% for BOD_5.

TABLE 9

SCREENING/STRAINING DEVICES

Type	Clear Opening			Typical Removals, %	
	Mesh	Inches	Microns	Susp. Solids	BOD_5
Bar Screens	-	3-1	-	1-5	1
Coarse Screens	-	1-3/16	-	-	-
Fine Screens	4-20	3/16-1/32	-	27	22
Micro-Strainers	20-400	0.03-0.001	833-23	20-80	Erratic

Level 4

High rate filters(24) have been studied extensively on a laboratory scale for the treatment of stormwater because of their ability to withstand the high variability of flow rates and contaminant loadings. In order to attain the higher flow-through rates necessary to reduce filters to a feasible size, the media must be both coarser and deeper than for conventional beds. Multimedia beds are common. Loading rates from 5 to 20 gpm per square foot with brief runs as high as 50 gpm per square foot have been successfully attempted. Drastically shortened filter runs between backwashes and high headlosses are associated with the higher rates. Suspended solids removals were found to be about 80% without chemicals and 95% with chemicals. BOD_5 removals were about 50% without chemicals and 80% with chemical additions. Pretreatment equivalent to Level 3 is required.

Biological processes including lagoons, trickling filters, contact-stabilization activated sludge, and rotating biological discs have been tested. All suffer the common problem of maintaining an adequate and active biomass between storms to support the high and immediate needs during storms. Also, the shock loadings associated with storm flows are highly disruptive to the biological processes. Where successful, the stormwater treatment facilities have been located adjacent to or within the dry weather flow plants. Treatment efficiencies similar to the high rate filters would be expected.

The use of chemicals to improve performance of the above processes is questionable(25). In some cases, the addition of polymers was fruitless because even though a floc could be formed, hydraulic short-circuiting washed it out of the basin before it could settle and be removed. Likewise, the use of ozone(26) as a substitute for the biological processes is highly unlikely because rather large and expensive dosage rates, up to 100 mg/liter, would be required.

Levels 5 and 6

Like most wastewaters, stormwater as also amenable to nutrient removal alone or to the highest levels of treatment, including carbon adsorption, ammonia stripping, etc., where reclamation is anticipated. No large scale facilities, however, are in operation upon which to draw experience.

Level 7

Disinfection of wastewater is a major undertaking. Providing and storing sufficient chlorine or hypochlorite solution to treat peak storm flows at 6 to 25 mg/liter requires tremendous quantities of the chemical. Two installations(27,28) have found it more economical to construct their own chlorine generation plants rather than purchase chlorine from commercial sources. The application of the solution requires good flow measurement and careful control. There is always the danger that a massive overdose will occur. A 15-minute contact time is a desired minimum and bacterial kills of 99.9% are common. Dechlorination is a potential requirement in the future.

Cost Data

Because of the limited number of full-size installations and their basically experimental and demonstration backgrounds, reliable cost data are not available. Table 10 gives installed costs(29) that are typically representative. The costs are based on an ENR 2000 and exclude land costs.

TABLE 10

COSTS FOR STORMWATER TREATMENT FACILITIES

(ENR 2000; Land Costs Excluded)

Item	Peak Design Flow 25 MGD	Peak Design Flow 100 MGD
Bar Racks	$ 189,000	$ 388,000
Fine Screens	457,000	1,826,000
Dissolved Air Flotation	2,060,000	7,624,000
Sedimentation Tanks	568,000	1,784,000
Microstrainers	761,000	3,044,000
High Rate Filters	882,000	2,233,000
Chlorine Contact Tank & Equipment	227,000	662,000

Other Stormwater/Combined Sewer Overflow Treatment Studies/Projects

In 1964 the U.S. Public Health Service(30) estimated that to provide complete separation of storm and sanitary sewers throughout the country would range from $20 to $30 billion. Since storm sewer discharges constitute a significant pollution load on the receiving waters, all storm runoffs should be considered for treatment. All proposed methods for controlling pollution from storm runoffs dwell on some aspect of storage, and subsequent means of treating the stormwater. Methods proposed for storage and subsequent treatment are quite varied. A few examples are discussed below.

In Boston, Massachusetts, complete separation of storm and sanitary sewer systems was considered infeasible(31). Chlorination of combined overflows in contact tanks constructed at selected outlets prior to discharge to nearby water courses was estimated to cost about $533 million. Construction of holding tanks and subsequent disposal with the normal wastewater flow in the sewerage system was estimated to cost about $814 million. The least expensive plan was found to be deep tunnel storage and subsequent disposal by an ocean outfall and diffuser system. A 15-year frequency rainstorm of 24-hour duration was considered for design purposes.

For the metropolitan Chicago area, a deep tunnel storage system consisting of conveyance tunnels and mined storage reservoirs, and subsequent treatment of combined sewer overflows at treatment plants was found to be the best solution for abating pollution from storm runoffs(32). The complete separation and holding tank concepts were found to be much more expensive. The deep tunnel conveyance and storage system, estimated to cost about $1 billion, would serve an area of 62 square miles in the Lake Calumet area. The envisioned 10-year program

377 sq miles in Chicago Metro area. city plus first ring of suburbs ±

would include the entire 300 square miles and the combined sewer area of the Chicago area. The system's first stage of development would have a storage capacity that would limit overflow to the waterway to a maximum of only 25 percent of the total storm runoff in all but one storm of the 96-year precipitation record.

Karl R. Rohrer Associates, Inc.(33) reported on the feasibility of off-shore underwater temporary storage of combined sewer flows in flexible tanks. A pilot demonstration facility was constructed in Sandusky, Ohio, where combined sewer overflows from a 14.86-acre residential drainage area was directed to two 100,000 gallon collapsible tanks anchored underwater in Lake Erie. The stored overflows were pumped back to the sewer system after a storm event for subsequent treatment. During one year of operation, a total of 988,000 gallons of stormwater overflow was contained and returned for treatment. As constructed, the facility cost was about $1.88 per gallon of storage capacity, however, future projections indicate possible costs of less than 40 cents per gallon.

Burgess and Niple, Lts.(15), in their study of the various aspects of combined sewer overflows in Bucyrus, Ohio, considered six alternatives. These alternatives and their estimated costs are:

(1)	Complete separation of sanitary waste and stormwater	$8,800,000
(2)	Interceptor sewer and lagoon system	5,220,000
(3)	Stream flow augmentation	5,000,000
(4)	Treatment of overflows with a system consisting of gravity interceptor,	

grit chamber, settling tanks, chlorination facilities, anaerobic digester, and sludge drying beds. (The treatment facility would provide 1.5 hours of detention time for a 2-year, 1-hour design storm). 8,810,000

(5) Chlorination of overflows with a system consisting of interceptor sewers, contact tanks, and chlorination facilities capable of providing a chlorine dosage of 40 mg/l. 3,000,000

(6) Off-stream treatment consisting of pump station, low head dam, and lagoon system. 1,700,000

The Envirogenics Company(34), considered three alternate storage systems for Sacramento, California, namely, underground storage, surface storage, and stabilization ponds. Costs for various storage facilities to accommodate rainstorms of three different frequencies are contained in their report. The company considered dissolved air flotation, mechanical screening, and chlorination for treating urban runoff.

Simpson and Curtis(35) reported on the feasibility of a large stabilization retention basin in the off-shore waters of Lake Erie as a method of treating combined sewer overflows from the Cleveland metropolitan area. The proposed plan included a shoreline collection system to convey flows to the basin and would serve an area of approximately 38,800 acres. The proposed stabilization basin would have a volume of 30,000 acre-feet. The capital cost for the basin and the complete collection system at 1968 cost levels was estimated to be approximately $83,500,000. Total annual cost of operation, maintenance, and amortization was estimated at $4,767,000.

Waller(36) reported on a retention tank for solving the combined sewage overflow problems facing the city of Halifax, Canada (population 100,000). The total cost for the complete installation would be $400,000. The retention tank would have a capacity of approximately 1 million gallons and provide 15 minutes detention for a peak flow of 150 cfs. Chlorination facilities would provide a dosage of 30 mg/l for flows up to 40 cfs.

IV. STORMWATER MANAGEMENT FOR STUDY AREA

Overview of Methodology

Stormwater management for the study area was accomplished by considering each of the communities within the study area as a separate management problem. This was necessary because the urban area information generated assumed that the urban stormwater runoff in each community could be collected and treated at a single point. While this could be true in a few cases, generally it is not; the urban area in a given community is often divided and the ground topography generally allows surface drainage within the community to be drained to several points.

Because of the deficiencies in the data, optimization of stormwater management could not be employed. No assurance could be placed in assumptions as to where stormwater discharges would take place or the amounts of runoff in the discharges, consequently, economic advantage could not be taken of several discharges from adjoining communities probably occurring in close proximity to each other and being treated jointly. Thus, the stormwater management proposed in this report cannot be considered as practicable because it fails to define actual points of discharge and the volumes of runoff that should be treated at those points. It considers all of the urban stormwater for a community to be drained to some undefined point on the perimeter of the community where it is to be stored and treated.

In spite of the shortcomings described above, however, the study is highly useful in that it offers valuable information regarding management of stormwater in each community assuming that all of the stormwater could be sent to a single plant for treatment.

Stormwater treatment requirements of each community were determined by:

(1) Selecting the level of stormwater treatment based on treatment goals which were considered feasible and valid,

(2) Determining the storage volume that would be necessary to hold the fraction of runoff which contained the greatest amount of pollutional matter which would be subsequently treated, and

(3) Selecting a treatment scheme alternate which would provide the most cost-effective treatment consistent with the treatment goal desired.

URBAN STORMWATER RUNOFF QUALITY AND QUANTITY(37)

Introduction

Rain falling on impervious surfaces, such as rooftops, streets and other paved surfaces, is apt to produce runoff due to the nature of the materials. Pervious areas, such as lawns and parks, are less conducive to runoff and contribute to the total runoff to a lesser degree. Materials lying on the surfaces of both areas can be either washed off or dissolved by the runoff. These materials contribute to the degradation of the quality of the runoff water by supplying various pollutants such as solids, oxygen-demanding substances, nutrients and bacteria. These pollutants frequently reach concentrations that are above established effluent criteria and, if not treated before discharge, could have a deleterious effect on a receiving water body.

It has only been within the past ten years that the need to predict the quality of urban stormwater runoff has been recognized. With this intention, several studies have been conducted on urban watersheds throughout the United States. Some of the urban areas studied are Chicago, Tulsa, Baltimore and Cincinnati. The approach generally used has been to relate, through statistical analysis, observed runoff pollutant loads to the physical and environmental characteristics of the watersheds. The results of these analyses have proved to be of use as a predictor of pollution potential in the specific areas studied. However, these "models" are not meant to be used as an absolute end, replacing the need for observed field data in design studies. Nor should they be applied to other geographic areas without proper calibration.

The study performed within the city of Chicago by the American Public Works Association (APWA)(12) has been a source of useful information in the quest for a generally applicable stormwater quality methodology. A major finding of the study was that litter accumulating on streets is a very significant source of pollution, and dust and dirt is the most abundant component of the litter. Various pollutants were identified as being present in the composition of the dust and dirt. This led to the finding that a direct relationship exists between runoff pollutant concentrations and dust and dirt buildup on the streets.

Several computer simulation models are based on the findings of the Chicago study. The most notable of these are the EPA Stormwater Mangement Model(38) developed by Metcalf & Eddy, Inc., University of Florida, and Water Resources Engineers, Inc., and the "STORM" Model(39) developed by Water Resources Engineers, Inc. for the Corps of Engineers Hydrologic Engineering Center. Each model is capable of predicting the quality and quantity of urban stormwater runoff. The EPA model is very comprehensive in its scope, whereas the "STORM" Model treats only the runoff quality and quantity process and the treatment, storage, and overflow interaction. Because of the generalized nature of the "STORM" Model, it was used in the inventory of urban stormwater runoff quality and quantity for this study.

Pollutant data necessary to predict the quality of stormwater runoff is difficult to obtain. Accordingly, the "STORM" Model is equipped with default values, most of which are derived from the APWA Chicago Study, for the quality variables.

When using a mathematical model as a predictive tool, it is usually advisable to calibrate the model against observed field data from the study area. However, due to time and funding constraints, field calibrating data for this study was not obtainable. Consequently, the stormwater inventory was developed using the default quality values after a degree of confidence in them was determined.

Since field calibrating data was not available, the main emphasis of this study was to make the available data as accurate as possible. This extensive effort was designed to, in part, compensate for the lack of field data and to add confidence to the results of the analysis.

The end product of the analysis is a comprehensive inventory of urban stormwater runoff quanitity and pollution loadings. The information contained therein will be of value if it is kept in the right context, that of a predictive mode. Despite the problems encountered during analysis, it is felt that the methodology employed incorporates the state-of-the-art in stormwater quality analysis.

Sources of Pollution

Pollutants carried by storm runoff from urban areas have many sources; accumulated debris and dirt on streets, chemical substances from grassy areas, atmospheric fallout, animal wastes, etc. It has been found that street surfaces are the most significant source of pollutants, mainly because streets are exposed to many diverse sources of pollutant loadings and, due to their impervious constitution, readily produce runoff. Using a hypothetical city as a basis for comparison, it has been estimated that for the first hour of a moderate-to-heavy storm, the pollution loadings from street surfaces would far exceed that from the raw sanitary sewage of the city over the same period as shown on Table 11. The streets of this city are cleaned, by sweeping or rainfall, an average of every five days. It should be noted that these computed figures are presented in the unit of pounds per time period, not concentration.

The APWA Chicago Study(12) categorized all materials that collect on street surfaces as either rags, paper, dust and dirt, vegetation or inorganics. The dust and dirt portion, that fraction of the solid material passing a 1/8-inch hardware cloth, was found to be the most abundant, except during the autumn months when vegetation was prevalent. During the period March through September, dust and dirt comprised 72 percent of the total refuse accumulation. The characteristics of street refuse components estimated by the APWA Study for a residential area of Chicago are given in Table 12.

The composition of the dust and dirt was studied to identify its pollution potential. The results showed that various pollutants were contained within and were released by the soluble portion of the dust and dirt. The non-soluble portion, though it can contribute to the solids load as it is washed off the street, was not specifically studied. Table 13 summarizes the findings of the APWA Study.

TABLE 11

STORMWATER RUNOFF POLLUTANTS

FOR HYPOTHETICAL CITY(40)

	Street Surface Runoff* (lb/hr)	Raw Sanitary Sewage (lb/hr)	Secondary Plant Effluent (lb/hr)
Settleable plus Suspended Solids	560,000	1,300	130
BOD_5	5,600	1,100	110
COD	13,000	1,200	120
Kjeldahl nitrogen	880	210	20
Phosphates	440	50	2.5
Total coliform bacteria (org/hr)	4000×10^{10}	$460,000 \times 10^{10}$	4.6×10^{10}

*Following 1-hour storm.

The hypothetical city has the following characteristics:

Population - 100,000 persons

Total land are - 14,000 acres

Land-use distribution:
- residential - 75%
- commercial - 5%
- industrial - 20%

Streets (tributary to receiving waters) - 400 curb miles

Sanitary sewage - 12×10^6 gal/day.

TABLE 12

MONTHLY SUMMARY OF ESTIMATED STREET LITTER COMPONENTS, FROM A 10-ACRE RESIDENTIAL AREA, CHICAGO

Street Refuse Components (Tons/Month)

Month	Rags	Paper	Dust & Dirt	Vegetation	Inorganic	Total
Jan.	.0015	.036	.55	.00	.09	.68
Feb.	.0015	.036	.55	.00	.09	.68
March	.0015	.036	.55	.08	.09	.76
April	.0015	.036	.55	.08	.09	.76
May	.0015	.036	.55	.08	.09	.76
June	.0015	.036	.55	.08	.09	.76
July	.0015	.036	.55	.08	.09	.76
Aug.	.0015	.036	.55	.08	.09	.76
Sept.	.0015	.036	.55	.08	.09	.76
Oct.	.0015	.036	.55	.83	.09	1.56
Nov.	.0015	.036	.55	.83	.09	1.56
Dec.	.0015	.036	.55	.00	.09	.68
TOTAL	.0180	.432	6.60	2.22	1.08	10.48

TABLE 13

APWA FINDINGS ON RATE OF POLLUTANT BUILDUP ON URBAN WATERSHEDS

Amount of Dust and Dirt and Strength of BOD by Land Use

Land Use	Amt. of Dust and Dirt (lb/day/100 ft of curb)	BOD Dust and Dirt (mg/g)
Commercial	3.3	7.7
Industrial	4.6	3
Multiple family	2.3	3.6
Single family residence	0.7	5
Assumed weighted average	1.5	5

Amount of Pollutant by Type of Land Use

Item	Single Family	Multiple Family	Commercial
Water Soluble (mg/g)	6.0	5.6	12.4
Volatile Water Soluble (mg/g)	3.8	3.4	6.9
BOD (mg/g)	5.0	3.6	7.7
COD (mg/g)	40	40	39
PO_4 (mg/g)	.05	.05	.07
N (mg/g)	.48	.61	.41
Total plate counts/g (x 1000)	10,900	18,000	11,700
Confirmed coliform/g (x 1000)	1,300	2,700	1,700
Fecal enterococci/g	645	518	329

Pollutant Buildup

Referring to Table 13, it can be seen that the rate of buildup and the composition of the dust and dirt varies with the type of land use. This is probably due to the fact that several factors, such as street sweeping and traffic volume, that influence accumulation rates also vary with land use. This relationship between land usage and pollution potential was one conclusion of the APWA Study and is generally accepted as being valid.

Several other factors directly influence the buildup of dust and dirt. The most important are the existence and extent of street gutters, street sweeping practices, and the length of dry period between runoff events. Street gutters perform a dual function; they provide a protected area for dust and dirt to accumulate against and they form a channel to collect and rapidly remove runoff. Studies(12) have shown that 60 to 100 percent of all solids lying on street surfaces accumulate on the area within 12 inches of the gutter, the average amount being approximately 90 percent. Without gutters, the dust and dirt would easily be blown away by wind, vehicular traffic, etc., probably being deposited on adjoining sidewalks, lawns or buildings. During runoff events, much water would be lost to bordering pervious areas in the absence of gutters. This would result in an inefficient runoff removal system.

Street sweeping is one of the most effective means of controlling stormwater runoff pollution. It treats the problem at its source by removing some portion of the polluting dust and dirt from the street, thus reducing the pollution potential. The percentage removal or efficiency is dependent upon make of equipment, local conditions and local practices. Unfortunately, even under well organized programs, today's street sweeping operations result in only an average 50 percent removal of dust and dirt.

The length of the dry period between runoff events is perhaps the most important factor in the buildup of the pollution load. This variable directly determines the amount of dust and dirt that can accumulate on the streets if not interrupted by runoff or street sweeping.

Pollutant Washoff

The washoff of pollutants lying on the surface of streets and along street gutters occurs somewhat in the following manner:

(1) Pollutants lying on the streets are dissolved or suspended by the runoff water. If the runoff rate is high enough, larger solid particles will be scoured from the streets.

(2) The pollutants are carried to the gutter by the sheet-flow across the street.

(3) The runoff is channeled along the gutters to the collection system.

It has been assumed that the amount of a pollutant washed off the street is proportional to the amount remaining and to the rate of runoff. This has led to the mathematical relationship(38):

$$P = P_o \ (1-e^{-4.6rt})$$

where:

P = pounds of the pollutant washed off

P_o = pounds of the pollutant initially on the street

r = runoff rate (in/hr)

t = time interval (hr)

The factor of 4.6 stems from the assumption that a uniform runoff rate of 1/2-inch per hour would wash off 90 percent of the pollutant in one hour. The runoff rate is that from the impervious surfaced area only, since the runoff contribution from the pervious surfaced areas is negligible in its effect on the pollutant washoff.

The "STORM" Model

The preceding theory of pollution buildup and washoff has been incorporated into a mathematical model called "STORM"; Storage, Treatment, Overflow and Runoff Model(39). The model analyzes six components of the urban storm water cycle; rainfall, runoff, pollutant buildup and washoff, treatment, storage, and overflow. It accomplishes this by first analyzing the input data that physically describes the urban area, then by computing the quantity and quality of runoff produced by a given rainfall event. Rainfall data may be input as either an historic record or a synthetic design storm. Runoff is computed by a modified rational method which makes the model most applicable to small drainage areas of up to five square miles. Pollutant loads which can be predicted are suspended and settleable solids, 5-day biochemical oxygen demand (BOD_5), total nitrogen and orthophosphate.

The data necessary to accurately apply the model are:

(1) Rainfall

(2) Dry period preceding each rainfall event

(3) Area of watershed

(4) Runoff coefficients for pervious and impervious areas

(5) Street sweeping efficiency and interval

(6) Amount of depression storage

(7) Daily evaporation rates

(8) Land use breakdown of the water shed

(9) Length of street gutters for each land use group

(10) Pollutant data-dust and dirt accumulation rates and composition of the dust and dirt

(11) Various combinations of treatment rates and storage amounts

Most of the data are either readily available or easily determinable.

The pollutant data is the most difficult to determine. Because of this, default values for the data are built into the model. The values, shown on Table 14, are taken from the results of the APWA Chicago Study(12) and from other sources. These data should be used with caution since they are the results of studies performed in specific geographic areas which are not necessarily congruous to all areas. The default values do, however, lend themselves quite readily to calibration with observed runoff quality data for any area. This procedure should be considered necessary in all applications of the model.

A major assumption made by the Stormwater Management Study(38) concerning the relationship between suspended solids and BOD_5 is incorporated in the "STORM" Model. The assumption was made that some percentage of the suspended solids load should be added to the BOD_5 load

TABLE 14

DEFAULT VALUES FOR STORM MODEL
POLLUTANT VARIABLES (41)

Daily Rate of Dust and Dirt (D/D) Accumulation

Land Use	Amt. of D/D by Land Use (lb/day/100 ft of gutter)
Single Family Residential	0.7
Multiple Family Residential	2.3
Commercial	3.3
Industrial	4.6
Open or Park	1.5

Pound of Pollutant in Dust and Dirt (D/D)

Land Use	Lbs of Pollutant/100 lbs of D/D				
	Sus. Solids	Sett. Solids	BOD	N	PO_4
Single Family Residential	11.1	1.1	0.5	0.048	0.005
Multiple Family Residential	8.0	0.8	0.36	0.061	0.005
Commercial	17.0	1.7	0.77	0.041	0.007
Industrial	6.7	0.7	0.3	0.043	0.003
Open or Park	11.1	1.1	0.5	0.048	0.005

of the dust and dirt in order to account for the BOD_5 of leaves, grass, organic material, and drainage from roofs, grassed areas, etc. These sources were not analyzed in the APWA Chicago Stucy; only the dust and dirt lying on the streets prior to the rainfall event were investigated. It was felt that contribution from these sources may range from 3 to 10 percent. A value of 5 percent was used during the study.

For the "STORM" Model, the maximum value of 10 percent was chosen for use. Furthermore, this concept was expanded to include a contribution to the BOD_5 load from the settleable solids. Also, percentage contributions of both forms of solids to the total nitrogen and the orthophosphate loads were assumed.

While the runoff quality routine of the "STORM" Model is useful for determining the pollution potential of an urban area, the quantity routines are useful in a system's design application. By analysis of the treatment-storage-overflow interaction, combinations of treatment rates and storage capacities which will optimize the stormwater system's response to various conditions can be determined.

Application of "STORM" Model

Because of its simplified method of runoff computation, the "STORM" Model is meant to be used for small drainage areas of up to two or three thousand acres. However, most of the watersheds within the study area are much larger, several being over 100 square miles in area. Consequently, a method had to be devised to make the model applicable to large watersheds.

The approach taken was to divide each watershed into its political components. The "STORM" Model was then applied to each town or portion thereof within each watershed. However, many of these towns or portions of towns are still in excess of 5 square miles in area. It was felt that further subdivision of these towns was outside the scope of this study. Also, the extent of the urban land area, not the total land area (rural plus urban), is the determining factor. The urban land area of most of these towns, throughout the planning period, is less than 5 square miles.

The "STORM" Model output is presented as hourly pollutant loads and concentrations, hourly peak runoff, total-storm pollutant loads, and total-storm pollutant loads broken down by contribution from each land use category for only the urban land portion of each town.

Design Storm Rainfall

Hydrologically, there is considerable information available on rainfall probabilities. However, little data have been developed on rainfall rates at which various percentages of total rainfall occur. For this study, test storms were developed by the Corps of Engineers which were considered applicable to the area, for both types of rainstorm criteria.

Using rainfall-duration data of a selected frequency, a "balanced" storm rainfall was derived which contains the appropriate rainfall for each duration. Such a "balanced" storm rainfall can be defined as a rainfall sequence reflecting rainfall-duration of a selected frequency. A system designed to manage the runoff from such a "balanced" storm can be said to have a level of design equal to the frequency of the selected storm rainfall. For this study, point rainfall rates versus percent of total rainfall were estimated, first for durations of 1 hour and then for 2 to 96 hours. These estimated data were derived as follows:

(1) Basic data on the number of hours during a 10-year period (1951-1960) in which rainfall at Boston occurred in each of eight rainfall rate categories were obtained from U.S. Weather Bureau Bulletin No. 82-19, "Climatography of the United States." Data contained in this bulletin were used as a basis for developing a curve relating hourly rainfall rate to percent of total rainfall.

(2) Having determined point rainfall rates for one-hour durations, rainfall rates for other durations from 2 to 96 hours were derived by multiplying the one-hour data by rainfall-duration ratios determined from U.S. Weather Bureau Technical Papers No. 40 and 49. Through rainfall data in T.P. 40 and 49 are for various frequencies and durations, the ratios between one-hour and other multi-hour duration rainfall are relatively constant for varying frequencies. These same rainfall relations between one-hour, and durations of from 2 to 96 hours, though based on probability rather than percent of volume, were considered generally applicable for determining rainfall rates versus total rainfall, particularly in the range of higher and less frequent rates of rainfall. Developed curves, relating rainfall rate to percent of total rainfall for durations of 1 to 96 hours, were then used to derive test storms for use in estimating system requirements for managing 90 and 95 percent of storm runoff. These storms have been designated Class 90 and Class 95 storms.

Subsequent simulation studies, using long-term rainfall records for Boston, indicated that assumptions discussed in the preceding paragraph may be somewhat in error, for it was found that a system designed to manage 90 and 95 percent test storms, in actuality, would only be capable of managing about 60 and 80 percent of the storm runoff, respectively. The hourly rainfall amounts of these storms are as shown in Table 15.

TABLE 15

BALANCED STORM HOURLY RAINFALL
(Inches)

	Recurrence Interval				
Hour	1-Year	2-Year	5-Year	Class 90	Class 95
1	0.95	1.15	1.50	.27	.47
2	0.30	0.35	0.40	.09	.15
3	0.27	0.30	0.40	.05	.10
4	0.17	0.30	0.24	.05	.08
5	0.13	0.21	0.21	.04	.07
6	0.10	0.12	0.15	.03	.06
7	0.10	0.11	0.12	.03	.04
8	0.08	0.10	0.09	.02	.04
9	0.08	0.10	0.08	.02	.03
10	0.08	0.09	0.08	.02	.03
11	0.08	0.09	0.08	.01	.02
12	0.07	0.08	0.07	.01	.02
13	0.07	0.03	0.06	.01	.02
14	0.04	0.01	0.06	.01	.02
15	0.03	0.01	0.06	.01	.02
16	0.03	0.01	0.05	.01	.02
17	0.02	0.01	0.05	.01	.01
18	0.02	0.01	0.04	.01	.01
19	0.02	0.01	0.04	.01	.01
20	0.02	0.01	0.03	.01	.01
21	0.01		0.03		.01
22	0.01		0.02		.01
23	0.01		0.02		
24	0.01		0.02		
25	0.01		0.02.		

Antecedent Dry Period

Observed rainfall records for several National Weather Service stations within the study area were analyzed in order to determine the average period between rainfall events. It was found that there are between 100 and 120 days per year in which precipitation occurs. This translates to approximately three days between events. For use in this study, this interval was expanded to five days to more accurately account for the interval between storms of 0.1 inch of precipitation or greater.

The "STORM" Model accepts the interval between storms and, starting from a zero pollution accumulation condition, builds up pollutants over that interval. The assumption that the watershed is completely clean before the pollution buildup is not totally accurate. Based on a "STORM" Model analysis of 22 years of rainfall record from Boston, Massachusetts, performed on the town of Framingham, Massachusetts, a 40 percent residual of a 5-day buildup was assumed to be the initial pollution condition. This 40 percent residual corresponds to the average annual value for all runoff events. In essence, a 7-day accumulation of pollutants was used as the design condition.

It is important to understand that the results of the stormwater quality analysis are greatly influenced by this value of the estimated antecedent accumulation period - a period twice as long would produce pollutant loads and concentrations twice as great, all other factors remaining constant.

Land Use

Land use data for present conditions was obtained from the University of Massachusetts(42). The data was developed with the aid of aerial-photographic methods and was presented in 100 land use categories. For this study, only five urban land categories were used, these being single-family residential, multifamily residential, commercial, industrial and urban open land. For each town, the approximate area of the five urban land use categories within each of its hydrologic divisions was determined through analysis of U.S. Geological Survey (USGS) quandrangle sheets and knowledge of the area.

Projected land use data was obtained from a socio-economic study(43) for the subject area and the same exercises that were performed on the present condition data were performed on this data.

Urban Land Surface Characteristics

Estimates of the degree of imperviousness of each of the five urban land use categories are presented in Table 16. This information was used in the computation of the runoff coefficient used in the modified rational method of runoff computation. The coefficient is weighted by area of each urban land use category and incorporates two runoff coefficients common to all land uses, one for impervious surfaces (0.9) and one for pervious surfaces (0.15). Runoff computed using the weighted coefficient represents the hourly peak rate of runoff from the urban land area only.

The amount of depression storage, the capacity of the watershed to retain water in puddles and depressions, etc., was estimated from literature sources(41) and knowledge of the area, to be approximately 0.06 inches. This amount was subtracted from the first hours of rainfall of each storm to approximate this watershed loss.

Curb densities (feet/acre) for each land use category were developed through analysis of USGS quandrangle sheets and knowledge of the area. It was found that the

TABLE 16

DEGREE OF IMPERVIOUSNESS BY LAND USE

Land Use	Percent Imperviousness
Single-family Residential	25
Multi-family Residential	45
Commercial	60
Industrial	80
Urban Open	10

curb densities for each land use varied with the degree of urbanization of the towns. Using residential density as an index of urbanization, an analysis was made of the relationship between curb density and land use type, with the results presented in Table 17.

Estimates of the frequency and efficiency of street sweeping operations for study area towns were made. The "STORM" Model has the capability of adjusting pollutant accumulation between rainfall events to reflect the removal due to street sweeping. However, the antecedent dry period in all cases, was less than the sweeping frequency. Therefore, the design conditions for this study did not include pollutant removal due to street cleaning operations.

Dust and Dirt Accumulation and Composition

Default data was used for the development of the urban stormwater runoff quality inventory, but not before a measure of confidence in the data was determined. This was accomplished by checking the APWA Chicago Study data(12) for dust and dirt buildup rates against similar data collected in the cities of Atlanta, Baltimore, Milwaukee and Seattle for the U.S. Environmental Protection Agency(40). Table 18 presents the results of this analysis. Chicago data for the BOD_5 fraction of the dust and dirt was also checked using similar data reported as composite average values of all cities studied. The results of this comparison are presented in Table 19. Both analyses showed that the Chicago data compared fairly well with the data collected from other cities around the country. This provided sufficient justification for the use of the default data developed during the Merrimack Study(44).

TABLE 17

CURB DENSITIES BY LAND USE
(feet/acre)

Residential Density (households per acre)	Single-Family Residential	Multi-Family Residential	Commercial	Industrial	Urban Open
1-2	300	400	300	250	250
3-5	400	500	400	350	250
6 & Up	500	600	600	400	250

TABLE 18

DUST AND DIRT BUILDUP RATES
(lbs/day/100 ft curb)

City	Land Use Category: Single-Family	Multi-Family	Commercial	Industrial
Chicago	0.7	2.3	3.3	4.6
Atlanta	3.1	0.4	1.9	13.6
Baltimore	2.5	9.7	0.6	3.2
Milwaukee	2.0	11.8	4.0	21.2
Seattle	2.5	2.4	1.3	4.8
Median Value	2.5	2.4	1.9	4.8

TABLE 19

BOD FRACTION OF DUST AND DIRT
(milligrams/gram)

Reference	Residential: General*	Residential: Single-Family	Residential: Multi-Family	Commercial	Industrial
Table 7(40)		13.4	19.3	12.0	21.8
Table 45(40)	12.7			11.6	10.4
Table 46(40)	8.5			7.6	7.1
APWA, Chicago Study(12)		18.2	11.8	25.0	10.0

Land Use Category

*Reported as residential only and includes both single- and multi-family type uses.

Results

Predicted concentrations and mass of suspended and settleable solids, biochemical oxygen demand (5-day), total nitrogen, and orthophosphate in the runoff were determined for each design storm. Hourly values for these parameters were given for each community and watershed in the study area. Similar data output was developed for each of the study years.

A sample data sheet presenting hourly pollutant concentrations and loads (mass) contributed by the town of Acton during the 5-year storm event under 2020 land use conditions is shown on Figure 3.

DEVELOPMENT OF STORMWATER MANAGEMENT METHODOLOGY

Introduction

The urban area within each community is characterized by a high proportion of impervious or nearly impervious surfaces which include impervious pathways for guiding the flow of stormwater runoff. Over the surface, stormwater flows in curbed gutters, lined channels, paved parking areas, streets, etc.; and underground, in storm, separate sanitary, and combined, sewers. The entire drainage system includes all appurtenances that guide, control or otherwise modify either the quantity, rate of flow, or quality of runoff from urban drainage, such as catch basins, storage basins, inlets, manholes, sediment traps, weirs, and outfall structures.

The urban drainage area as a whole is made up of a number of subsystems consisting of surface elements, each of which is characterized by its area, degree of imperviousness, slope and certain coefficients that relate to the area's production of runoff and its quality.

EVENT NO. 5 - 5-YEAR STORM

TOWN AND WATERSHED ACTON - ASSABET RIVER 2020

TOTAL AREA OF TOWN IN WATERSHED 12998 ACRES (URBAN LAND AREA = 7806)

	SINGLE-FAMILY RESIDENTIAL(SFR)	MULTI-FAMILY RESIDENTIAL(MFR)	COMMERCIAL (COMM)	INDUSTRIAL (IND)	URBAN OPEN LAND
PCNT IMPERVIOUSNESS	25	45	60	80	10
TOTAL ACRES	2596	1731	836	2399	244
LENGTH OF STREET GUTTERS (FT/ACRE)	400	500	400	350	250
STREET SWEEPING INTERVAL (DAYS)	60	14	14	14	60

STORM RAINFALL (MINUS .06IN. LOSS TO DEPRESSION STORAGE),HUNDREDTHS OF INCHES

0 0 3 5 6 7 8 9 15 24 40 150 40 21 12 8 8 6 6 5 4 3 2 2

COMPUTED RUNOFF COEFFICIENT 0.52213

ANTECEDENT DRY DAYS 5

INTERVAL	SUSPENDED SOLIDS (LBS)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (LBS)	SETTLEABLE SOLIDS (MG/L)	B O D (LBS)	B O D (MG/L)	NITROGEN (LBS)	NITROGEN (MG/L)	PHOSPHATE (LBS)	PHOSPHATE (MG/L)	RUNOFF (CFS)
3	475.	17.1	18.	0.6	305.	11.0	55.	1.96	6.	0.18	123.
4	932.	20.2	30.	0.6	457.	9.9	90.	1.95	9.	0.19	205.
5	1182.	21.3	36.	0.6	466.	8.4	101.	1.81	10.	0.17	247.
6	1440.	22.3	43.	0.7	454.	7.0	110.	1.69	11.	0.16	288.
7	1696.	23.0	51.	0.7	430.	5.8	117.	1.57	12.	0.15	329.
8	1944.	23.4	58.	0.7	401.	4.8	123.	1.47	12.	0.14	370.
9	4024.	29.0	121.	0.9	616.	4.4	228.	1.64	23.	0.16	616.
10	7386.	33.3	265.	1.2	898.	4.1	391.	1.76	39.	0.18	986.
11	12296.	33.3	656.	1.8	1316.	3.6	631.	1.71	63.	0.17	1644.
12	17348.	12.5	3071.	2.6	1826.	1.3	907.	0.65	91.	0.07	6165.
13	15.	0.0	2.	0.0	2.	0.0	1.	0.00	1.	0.00	1644.
14	4.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	863.
15	2.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	493.
16	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	329.
17	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	329.
18	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	247.
19	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	247.
20	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	205.
21	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	164.
22	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	123.
23	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	82.
24	1.	0.0	1.	0.0	1.	0.0	1.	0.00	1.	0.00	82.
TOTAL	48740.		4945.		7167.		2747.		272.		
SFR	5646.		559.		830.		312.		31.		
MFR	11145.		1114.		1638.		653.		64.		
COM	13128.		1312.		1934.		701.		72.		
IND	18110.		1890.		2660.		1041.		101.		
OPN	711.		70.		105.		39.		4.		
TOTAL	48740.		4945.		7167.		2747.		272.		

FIGURE 3. Example of "STORM" Model Computer Program Data

The runoffs from the subsystems, in turn, become the inputs to the storm sewer, or transport system, which drains the urban area. These inputs may be described in terms of a flow rate-time graph, or hydrograph; and a pollutant time graph, or pollutograph.

Figure 4 illustrates the input-output relationships for a typical stormwater management system(45). Input to the drainage area is comprised of rainfall that may be described in terms of an intensity-time graph, or rainfall hyetograph, as shown at the left in Figure 4(a). Within the drainage area a certain mass of a quality constituent, or pollutant, may exist at the outset of the storm. The pollutant may be taken up or delivered by the flow at mass rates and concentrations that may depend on the nature of the storm, the character of the surface, and the sources of the pollutant, as shown at the right in Figure 4(a).

The overland flow process modifies the rainfall hyetograph by infiltration, surface retention, and transient storage so that at the inlet to the storm sewer, a much modified hydrograph is observed, such as is shown at the left in Figure 4(b). In addition, the combined flow and quality processes produce an inlet pollutograph, a time-concentration graph of a particular pollutant as it leaves the surface runoff subsystem and enters the storm sewer, as shown at the right in Figure 4(b). These two graphs, one of flow and the other of quality, comprise the output of the surface runoff subsystem and become the input to the storm sewer transport system(45).

