AD-A036 799 METCALF AND EDDY INC BOSTON MASS F/G 13/2

WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - --ETC(U)

OCT 75

UNCLASSIFIED NL

1 OF 4

AD
A036799

WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - EASTERN MASSACHUSETTS METROPOLITAN AREA

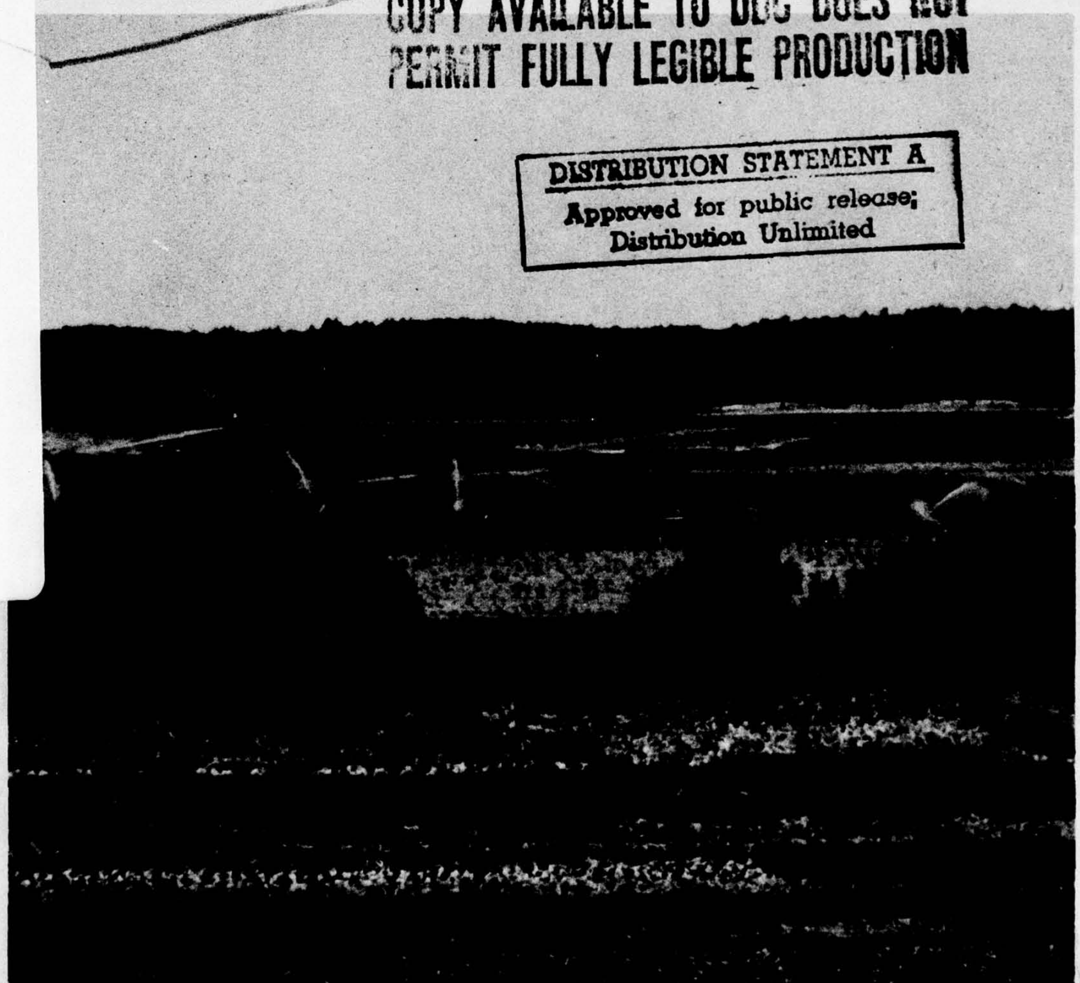
EMMA STUDY

TECHNICAL DATA [redacted] Volume 5.

LAND ORIENTED WASTEWATER UTILIZATION CONCEPT

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

ADA036799



DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE

OCTOBER 1975

MAR 14 1977

201 p.

410 091

EMMA ST... - LAND ORIENTED WASTEWATER UTILIZATION CONCEPT

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

INDEX TO REPORT VOLUMES

ACCESSION for
NTIS White Section ☑
DDC Buff Section ☐
UNANNOUNCED ☐
JUSTIFICATION Per ltr. on file
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

FOREWARD

The U.S. Army Corps of Engineers, NED, in cooperation with several agencies under the administration of the Technical Subcommittee on Boston Harbor, is directing a segment of the Wastewater Management Study for Eastern Massachusetts which proposed the utilization of land application methods to further treat and make use of conventionally treated wastewaters.

The entire wastewater management study for Eastern Massachusetts consisted of five alternatives. Four of the conceptual alternatives are being prepared under the direction of the Metropolitan District Commission (MDC). These are labeled "Concept 1," etc. The land application alternative is labeled "Concept 5" and may be considered as a partial alternative to Concept 4 because it provides land application treatment for effluents from five of the regional waste treatment plant locations described in Concept 4.

The report presented herein constitutes the land-oriented treatment system known as Concept 5.

After giving due consideration to this and the other proposed alternatives, the Technical Subcommitte, which is made up of the Metropolitan District Commission, the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, the Metropolitan Area Planning Control, the Department of Public Health, and the Resource Management Policy Council, will decide which alternative or plan to adopt as the optimum wastewater management system.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. General

The national objectives of cleaning up and maintaining our environment have made people realize that municipal and industrial wastes can no longer be dumped indiscriminately into our lakes, streams and groundwater aquifers. Dumping raw or inadequately treated wastes to our water resources by individuals or communities results in the tainting and degradation of water supplies available to other individuals. Discharging effluents from secondary treatment facilities which have sufficient nutrients can lead to rapid and excessive aquatic plant growth which in turn degrade the quality of surface water.

The soil has long been known as an effective decomposing system. Animal matter, plant material and animal manures, including human excrement, have been spread and worked into soils from time immemorial. Thus plant nutrients have been recycled, essential soil micro-organisms fed and soil structure maintained or improved. It has always been essential that these wastes additions were not excessive, in order that the renovation capability of the plant-soil system was not exceeded.

Treatment of municipal and industrial wastes in facilities constructed explicitly for this purpose are utilized by some New England communities. At best, these systems are "secondary" treatment facilities, which remove settleable solids and oxidize organic matter and nitrogenous compounds. Removal of nutrients and very stable organics, as well as soluble ions require additional treatment methodologies, i.e., advanced waste treatment systems.

An alternative to constructing advanced waste treatment plants is that of using the vegetative-soil ecosystem with crop production and harvesting, as a means of further treating sewage effluent. By growing crops on the land, wastewater nutrients are immediately recycled into food production while stable organics and cations contained in the wastewater are removed by the soil exchange complex.

Every state allows waste treatment using the land by permitting the use of the universal land treatment system: the domestic septic tank and leach field. Larger land treatment operations for renovating municipal and industrial wastewaters have been practiced for many years in California, Texas, Arizona and Pennsylvania (49). The large elaborate spray irrigation systems for treatment of substantial quantities of municipal and industrial wastewaters are best exemplified by systems at Pennsylvania State University (25), the Muskegon, Michigan project and the Gray Farm in Lubbock, Texas (21). In these projects, wastewater renovation is an integral part of an agricultural operation supplying the necessary nutrients and water for crop growth. The Santee project in California (33) and the Rio-Salata project in Phoenix, Arizona (8) typify multiple use of rapid infiltration treatment facilities and urban use of reclaimed water.

Land treatment methodologies considered in the Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study were spray irrigation and rapid infiltration. Each approach utilizes the soil biological system to further renovate secondary treated wastewater. Since abiotic and biotic processes differ in intensity between various soils, the land treatment method considered and the management procedures used must be carefully selected for the site and contemplated land treatment approach to ensure acceptable wastewater renovation is achieved and adverse impacts are minimized.

B. Purpose and Scope

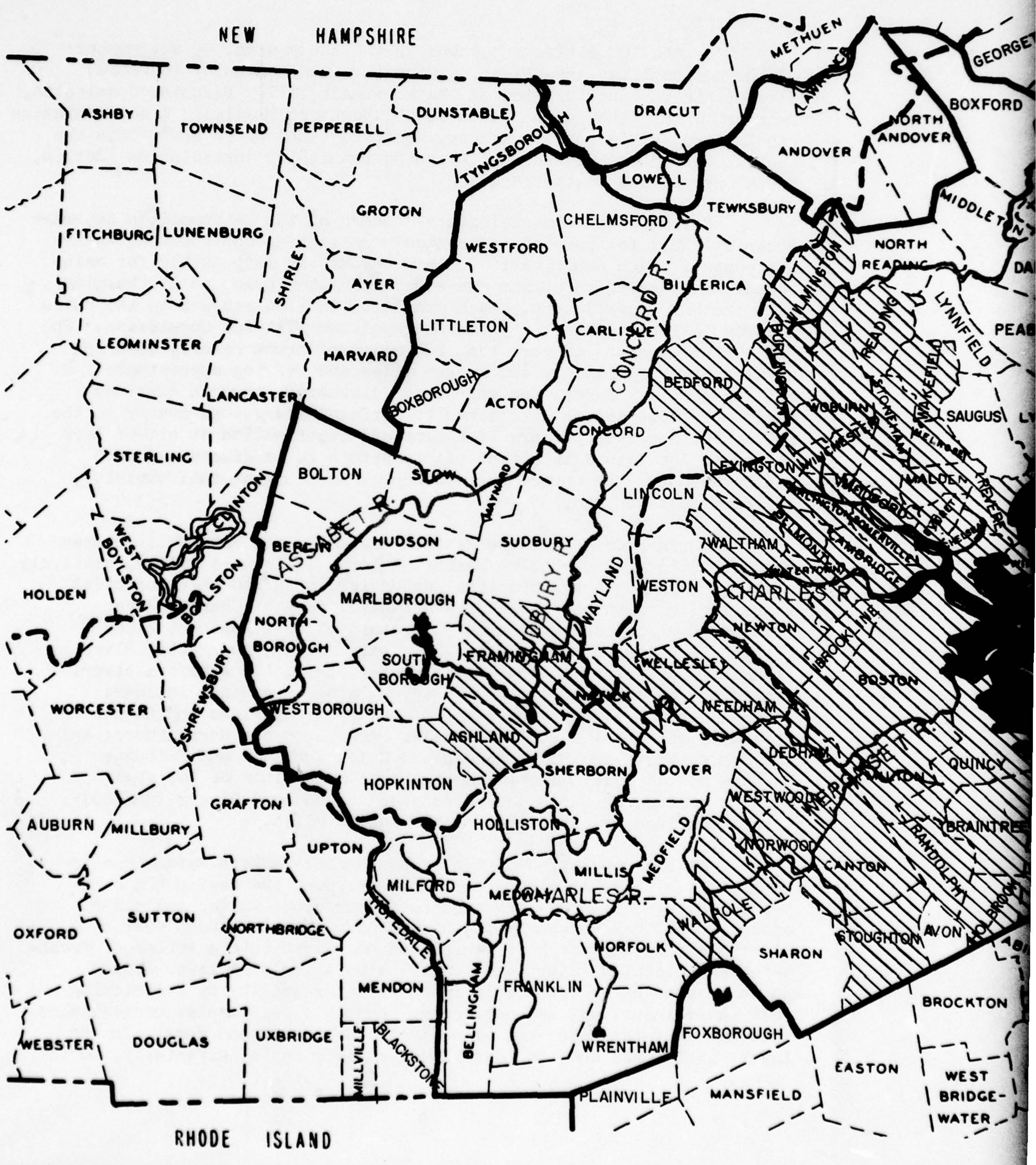
The purpose of this element of the Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study is to explore various possibilities of utilizing land application methods to provide additional treatment of effluents from secondary treatment plants. This is in keeping with the Federal Water Pollution Control Act Amendments of 1972 and the expressed desires of the study participants to determine the best solution for managing wastewater in the Eastern Massachusetts Metropolitan Area.

The principal features of the alternative presented here include: (1) functional design of secondary treatment facilities; (2) conveyance system to transport secondary effluents to Canton; (3) functional design for a tunnel lift pumping station, equalizing storage lagoons, and high pressure pumping station at Canton; (4) a pressure conduit conveyance system to transport the secondary effluent to storage facilities at the land application sites, and (5) land application facilities including effluent storage lagoons, pumping stations, land areas to be utilized and methods of application. Sludges produced at the five regional Water Pollution Control Facilities will be pumped to the Dedham facility and incinerated. Energy will be recovered from the heat generated by incineration of the sludge.

Capital and Operation and Maintenance Costs for the treatment plants, interceptors and lands associated with the land application systems are presented. All costs are projected to reflect a uniform Engineering New Record Cost index of 2200 which was estimated to reflect costs on 1 January 1975.

C. The Study Area

The Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study encompasses 109 cities and towns within a 30-mile radius of the City of Boston (Figure 1). In 1970, some 3,129,200 people resided within this area of 1760 square miles. It is projected that this population will rise to 3,800,000, 4,200,000 and 4,600,000 by the years 2000, 2020, and 2050 respectively.


NEW HAMPSHIRE
RHODE ISLAND
ASHBY
TOWNSEND
PEPPERELL
DUNSTABLE
TYNGSBOROUGH
DRACUT
METHUEN
LAWRENCE
BOXFORD
NORTH ANDOVER
ANDOVER
LOWELL
TEWKSBURY
MIDDLETON
GROTON
CHELMSFORD
FITCHBURG
LUNENBURG
SHIRLEY
WESTFORD
NORTH READING
AYER
BILLERICA
WILMINGTON
LYNNFIELD
LITTLETON
CARLISLE
BURLINGTON
READING
WAKEFIELD
LEOMINSTER
HARVARD
CONCORD R.
BEDFORD
BOXBOROUGH
ACTON
WOBURN
SAUGUS
LANCASTER
CONCORD
STERLING
BOLTON
STOW
LEXINGTON
MELROSE
MALDEN
REVERE
CLINTON
MAYNARD
LINCOLN
WEST BOYLSTON
ASSABET R.
BERLIN
HUDSON
SUDBURY
WALTHAM
BELMONT
CAMBRIDGE
HOLDEN
BOYLSTON
MARLBOROUGH
SUDBURY R.
WAYLAND
WESTON
CHARLES R.
NORTHBOROUGH
NEWTON
SOUTHBOROUGH
FRAMINGHAM
WELLESLEY
WORCESTER
SHREWSBURY
NATICK
NEEDHAM
BOSTON
WESTBOROUGH
ASHLAND
DEDHAM
QUINCY
SHERBORN
DOVER
HOPKINTON
GRAFTON
WESTWOOD
BRAINTREE
AUBURN
MILLBURY
HOLLISTON
UPTON
NORWOOD
RANDOLPH
MEDFIELD
CANTON
MILLIS
MILFORD
MEDWAY
CHARLES R.
SUTTON
OXFORD
NORTHBRIDGE
HOPEDALE
WALPOLE
SHARON
STOUGHTON
AVON
NORFOLK
MENDON
FRANKLIN
BELLINGHAM
BROCKTON
WEBSTER
DOUGLAS
UXBRIDGE
MILLVILLE
BLACKSTONE
WRENTHAM
FOXBOROUGH
EASTON
WEST BRIDGEWATER
PLAINVILLE
MANSFIELD

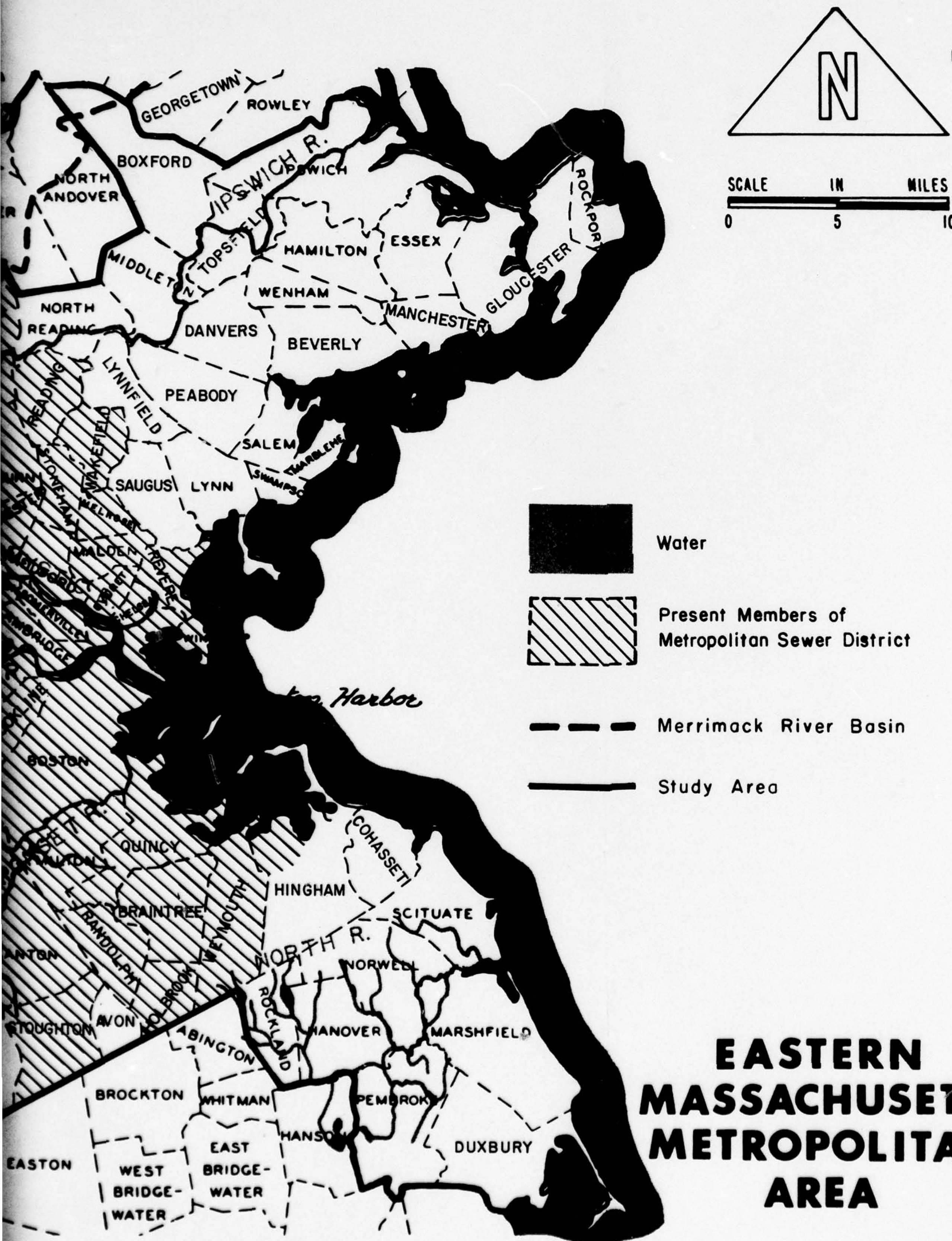


FIG. 1

EASTERN MASSACHUSETTS METROPOLITAN AREA

Of the 109 cities and towns in the study area, 99 are members of the Metropolitan Area Planning Council. One community (Boxford) lies within the jursidiction of the Merrimack Valley Planning Commission, four are within the jurisdiction of the Northern Middlesex Area Commission (Chelmsford, Billerica, Tewksbury, Westford), and three are within the Central Massachusetts Regional Planning Commission jurisdiction (Berlin, Northborough, and Westborough).

Forty-three communities are members of the Metropolitan Sewerage District (MSD) for purposes of commonly collecting and treating their wastewater. Each municipality within the MSD is responsible for maintenance and operation of its own sewerage system prior to discharging into the MSD trunk sewers. Each community is also subject to the rules and regulations set forth by the Metropolitan District Commission. The MSD system consists of more than 200 miles of trunk sewers, covering an area of approximately 400 square miles and serving approximately 2 million people. Except for wastewater discharged through combined sewer overflows and/or discharged to surface waters, wastewater in the MSD system receives primary treatment and chlorination at either Deer Island or Nut Island treatment plants before it is discharged into Boston Harbor. The entire MSD system is operating at full capacity, approximately 440 mgd.

Surface waters in the Eastern Massachusetts Metropolitan Area (Figure 1) consist of Boston Harbor, a large (47 square miles) relatively shallow complex of bays and tidal estuaries, with 180 miles of tidal shoreline; plus three rivers of substantial length: Charles River (length 80 miles, drainage area 308 square miles), Neponset River (length 30 miles, drainage area 120 square miles), and Mystic River (length 17 miles, including its major tributary, the Aberjona River, drainage area 69 square miles). Regions along the coast include: river and tidal estuarine systems of the Ipswich, Pines and Saugus Rivers; Gloucester, Beverly and Salem Harbors on the North Shore; and the Jones, North and South Rivers and Gulf, Cohasset and Scituate Harbors on the South Shore. The northwestern sector of the study area is drained by the Sudbury, Assabet and Concord Rivers (SUASCO) with a combined drainage area of 407 square miles.

As the population of the Boston Harbor-Eastern Massachusetts Metropolitan Study Area has continuously grown, the region has been subjected to ever increasing amounts of municipal wastes and other abuses. The Charles and Mystic Rivers have been impounded over considerable portions of their length and now constitute a series of freshwater and brackish water lakes. This alteration of a river system which in some cases ostensibly improves water quality by restricting salt water incursion, has not been without its detrimental consequences. Upstream pollutants are not effectively carried beyond dams. In the Lower Mystic Lake and the Lower Charles River Basin, especially, toxic materials have built up in the bottom waters over time. Installation of primary sewage treatment facilities at Deer and Nut Island in Boston Harbor have transplanted much of the pollution load from these river systems to marine waters, thereby alleviating some pressures. However, overflow of sewage into the stormwater system (especially via combined sewer systems) and scores of unidentified illicit discharges continue to degrade freshwater quality within the study area.

The Boston Harbor-Eastern Massachusetts Metropolitan Area north of the Cape Cod Canal lies in the Seaboard lowland subprovince of the New England Physiographic Province. The bedrock of the area, consisting chiefly of paleozoic and older igneous and metamorphic rocks, is overlain by wide-spread unconsolidated deposits of glacial origin. The topography is controlled by structural features which are masked and modified by the mantle of glacial drift.

The entire area is characterized by an irregular topography of relatively flat lowlands, low rolling hills of unconsolidated glacial material and exposures of bedrock. The higher hills are generally bedrock outcrops or have a rock core overlain with glacial material. The area slopes relatively gently in an easterly or southeasterly direction where it drains to the Atlantic Ocean at Massachusetts Bay, Buzzard's Bay or Narragensett Bay. The highest relief in the area is found at its western border around Worcester and Leicester where elevations approach 1400 feet. Easterly the topography exhibits lower relief as the land surface descends to the shoreline. The exception to this general rule is the Blue Hills just south of Boston which rise predominately to an elevation of 640 feet. Elevations of the surrounding lands of Greater Boston and the SouthShore seldom exceed 300 feet with most of the higher elevations seen to the west. Cape Cod and the Islands exhibit a varied topography characterized in many places by relatively sttep ridges meeting flat or gently sloping areas. The maximum relief on the outer Cape is 150 feet while in the upper Cape near the Town of Bourne, it reaches 300 feet. Glacially originated topographic features include the many low spoon-shaped drumlin hills which dot the area in which Bunker Hill is an example, and the stoney ridge shaped "spine" of Middle Cape Cod which is the remnant of a terminal moraine deposited during a period of still-stand of the most recent advance of glacial ice.

The bedrock of the study area consists of igneous, sedimentary and metasedimentary, and metamorphic rocks mantled discontinously by unconsolidated deposits. The ages of the bedrock range from Precambrian to late Paleozoic with some minor volcanics of Triassic age also being mapped. The predominate igneous rocks mapped are syenites, volcanics and gabbrodiorites. Outcrops of sedimentary and metasedimentary rocks are chiefly confined to the eastern and southeastern parts of the study area in the Boston and Narragansett basins. Slates, argillites, and conglomerates as well as some sandstones are mapped. Metamorphic rocks exhibiting both foliated (phyllites, schists and gneisses, and non-foliated (quartzites) texture are abundant and outcrop in all parts of the study area.

The surficial geology of the study area is made up predominately of glacial drift with some deposits of recent alluvium. Till is found throughout the area and is the most abundant and wide-spread glacial deposit. Stratified drift is common and is found principally in the lower-lying flatter areas and is thickest along present or buired pre-glacial stream valleys. Thick deposits of well-sorted, medium to coarse grained stratified drift make up the most productive aquifers in the region.

Drainage of the area was interrupted and altered by the advance of glacial ice from the north. The many swamps and marshes which dot the area and the poorly developed drainage pattern of many of the streams testify to the fact that the drainage in many parts of the region has not yet been fully re-established.

Eastern Massachusetts is a humid region with annual precipitation averaging greater than 43 inches. 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 and storms of extra-tropical nature often called "northeasters." Precipitation is generally uniformly distributed throughout the year with much of the winter precipitation occurring as snow. Melting of the snow cover generally occurs in March and early April although intermittent warming periods between snowfalls will often cause much snow to melt or be removed by sublimation.

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, Framingham and New Bedford, Massachusetts were selected as representative of the coastal, interior, and southern portions of the area, respectively. A summary of these data is presented in Table 1.

Hydrologically, the study area is characterized by unusually flat, swampy watersheds containing numerous man-made storage facilities. These conditions are inclined to attentuate 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 sewered portions of the study area. Population development is virtually complete in the core city of Boston with saturation radiating outward into the surrounding towns and cities.

The mean annual precipitation at Boston is 43 inches, with recorded annual maximum and minimum values of 67.7 and 23.7 inches,

TABLE 1

MONTHLY TEMPERATURE RECORD
(In Degrees Fahrenheit)

	Boston, Mass. Elevation 15 feet msl 101 Years of Record Through 1972			Framingham, Mass. Elevation 170 feet msl 87 Years of Record Through 1971			New Bedford, Mass. Elevation 70 feet msl 81 Years of Record Through 1970		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	29.0	72	-13	26.3	72	-24	30.1	66	-11
February	29.2	68	-18	26.8	66	-21	29.9	69	-12
March	37.6	86	-8	36.2	85	-3	37.3	77	2
April	47.2	91	11	47.3	93	10	46.8	85	18
May	57.9	97	31	58.3	96	25	56.9	95	30
June	67.3	100	41	67.2	100	35	65.7	102	41
July	72.3	104	50	72.3	102	42	71.5	99	45
August	71.5	101	46	69.9	104	34	70.2	96	44
September	64.4	102	34	62.9	95	27	63.9	94	30
October	55.0	90	25	52.4	91	16	54.2	90	22
November	44.5	83	-2	41.0	83	6	44.2	76	9
December	32.7	69	-17	29.9	71	-16	33.4	65	-11
Annual	50.7	104	-18	49.2	104	-24	50.3	102	-12

respectively. At Framingham, the average annual precipitation is 43.8 inches, with extremes of 60 and 29 inches, respectively. At New Bedford, the average annual precipitation is 43.6 inches, with extremes of 64 and 22 inches, respectively.

Table 2 summarizes precipitation data recorded at the three selected Weather Service stations in the 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 area is characterized by periods of rain or snow. Average annual snowfall varies from 43 inches at Boston to over 51 inches at Framingham to 35 inches at New Bedford.

The U. S. Geological Survey maintains flow records of several stream gaging stations in the study area. A summary of monthly and annual runoff for stations on the Assabet, Sudbury, Ipswich, Concord, Charles and Neponset Rivers is presented in Table 3. In general, the mean annual runoff is slightly less than 50 percent of the mean annual precipitation.

Peak discharge frequently curves, computed for selected streams in the study area, are presented in Figure 2. Flow data for the Assabet, Concord, Ipswich, Charles, Neponset, Parker, and Aberjons Rivers are extensive and complete, thus allowing analyses by the Log Pearson Type III distribution method. Annual peak discharges were analyzed for each water year of record throughSeptember 1969. In the case of the Sudbury River, where annual peak discharge data are incomplete, discharge-frequencies were derived through comparison of computed peak floodflows at Framingham and analyses of flow records of the nearby, and hydrologically similar, Assabet River at Maynard.

An IBM 1130 computer was used to determine the mean logarithms and standard deviations -- the bases of curve definition. A regional skew coefficient of 0.5 was adopted based on a recently completed regional study of all stream gages in southeastern New England. Frequencies were further adjusted for length of record and partial duration in accordance with the method prescribed by Beard (7).

Low flow duration frequency analyses were made using historical flow data for selected long-term U.S. Geological Survey stations in the study area. Low flow frequencies were determined for durations of 1, 3, 7, 14, 30 and 60 days using a Pearson Type III statistical distribution. Results of the study are illustrated graphically in Figures 3 and 4. It is noted that the analyses were based on recorded flows which may be affected somewhat by upstream storage regulation and diversions for water supply.

Flow duration data were provided by the U.S. Geological Survey for all of the long-term gaging stations in the study area and are shown graphically in Figures 5 and 6.

TABLE 2

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			New Bedford, Mass. Elevation 70 feet msl 157 Years or Record Through 1970		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	3.62	9.54	0.89	3.86	9.67	0.75	3.86	10.75	0.77
February	3.47	7.08	0.45	3.77	8.82	0.26	3.68	8.30	0.91
March	3.96	11.00	T	4.16	9.61	0.04	4.10	9.77	0.09
April	3.73	9.14	0.93	3.65	8.78	0.85	3.82	9.64	0.91
May	3.45	13.38	0.25	3.24	7.01	0.72	3.63	9.80	0.32
June	3.19	9.13	0.27	3.28	9.33	0.38	2.98	9.31	0.01
July	3.32	11.69	0.52	3.47	11.80	0.73	2.97	12.00	0.02
August	3.78	17.09	0.39	3.62	15.69	0.54	3.47	18.72	0.24
September	3.34	10.94	0.21	3.53	10.65	0.18	3.36	12.06	0.21
October	3.35	8.84	0.06	3.29	10.26	0.10	3.61	10.09	0.15
November	4.02	11.03	0.59	4.04	7.94	0.89	4.06	9.74	0.35
December	3.77	9.74	0.66	3.91	10.87	0.92	4.01	11.70	0.45
Annual	43.01	67.7	23.7	43.82	59.94	28.96	43.55	65.41	21.87

T = Trace

TABLE 3

MONTHLY RUNOFF (cfs)

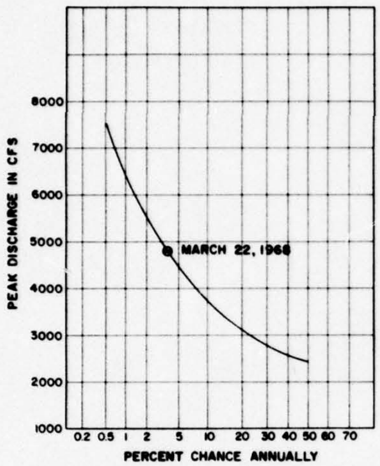
Month	Sudbury River at Framingham Center, Mass. D.A. = 75.2 Sq. Mi. Jan 1875-Sep 1971			Assabet River at Maynard, Mass. D.A. = 116 Sq. Mi. Jul 1941-Sep 1971			Concord River Below River Meadow Brook at Lowell, Mass. D.A. = 405 Sq. Mi. Oct 1936-Sep 1971		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	135	352	12.4	190	439	38	574	1,135	160
February	171	559	34.9	230	696	72	704	1,856	318
March	303	753	69.0	413	752	229	1,125	1,931	660
April	236	489	68.6	375	741	127	1,143	2,189	616
May	127	344	29.7	228	443	115	691	1,235	283
June	59	231	-24.9*	131	336	39	408	962	116
July	23	401	-36.7*	61	254	12	219	1,512	50
August	23	532	-39.0*	56	561	10	182	1,208	33.1
September	30	345	-42.1*	59	542	5	209	1,151	22.8
October	42	264	-24 *	69	375	10	235	1,079	38.3
November	93	468	1.7	138	542	22	402	1,346	86.9
December	121	382	15.8	164	458	36	566	1,152	133
Annual									
cfs	113	188	42.0	176	286	74	538	889	242
Inches	20.4	33.9	7.6	20.4	33.5	8.7	18.0	29.8	8.1

*Negative values due to evaporation from reservoirs.

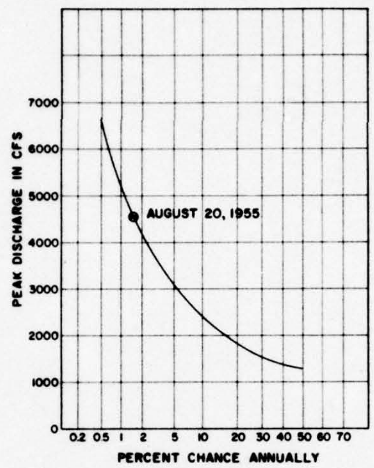
TABLE 3 (cont.)

MONTHLY RUNOFF (cfs)

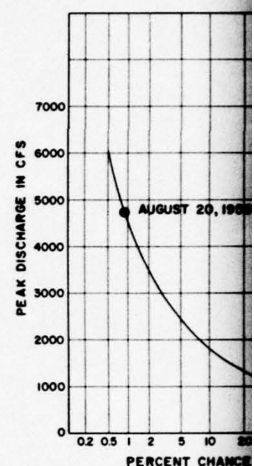
Month	Ipswich River Near Ipswich, Mass. D.A. = 124 Sq. Mi. Jun 1930-Sep 1971			Charles River at Charles River Vil., Mass. D.A. = 184 Sq. Mi. Oct 1937-Sep 1971			Neponset River at Norwood, Mass. D.A. = 35.2 Sq. Mi. Oct 1939-Sep 1971		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	222	573	10	331	562	71	60	135	12
February	229	493	16	403	1,005	143	72	188	19
March	482	1,059	27	641	1,164	304	111	211	49
April	443	885	31	578	1,137	175	96	189	32
May	253	846	80	353	746	164	61	146	26
June	130	328	99	204	468	67	34	89	11
July	64	525	170	131	1,060	25	19	79	7
August	39	363	124	111	956	9	22	226	6
September	48	386	29	97	640	8	21	88	7
October	77	706	13	119	600	13	25	126	6
November	132	525	8	230	892	38	44	188	6
December	194	520	7	307	685	60	55	127	8
Annual									
cfs	193	299	70	292	466	122	52	88	22
Inches	21.1	32.7	7.7	21.5	32.9	9.0	20.0	33.9	8.5



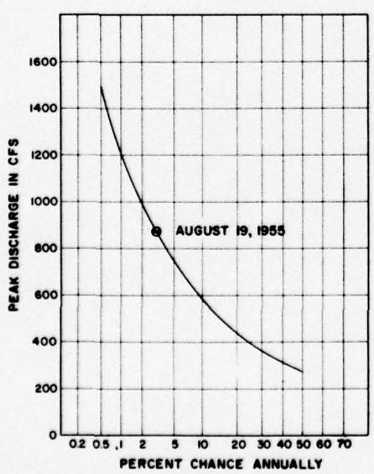
CONCORD RIVER
BELOW RIVER MEADOW BROOK AT LOWELL, MASS.
D.A.=405 SQ. MI.



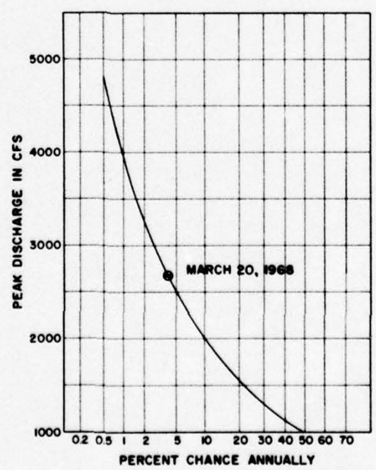
ASSABET RIVER AT MAYNARD, MASS.
D.A.=116 SQ. MI.



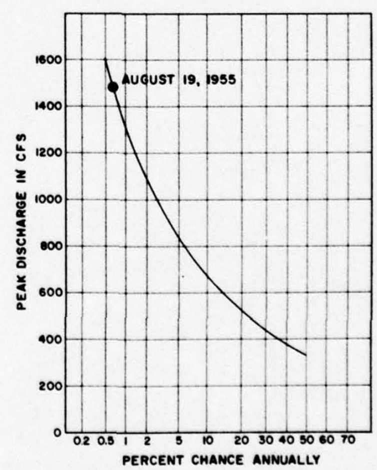
SUDBURY RIVER AT FRAM
D.A.=75.2 S



ABERJONA RIVER AT WINCHESTER, MASS.
D.A.=23.3 SQ. MI.

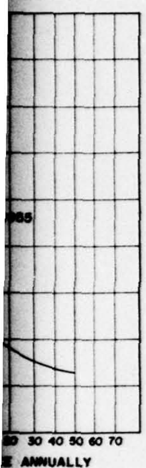


IPSWICH RIVER NEAR IPSWICH, MASS.
D.A.=124 SQ. MI.



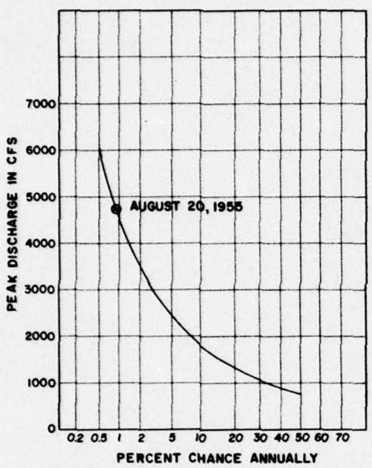
NEPONSET RIVER AT NORWOOD, MASS.
D.A.=35.2 SQ. MI.

U. S ARMY



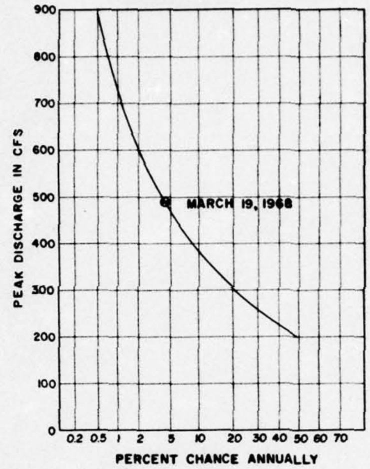
MAYNARD, MASS.

SQ. MI.



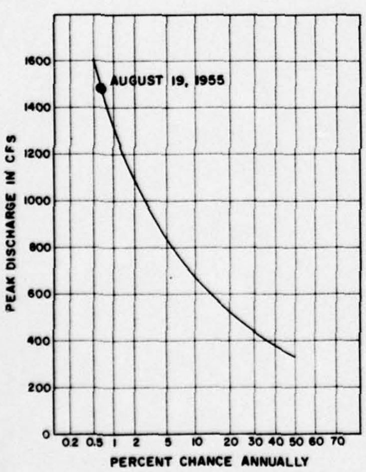
SUDBURY RIVER AT FRAMINGHAM CENTER, MASS.

D.A.=75.2 SQ. MI.



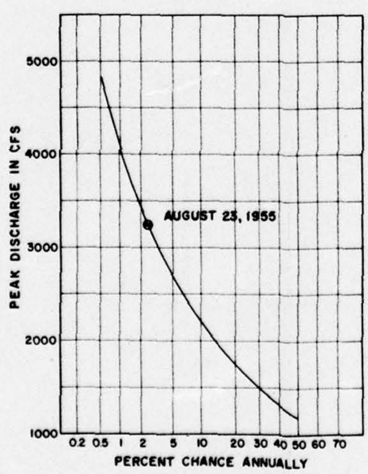
PARKER RIVER AT BYFIELD, MASS.

D.A.=21.6 SQ. MI.



NEPONSET RIVER AT NORWOOD, MASS.

D.A.=35.2 SQ. MI.



CHARLES RIVER
AT CHARLES RIVER VILLAGE, MASS.

D.A.=184 SQ. MI.

NOTE:

⊗ INDICATES MAXIMUM DISCHARGE OF RECORD.

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

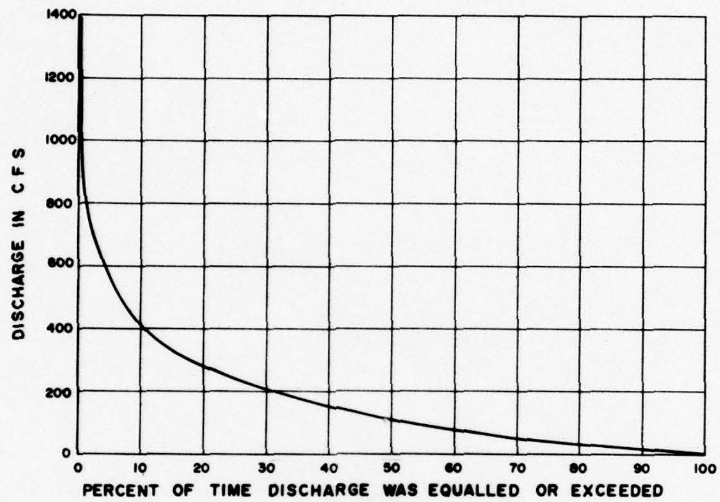
BOSTON HARBOR - EASTERN MASSACHUSETTS METROPOLITAN AREA
WASTEWATER MANAGEMENT STUDY

LOW FLOW FREQUENCY DURATION GRAPHS

NOVEMBER 1973

SCALE | SPEC. NO. | DRAWING NUMBER | SHEET

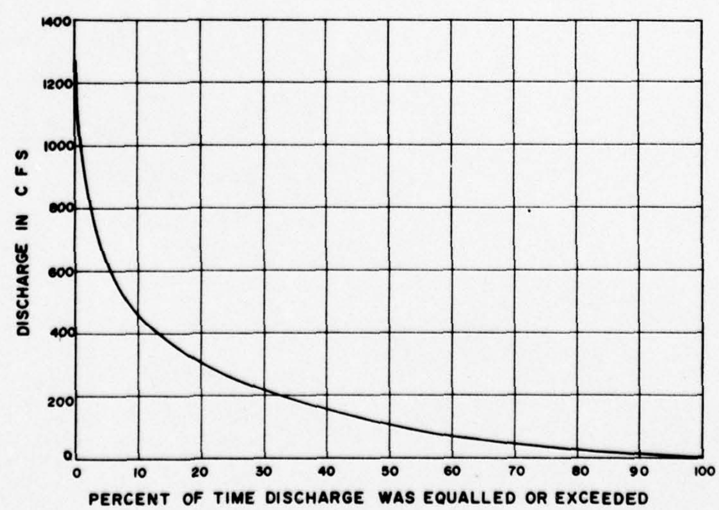
FIGURE 2



ASSABET RIVER

AT MAYNARD, MASS

(D.A.=116 SQ. MI. 1943-1967)

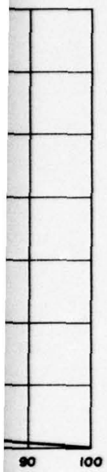


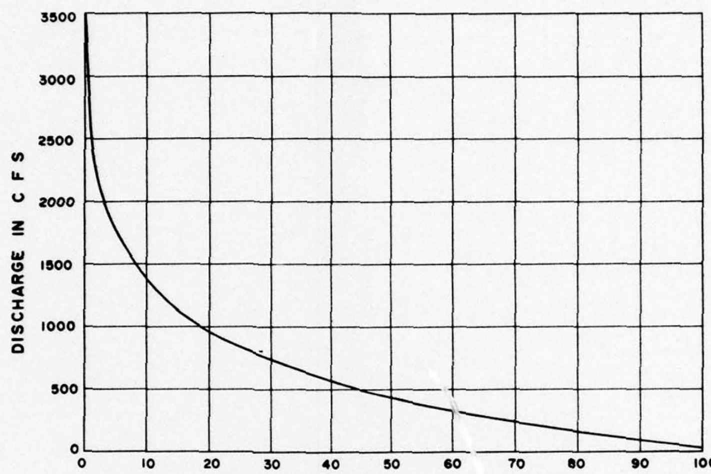
IPSWICH RIVER

NEAR IPSWICH, MASS.

(D.A.=124 SQ. MI. 1931-1967)

D E F G H U. S ARMY

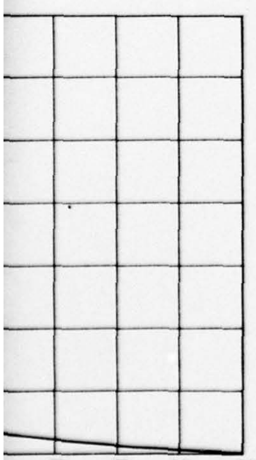




CONCORD RIVER BELOW

RIVER MEADOW BROOK AT LOWELL, MASS.

(D.A.= 405 SQ.MI. 1938-1967)



ASS.

-1967)

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

BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA

WASTEWATER MANAGEMENT STUDY

FLOW DURATION CURVES

NOVEMBER 1973

SCALE SPEC. NO.

SHEET

FIGURE 3

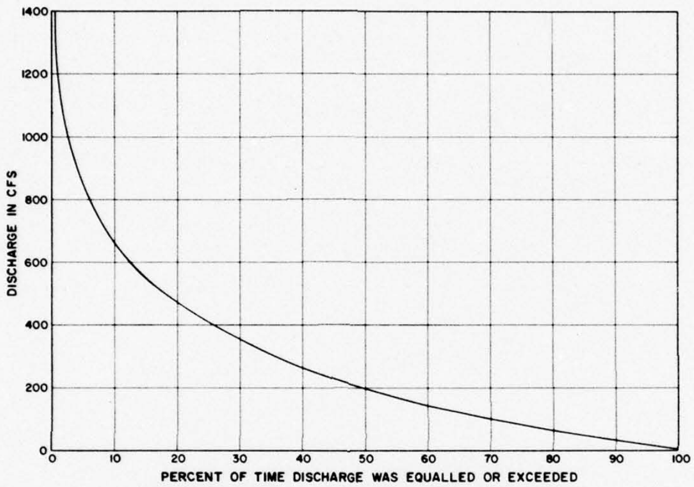
CORPS OF ENGINEERS A B C D E

1

2

3

4



CHARLES RIVER AT CHARLES RIVER VILLAGE, MASS.