The transport system, or storm drainage system, is comprised of the physical works for conveying storm waters and their associated pollutant loads from all of the inlets in the system through a network of underground conduits to a point, or points, of disposal. Enroute, flow and quality are both modified by accretions to the

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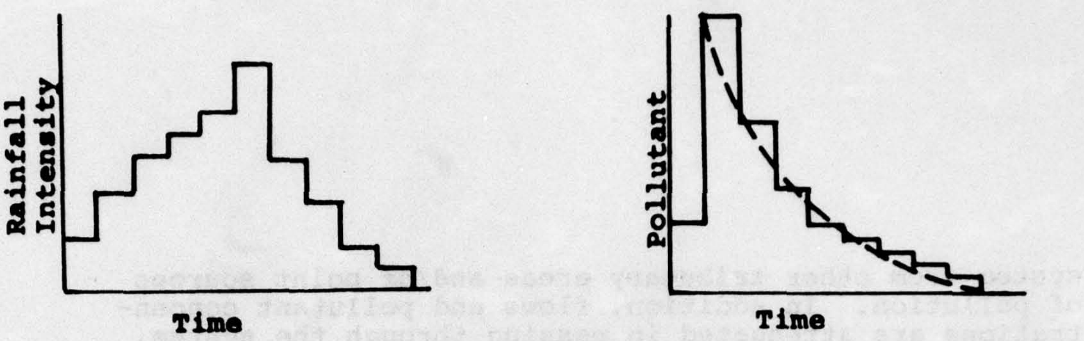
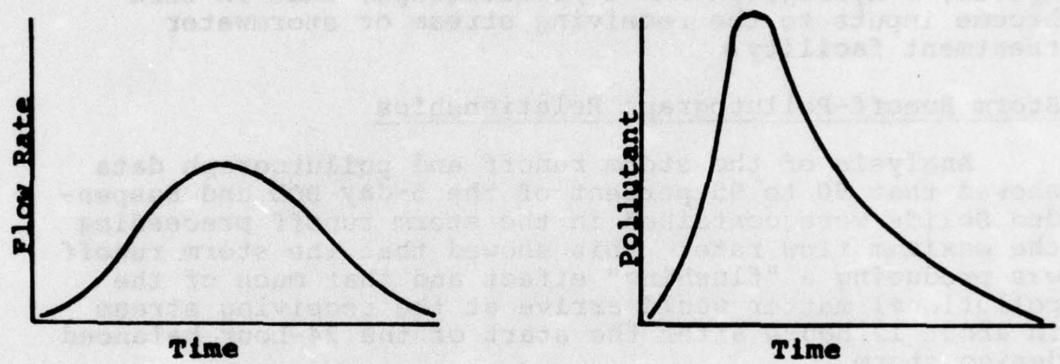
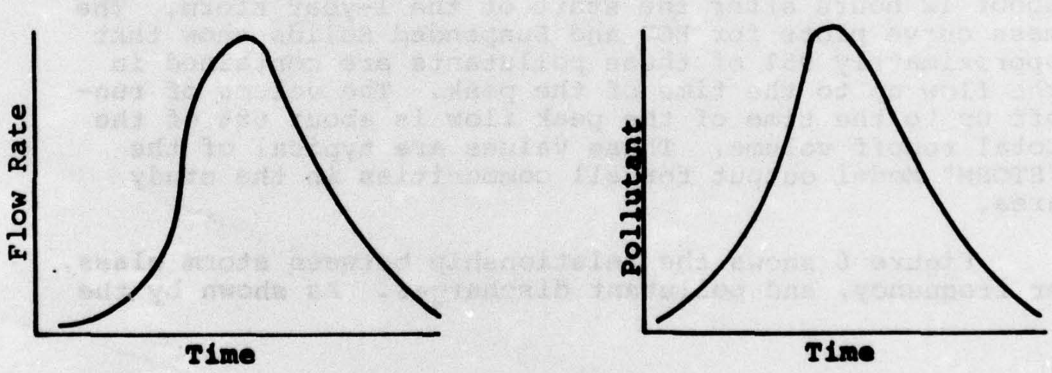


(a) Input to Drainage Area



(b) Drainage Area Output Storm Sewer Input



(c) Storm Sewer Outfall Output-Input to Stormwater Treatment Facility

FIGURE 4. Stormwater Management System Input-Output Relationships

system from other tributary areas and/or point sources of pollution. In addition, flows and pollutant concentrations are attenuated in passing through the system, the degree of modification depending on such factors as system storage, off-line storage, phase relationships of inflow hyetographs and pollutographs, and certain properties of the system. The two inserts in Figure 4(c) illustrate a typical set of outputs from the transport system, a hydrograph and a pollutograph, that in turn become inputs to the receiving stream or stormwater treatment facility.

Storm Runoff-Pollutograph Relationships

Analysis of the storm runoff and pollutograph data showed that 90 to 95 percent of the 5-day BOD and Suspended Solids were contained in the storm runoff preceeding the maximum flow rate. This showed that the storm runoff was producing a "flushing" effect and that much of the pollutional matter would arrive at the receiving stream in about 12 hours after the start of the 24-hour balanced design storm.

Figure 5 shows the relationship of two mass pollutographs to the storm runoff for the Town of Canton. As shown by the figure, the storm runoff peak flow occurred about 12 hours after the start of the 1-year storm. The mass curve plots for BOD and Suspended Solids show that approximately 95% of these pollutants are contained in the flow up to the time of the peak. The volume of runoff up to the time of the peak flow is about 68% of the total runoff volume. These values are typical of the "STORM" Model output for all communities in the study area.

Figure 6 shows the relationship between storm class, or frequency, and pollutant discharges. As shown by the

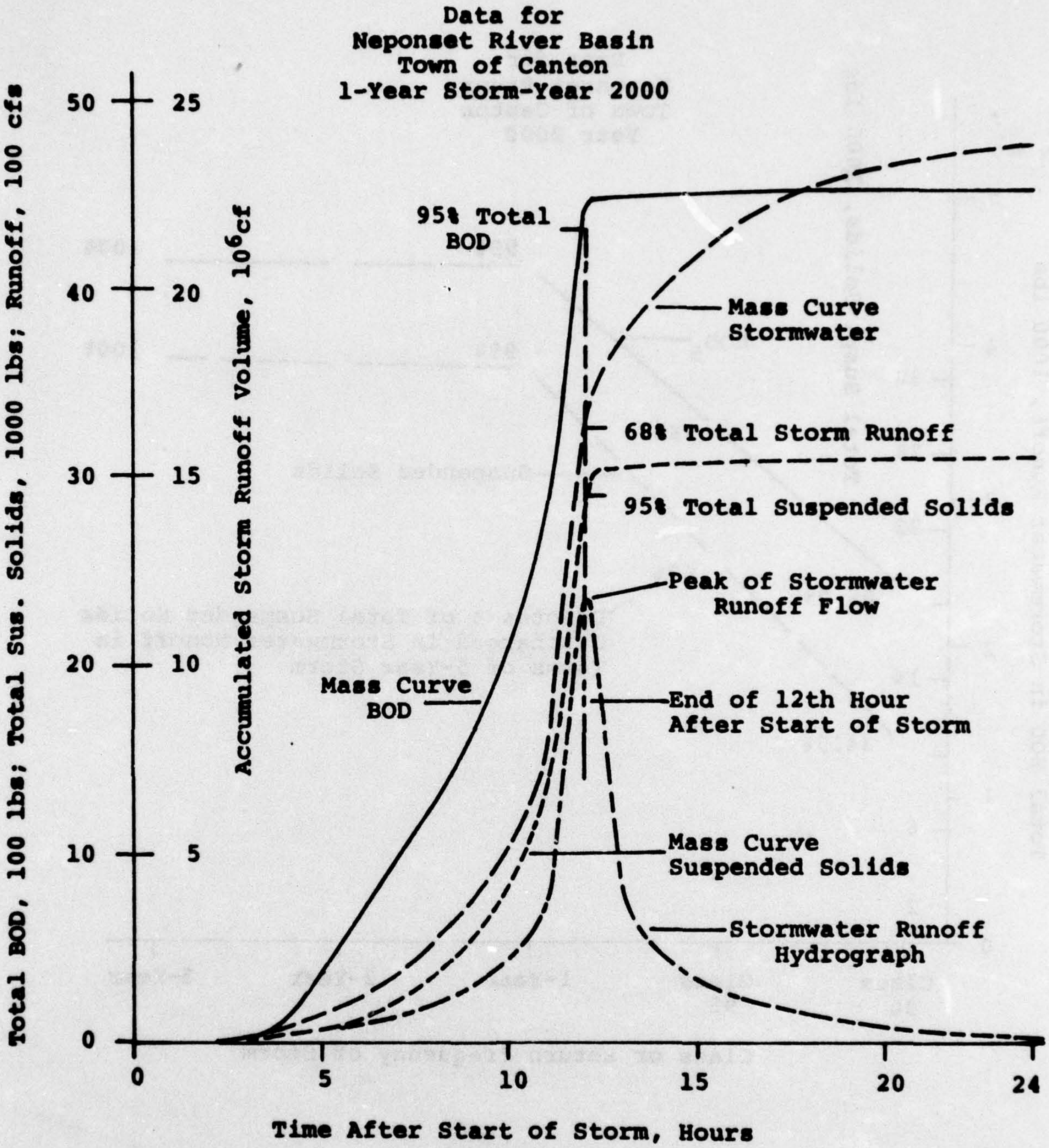


FIGURE 5. Stormwater Runoff-Pollutograph Relationships

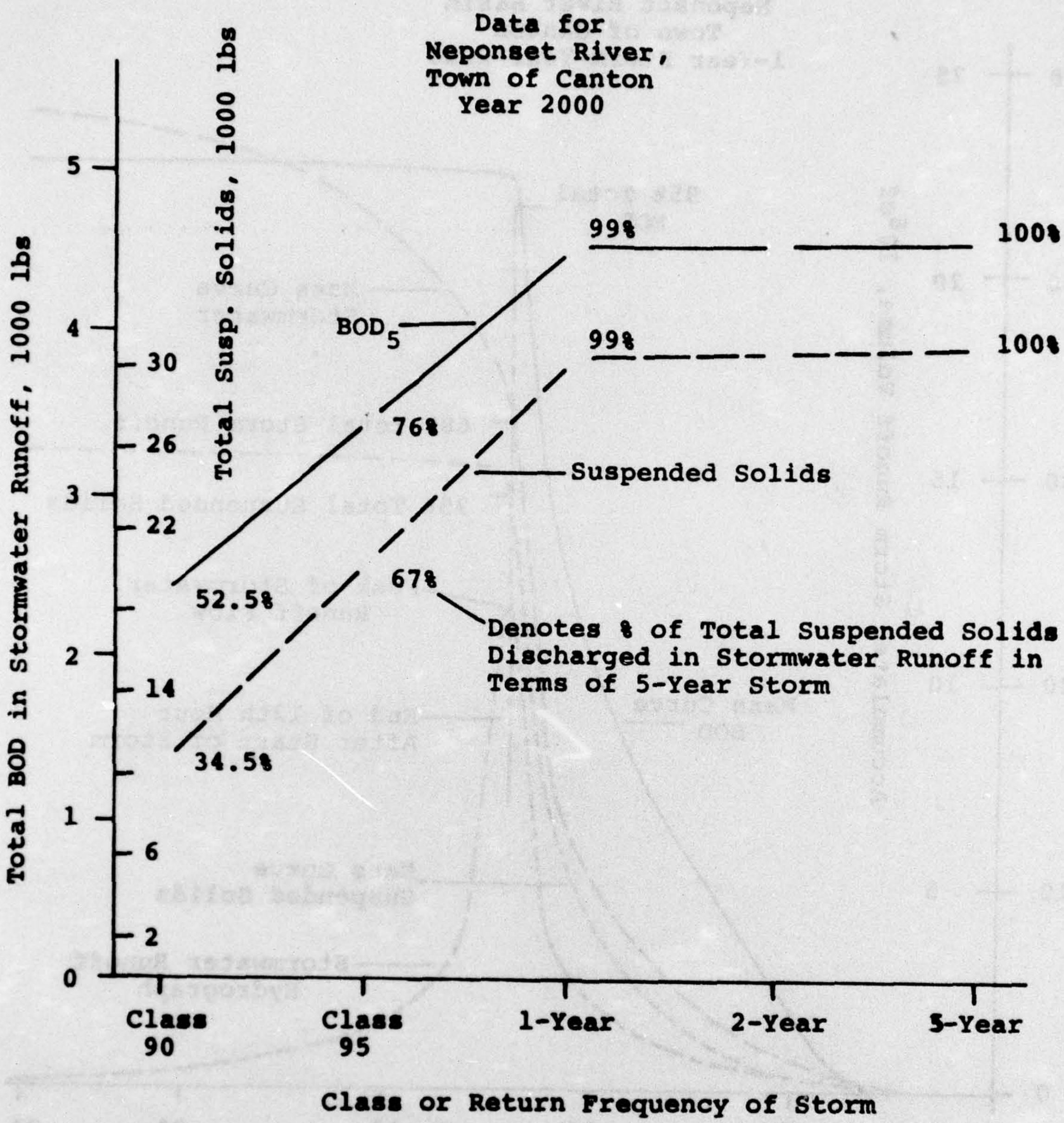


FIGURE 6. Relationships Between Storms and Pollutant Discharges

figure, the total pounds of suspended solids discharged from the drainage area ranged from 34.5% for the Class 90 storm, to 99% for the 1-Year Return Frequency Storm, to 100% for the 5-Year Storm. Similarly, the 5-day BOD discharged from the community varied from 52.5% for the Class 90 storm, to 99% for the 1-Year Storm, to 100% for for the 5-Year Storm. This indicates that the maximum discharge of pollutants from storm runoff can be expected from a 1-Year Storm for all practical purposes. The peak runoff from a drainage area for a given duration storm can be expected to occur at the same time from the start of the storm, regardless of the storm class or frequency. The best cost-effective storm management will probably be obtained by treating all of the storm flow up to the peak flow rate for the 1-Year Storm. This will insure that 90-95% of the major pollutants, i.e. BOD, and Suspended Solids, will be retained in storage for subsequent treatment. The 1-Year Storm was selected as the design storm for this study.

Other pollutant discharge data had also been provided by the "STORM" Model Computer Program; these included pollutographs on settleable solids, nitrogen, and orthophosphate. It was felt that treatment consideration of suspended solids would also provide for the settleable solids, and that treatment of storm flows for nutrient removal would be extremely expensive. Thus, stormwater treatment alternates for nitrogen or phosphate removal were not developed for inclusion in the study.

STORMWATER MANAGEMENT ALTERNATIVES

Methodology

Prior to the selection of stormwater treatment alternatives, for use throughout the study area, a watershed considered likely to offer a wide range in treatment facility requirements was studied, the Charles River Basin. A previous report(46) on the Charles River Basin provided valuable information regarding this watershed particularly in respect to its drainage sub-areas. The report showed that the watershed could be subdivided into drainage sub-areas, each of which drained to a different point on the Charles River and that the urban areas in the watershed would logically drain in accordance with topographical features, not political boundaries. This indicated that limitations would have to be imposed upon utilizing the "STORM" Model data, restricting its usage to a general purpose design and not specific, definitive design.

When the general stormwater treatment requirements for the Charles River Basin were taken into consideration along with the information obtained from the analysis of storm runoff-pollutographs, four stormwater management alternatives were developed to handle all situations. The alternatives are shown schematically in Figure 7 (with one exception, Alternate No. 1), and are briefly described in Table 20. They are labelled Alternate 1, Alternate 2, etc.

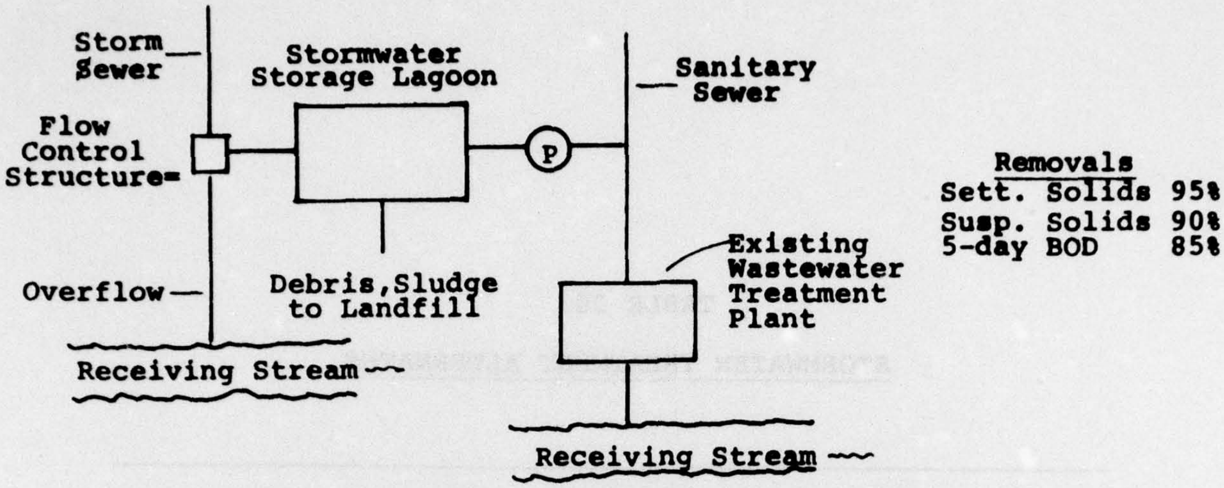
Alternate No. 1: No Treatment

As indicated in Table 20, Alternate No. 1 is to be used where the drainage area is relatively small and the amount of pollutional matter is insignificant and relatively harmless. This situation usually occurs

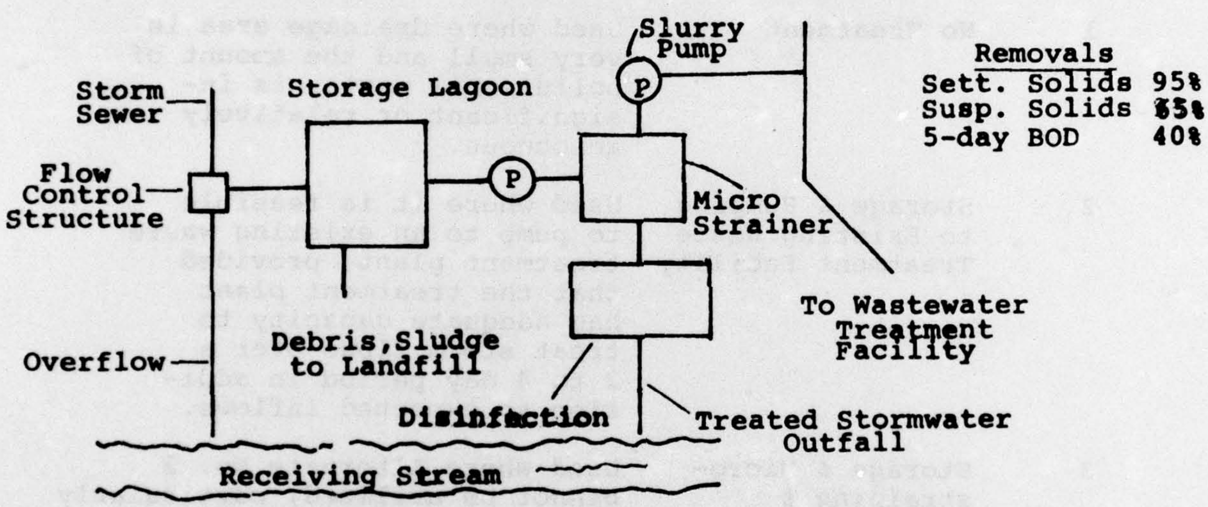
TABLE 20

STORMWATER TREATMENT ALTERNATES

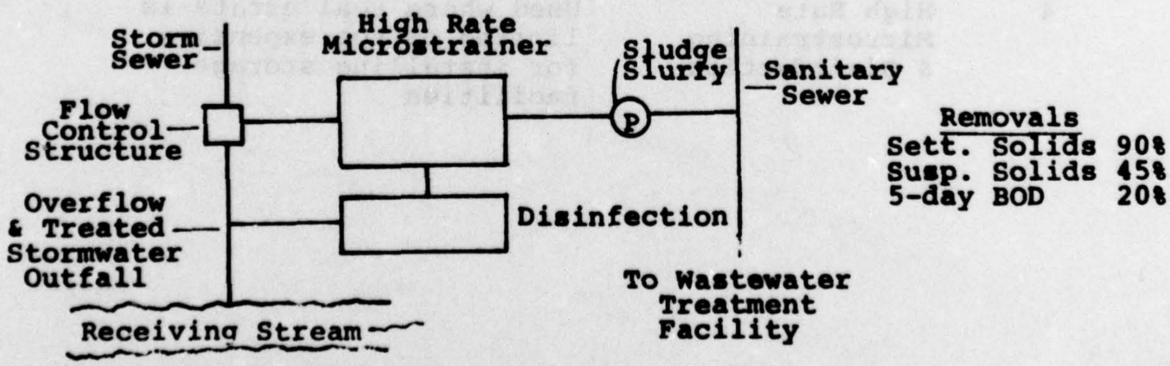
No.	Description	Conditions for Use
1	No Treatment	Used where drainage area is very small and the amount of pollutional matter is insignificant or relatively innocuous.
2	Storage & Pumping to Existing Waste Treatment Facility	Used where it is feasible to pump to an existing waste treatment plant, provided that the treatment plant has adequate capacity to treat storm flows over a 2 to 4 day period in addition to expected inflows.
3	Storage & Microstraining & Disinfection	Used where Alternate No. 2 cannot be utilized, particularly in remote areas some distances from an existing treatment facility.
4	High Rate Microstraining & Disinfection	Used where real estate is limited or too expensive for installing storage facilities



ALTERNATE NO. 2: STORAGE & PUMPING



ALTERNATE NO. 3: STORAGE, FILTRATION & DISINFECTION



ALTERNATE NO. 4: HIGH RATE FILTRATION & DISINFECTION

FIGURE 7. Schematic Diagrams for Stormwater Treatment Alternates

where fringe towns are overlapped by two or more watersheds. Because such watershed overlapping of a town's area takes place at the highest elevation in the watershed, the tributary area of interest must frequently be drained by a small stream which later joins the main watershed drainage stream. It was assumed that small streams probably exert little pollutional effect on larger rivers, hence, the "no treatment" alternate was established. Careful land use policy could extend use of this alternate for some time in the future.

Alternate No. 2: Storage and Pumping

In many areas it may be possible to simply store the stormwater runoff immediately following a storm and to pump it later to an existing wastewater treatment facility for treatment. This alternative is next in line to alternate 1 as far as cost is concerned. Since many communities within the study area do have sanitary sewers, this alternate should receive first consideration wherever stormwater treatment is required. Of course, the existing wastewater treatment facility should have sufficient treatment capability to handle the stormwater it receives, although such treatment may be performed during periods of low flow at the plant over a 3 to 4 day period.

In the event that the treatment plant capacity is relatively small, consideration should be given to expanding the treatment capacity of the plant. Pollutant removals will be similar to those normally experienced at the facility which are assumed to be as indicated in Figure 7.

Alternate No. 3: Storage, Filtration and Disinfection

In the event that Alternate 2 cannot be employed, a stormwater treatment facility may be provided. The facility should be able to remove a reasonable amount of pollutional matter, however, in view of the high storm runoff that has to be treated and the requirement that such stormwater treatment should proceed automatically with no manpower attendance, the facility should be simple in design and operational requirements. As shown by Figure 7, stormwater is first stored, then taken from storage at a constant rate and passed through a microstrainer. The flow is then disinfected and discharged to the receiving stream.

Figure 7 also presents estimates regarding pollutant removals. These estimates represent a general concensus of removal rates as given by the literature. The storage lagoon is assumed to provide some treatment through sedimentation.

Alternate No. 4: High Rate Filtration & Disinfection

As indicated by previous cited studies, the best way to achieve reasonable stormwater treatment costs is to incorporate storage with treatment. In some situations, however, this may not be possible, especially when land for stormwater storage is limited or very expensive. Alternate 4 is designed to handle the incoming stormwater flow rate on a variable flow basis by providing high-rate microstraining filtration plus disinfection. The pollutant removals for this alternate are not as good as they are for Alternate 3 because of the absence of the storage facility which aids considerably in the treatment of stormwater. Figure 7 indicates estimates of pollutant removals using this alternate.

Basis of Design Summary

Criteria and data employed or found useful in the design of stormwater treatment facilities for the study area are presented in Table 21. These data are integrated with the following discussion which presents details on specific aspects of stormwater treatment facilities.

Flow Regulations to Treatment Facility

Under the arrangement proposed to treat stormwater runoff from an urban area for a design storm having a return frequency of one year and a duration of 24 hours, the stormwater runoff will be directed into a storage lagoon which has a retention capacity equal to all storm runoff from the start of the storm up to the time of the peak flow rate. This stored runoff calculated from the "STORM" Model output, would then receive treatment or be transferred according to the alternate treatment scheme considered suitable for the particular situation at hand. Storm flow volumes exceeding the accumulated volume for the design storm up to its peak flow rate would not be stored for treatment. As explained previously, such flows would contain very little pollutant matter since the "first flush" of the stormwater that is stored will contain 90 to 95% of the BOD and suspended solids.

Since the stormwater from the design storm will continue to enter the lagoon until the lagoon fills, only a simple flow control structure is needed to divert the stormwater. This could be a simple chamber fitted with an overflow weir whose overflow elevation is equal to the elevation of the desired lagoon capacity. Thus when the proper lagoon depth is attained, excess stormwater will simply spill over the weir and pass on to the receiving stream. A simple electrical control or probe could be used to actuate valves to close and thereby prevent further flows from entering the lagoon.

The above arrangement would be suitable for Alternate treatment schemes 2 and 3. In the case of Alternate 4, storage is not provided. The diversion structure

TABLE 21

BASIS OF DESIGN-DATA SUMMARY

URBAN AREA DEVELOPMENT	
Design Year	2000
DESIGN STORM	
Return Frequency	1-Year
Duration, Hours	24
Antecedent Dry Period, days	5
AVERAGE NO. STORM EVENTS	
Per Year	50
STORAGE LAGOONS	
Capacity	Varies-See Text
Maximum Water Depth, ft.	25
Freeboard, ft.	3
Dike Side Slopes, ratio	3:1
Pump Out Rate, days	3.5
FILTRATION EQUIPMENT	
Rotating Drum Type	
Design Flow Rate, gpm/sf	
Alt. No. 3:	10
Alt. No. 4:	45
Max. Flow Rate through High Rate Microstrainer to be 75% of Max. Class 95 Flow Rate	
Sludge Produced = 1% Stormwater Flow Rate	
DISINFECTION	
By On-Site Sodium Hypo-Chlorite Generation	
Chlorine Dosage, Applied, mg/l	5
Detention Time @ Peak Flow, min.	15
LAGOON DEBRIS & SLUDGE	
Debris Disposal by Landfill	
Lagoon Sludge to be Pumped to Existing Sanitary Interceptor	
Time for Lagoon Cleanup, days	1.5

will direct flow to the filtration equipment, however, only those flow rates which do not exceed 75% of the maximum Class 95 stormwater flow rate will be treated. Excess flows will spill over the overflow weir in the flow control structure and pass untreated to the receiving stream.

Storage Lagoons

Storage facilities for stormwater management may be constructed in-line or off-line; they may be open or closed; and they may be located inland or at the receiving stream shore. Storage facilities should have a basic simplicity in design and operation. They should be capable of responding without difficulty to intermittent and random storm behavior. Because they are capable of providing flow equalization at as low a rate as possible, consistent with the objectives of treating stormwater pollution, they are the most cost-effective means available for management of urban stormwater runoff. Their principal drawbacks are the large land area they may take up and their cost.

In this report, only off-line, open storage lagoons are considered for stormwater management. The lagoons will be designed to have a maximum water depth of 25 feet and a minimum freeboard of 3 feet. The lagoons will have side slopes having a ratio of 3 to 1 and will be constructed with an asphalt bottom surface so that debris and sludge left behind after the treatment phase can be swept up or moved by street cleaning type vehicles.

Microstrainers

The microstrainer uses finely woven stainless steel mesh mounted on the periphery of a continusouly revolving drum. The drum is partially submerged in the flowing stormwater, the top of the drum rotating in air and being backwashed downwards into a trough placed inside the microstrainer. Backwash is continuous with water taken from the downstream side of the drum, that is, the strained effluent. The wastewater containing the intercepted solids flows from the waste hopper to a conduit from which it is removed for treatment at an existing waste treatment facility.

Organic filming on the fabric mesh may be removed by shock chlorination or use of UV equipment arranged horizontally across the drum top. This eliminates biological slime by irradiation. The nature of the suspended solids in storm flows indicates that the solids are "noncompressible" (38) which produces a lower rate of plugging. Consequently, it is possible to maintain a higher flow rate than is normally achieved in tertiary sewage treatment. Operating heads have been increased to a maximum of 24 inches for stormwater treatment because the microstrainers are in operation infrequently. In the case of storm sewer overflow, which averages only 3% of the operating time, 30 years of such intermittent service would equal one year of continuous operation.

Design flow rates for microstrainers range from an optimum maximum treatment rate of 10 gpm/sf to 45 gpm/sf for high rate installations without storage facilities.

Disinfection

Disinfection of stormwater treated under Alternates 3 and 4 will be accomplished by on-site sodium hypochlorite generation facilities. The sodium hypochloride is produced from an electrochemical process requiring only sea water or brine and electricity. These facilities will eliminate the need to bring in liquid chlorine which could pose a safety hazard to the sourrounding area.

Proposed Stormwater Management Facilities

The stormwater management requirements for each community within the study area were determined and are presented in the Appendix (Volume II of this Report). Because sufficient data and information were not available regarding probable locations of treatment facilities, availability of land for storage lagoons and treatment plants, locations of existing and future storm and sanitary sewers, it was not possible to reliably specify the treatment alternate that should defintely be used in a particular community. Thus, where doubt existed as to the choice of an alternate, a second and even a third alternate are presented.

In the process of selecting treatment alternates, there is a tendency to choose the simplest alternate, No. 2, consisting of storage of the stormwater runoff and pumping it later to an existing wastewater treatment plant. There is substantial merit in using this alternate; a simpler, more economical installation results; the degree of treatment is the highest possible; sludge disposal problems are reduced; and power consumption costs for sodium hypochlorite generation facilities are eliminated.

As indicated in the preface to the appendix in Volume II, the treatment alternates, their code designations, and the treatment accorded are as follows.

Alternate	Treatment
No. 1 (NT)*	No treatment is required.
No. 2 (SP)	Stormwater runoff is to be stored in lagoons and pumped to existing or future wastewater treatment facilities over a 3 to 4 day period.

No. 3 (SMD)	Stormwater is to be stored and subsequently treated by microstaining and disinfection over a 3 to 4 day period.
No. 4 (MD)	Stormwater is to be treated as it enters a stormwater treatment facility by high rate microstaining and disinfection.

*Denotes treatment code for alternate.

The treatment alternate finally chosen for each community is shown in Table 22 along with a summary of costs. In many cases the use of Alternate No. 2 was not chosen because it was felt that a more realistic stormwater management program should include specific stormwater treatment facilities such as those provided by Alternates 3 or 4. Only in cases where there was substantial belief that storage with pumping provided the best way to manage the stormwater problem was Alternate No. 2 employed.

As indicated in the Appendix and in Table 22, the stormwater management alternates, initially and finally chosen for the communities, appear, in general, to be dependent upon the character of the community and its location in the watershed. Communities located upstream usually have low population densities. These communities are rural-type in nature and are considered to be likely candidates for Alternates 1 (no treatment), and 2 (storage and pumping), because they probably would have land available for storage lagoons and also because their urban areas are usually unbothered by high density vehicular traffic and high population activity. Also, these areas would probably produce stormwater runoffs which are less pollutant intensive than the more densely settled communities having high amounts of commercial and industrial activities.

The densely settled communities would probably not have much land available for stormwater storage and any land useful for such purposes would probably be very expensive. Stormwater alternates for these communities would probably be limited to Alternate 2; 3, (storage, microstraining, and disinfection); and 4, (high rate microstraining or filtration and disinfection), with the latter of the 3 probably dominating.

In between the two types of communities described above would be the usual suburban, "bedroom" type community. In this type of community, Alternates 2 and 3 probably would be used most with an occasional use of Alternate 4.

Those communities in watersheds near the ocean, some of which are described as "locals," probably would use Alternate 3 or 4 because they are not densely settled and their urban area runoff would probably have low pollution intensity.

As mentioned above, the selection of a definite alternate for a given community was rather arbitrary, however, as much care as possible was taken in selecting the alternates for a given watershed so that each watershed might have the proper "mix" of Alternates and thereby assure a truer picture of stormwater management costs.

COSTS FOR STORMWATER MANAGEMENT IN STUDY AREA

Table 22 presents a summary of all stormwater management costs for the study area watersheds by community. Costs for each community alternate were determined from cost curves which were specially prepared for

TABLE 22

SUMMARY OF STORMWATER MANAGEMENT COSTS

FOR STUDY AREA WATERSHEDS BY COMMUNITY

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
ASSABET RIVER				
Acton	SMD	6,000	410	9.9
Berlin	SMD	2,250	80	16.0
Bolton	SMD	2,150	70	16.5
Boxborough	SMD	1,500	35	22.3
Boylston	NT	-	-	-
Carlisle	SMD	1,950	55	17.4
Clinton	NT	-	-	-
Concord	SMD	2,350	85	14.6
Grafton	NT	-	-	-
Harvard	NT	-	-	-
Hudson	SMD	3,125	140	12.5
Littleton	SMD	1,950	55	16.9
Marlborough	SMD	2,350	85	14.5
Maynard	SMD	2,200	75	16.5
Northborough	SMD	3,040	135	12.8
Shrewsbury	SMD	2,350	85	15.0
Stow	SMD	2,250	80	14.9
Sudbury	SP	250	5	6.6
Westborough	SMD	2,250	80	14.8
Westford	SP	250	5	7.1
TOTAL		36,235	1,480	13.4

*Treatment Alternates=
NT = No Treatment
SP = Storage & Pumping
SMD = Storage, Microstraining, Disinfection
MD = High Rate Microstraining, Disinfection

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
BEVERLY HARBOR				
Beverly	SMD	3,750	195	11.6
Danvers	SMD	4,125	130	11.1
Lynn	NT	-	-	-
Lynnfield	NT	-	-	-
Peabody	SMD	4,675	275	10.7
Salem	SMD	1,800	45	18.4
Wenham	NT	-	-	-
TOTAL		14,350	745	11.5
BLACKSTONE RIVER				
Bellingham	SMD	2,250	80	14.6
Franklin	NT	-	-	-
Hopkinton	NT	-	-	-
Milford	NT	-	-	-
Westborough	NT	-	-	-
Wrentham	SP	290	6	6.8
TOTAL		2,540	86	13.1
CHARLES RIVER				
Arlington	SP	160	3	10.1
Ashland	NT	-	-	-
Bellingham	SMD	2,000	70	16.2
Belmont	SMD	1,700	40	18.0
Dedham	SMD	2,650	110	12.9

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
Dover	SMD	2,600	120	16.8
Franklin	SMD	3,500	170	12.1
Holliston	SMD	3,400	170	12.2
Hopedale	NT	-	-	-
Hopkinton	NT	-	-	-
Lexington	SMD	2,500	100	13.8
Lincoln	SMD	2,150	75	15.0
Medfield	SMD	3,000	135	12.9
Medway	SMD	2,600	105	13.4
Mendon	NT	-	-	-
Milford	SMD	2,850	125	9.1
Millis	SMD	2,300	82	14.0
Natick	SMD	2,800	125	12.9
Needham	SMD	4,500	270	11.0
Newton	SMD	6,200	420	9.7
Norfolk	SMD	4,200	235	11.2
Sherborn	SMD	3,100	140	12.7
Somerville	SMD	1,750	41	17.6
Walpole	NT	-	-	-
Waltham	SMD	5,400	350	10.2
Watertown	SMD	2,200	75	14.9
Wayland	NT	-	-	-
Wellesley	SMD	4,400	245	11.1
Weston	SMD	2,850	125	12.7
Westwood	SMD	1,800	65	16.8
Wrentham	SMD	1,900	75	17.1
TOTAL		72,510	3,471	12.2

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
CHELSEA RIVER				
Everett	NT	-	-	-
Revere	SMD	1,250	24	26.3
TOTAL		1,250	24	26.3
CONCORD RIVER				
Bedford	SMD	2,000	60	17.2
Billerica	SMD	3,475	170	11.8
Carlisle	SMD	2,450	90	14.4
Chelmsford	SMD	4,300	245	10.5
Concord	SMD	2,000	60	16.8
Lincoln	NT	-	-	-
Lowell	SMD	3,100	140	12.9
Tewksbury	SP	260	5	6.9
Westford	SP	150	3	9.5
TOTAL		17,735	773	12.6
ESSEX BAY				
Beverly	NT	-	-	-
Essex	SMD	2,000	60	16.3
Gloucester	SP	200	5	8.4
Hamilton	NT	-	-	-
Ipswich	NT	-	-	-
Wenham	NT	-	-	-
TOTAL		2,200	65	15.1

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
GLOUCESTER HARBOR-ANNISQUAM RIVER				
Gloucester	SMD	3,200	150	12.5
Rockport	NT	-	-	-
TOTAL		3,200	150	12.5
IPSWICH RIVER				
Andover	SP	325	7	6.8
Beverly	SMD	2,250	80	14.9
Billerica	NT	-	-	-
Boxford	SMD	2,750	110	13.8
Burlington	SMD	2,500	100	14.5
Danvers	SMD	1,900	55	18.5
Hamilton	SMD	2,750	110	13.1
Ipswich	SMD	3,750	195	11.7
Lynnfield	NT	-	-	-
Middleton	SMD	4,475	255	10.9
North Andover	SMD	1,400	30	21.4
North Reading	SMD	3,200	150	12.7
Peabody	SMD	1,950	55	17.2
Reading	SMD	1,900	55	18.0
Tewksbury	NT	-	-	-
Topsfield	SMD	3,000	130	12.9
Wenham	SMD	2,250	80	14.7
Wilmington	SMD	4,850	100	14.5
TOTAL		39,250	1,627	12.7

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
LOCAL NO. 1 CAPE ANN				
Gloucester	SMD	1,500	35	19.8
Rockport	SMD	2,425	85	14.7
TOTAL		3,925	120	16.2
LOCAL NO. 2 MANCHESTER HARBOR AREA				
Beverly	SMD	1,400	30	20.9
Gloucester	SP	250	5	7.6
Manchester	SMD	2,900	125	12.8
Wenham	NT	-	-	-
TOTAL		4,550	160	13.8
LOCAL NO. 3 MARBLEHEAD HARBOR-LYNN HARBOR AREA				
Lynn	SMD	2,650	105	13.7
Marblehead	SMD	2,050	60	17.0
Nahant	SP	325	7	7.2
Swampscott	SMD	1,950	55	16.9
TOTAL		6,975	227	14.7
LOCAL NO. 4 BOSTON HARBOR				
Revere	SP	325	7	7.0
Winthrop	MD	1,750	88	35.8
TOTAL		2,075	95	23.6

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
LOCAL NO. 6 QUINCY BAY				
Milton	SP	200	5	9.3
Quincy	SMD	2,525	100	13.6
TOTAL		2,725	105	13.2
LOCAL NO. 7 HINGHAM HARBOR-HULL BAY				
Cohasset	SP	290	6	6.6
Hingham	SMD	3,750	195	11.7
Hull	SMD	1,850	55	19.2
Norwell	NT	-	-	-
Rockland	NT	-	-	-
Weymouth	SP	200	5	7.6
TOTAL		6,090	261	12.5
LOCAL NO. 8 COHASSET HARBOR-SCITUATE HARBOR				
Cohasset	SMD	2,800	115	13.0
Norwell	NT	-	-	-
Scituate	SMD	4,000	210	11.3
TOTAL		6,800	325	11.9
LOCAL NO. 9 GREEN HARBOR-DUXBURY BAY				
Duxbury	SMD	3,400	165	11.8
Marshfield	SMD	2,000	60	16.6
Pembroke	NT	-	-	-
TOTAL		5,400	225	13.0

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
MERRIMACK RIVER				
Boxford	SP	150	3	9.9
Chelmsford	SMD	1,800	50	19.0
Tewksbury	SMD	1,900	55	18.2
Westford	NT	-	-	-
TOTAL		3,850	108	15.9
MYSTIC RIVER				
Arlington	SMD	3,000	130	13.1
Belmont	SMD	2,200	70	15.5
Burlington	SMD	1,500	35	21.5
Everett	SMD	2,100	65	16.4
Lexington	SMD	2,250	80	14.6
Malden	SMD	2,200	70	15.3
Medford	SMD	3,400	165	11.9
Melrose	SMD	2,350	85	14.9
Reading	SMD	2,100	65	15.3
Somerville	SMD	2,000	60	16.4
Stoneham	SMD	2,750	110	12.7
Wakefield	SMD	2,150	70	16.6
Watertown	SMD	1,130	19	28.2
Wilmington	NT	-	-	-
Winchester	SMD	2,750	110	13.2
Woburn	SMD	5,000	300	10.5
TOTAL		36,880	1,434	13.7

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
NEPONSET RIVER				
Canton	SMD	4,650	275	10.8
Dedham	SMD	2,900	120	13.1
Dover	SP	275	7	6.5
Foxborough	SMD	1,500	35	21.6
Medfield	SMD	1,350	30	24.2
Milton	SMD	4,100	225	11.3
Norwood	SMD	4,200	235	11.2
Quincy	SMD	1,950	55	17.2
Randolph	SP	150	3	9.7
Sharon	SMD	5,650	365	10.1
Stoughton	SMD	3,650	190	11.8
Walpole	SMD	4,400	250	10.9
Westwood	SMD	3,350	160	12.4
TOTAL		38,125	1,950	11.6
NORTH RIVER				
Abington	SMD	1,350	30	25.1
Duxbury	NT	-	-	-
Hanover	SMD	4,100	225	11.3
Hanson	SMD	2,175	70	16.0
Marshfield	SMD	2,500	100	14.5
Norwell	SMD	3,000	130	12.8
Pembroke	SMD	3,100	140	12.9
Rockland	SMD	2,650	105	13.4
Scituate	SMD	1,500	35	19.4
Weymouth	NT	-	-	-
TOTAL		20,375	835	13.6

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
PARKER RIVER				
Boxford	NT	-	-	-
Ipswich	SP	150	3	11.4
TOTAL		150	3	11.4
ROWLEY RIVER				
Ipswich	SMD	2,500	120	15.5
TOTAL		2,500	120	15.5
SALEM HARBOR				
Lynn	NT	-	-	-
Marblehead	SMD	1,450	35	23.5
Salem	SMD	2,500	120	22.5
Swampscott	SP	190	4	10.5
TOTAL		4,140	159	21.8
SAUGUS RIVER				
Everett	NT	-	-	-
Lynn	SMD	2,250	80	15.4
Lynnfield	SMD	2,800	115	12.6
Malden	SMD	1,850	55	19.1
Melrose	SP	450	10	6.6
Reading	SMD	2,350	85	14.9
Revere	SMD	2,350	85	14.5
Saugus	SMD	3,400	165	11.9
Wakefield	SMD	2,450	90	14.8
TOTAL		17,900	685	13.7

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
SHAWSHEEN RIVER				
Andover	SMD	5,100	320	10.5
Bedford	SMD	4,750	280	10.5
Billerica	SMD	3,100	140	12.3
Burlington	SMD	4,200	235	10.9
Corcord	SMD	1,350	30	23.8
Lawrence	SMD	1,300	25	24.4
Lexington	SMD	3,200	150	12.4
Lincoln	SMD	1,800	50	19.4
North Andover	SMD	1,650	40	19.5
Tewksbury	SMD	3,750	195	11.7
Wilmington	SP	350	8	6.9
Woburn	NT	-	-	-
TOTAL		30,550	1,473	14.6
SOUTH RIVER				
Duxbury	SP	325	7	7.0
Marshfield	SMD	3,000	140	12.5
Scituate	NT	-	-	-
TOTAL		3,325	147	11.8
STONY BROOK				
Boxborough	SP	300	6	6.8
Chelmsford	SMD	2,250	80	15.7
Harvard	NT	-	-	-
Littleton	SMD	2,250	80	14.7
Westford	SMD	4,250	235	16.8
TOTAL		9,050	401	15.4

TABLE 22 (Cont.)