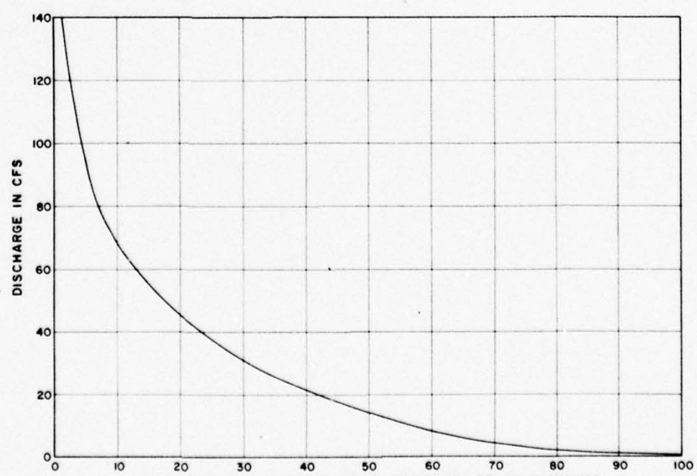
(D.A.= 184 SQ. MI. 1938-1967)

5

6

7

8

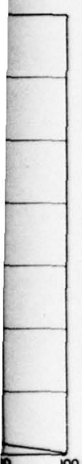


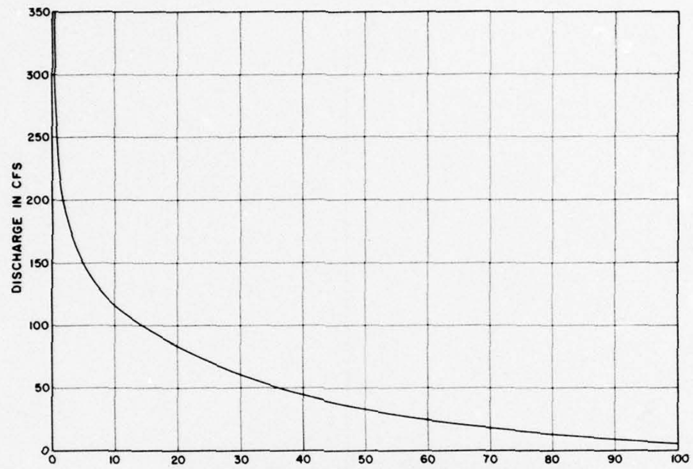
ABERJONA RIVER AT WINCHESTER, MASS.

(D.A.= 23.3 SQ. MI. 1940-1967)

D E F G H U. S ARMY

1 2 3 4 5 6 7 8

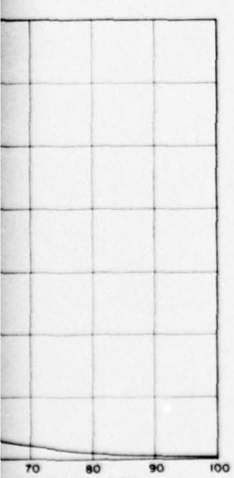




PERCENT OF TIME DISCHARGE WAS EQUALLED OR EXCEEDED

NEPONSET RIVER AT NORWOOD, MASS.

(D.A.=35.2 SQ. MI. 1941-1967)



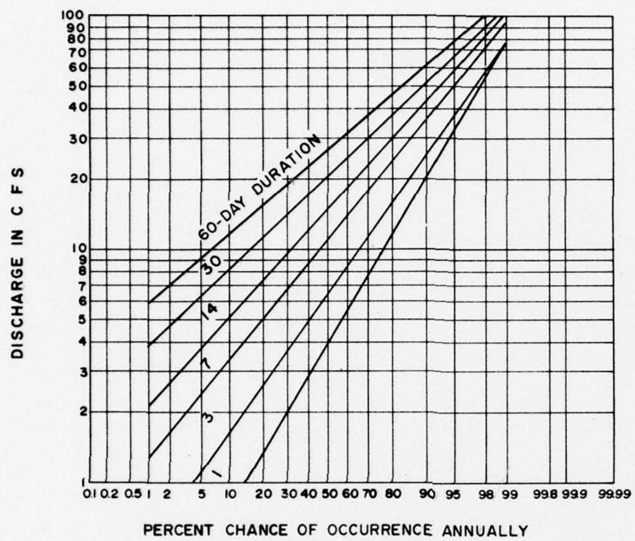
LLED OR EXCEEDED

TER, MASS.

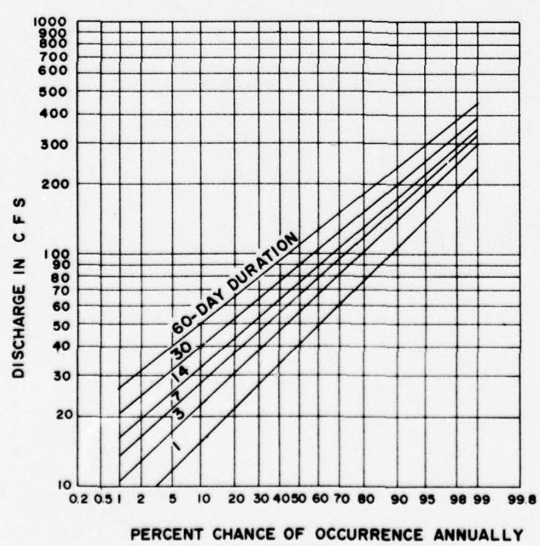
40-1967)

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASS.	
DES. BY / DR. BY / CK. BY SUBMITTED: CHIEF, SECTION APPROVAL RECOMMENDED: CHIEF, TECH. ENG. BRANCH REVIEWED: PROJECT ENGINEER APPROVAL RECOMMENDED: CHIEF BRANCH	BOSTON HARBOR - EASTERN MASSACHUSETTS METROPOLITAN AREA WASTEWATER MANAGEMENT STUDY **FLOW DURATION CURVES** NOVEMBER 1973
	APPROVED DATE CHIEF, ENGINEERING DIVISION
	SCALE / SPEC. NO. DRAWING NUMBER SHEET

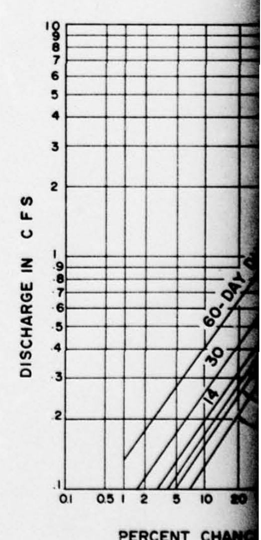
FIGURE 4



ASSABET RIVER
AT MAYNARD, MASS.
(D.A.=116 SQ. MI. 1942-1967)

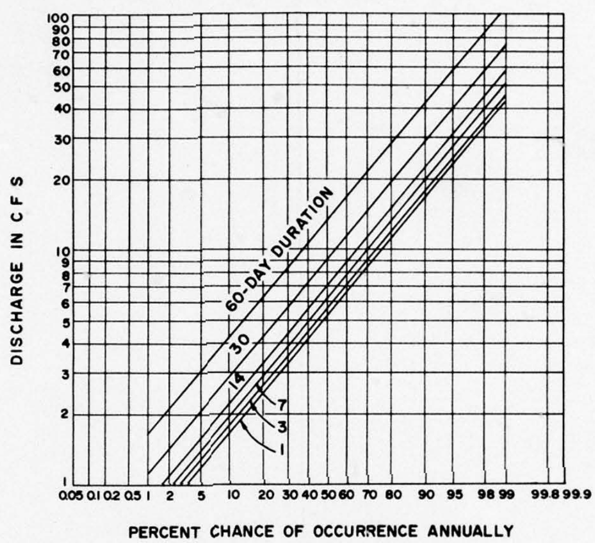


CONCORD RIVER
BELOW RIVER MEADOW BROOK AT
LOWELL, MASS.
(D.A.=405 SQ. MI. 1936-1967)



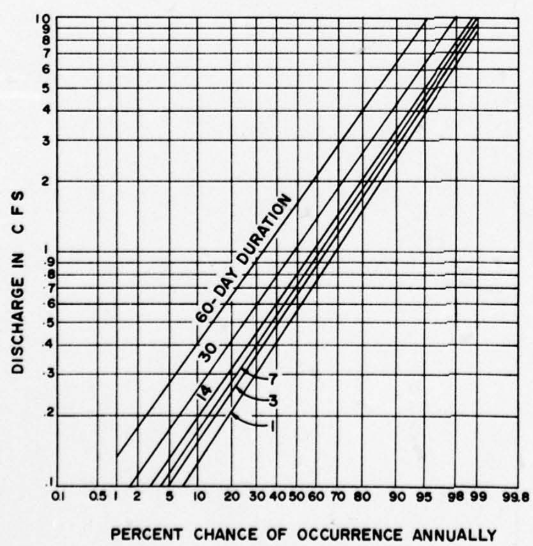
PA
AT
(D.A.=21

D E F G H U. S ARMY



IPSWICH RIVER
NEAR IPSWICH, MASS.

(D.A.=124 SQ.MI. 1931-1968)



PARKER RIVER
AT BYFIELD, MASS.

(D.A.=21.6 SQ. MI. 1946-1968)

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

DES. BY | DR. BY S.D.L. | CK. BY

SUBMITTED:
CHIEF, SECTION
APPROVAL RECOMMENDED:
CHIEF, TECH. ENG. BRANCH
REVIEWED:
PROJECT ENGINEER
APPROVAL RECOMMENDED:
CHIEF BRANCH

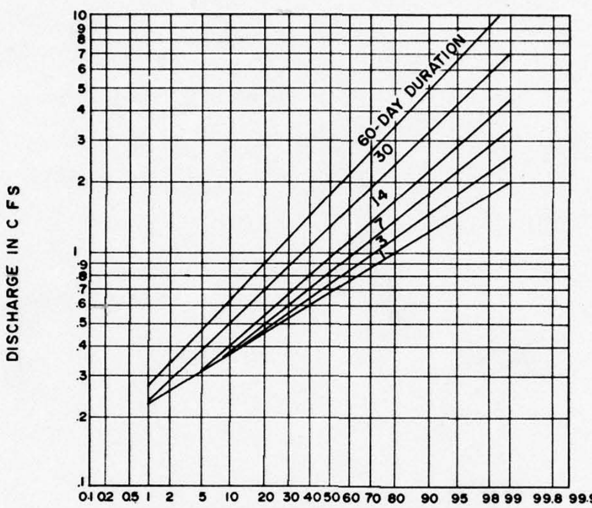
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA
WASTEWATER MANAGEMENT STUDY

PEAK DISCHARGE
FREQUENCY CURVES

NOVEMBER 1973

APPROVED DATE
CHIEF, ENGINEERING DIVISION
SCALE SPEC. NO.
DRAWING NUMBER
SHEET

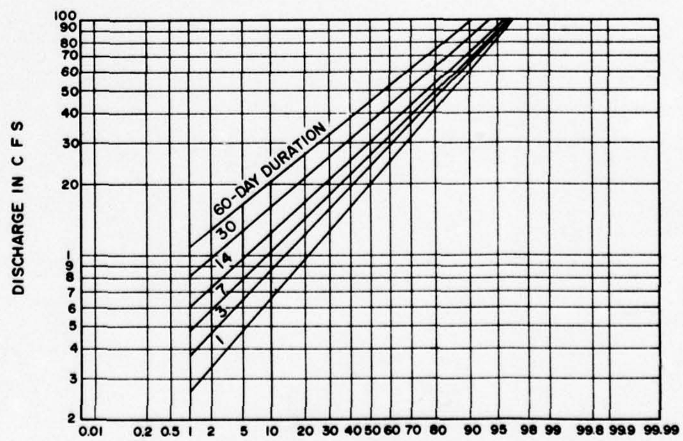
FIGURE 5



PERCENT CHANCE OF OCCURRENCE ANNUALLY

ABERJONA RIVER
AT WINCHESTER, MASS.

(D.A. = 23.3 SQ. MI. 1940-1968)



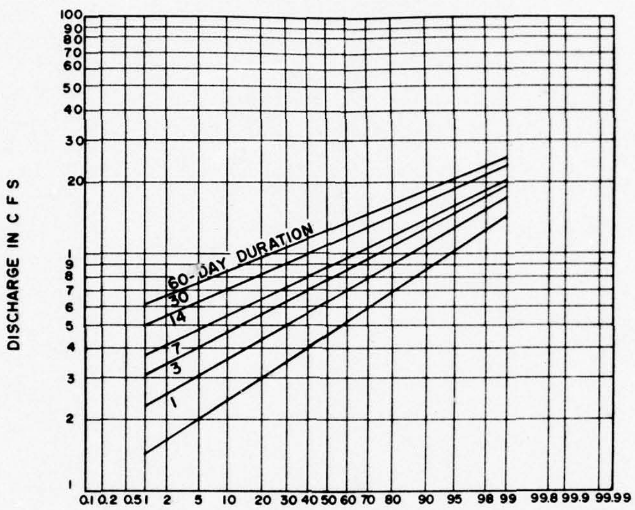
PERCENT CHANCE OF OCCURRENCE ANNUALLY

CHARLES RIVER
AT CHARLES RIVER VILLAGE, MASS.

(D.A. = 184 SQ MI 1938-1968)

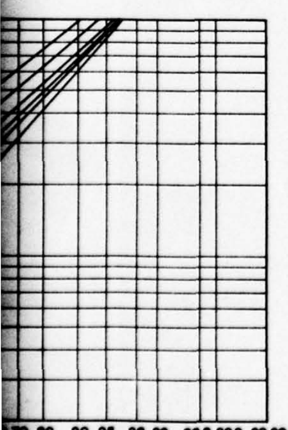
DISCHARGE IN C F S

D E F G H U. S. ARMY



NEPONSET RIVER
AT NORWOOD, MASS.

(D.A.= 35.2 SQ. MI. 1940 - 1968)



LAGE, MASS.

8-1968)

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

DES. BY	DR. BY S.D.L.	CK. BY

SUBMITTED:
CHIEF, SECTION
APPROVAL RECOMMENDED:
CHIEF, TECH. ENG. BRANCH
REVIEWED:
PROJECT ENGINEER
APPROVAL RECOMMENDED:
CHIEF BRANCH

BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA
WASTEWATER MANAGEMENT STUDY

LOW FLOW FREQUENCY
DURATION GRAPHS

NOVEMBER 1973

APPROVED DATE
CHIEF, [illegible] [illegible]
SCALE SPEC. NO.
DRAWING NUMBER
SHEET

FIGURE 6

D. Other Regional Wastewater Management Studies in Eastern Massachusetts

During the conduct of the Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study, two additional comprehensive wastewater management studies were taking place in areas contiguous to the Eastern Massachusetts Metropolitan Area.

The Merrimack Wastewater Management Study, conducted by the New England Division, U.S. Army Corps of Engineers in cooperation with the Commonwealth of Massachusetts, focused on the 24 communities along the mainstem of the Merrimack River in Massachusetts. This study area bordered the Eastern Massachusetts Metropolitan Area to the north. The objective of this study was to design regional wastewater management systems that address the long-range goal of Public Law 92-500, as well as the broad planning objectives of the people in the Merrimack River Basin in Massachusetts.

To the west, the communities in the Nashua River Basin were the subject of a similar study by the Nashua River Program under the supervision of the New England Interstate Water Pollution Control Commission. The objective of this study was to propose regional wastewater treatment alternatives which would achieve stream standards as set in the Nashua River Basin by the Commonwealth of Massachusetts.

II. IDENTIFICATION OF POTENTIAL LAND APPLICATION AREAS AND DETERMINATION OF ACREAGES NEEDED

A. General

Developing a land-oriented treatment alternative for renovation of municipal and industrial wastewater using the soil-vegetative complex requires consideration of many factors. Specifically, those factors pertaining to land use, geological characteristics of sites; both surficial and subsurface, and projected wastewater flows for the planning period.

Methodology used to identify potential land treatment sites and sizing of land treatment sites for the regional sewage treatment plants included:

1. Identification of recent land use for each community in the study area.

2. Assembly and evaluation of available geologic information describing unconsolidated surficial materials, bedrock, and groundwater for the study area with respect to land treatment techniques.

3. Determine acreages needed for land treatment of projected year 2000 flows using either spray irrigation or rapid infiltration.

4. Comparison of lands potentially available with acreage needed.

B. Land Use

Information describing existing land use in the Boston Harbor-Eastern Massachusetts Metropolitan Area was obtained by interpreting 1:20,000 aerial panchromatic photographs taken during the summers of 1970 and 1971(34). Community land use was categorized into one of six major categories: agricultural and open lands, forested lands, wetlands, urban lands, mining or waste disposal lands, and outdoor recreational lands for Essex, Middlesex, Norfolk, Plymouth, Suffolk, and Worcester Counties (Table 4).

Agricultural and open lands include tilled or tillable crop lands currently used for intensive farming, unused tillable land only recently not tilled, pasture or wild hay land not suitable for tillage, abandoned fields, productive fruit orchards, abandoned orchards, productive cranberry bogs, plant nurseries, heath plant vegetation, sandy beaches, and power lines and other rights-of-way.

Forested lands were delineated by the height and density of the softwood and hardwood tree species found in the study area. These lands include state and town forests and wooded swamplands.

TABLE 4

Land Use for Communities in Boston Harbor-Eastern Massachusetts Metropolitan Area Study

ESSEX COUNTY

Community	Total Acreage	Agriculture and Open Land Acres	%	Forest Land Acres	%	Urban Land Acres	%	Wetlands Acres	%	Mining, Waste Disposal Lands Acres	%	Outdoor Recreation Land Acres	%
Beverly	9926	769	8	4254	43	3929	40	627	6	78	0.8	269	3
Boxford	15760	1536	10	11604	74	1733	11	719	5	22	0.1	146	0.9
Danvers	8738	1351	15	2362	27	3920	45	929	11	77	0.9	99	1
Essex	9336	820	9	4586	49	739	8	3119	33	14	0.2	58	0.6
Gloucester	16973	402	2	9666	57	4075	24	2354	14	154	0.9	322	2
Hamilton	9574	1265	13	5678	59	1804	19	666	7	11	0.1	150	2
Ipswich	23204	3388	15	9284	40	2698	12	7047	30	122	0.5	665	3
Lynn	7384	83	1	2319	31	4008	54	682	9	72	1	220	3
Lynnfield	6776	442	7	3019	45	2354	35	657	10	0	-	304	4
Manchester	4984	76	2	2960	59	1602	32	160	3	18	0.4	168	3
Marblehead	2903	110	4	502	17	2072	71	64	2	0	-	155	5
Middleton	9332	1097	12	6132	66	1186	13	671	7	92	1	154	2
Nahant	737	17	2	99	13	448	61	12	2	0	-	161	22
Peabody	10768	1098	10	3563	33	4988	46	609	6	264	2	246	2
Rockport	4636	242	5	2636	57	1251	27	289	6	60	1	158	3
Salem	6016	752	13	1339	22	2424	40	1138	19	47	0.8	316	5
Saugus	7320	426	6	2946	40	2227	30	1410	19	194	3	117	2
Swampscott	1956	82	4	534	27	1059	54	42	2	82	4	157	8
Topsfield	8188	1154	14	4459	54	1525	19	835	10	41	0.5	174	2
Wenhan	5321	714	13	3051	57	1014	19	449	8	0	-	93	2

MIDDLESEX COUNTY

Community	Total Acreage	Agriculture and Open Land Acres	%	Forest Land Acres	%	Urban Land Acres	%	Wetlands Acres	%	Mining, Waste Disposal Lands Acres	%	Outdoor Recreation Land Acres	%
Acton	12838	1416	11	7317	57	3064	24	698	5	291	2	52	0.4
Arlington	3484	23	0.6	191	5	2874	82	243	7	0	0	153	4
Ashland	7942	553	7	5192	65	1480	19	414	5	188	2	115	1
Bedford	8787	725	8	3844	44	3323	38	674	8	62	0.7	159	1.8
Belmont	2920	120	4	490	17	2021	69	81	3	11	0.4	197	6
Billerica	16653	1548	9	8870	53	5052	30	860	5	163	1	160	1
Boxborough	6650	1028	15	4746	71	605	9	223	3	37	0.5	11	0.2
Burlington	7578	427	6	2655	35	4180	55	127	2	101	1	88	1
Cambridge	4693	19	0.4	106	2	3667	78	592	13	53	1	256	5
Carlisle	9837	1134	12	7386	75	967	10	343	3	-	-	7	-
Chelmsford	14758	1897	13	5978	41	5742	39	844	6	187	1	110	0.7

TABLE 4 (CONT'D)

Community	Total Acreage	Agriculture and Open Land Acres	%	Forest Land Acres	%	Urban Land Acres	%	Wetlands Acres	%	Mining, Waste Disposal Lands Acres	%	Outdoor Recreation Land Acres	%
Concord	15974	2956	19	7654	48	3382	21	1610	10	91	0.6	281	2
Everett	2344	7	0.3	8	0.3	2092	89	196	8	4	0.2	37	2
Framingham	16416	1292	8	5980	36	7490	46	1177	7	121	0.7	356	2
Holliston	21176	946	4	8414	40	2053	10	444	2	219	1	100	0.5
Hopkinton	16896	1361	8	12000	71	2030	12	1223	7	150	0.9	132	0.8
Hudson	7462	743	10	3941	53	2092	28	493	7	150	2	43	0.6
Lexington	10547	759	7	3032	29	5584	53	860	8	58	0.6	254	2
Lincoln	9318	1342	14	4844	52	2388	26	703	8	15	0.2	26	0.3
Littleton	10534	2328	22	5469	52	1777	17	848	8	68	0.6	45	0.4
Malden	3252	52	2	440	14	2582	79	30	0.9	52	2	96	3
Marlborough	13434	1581	12	7051	52	3513	26	862	6	220	2	207	2
Maynard	3354	292	9	1635	49	1120	33	200	6	39	1	68	2
Medford	5648	88	2	1485	26	3412	60	436	8	26	0.5	201	4
Melrose	3036	14	0.5	789	26	1989	66	58	2	33	1	153	5
Natick	9523	878	9	3780	40	3814	40	763	8	51	0.5	237	2
Newton	11252	156	1	1461	13	8437	75	354	3	29	0.3	815	7
North Reading	8680	497	6	5059	58	2086	24	686	8	90	1	262	3
Reading	6388	170	3	3033	47	2817	44	151	2	26	0.4	191	3
Sherborn	9702	1625	17	6562	68	948	10	518	5	35	0.4	14	0.1
Somerville	2636	0	0	7	0.3	2443	93	68	3	22	0.8	95	4
Stoneham	4332	191	4	1667	38	1812	42	452	10	4	-	206	5
Stow	11315	1718	15	7254	64	1269	11	698	6	119	1	257	2
Sudbury	15597	2464	16	8133	52	3350	21	1339	9	86	0.5	225	1
Tewksbury	13670	2470	18	5360	39	4782	35	689	5	192	1	177	1
Wakefield	5112	166	3	1443	28	2855	56	511	10	16	0.3	121	2
Waltham	8812	501	6	2411	27	4866	55	878	10	22	0.3	134	2
Watertown	2708	53	2	92	3	2324	86	76	3	4	0.2	159	6
Wayland	9779	1269	13	4152	42	2620	27	1469	15	43	0.4	226	2
Westford	19974	2424	12	12945	65	2652	13	1449	7	373	2	131	0.7
Weston	10752	663	6	5570	52	3630	34	482	4	71	0.7	336	3
Wilmington	10931	670	6	5108	47	4166	38	487	4	373	3	127	1
Winchester	4060	105	3	1233	30	2365	58	219	5	0	0	138	3
Woburn	8275	867	10	2386	29	4260	51	475	6	195	2	92	1

TABLE 4 (CONT'D)