	Treat- ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
SUDBURY RIVER				
Ashland	SMD	2,925	125	13.1
Concord	SMD	2,500	120	23.0
Framingham	SMD	7,100	520	9.4
Hopkinton	SMD	2,800	115	13.2
Hudson	NT	-	-	-
Lincoln	SP	260	5	6.5
Marlborough	SMD	3,450	165	12.1
Natick	SMD	3,500	175	11.8
Northborough	NT	-	-	-
Sherborn	SP	275	6	7.8
Southborough	SMD	3,050	135	12.8
Sudbury	SMD	5,000	310	10.4
Wayland	SMD	4,500	265	10.9
Westborough	SMD	3,750	195	11.7
Weston	SP	240	4	7.4
TOTAL		39,350	2,140	11.3
TAUNTON RIVER				
Avon	SMD	2,000	60	17.2
Holbrook	NT	-	-	-
Pembroke	NT	-	-	-
Rockland	NT	-	-	-
Sharon	SMD	1,500	35	20.7
Stoughton	SMD	1,800	50	18.0
Wrentham	SMD	1,850	55	17.9
TOTAL		7,150	200	18.2

TABLE 22 (Cont.)

	Treat-ment*	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Treatment Costs (¢/1000 gal)
WEYMOUTH BACK RIVER				
Abington	NT	-	-	-
Braintree	NT	-	-	-
Hingham	SMD	2,250	80	14.5
Holbrook	NT	-	-	-
Rockland	SP	375	9	6.8
Weymouth	SMD	4,250	235	11.1
TOTAL		6,875	324	11.6
WEYMOUTH FORE RIVER				
Avon	NT	-	-	-
Braintree	SMD	4,850	290	10.4
Brockton	NT	-	-	-
Canton	NT	-	-	-
Holbrook	SMD	2,525	100	13.9
Milton	NT	-	-	-
Quincy	SMD	3,625	185	11.8
Randolph	SMD	3,750	193	11.5
Stoughton	NT	-	-	-
Weymouth	SMD	2,250	80	14.7
TOTAL		17,000	848	11.8

TOTAL COSTS FOR STUDY AREA

Total Capital Costs	$465,030,000
Total Annual O & M Costs	$ 55,865,800
Avg. Treatment Cost, ¢/1000 gals.	12.9

the study by estimating the costs for modular facilities which bracketed the expected range of design flows. Facilities having at least 3 flow rates were used to construct each curve for each alternate requiring treatment. These covered the high, low, and middle flow ranges which the alternate was to cover.

Each cost includes a contingency factor of 35% to cover construction contingencies, engineering design and supervision, and legal and administrative costs. All costs are adjusted to reflect an ENR Cost Index of 2200. In determining annual costs, amortization of treatment facilities was assumed over a 25 year period with interest at 5 5/8%. Figures 8 through 16 show cost curves for the three alternate schemes which employ treatment of the stormwater.

Estimates for capital and operation and maintenance costs were developed using the most recent cost information available from projects of comparable magnitude. Because much of the cost estimating for the report is dependent upon assumptions regarding treatment facility sites, land costs, etc., the costs presented can be described as being only probably average costs exclusive of recent inflationary trends. Actual costs may vary as much as 40% from average costs depending upon design requirements, construction site conditions, and perhaps most important of all, the economic climate at the time construction bids are taken(4). Preliminary construction cost estimates of the type made for this report do not allow for extraordinary costs such as those related to rock excavation, site dewatering, or the use of piling. Such costs cannot be foreseen or accounted for without making thorough field investigations. Such investigations are beyond the scope of this report.

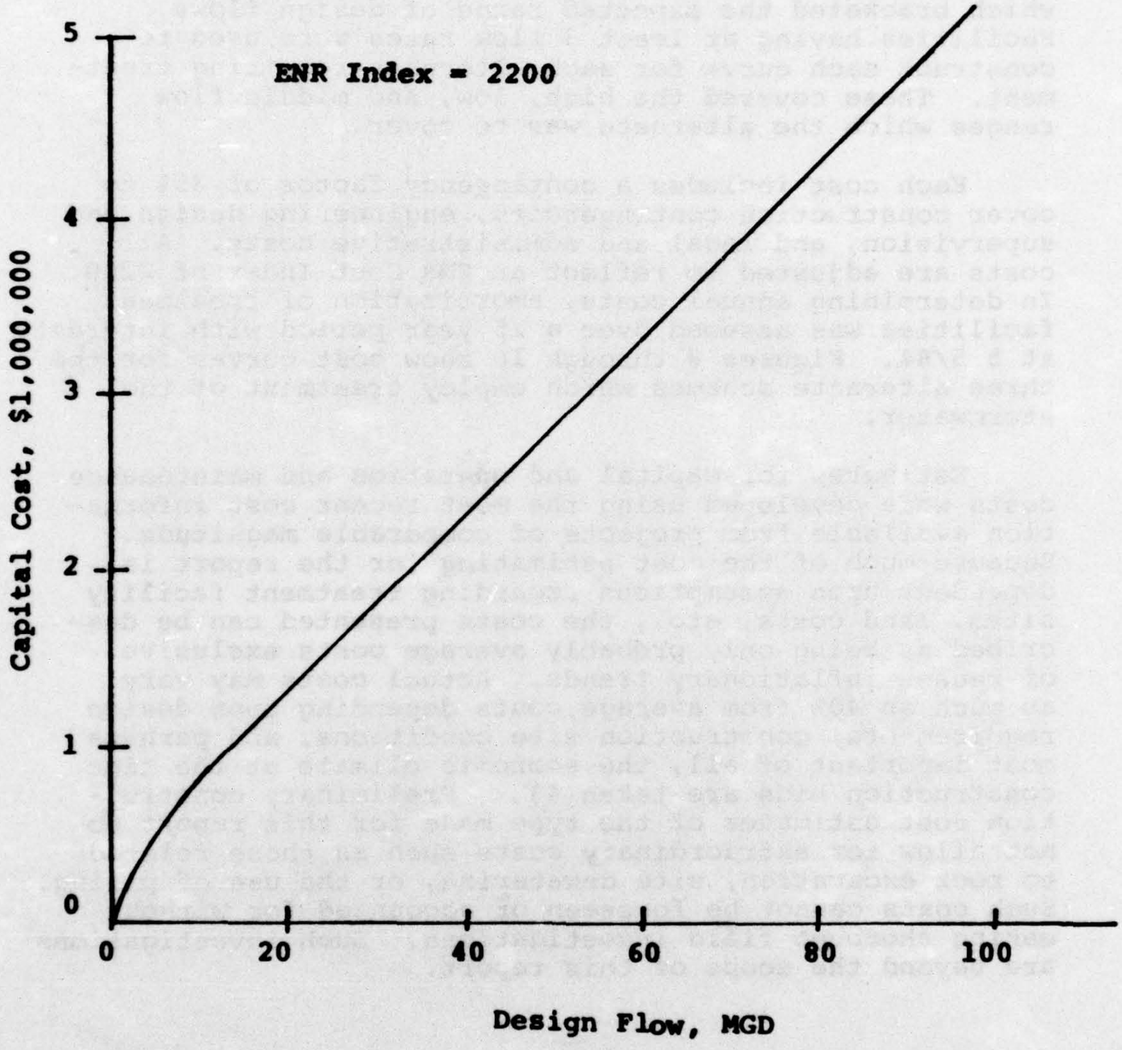


FIGURE 8. CAPITAL COSTS FOR ALTERNATE NO. 2, STORAGE & PUMPING

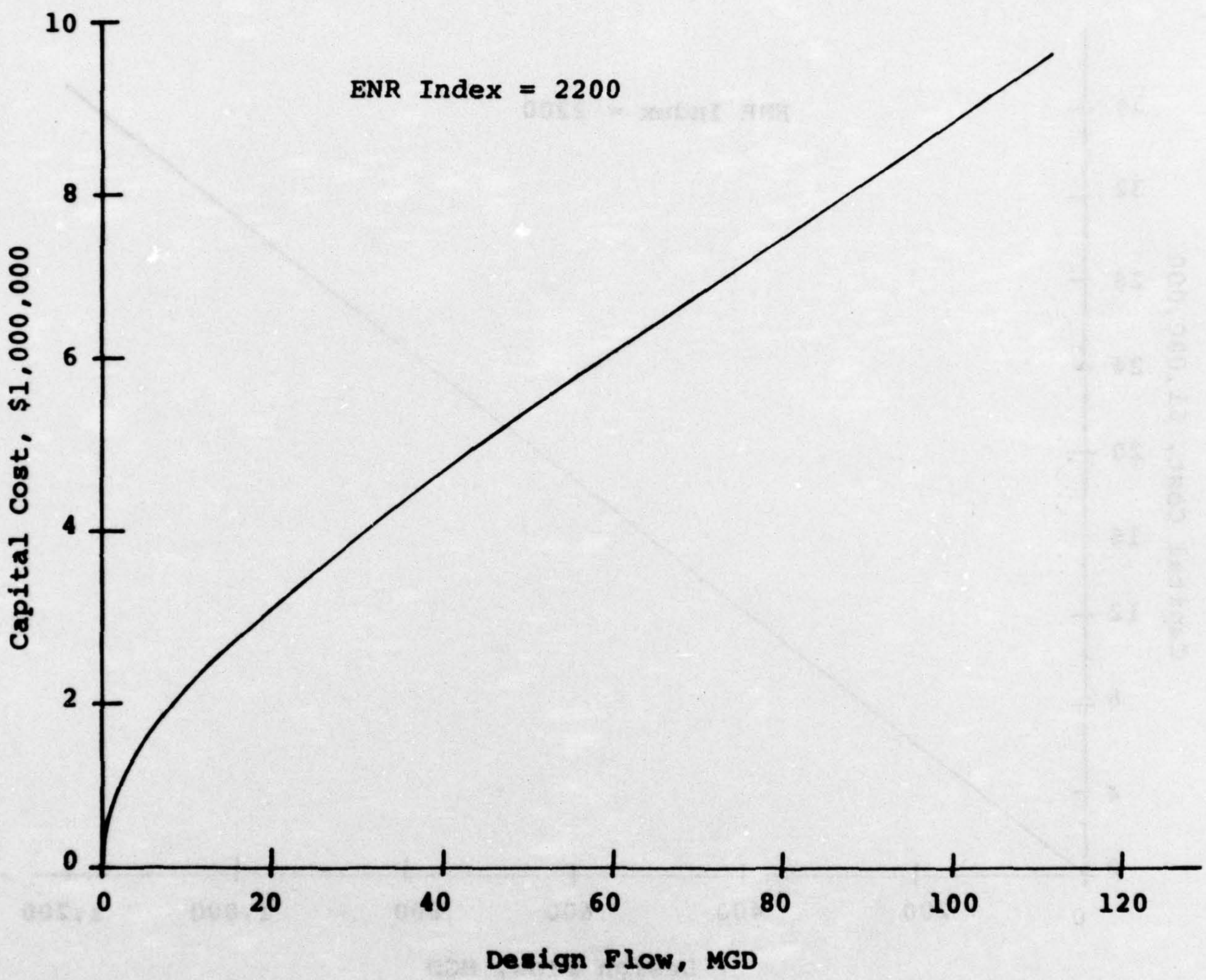


FIGURE 9. CAPITAL COSTS FOR ALTERNATE NO. 3, STORAGE, MICROSTRAINING & DISINFECTION

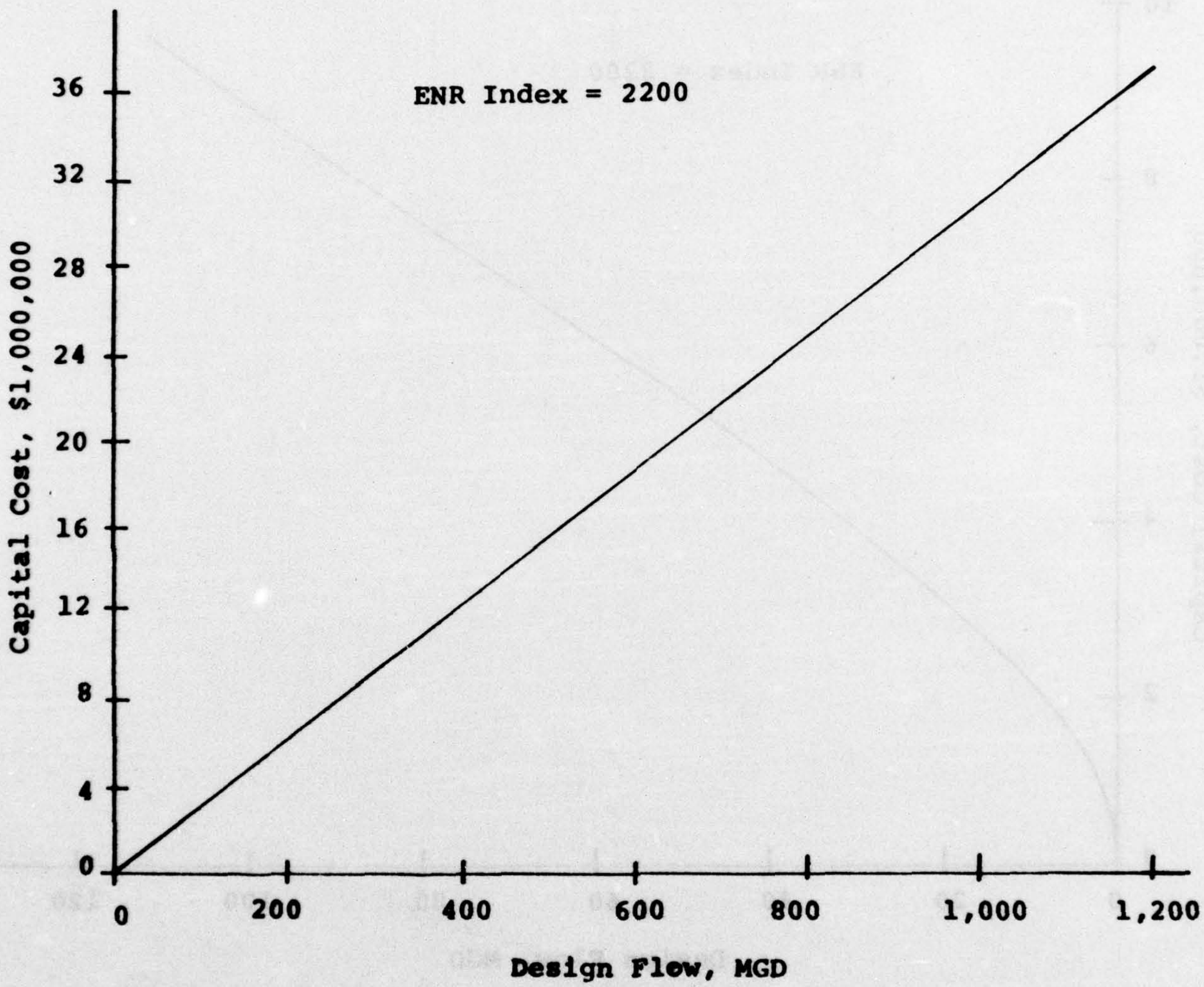


FIGURE 10. CAPITAL COSTS FOR ALTERNATE NO. 4, HIGH RATE MICROSTRAINING & DISINFECTION

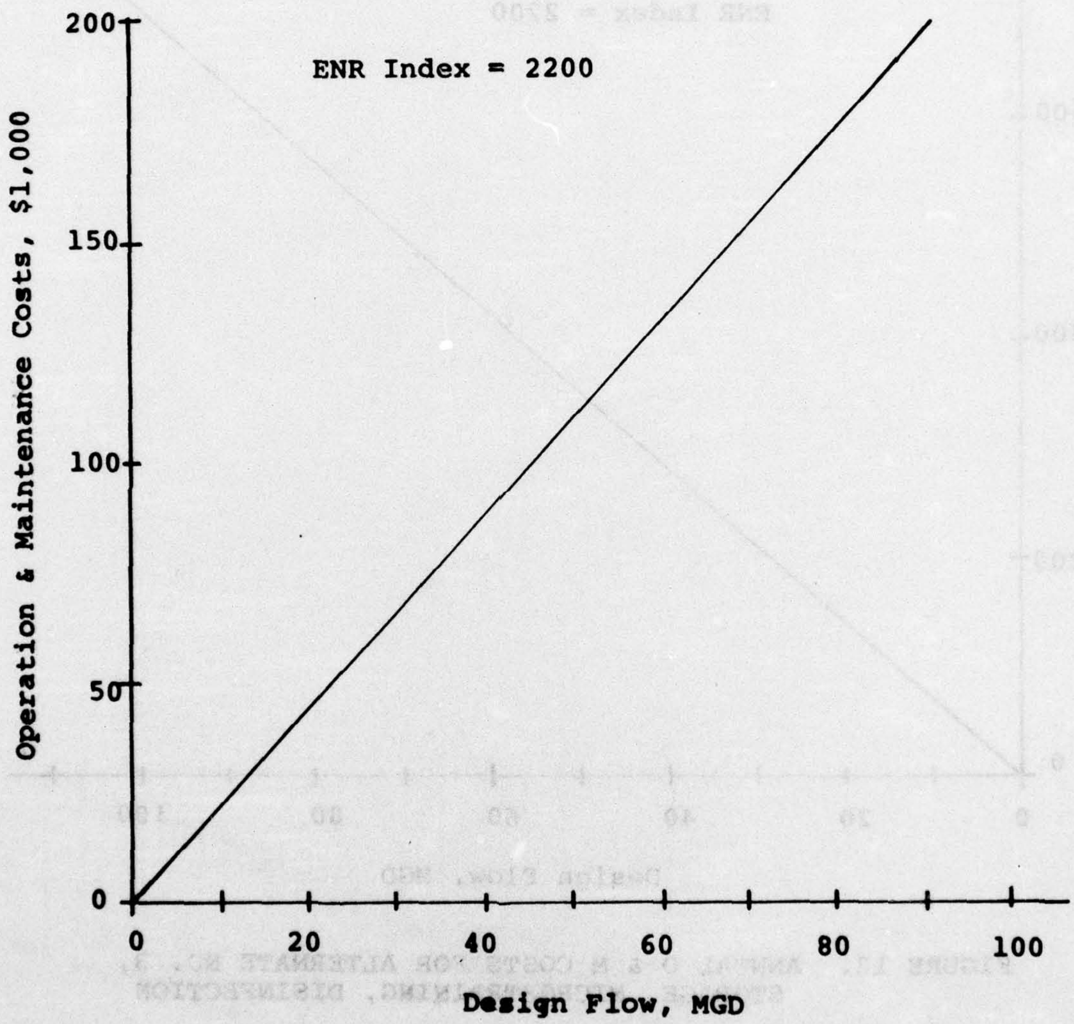


FIGURE 11. ANNUAL O & M COSTS FOR ALTERNATE NO. 2 STORAGE & PUMPING

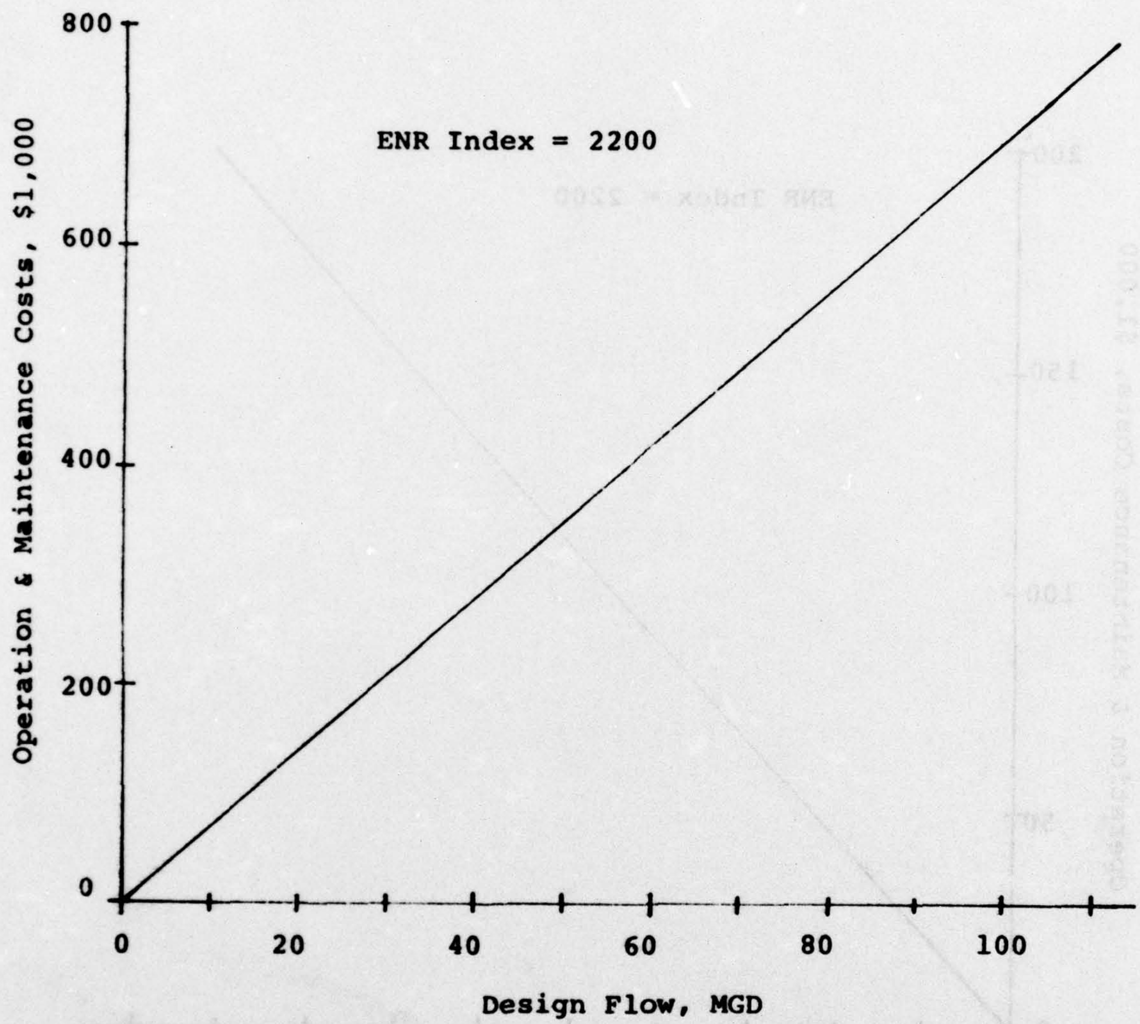


FIGURE 12. ANNUAL O & M COSTS FOR ALTERNATE NO. 3, STORAGE, MICROSTRAINING, DISINFECTION

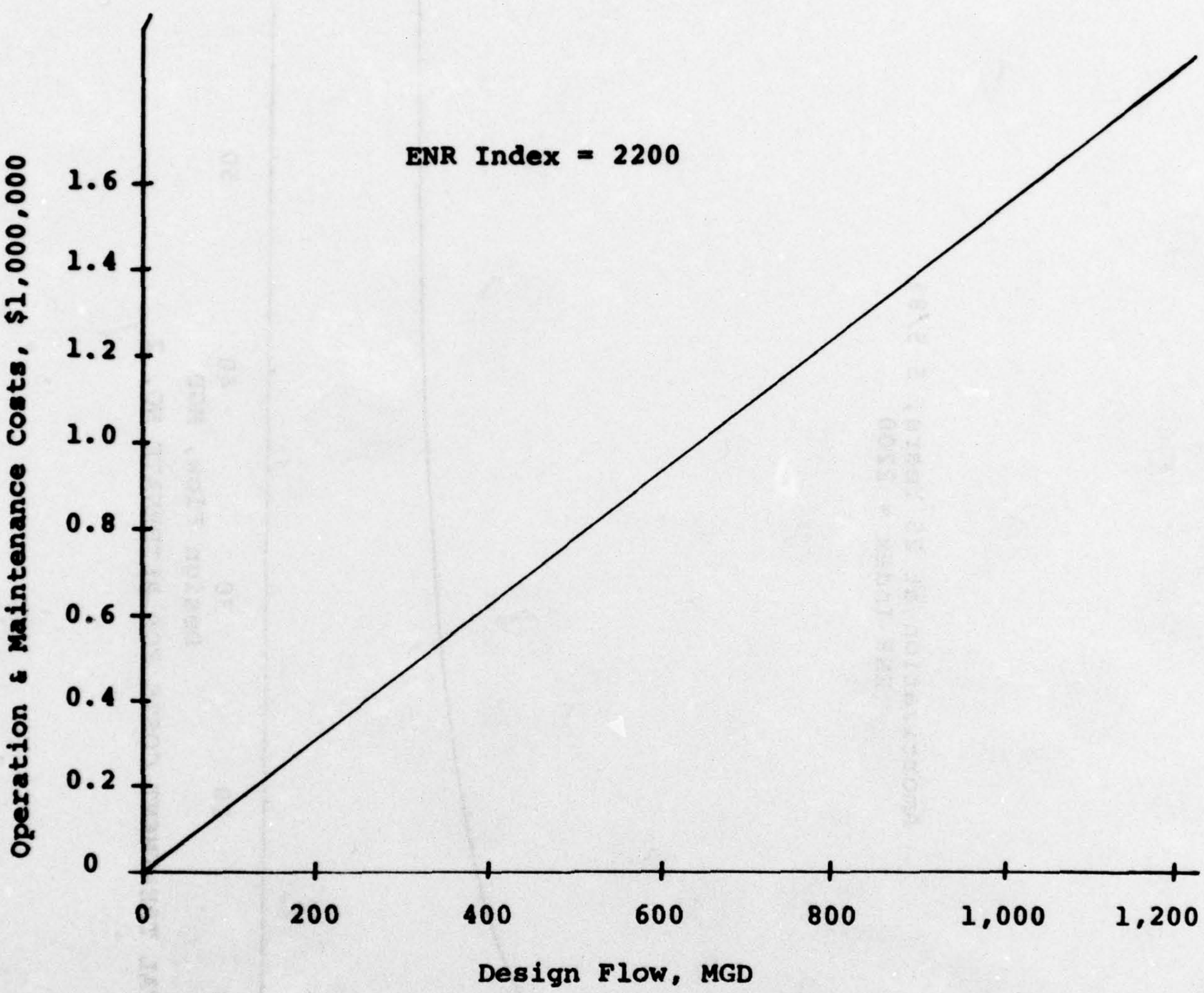


FIGURE 13. ANNUAL O & M COSTS FOR ALTERNATE NO. 4
HIGH RATE MICROSTRAINING & DISINFECTION

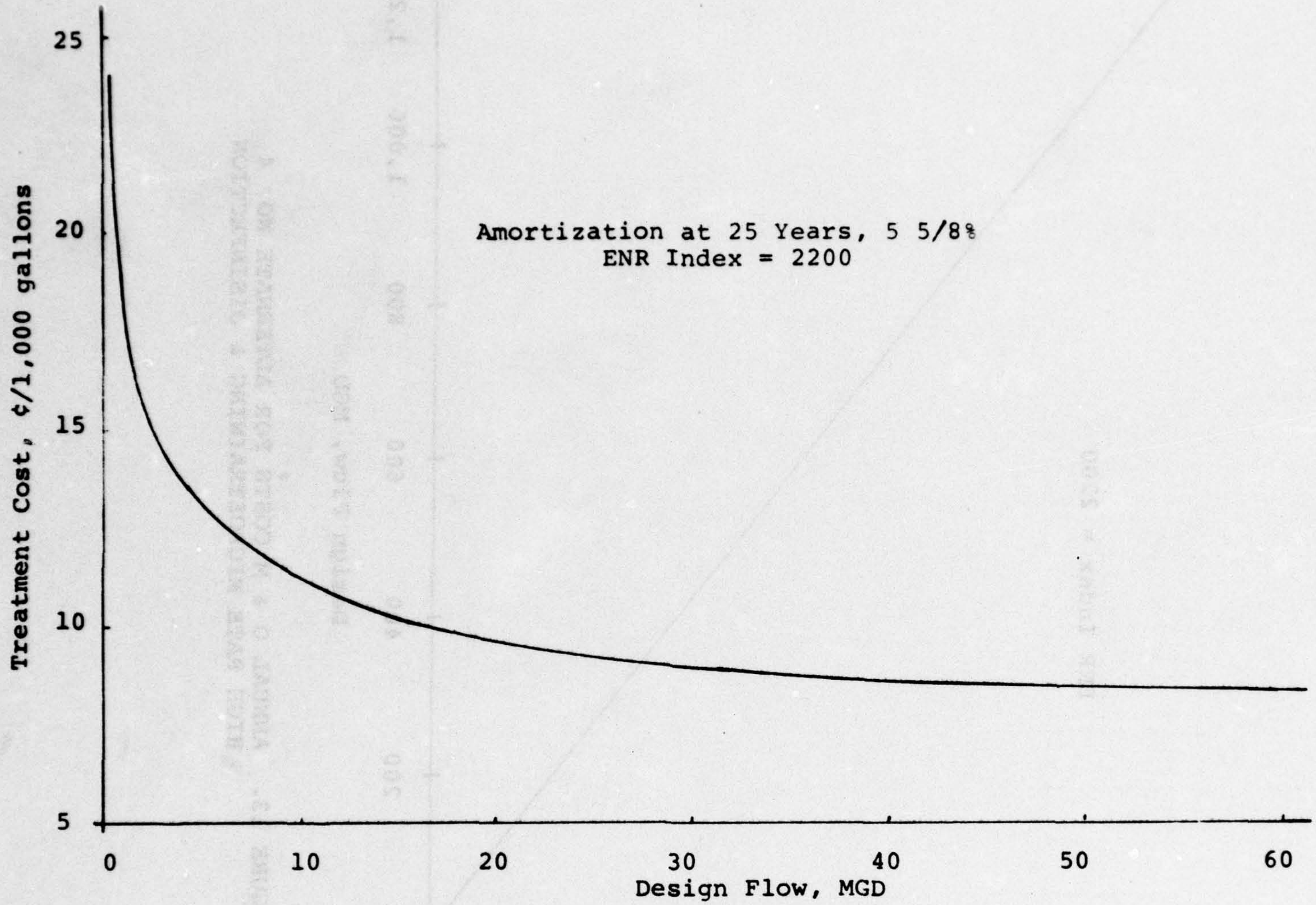


FIGURE 14. TOTAL TREATMENT COSTS FOR ALTERNATE NO. 2

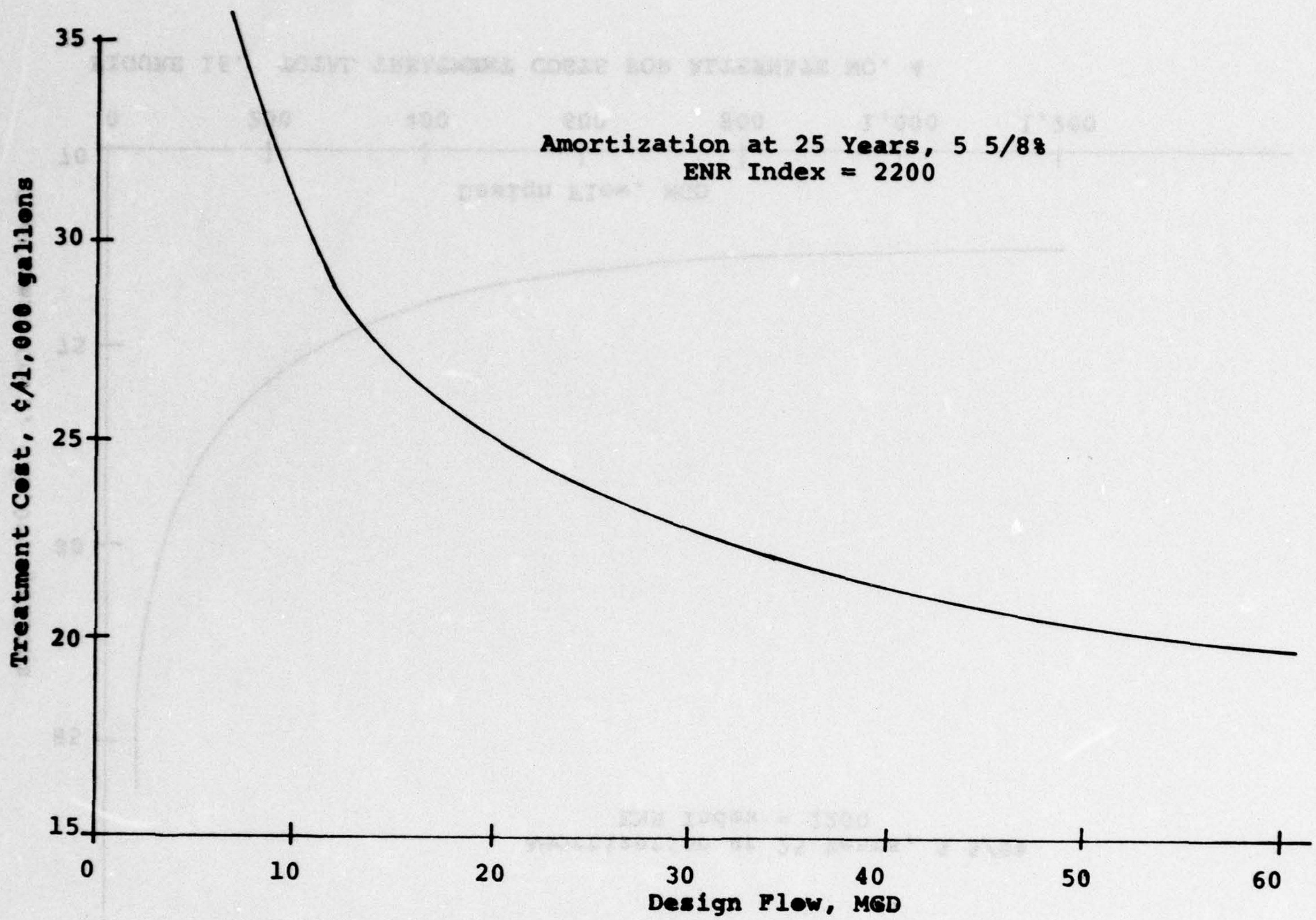


FIGURE 15. TOTAL TREATMENT COSTS FOR ALTERNATE NO. 3,

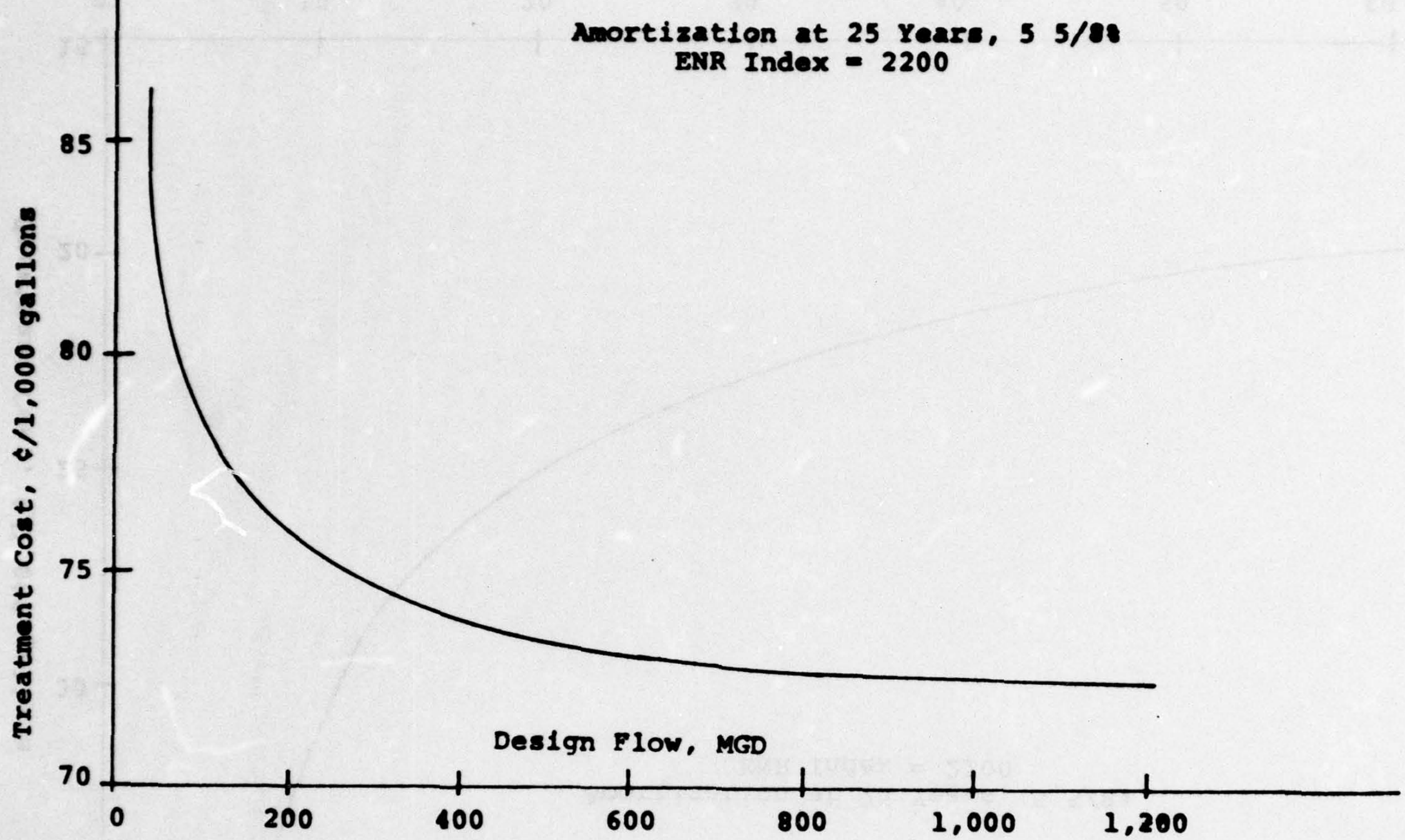


FIGURE 16. TOTAL TREATMENT COSTS FOR ALTERNATE NO. 4

Capital Costs

Capital costs for stormwater management include costs for land, flow control structures, pumping stations, storage lagoons, microstraining equipment, disinfection facilities, and suitable sheltering structures, where such items apply in treatment alternate schemes. No cost allowances are made for extensions of sewerage systems or construction of force mains which transport sludges to the sanitary system. Land costs are estimated at $10,000 per acre as an average for the study area.

Table 22 lists the capital costs for each watershed by community. The costs range from nothing, where no treatment is employed, to a maximum of $6,200,000 for the city of Newton in the Charles River Basin. Most of the treatment facilities listed in Table 22 utilize Alternate No. 3 which consists of storage, microstraining, and disinfection. As indicated in the Table, costs for such facilities generally range from $2,000,000 to $3,000,000. The maximum capital cost for any waterhsed is $72,510,000. The total capital costs for all communities in the study area are $465,030,000.

Operation and Maintenance Costs

Annual operation and maintenance costs include costs for manpower, clean-up equipment and vehicles, power, salt, maintenance and repair. Manpower requirements are estimated on the basis of modular facilities. Treatment flow rates are estimated to average 50% of the peak 1-year storm flow rate and each facility is estimated to be activated 50 times annually. Power costs are estimated at $0.041/KWH (Boston Edison Commercial Rate). Microstrainer maintenance is estimated at $0.019/1000 gallons. Amortization of facilities is assumed over a 25-year period with interest rates at 5 5/8%.

Annual operation and maintenance costs are listed in Table 22 for each watershed by community. These costs range from nothing, where no treatment is employed, to a maximum of $420,000 for the city of Newton in the Charles River Basin. Most of the operation and maintenance costs range from about $50,000 to $200,000 per year. The maximum O & M costs for any watershed is $3,471,000. Total annual operation and maintenance costs for all communities in the study area are $55,865,800.

Treatment costs per 1000 gallons were found to average 12.9¢ for the study area. Some treatment costs are as high as 35.8¢/1000 gallons where high rate microstraining (Alternate No. 4) is employed. In general, treatment costs can be expected to range from about 10 to 18¢/1000 gallons.

Effects on Receiving Streams

The disposal of untreated stormwater with its concomitant pollutants can have deleterious effects on the water quality in streams as previously mentioned. Conversely, the removal of these pollutants can have salubrious effects on receiving streams albeit such benefits may be difficult to quantify or specify precisely. In general, however, the state of the stream would be greatly improved; it would become clearer, free of floating slicks, scum, and odors; and it would support desirable flora and fauna.

Because of its limited nature, this study is not able to delve into the actual physical state of each receiving stream or water body and indicate how effective stormwater management will benefit the stream specifically. However, in an effort to show what results the stormwater management program advanced by this study might attain, comparative illustrations have been prepared for the principal watersheds in the study area showing the discharges of pollutants before and after treatment. The pollutant discharges compared, Suspended Solids and 5-day Biochemical Oxygen Demand (BOD), are shown for 13 principal watersheds in Figures 17 through 55 along with maps of the respective river basins or watersheds.

Data for the untreated pollutant discharges was obtained from the "STORM" Model computer program. The pollutant discharges after treatment were calculated after arbitrary judgement was used to select the best stormwater management that was possible by community. This judgement was guided by one primary hypothesis: to furnish the best treatment possible at the lowest possible cost. In many cases, the Alternate of choice was No. 2, the use of storage lagoons followed by pumping over 3 to 4 day period to an existing sanitary trunk sewer.

The reasoning employed for illustrating the pollutant discharge comparisons was not applied in the selection of the alternate treatment schemes as prescribed for each community and indicated in Table 22. The former assumed that the best possible treatment would be obtained by each community; it is idealistic and at best, presents an idea of the maximum removals that stormwater management could be expected to attain in the various watersheds.

On the other hand, the alternate selections indicated in Table 22 were based on a form of statistical selection to obtain what was considered to be a satisfactory "mix" of alternates through each watershed. It was hoped that this type of selection would give more realistic costs for stormwater management. The predominant alternate in this selection process was No. 3 which employs storage, microstraining, and disinfection for which the pollutant removals would be considerably

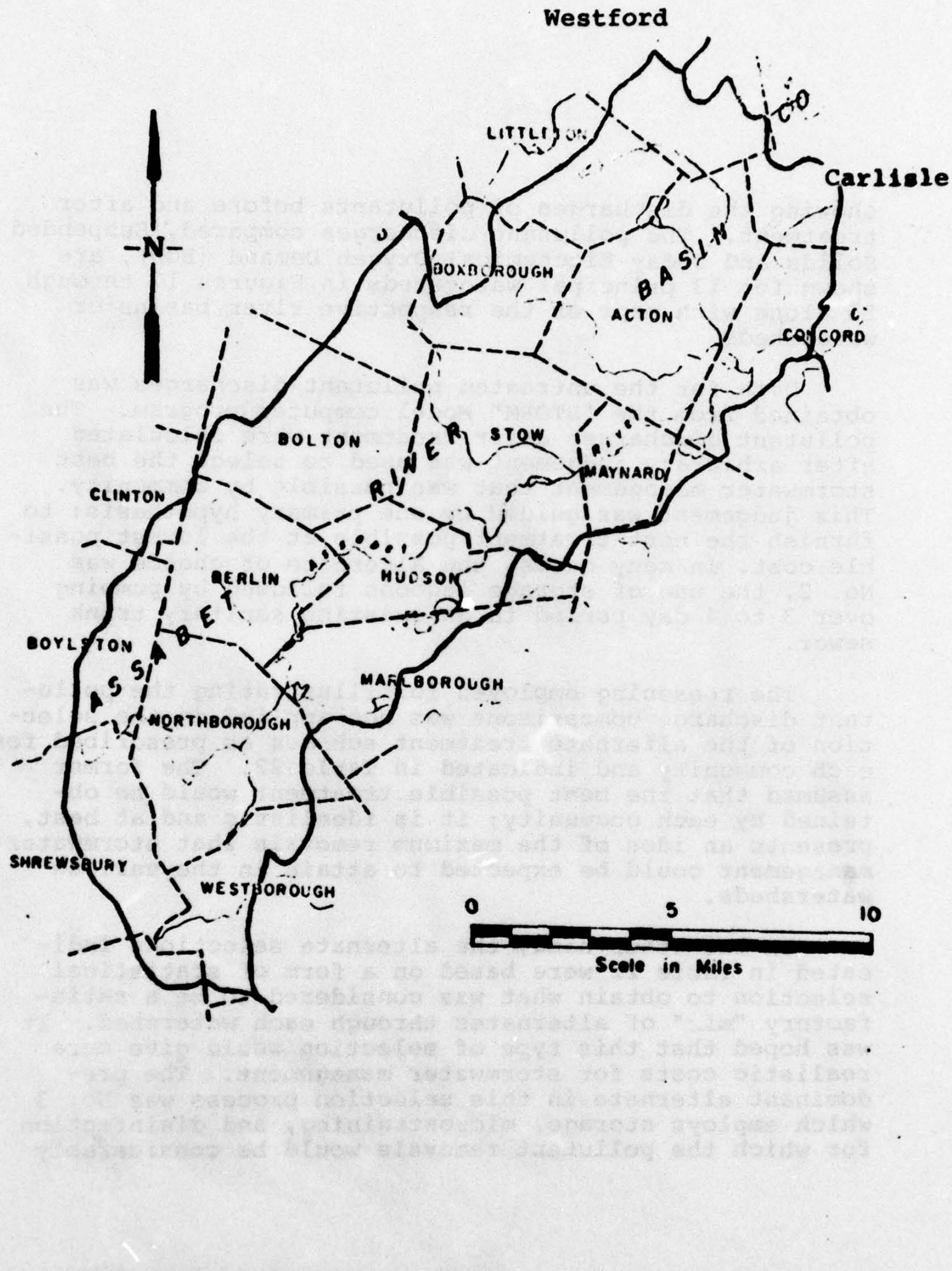


FIGURE 17. ASSABET RIVER BASIN

FIGURE 18

SUSPENDED SOLIDS DISCHARGE
TO ASSABET RIVER

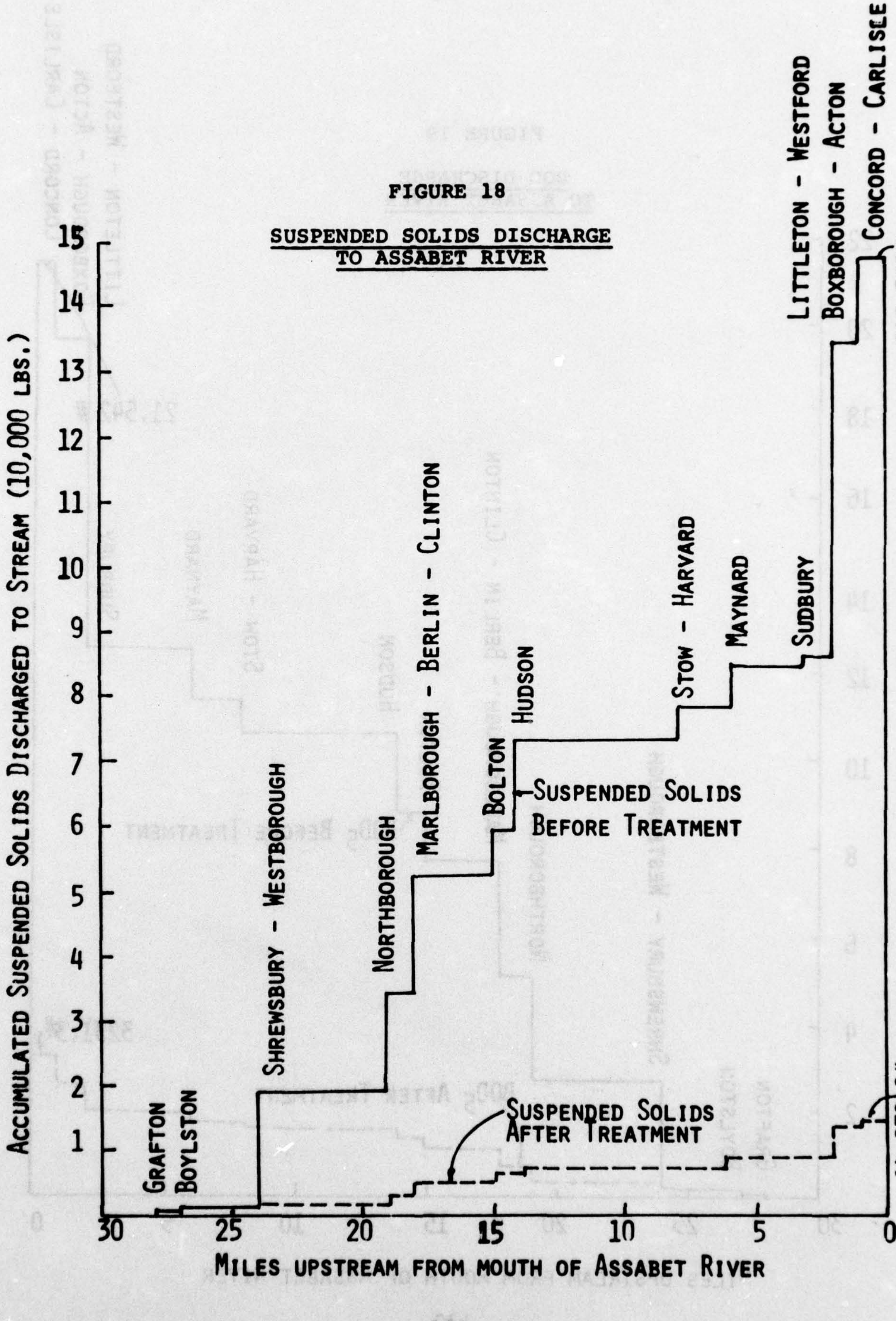
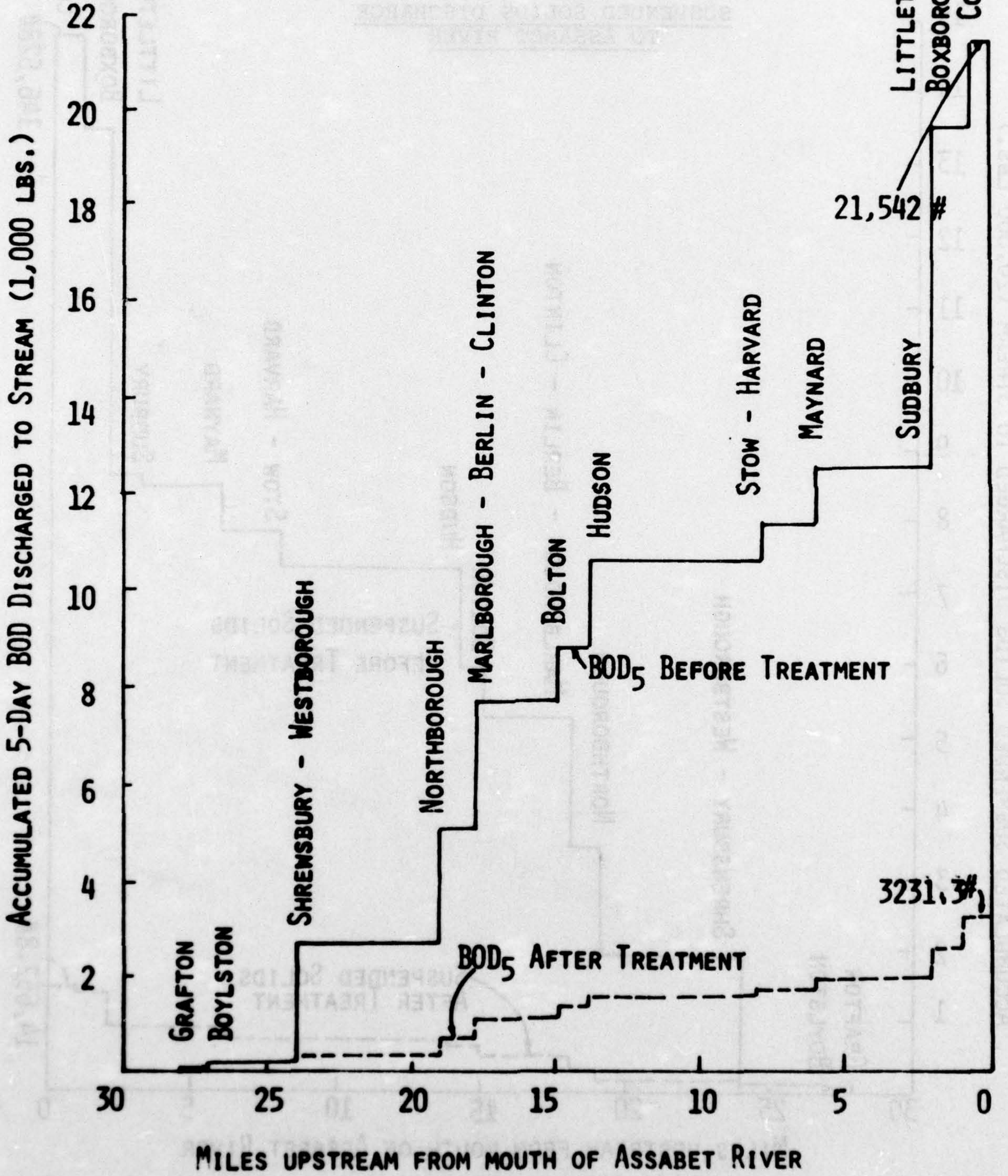


FIGURE 19

BOD DISCHARGE TO ASSABET RIVER



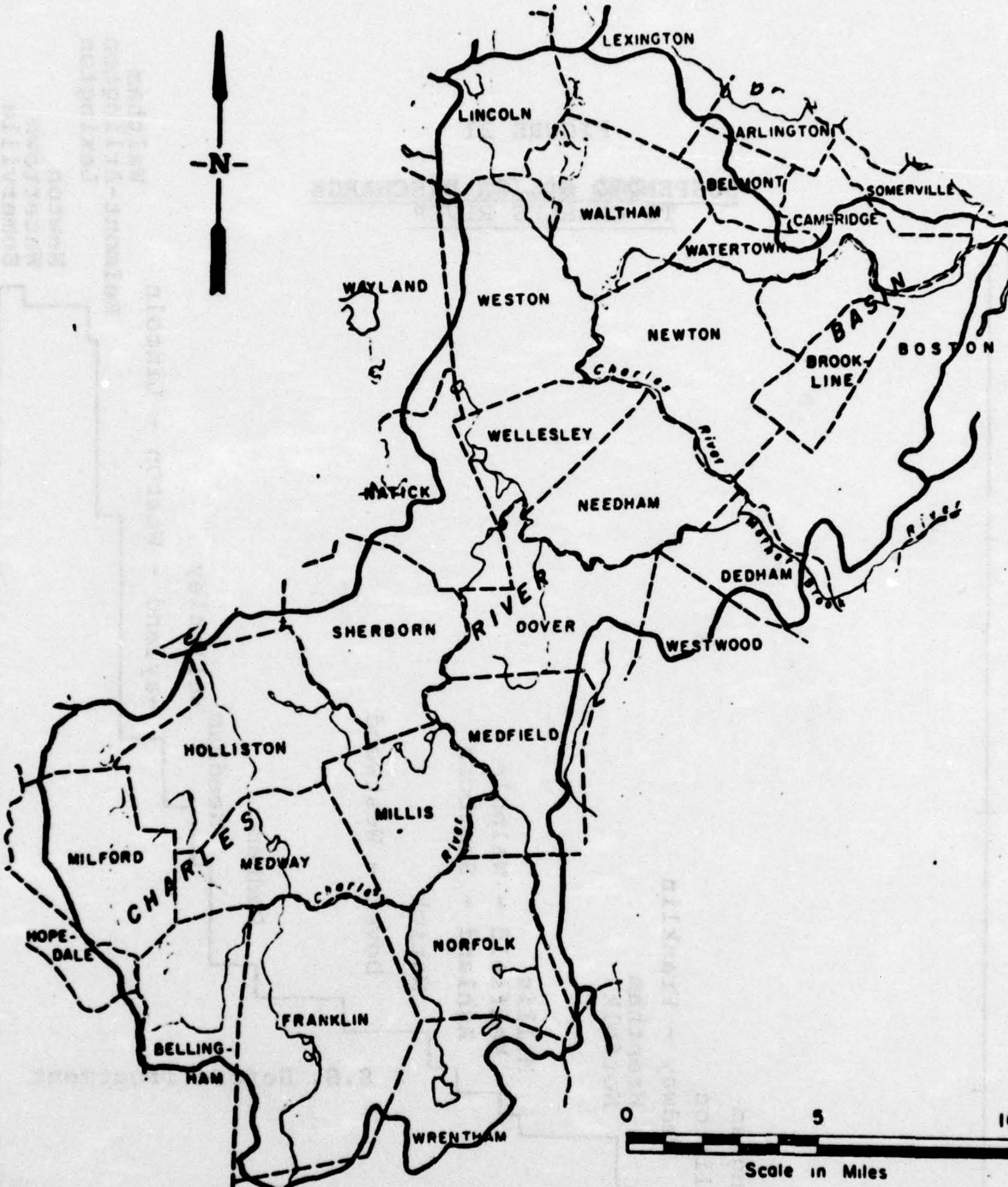


FIGURE 20. CHARLES RIVER BASIN

FIGURE 21

SUSPENDED SOLIDS DISCHARGE TO CHARLES RIVER

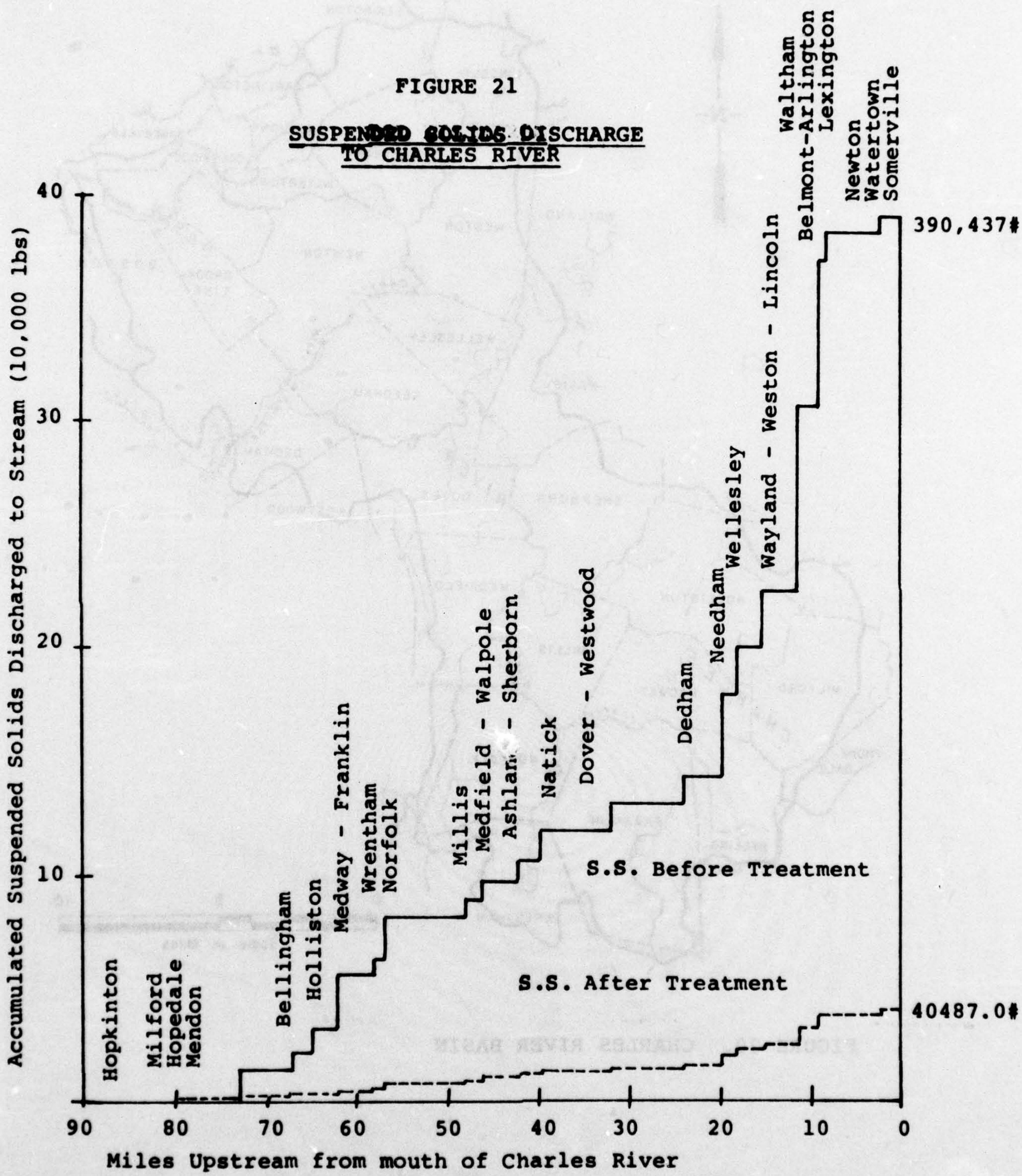
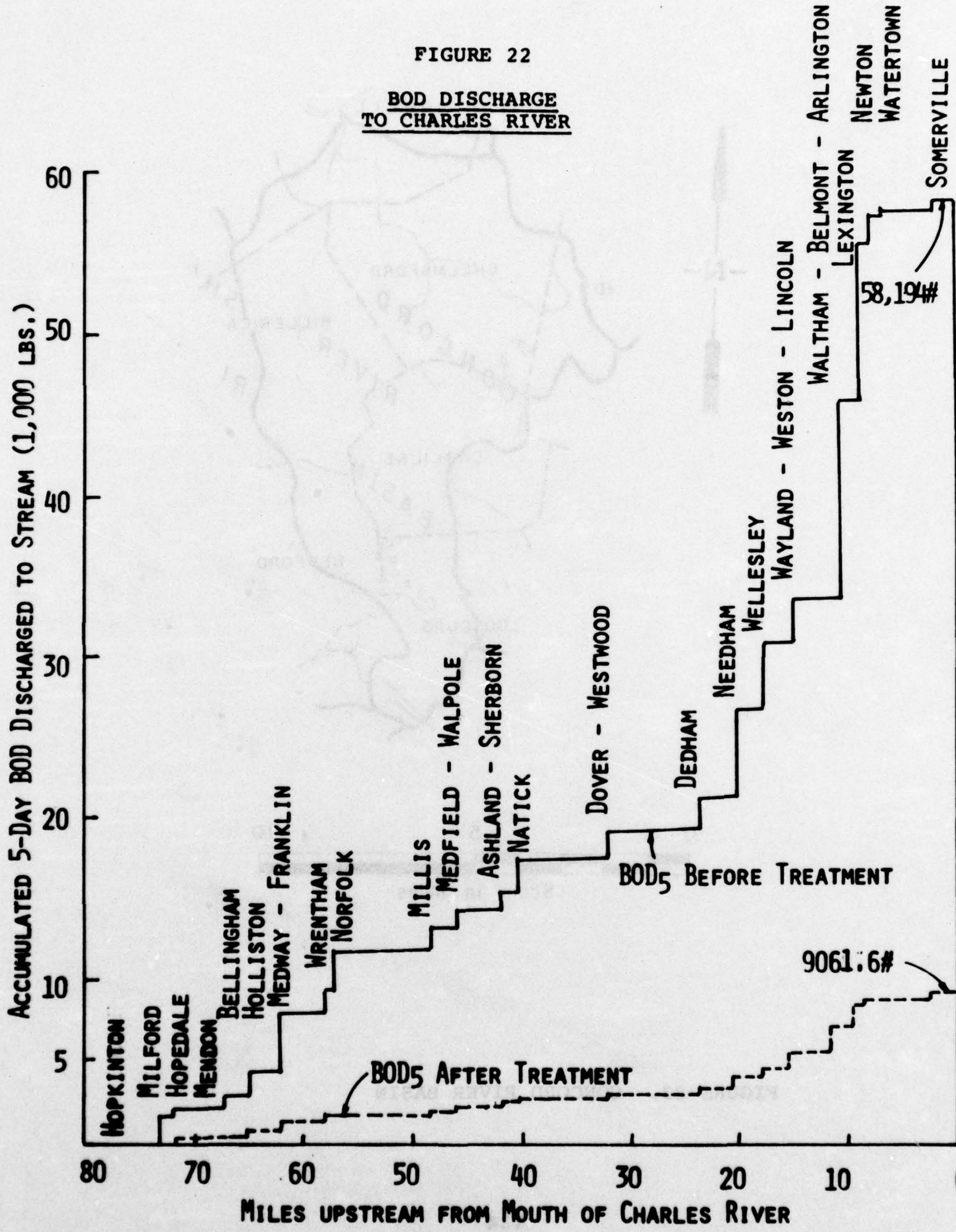


FIGURE 22

<u>BOD DISCHARGE TO CHARLES RIVER</u>



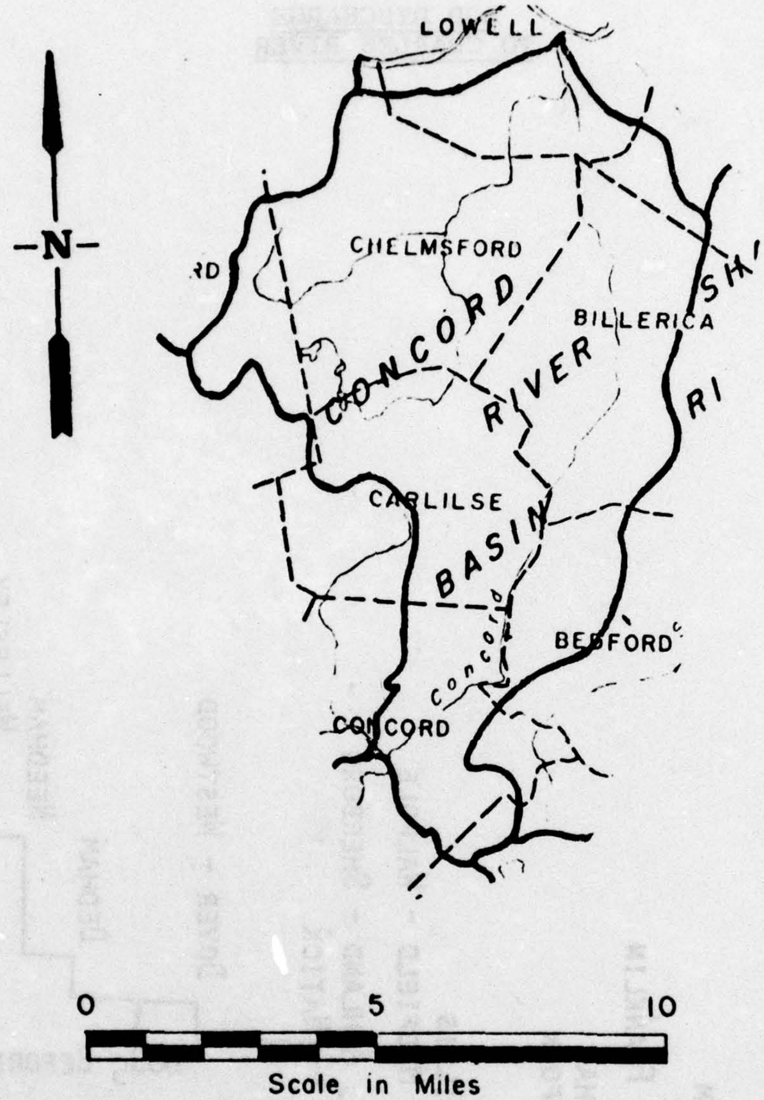
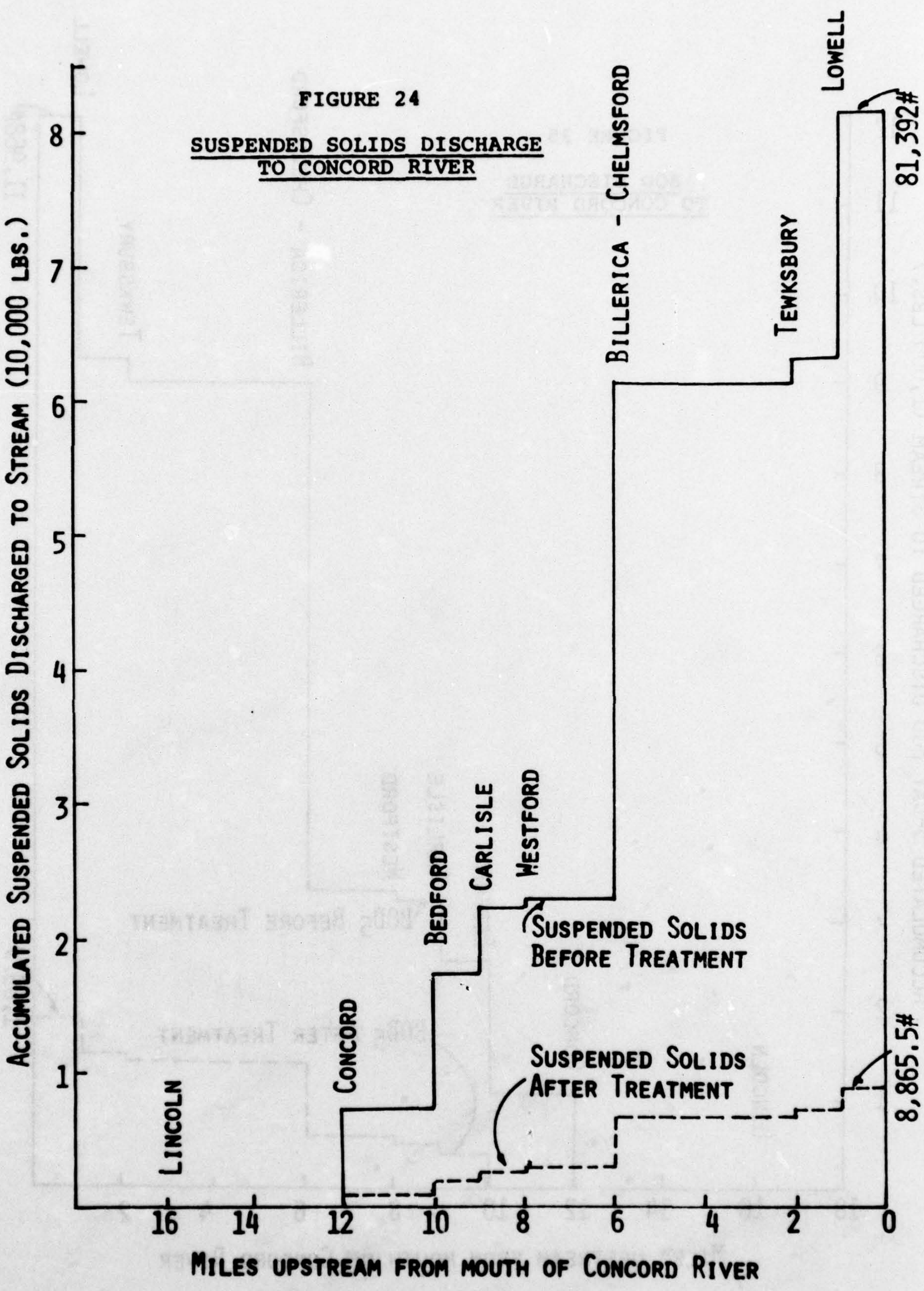