NORFOLK COUNTY

Community	Total Acreage	Agriculture and Open Land Acres	%	Forest Land Acres	%	Urban Land Acres	%	Wetlands Acres	%	Mining, Waste Disposal Lands Acres	%	Outdoor Recreation Land Acres	%
Avon	3013	142	5	1612	54	1039	34	179	6	15	0.5	26	0.9
Bellingham	11949	1836	15	6648	56	2228	19	661	6	411	3	165	1
Braintree	9100	352	4	3467	38	4278	47	637	7	88	1	278	3
Brookline	4359	80	2	567	13	3235	74	58	1	18	0.4	401	9
Canton	12460	1167	9	6126	49	3295	26	1033	8	257	2	582	5
Cohasset	6412	221	3	3936	61	1769	28	348	5	0	0	138	2
Dedham	6958	171	2	2761	40	3171	46	696	10	29	0.4	130	2
Dover	9970	1200	12	6416	64	2011	20	299	3	7	0	37	0.4
Franklin	17227	2664	15	10662	62	2918	17	632	4	233	1	118	1
Hingham													
Holbrook	4769	274	6	2868	60	1364	29	111	2	122	3	30	0.6
Hull													
Medfield	9479	1096	12	5734	60	1768	19	766	8	63	0.7	52	0.6
Medway	7372	1677	23	4037	55	1384	19	111	2	122	2	41	0.6
Millis	7328	1578	20	4251	54	1003	13	654	8	184	2	160	2
Milton	8495	450	5	3845	45	3572	42	362	4	31	0.4	235	3
Needham	8194	357	4	2864	35	4184	51	632	8	33	0.4	124	2
Norfolk	10159	1537	15	6855	67	1074	11	536	5	123	1	34	0.3
Norwood	6610	441	7	2101	32	3524	53	328	5	31	0.5	179	3
Quincy	10752	372	3	3586	33	5484	51	806	8	256	2	248	2
Randolph	6569	337	5	2474	38	3200	49	472	7	41	0.6	45	0.7
Sharon	15432	1218	8	10262	67	2795	18	733	5	127	0.8	297	0.2
Stoughton	10492	663	6	5674	54	3564	34	299	3	177	2	115	1
Walpole	13330	1617	12	7566	57	3141	24	512	4	344	3	150	1
Wellesley	6580	94	1	1508	23	4354	66	362	6	7	0.1	255	4
Westwood	7118	561	8	3705	52	2507	35	159	2	30	0.4	156	2
Weymouth	11528	245	2	4219	37	5587	48	1148	10	167	1	162	1
Wrentham	14447	2501	17	9262	64	1509	10	785	5	336	2	54	0.4

PLYMOUTH COUNTY

Community	Total Acreage	Agriculture and Open Land Acres	%	Forest Land Acres	%	Urban Land Acres	%	Wetlands Acres	%	Mining, Waste Disposal Lands Acres	%	Outdoor Recreation Land Acres	%
Duxbury	15454	1477	10	8095	52	3197	21	2135	14	98	0.6	452	3
Hanover	9978	668	7	5979	60	2791	28	405	4	95	1	40	0.4
Marshfield	18678	1144	6	9498	51	3928	21	3469	19	280	2	359	2
Norwell	13133	630	5	9141	70	2470	19	734	6	144	1	14	0.1
Pembroke	15284	1063	7	9191	60	2846	19	1818	12	183	1	183	1
Rockland	6421	485	8	3534	55	1971	31	221	3	113	2	97	2
Scituate	11281	467	4	4725	42	3686	33	1899	17	80	0.7	424	4
Hingham	14501	583	4	8501	59	4399	30	725	5	72	0.5	221	2
Hull	1738	59	3	250	14	1159	67	82	5	11	0.6	177	10

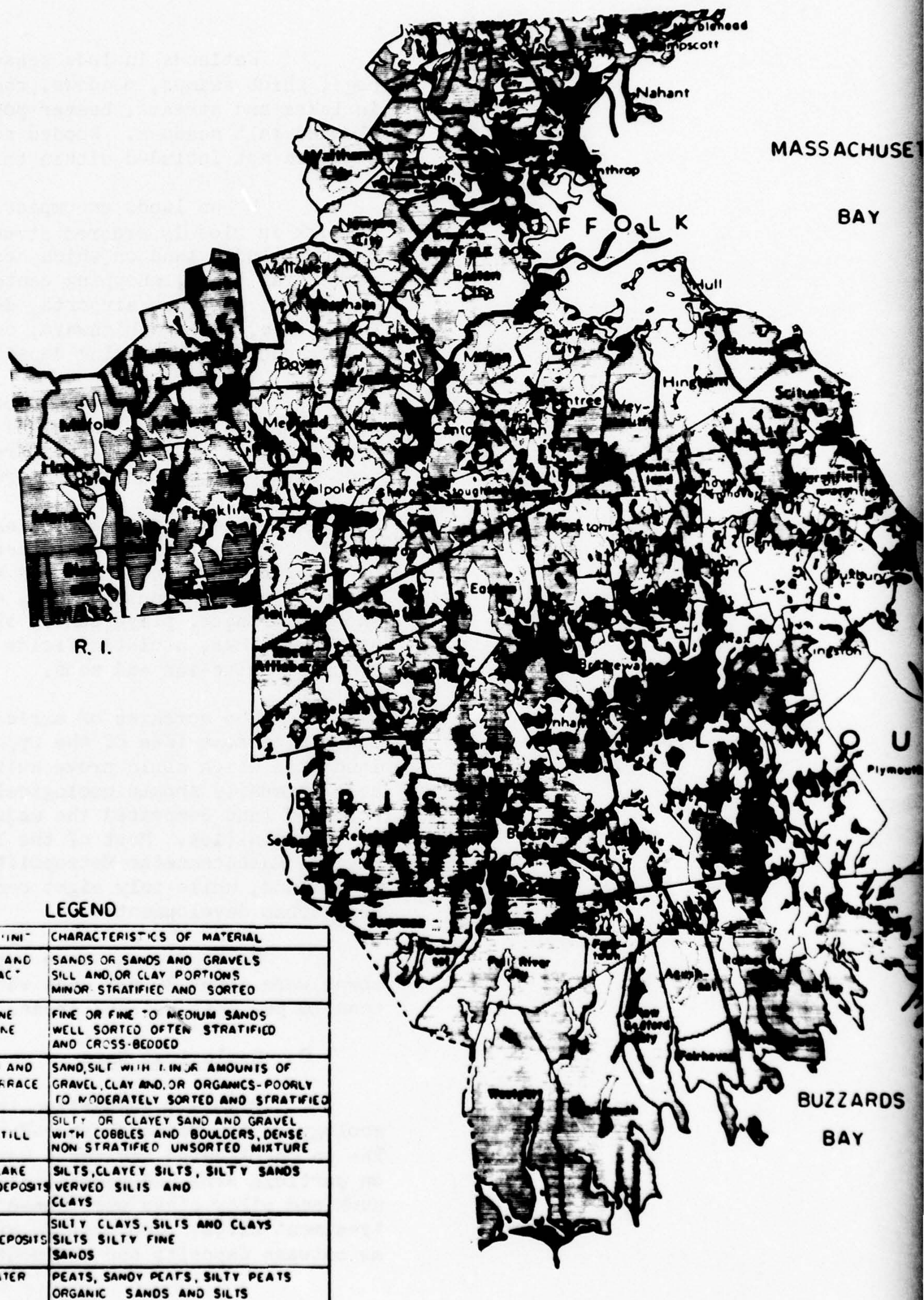
TABLE 4 (CONT'D)

SUFFOLK COUNTY

Community	Total Acreage	Agriculture and Open Land		Forest Land		Urban Land		Wetland		Mining, Waste Disposal Land		Outdoor Recreation Land	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Boston	31244	988	3	2262	7	23907	77	1925	6	262	0.8	1900	6
Chelsea	1604	57	4	0	0	1306	81	203	13	11	0.7	27	2
Revere	4054	193	5	181	4	2487	61	854	21	37	0.9	302	7
Winthrop	1256	25	2	0	0	985	78	74	6	25	2	147	12

WORCESTER COUNTY

Community	Total Acreage	Agriculture and Open Land		Forest Land		Urban Land		Wetland		Mining, Waste Disposal Lands		Outdoor Recreation Land	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Berlin	8435	1625	19	5736	68	542	6	332	4	172	2	25	0.3
Bolton	12755	2366	19	8923	70	880	7	281	2	51	0.4	246	2
Milford													
Northborough	11981	1963	16	6999	58	2179	18	442	4	98	0.8	300	3
Southborough	8814	1146	13	4917	56	1543	17	1048	12	6	-	159	2
Westborough	13766	2814	20	6982	51	2731	20	1008	7	106	0.8	185	0.9



LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
CORSE-GRAINED SOILS	Qsc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS OR SANDS AND GRAVELS SILT AND/OR CLAY PORTIONS MINOR STRATIFIED AND SORTED
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	FINE OR FINE TO MEDIUM SANDS WELL SORTED OFTEN STRATIFIED AND CROSS-BEDDED
	Qec	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT WITH MINOR AMOUNTS OF GRAVEL, CLAY AND/OR ORGANICS - POORLY TO MODERATELY SORTED AND STRATIFIED
	Qtc	GLACIAL TILL	SILTY OR CLAYEY SAND AND GRAVEL WITH COBBLES AND BOULDERS, DENSE NON STRATIFIED UNSORTED MIXTURE
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, CLAYEY SILTS, SILTY SANDS VERVED SILTS AND CLAYS
	Qmf	MARINE DEPOSITS	SILTY CLAYS, SILTS AND CLAYS SILTS SILTY FINE SANDS
	Qef	FRESH-WATER ORGANIC DEPOSITS	PEATS, SANDY PEATS, SILTY PEATS ORGANIC SANDS AND SILTS "MUCK"
	Qem	MARINE ORGANIC DEPOSITS	ORGANIC SILT, CLAYEY ORGANIC SILTS, ORGANIC SANDS MARSH MATS, "OOZE"

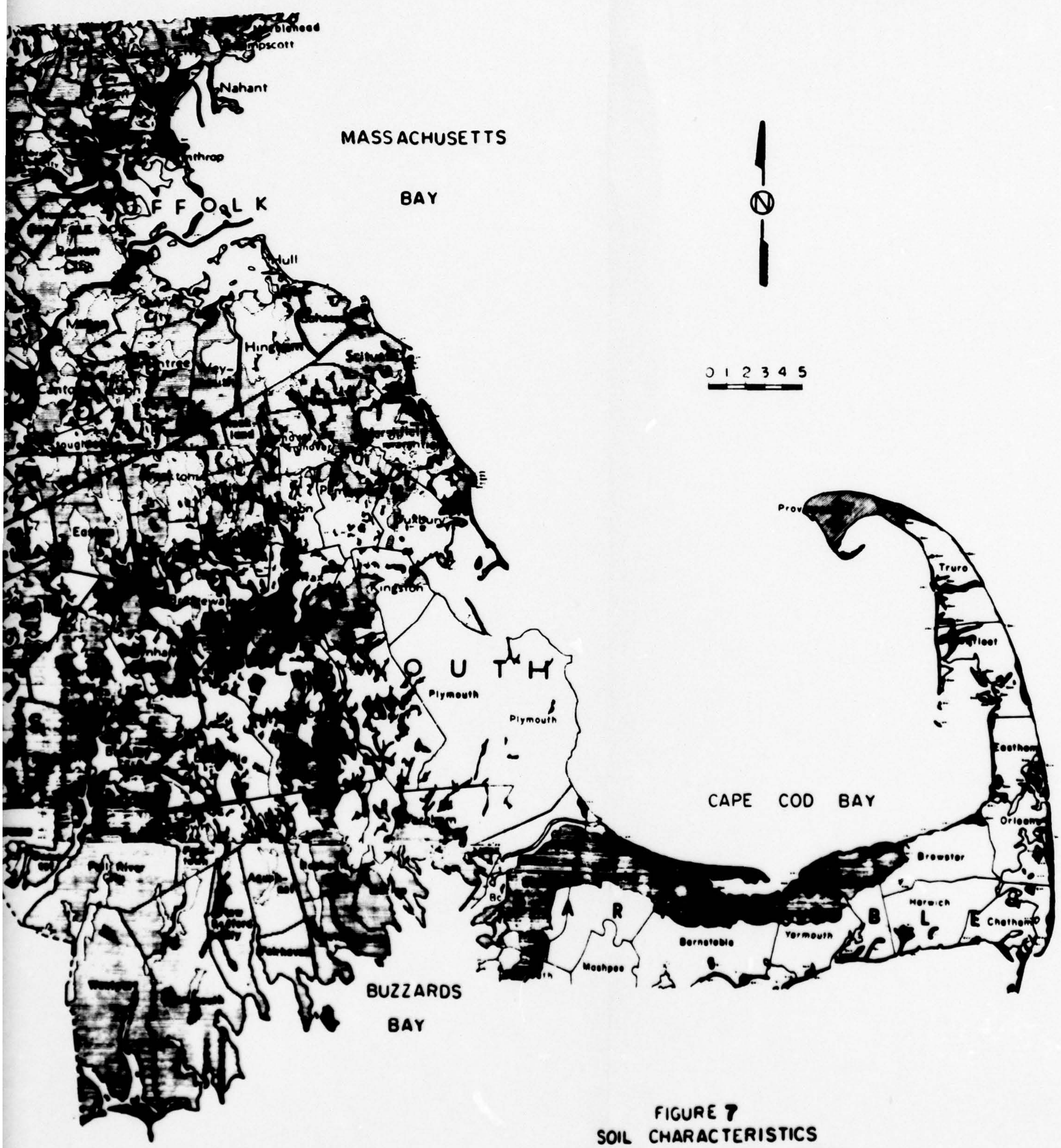


FIGURE 7
SOIL CHARACTERISTICS
OF LAND APPLICATION SITES
FOR BH-EMMA WASTE MANAGEMENT PLAN

Wetlands include seasonally flooded basins of low-lying lands, bogs, shrub swamps, meadows, shallow and deep marshes, fresh open water in lakes and streams, beaver ponds, tidal salt marshes, and irregularly flooded salt meadows. Wooded swamps were delineated as forested areas and were not included within this land use grouping.

Urban lands encompass those land areas on which people live or work in closely ordered structures in confined land spaces. This group includes land on which heavy and light industrial practices occur, commercial lands, shopping centers, schools, colleges, churches, state hospitals, prisons, airports, docks, warehouses, railroads and associated facilities, divided highways, cemeteries, and residential lands with dispersed to high housing densities.

Mining or waste disposal areas in the basin are those lands used for sand, gravel and stone excavation, solid waste disposal, automobile dumps, and wastewater treatment facilities which use sand filter beds as a part of the sewage treatment process.

Outdoor recreation lands are those land areas and associated access roads, parking facilities, buildings, and related facilities used for recreational pursuits associated with marinas, sandy beaches, swimming pools, tennis courts, golf courses, driving ranges, skeet shooting ranges, playgrounds, ski areas, and spectator recreation such as race tracks, athletic fields and stadiums, amusement parks, fairgrounds, drive-ins and zoos.

The acreages of agricultural and open land as well as forested lands give some idea of the upper limit of the potentially available land area which could prove suitable for a land treatment system within each community should geological and soil considerations prove favorable. Forested land comprised the major portion of the non-urban land use in most communities. Most of the 109 communities in the Boston Harbor-Eastern Massachusetts Metropolitan Area had greater than 30 per cent urban land, while only eight communities consisted of less than 10 per cent urban development.

Wetland areas were variable among the communities. Coastal towns were about 30 per cent wetlands while inland communities had less than 10 per cent wetland areas.

C. Geological Data

Figure 7 summarizes the type and distribution of the surficial geology of the Boston Harbor-Eastern Massachusetts Metropolitan Area. The unconsolidated sediments were subdivided into different units based on particle size and genetic classification. Areas underlain by peat, muck and silty clays were immediately removed from consideration as land treatment sites. Conversely, areas of stratified sand and gravels such as outwash deposits and ice contact deposits were easily recognized and flagged for further investigation as highly probable sites for rapid infiltration and possibly spray irrigation, using special management practices. Large areas mapped as glacial till were suitable for spray irrigation where slope and land use permitted. Till areas were not suitable for rapid infiltration due to the low vertical permeability. A more complete discussion with additional maps covering the geological aspects of the study area may be found in Appendix A to this report.

The quantity of secondary effluent which could be applied to agricultural or forested lands for renovation without adversely affecting crop growth is closely aligned with soil properties of the application sites and crops to be grown. The extent of each soil series in the study area was obtained where possible from the U.S. Department of Agriculture Soil Conservation Service.

Each soil series was evaluated according to its suitability for land treatment using spray irrigation or rapid infiltration on the basis of: soil depth, flooding frequency, longevity of high water table, permeability, slope, stoniness and drainage.

1. Soil Depth

Soils for spray irrigation must be at least five feet deep without a perched or seasonal high water table. Soils with impermeable horizons, "pans", were considered suitable for spray irrigation provided the application rate was adjusted for the presence of the pan horizon.

Primary sites for rapid infiltration were those 20-30 feet above the underlying water tables and surrounding lowland or wetland, with a saturated thickness below these sites of 20-30 feet. Distance from application area to slope of the application area was +200 feet.

2. Flooding

Flood plain soils subject to annual or frequent flooding were not considered for either spray irrigation or rapid infiltration.

3. Water Table

Soils with water tables within five feet of the ground surface for less than four months of the year were considered plausible for spray irrigation if an underdrain system could be installed in order to maintain a three-foot unsaturated root zone throughout the growth season. Soils with water tables within five feet of the surface for more than four months were either not considered or given special management considerations.

The water table beneath rapid infiltration areas should be 20-30 feet below the application surface. Vertical and horizontal movement of applied water should not be restricted by an impermeable layer nor should application result in the water table rising to the treatment bed surface.

4. Permeability

Soils considered for spray irrigation had moderate to moderately rapid hydraulic permeability (0.63-6.3 inches per hour). Soils which were very permeable (+6.3 inches per hour) were believed suitable for spray irrigation providing the application rate and frequency were adjusted to keep nutrients within the root zone.

Soils for rapid infiltration sites had moderately rapid to very rapid permeabilities (2.0 to +6.3 inches/hour).

5. Slope

Spray irrigation sites should have a slope less than 15 per cent. Rapid infiltration sites would require grading to level slope.

6. Soil Texture

Soils for spray irrigation sites were those with fine sandy loam to silt loam surface horizon with similar horizons through the underlying strata. Soil series belonging to the above classes but which have varying amounts of stoniness would require special management considerations. Soils of potential rapid infiltration sites were sandy gravel or gravelly sand throughout the path of effluent travel.

7. Stoniness

Where row crops and soil tillage were not integral to the management operation, stones should not be a deterrent since surface stones would be removed during site preparation for spray irrigation. Where underdrains were necessary to maintain the unsaturated root zone, very stony and extremely stony soils could create installation problems and thus should be avoided where possible.

Stones should not present a problem in the rapid infiltration sites. Even so, stones should not comprise a major portion of the surface horizon. Deep alluvial sandy gravels and gravelly sand terraces along streams and rivers would be ideal.

8. Drainage

Moderately well to well drained soils with groundwater tables which can be maintained below the three-foot depth were acceptable for spray irrigation sites. Rapid infiltration sites should not have groundwater problems.

Soils suited for spray irrigation or rapid infiltration are summarized in Table 5. Soils for rapid infiltration may be used for spray irrigation if wastewater applications are adjusted to the water-holding capacity and permeability of the soil. Some low lying very permeable soils could prove practical for spray irrigation by similar adjustment, although they would be marginal for rapid infiltration. Some soils were classified as moderately suitable for spray irrigation because they may require special management considerations. For example, Bernardston, Essex, and Paxton soils have pan layers at depths of 10-30 inches, which may affect periodicity of the effluent applications. Soils with surface stones would require grooming to permit operation of field equipment and installation of application apparatus. If stones were found throughout the plow layer, these soils may be limited to a forage operation depending upon the degree of stoniness and its affect on cultivation practices.

Surficial geology data as well as bedrock and groundwater information were used in conjunction with land use to select land sites for land application. Maps prepared from this information were compared and commonly superimposed over one another. Areas which appeared visible through "windows" after the constraints and criteria inherent in the various maps were satisfied were selected as potential sites. These were then discussed at public workshops to obtain first hand information concerning future development.

Land areas in the Boston Harbor-Eastern Massachusetts Metropolitan Area suited for either spray irrigation and/or rapid infiltration are depicted in Figure 8. The preponderance of potential areas were found in the southwestern portion of the Boston Harbor-Eastern Massachusetts Metropolitan Area. Some spray irrigation and rapid infiltration sites were found in coastal communities north and south of Boston Harbor. Several spray irrigation sites were larger than 300 acres in extent, but for the most part potential spray irrigation sites were less than 300 acres and rather fragmented. Only a few small rapid infiltration sites less than 100 acres were found within the Boston Harbor-Eastern Massachusetts Metropolitan Area.

Each site was carefully studied before assigning it for land application use. In addition to geological and soil considerations, other constraints also had to be satisfied. To safeguard public health, a buffer zone of 1,000 feet was placed around all known points of human habitation to prevent any drift or carryover of aerosol spray from the land application site from reaching the inhabited area. Buffer zones of 200 feet were placed next to all public roads and particular care was taken to avoid any possibility of contaminating water supplies or bodies of water used for recreation or water supply.

Although a certain amount of arbitrary judgment was employed in selecting land application sites, every effort was made to not include those sites which could adversely affect unit area development

TABLE 5

SOILS SUITABLE FOR WASTEWATER MANAGEMENT

Spray Irrigation	Rapid Infiltration 1/
Highly Suitable	
Brookfield	Enfield
Canton	Hinckley
Carver	Merrimack
Charlton	
Enfield	
Hartland	
Melrose	
Newport	
Suffield	
Moderately Suitable	
Agawam (W)	Quonset
Bernardston (P) (W)	Windsor
Broadbrook (W)	
Buxton (D)	
Colona	
Essex (P) (S)	
Gloucester	
Hartland	
Millis	
Paxton (P) (S)	
Poquonock (W)	
Plymouth	

W - Manageable seasonal high water table
P - Pan usually 18" - 30" deep
D - Drainage slowly permeable subsoil
S - Stones
1/- Soil series moderately suited for spray irrigation by adjusting the application

POTENTIAL LAND APPLICATION SITES
EASTERN MASSACHUSETTS METROPOLITAN AREA

FIGURE 8

costs. For example, areas less than 100 acres in size and located more than 2,000 feet from the nearest complex center were usually excluded from consideration. In general, sites were chosen which were sparsely populated, forested, of suitable size, and as close together as possible.

Land utilization factors selected for spray irrigation and rapid infiltration sites are 0.7 and 0.5, respectively. These factors represent the ratio of the area receiving the applied flow to the gross area available for land application. In the case of spray irrigation, some land is lost because of the inability of circular spray patterns to completely cover the surface area without undesirable overlapping. Spray irrigation can be carried out without much site development although land slopes exceeding 10 to 15 per cent are undesirable and may require some preparation.

Because rapid infiltration sites are flooded during land application, a certain amount of site preparation is usually required to make them hold water at a uniform depth. Some useful land must necessarily be lost to berm construction and roadways, while steep or heavily forested areas may have to be by-passed.

Spray irrigation facilities would be designed on a modular basis. The requirements for each particular module would vary somewhat, however, in general they would consist of: (1) a distribution network of pipes laid over the ground from the storage lagoon to the module, and (2) revolving sprinklers set on riser pipes at periodic intervals on the distribution network. The maximum radius or throw of the sprinkler discharge would be about 120 feet and require pressures at the nozzle on the order of 100 pounds per square inch. Because of such high pressures, it may be necessary to set up small booster pumps within the distribution network.

A system of electrically controlled valves having automatic timers would allow applications to be made to different sections of the land application site at different times. Pumps supplying flow to the sprinklers would be controlled by timers since continual sprinkling will not be necessary. The sprinklers would have a trajectory of about 21 degrees to minimize aerosol spray effects. The total pattern of spray application around a given sprinkler would have a diameter of 240 feet. In order to cover evenly as much of the site as possible some overlapping of the spray patterns would take place. The area covered by one spray nozzle is about one acre.

The use of a flexible, easily dismantled piping system will enable harvesting of grass or alfalfa crops should such vegetation be grown to increase nutrient uptake and removal.

Spray irrigation would be employed during the summer months to the maximum extent that spray irrigation land is available. During the winter months, these facilities would not be used; only rapid infiltration would be employed. This method of operation would eliminate the need for large areas of land for storage facilities.