FIGURE 23, CONCORD RIVER BASIN

FIGURE 24

SUSPENDED SOLIDS DISCHARGE TO CONCORD RIVER



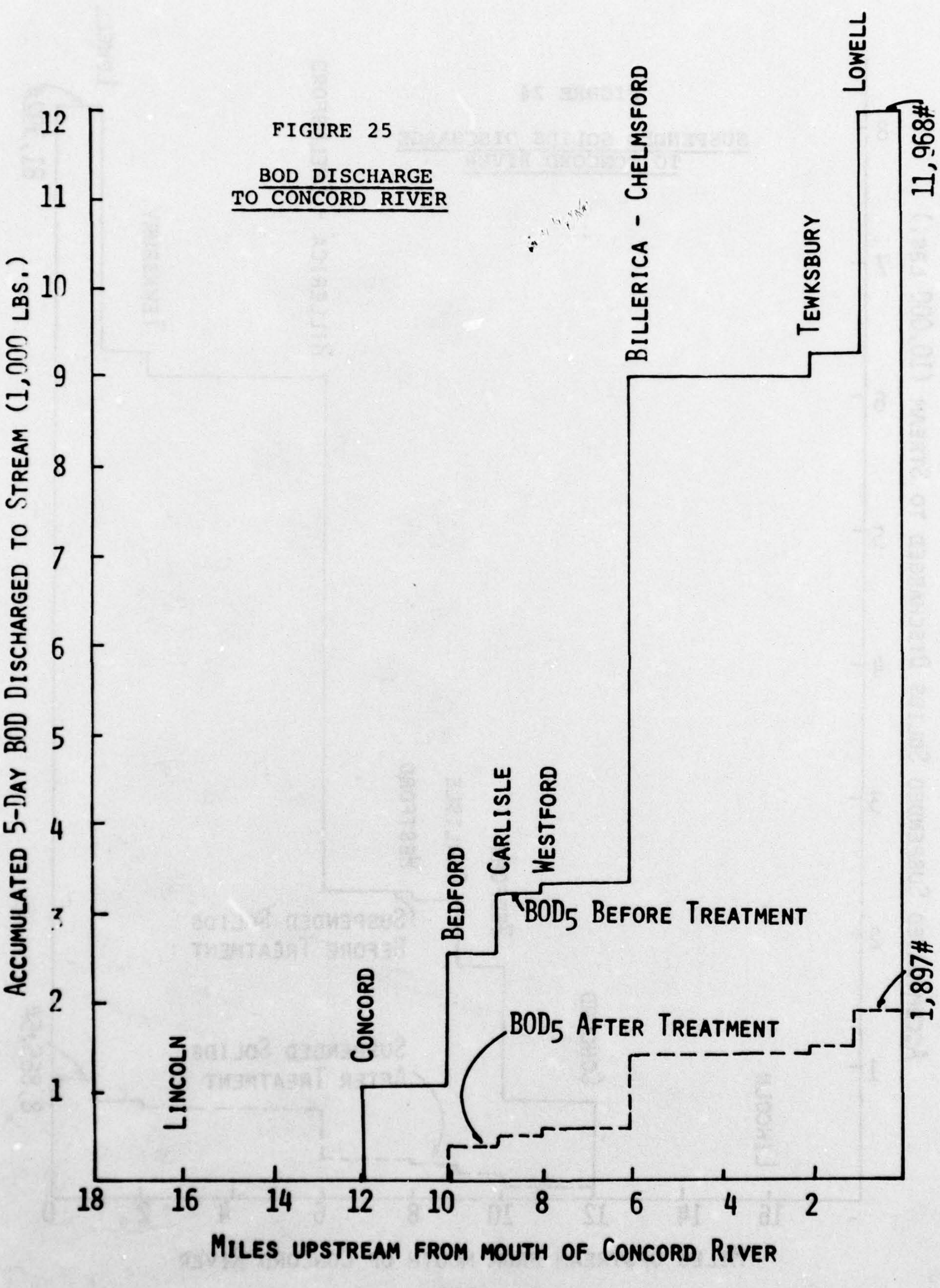


FIGURE 25
BOD DISCHARGE
TO CONCORD RIVER
Accumulated 5-Day BOD Discharged to Stream (1,000 lbs.)
Miles upstream from mouth of Concord River
Lincoln
Concord
Bedford
Carlisle
Westford
Billerica - Chelmsford
Tewksbury
Lowell
11,968#
1,897#
BOD5 Before Treatment
BOD5 After Treatment
12
11
10
9
8
7
6
5
4
3
2
1
18
16
14
12
10
8
6
4
2

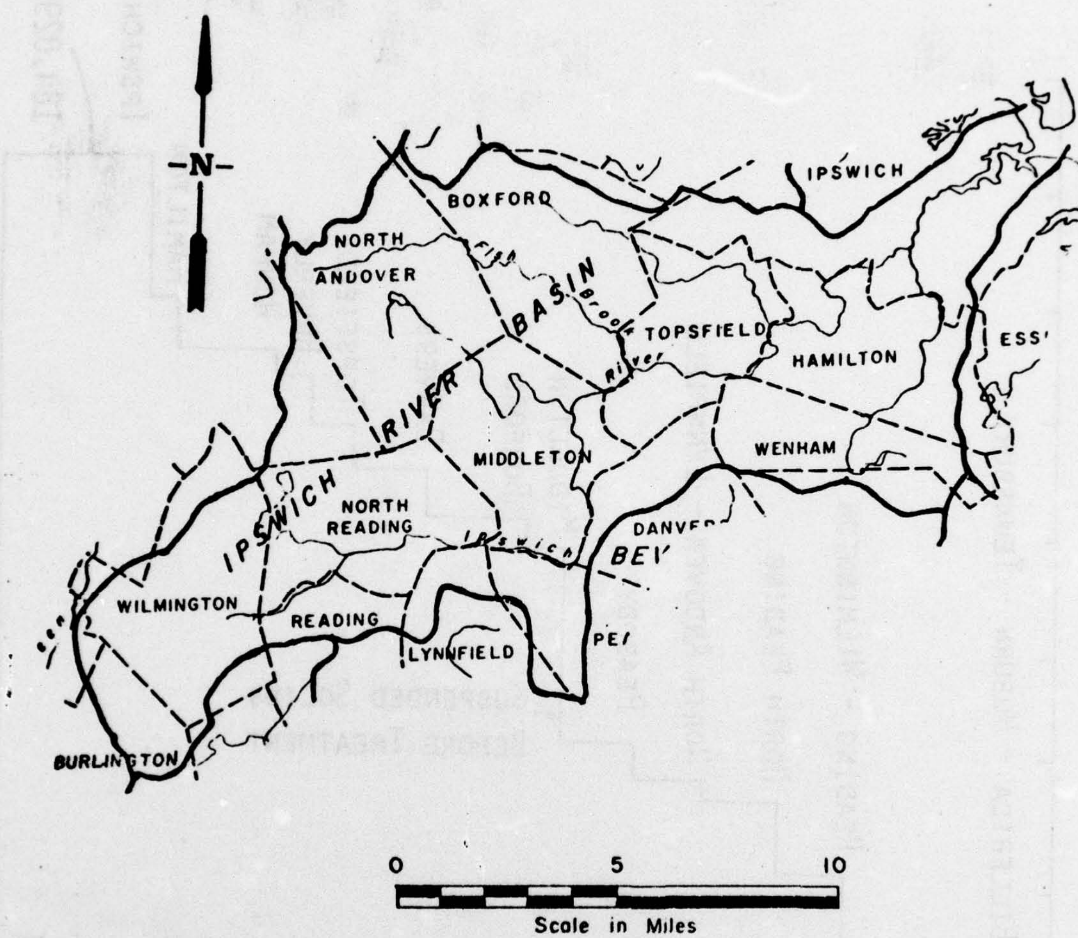


FIGURE 26. IPSWICH RIVER BASIN

FIGURE 27

SUSPENDED SOLIDS DISCHARGE TO IPSWICH RIVER

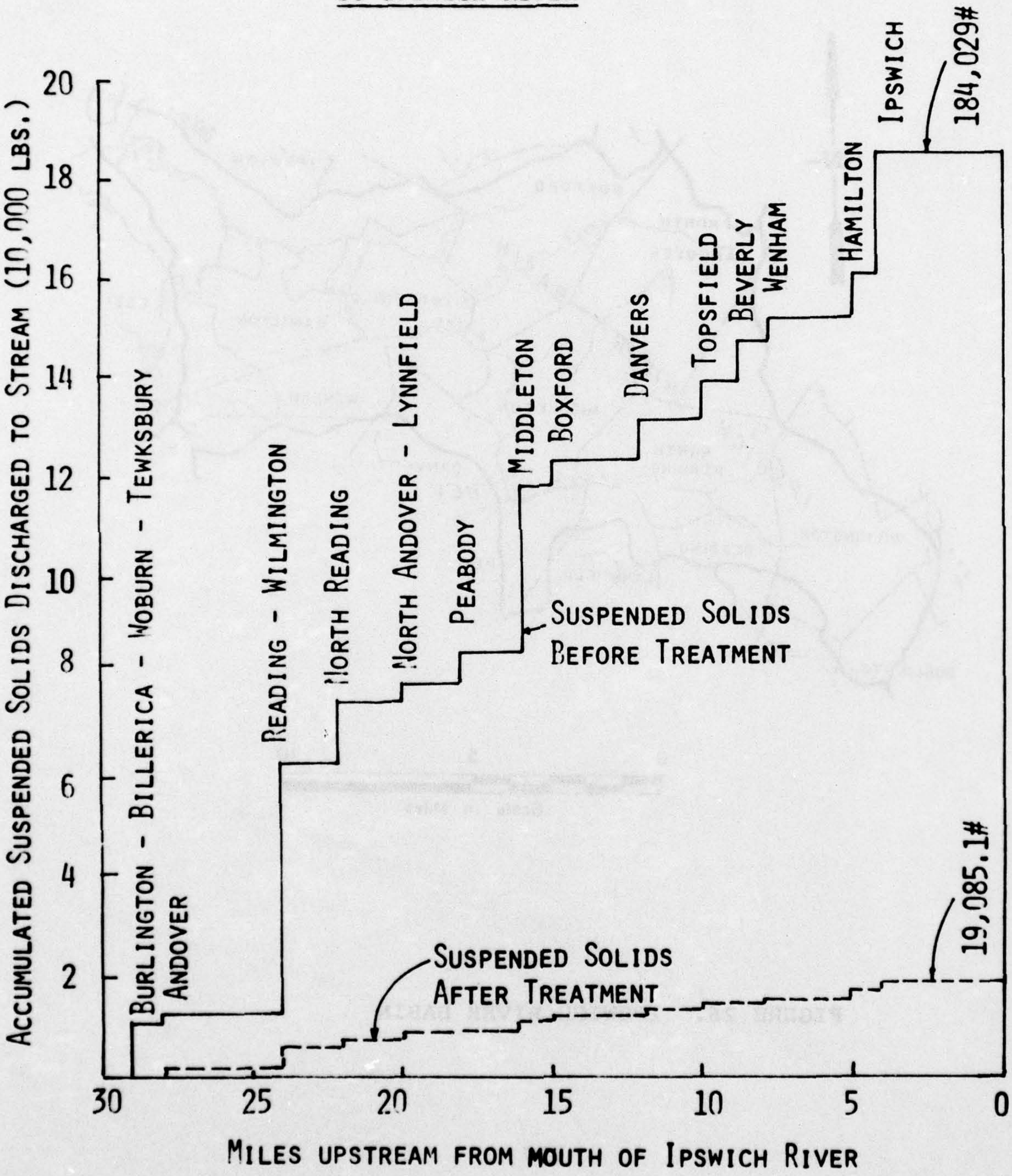
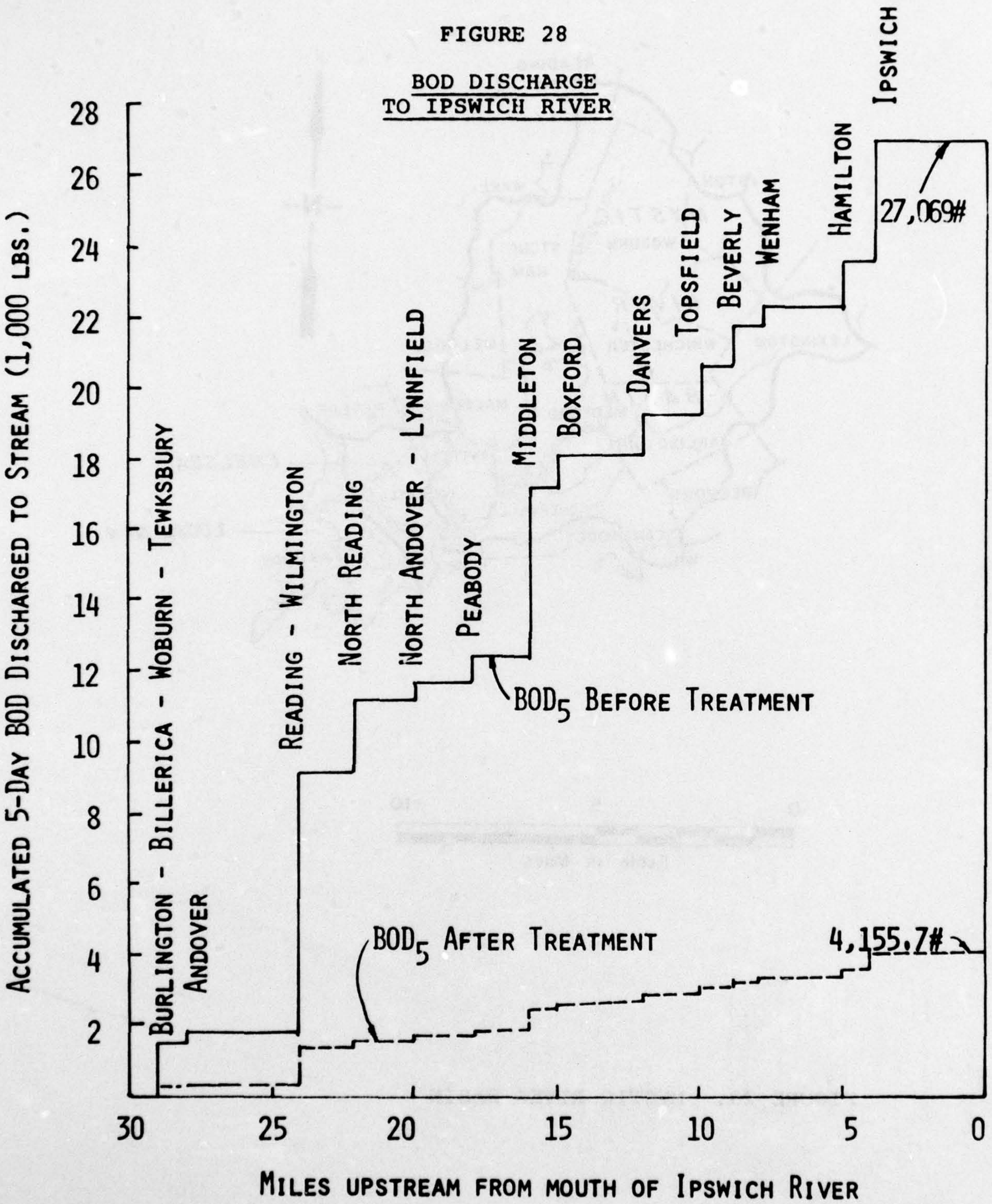


FIGURE 28

BOD DISCHARGE
TO IPSWICH RIVER



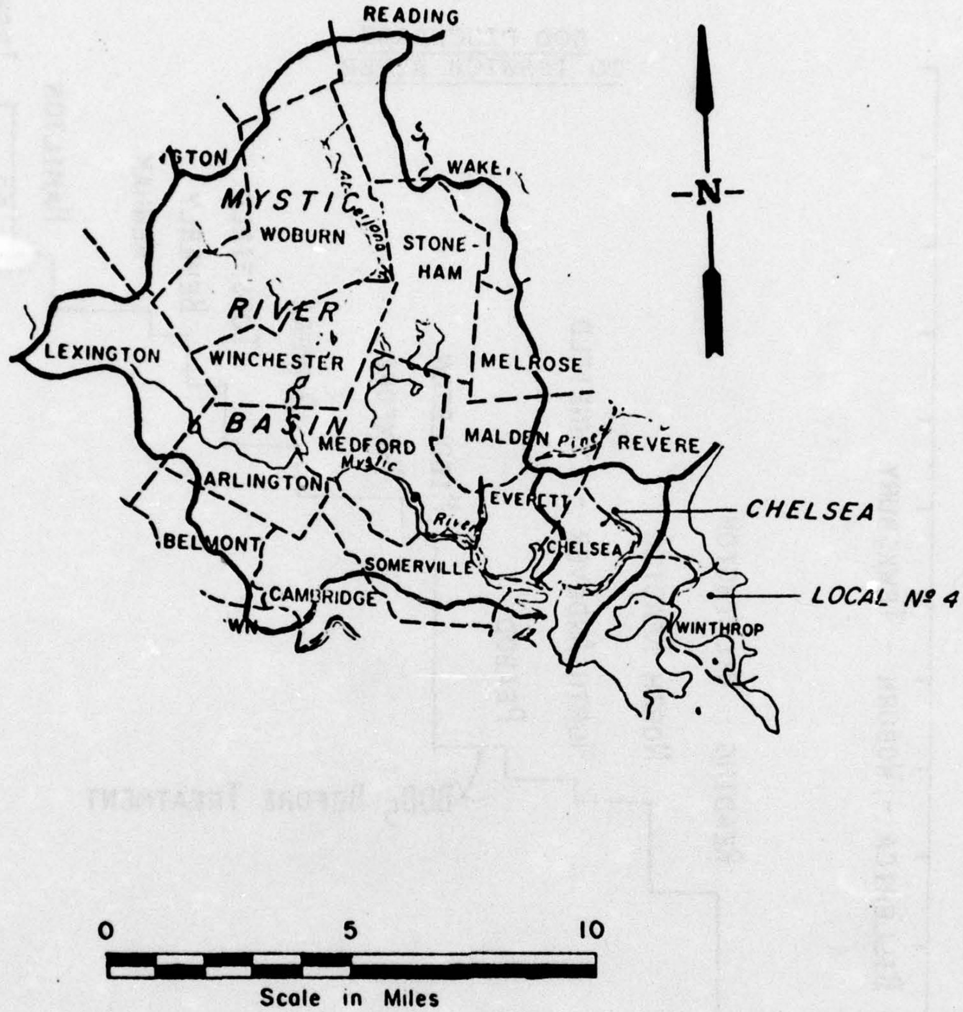


FIGURE 29. MYSTIC RIVER BASIN

FIGURE 30

SUSPENDED SOLIDS DISCHARGE
TO MYSTIC RIVER

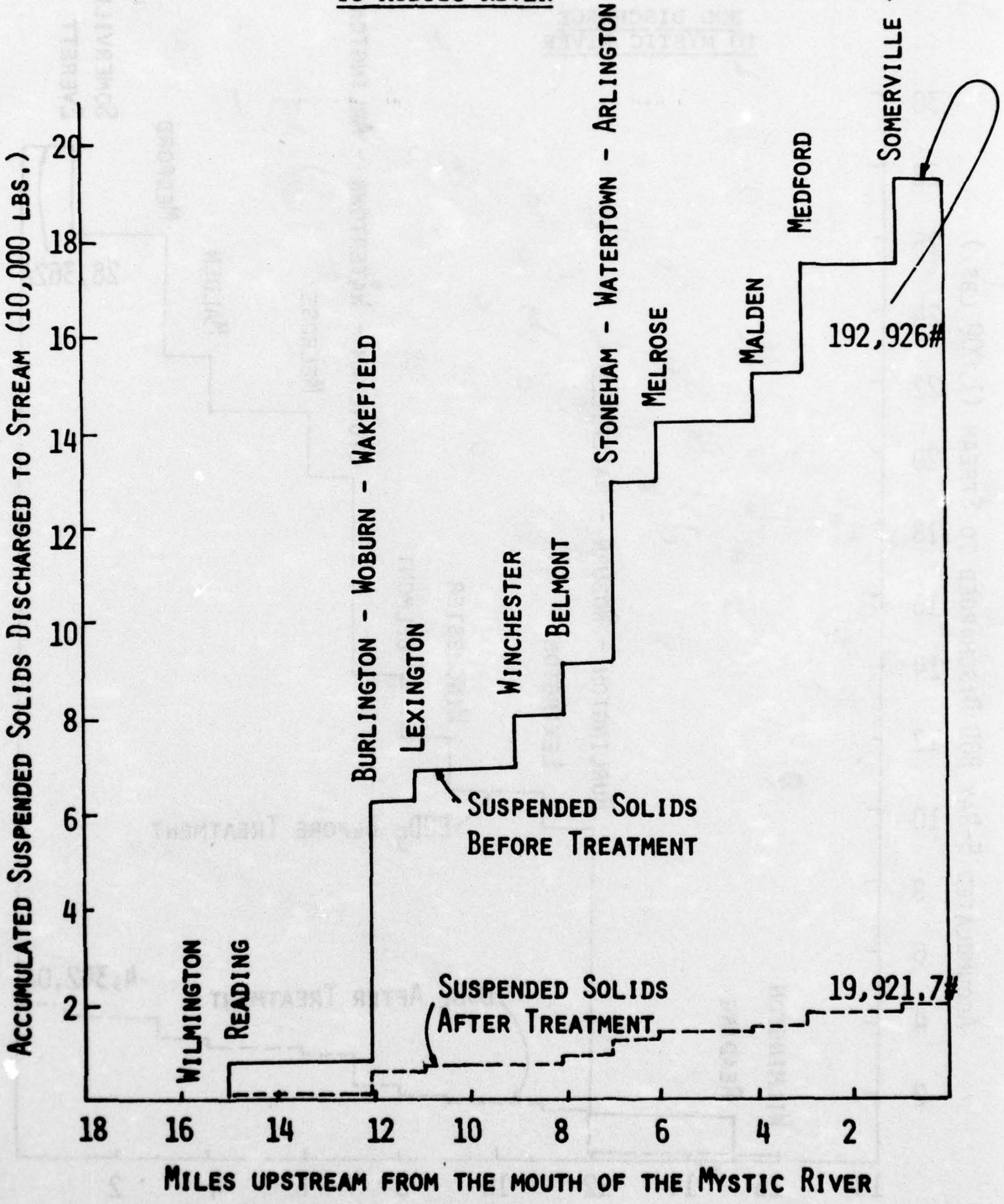
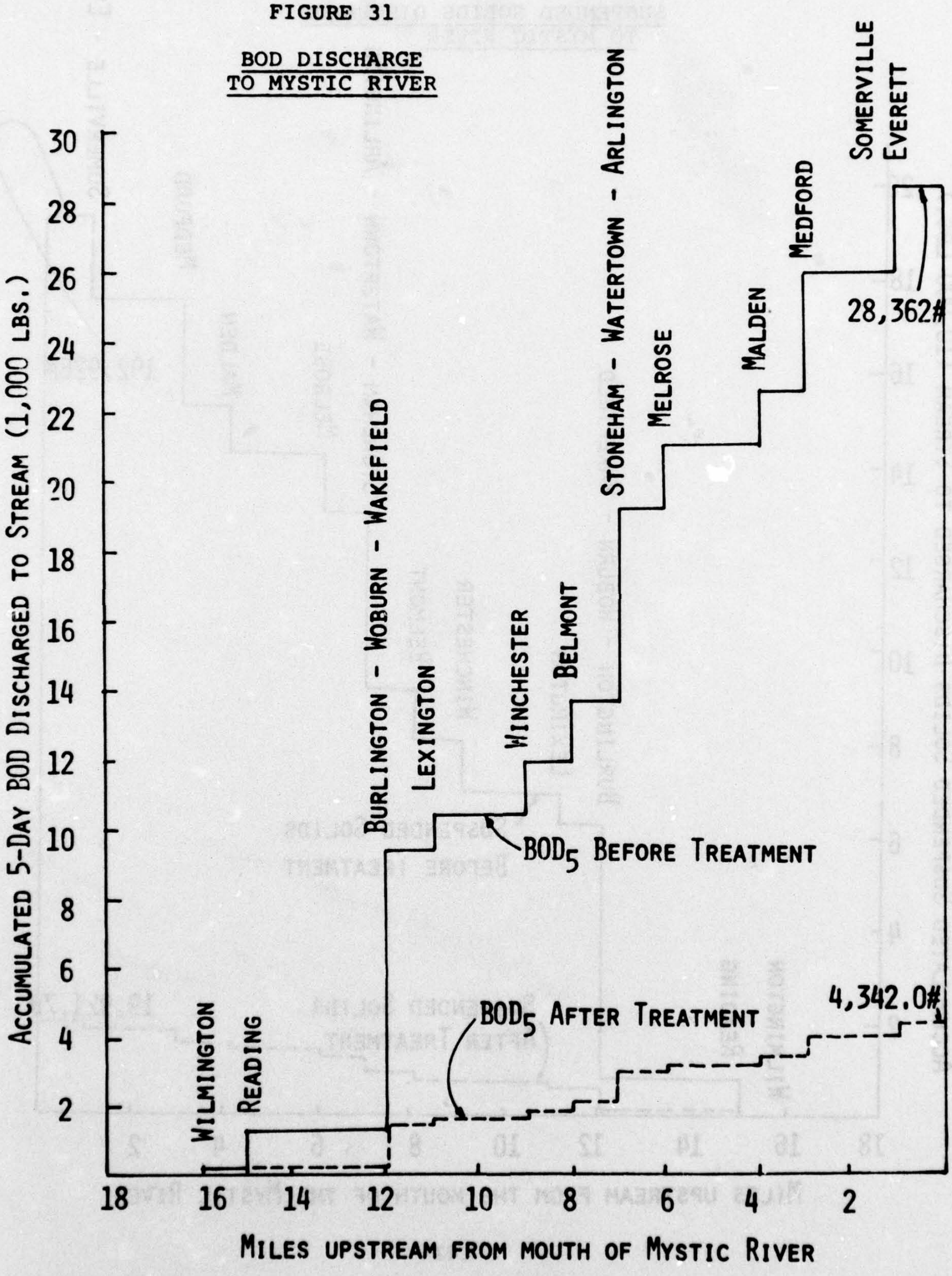


FIGURE 31

BOD DISCHARGE
TO MYSTIC RIVER



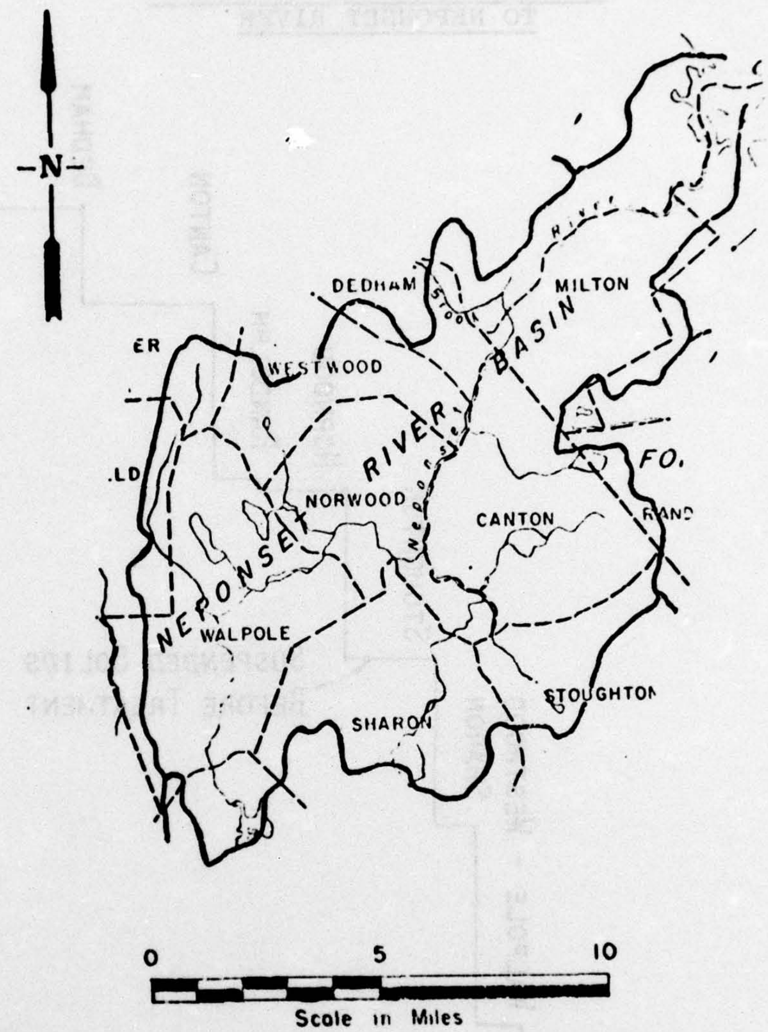


FIGURE 32. NEPONSET RIVER BASIN

FIGURE 33

SUSPENDED SOLIDS DISCHARGE
TO NEPONSET RIVER

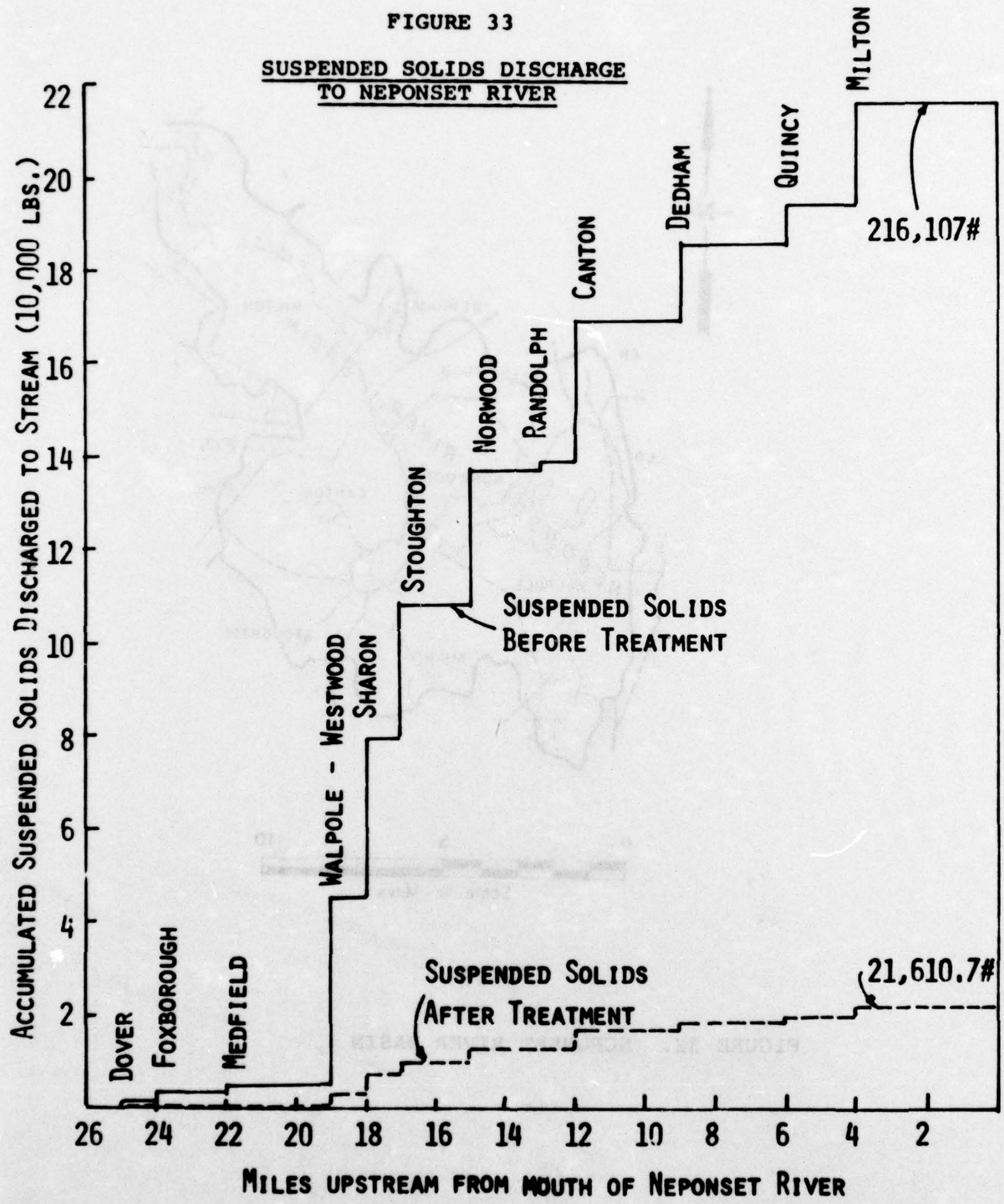
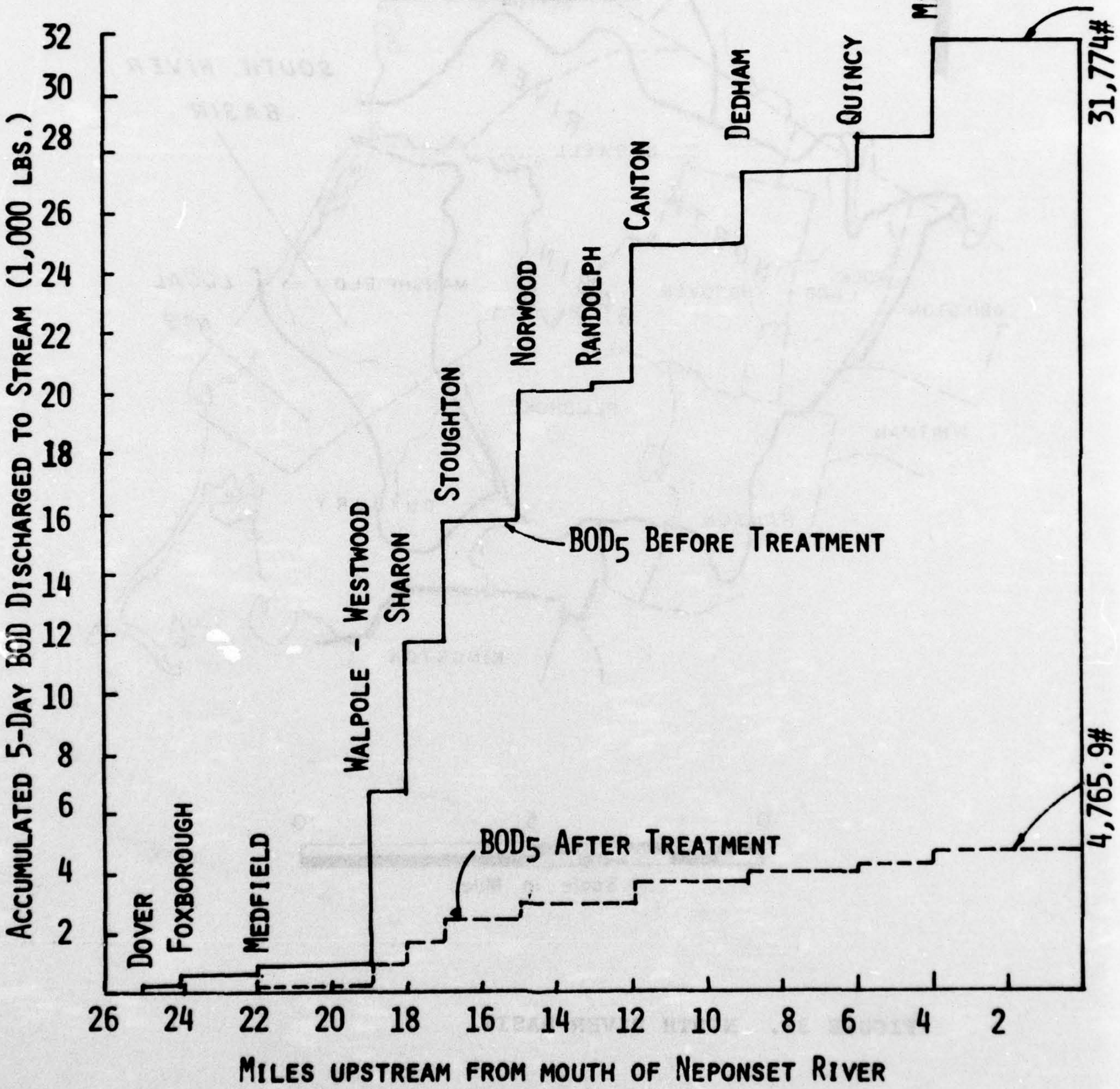