A typical rapid infiltration system consists of a pumping station and shallow basins into which flow is pumped at intervals. The basins are charged with flow to the desired depth, then allowed to stand until the next application. The applied liquid percolates through the highly drainable soil. Following 14 days of application, a rest period of 7 days is allowed to allow the soil to digest the organic matter and restore the soil to a more drainable character.

Because of their ability to accept daily applications without appreciable effect on their performance even during cold weather, the rapid infiltration basins would be used during the winter months when spray irrigation would not be used.

D. Application Areas Required

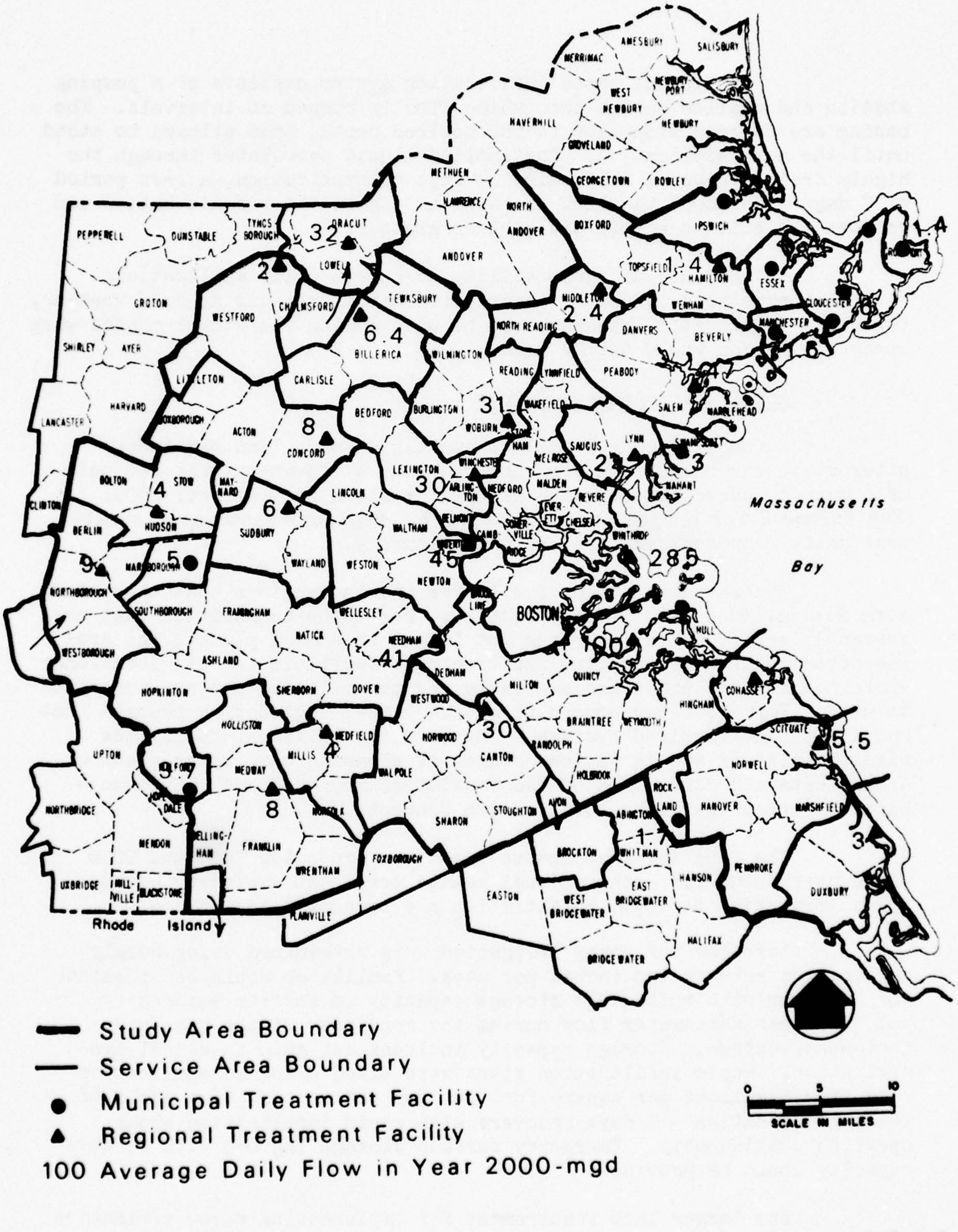
Acreages required for implementation of a land treatment alternative was calculated for each regional wastewater treatment unit or community based on projected wastewater flows for the year 2000. (See Volume 2 for projection methodology). Regional wastewater treatment units proposed here are shown in Figure 9.

The waste treatment facilities and the regions that they serve were determined by two primary factors. For those communities that are currently served by the Deer and Nut Island treatment plants, the area was decentralized by locating new treatment facilities at six locations where a discharge point was available and the existing interceptor could be used. For the other communities, the latest engineering reports that had identified required systems. Many of the treatment facilities already exist or are in various stages of planning and implementation. A more detailed discussion of the facilities may be found in Volume 4 Water-Oriented Wastewater Utilization Concepts.

The land areas needed to treat the projected 2000 and 2050 wastewater flows for each regional sewage treatment system by either spray irrigation or rapid infiltration are presented in Table 6.

Acreages for spray irrigation were determined using weekly application rate of two inches per week. Facilities would be operated for 26 weeks with sufficient storage capacity in surface lagoons to hold 30 weeks wastewater flow during the remainder of the year and inclement weather. Storage capacity includes net gain in annual precipitation. Rapid infiltration sites were sized using an application rate of 2.5 gallons per square foot per day and an operation cycle of 14 days inundation - 7 days recovery with rapid infiltration areas operated continuously. Emergency surface storage lagoons with 14 days capacity would be provided.

The larger land requirement for implementing spray irrigation stems from the smaller application rate and storage of wastewater flows during winter months and inclement weather which must be applied during favorable operating conditions.



BH-EMMA Wastewater Management Study
New England Division Corps of Engineers

Figure 9 Proposed Regional Sewage Treatment Configuration

TABLE 6
Land Requirements to Treat Projected 2000 and 2050 Wastewater Flows
by Spray Irrigation or Rapid Infiltration

Regional STP	Communities Served	Wastewater Flows 2000 (mgd)	Wastewater Flows 2050 (mgd)	Spray Irrigation: Spray Area Acres 2000	Spray Irrigation: Spray Area Acres 2050	Spray Irrigation: Lagoons Acres 2000	Spray Irrigation: Lagoons Acres 2050	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2000	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2050
Billerica		6.4	12	1732	3247	223	418	118	221
	Billerica								
	Carlisle after 2000								
Canton	Canton	30	43	8118	11636	1046	1499	552	791
	Norwood								
	Sharon								
	Stoughton								
	Walpole								
	Westwood								
N. Chelmsford		2.1	9.3	568	2517	73	324	39	171
	Chelmsford (part)								
	Littleton (part)								
	Westford								
Cohasset		2.0	4.4	541	1191	70	153	37	81
	Cohasset								
	Scituate (part)								
Concord	Acton	8.3	23	2246	6224	289	802	153	423
	Boxborough after 2000								
	Concord								
	Littleton (part)								
	Maynard								
Dedham	Ashland	41	59	11095	15966	1430	2057	255	1086
	Dedham (part)								
	Dover after 2000								
	Framingham								
	Hopkinton								
	Natick								
	Needham								
	Sherborn after 2000								
	Southborough								
	Wellesley								

TABLE 6 (CONT'D)

Regional STP	Communities Served	Wastewater Flows 2000 (mgd)	Wastewater Flows 2050 (mgd)	Spray Irrigation: Spray Area Acres 2000	Spray Area Acres 2050	Lagoons Acres 2000	Lagoons Acres 2050	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2000	Acres 2050
Deer Island	Belmont (part) Boston (part) Brookline (part) Cambridge Chelsea Everett Lynnfield Malden Medford (part) Melrose Milton (part) Revere Somerville Stoneham (part) Wakefield (part) Winthrop	285	305	77125	82537	9938	10636	5244	5612
Essex	Essex	0.4	2.1	108	568	14	73	7	39
Gloucester	Gloucester (3 plants)	5.8	7.9	1570	2138	202	275	107	145
Hamilton	Hamilton Topsfield Boxford after 2000 Wenham after 2000	1.4	5.3	379	1434	49	185	26	98
Hudson	Hudson Bolton after 2000 Stow after 2000	3.9	11	1055	2977	136	384	72	202
Hull	Hull	1.0	1.3	271	352	35	45	18	24
Ipswich	Ipswich	2.4	4.6	649	1245	84	160	44	85
Lowell	Tewksbury Chelmsford (part)	Out of Study Area See Merrimack Study							
Lynn	Lynn Nahant Saugus	24	23	6495	6224	837	802	442	423
Manchester	Manchester	1.6	2.7	433	731	56	94	29	50

TABLE 6 (CONT'D)

Regional STP	Communities Served	Wastewater Flows 2000 (mgd)	Wastewater Flows 2050 (mgd)	Spray Irrigation: Spray Area Acres 2000	Spray Irrigation: Spray Area Acres 2050	Spray Irrigation: Lagoons Acres 2000	Spray Irrigation: Lagoons Acres 2050	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2000	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2050
Marlboro (E)	Marlboro (part)	4.8	7.1	1299	1921	167	248	88	131
Marlboro (W)	Berlin after 2000 Marlboro (part) Northborough Shrewsbury Westborough	9.3	25	2517	6765	324	872	171	460
Marshfield	Marshfield Duxbury after 2000	3.0	8.4	811	2273	105	293	55	155
Medfield	Medfield Millis Norfolk (part) after 2000	4	11	1082	2977	139	384	74	202
Medford	Arlington Bedford Belmont (part) Lexington Medford (part) Winchester (part)	30	32	8118	8660	1046	1116	552	582
Medway	Franklin Medway Bellingham (part) Holliston Norfolk (part) after 2000 Wrentham	8	23	2165	6224	279	802	147	423
Middleton	North Reading Middleton	2.4	6.1	649	1651	84	213	44	112
Milford	Milford	3.7	4.9	1001	1326	129	171	68	90
Nut Island	Boston (part) Brookline (part) Braintree Dedham (part) Hingham Holbrook Milton (part) Newton (part) Quincy Randolph Weymouth	100	110	27061	29767	3487	3836	1840	2024

TABLE 6 (CONT'D)

Regional STP	Communities Served	Wastewater Flows 2000 (mgd)	Wastewater Flows 2050 (mgd)	Spray Irrigation: Spray Area Acres 2000	Spray Irrigation: Spray Area Acres 2050	Spray Irrigation: Lagoons Acres 2000	Spray Irrigation: Lagoons Acres 2050	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2000	Rapid Infiltration 0.33'/day at 14 days wet-7 days dry Acres 2050
Rockland	Rockland	1.7	2.7	460	731	59	94	31	50
Rockport	Rockport	1.4	2.7	379	731	49	94	26	50
Scituate	Hanover Norwell Pembroke Marshfield (part) Scituate (part)	5.5	15	1488	4059	192	523	101	276
SESD	Beverly Danvers Marblehead Peabody Salem	47	47	12719	12719	1639	1639	865	865
Sudbury	Sudbury Wayland	5.9	16	1597	4330	206	558	109	294
Swampscott	Swampscott	3.2	4.0	866	1082	112	139	59	74
Watertown	Lincoln Newton (part) Waltham Watertown Weston	45	51	12178	13801	1569	1778	828	938
Woburn	Burlington Reading Stoneham (part) Wakefield (part) Wilmington Winchester (part) Woburn	31	34	8389	9201	1081	1186	570	626

To determine whether sufficient acreage of suitable lands (agricultural, open and forested lands) were available to treat the projected 2000 wastewater flows, a comparison of data in Tables 4 and 6 was made. Most communities within the study area, particularly those less urbanized communities outside of Route 128, had substantial acreages of agricultural, open, or forested lands. Total agricultural and open lands reported were found in small units, usually less than 50 acres in size. Forested lands included areas where productive agriculture had been difficult to pursue, or were lands which had once been good agricultural lands but had been permitted to revert back to a forest cover. Soils in these and other forested areas lent themselves suitable to agricultural pursuits but remained forested for other reasons. Evaluation of the soils and geologic information for forested areas proved many forested areas were acceptable for land application, however, the acreage available was insufficient for projected flows for many of the regional wastewater treatment units. In those instances where projected 2000 flows were less than 3.0 million gallons per day (mgd), land treatment within the region was possible.

Of the 109 communities, only seven communities belonging to three regional wastewater treatment systems have the opportunity to implement land application within their region; 1) Hamilton, Boxford, Tospfield, Wenham; 2) Ipswich, 3) Middleton, North Reading. The Hamilton regional treatment units had adequate lands to implement spray irrigation or rapid infiltration while the other two regions had sufficient acreage suited to rapid infiltration.

The remaining regional units in the Boston Harbor-Eastern Massachusetts study area were either too highly urbanized with large wastewater flows or were less populated communities with lands not suited for wastewater treatment according to the design criteria used here. In either case, the projected 2000 effluent flows from the regional treatment facilities were too large to receive treatment using the lands identified within the regional sewage treatment units. For this reason, suitable lands outside the regional treatment configuration and the Boston Harbor-Eastern Massachusetts Metropolitan Study Area were evaluated as to their plausible use for either the spray irrigation or rapid infiltration-land treatment method.

Land areas west of the Nashua and Blackstone River Basins within Massachusetts were evaluated for availability of suitable land application areas using procedures described above. Initial investigations revealed some 21,000 acres, well-suited for land treatment, were available in the Connecticut River Basin; 16,800 acres for spray irrigation and 4200 acres for rapid infiltration. These areas could treat about 55 mgd using spray irrigation techniques and about 228 mgd by rapid infiltration for a total of some 263 mgd.

Additional renovation capacity could be provided by including sites less than 50 acres that were clustered near each other or near larger potential treatment sites. This would increase the total volume of wastewater effluent that could be treated to around 340 mgd. For a more detailed explanation of site identification in western Massachusetts, see Appendix B.

Potential spray irrigation and rapid infiltration treatment sites in the southeastern Massachusetts were identified using the methodology described above. Sites lending themselves to land treatment totaled approximately 49,200 acres; 35,500 for spray irrigation and 12,700 for rapid infiltration. Using application rates and operations cycles proposed here, this acreage could receive about 116 mgd by spray irrigation sites and 690 mgd using rapid infiltration for a total of about 800 mgd.

Total wastewater flows generated in the Boston Harbor-Eastern Massachusetts Study were projected to be about 721 mgd by the year 2000. Much of this projected wastewater flow should remain within the study area to maintain stream flow or be discharged to the ocean. Diversion of wastewater flows from the Sudbury-Assabet-Concord River Basin (SUASCO) could have serious impact upon the stream flow and aquatic environment. This would be especially critical during low flow periods if the projected 2000 effluent flows, about 38 mgd, for the six regional treatment facilities (Billerica, Concord, Sudbury, Hudson, Marlborough (east and west),) in the SUASCO Basin were diverted outside the Basin. This volume would be greater than the 7-day, 10-year low flow in the Concord River at the confluence with the Merrimack River at Lowell, Massachusetts (Figure 3).

Similarly, diversion of some 16 mgd by the year 2000 from the upper Charles River Basin; Milford, Medway, and Medfield, STP would cause negative impacts to the aquatic environment stemming from reduced stream flow. (See Volume 13 for assessment of environmental impacts).

Future urban growth in these river basins will undoubtedly lead to additional demands for municipal and industrial water supplies which could be provided by these streams. In order to meet these demands with high quality water, wastewaters discharged to these streams should be renovated beyond conventional secondary treatment to safeguard public health and enhance the aquatic environments in the receiving streams.

Chemical analysis of the wastewater flows to the Deer and Nut Island treatment facilities show a substantial proportion of these flows are made up of sea water (34). Because of hazards to crop production, soil properties and groundwater quality beneath land treatment sites, treatment of saline wastewater effluents on the land is not a practical consideration. Calculations using "typical" secondary effluent quality (39) and "normal sea water" show that land treatment of wastewater effluents should not be considered where sea water comprises one percent or more of the wastewater flow.

For this reason, land treatment of some 466 mgd, from the regional wastewater treatment plants proposed, under construction or on-line at; Salem, Lynn, Deer Island, Nut Island, Hull, Swampscott and Marshfield (part) was not proposed here. This decision was based upon the belief that collection and transmission lines within the tidal zone are subject to salt water infiltration or direct inflow and that the resulting wastewater salinity would be hazardous it applied to the land. Further analysis of the sea water inflow problem is warrented. However, data available at this time shows that without preventive measures, sea water will make the effluent unsuitable for land treatment.

Sufficient land areas suited to land treatment in the Canton, Dedham, Medford, Watertown or Woburn regional wastewater treatment units were not found. But, because the quality of some of the effluent following conventional activated sludge secondary treatment was believed adequate for land treatment, diversion of effluent to areas outside of these regional units is proposed.

The impacts to the aquatic environment were not believed as crucial a consideration in this area as diversions from other river basins since wastewater flows from all or most of the area included within the five regional units are now directed to either the Deer or Nut Island treatment facilities where effluent is discharged into Boston Harbor. Projected wastewater flows totaling 177 mgd from the 29 communities serviced by these five regional treatment facilities would be diverted to outside areas. (Figure 9).

Potential land treatment sites in the Connecticut River Basin were sufficient to treat the approximate 180 mgd of effluent, however, several important factors constrain this alternative:

1. Sites identified in the Connecticut River Basin in Massachusetts were rather disjointed and were not found in large contiguous areas. Approximately half of the acreage consisted of areas less than 100 acres and about 15 percent was less than 50 acres in size. Although many potential sites were located adjacent to the Connecticut River, within the Connecticut River Valley and in the south central portion of the state, these potential sites were rather scattered and would require an extensive distribution system (See Appendix B for further discussion).

2. Preliminary cost estimates for transporting the projected wastewater flows to land sites in the western part of the state were shown to be some $70 million greater than costs to transport to southeastern Massachusetts.

Diversion of 180 mgd of wastewater effluent to southeastern Massachusetts proved more economical when compared to initial costs associated with the proposed western Massachusetts diversion. Since the acreages needed for land treatment were similar, major differences between the two areas were primarily those associated costs of the transmission and distribution systems.

The distribution system for the southeastern Massachusetts would be less extensive because of the larger size treatment area and close proximity of treatment sites. Distance over which effluent must be transported was somewhat shorter for the southeastern Massachusetts option which would reduce construction and operation and maintenance costs. Initial cost estimates for these two options revealed substantial differences of some $70 million.

E. Effluent Quality

Effluent quality from activated sludge secondary treatment facilities is dependent, in part, upon the quality of wastewaters furnished to the facility from industrial, commercial and domestic sources. Extensive efforts to describe quantitatively the wastewaters within the Boston Harbor-Eastern Massachusetts Metropolitan Study Area proved to be beyond the scope of this study (12,55). Therefore, it was assumed that current EPA requirements for pretreatment of industrial wastewaters prior to discharge to municipal sewer systems will be enforced and industrial pretreatment will remove excessive trace minerals (heavy metals) and refractory organics so the wastewaters will be compatible with the biological processes of the secondary treatment process.

It was further assumed that the overall management and operation of the activated sludge secondary treatment systems would result in adequate secondary treatment. Effluents from secondary treatment facilities were assumed to be of a quality closely comparable to that proposed for irrigation waters applied for more than 20 years, with respect to trace minerals and refractory organics (Table 7) (19). Concentrations of organic matter measured as COD and BOD, nitrogen, phosphorous, and cations would be comparable to typical secondary effluent (39).

It was assumed that wastewaters with high concentrations of trace minerals (heavy metals) or refractory organics will be treated at the source rather than dischraging to municipal sewage systems for dilution.

No treatment beyond conventional secondary treatment was believed necessary for removing nitrogenous oxygen demand (NOD) or biochemical oxygen demand (BOD), since nitrogenous constituents and organics giving rise to the NOD and BOD will be removed within the land treatment process. From the perspective of crop utilization and soil fixation, it would be more desirable to leave nitrogen in the ammonical form so it would be fixed within the soil and thereby be available over a longer period for crop uptake.

TABLE 7

Maximum acceptable concentration for elements in irrigation waters applied continuously and over a 20-year period

Constituent	Continuous Application	Application for 20-year period
pH (standard units)	4.5-9.0	4.5-9.0
BOD	a/	a/
Al (mg/l)	5.0	20
Ar (mg/l)	0.1	2.0
Be (mg/l)	0.1	0.5
Bicarbonates (mg/l)	a/	a/
B (mg/l)	1.0	2.0
Cd (mg/l)	0.01	0.05
Chlorides (mg/l)	no limit	no limit
Cr (mg/l)	0.1	1.0
Co (mg/l)	0.05	5.0
Cu (mg/l)	0.2	5.0
F (mg/l)	2.0	15.0
Fe (mg/l)	5.0	20.0
Pb (mg/l)	5.0	10.0
Li (mg/l)	2.5	a/
Mn (mg/l)	0.2	10.0
Mo (mg/l)	0.01	0.05
Ni (mg/l)	0.2	2.0
NO_3-N (mg/l)	no limit	no limit
Se (mg/l)	0.02	0.02
Na (mg/l)	a/	a/
Fecal coliforms	1,000/100ml	1,000/100ml
Total Dissolved Solids	2,000-5,000	2,000-5,000
Suspended Solids	a/	a/

a/ Specific concentrations must be set according to soil properties and/or crops grown.

U.S. Environmental Protection Agency. 1973. Proposed Criteria for Water Quality, Volume 1, USEPA, Washington, D.C.(19)

III. PROPOSED LAND WASTEWATER MANAGEMENT ALTERNATIVE

A. General

Land treatment of municipal and industrial wastewater flows offers a viable alternative to the conventional approach to wastewater treatment. Using land treatment strategies, effluents normally discharged from conventional treatment facilities to nearby surface waters would be applied to agricultural and forested areas for further renovation. Effluent nutrients would be used to increase crop growth rather than fertilize our lakes and streams. By pursuing an attitude to recovery-reuse, much of our natural resources needed to produce fertilizers and provide energy for the operation of advanced wastewater treatment processes would be eliminated.

Land treatment is available at cost to those who desire it. These costs include setting aside lands for agriculture and forest pursuits on which houses, factories and stores could be built. Land treatment requires that we change our attitudes concerning wastewater effluents and view it as a resource that can be used to increase agricultural output and cut farm operating expenses, while providing a degree of independence through local production of more of the food consumed within the state. Although overall agricultural production in eastern Massachusetts may not be competative with the major farming areas in the U.S., the desirability to increase production of specific truck garden crops becomes more attractive as food production and transportation costs increase. The significance and potential consequences of a national transportion breakdown also should be considered when looking at land treatment.

This proposal for land treatment of wastewater effluent addresses the 1983 and 1985 water quality objectives of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) by 1) providing an alternative to conventional secondary wastewater treatment facilities and 2) achieving greater wastewater renovation at less cost.

As explained previously, not all wastewater effluents discharged from regional treatment facilities proposed in the Boston Harbor-Eastern Massachusetts Study Area can receive additional renovation using land treatment methods. Effluents from the Hamilton, Ipswich, and Middleton regional treatment facilities can receive renovation using lands within the communities comprising these regional configurations (Figure 10). In the case of the Canton, Dedham, Medford, Watertown, and Woburn regional facilities, additional treatment will be achieved on proposed sites in southeastern Massachusetts. Diversion of these effluents from the study area is not expected to adversely affect stream environs or water supplies.

CONCEPT 5
WASTE MANAGEMENT PLAN UTILIZING LAND APPLICATION

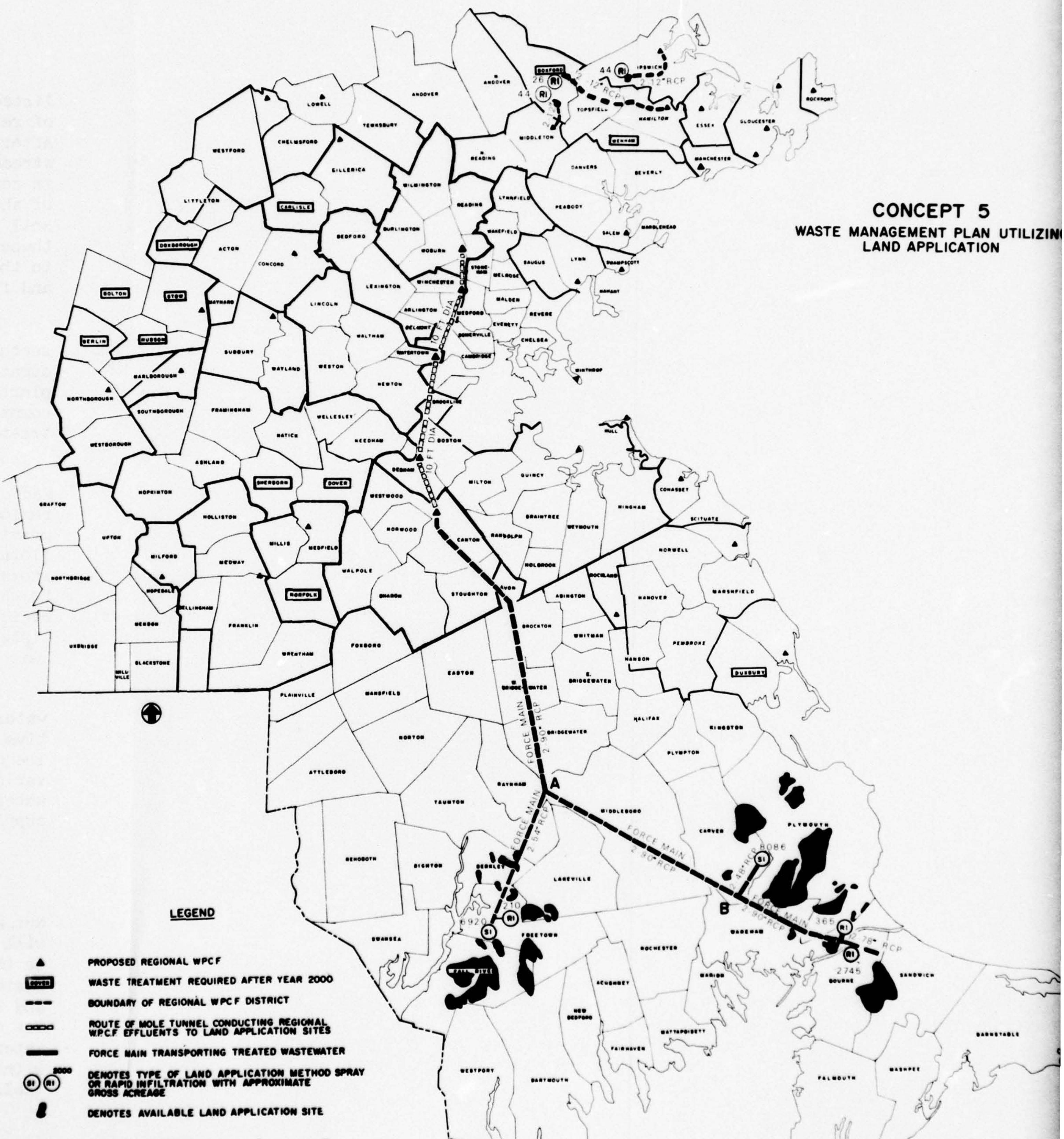


FIGURE 10

Effluents from the remaining 22 regional treatment facilities listed in Table 8 will require additional treatment to achieve a degree of renovation comparable to that anticipated at land treatment sites. After final treatment, effluents will be discharged directly to receiving streams to maintain stream flow or into the ocean. Salinity problems in sewerage systems in which sea water comprises one percent or more of the effluent flow would have serious repercussions to crop growth, soil properties, and groundwater quality if applied to the land. For these reasons, some 466 mgd of wastewater effluents must be discharged to the ocean in order to maintain the integrity of both terrestiral and fresh water aquatic environments. (Table 8).

The schematic of the regional treatment facilities providing secondary treatment as part of the land application systems is illustrated in Figure 11. All wastewater flows to each regional treatment plant would receive secondary treatment consisting of: screening, comminution, grit removal, primary sedimentation, activated sludge treatment followed by final clarification and disinfection.

The sludge from the four regional plants located at Woburn, Medford, Watertown, and Canton will be thickened and pumped to the regional treatment plant located at Dedham. Primary sludges will be gravity thickened and secondary biological sludges will be thickened by flotation. The thickened sludges will be blended and stored in suitable storage tanks at each of the four treatment sites prior to being pumped to the fifth location for further treatment. Sludge at the Dedham regional treatment plant will be vacuum filtered and incinerated in multiple hearth furnaces or steam generation facilities which will permit heat to be recovered.

Figure 11 presents a schematic diagram of the entire wastewater management plan utilizing land application, which include productive reuse of the renovated water and energy recovery from incineration. The diagram traces the pathway of wastewater as it passes through the various treatment steps or phases before ending up either as renovated water that is suitable for selective reuse, or as part of the groundwater supply from which it may be used as a "normal" water source.

B. Design of the Regional Wastewater Treatment Facilities

Proposed regional wastewater treatment facilities were designed to treat wastewater flows for the design year 2000. Allowance will be made for future plant expansion so as to accommodate flows up to the year 2050. Because much of the lands with the Boston Harbor-Eastern Massachusetts Metropolitan Study Area are highly urbanized and land use patterns are well established future wastewater flows are not expected to increase significantly in many cities and towns. Wastewater design flows for all regional water pollution control facilities within the Boston Harbor-Eastern Massachusetts Study are given in Table 6 for the years 2000 and 2050.

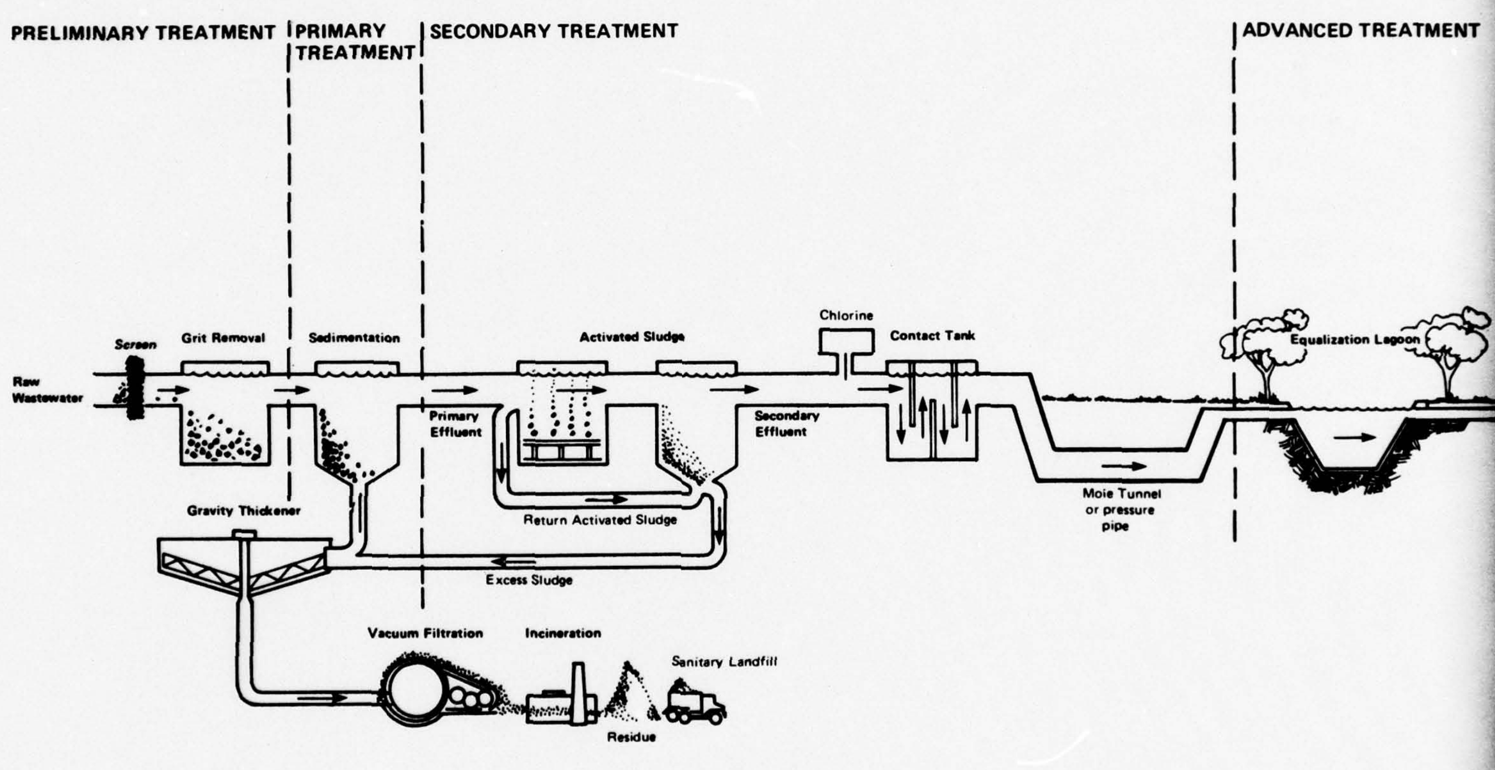
TABLE 8

PROPOSED REGIONAL WATER POLLUTION CONTROL FACILITIES DISCHARGING EFFLUENTS DIRECTLY TO RECEIVING STREAMS OR OCEAN

Billerica (S)	Medfield (S)
Chelmsford (S)	Medway (S)
Concord (S)	Milford (S)
Deer Island (O)	Nut Island (O)
Gloucester (O)	Rockland (S)
Hudson (S)	Rockport (O)
Hull (O)	Scituate (O)
Lynn (O)	SESD (O)
Manchester (O)	Sudbury (S)
Marlborough (West) (S)	Swampscott (O)
Marlborough (East) (S)	

S - Discharge to stream
O - Discharge to ocean

LAND-ORIENTED ADVANCED WASTEWATER TREATMENT



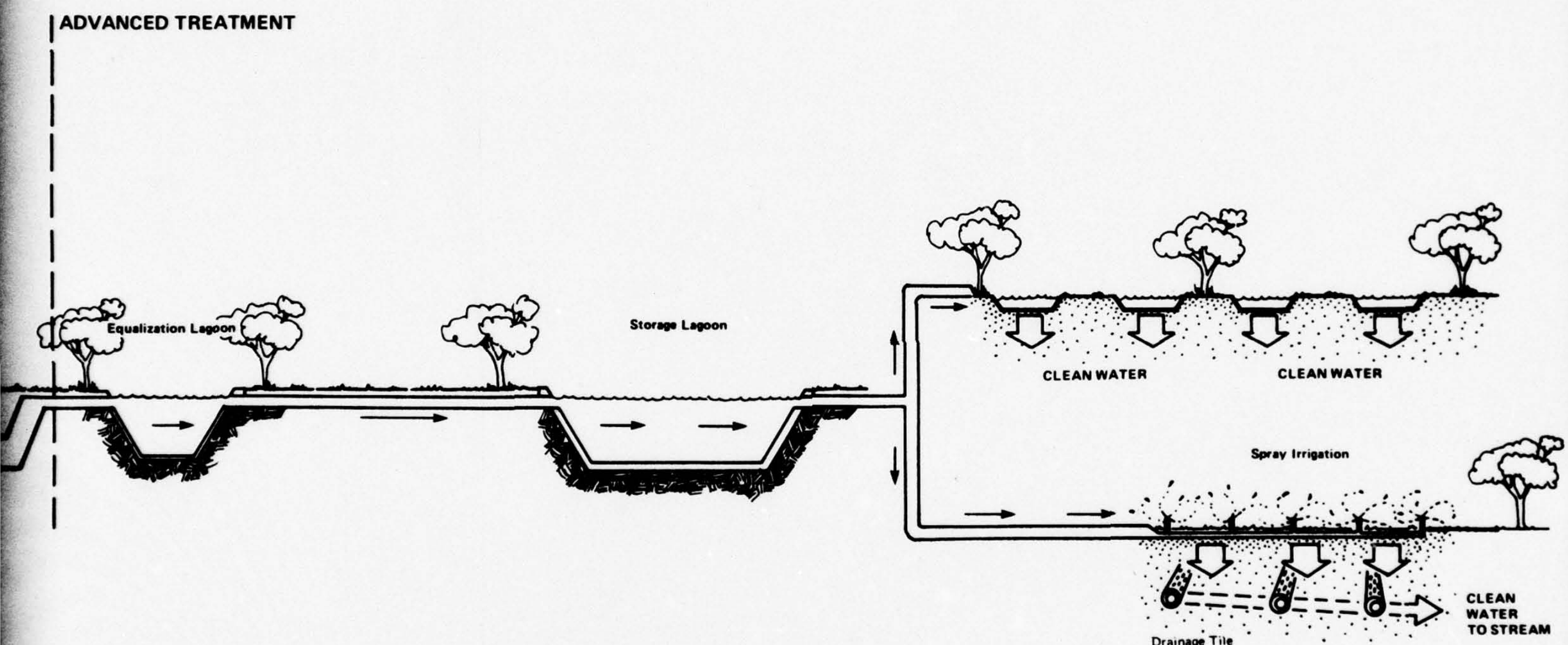


FIGURE II

Land-Oriented Advanced Wastewater Treatment

The activated sludge process consists of biological treatment that employs a sludge which by aeration and agitation, has achieved flocculating and purification properties. The sludge is mixed with raw or previously settled wastewater to form what is known as "mixed liquor." After agitating the mixed liquor in the presence of atmospheric oxygen for a suitable period, the sludge is allowed to settle. The supernatant or process effluent is normally discharged after disinfection, but if higher effluent quality is desired it may receive further treatment. The pollutants in the original wastewater are entrained in the sludge. During the aeration and agitation process, the soluble organic pollutants are metabolized by the bacteria in the sludge floc. Following metabolization, the floc bacteria are ready to receive more wastewater pollutants to continue the purification process. During the time when the sludge is in contact with the waste matter, the bacteria multiply and produce more sludge. The excess sludge over that required to maintain the activated sludge process is drawn off while the remainder is kept and returned to the aeration tanks.

The basic activated sludge process requires from two to eight hours aeration to achieve the necessary treatment. Air requirements range from 0.2 to 1.5 cubic feet per gallon of wastewater with one cubic foot per gallon being the general rule of thumb. Aeration may be provided by air diffusers which are fed air under pressure or by mechanical aerators. The latter may be actuated by dissolved oxygen sensors which are placed in the aeration basins (35).

The basis of design for the treatment plant units listed above is given in Table 9. Because only rudimentary knowledge is available regarding wastewater characteristics, amounts of infiltration, peak flow rates, per capita wastewater production, etc., only nominal design data can be offered. However, these have been carefully chosen on the basis of past experience and numerous other sources, and are considered to reflect realistic and most probable design requirements.

After receiving treatment, the plant effluents will be discharged to a conveyance system which will transport the effluents to the land treatment area.

C. Conveyance System

1. Mole Tunnel System

The effluents from the five regional water pollution control facilities will be conducted to the land application sites in Southeast Massachusetts by means of a mole tunnel system and force mains. The mole tunnel will conduct the effluents from the Woburn, Medford, Watertown and Dedham WPCF's to storage lagoons near the Canton plant. The tunnel will have a circular cross-section and is to be constructed through rock. Because the subsurface strata along the

TABLE 9

DESIGN DATA SUMMARY FOR

REGIONAL WATER POLLUTION CONTROL PLANTS

DESIGN YEAR	2000
WASTEWATER FLOW & QUALITY	
Flow Rate, ADF	Table
Peak Flow Factor	1.7
5-day BOD	240 mg/liter
Suspended Solids	240 mg/liter
DEGREE OF TREATMENT	
Biological Process	Activated Sludge
Overall Removals: BOD_5	90%
Suspended Solids	90%
PRETREATMENT	
Bar Screens Mech. Cleaned	
Size of Openings	3/4 in.
Screenings, per MGD	1 cu. ft.
Disposal	Landfill
Comminutor	
Grit Removal Aeration	
Detention Time	3 min.
Air Supply	6 cfm/ft.
Disposal	Landfill
FLOW MEASUREMENT	Parshall Flume
PRIMARY SETTLING TANKS	
Detention Time @ ADF	2 hours
Overflow Rate @ ADF	900 gpd/sf
AERATION TANKS	
BOD_5 Loading	35 lb/1000 cf
Air Requirements	1000 scf/lb BOD5
Detention Time	6 hours

TABLE 9 (Continued)

FINAL CLARIFIERS	
Center Feed Type with Skimmer	
Detention Time @ ADF	2 hours
Overflow Rate	900 gpd/sf
Minimum SWD	10 ft.
DISINFECTION	
Chlorination	
Detention Time @ Peak Flow	15 minutes
SLUDGE PRODUCTION TOTAL	1.0 TDS/MG
SLUDGE THICKENERS	
Gravity for Primary Sludge	
Overflow rate	400 gpd/sf
Loading	22 lb/sf/day
SWD	15 ft.
Detention time, minimum	6 hours
Flotation, for Waste Activated Sludge	
Loading	15 lb/sf/day
Air to Solids Ratio	0.02
SLUDGE VACUUM FILTERS	
Loading	3.5 lb/sf/hr
SLUDGE INCINERATOR	
Multiple Hearth	
Exhaust Gas Temp.	1400° F.

proposed tunnel route is expected to include random formation of weak and structurally unsound rock such as shale, limestone, and easily fragmented volcanic rock, concrete lining will be provided along the entire route of the tunnel. The tunnel will be of earthquake resistant construction. Figure 12 shows the general route and profile of the tunnel and the locations of the shafts through which treatment plant effluents will be discharged to the tunnel. Table 10 presents a summary of design data for the tunnel which will have a total length of about 100,000 feet.

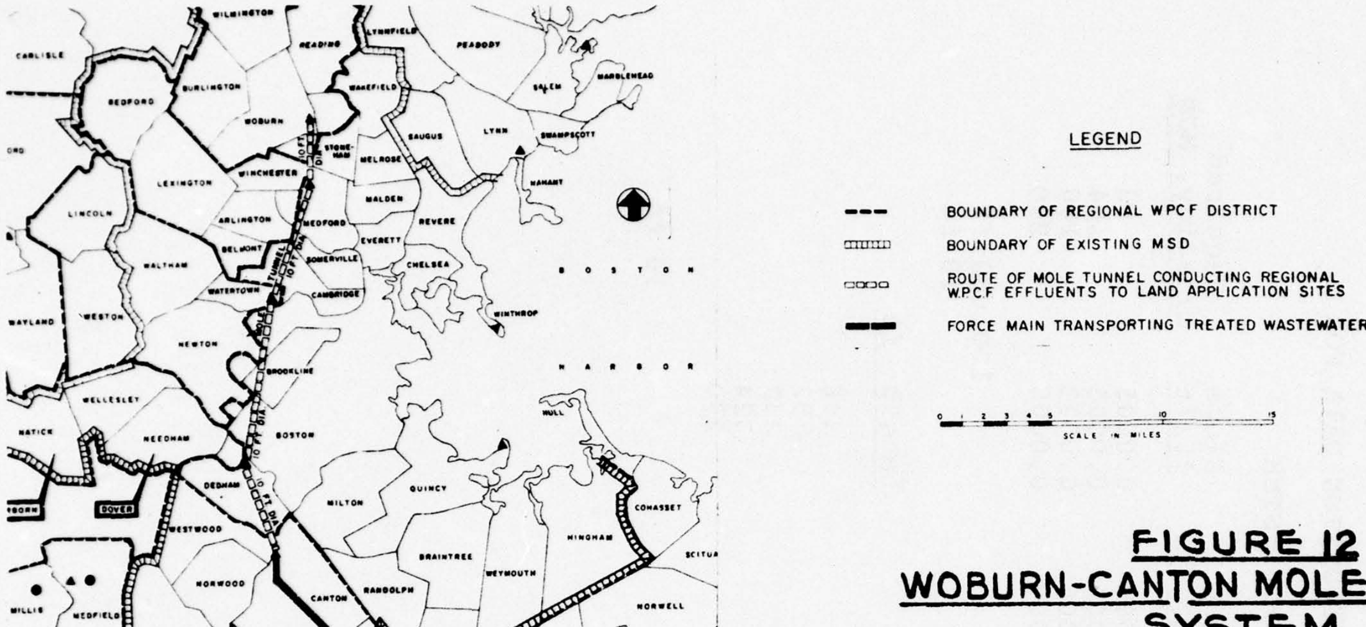
The vertical location of the tunnel was determined from the elevations of possible buried valleys along the alignment route. The tunnel is assumed to be excavated by mole methods except at fault zones where conventional excavation methods will be required. Shaft depths will range from 237 feet to 352 feet, and like the tunnel, will be fully lined.

The treated wastewater will flow down the mole tunnel to a terminus near the Canton WPCF. At this point, the flow will enter the wet well of the tunnel lift station from which it will be pumped to the ground surface into equalizing storage lagoons. Table 11 presents a summary of the Canton tunnel lift station design data and Table 12 presents data related to the design of the equalization lagoons.

The tunnel system is designed to carry the peak flows for the year 2050 at velocities ranging from 6 to 10 fps. A net tunnel diameter of 10 feet was selected to facilitate construction and provide sufficient storage capacity during periods when excess stormwater infiltration occurs. Under normal operating conditions, the tunnel should conduct flows at self-cleaning velocities thereby minimizing solids deposition.

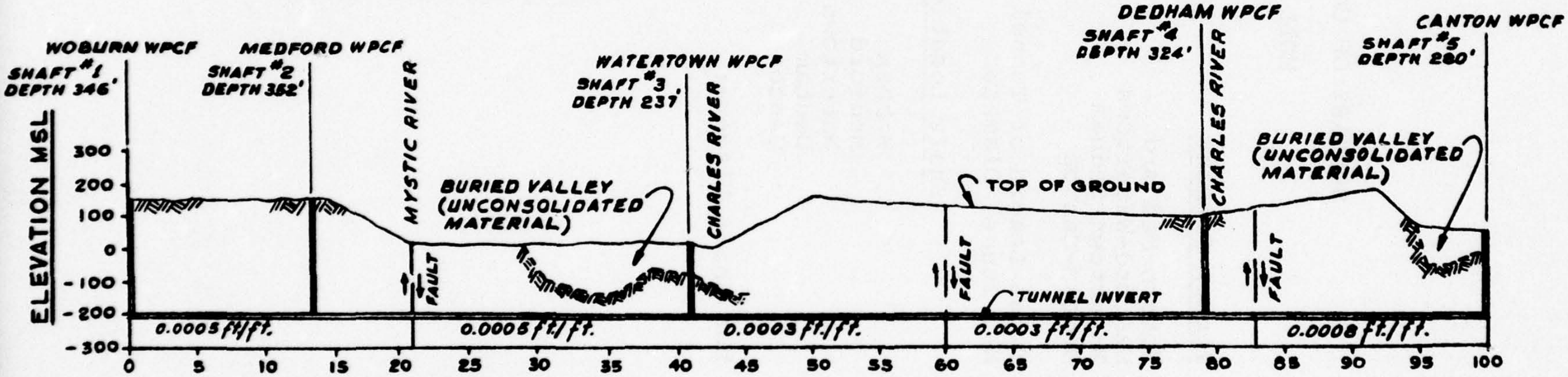
Because of the high flow rates that must be handled and the many difficulties that would be encountered in routing and constructing a gravity sewer conduit near the surface in the metropolitan area, no other alternative to the mole tunnel conveyance system appears to be economically feasible or possess a comparable degree of reliability.