FIGURE 34

BOD DISCHARGE
TO NEPONSET RIVER



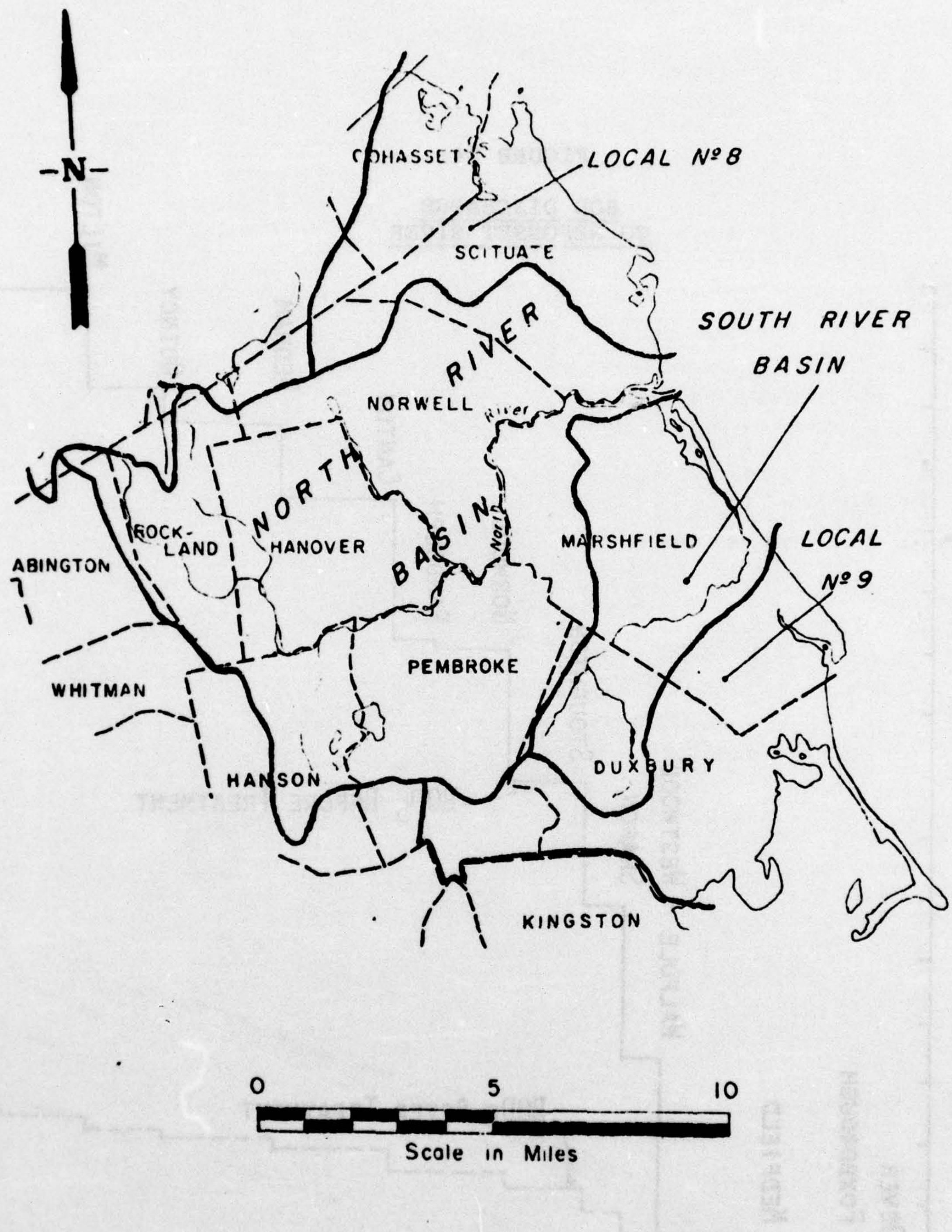


FIGURE 35. NORTH RIVER BASIN

FIGURE 36

SUSPENDED SOLIDS DISCHARGE
TO NORTH RIVER

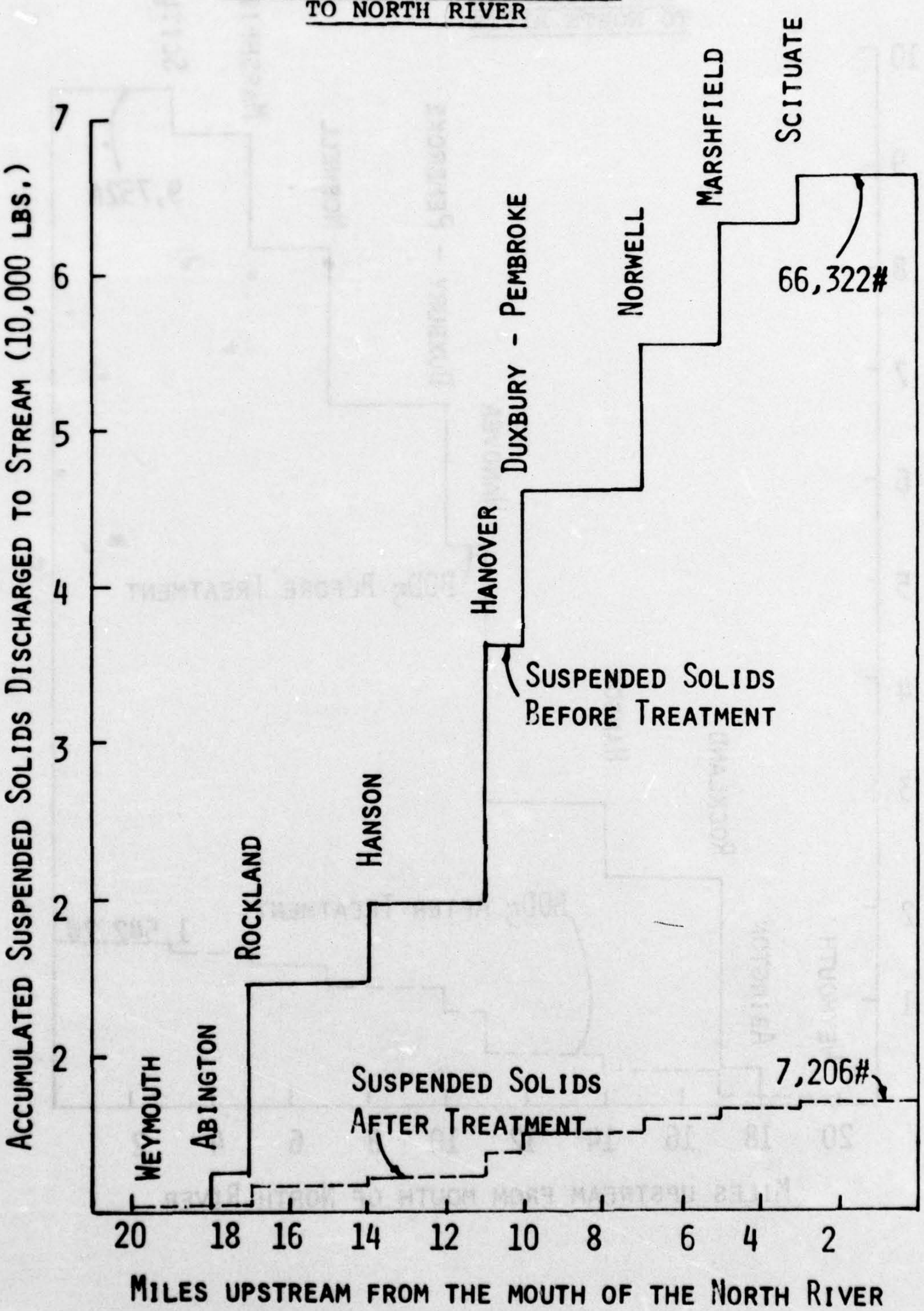
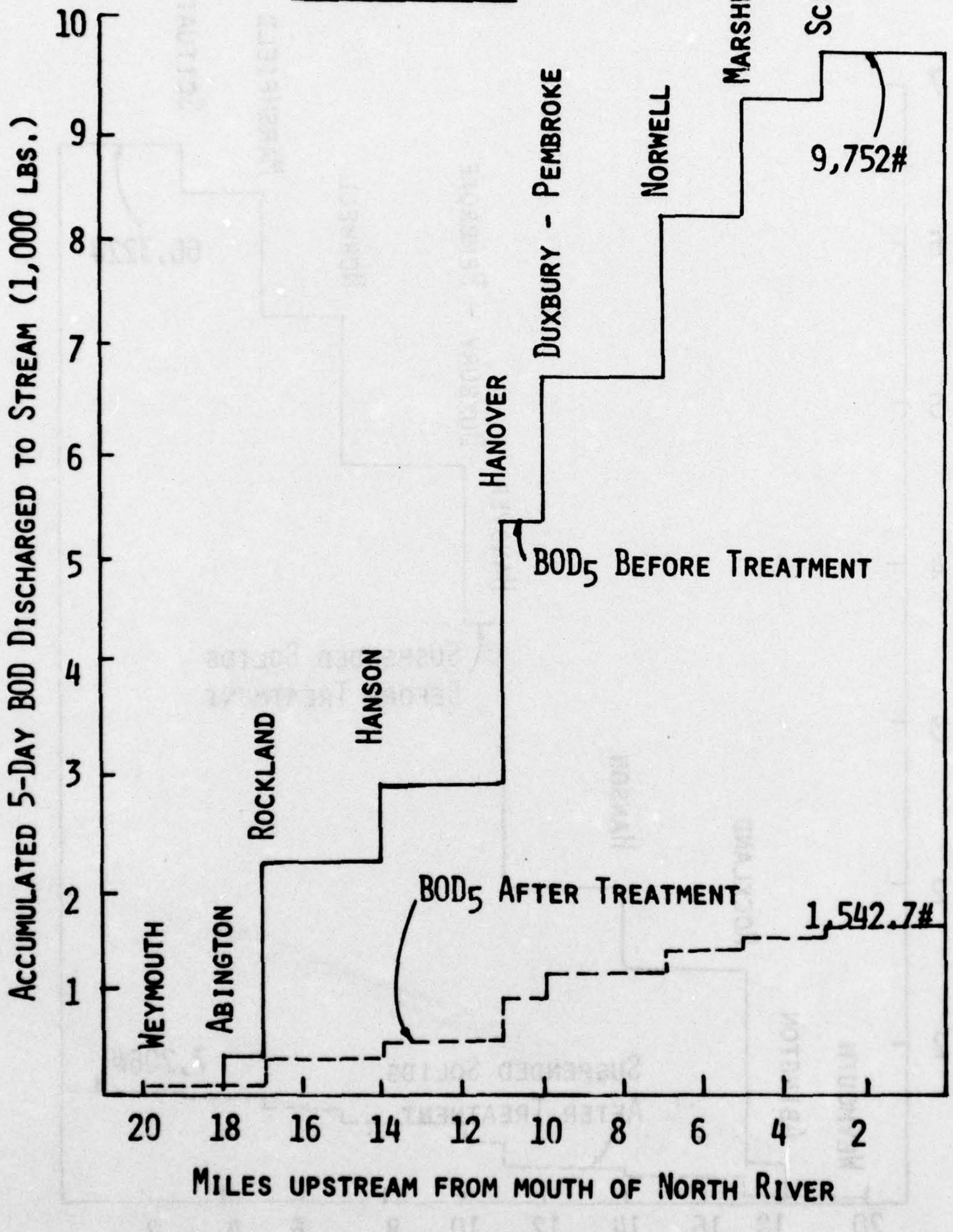


FIGURE 37

BOD DISCHARGE
TO NORTH RIVER



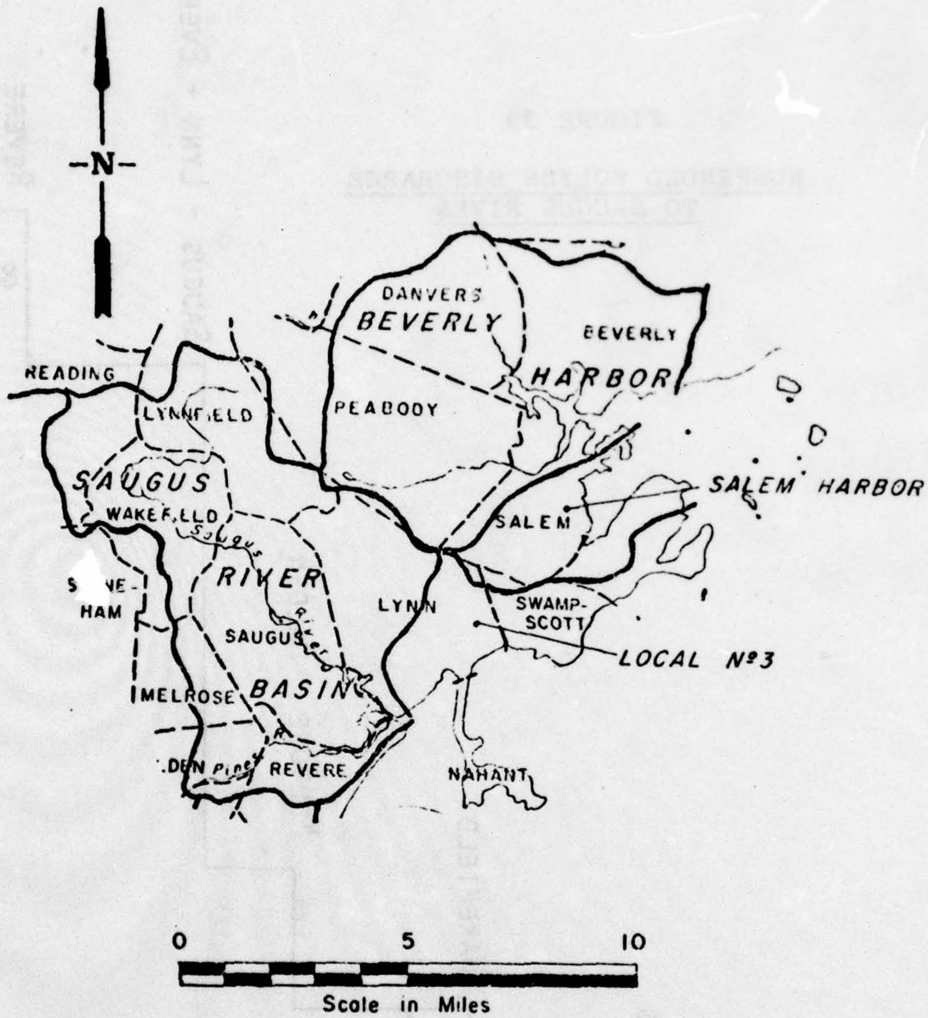


FIGURE 38. SAUGUS RIVER BASIN

FIGURE 39

SUSPENDED SOLIDS DISCHARGE
TO SAUGUS RIVER

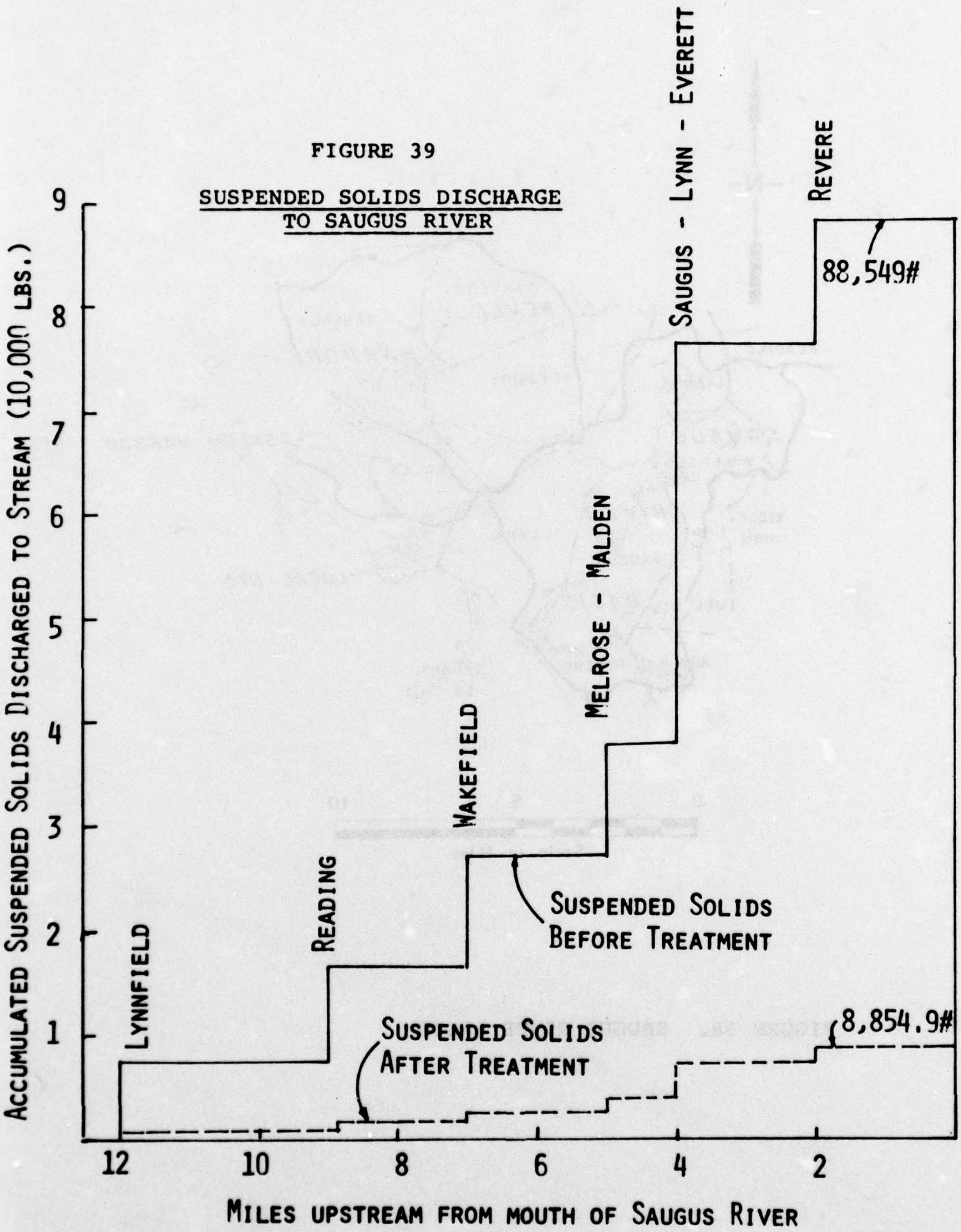
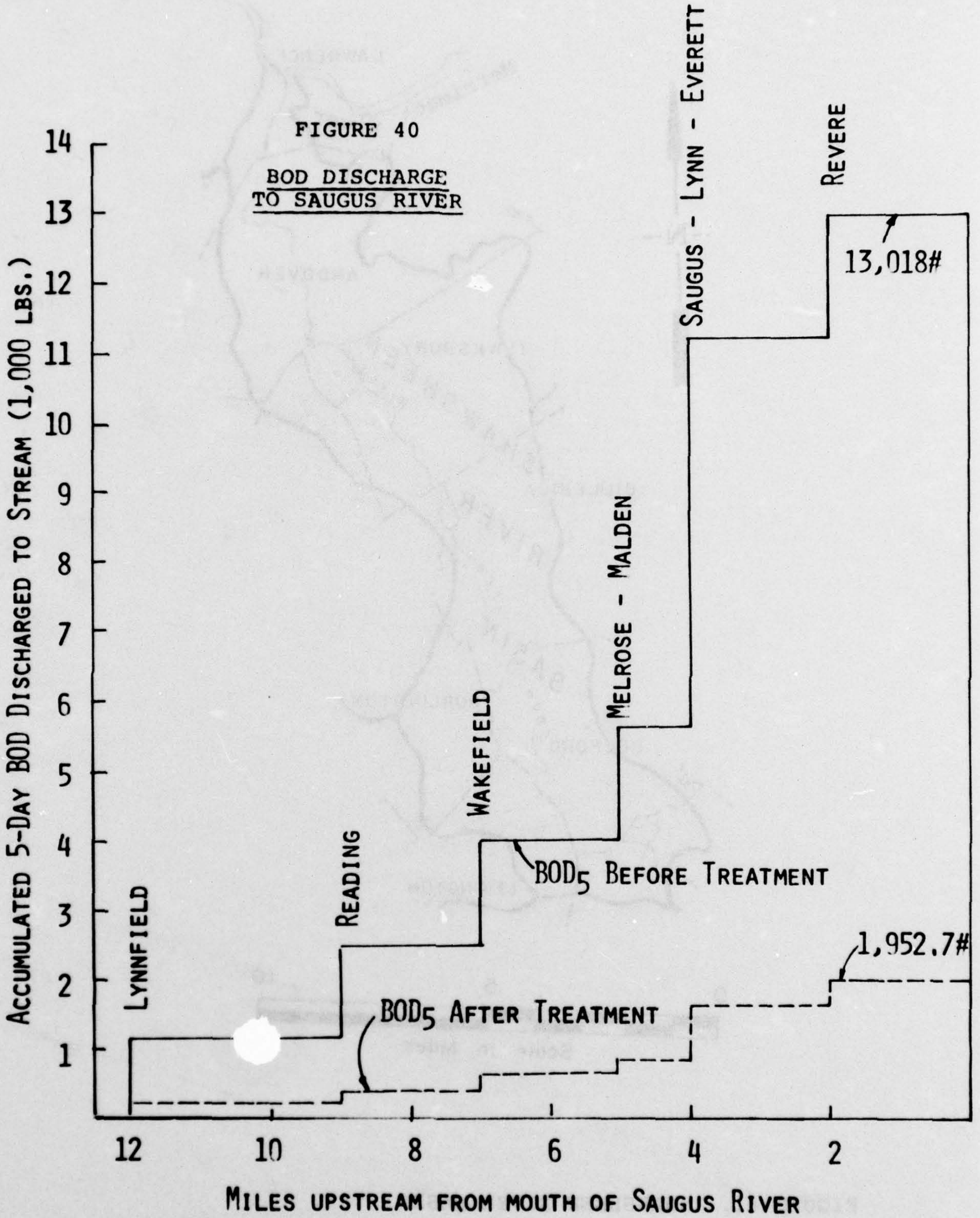


FIGURE 40

BOD DISCHARGE TO SAUGUS RIVER



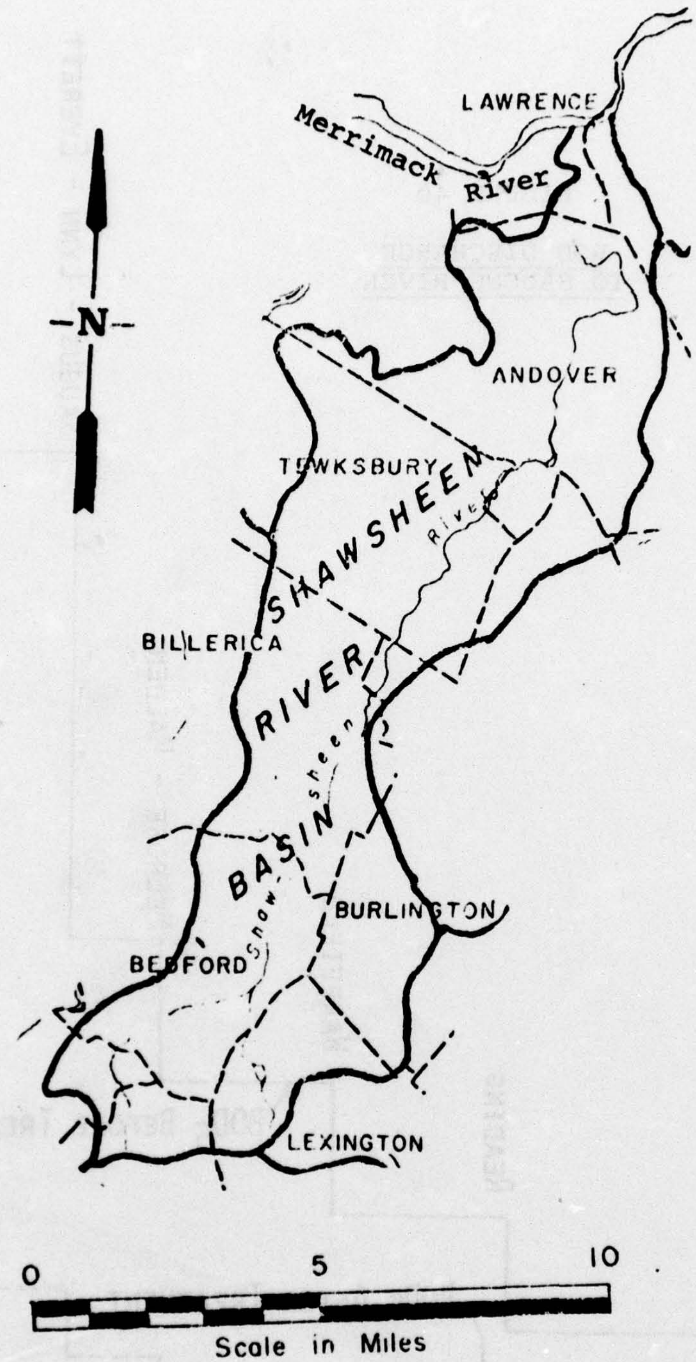


FIGURE 41. SHAWSHEEN RIVER BASIN

FIGURE 42

SUSPENDED SOLIDS DISCHARGE TO SHAWSHEEN RIVER

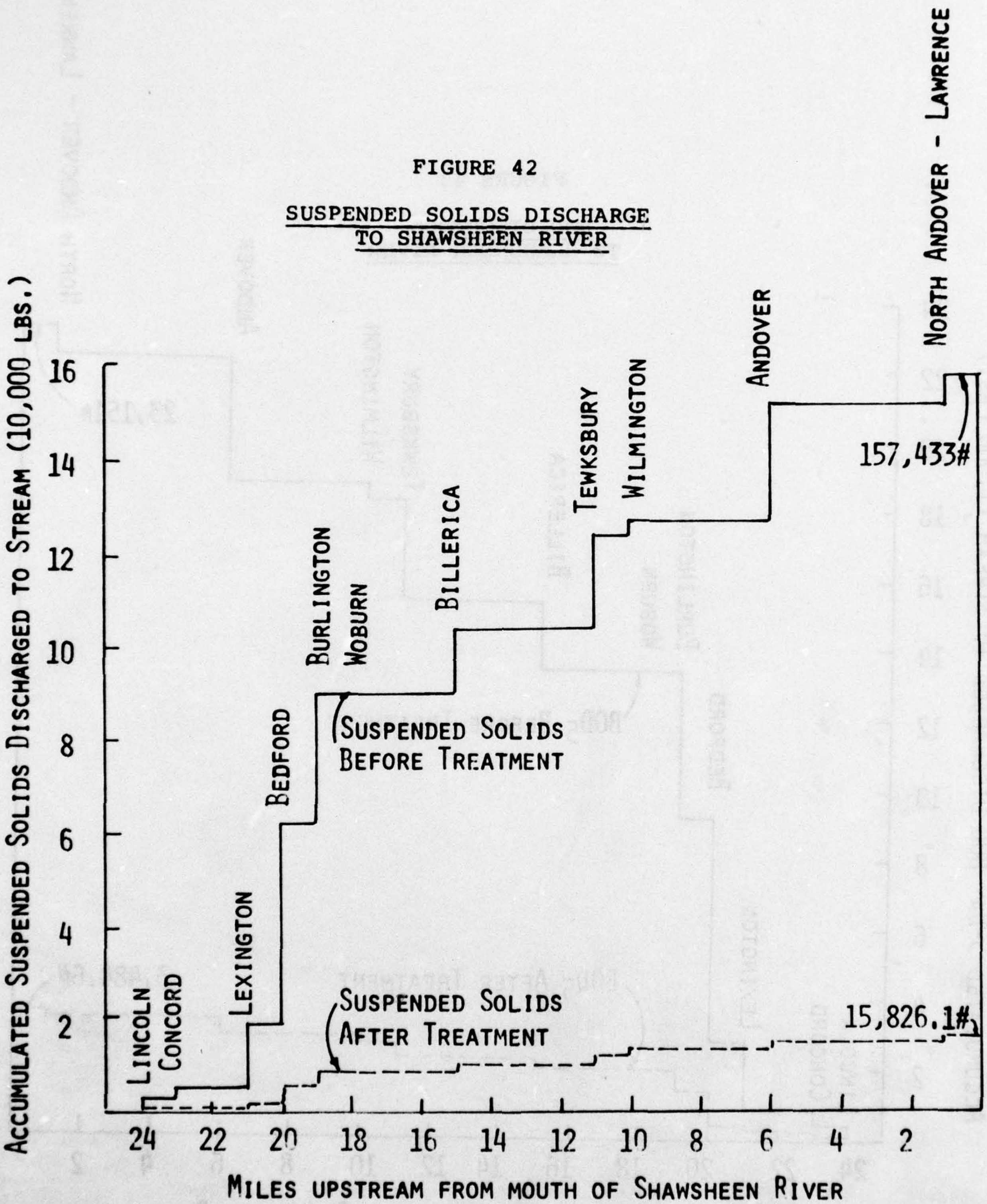
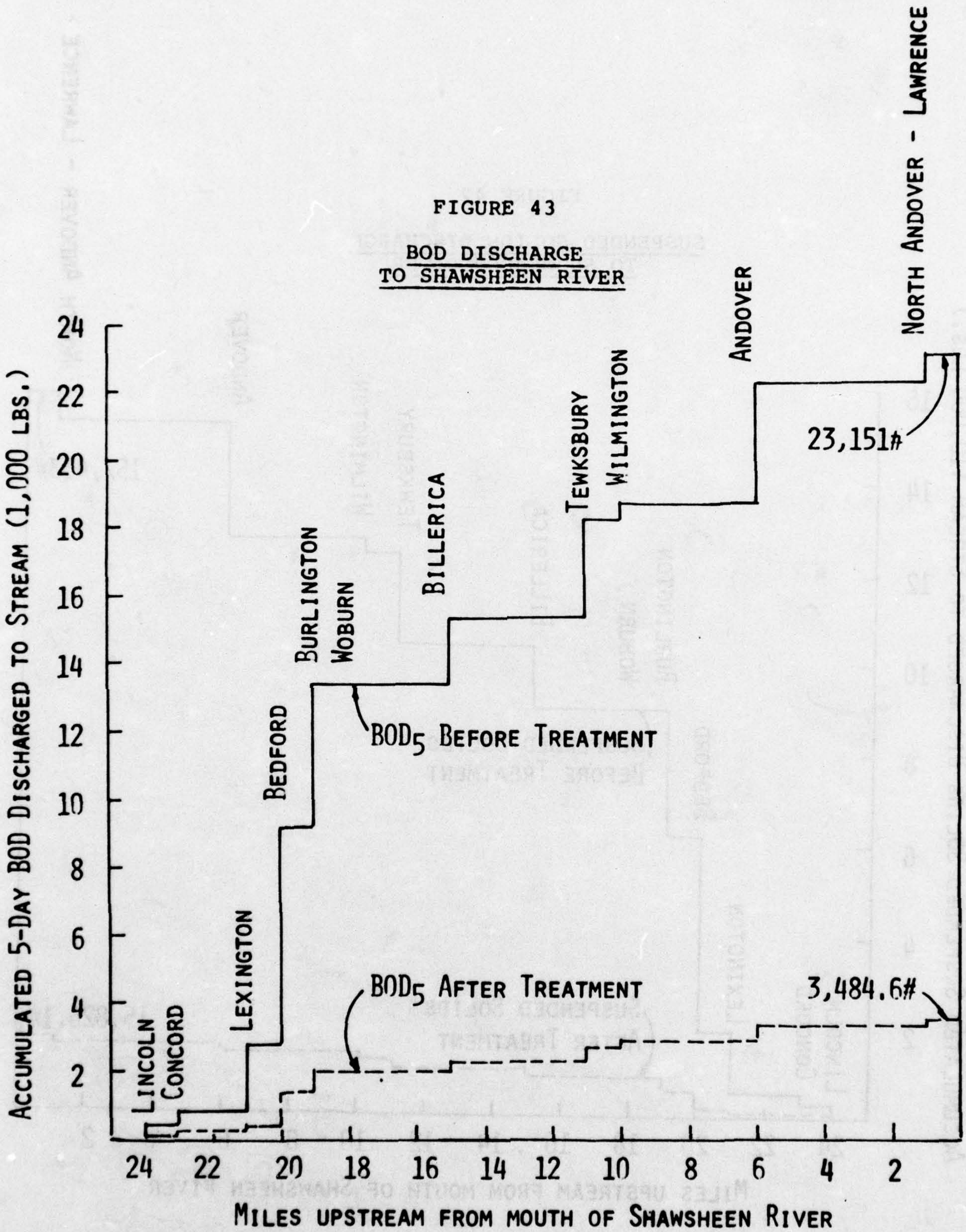


FIGURE 43

BOD DISCHARGE
TO SHAWSHEEN RIVER



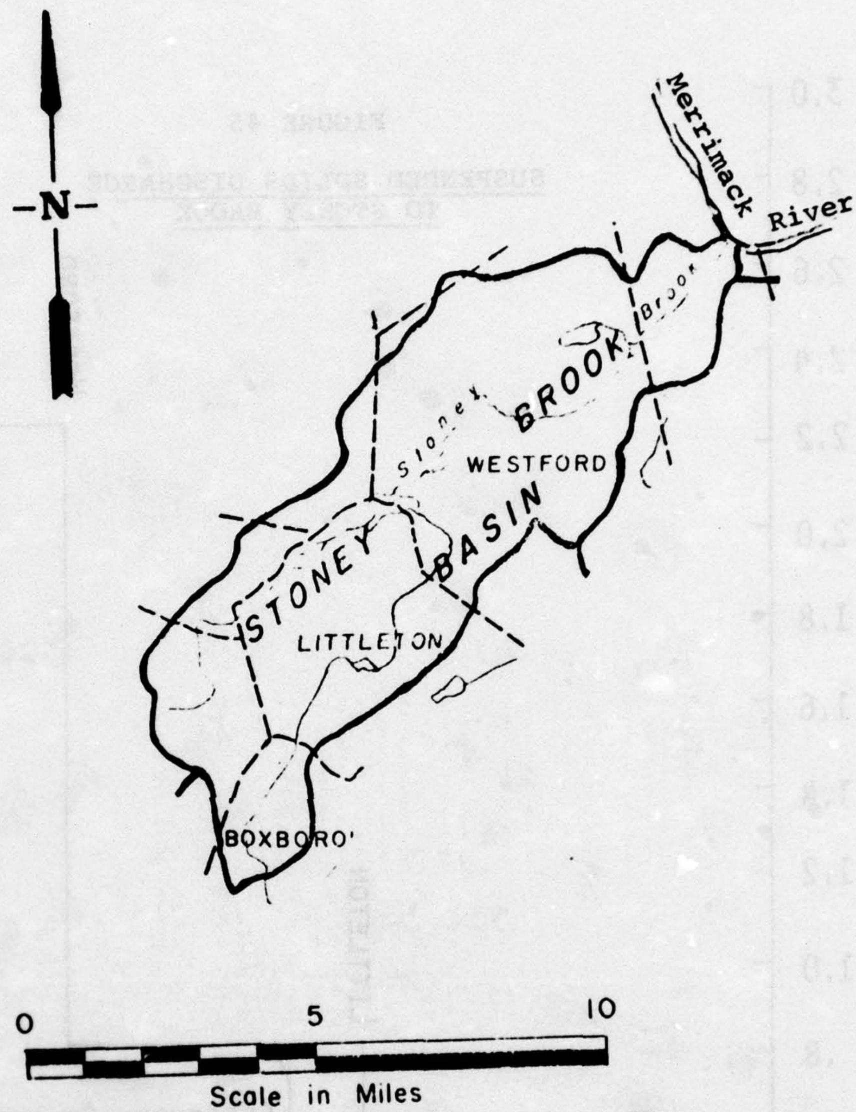


FIGURE 44. STONEY BROOK BASIN

FIGURE 45

SUSPENDED SOLIDS DISCHARGE TO STONEY BROOK

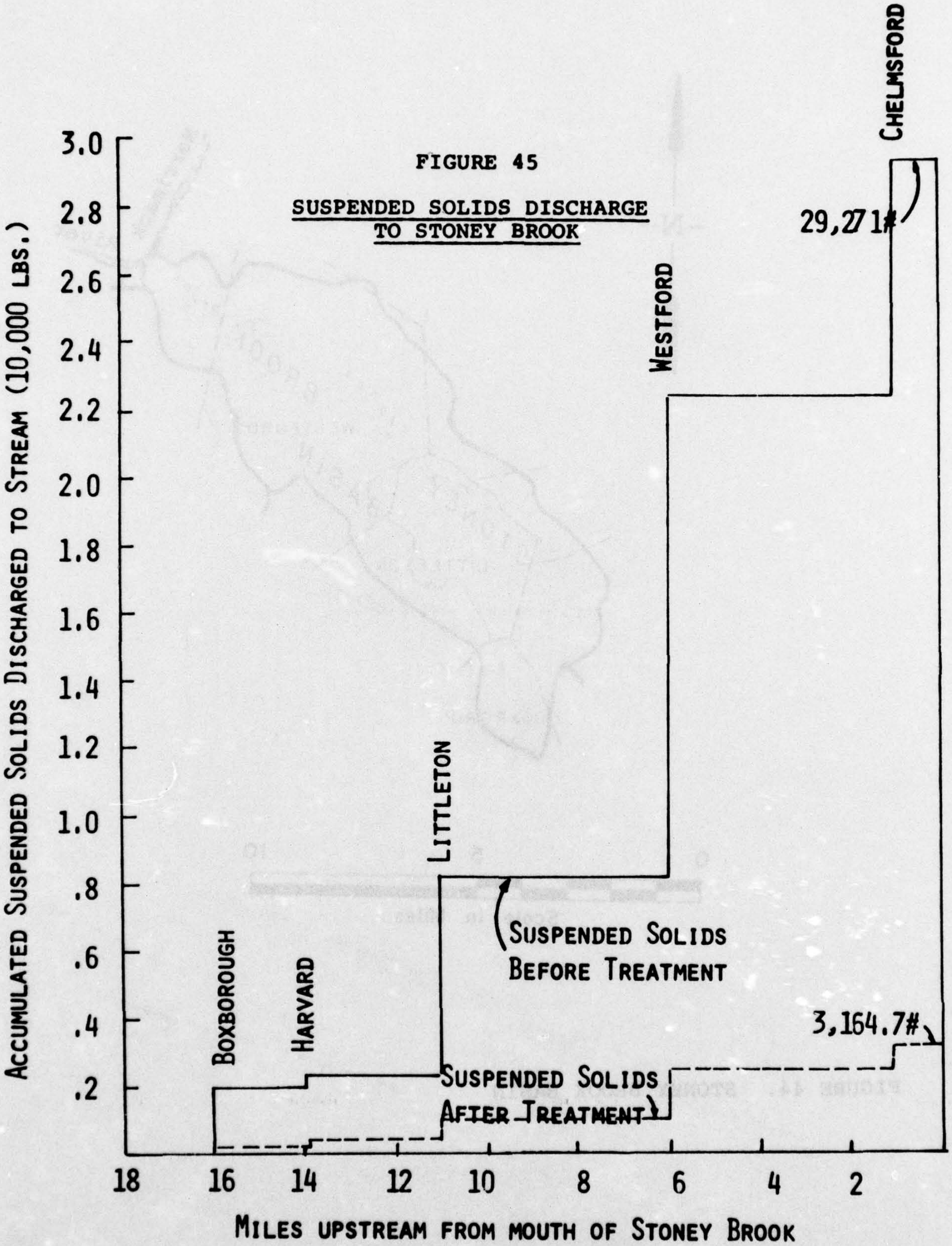
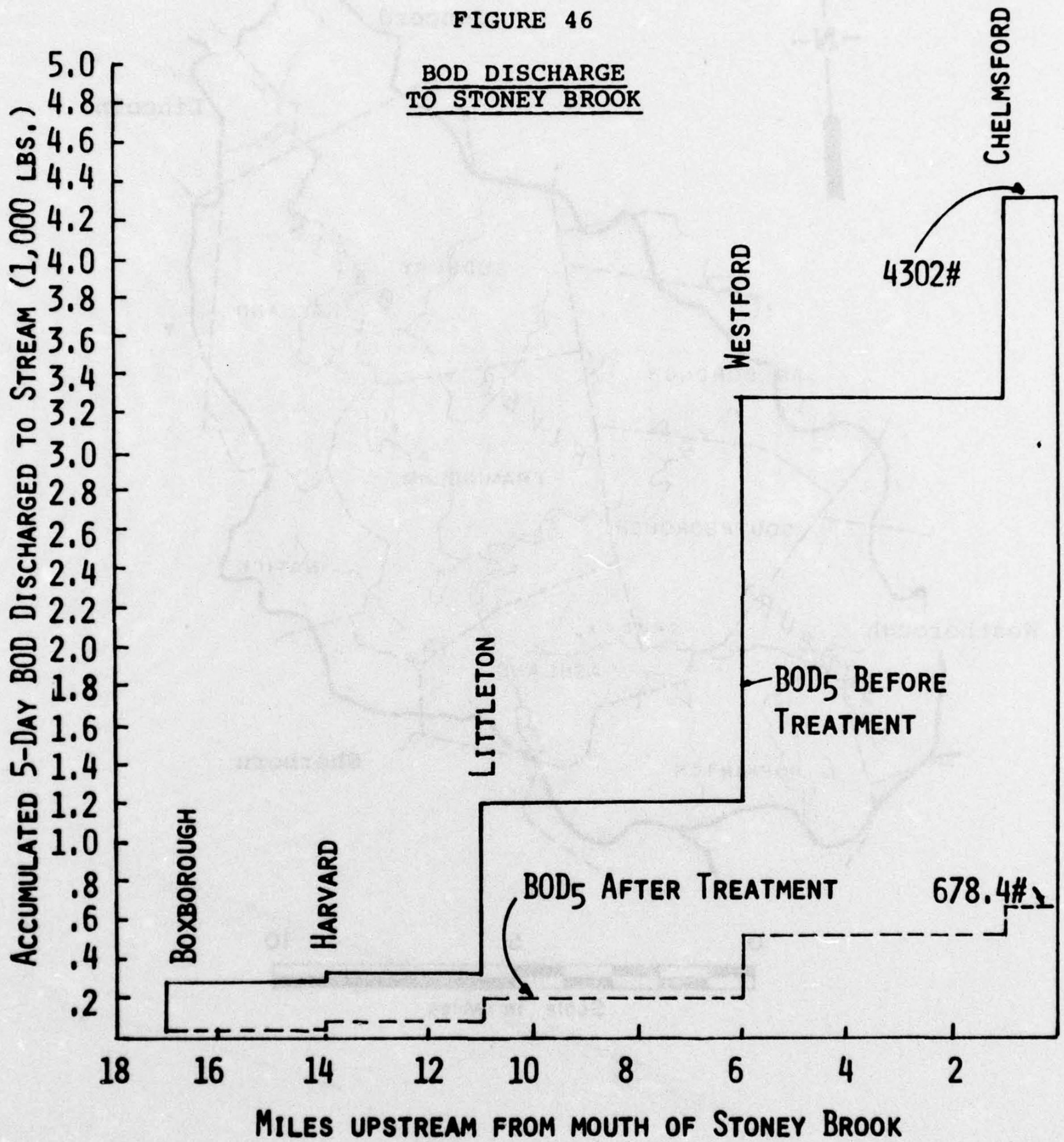