The construction of a mole tunnel will present some problems with regard to disposal of the excavated rock. Moled rock ranges in size from a maximum of four inches down to powder-like particles. Because of the preponderance of the latter, effective utilization of the rock for commerical purposes is impractical. It may be possible to use a portion of the rock for construction, to improve harbors, shoreline protection, breakwaters or public and private landfilling.



LOCATION SKETCH

FIGURE 12
WOBURN-CANTON MOLE TUNNEL SYSTEM



DISTANCE FROM WOBURN IN THOUSAND FEET

TABLE 10

SUMMARY OF CONDUIT DESIGN DATA FOR

MOLE TUNNEL SYSTEM

Tunnel Segment	Approx. Length, ft.	Slope ft/ft	Required Capacity, MGD
Woburn-Medford	13,000	0.0005	53
Medford-Watertown	28,000	0.0005	104
Watertown-Dedham	37,000	0.0003	180
Dedham-Canton	22,000	0.0008	250

Total Length of Tunnel	100,000 ft
Net Tunnel Diameter	10 ft

Shaft Location	Length, ft
Woburn	346
Medford	352
Watertown	237
Dedham	324
Canton	280

Net Shaft Diameter	10 ft

TABLE 11

MOLE TUNNEL LIFT STATION DESIGN DATA

TUNNEL FLOWS		
Average (Yr 2000)		150 MGD
Peak (Yr 2000)		250 MGD
STATIC LIFT, AVG		300 ft
NO. OF PUMPS		3
PUMP CAPACITIES & POWER		
No. 1	150 MGD	5,200 HP
No. 2	250 MGD	8,800 HP
No. 3	100 MGD	3,600 HP
TOTAL STATION HORSEPOWER		17,600
FIRM PUMPING CAPACITY		250 MGD

TABLE 12

DESIGN DATA FOR EQUALIZATION LAGOONS

AT CANTON

STORAGE PROVIDED	3 Days
TOTAL LAGOON VOLUME	900 MG
LAGOON DIMENSIONS:	
No. Lagoons Required	4
Surface Area, each	28 acres
Max. Water Depth	25 feet
Freeboard, Min.	5 feet
Total Dike Height	30 feet
Side Slopes	3:1
Berm Width	15 feet

2. High Pressure Transmission Systems

The effluent destined for land treatment sites in southeast Massachusetts will be transported via a high pressure transmission system from the equalization lagoons at Canton to the principal land application sites located at Freetown, Fall River, Carver, Plymouth, Bourne and Sandwich. Transport to land within the Hamilton, Ipswich and Middleton regional units will be via a 12 inch diameter high pressure system. Figure 10 shows a schematic piping diagram of the high pressure transmission systems to southeast Massachusetts. Table 13 presents a summary of design data for the high pressure transmission systems. Design data for the high pressure pump stations at Canton, Hamilton, Ipswich and Middleton are shown in Table 14.

In general, treated wastewater from the regional water pollution control facilities will be pumped from the equalization lagoons through dual force mains to storage lagoons at the land application sites. The force mains are used in pairs to provide maximum system reliability. The conduits will be placed within the rights-of-way of the public highway system whever possible. State routes 27, 24 and 25 will be used as much as possible. The conduits will be made of reinforced concrete pipe and provided with a minimum cover of three feet for protection against weathering and extreme temperatures. The flows through the piping system will be controlled by a computer at the Canton high pressure pump station. The depth of liquid in the storage lagoons will be relayed via telephone circuits to the computer which will regulate the discharge of flow at the various storage lagoons.

During normal year-round operation, the transmission pump station will pump treated wastewater continuously to the storage lagoons. Sufficient storage will be provided at each principal land application site area so as to minimize fluctuations in the pumping routing. It is believed that the entire pumping opration, including the mole tunnel lift station operation, can be automated to a high degree and that supervision and maintenance costs for the transmission of treated wastewater will probably be the least troublesome part of the entire concept.

To minimize transmission cost, suitable land treatment sites were located as close to treatment facilities as possible. In the case of the Woburn-Medford-Watertown-Dedham-Canton facilities, sufficient land treatment sites, including both spray irrigation and rapid infiltration sites were found in the general vicinity of Fall River-Freetown and Carver-Plymouth-Bourne-Sandwich Massachusetts (Figure 10). A combined total of some 18,700 acres were believed suitable for implementing land treatment systems.

This included some 3320 acres designated for rapid infiltartion and 15,000 acres for spray irrigation. The volume of effluent

TABLE 13

SUMMARY OF DESIGN DATA FOR

HIGH PRESSURE TRANSMISSION SYSTEM

Pipeline Segment	Pipeline* Length ft	Dia in	Design Flow (MGD) Winter	Summer
Canton P.S. to Point A	116,000	90	177	177
Point At to Freetown S.L.	58,000	54	11	53
Point A to Point B	85,000	90	166	124
Point B to Carver-Plymouth	16,000	48	0	62
Point B to Point C	42,000	90	162	62
Point C to Bourne	-	-	20	20
Point C to Sandwich	37,000	78	146	42
Hamilton P.S. to Boxford(North)	35,000	12	1.4	1.4
Ipswich P.S. to Ipswich	26,000	12	2.4	2.4
Middleton P.S. to Boxford(South)	12,000	12	2.4	2.4

* All pipe to be RCP

TABLE 14

DESIGN DATA FOR PUMP STATIONS

	CANTON	IPSWICH	HAMILTON	MIDDLETON
DESIGN FLOWS				
Average (Yr 2000)	180 mgd	2.4 mgd	1.4 mgd	2.4 mgd
Peak (Yr 2000)	300 mgd	4.0 mgd	2.4 mgd	4.0 mgd
TOTAL DYNAMIC HEAD	600 ft	300 ft	200 ft	120 ft
NO. OF PUMPS	3	2	2	2
PUMP CAPACITIES (EACH)		1500 gpm	1000 gpm	1500 gpm
No. 1	150 mgd			
No. 2	200 mgd			
No. 3	350 mgd			
PUMP POWER (EACH)				
No. 1	15,800 hp	120 hp	50 hp	50 hp
No. 2	21,100 hp	120 hp	50 hp	50 hp
No. 3	36,900 hp			
TOTAL STATION HORSEPOWER	73,800 hp	240 hp	100 hp	100 hp
FIRM PUMPING CAPACITY	350 mgd			

which could be treated on acreage was calculated to be about 230 mgd, however, not all of this area would be needed since projected 2000 flows proposed for diversion total about 180 mgd. The specific sites are described more fully in Appendix B.

D. Management of Effluent Application

Prior formulations of land treatment alternatives for renovation of secondary effluent have essentially considered land treatment methods as single operation employing either spray irrigation or rapid infiltration. After careful consideration of their respective advantages and disadvantages, one or the other land treatment methods was selected for the acreage available and characteristics of the site. Fortunately, the two land treatment systems are compatible with many synergistic benefits when used in combination in a single land treatment alternative.

The advantages of spray irrigation lie in the cycling of nutrients and water through agricultural and silvicultural activities. However, large land areas are needed for the application areas and storage facilities. The storage requirement for the inclement weather and non-growing periods more than doubles the spray irrigation acreage needed since any effluent stored together with net precipitation gain must be applied during the ensuing suitable application period. Even so, this approach provides best control of the additions of effluent constituents to the land.

Rapid infiltration systems require considerably less land area since loading rates are much higher and the systems are operable continuously throughout the year, a feature which eliminates the necessity for storage facilities. Prime considerations are not facilitating nutrient recovery or enhancement of agricultural activities, but achieving additional renovation and water recovery.

1. Southeastern Massachusetts

Integrating spray irrigation and rapid infiltration into a single treatment approach optimizes the major advantages of each land treatment system and at the same time minimizes or eliminates the more undesirable aspects of each. The land alternative proposed here for the treatment of approximate 180 mgd of secondarily treated wastewater from the Woburn (31 mgd), Medford (30 mgd), Watertown (45 mgd), Dedham (41 mgd), and Canton (30 mgd), sewage treatment plants entails using agricultural and forested lands for spray irrigation during early spring through late fall, then switching to rapid infiltration systems for treatment during winter periods. This combined approach minimizes the acreage needed for surface storage lagoons in that only emergency storage facilities with 14 days capacity will be provided. Land areas, otherwise used for effluent storage or application areas for stored effluent under an all spray irrigation approach would be used to treat a greater proportion of the summerflows.

This approach increases the percentage of the total land area which will be used primarily for agricultural activities. Evaluation of lands in southeastern Massachusetts for potential land treatment sites revealed two reasonably close areas where both spray irrigation and rapid infiltration land treatment could be implemented; a) the Freetown-Fall River area and b) Plymouth-Carver-Bourne-Sandwich area (Figure 10).

For convenience, the discussion of the land alternative has been divided into two operational segments; 1) summer operation and 2) winter operation.

Summer Operation

During the crop growing season, mid-April through mid-October, land treatment of secondary effluents would be achieved primarily by using the spray irrigation technique. Through the site selection process, approximately 6020 acres were identified in the Freetown-Fall River area which could treat about 53 mgd using the spray irrigation technique proposed here. Approximately 8090 acres identified in the Carver-Plymouth area would treat about 62 mgd by spray irrigation, while the remaining 65 mgd of the approximately 180 mgd diverted to southeastern Massachusetts would be treated using the rapid infiltration method. Rapid infiltration treatment would require about 1200 acres of land suited to rapid infiltration.

By using all 3320 acres of the rapid infiltration sites in a rotation sequence, longer recovery periods would be permitted during the summer periods. It may be entirely possible that some lands designated for rapid infiltration could be used for spray irrigation sites with agriculture activities during the summer.

Summer operation of the spray irrigation and rapid infiltration site would ential diversion of some 53 mgd to Freetown-Fall River for treatment by spray irrigation. The remaining 127 mgd would be carried in high pressure pipes to the other spray irrigation and rapid infiltration sites. At point B (Figure 10), approximately 62 mgd would be diverted for spray irrigation in the Carver-Plymouth area while the remaining 65 mgd would be treated at rapid infiltration sites at Bourne (20 mgd) and Sandwich (45 mgd). Since the Sandwich site could treat about three times the summertime flow directed to it, several management options are possible:

a. the entire rapid infiltration acreage could be used in a rotation sequence with either shorter application periods or longer recovery periods.

b. a portion of the 45 mgd, say 35 mgd, could be treated by rapid infiltration on some 645 acres while 10 mgd was treated by spray irrigation on 2100 acres.

Winter Operation

Treatment of the 180 mgd of secondary effluent between mid-October and mid-April would be accomplished entirely by rapid infiltration on some 3320 acres. The rapid infiltration sites are segmented into three parcels; a) 210 acres in the Freetown-Fall River area, which could treat about 15 mgd; b) 365 acres in Bourne, about 20 mgd; and c) 2745 acres in the Sandwich area, about 150 mgd. (Figure 10)

2. Land Treatment in Hamilton, Ipswich and Middleton

Land treatment of the effluents from the regional wastewater treatment facilities located at Hamilton, Ipswich and Middleton would be treated entirely by the rapid infiltration method.

E. Storage Facilities

The storage lagoons, which are included here, serve three general purposes. First of all, they provide detention storage for equalizing flows, and thereby enable pumping schedules to be optimized. Second, they provide for emergency situations, such as the repair of pumping units or transmission lines. And third, they provide for storage of treated wastewater during periods when high winds or heavy rains prevent spray application.

Although the storage lagoons will be used to contain only treated wastewater, it is anticipated that they will also provide some additional treatment to stored wastewater through sedimentation of fine suspended matter and biological action by bacteria and algae on remaining BOD.

To conserve land area, lagoon depths will range from 25 to 30 30 feet and have a minimum of five feet for freeboard. Lagoon dikes will have a slope of one vertical to four horizontal. Lagoons will not be aerated as it is expected that odor production can be kept to a minimum by utilizing only the minimum number of lagoons that are necessary for equalization purposes. By doing so, detention times within the lagoons will be kept to a minimum. Figure 13 shows a cross-section of a typical lagoon.

Sludge deposits in the lagoons are expected to be minimal and will be removed during those periods when lagoon capacity requirements are minimal. It is believed that lagoon liquor can be removed without disturbing sludge deposits and that sludge can be removed by using scavenger trucks and trash sweeping vehicles.

The flow of water between adjacent lagoons will be controlled at interconnecting structures and will enable lagoons to be operated in either series or parallel arrangement. Storage lagoons at land

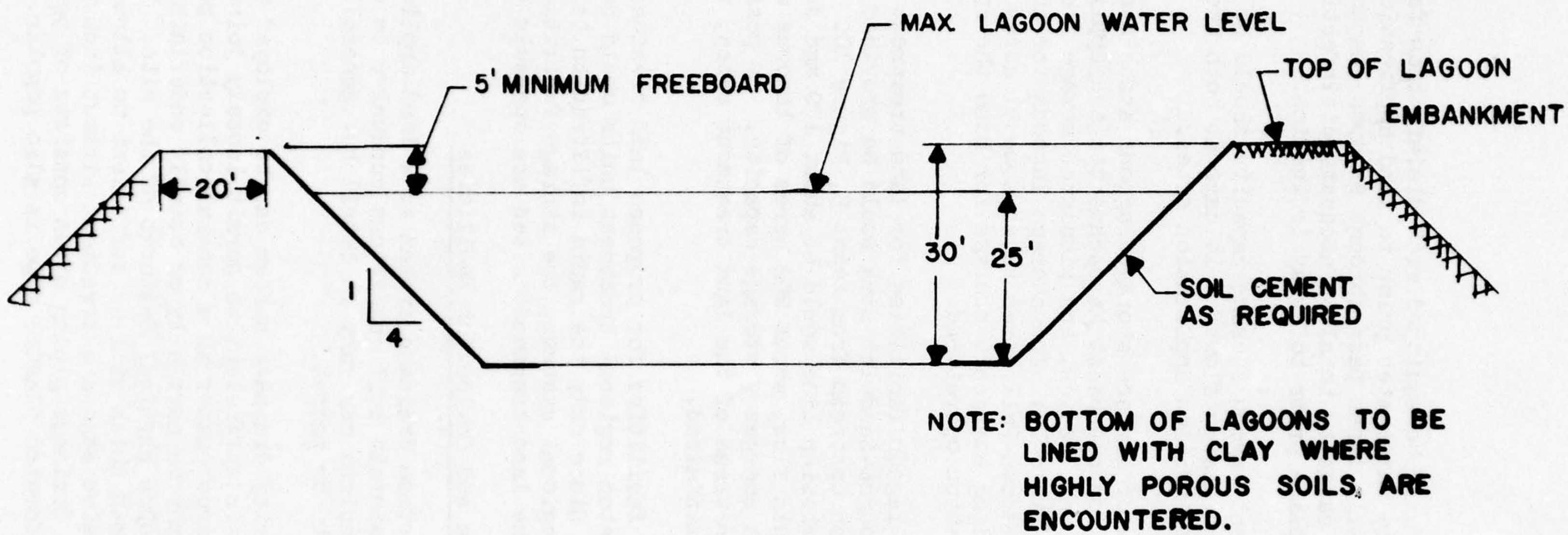


FIGURE 13. TYPICAL EQUALIZATION LAGOON

application sites will be equipped with disinfection facilities which will chlorinate the wastewater prior to land application. The chlorinated flow will first pass through an open channel having sufficient detention capacity to allow adequate disinfection and dechlorination to take place prior to spray irrigation.

Sufficient lagoon storage capacity should be provided to contain the average design flow for 14 days at both the spray irrigation and rapid infiltration application sites.

The area of surface storage lagoons associated with land application sites for southeast Massachusetts and application sites serving the Hamilton, Ipswich, and Middleton sewage treatment facilities are shown in Table 15. The storage lagoons for the spray irrigation site at Freetown-Fall River total some 91 acres to serve a dual capacity by providing emergency storage for both the spray irrigation and rapid infiltration operations.

Storage lagoon facilities for land treatment sties in the Carver-Plymouth-Bourne-Sandwich area would be provided in a series of lagoons in position upstream from Point B, Figure 10. Maximum flow through the transmission line would be about 170 mgd during winter operation. For this flow, about 292 acres of lagoons would be needed to provide 14 days emergency storage capacity. By positioning the storage lagoons upstream of the land treatment sites, the lagoon requirements are minimized.

Storage facilities for proposed land treatment at the Hamilton, Ipswich and Middleton regional treatment units would be about three to four acres each. Since only the rapid infiltration technique was proposed for these regional systems, the storage facilities may not be necessary since the land treatment sites are operable continuously.

F. Drainage and Collection Facilities

A subsurface drainage system at a land application site may be necessary to maintain soil conditions conducive to crop growth. Drainage system designs may vary in detail but generally are one of two types: gravity or pumped.

The gravity drainage system can be employed wherever the slope of the site is sufficient to permit loosely jointed drain pipes to transport the groundwater to a central collection point. The land application site may be partially or totally underlain with the drainage piping depending upon physical features of the site. The piping must be placed at a depth which will be sufficient to allow the applied wastewater to receive adequate treatment without incurring excessive placement costs. Drainage piping often consists of perforated clay tile although perforated plastic pipe is also popular.

TABLE 15

SURFACE STORAGE LAGOONS

Location	Ave Daily Flow (MGD)	Storage (Days)	Cap (MG)	Required Lagoon Area, Acres[a/] SI	RI	Total
Freetown-	53	14	742	91	-	91
Fall River	11	14	160	-	20	-
Carver-Plymouth	62	14	868	107	-	107
Bourne	20	14	280	-	34	34
Sandwich	150	14	2100	-	258	258
Hamilton (North)	1.4	14	70	-	3	3
Middleton (South)	2.4	14	34	-	4	4
Ipswich	2.4	14	34	-	4	4

a/ Storage lagoon 25 ft effective depth
SI = Spray irrigation
RI = Rapid Infiltration

The method used for land application of the wastewater and the permeability of the soil play important roles in determining the desirability or necessity of a drainage system as well as the depth and lateral spacing of the drain pipes. Basically, the reclaimed water is collected after passing through the soil or living filter which imparts aerobic treatment to the applied wastewater. It is considered essential, in most cases, that a minimum aerobic soil zone depth of three feet be maintained in order for the chemical, physical and biological soil treatment processes to effectively treat the wastewater and attain desired effluent standards. Drainage systems also relieve soils of prolonged saturation and salt buildup thereby reducing crop losses and prolonging the viability of the soil treatment processes.

Gravity drainage systems must be specially designed to fit existing topographical conditions, hence, typical or standardized designs cannot be established for any practical purpose. Depending on the particular location and topography, the gravity drain pipe may either discharge to a surface channel, interconnect with a larger gravity sewer pipe carrying drainage from other drains, or discharge to a wet well for force main transmission.

The subsurface gravity drainage system should be integrated with a surface runoff detention system. Under certain climatic conditions, surface runoff from the land application site can contaminate or degrade reclaimed water or streams. To prevent this, berms having heights of one or two feet should be constructed perpendicular to the direction of the runoff flow. Such berms, placed a minimum of 500 feet apart, will usually be sufficient to retain heavy storm runoff from the irrigated land. The retained runoff would eventually percolate through the soil and be collected by the drainage system. Surface runoff detention systems should be provided under all circumstances even when a subsurface drainage system is not employed.

The design slopes and lateral spacing of drain tiles are dependent upon the flow rates to be carried and the characteristics of the soil. For the permeable, sandy-type soils (permeability = 400 gpd/sf), the tile spacing is 400 feet and six or eight inch diameter plastic pipe is used. For less permeable sandy or silt loam type soils (permeability = 100 gpd/sf), the tile spacing is 100 feet using four-inch diameter plastic pipe. The design velocities in the drain tile range from 0.5 to 1.0 fps. Four four and six-inch diameter tile, the slope is 0.3 percent. For eight-inch diameter tiles, the slope is 0.2 percent (16).

In the pumped-type drainage system, a system of well points is established at the land application site. The well spacing is dependent upon the soil permeability. Table 16 presents design criteria for pumped sub-surface drainage systems. Under typical conditions,

TABLE 16

DESIGN CRITERIA FOR PUMPED

SUBSURFACE DRAINAGE SYSTEMS (15)

Soil Permeability (gpd/sf)	Well Spacing (ft)	Well Dia (in)	Well Depth (ft)	Draw-Down (ft)	Discharge (gpm)
1	60	2.5	30	10	*
10	180	2.5	30	5	1
100	600	2.5	30	5	11
1,000	2,000	4.0	30	10	243
10,000	5,000	4.0	30	2	512

* Less than 1 gpm

2.5 inch diameter wells are driven to a depth of 30 feet and furnished with a five foot screen. If the groundwater table is located 10 feet below ground and the soil permeability is 100 gpd/sf, each well will discharge about 11 gpm under steady state conditions, and develop a cone of influence having a radius of 300 feet and a drawdown of five feet. The cones of influence around each pumped well site will keep the groundwater level from encroaching on the aerobic treatment zone during periods of high groundwater recharge (14).

The installation of a pumped subsurface drainage system has certain advantages over a gravity system. Wells may be installed at random locations using a portable drill rig. The piping connecting the wells to the pump can be assembled on the surface of the ground and sections of the land application site can be dewatered as desired. Where soils are highly permeable, fewer wells having larger diameters can be used thus greatly reducing unit development costs. Unlike the gravity type systems, the pumped underdrainage system allows samples of reclaimed water at particular points to be examined or monitored for quality of treatment.

G. Spray Irrigation for Treatment of Wastewater Effluents

1. Application Rates

The recommended rate of application for wastewater application of the various soil groups would be +0.25 inches per hour.

Weekly applications up to two inches per week could either be a single application or two equal applications, however, drainage considerations would probably favor the latter. Weekly applications greater than 2.5 inches would be sufficient to saturate even very permeable soils during wet years.

2. Effluent inputs of wastewater constituents under the two inches per week spray irrigation application were calculated for an assumed quality of secondary effluent for systems operated for 26 weeks each year (Table 17).

a. Nitrogen

Total nitrogen in the secondary effluent was assumed to be about 20 mg/l consisting of organic-nitrogen (2 mg/l), ammonia-nitrogen (10 mg/l), nitrate-nitrogen (8 mg/l) and a negligible amount of nitrite-nitrogen. Only about 95 percent (19 mg/l) of the total nitrogen in the secondary effluent is readily available for crop use. The remaining 1.0 mg/l consists of resistant nitrogenous organic compounds which are not easily degraded.

TABLE 17

Annual Nutrient Additions to Spray Irrigation Sites for Applications of 2.0" of Secondary Effluent per Week

Nutrient	Effluent Quality (mg/l) a/ b/	Annual Inputs pounds per acre-year
N	20	235
P	13	153
SO_4	42	499
Cl	100	1178
Ca	40	471
Mg	17	200.3
K	12	141.4
Na	40	471
Mn	0.2	2.4
Phenols	0.3	3.5
Cd	0.1	1.2
Cr	0.2	2.4
Hg	0.005	0.06
Pb	0.1	1.2
Al	1.0	11.78
Fe	0.1	1.2
Cu	0.1	1.2
B	0.7	8.2
Zn	0.2	2.4

a/ Ref 19 and 39

Under normal agricultural practices, nitrogen losses due to denitrification in the soil can be about 30 percent of the nitrogen inputs. Therefore, crop available nitrogen as well as the amount which could conceivably be leached through the soil is only about 13 mg/l or about 65 percent of that applied. Total annual additions in spray irrigation system inputs would be about 235 pounds per acre, however, only about 157 lb/ac of crop available nitrogen is applied during the 26 week application period.