FIGURE 46

BOD DISCHARGE TO STONEY BROOK



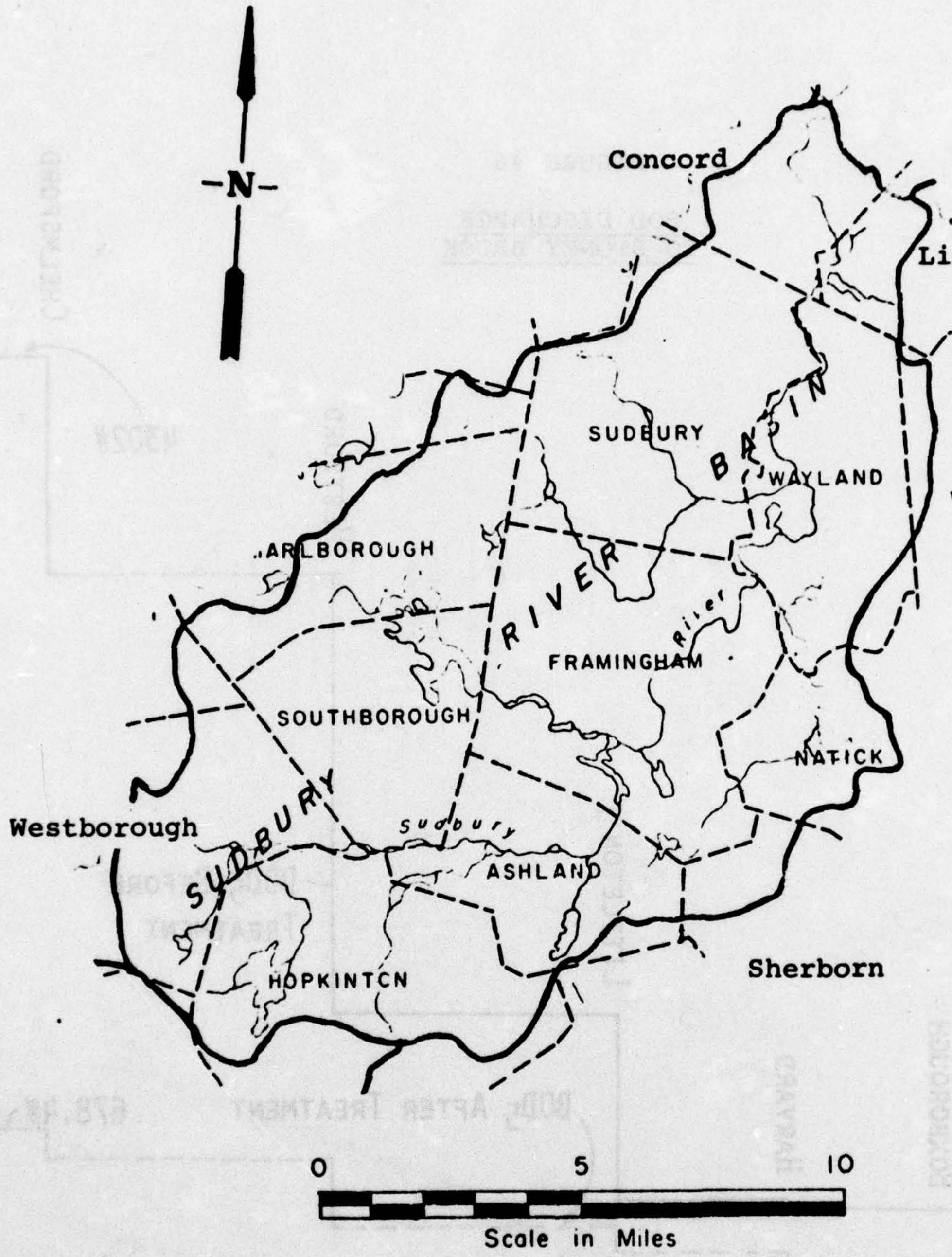


FIGURE 47. SUDBURY RIVER BASIN

FIGURE 48

SUSPENDED SOLIDS DISCHARGE TO SUDBURY RIVER

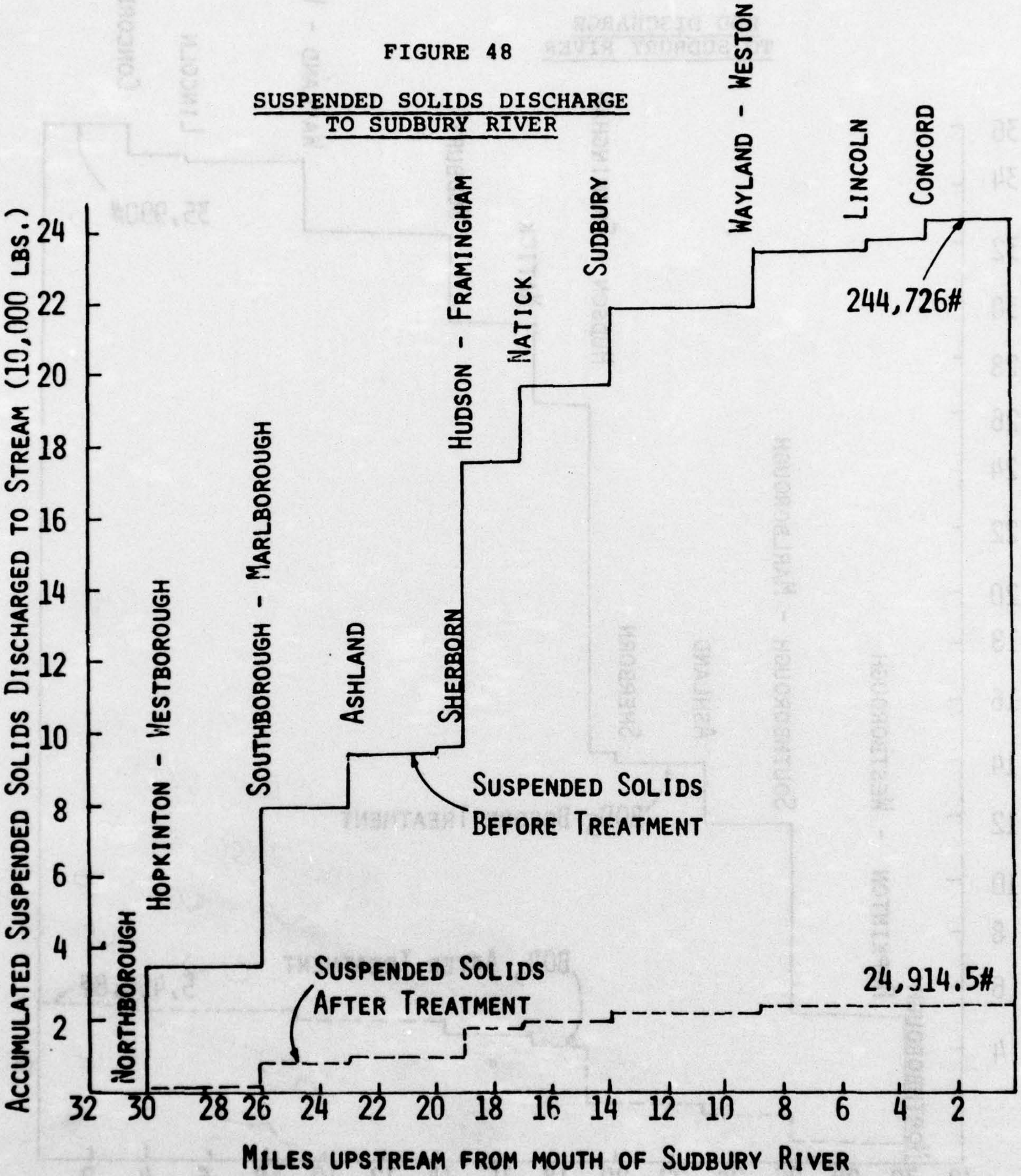
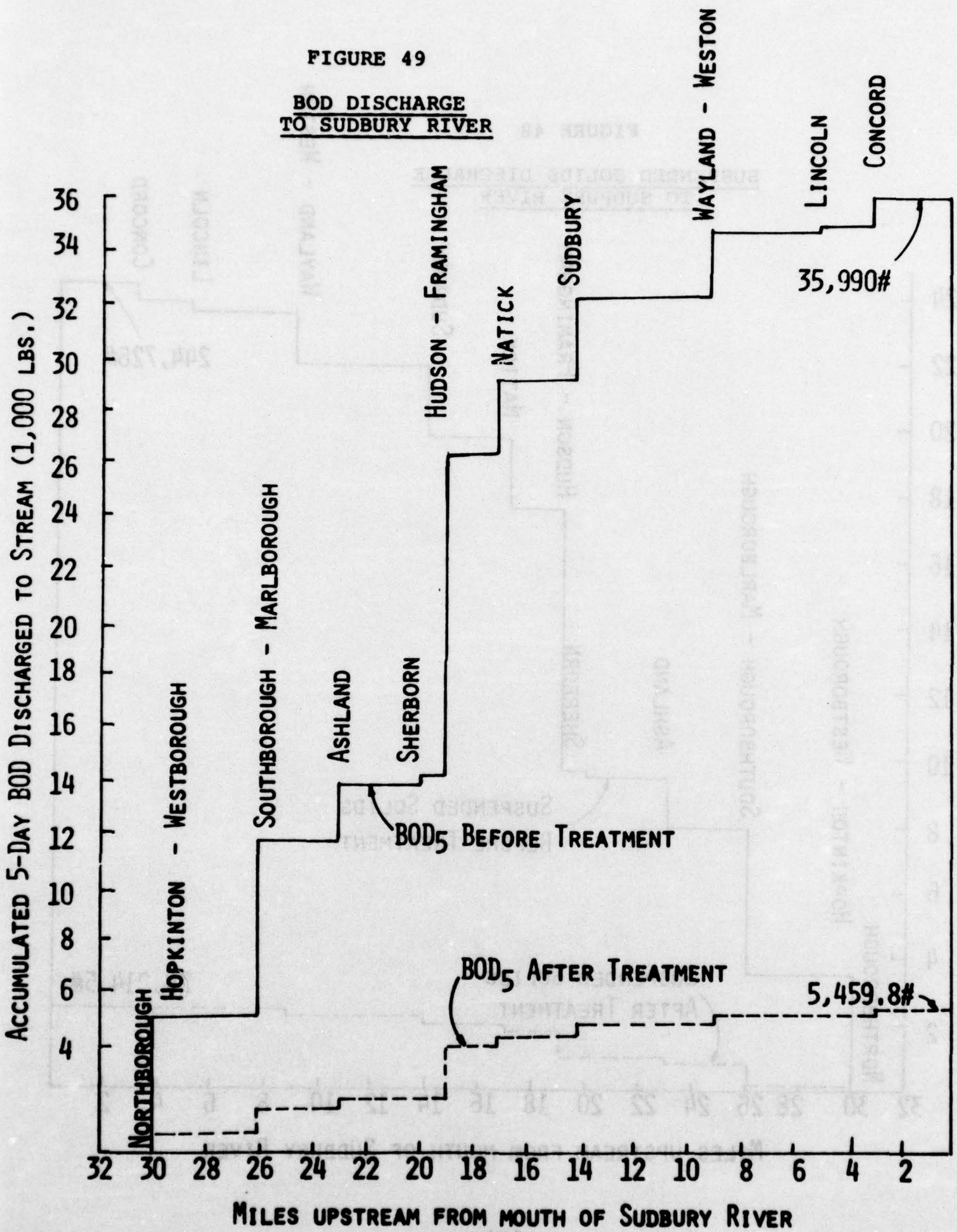


FIGURE 49

BOD DISCHARGE
TO SUDBURY RIVER



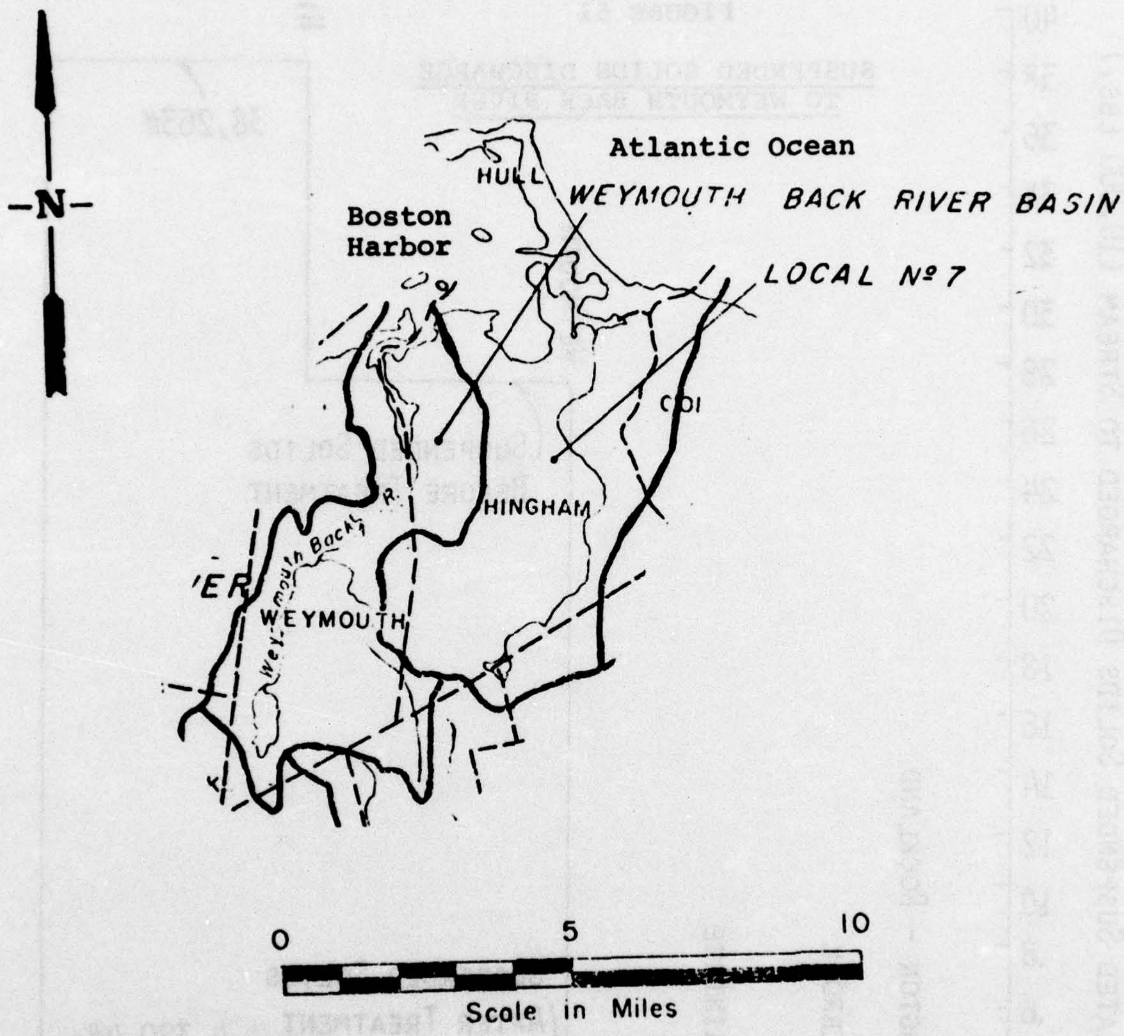


FIGURE 50. WEYMOUTH BACK RIVER BASIN

FIGURE 51

SUSPENDED SOLIDS DISCHARGE TO WEYMOUTH BACK RIVER

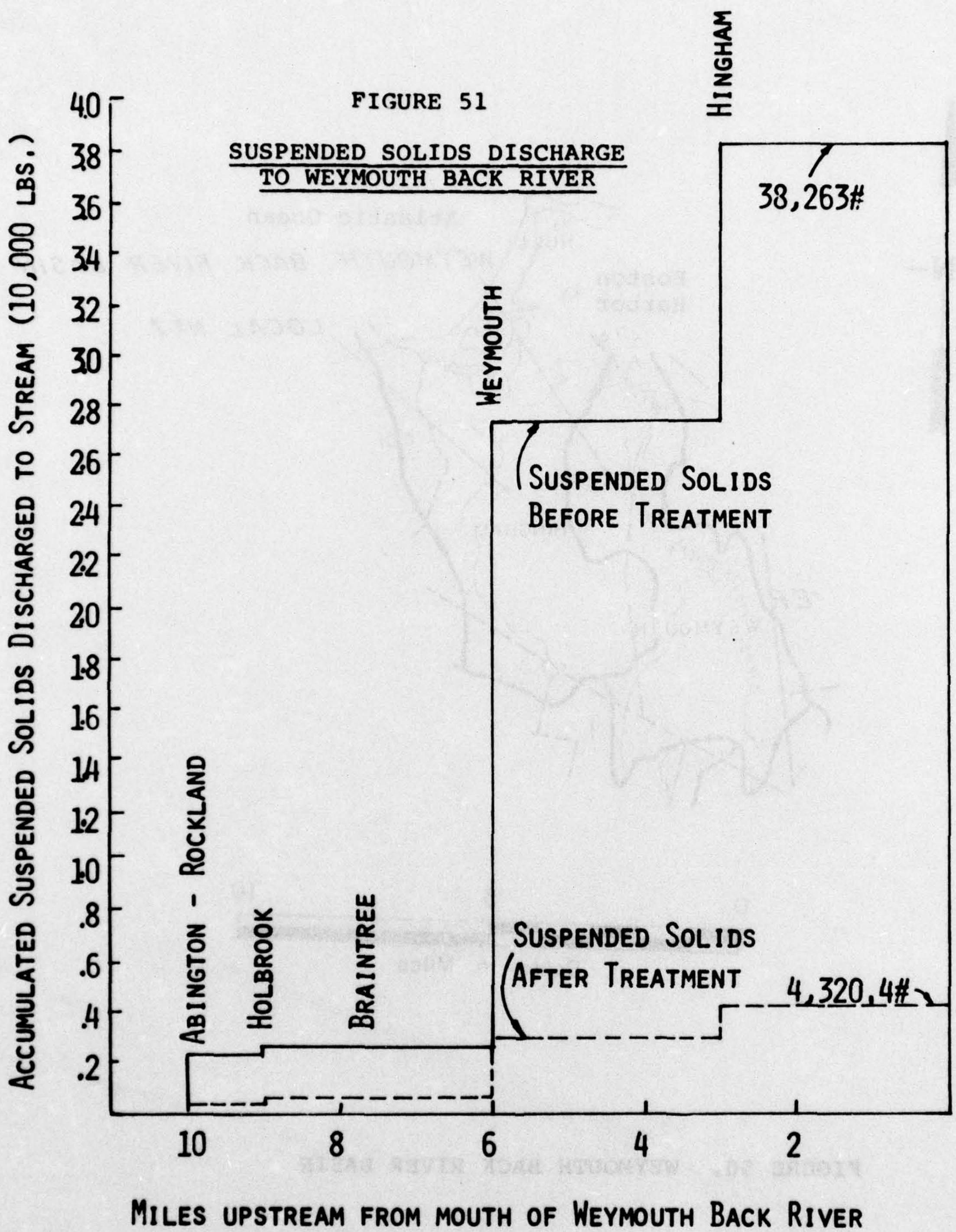
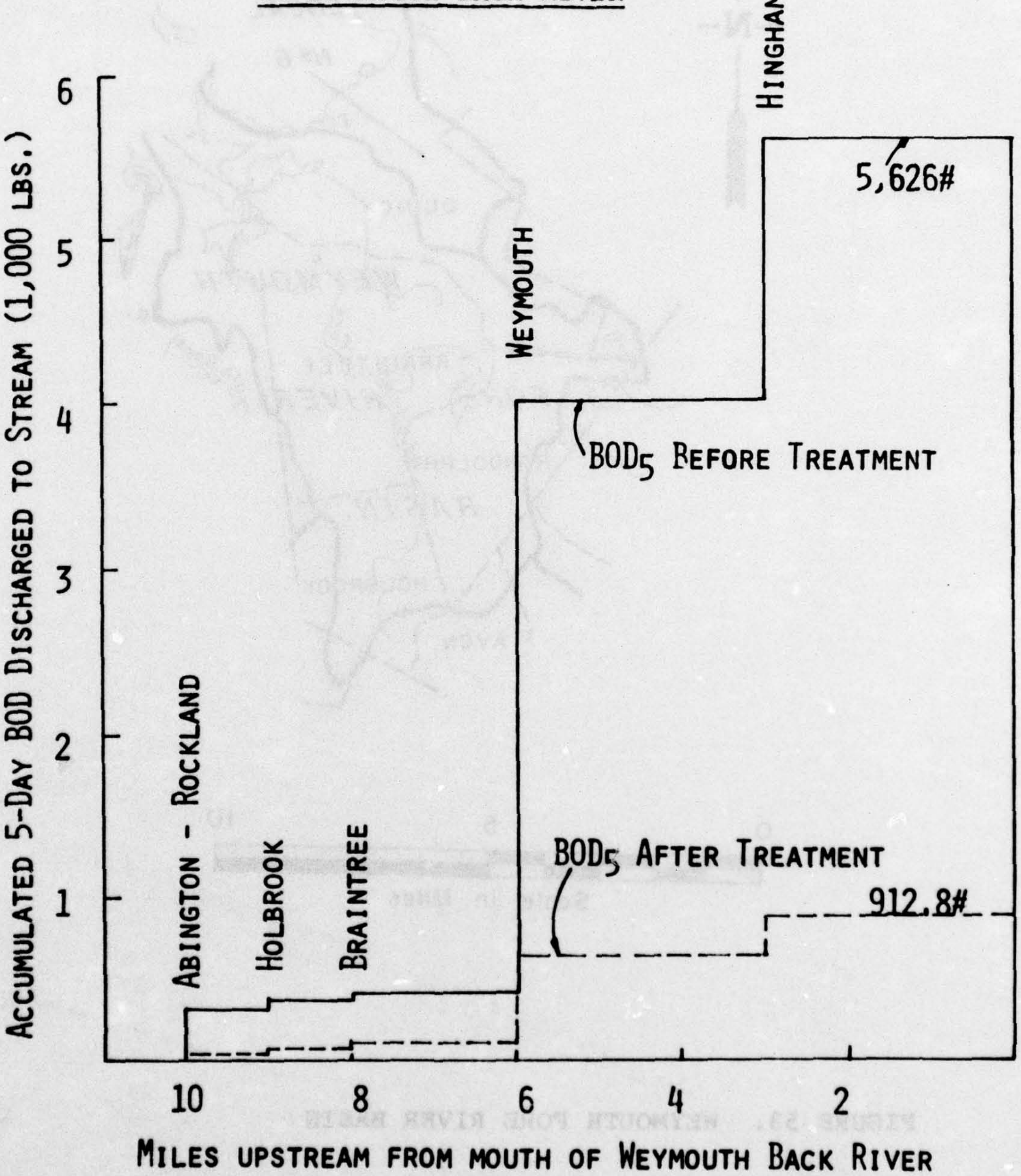


FIGURE 52

BOD DISCHARGE
TO WEYMOUTH BACK RIVER



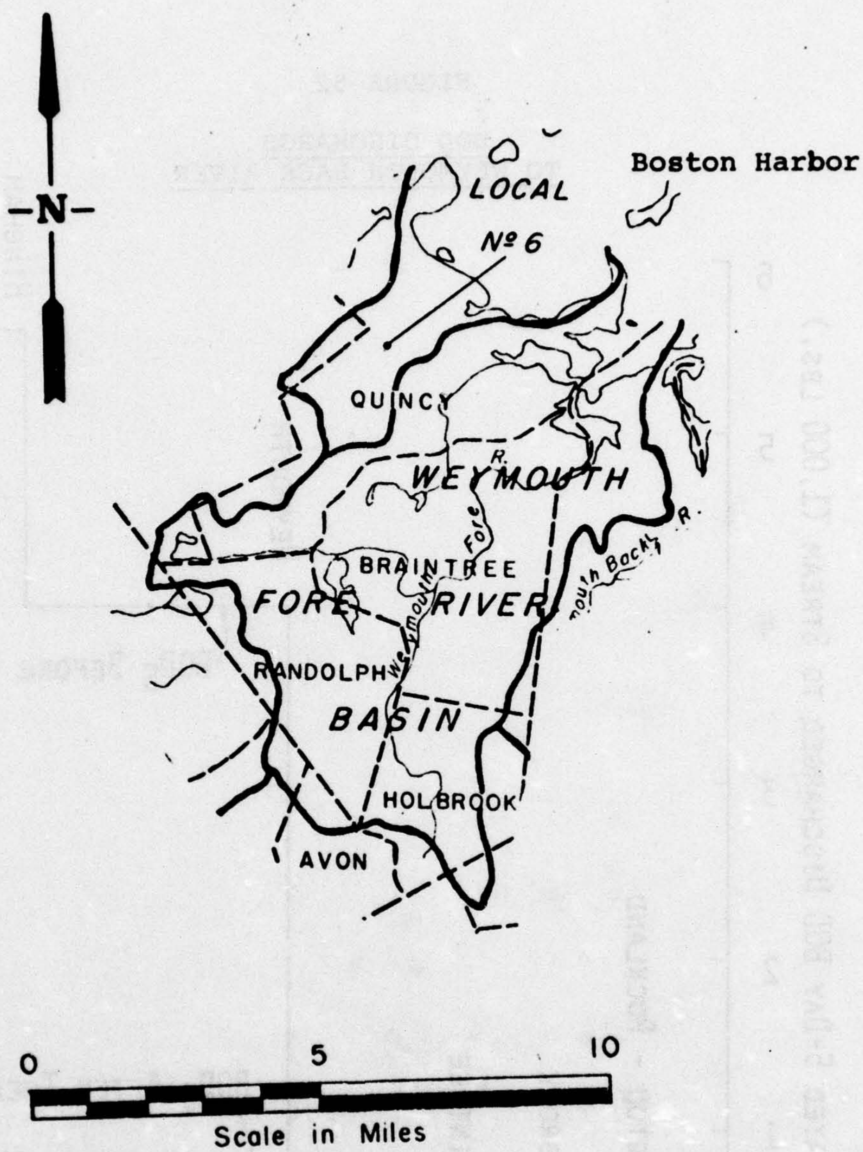


FIGURE 53. WEYMOUTH FORE RIVER BASIN

FIGURE 54

SUSPENDED SOLIDS DISCHARGE
TO WEYMOUTH FORE RIVER

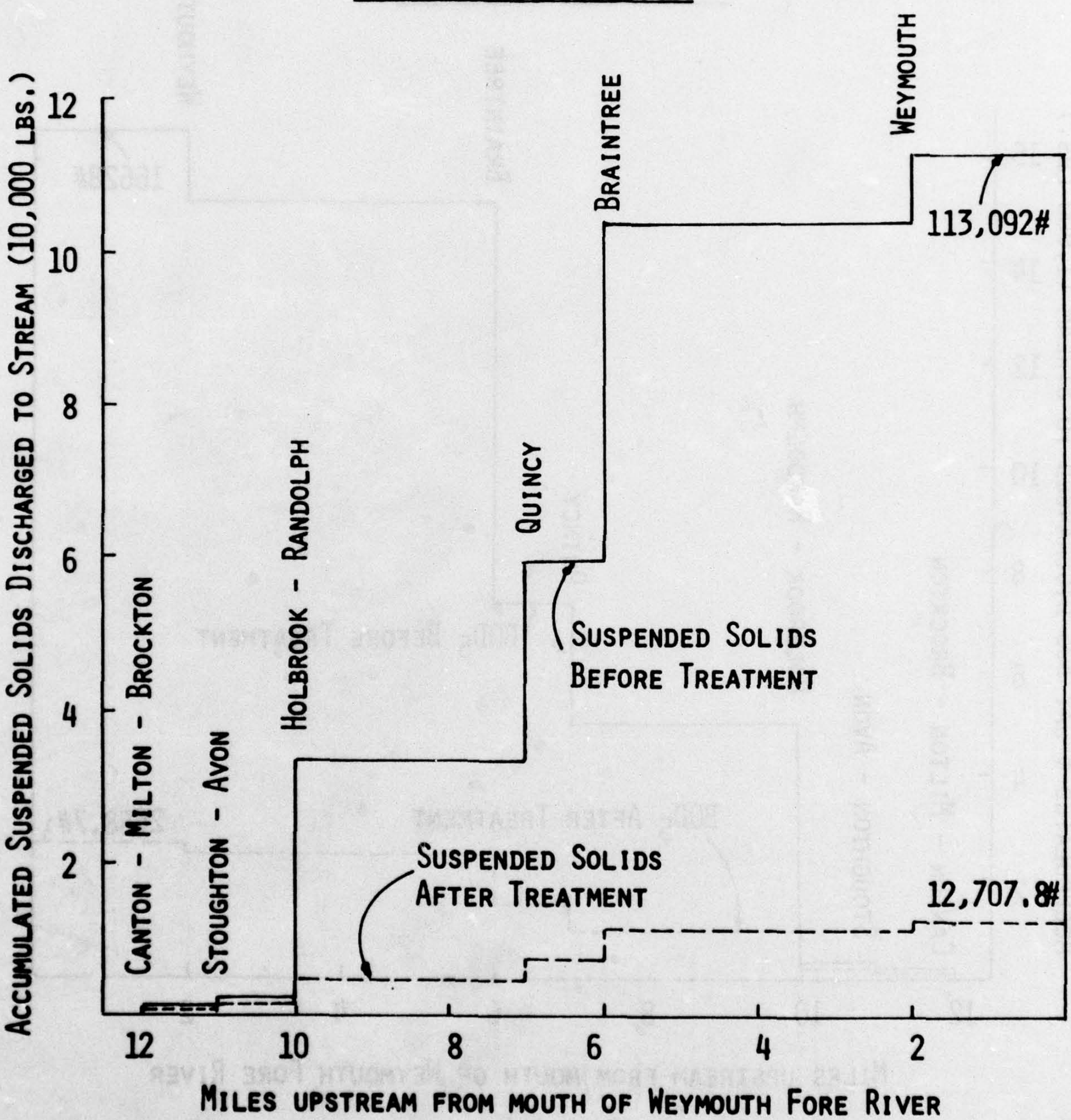
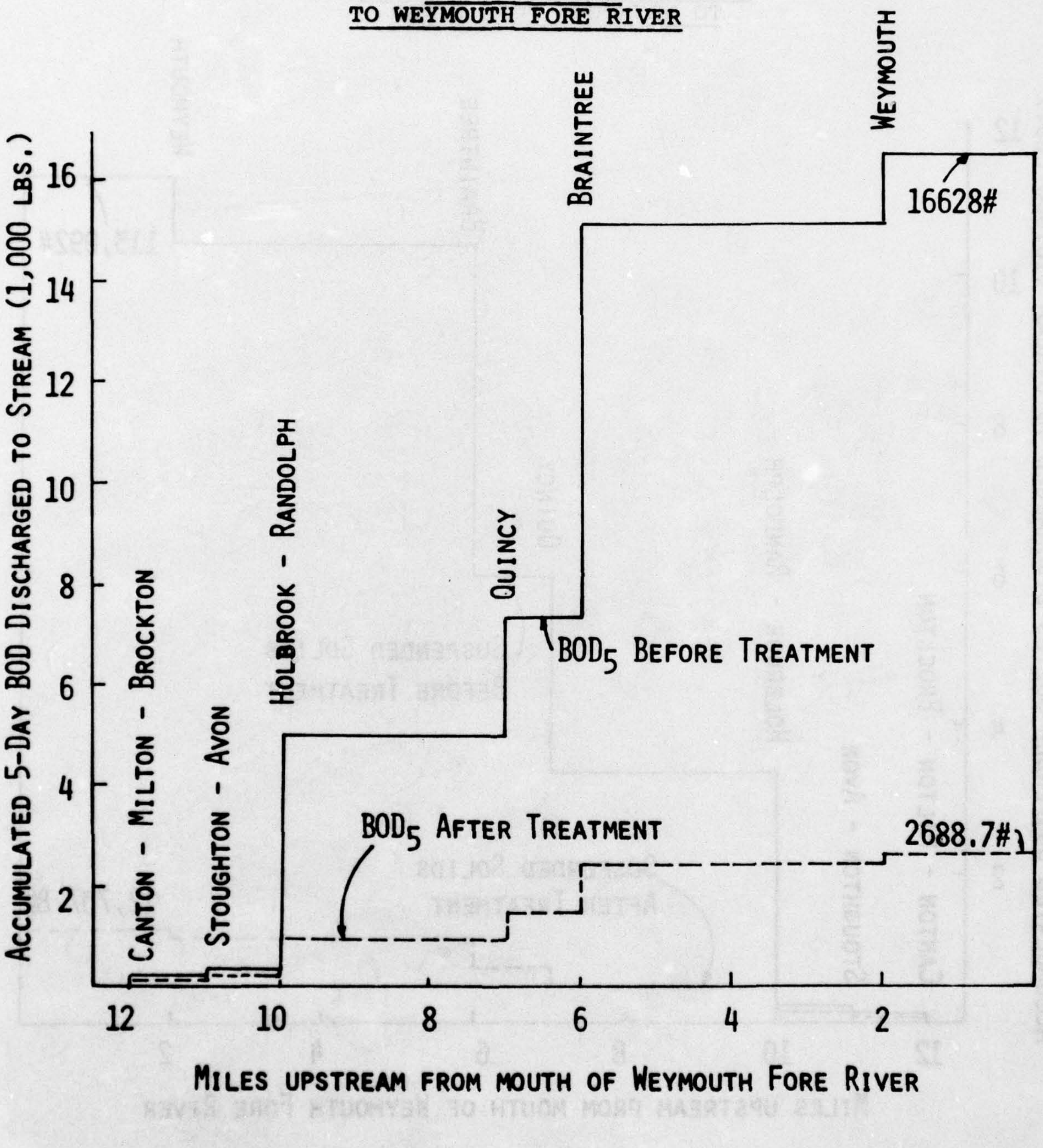


FIGURE 55

BOD DISCHARGE
TO WEYMOUTH FORE RIVER



lower. Whereas BOD and Suspended Solids removals on the order of 80 to 90% can be expected under idealistic conditions employing storage and pumping, such removals are on the order of 30% for BOD and 50% for Suspended Solids when stormwater is stored, microstrained and disinfected. Thus, the removals of BOD and Suspended Solids as presented in Figures 17 through 55 should be modified if measures other than storage and pumping are to be employed.

Future Requirements

Table 23 shows how the urban land portion of each community within the study area is anticipated to increase. The total area of each community is shown along with forecasted urban land development for the design year 2000 and for future years 2020 and 2050. The percent increase in urban land development over the design year 2000 is also shown for each community.

The data show that a wide range in urban development in particular watersheds can be expected ranging from a decrease of 83%, for the town of Weymouth in the North River Basin, to an increase of 644% for the town of Milford in the Blackstone River Basin. The reasons for such extremes are not specifically known, however, since both communities are relatively small and partial sectors are involved, such extremes should not be unexpected or unusual.

Analyzing the data by watersheds, which probably gives a much more accurate picture, urban land development ranges from a decrease of 14%, for the Salem Harbor area, to an increase of 125% for the Blackstone River Basin. In general, the data show that wide ranges in urban land development will occur from watershed to watershed and from community to community within a particular watershed.

TABLE 23

URBAN LAND DEVELOPMENT WITHIN STUDY AREA

WATERSHEDS BY COMMUNITIES

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
ASSABET					
Acton	12,998	6,674	7,806	8,280	24
Berlin	8,435	1,610	3,330	4,520	181
Bolton	9,875	1,341	2,347	3,792	183
Boxborough	4,960	696	1,484	2,152	209
Boylston	4,147	291	536	674	132
Carlisle	2,835	1,309	1,741	1,926	47
Clinton	460	225	150	155	-31
Concord	5,638	1,658	2,179	2,845	72
Grafton	908	178	216	648	264
Harvard	3,801	218	260	273	25
Hudson	6,220	2,970	3,843	4,011	35
Littleton	4,793	1,234	1,969	1,823	48
Marlborough	5,452	1,575	1,889	2,030	29
Maynard	3,424	1,302	1,583	1,727	33
Northborough	11,091	2,606	3,863	4,634	78
Shrewsbury	5,337	1,764	2,290	2,401	36
Stow	11,436	1,816	3,106	4,343	139
Sudbury	1,331	415	524	564	36
Westborough	5,312	1,249	1,516	1,671	34
Westford	4,224	413	681	873	111
TOTAL	112,677	29,544	41,313	49,342	67%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
BEVERLY HARBOR					
Beverly	5,516	3,669	4,251	4,225	15
Danvers	6,489	4,323	4,824	4,574	6
Lynn	44	44	44	38	-14
Lynnfield	160	46	54	53	15
Peabody	7,616	4,660	5,052	4,952	6
Salem	2,009	855	774	729	-15
Wenham	12	12	12	12	0
TOTAL	21,846	13,609	15,011	14,583	7%
BLACKSTONE RIVER					
Bellingham	6,988	1,510	2,317	2,800	85
Franklin	1,606	93	102	117	26
Hopkinton	3,520	378	818	1,074	184
Milford	1,305	116	108	863	644
Westborough	166	12	15	11	8
Wrentham	4,384	364	491	672	85
TOTAL	17,969	2,473	3,851	5,537	124%
CHARLES RIVER					
Arlington	244	140	177	115	-18
Ashland	358	121	129	196	62
Bellingham	5,081	1,274	1,306	1,582	24
Belmont	1,196	832	817	833	0
Dedham	4,620	2,144	2,158	1,962	8

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
CHARLES RIVER (Cont.)					
Dover	8,390	2,703	3,878	4,668	73
Franklin	15,673	3,528	5,590	6,852	94
Holliston	12,211	3,407	5,220	6,091	79
Hopedale	633	316	393	328	4
Hopkinton	1,824	182	369	478	163
Lexington	3,142	2,284	2,466	2,740	20
Lincoln	5,856	1,863	2,786	3,675	97
Medfield	7,264	2,786	3,947	4,388	58
Medway	7,462	2,078	3,176	3,838	85
Mendon	185	155	185	185	19
Milford	8,288	2,528	3,343	3,595	42
Millis	7,846	1,781	3,089	3,661	106
Natick	5,344	2,383	2,742	2,457	3
Needham	8,160	4,879	5,593	5,553	14
Newton	11,731	8,152	6,064	8,160	0
Norfolk	9,804	4,372	5,419	5,925	36
Sherborn	8,953	2,908	4,045	4,726	63
Somerville	896	656	614	608	-7
Walpole	1,324	151	149	163	8
Waltham	8,652	5,789	5,535	5,232	-10
Watertown	2,304	1,309	1,322	1,162	-11
Wayland	275	227	258	176	-22
Wellesley	6,726	5,078	4,863	4,598	-10
Weston	10,112	2,328	7,974	7,531	223
Westwood	2,470	1,259	979	940	-25
Wrentham	6,284	1,132	1,732	2,285	102
TOTAL	173,288	68,745	86,136	92,820	35%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
CHELSEA RIVER					
Everett	307	156	129	172	10
Revere	556	348	269	324	-7
TOTAL	863	504	398	496	-2%
CONCORD RIVER					
Bedford	3,046	988	975	910	-8
Billerica	9,702	3,686	4,544	4,532	23
Carlisle	7,046	2,136	2,868	3,208	50
Chelmsford	11,475	5,278	6,523	6,629	26
Concord	5,164	1,195	1,625	2,083	74
Lincoln	326	128	199	255	99
Lowell	2,438	2,438	2,438	2,438	0
Tewksbury	1,004	294	294	326	11
Westford	2,259	192	309	389	103
TOTAL	42,460	16,335	19,775	20,770	27%
ESSEX BAY					
Beverly	96	20	23	22	10
Essex	8,841	1,335	2,700	3,668	175
Gloucester	3,180	303	176	178	-41
Hamilton	1,600	216	353	419	94
Ipswich	2,048	123	157	175	42
Wenham	339	73	98	109	49
TOTAL	16,104	2,070	3,507	4,571	121

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
GLOUCESTER HARBOR					
Gloucester	8,736	3,092	4,354	4,588	48
Rockport	364	20	27	30	50
TOTAL	9,100	3,112	4,381	4,618	48%
IPSWICH RIVER					
Andover	3,276	547	613	648	18
Beverly	2,240	1,517	1,759	1,752	15
Billerica	384	78	47	48	-38
Boxford	9,504	2,524	3,990	5,311	110
Burlington	2,323	1,782	1,826	1,261	-29
Danvers	2,368	924	1,017	1,030	11
Hamilton	7,993	2,368	3,882	4,563	93
Ipswich	11,225	3,328	4,053	4,459	34
Lynnfield	1,817	326	417	436	34
Middleton	9,254	4,165	4,820	5,481	32
North Andover	10,777	734	796	942	26
North Reading	8,659	2,906	3,876	4,387	51
Peabody	2,950	1,286	434	427	-67
Reading	3,167	1,045	1,139	1,172	12
Tewksbury	217	142	121	129	-9
Topsfield	8,230	3,017	4,081	4,594	52
Wenham	4,774	1,781	2,372	2,565	44
Wilmington	9,497	4,797	5,459	5,708	19
TOTAL	98,655	33,267	40,702	44,913	35%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
LOCAL NO. 1 CAPE ANN					
Gloucester	2,860	830	767	801	-3
Rockport	4,166	1,689	2,250	2,497	48
TOTAL	7,026	2,519	3,017	3,298	31%
LOCAL NO. 2 MANCHESTER HARBOR AREA					
Beverly	1,977	625	727	733	17
Gloucester	2,150	337	286	317	-6
Manchester	4,204	2,980	3,789	3,232	8
Wenham	127	72	98	109	51
TOTAL	8,458	4,014	4,897	4,391	9%
LOCAL NO. 3 MARBLEHEAD HARBOR-LYNN HARBOR AREA					
Lynn	2,310	1,739	1,544	1,262	-27
Marblehead	1,881	1,219	1,164	1,183	-03
Nahant	678	417	383	430	19
Swampscott	1,708	1,023	1,126	1,213	19
TOTAL	6,577	4,398	4,217	4,088	- 7%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
LOCAL NO. 4 BOSTON HARBOR					
Revere	755	339	318	309	-9
Winthrop	742	476	473	600	26
TOTAL	1,497	815	791	909	12
LOCAL NO. 6 QUINCY BAY					
Milton	422	222	219	221	0
Quincy	3,161	1,802	1,810	1,631	-9
TOTAL	3,583	2,024	2,029	1,852	-8%
LOCAL NO. 7 HINGHAM HARBOR-HULL BAY					
Cohasset	1,689	433	525	486	12
Hingham	10,873	4,000	4,929	4,993	25
Hull	1,619	904	834	921	2
Norwell	761	174	157	226	30
Rockland	115	107	83	72	-33
Weymouth	569	274	220	220	-20
TOTAL	15,626	5,892	6,748	6,918	17%

TABLE 23 (Cont)

Community	Tctal Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
LOCAL NO. 8 COHASSET HARBOR-SCITUATE HARBOR					
Cohasset	4,748	2,633	3,184	2,932	11
Norwell	1,600	170	152	232	41
Scituate	6,182	4,938	5,399	5,360	09
TOTAL	12,530	7,741	8,735	8,531	10%
LOCAL NO. 9 GREEN HARBOR-DUXBURY BAY					
Duxbury	10,054	3,817	4,694	5,444	43
Marshfield	4,288	1,218	2,311	2,321	91
Pembroke	3,168	317	387	304	-03
TOTAL	17,510	5,352	7,392	8,069	51%
MERRIMACK RIVER					
Boxford	2,246	175	306	467	167
Chelmsford	1,088	1,088	1,088	1,088	0
Tewksbury	1,228	940	949	1,051	1
Westford	3,142	42	56	65	33
TOTAL	7,704	2,245	2,399	2,671	19%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
MYSTIC RIVER					
Arlington	3,347	2,319	2,133	1,918	-17
Belmont	1,785	1,350	1,224	1,245	-8
Burlington	1,280	615	482	447	-27
Everett	1,664	970	878	1,025	6
Lexington	3,193	1,825	2,180	2,453	34
Malden	1,792	1,209	1,063	927	-23
Medford	5,606	3,062	2,791	2,520	-18
Melrose	1,606	1,441	1,383	1,337	-2
Reading	1,536	1,321	1,268	1,298	-2
Somerville	1,740	962	912	906	-6
Stoneham	4,256	2,206	1,989	2,149	-3
Wakefield	1,164	1,147	1,162	1,164	1
Watertown	364	316	314	287	-9
Wilmington	185	90	101	101	12
Winchester	4,019	2,435	2,452	2,337	-4
Woburn	8,012	5,362	5,458	4,901	-9
TOTAL	41,549	26,630	25,790	25,015	-6%
NEPONSET RIVER					
Canton	12,083	5,311	6,664	7,023	32
Dedham	2,284	2,024	2,055	1,925	-5
Dover	1,048	470	677	813	73
Foxborough	2,796	669	814	852	27
Medfield	2,028	570	812	892	56

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
NEPONSETT RIVER (Cont.)					
Milton	7,257	4,551	4,503	4,571	0
Norwood	6,777	3,971	4,073	3,653	-8
Quincy	1,600	915	910	810	-11
Randolph	896	167	155	119	-29
Sharon	10,297	5,754	6,402	7,017	22
Stoughton	5,056	3,364	3,933	4,157	24
Walpole	12,147	5,075	6,995	7,570	49
Westwood	4,723	3,079	3,927	3,733	21
TOTAL	69,352	35,920	41,920	43,135	20%
NORTH RIVER					
Abington	985	462	533	503	9
Duxbury	768	48	53	63	31
Hanover	10,003	4,415	5,282	5,687	29
Hanson	4,192	1,661	2,703	3,082	86
Marshfield	5,510	2,108	2,230	2,268	8
Norwell	11,289	2,839	3,712	4,511	59
Pembroke	10,822	2,931	3,587	4,500	54
Rockland	5,555	2,076	2,273	2,134	3
Scituate	4,294	721	721	667	-7
Weymouth	236	169	29	29	-83
TOTAL	53,654	17,430	21,122	23,444	35%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
PARKER RIVER					
Boxford	3,859	511	888	1,222	122
Ipswich	832	127	164	183	44
TOTAL	4,691	678	1,052	1,405	107%
ROWLEY RIVER					
Ipswich	7,238	1,649	2,012	2,216	34
TOTAL	7,238	1,649	2,012	2,216	34
SALEM HARBOR					
Lynn	64	60	52	38	-37
Marblehead	947	582	560	567	-3
Salem	3,078	992	885	825	-17
Swampscott	275	143	155	92	-36
TOTAL	4,364	1,777	1,652	1,522	-14%
SAUGUS RIVER					
Everett	428	325	298	342	5
Lynn	4,755	1,302	1,149	970	-25
Lynnfield	4,729	2,605	3,212	3,325	28
Malden	1,491	877	780	690	-21
Melrose	1,465	593	573	538	-9
Reading	1,600	1,581	1,551	1,591	1
Revere	2,732	1,538	1,463	1,422	-8
Saugus	7,411	3,064	2,835	3,039	-1
Wakefield	3,884	1,806	2,045	2,101	16
TOTAL	28,495	13,691	13,906	14,018	2%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	& Increase
SHAWSHEEN RIVER					
Andover	10,950	7,291	10,858	10,851	49
Bedford	5,817	4,710	4,633	4,734	1
Billerica	6,528	3,096	3,605	3,641	18
Burlington	4,000	4,000	4,000	3,998	0
Corcord	857	343	435	672	96
Lawrence	556	548	533	519	-5
Lexington	4,307	3,235	3,792	3,814	18
Lincoln	1,132	740	1,055	1,125	52
North Andover	1,107	907	1,082	1,104	22
Tewksbury	9,017	3,854	4,954	5,219	35
Wilmington	1,273	421	459	445	6
Woburn	313	34	9	8	76
TOTAL	45,857	29,179	35,415	36,130	24
SOUTH RIVER					
Duxbury	4,864	452	523	603	33
Marshfield	8,454	3,125	3,117	3,175	2
Scituate	448	157	310	398	154
TOTAL	13,766	3,734	3,950	4,176	12%

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
STONEY BROOK					
Boxborough	1,696	512	888	1,302	154
Chelmsford	2,131	1,633	1,942	1,967	20
Harvard	2,694	126	147	153	21
Littleton	6,304	1,723	2,750	3,089	79
Westford	11,884	2,898	4,954	6,406	121
TOTAL	24,709	6,892	10,681	12,917	87%
SUDBURY RIVER					
Ashland	7,936	2,183	3,352	3,616	66
Concord	4,832	1,270	1,753	2,191	73
Framingham	16,345	9,824	10,675	10,406	6
Hopkinton	12,524	2,368	4,223	5,598	136
Hudson	1,337	16	21	22	38
Lincoln	2,233	441	678	870	97
Marlborough	8,588	3,102	3,824	4,057	31
Natick	4,889	3,199	3,757	3,507	10
Northborough	889	70	108	126	80
Sherborn	2,003	360	505	579	61
Southborough	9,868	2,512	3,306	3,925	56
Sudbury	14,348	6,742	8,779	9,613	43
Wayland	9,888	5,830	6,930	6,927	19
Westborough	8,288	3,324	4,057	4,642	40
Weston	998	334	434	403	21
TOTAL	104,966	41,575	52,402	53,501	29%

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TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
TAUNTON RIVER					
Avon	2,240	1,176	1,505	1,570	34
Holbrook	1,075	234	279	408	74
Pembroke	832	244	296	375	54
Rockland	44	40	35	27	-32
Sharon	5,260	700	651	712	2
Stoughton	4,857	820	942	982	20
Wrentham	3,526	1,055	2,064	2,697	156
TOTAL	17,834	4,269	5,772	6,771	59%
WEYMOUTH BACK RIVER					
Abington	96	95	49	44	-54
Braintree	454	48	54	54	13
Hingham	2,700	1,549	1,606	1,708	10
Holbrook	576	64	71	169	164
Rockland	755	459	386	385	-16
Weymouth	8,198	4,485	4,375	4,387	-2
TOTAL	12,779	6,700	6,541	6,747	1%
WEYMOUTH FORE RIVER					
Avon	640	169	160	160	0
Braintree	8,768	5,177	5,704	5,790	12
Brockton	204	44	44	40	-9
Canton	320	108	127	132	22
Holbrook	3,033	1,723	2,042	3,027	76

TABLE 23 (Cont.)

Community	Total Area, Ac.	Urban Area, Ac. 2000	2020	2050	% Increase
WEYMOUTH FORE RIVER (Cont.)					
Milton	768	112	94	73	-35
Quincy	5,888	2,920	2,818	2,529	-13
Randolph	5,708	3,845	3,555	3,602	-6
Stoughton	576	80	87	91	14
Weymouth	2,259	1,489	1,928	1,934	30
TOTAL	28,164	15,667	16,559	17,387	11%

Table 24, in a manner similar to Table 23, shows the expected increase in the stormwater runoff pollutants, suspended solids and BOD, from the design year 2000 to the future in 2050. As in the case of the urban land development data, the pollutant discharge data vary widely as to changes with time.

It is difficult to assess how the forecasted urban land development together with the associated increase (or decrease) in pollutants will effect the performance of stormwater management facilities constructed to fit the needs of the study area for the year 2000. More information must be known concerning where such increases will take place within each community so that a detailed study can be made with some degree of reliability.

In general, it can be said that in the vast majority of cases there will be increases in the urban land development by the year 2050 in those communities which are only 40 to 50% developed or less by the year 2000, and that pollutant concentrations will increase in proposition to the urban land development. The need for additions to stormwater management facilities will vary, however, there should not be any difficulty in arranging to treat pollutant increases if careful throught is given to the design needed for the year 2000.

TABLE 24

STORMWATER RUNOFF POLLUTANTS FOR WATERSHEDS

WITHIN STUDY AREA BY COMMUNITIES

Community	B.O.D., lbs 2000	B.O.D., lbs 2020	B.O.D., lbs 2050	% Inc	Suspended Solids, lbs. 2000	Suspended Solids, lbs. 2020	Suspended Solids, lbs. 2050	% Inc
ASSABET RIVER								
Acton	6,000	7,122	7,800	30%	40,832	48,459	53,069	30%
Berlin	683	1,497	2,319	240	4,645	10,178	15,767	239
Bolton	1,051	1,992	3,051	190	7,140	13,540	20,742	190
Boxborough	354	811	1,411	299	2,407	5,514	9,593	299
Boylston	84	143	176	110	574	971	1,195	108
Carlisle	445	809	1,093	146	3,028	5,502	7,433	145
Clinton	72	60	62	-14	487	405	410	-14
Concord	1,371	2,739	4,296	213	9,320	18,621	29,201	213
Grafton	100	153	573	473	681	1,044	3,902	473
Harvard	63	73	76	21	430	498	519	21
Hudson	1,880	2,413	2,718	45	12,788	16,410	18,480	45
Littleton	502	1,448	1,415	182	3,412	9,854	9,621	181
Marlborough	1,885	2,464	2,825	50	12,821	16,757	19,208	50
Maynard	1,100	1,522	1,972	79	7,483	10,399	13,409	79
Northborough	2,318	3,608	4,534	96	15,762	24,531	30,829	96
Shrewsbury	1,131	1,472	1,567	39	7,694	10,012	10,662	39
Stow	536	1,336	2,214	313	3,164	9,083	15,056	376
Sudbury	136	171	190	40	922	1,165	1,293	40
Westborough	1,456	1,737	2,824	94	9,901	11,811	19,202	94
Westford	203	406	566	179	1,383	2,757	2,844	152
TOTAL	21,370	31,976	41,682	95%	144,874	217,461	283,444	96%

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
BEVERLY HARBOR								
Beverly	2,984	3,445	3,489	17	20,297	23,433	23,736	17
Danvers	4,077	4,495	4,587	13	27,723	30,566	31,191	13
Lynn	17	17	15	-12	119	119	103	-13
Lynnfield	11	17	17	55	75	117	115	53
Peabody	6,028	6,651	6,684	11	41,005	45,244	45,462	11
Salem	1,141	1,023	1,007	-12	7,758	6,958	6,844	-12
Wenham	3	4	4	33	19	26	26	37
TOTAL	14,261	15,652	15,803	11	96,996	106,463	107,477	11
BLACKSTONE RIVER								
Bellingham	1,230	2,216	2,899	136	8,364	15,075	19,714	136
Franklin	43	58	74	72	292	392	505	73
Hopkinton	170	389	567	234	1,154	2,643	3,856	234
Milford	54	99	419	676	369	676	2,853	673
Westborough	4	5	5	25	30	36	31	3
Wrentham	293	484	739	152	1,995	3,288	5,024	152
TOTAL	1,794	3,251	4,703	162	12,204	22,110	31,983	162

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
CHARLES RIVER								
Arlington	135	122	188	-20	920	829	737	-20
Ashland	50	78	96	92	342	531	653	91
Bellingham	900	1,094	1,490	66	6,121	7,443	10,128	65
Belmont	943	934	975	3	6,414	6,351	6,629	3
Dedham	1,863	1,875	1,840	-1	12,668	12,753	12,508	-1
Dover	961	1,455	2,022	110	6,535	9,898	13,754	110
Franklin	2,218	4,639	6,227	181	15,089	31,554	42,345	181
Holliston	1,637	3,575	4,737	189	11,137	24,308	32,206	189
Hopedale	75	94	78	4	513	637	532	4
Hopkinton	80	173	245	206	543	1,176	1,667	207
Lexington	1,300	2,554	3,523	171	8,840	17,369	23,948	171
Lincoln	583	954	1,286	121	3,967	6,488	8,747	120
Medfield	1,280	2,649	3,248	154	8,709	18,015	22,087	154
Medway	1,412	2,462	3,314	135	9,607	16,740	22,533	135
Mendon	49	59	59	20	335	400	402	20
Milford	1,886	4,181	4,882	159	12,829	28,431	33,193	159
Millis	1,106	2,638	3,413	209	7,522	17,942	23,208	209
Natick	1,991	3,325	3,686	85	13,541	22,614	25,064	85
Needham	5,337	7,163	7,175	34	36,299	48,723	48,806	34
Newton	9,621	8,367	10,919	13	65,425	56,899	74,258	14

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
CHARLES RIVER (Cont.)								
Norfolk	2,807	4,342	4,783	70	19,086	29,521	32,519	70
Sherborn	1,202	2,453	3,455	187	8,180	16,687	23,492	187
Somerville	894	820	812	-9	6,085	5,578	5,528	-9
Walpole	78	93	113	45	528	632	769	46
Waltham	9,419	8,822	8,521	-10	63,983	59,982	57,937	-9
Watertown	1,698	1,723	1,402	-17	11,547	11,721	9,540	-17
Wayland	60	85	59	-2	406	580	403	-1
Wellesley	4,291	4,868	5,146	20	29,167	33,093	34,977	20
Weston	1,941	4,804	4,893	152	13,196	32,671	33,273	152
Westwood	733	1,056	1,098	50	4,982	7,180	7,463	50
Wrentham	905	1,655	2,394	165	6,156	11,256	16,278	164
TOTAL	57,455	79,112	88,504	54	390,672	537,993	601,822	54%
CHELSEA RIVER								
Everett	197	162	238	21	1,340	1,101	1,620	21
Revere	472	369	434	-8	3,207	2,507	2,954	-8
TOTAL	669	531	672	1	4,547	3,608	4,574	1

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
CONCORD RIVER								
Bedford	1,470	1,543	2,381	62	9,985	10,479	16,176	62
Billerica	2,269	5,265	5,673	150	15,435	35,809	38,574	150
Carlisle	719	1,341	1,829	150	4,891	9,122	12,441	154
Chelmsford	3,399	4,531	4,820	26	23,115	30,811	32,776	42
Concord	1,014	2,086	3,240	220	6,895	14,185	22,024	219
Lincoln	42	77	96	129	288	525	656	128
Lowell	2,695	2,695	2,695	0	18,335	18,335	18,335	0
Tewksbury	282	335	401	42	1,919	2,279	2,725	42
Westford	78	141	184	136	529	957	1,251	136
TOTAL	11,968	18,014	21,319	78	81,392	122,502	144,958	78
ESSEX BAY								
Beverly	11	12	12	10	75	82	80	7
Essex	573	1,298	1,964	242	3,900	8,826	13,352	242
Gloucester	100	71	72	-28	681	483	488	-28
Hamilton	113	168	205	81	768	1,144	1,396	82
Ipswich	78	119	131	68	532	810	890	67
Wenham	44	79	97	120	298	540	662	122
TOTAL	919	1,747	2,481	170	6,254	11,885	16,868	170

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
GLOUCESTER HARBOR								
Gloucester	2,047	5,266	5,993	193	13,922	35,897	40,752	193
Rockport	6	9	10	67	43	58	65	51
TOTAL	2,053	5,275	6,003	192	13,965	35,955	40,817	192
IPSWICH RIVER								
Andover	200	234	259	30	1,358	1,595	1,764	30
Beverly	1,160	1,332	1,364	18	7,889	9,062	9,274	18
Billerica	37	49	59	59	249	334	399	60
Boxford	874	2,175	3,780	332	5,950	14,799	25,708	332
Burlington	1,512	2,202	1,522	1	10,286	14,975	10,351	1
Danvers	1,198	1,294	1,442	20	8,138	8,790	9,793	20
Hamilton	1,243	1,878	2,251	81	8,453	12,769	15,304	81
Ipswich	3,460	5,184	5,512	62	23,508	35,222	38,133	62
Lynnfield	133	293	341	156	902	1,991	2,315	157
Middleton	4,783	6,908	7,705	61	32,498	46,937	52,349	61
North Andover	275	341	440	60	1,868	2,319	2.993	60
North Reading	2,131	3,613	4,449	109	14,481	24,569	30,250	109
Peabody	793	448	466	-41	5,392	3,045	3,170	-41
Reading	780	1,227	1,234	58	5,311	8,346	8,395	58
Tewksbury	75	74	89	19	509	504	602	18

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
IPSWICH RIVER (Cont.)								
Topsfield	1,108	2,357	3,005	171	7,537	16,027	20,436	171
Wenham	761	1,363	1,587	109	5,174	9,268	10,791	109
Wilmington	6,550	7,997	9,107	39	44,554	54,389	61,921	39
TOTAL	27,073	38,969	44,712	65	184,057	264,941	303,948	65
LOCAL NO. 1								
Gloucester	404	753	859	113	2,745	5,120	5,884	113
Rockport	1,302	1,743	1,958	50	8,856	11,852	13,318	50
TOTAL	1,706	2,496	2,817	65	11,601	16,972	19,162	65
LOCAL NO. 2								
Beverly	497	576	608	22	3,378	3,919	4,133	22
Gloucester	209	390	492	135	1,421	2,651	3,342	135
Manchester	1,038	1,460	1,301	25	7,062	9,928	8,846	25
Wenham	41	73	90	120	282	502	611	39
TOTAL	1,785	2,499	2,491	40	12,143	17,000	16,932	

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
LOCAL NO. 3								
Lynn	2,217	1,914	1,561	30	15,085	13,022	10,619	-30
Marblehead	866	775	830	-4	5,890	5,274	5,649	-4
Nahant	322	338	635	97	2,192	2,295	4,320	97
Swampscott	1,134	1,218	1,521	34	7,715	8,289	10,351	34
TOTAL	4,539	4,245	4,547	0	30,882	28,880	30,939	0
LOCAL NO. 4								
Revere	494	463	448	-10	3,361	3,147	3,047	-9
Winthrop	634	767	1,039	63	4,310	5,218	7,062	64
TOTAL	1,128	1,230	1,487	32	7,671	8,365	10,109	32
LOCAL NO. 6								
Milton	144	207	259	80	983	1,407	1,764	79
Quincy	2,266	2,233	1,994	-13	15,413	15,190	13,561	-12
TOTAL	2,410	2,440	2,253	-7	16,396	16,597	15,325	-7

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
LOCAL NO. 7								
Cohasset	215	277	272	27	1,462	1,883	1,847	26
Hingham	2,807	4,182	4,411	57	19,089	28,441	29,998	57
Hull	1,161	1,156	1,364	17	7,896	7,861	9,269	17
Norwell	126	297	485	285	856	2,017	3,295	285
Rockland	38	30	27	-29	258	206	182	-30
Weymouth	155	233	235	52	1,053	1,586	1,601	52
TOTAL	4,502	6,175	6,794	51	30,614	41,994	46,192	51
LOCAL NO. 8								
Cohasset	1,158	1,484	1,440	24	7,871	10,092	9,792	24
Norwell	124	295	490	295	844	2,002	3,333	295
Scituate	1,836	3,695	5,458	197	12,491	25,132	37,126	197
TOTAL	3,118	5,474	7,388	137	21,206	37,226	50,251	137

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
LOCAL NO. 9								
Duxbury	1,655	1,970	2,352	42%	11,252	13,394	15,998	42%
Marshfield	864	2,045	2,133	147	5,878	13,915	14,507	147
Pembroke	92	157	166	80	625	1,006	1,128	80
TOTAL	2,611	4,172	4,651	78%	17,755	28,315	31,633	78%
MERRIMACK RIVER								
Boxford	48	194	471	88%	324	1,321	3,202	888%
Chelmsford	565	554	628	11	3,845	3,768	4,267	11
Tewksbury	900	1,076	1,291	43	6,118	7,315	8,772	43
Westford	16	20	23	44	108	138	157	45
TOTAL	1,529	1,844	2,413	58%	10,395	12,542	16,398	58%
MYSTIC RIVER								
Arlington	2,619	2,365	2,129	-19%	17,817	16,093	14,489	-19%
Belmont	1,730	1,364	1,416	-18	11,700	9,274	9,633	-18
Burlington	536	655	633	18	3,647	4,449	4,304	18
Everett	1,175	1,050	1,362	16	7,997	7,144	9,270	16
Lexington	1,042	2,479	3,446	231	7,088	16,856	23,427	231
Malden	1,545	1,342	1,153	-25	10,511	9,130	7,845	-25
Medford	3,445	3,040	2,758	-20	23,437	20,682	18,766	-20

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
Melrose	1,774	1,694	1,691	-5%	12,066	11,526	11,507	-5%
Reading	1,090	1,539	1,571	44	7,410	10,467	10,685	44
Somerville	1,315	1,208	1,201	-9	8,947	8,217	8,168	-9
Stoneham	2,616	2,790	3,102	19	17,790	18,971	21,095	19
Wakefield	1,448	1,547	1,633	13	9,848	10,523	11,108	13
Watertown	386	385	327	-15	2,625	2,617	2,222	-15
Wilmington	103	124	134	30	699	843	911	30
Winchester	1,483	2,130	2,139	44	10,191	14,493	14,554	44
Woburn	6,064	6,802	6,410	6	41,253	46,278	43,602	6
TOTAL	28,371	30,514	31,105	10%	192,926	207,563	211,586	10%
NEPONSET RIVER								
Canton	4,547	5,689	6,194	36%	30,928	38,692	42,121	35%
Dedham	2,471	2,504	2,495	17	16,797	17,022	16,960	1
Dover	164	251	346	111	1,117	1,707	2,355	111
Foxborough	397	483	509	28	2,699	3,285	3,464	28
Medfield	250	525	638	155	1,701	3,569	4,337	115
Milton	3,226	4,674	5,771	79	21,946	31,792	39,255	79
Norwood	4,506	5,181	4,984	11	30,656	35,248	33,901	11
Quincy	1,162	1,141	1,012	-13	7,908	7,765	6,884	-13
Randolph	85	79	90	6	579	535	614	6
Sharon	5,053	6,093	7,178	42	34,389	41,451	48,817	42
Stoughton	4,091	5,077	5,832	43	27,822	34,525	39,657	15
Walpole	3,538	5,963	6,823	93	24,063	40,552	45,398	93
Westwood	2,258	4,755	4,768	111	15,357	32,343	32,424	111
TOTAL	31,748	42,415	46,640	47%	215,962	288,486	317,187	47%

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
NORTH RIVER								
Abington	284	528	508	79%	1,934	3,593	3,461	79%
Duxbury	40	43	54	35	271	293	370	37
Hanover	2,453	4,614	5,219	113	16,684	31,381	35,493	113
Hanson	741	1,780	2,162	192	5,039	12,107	14,704	192
Marshfield	1,116	1,540	1,687	51	7,590	10,473	11,471	51
Norwell	1,428	4,330	5,899	313	9,714	20,449	40,109	313
Pembroke	1,388	2,370	4,258	207	9,440	16,115	28,951	207
Rockland	1,830	2,399	2,621	43	12,439	16,312	17,815	43
Scituate	418	711	1,032	147	2,844	4,831	7,015	147
Weymouth	54	12	12	-78	365	78	78	-79
TOTAL	9,752	18,327	23,452	140%	66,320	124,632	159,467	140%
PARKER RIVER								
Boxford	149	452	945	534	1,015	3,074	6,419	532%
Ipswich	79	123	133	68	539	839	907	68
TOTAL	228	575	1,078	373%	1,554	3,913	7,326	371%

TABLE 24 (Cont.)

Community	B.O.D., lbs. 2000	2020	2050	% Inc.	Suspended Solids, lbs. 2000	2020	2050	% Inc.
ROWLEY RIVER								
Ipswich	1,680	2,514	2,719	62%	11,412	17,080	18,477	62%
TOTAL	1,680	2,514	2,719	62%	11,412	17,080	18,477	62%
SALEM HARBOR								
Lynn	24	20	15	37%	162	140	103	-36%
Marblehead	426	390	412	-3	2,900	2,655	2,806	-3
Salem	1,488	1,327	1,299	-13	10,121	9,023	8,834	-13
Swampscott	111	118	99	-11	756	806	674	-11
TOTAL	2,049	1,855	1,825	-11%	13,939	12,624	12,417	-11
SAUGUS RIVER								
Everett	231	206	271	17%	1,572	1,403	1,845	17%
Lynn	1,648	1,390	1,151	-30	11,211	9,457	7,828	-30
Lynnfield	1,165	2,227	2,481	113	7,922	15,141	16,867	113
Malden	962	837	721	-25	6,544	5,692	4,908	-25
Melrose	611	589	567	-7	4,160	4,010	3,855	-7
Reading	1,288	1,795	1,871	45	8,760	12,210	12,724	45
Revere	1,757	1,658	1,613	-8	11,953	11,280	10,971	-8
Saugus	2,773	3,712	4,289	14	25,657	25,242	29,162	14
Wakefield	1,583	2,258	2,388	51	10,770	15,365	16,245	51
	13,018	14,672	15,352	18%	88,549	99,800	104,405	18%

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
SHAWSHEEN RIVER								
Andover	3,516	6,646	6,672	90%	23,924	45,218	45,397	90%
Bedford	6,380	6,594	10,032	57	43,359	44,818	68,171	57
Billerica	1,995	4,463	4,926	147	13,570	30,348	33,494	147
Burlington	4,189	5,938	6,075	45	28,485	40,373	41,304	45
Concord	326	513	824	153	2,217	3,492	5,611	153
Lawrence	439	425	394	-10	2,988	2,891	2,681	-10
Lexington	1,986	4,399	4,519	128	13,505	29,914	30,732	128
Lincoln	449	640	648	44	3,058	4,353	4,411	44
North Andover	464	481	815	76	3,160	4,635	5,543	75
Tewksbury	2,933	4,498	5,024	71	10,946	30,588	34,161	71
Wilmington	460	508	505	10	3,129	3,459	3,437	10
Woburn	14	4	3	-79	92	24	22	-76
TOTAL	23,151	35,309	40,437	75%	157,433	240,113	274,964	75%
SOUTH RIVER								
Duxbury	261	293	353	35%	1,772	1,991	2,402	36%
Marshfield	1,615	2,073	2,296	42	10,984	14,101	15,611	42
Scituate	74	258	432	484	501	1,752	2,938	486
TOTAL	1,950	2,624	3,081	58%	13,257	17,844	20,951	58%

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
STONEYBROOK								
Boxborough	292	621	1,193	309%	1,986	4,221	8,108	308%
Chelmsford	1,010	1,284	1,369	36	6,871	8,730	9,311	36
Harvard	39	44	45	15	264	298	308	17
Littleton	874	2,377	3,001	243	5,948	16,164	20,403	243
Westford	2,087	3,932	5,333	156	14,202	26,744	36,263	155
TOTAL	4,302	8,258	10,941	154%	29,271	56,157	74,393	154%
SUDBURY RIVER								
Ashland	2,114	3,660	3,946	87%	14,377	24,885	26,828	87%
Concord	1,021	2,110	3,121	206	6,940	14,350	21,219	206
Framingham	12,142	15,079	15,317	26	82,563	102,541	104,151	26
Hopkinton	1,798	3,525	5,249	192	12,226	23,970	35,685	192
Hudson	8	11	12	50	56	72	80	43
Lincoln	135	236	297	120	917	1,640	2,016	120
Marlborough	3,881	5,119	5,800	49	26,388	32,696	39,432	49
Natick	2,866	4,808	5,403	89	19,489	670	36,740	89
Northborough	64	98	115	80	435	2,001	785	80
Sherborn	144	294	402	179	981	35,570	2,730	178
Southborough	2,726	5,233	6,581	141	18,531	29,386	44,729	141
Sudbury	3,125	4,322	4,994	60	21,253	27,070	33,958	60
Wayland	2,431	3,981	5,349	120	16,532	27,860	36,380	120
Westborough	3,394	4,097	6,701	97	23,083	1,638	45,563	97
Weston	141	241	247	75	955		1,679	76
TOTAL	35,990	52,951	57,951	61%	244,726	359,153	394,034	61%

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Ouspended Solids,lbs. 2000	2020	2050	% Inc
TAUNTON RIVER								
Avon	878	1,379	1,529	74%	5,968	9,377	10,395	74%
Holbrook	177	236	359	103	1,201	1,602	2,443	103
Pembroke	84	124	260	210	569	912	1,771	211
Rockland	13	11	9	-31	86	76	58	-33
Sharon	399	393	462	16	2,717	2,672	3,143	16
Stoughton	949	1,129	1,256	32	6,458	7,682	8,545	32
Wrentham	796	1,914	2,711	241	5,412	13,017	18,435	241
TOTAL	3,296	5,196	6,586	100%	22,411	35,338	44,790	100%
WEYMOUTH BACK RIVER								
Abington	30	19	17	-43%	205	132	119	-42%
Braintree	21	23	23	10	141	158	158	12
Hingham	1,600	1,829	2,040	28	10,875	12,434	13,867	28
Holbrook	30	34	89	197	203	228	607	199
Rockland	329	328	373	13	2,240	2,235	2,541	13
Weymouth	3,616	5,700	5,825	61	24,599	38,770	39,620	61
TOTAL	5,626	7,933	8,367	49%	38,263	53,957	56,912	49%

TABLE 24 (Cont.)

Community	B.O.D., lbs 2000	2020	2050	% Inc	Suspended Solids, lbs. 2000	2020	2050	% Inc
WEYMOUTH FORE RIVER								
Avon	107	124	142	33%	725	842	967	33%
Braintree	6,559	7,176	7,521	15	44,609	48,799	51,144	15
Brockton	17	17	16	-6	119	119	108	-9
Canton	69	83	89	29	467	562	608	30
Holbrook	1,651	2,123	3,390	105	11,230	14,435	23,048	105
Milton	100	136	149	49	678	922	1,010	49
Quincy	3,763	3,580	3,182	-15	25,600	24,358	21,651	-15
Randolph	2,997	2,774	4,023	34	20,385	18,866	27,363	34
Stoughton	43	64	72	67	290	433	491	69
Weymouth	1,322	2,503	2,549	93	8,989	17,029	17,340	93
TOTAL	16,628	18,580	21,133	27%	113,092	126,365	143,730	27%

V. SUMMARY AND RECOMMENDATIONS

Summary

A stormwater management plan for Eastern Massachusetts is presented in accordance with the objectives and scope delineated by the Corps of Engineers, NED. Data regarding pollutant discharges, stormwater runoff, and urban area development were furnished by the Corps of Engineers through the use of a "STORM" Model computer program; this data was provided for each community in the study area. Because the data furnished was unsufficiently detailed with respect to urban area locations and runoffs from subdrainage areas in each community, only general stormwater management results for each community were obtained. However, these general results are sufficently adequate to allow an overall evaluation of stormwater management feasibility for the study area to be made.

Stormwater treatment alternates for the study area are proposed. Basically these consist of storage-treatment schemes to obtain the most cost-effective management system. Capital and operation and maintenance costs are also provided.

Recommendations

In spite of the general character of the study, sufficient knowledge has been gained to make constructive recommendations concerning further development of a stormwater management plan for Eastern Massachusetts. The recommendations are as follows:

1. Efforts should be made to calibrate the existing "STORM" Model computer program or to make adjustments to the program through the use of field studies. Such studies would include surveillance of flows at storm sewer inlets, within storm sewer systems, and at storm sewer outfalls.

2. Studies should be conducted in various watersheds to determine what variables should be used as input to the "STORM" Model program.

3. The first "flush" theory should be tested by field studies to determine if it actually occurs and under what conditions.

4. The effects of storage and treatment of stormwater runoff should be carefully studied to determine which conditions limit or optimize this stormwater management method.

5. The effects of employing storage of storm water runoff alone with slow release to the receiving stream should be studied in the field.

6. The effects of stormwater on the water quality in the stream should be studied to determine which are the pollutional parameters of significance.

7. More study is required to determine how the storage-treatment methodoloby can be applied to combined sewer overflows.

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ADDENDUM A

Evaluation of a Stormwater Management Alternative (Storage, Microstraining, Disinfection)

In the analysis described in the foregoing pages, four urban stormwater management alternatives were proposed for the communities within the Eastern Massachusetts Metropolitan Area. The reliability of the most frequently recommended alternative - storage, microstraining and disinfection (SMD) - was evaluated using the complete version of the "STORM" Model. One index town from the study area, Framingham, was used for the analysis. The actual computer simulation work was performed by personnel at the Corps Hydrologic Engineering Center, Davis, California.

Design criteria for the SMD alternative were based on hydrologic and climatologic conditions prevalent in the area. The storage lagoons were sized to capture all runoff up to the time of peak flow resulting from the 1-year rainfall event, and the pump-out rate was set at 3.5 days, which is the approximate average period between precipitation events. Equivalent amounts of storage capacity, in terms of inches of runoff, and treatment rate, in terms of inches of runoff per hour, will vary with each town in the study area. For Framingham, these amounts figured out to be a storage capacity of approximately 0.8 inch and a treatment rate of approximately 0.01 inch per hour.

These values, together with other required data pertinent to the Town of Framingham, were input to the "STORM" Model. The historic hourly rainfall record for Boston's Logan Airport, spanning 22 years from 1948 to 1970, was analyzed. Default values provided in the "STORM" Model for all runoff pollutant variables were used.

The results of the analysis were very conclusive and encouraging. The proposed stormwater management scheme would, on an annual basis, control 96 percent of all urban runoff volume and provide treatment of 98-99 percent of all pollutants. The average annual number of overflows from storage would be a little more than one. These results are based on the premise that treatment will commence as soon as runoff reaches the treatment facility, and storage is utilized as soon as the treatment rate is exceeded. Any deviation from this operational scheme will have a measurable effect upon the results obtained.

One other significant conclusion can be drawn from the analysis. With regard to storage utilization, it appears that the storage lagoons would be free of water only 13 percent of the time. This is a result of the rather large storage capacity.

Further sensitivity analysis utilizing various combinations of treatment rates and storage capacities will be necessary in later studies to determine the most efficient and cost-effective design.