Compared with amount of nitrogen taken up by various forage crops, annual inputs of available nitrogen would not be sufficient to satisfy crop needs (Table 18). Under normal agricultural conditions growth and harvesting of forage crops can remove about 165-220 pounds of nitrogen per acre per year. Therefore, if crop nitrogen needs are to be satisfied, additional nitrogen may be needed in spray irrigation areas. Field studies (25) have shown that application of secondary sewage effluent can increase crop production and the uptake of applied nitrogen. Nutrient requirements can be easily satisfied by adjusting upwards the weekly application rates to supply the additional fertilizer needed, but care must be taken to ensure that an aerobic root zone is maintained. Larger additions of wastewater may waterlog agricultural soil, which could reduce crop production.

Since crop uptake of applied nitrogen will be greater than that applied during weekly application(s), it may be assumed that the amount of nitrogen available for leaching through the soil will be quite low, probably less than 2.0 mg/l beneath cropped areas.

Spray irrigation to forested land has been shown to increase tree growth through nutrient use. Sopper (46, 47) observed 2-4 in/wk application of secondary effluent to mixed hardwood forests significantly increased tree diameter and height.

Initially, effluent applied to the forest areas received substantial renovation. Nitrogen removal was about 70-80 percent during the initial two years of the study, however, removals decreased to about 30-50 percent (10-20 mg/l) after six years. One reason for the reduction in the nitrogen renovation was the total annual nitrogen inputs to the forest operation were not offset by comparable removals through crop harvesting or nitrogen loss through natural processes. Effluent addition in association with the annual recycling of foliage, twig, and bark nitrogen without substantial nitrogen removal eventually results in NO_3-N being carried through the soil, It may be possible that with proper management practices to include rapid maturing tree species, with frequent harvesting plus operational practices to enhance denitrification processes, an acceptable nitrate level could be maintained (i.e., less than 10 mg/l).

TABLE 18

Crop Yields and Removals of Major and Secondary Nutrients

Crop	Production	Nutrient Removed (lb/ac)					
		N	P	K	Ca	Mg	S
Corn grain (15.5% moisture) a/	150bu/ac	125	22	28	3	10	10
Corn silage (75% moisture) a/	25T/ac	165	30	150	45	30	15
Alfalfa-Brome (10%) a/	5T/ac	220	30	166	90	37	21
Grasses 1/ b/	5T/ac	170	18	165	45		
Sudangrass b/	5T/ac	141	27	188	36		
Millet (Japanese) b/	5T/ac	123	16	210	20		
Reed Canary grass b/	5T/ac	157					

1/ Timothy, bromegrass, orchard grass, bluegrass
a/ Ref 16
b/ Ref 36

b. Phosphorus

Phosphorus applied to the land in spray irrigation areas should be effectively removed through crop uptake and harvesting and reactions in the soil complex; ion exchange, chemical reaction and physical adsorption. Plants are known to take up phosphate for use in photosynthetic and metabolic processes, thus periodic cropping of the application site will remove an important amount of phosphorus annually. Although phosphorus uptake can vary among plant species; alfalfa and various grass species generally remove about 20 to 30 pounds of phosphorus per acre during the growing season (36). Thus, under good agricultural management, phosphorus must be periodically applied as fertilizer to compensate for this removal. Under the 2 in/wk application rate, annual phosphorus addition would be about 153 lb/ac-yr of which cropping would remove from about 16 percent of the annual inputs (Tables 17 and 18).

Phosphorus remaining would be available for fixation in the soil through various soil chemical reactions. Although the reactive mechanisms are not well-defined, it is known that soil adsorption and fixation can immobilize considerable phosphorus. Investigations of long-term fertilizer applications has found that very little phosphate is carried in rain water percolating through the soil (21). Studies in which sewage effluent or industrial wastewaters were applied to the land have shown that soil immobilization mechanisms can remove 90-99 percent of the applied phosphorus (44).

Studies of soil which received large amounts of phosphorus over long periods, give some idea of the magnitude of the soil-fixation capacity. Kardos (26) determined adsorption capacities of about 2,000 pounds per acre foot; while Murphy (37) found California Aiken clay loam capable of fixing 8,000 pounds of phosphorus per million pounds of soil. In light of these studies, it seems safe to assume the loamy and medium to coarse sand soils in the study area may have the capacity to fix at least 4,000 pounds of phosphorus per acre-foot of soil before losing their ability to effect a 90 percent reduction in the phosphorus content of percolating wastewater. Assuming the phosphorus content of the secondary effluent applied to the soil during the 26-week effluent application period is about 13 mg/l as PO_4-P, approximately 153 pounds of phosphorus per acre would be applied annually. Subtracting the phosphorus removed by forage cropping, the net gain in phosphorus would be about 128 lb/ac-yr (Table 19). If the soil removal capacity was 4,000 lb/ac-ft as P and effective soil depth was five feet to water table or drainage tile, the projected useful site life to remove P would be about 150 years at 2.0 inches per week. The projected longevity could well change following the necessary field and laboratory investigations defining the phosphorus adsorption and fixation.

TABLE 19

PHORPHORUS ADDITIONS AS A FUNCTION OF TIME
UNDER 2 INCH/WEEK APPLICATIONS

Phosphorus Input 1/		Net Phosphorus Applied 2/					
Total	Net	years					
(lb/ac-yr)		10	20	30	40	50	60
153	128	1280	2560	3840	5120	6400	12800

1. Assumes 26-week application period annually, and P concentration of 13mg/l
2. Assumes a 25 lb/ac-yr P removal by crops harvesting (39)

c. Sodium, Calcium, Potassium and Magnesium

Although these elements are all found in natural soil systems, they are usually present in limited available amounts in the New England soils. In certain circumstances particularly near the seacoast and in tidal areas, the soil salt concentration can be sufficiently high to limit growth of certain kinds of plants. Salt levels (Table 7) in sewage effluents proposed for application to crop land are not sufficiently high to adversely affect more than the most sensitive plants and should not present any difficulties to agricultural crops (41). Salt sensitive crops such as radishes and green beans could possibly receive effluent application under proper management situations; however, effluent application to vegetable crops is not likely, at this time, for reasons related to public health. Fruit trees have a low salt tolerance but should not be adversely affected by the effluent salt levels assumed here. Forage crops, corn, alfalfa, and grass species are moderate to highly salt tolerant. Therefore, effluent quality anticipated here should not result in any adverse plant responses due to salinity.

On the other hand, soils themselves may be susceptible to degradation due to excess adsorption of monovalent ions in the applied wastewater. The relationship between such cations in wastewater as calcium, magnesium, sodium and potassium, is important to soil structure. When the ratio of Na^+ ions to the other cations, especially Ca^{+2} and Mg^{+2}, become too high, sodium tends to replace Ca^{+2} and Mg^{+2} ions from the clay particles. Predominance of Na^+ ions on clay particles has the effect of dispersing soil particles when freshwater is applied resulting in decreased infiltration and permeability which in effect can "seal" the soil surface horizon.

Identification of potential salinity hazards due to application of wastewater effluents to soil and crop can be ascertained from the electrical conductivities of the irrigation water. The U.S. Department of Agriculture Salinity Laboratory (41) determined that irrigation waters with electrical conductivities in the range of 100-250 umhos/cm at 25°C have a low salinity hazard; those with conductivities of 250-750 have a medium hazard; those of 750-2, 250 umhos/cm are highly hazardous; and waters with electrical conductivities above 2,250 umhos/cm are considered very hazardous to crop production. The electrical conductivity of the irrigation water proposed for cropland would fall within the medium salinity hazard category. However, precipitation falling over the year would leach some accumulated salts through the soil and thus alleviate some possible salinity hazards to salt intolerant crops.

Coastal communities with sewer lines in the "Saline Plain" (the land area in which the sewer collection and transmission lines are susceptible to seawater infiltration or direct inflow during the tidal cycle) should carefully consider the potential salinity problems to crop and soils when considering land application as a wastewater treatment method. Where seawater comprises even a small portion of wastewater flow, a substantial increase in conductivity would occur, making the effluent undesirable for irrigation purposes. For example, if five percent of a community's wastewater flow was made up of seawater (electrical conductivity of 35,000 umhos/cm), the resulting effluent conductivity would be around 2,225 umhos/cm, which would be highly hazardous to crop production and soil structure if applied to agricultural land. If saltwater comprised even one percent of the total wastewater flow, the effluent conductivity would be about 825 umhos/cm which would still be highly hazardous to crop production and soil structure.

In view of the fact that sewer lines degrade over time, the percentage of seawater in the wastewater flow could be anticipated to increase where collection systems lay in the "saline plain." Coastal communities considering land treatment methodologies would have to install sewer collection systems above the "saline plain" plus implement measures which would prohibit direct saltwater inflow to sewer lines.

Calcium, magnesium, potassium and sodium levels assumed for the effluent applied to the land are given in Table 17. The sodium adsoprtion ratio (SAR) of the effluent is 1.34, thus the effluent should not create problems when applied to crop land. The exchaneable sodium percentage should increase slightly but would not lead to excessive levels of exchangeable sodium.

d. Chloride

The chloride ion is not adsorbed by soils to any extent. The actual quantity of chloride being applied appears to be substantial, but since it readily leaches, these levels are not viewed as being critical. Since the soil does not adsorb chloride, the total quantity of chloride applied is of lesser importance providing sufficient water is applied to leach the soil (one inch per week or greater). The concentration of chloride in the drainage effluent is expected to be near that being irrigated. Most of the crops under consideration will tolerate this level of chloride, including hay and corn.

e. Sulfate

No values for sulfate were available, thus, it is not possible to calculate the quantities that would accumulate in soil. Sulfate adsorption by soils is discussed by Ellis (16).

f. Trace Nutrients ("heavy metals")

The following section explicitly addresses trace nutrients and their plausible impact upon the soil-vegetative system. After considerable effort to identify and quantify trace nutrients present in municipal and industrial wastewater of the Boston Harbor-Eastern Massachusetts Metropolitan Area, it became apparent that only an extensive wastewater monitoring program could provide this information. Present EPA guidelines specify the quantity and concentration of pollutants in industrial wastes which may be discharged to receiving streams and municipal sewers. It is assumed that pretreatment of industrial wasetwaters would be sufficient to meet the "Proposed 1973 Water Quality Criteria" (19) for trace nutrient in irrigation waters under continuous application. Further, it was assumed that industries discharging to municipal sewers would not dilute toxic industrial wastes in the municipal wastewater flow. Rather, the municipalities permitting industrial discharges to municipal sewers would police these discharges to prevent dilution of trace nutrients of industrial origin in domestic wastewater flows.

For purposes of this discussion, the following trace nutrients (sometimes referred to as heavy metals) were considered: aluminum, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc.

Levels of trace nutrients in secondary effluent, i.e., proposed "1973 Water Quality Criteria" for irrigation water, the quantities of trace nutrients taken up by plants and the net annual additions under 2.0 inches per week are displayed in Table 20.

TABLE 20

Annual Inputs of Trace Nutrients Under 2 inches/week Effluent Compared to Crop Uptake and Average Soil Composition

Trace Nutrient	EPA Proposed Irrigation Water Quality[a] Criteria	Crop Removal[b]	Annual Metal Additions to Soil	Soil Composition[a] average	range
	(mg/l)		---pounds/acre-year---	lbs/acre-6 inches	
Aluminum	5.0				
Arsenic	0.1	0.006	0.59	12	(0.2-80)
Boron	0.75	0.18	8.25	20	(4-200)
Cadmium	0.01	0.0036	1.18	0.1	(0.02-14)
Chromium	1.0	0.0014	2.36	200	(10-6,000)
Copper	0.2	0.084	1.18	40	(4-200)
Iron	5.0	1.74	1.18	38,000	-
Lead	5.0	0.0162	1.18	20	(4-400)
Manganese	0.2	0.312	2.36	1,700	(200-8,000)
Mercury	-	0.00009	0.06	0.8	(0.03-0.8)
Nickel	0.2	0.018	2.36	80	(20-2,000)
Zinc	-	0.102	2.36	100	(20-600)

a/ Ref 19

b/ 3 ton corn silage per acre - dry weight (18)

Data given in Table 20 shows the pounds of each nutrient added to each acre under the 2.0 inches per week effluent application rates over 26 weeks of spraying time each year. Nutrients added under a particular spray regime can be compared with the average total amount of the metal found in an acre of soil. Although most trace nutrients may be considered fairly evenly distributed through the soil profile, there can be important changes in composition with depth. As a result, average values discussed will pertain to the acre furrow slice unless otherwise specified. Accumulation of nutrients in the soil with respect to "normal residual" content of metals already present in the soil gives one measure of the impact that trace nutrients addition may have on the soil system. Such information is of limited value, however, because the fixation, leaching and plant uptake potentials are governed by the form in which metal exist in the soil solution.

Knezek (16) has assessed the probable impact of 13 micronutrients and heavy metals on soils and crops in land treatment systems. It was pointed out effluent additions would greatly exceed crop removal, a point which is illustrated by data in Table 20.

Data clearly show three tons of corn silage (dry weight) per acre would remove one percent or less of most trace nutrients added on an annual basis. Generally, the rooting zone of a plant already contains one hundred to one hundred thousand times the amount of a trace element likely to be removed by any one crop (Table 20). A real potential danger in spray irrigation using effluents containing metals, is in surface adherence to leaves of crops and possible foliar adsorption into the plant.

Basically, the proposed spray irrigation system must be viewed in terms of the capacity of the soil to fix metals so that they will not be toxic to plants or soil microbes nor leach into the drainage water. Each of the elements will be discussed in terms of adding effluent at the rate of two inches per week for 26 weeks per year. Unless otherwise stated, metal will be assumed to remain in the acre furrow slice of the soil.

Arsenic

Arsenates in soils compete for the same fixation sites that are utilized by phosphorus. However, the arsenates are bound in the soil with less strength than phosphates and there is a greater potential of leaching arsenates through the soil profile as the phosphorus adsorbing capacity of the soil becomes saturated. A whole range of total arsenic values from 0.3 to over 100 pounds per acre have been reported on normal and arsenic contaminated soils. Although arsenic concentration may be increased in plant tops, there is little danger of animal toxicity. The effect of arsenic toxicity on plants is such that plant growth is limited before large amounts of arsenic are adsorbed and translocated to the top (1, 33). The concentration of arsenic in corn tops has been increased to about 3 mg/l without plant toxicity. There should be little problem with leaching, plant uptake or plant toxicity or arsenic unless the phosphorus adsorbing capacity of the soil is nearing saturation. Several recent articles (15, 61, 62) tend to confirm the soil and plant reactions of arsenic.

Boron

If the relatively high amounts of boron projected for effluents are applied to the soil, there may be serious leaching to the drainage water and possible plant toxicity depending upon the crop being grown. Rhoades, et. al. (42) have stated that many plants are deleteriously affected by boron concentrations in the range 0.5 to 5 mg/liter. Toxic levels of soluble boron may be removed from soils by leaching, but not as fast as chloride or sulfate. Ellis and Knezek (17) have reviewed the bonding mechanisms for boron in soils. The soil may adsorb sufficient excess boron over a period of time to actually increase the level of soluble boron above the 1.0 mg/liter limit after the first year (43). Corn and most other cereal grains are semitolerant to boron while most sensitive plants, such as navy beans, will tolerate 0.7 mg/liter of boron (41). The soluble boron levels could approach toxic levels in the soil even for corn. A further assumption must be made that after the first year of spraying wastewater, boron will essentially be moving out in the drainage water at a concentration equal to or greater than that which is applied depending upon the rate of water loss by evapotranspiration.

Cadmium

The chemistry of cadmium is similar to that of zinc and the soil bonding mechanisms of zinc have been recently reviewed by Ellis and Knezek (17). Recent research by John, et al. (24) has shown that 90 pounds of cadmium added to a soil surface over several years did not move more than four inches into the soil profile. Their work on cadmium uptake by oats and studies by Traynor and Knezek (51) in Michigan on corn show little increase in plant uptake at the levels of cadmium to be applied. Unless very soluble and mobile complexes are formed with low molecular weight organics, there should be little or no movement into drainage.

Lagerwerff (28) has recently reviewed cadmium in the environment, including soils and plants.

Chromium

The amount of chromium which will be added to the soil is well within the amounts normally found in soils (Table 20). Walter, Traynor, and Knezek (59) have found that certain soils have a large capacity to fix chromium and leaching into the drainage water should not be a problem. Many times when naturally occurring chromium toxicity to plants was suspected, the concentrations of chromium in plant tops was the same as for normal plants. Walter, et. a. (59), found similar results with corn in Michigan, but Turner and Rust (52) found uptake of chromium by soybeans from nutrient solution. They did show apparent toxicity to soybeans in soil culture at ten pounds of chromium per acre, but no uptake data were given for plants grown on soil culture. Apparently, no danger exists from the injection into the food chain, but the toxicity potential of chromium in the proposed system is not clear.

Copper

Most of the copper will be bound in organic or clay complexes near the soil surface. The bonding of copper in soils has been reviewed by Ellis and Knezek (17). There should be no toxicity problems and minimal leaching of organic complexes containing copper into the drainage water will occur. Reuther and Labanauskas (40) have reviewed the chemistry and toxicity of copper in soils. The soils proposed should adsorb the copper being added for an indefinite period of time at the rate and quantity being proposed if the soil pH is maintained near 7.0.

Iron

The iron added to the soil is considerable in quantity but will be rapidly fixed by precipitation and surface adsorption. Iron is rarely toxic to plants. There may be some leaching into the drainage water in the form of organic complexes due to high level of iron addition, but the level should be less than the 0.3 ppm drinking water standard. Addition of such large quantities of iron to the root zone of plants could influence plant nutrition by interaction with the uptake of several nutrients such as manganese and zinc (45, 58).

Lead

Lead addition to the soil will be relatively low. There should be no movement into the drainage water, and plant uptake will probably not be influenced at the levels applied. However, Cox and Rains (13) have reported considerable lead uptake from severely contaminated soils (64 to 196 lbs of lead per acre). The subject has been reviewed by Lagerwerff (28).

Manganese

When manganese is added in excessive quantities, soluble organic complexes can move through the profiles. In the amounts to be added in wastewater effluent, all of the manganese will be fixed in the profile with no significant quantity going to the drainage water. There is no possible plant toxicity danger if the pH is maintained at pH 7 or above and there may be real possibility of manganese deficiency induced by the high pH and iron application levels (45). The subject of manganese in soil and plant systems has been effectively reviewed (40).

Mercury

The chemistry of mercury in soils is similar to that of copper and lead. The soluble mercury will be rapidly fixed by the organic and clay fractions of the soil and there will be little movement through the profile and probably no significant increase in plant uptake at the levels being applied in the effluent. Extreme potential toxicity of certain forms of mercury, such as methyl mercury, warrant a close investigation of the form being added to the soil and subsequent soil conversions. Lagerwerff (28) has recently reviewed mercury chemistry and toxicity in plants and soils.

Nickel

The chemistry of nickel in the soil is similar to that of cadmium or zinc. The soil should have adequate capacity to adsorb nickel without appreciable leaching to drainage water and without toxicity to plants (51). The high amount of iron being added in the effluent will probably retard the plant uptake of nickel. Numerous studies of mickel toxicity from serpentine soils have been made. The levels being added in the effluent of the present system should give no serious problems (23). The soil and plant chemistry of nickel has been reviewed by Vanselow (56).

Selenium

The knowledge of selenium chemistry in soils is limited. Where selenium additions to low-selenium soils have been followed by repeated measurements of selenium uptake by plants, over 90 percent of the added selenium remains in the soil even after two or three years of continuous cropping and plant removal (1). Nearly all of the soils on which high selenium (above 5 ppm) grasses and grains have been grown are neutral to alkaline and frequently contain free calcium carbonate and calcium sulfate. The difference in selenium availability in acid and alkaline soils has been attributed to the formation of insoluble compounds or complexes of ferric iron and selenite in acid soils and to the formation of relatively soluble selenates in alkaline soils (27).

Underwood (53) has quoted work indicating that soils containing more than 0.5 ppm selenium should be regarded as dangerous. Plants have been divided, from the point of view of toxicity, into three classes according to their capacity to assimilate selenium. These are: (1) those showing a limited tolerance (up to about 5ppm); (2) those which adsorb moderate amounts (up to 30 ppm); and (3) those accumulator plants that adsorb more than 30 ppm. Most grasses are in the first class and all cerals are in the second class. There could some leaching into the drainage water as some forms of selenium are mobile, some potential for plant uptake from soil at toxic levels for animals and humans and a possibility of plant toxicity after a few years of application exists.

Zinc

Although the zinc additions appear to be high, similar amounts of zinc have been added to comparable soils to prevent deficiency in field beans and corn (57). The soil bonding reactions have been reviewed by Ellis and Knezek (17). There should be no leaching to the drainage water and no plant toxicity danger unless a sensitive crop such as field beans is grown on the soil. Allaway (1) has indicated that some increase in the zinc content of crops used for feed would be nutritionally beneficial. The soil and plant chemistry of zinc has been reviewed by Chapman (11).

Special Considerations

The foregoing evaluation has been made on the assumption that the metals in the effluent will be inorganic ions, metal precipitate suspensions or weak natural metal organic complexes. Addition of relatively powerful synthetic chelating ligands or metal chelates of substances such as nitrilotriacetic acid (NTA) or ehylenediaminetetraacetic acid (EDTA) or similar compounds will drastically alter the conclusions of this report. The presence of chelating ligands will increase the mobility of metals through the soil profile, increase plant uptake, reduce soil fixation of metals and either increase or decrease plant toxicity depending upon the nature of the system. Substantial quantities of metals could leach into the drainage water if synthetic chelates are present.

At the organic loads specified in the data provided for this report, it appears that there should not be a significant danger of mobilizing metals through the profile and into the drainage. However, if the organic load is increased and contains 50 percent fulvic acid compounds as indicated for secondary effluent, significant metals loads could be moved through the soil profile and into the drainage water.

The possibility that boron might be toxic to some crops was pointed out. The eight pound/ac of B calculated for 2.0 inch/week effluent would exceed the three lb/ac recommended for correcting deficiencies in responsive crops such as alfalfa. If this quantity was used in a banded fertilizer application for sensitive crops (beans, soybeans, small grains), it would almost certainly produce severe injury. Broadcast applications of three pounds or more on pea beans have produced toxic symptoms, whereas up to eight or ten pounds were broadcast on soybeans before toxic effects were produced.

While there is a potential hazard to sensitive crops from boron, the conditions of application in wastewater will greatly minimize potential hazard. Annual inputs will be distributed by small increments over 26 weeks of the year. The effective concentrations will be attenuated by leaching, redistribution through larger volumes of soil and be reversioned to complexed forms not directly available for uptake by plants.

There remains the possibility that the boron-adsorbing capacity of soils may be saturated over time and that the concentration in soil solution and percolating water will approach that of the applied effluent. Consideration should be given to identifying and reducing sources of the boron which appear in waste effluents.

Another possible nutritional problem stems from the concentration of zinc in the effluent. Deficiencies in beans and corn may be accentuated on certain glacial outwash soils, as well as on acid soils if excessive quantities of lime are used to correct acidity. Such deficiencies are readily identified and can be corrected.

With the possible exception of boron, there is little likelihood that any of the micro-nutrients or heavy metals in the effluent of Table 18 will accumulate to dangerous levels in plants or move into drainage in concentrations to exceed drinking water standards. Most will be immobilized by interacting with mineral and organic colloids, most probably in the soil surface.

As noted by Ellis, et. a. (16), toxic activities will be reduced and stabilization of heavy metals promoted by maintaining soil pH near neutrality. Liming acid soils to pH 6.5 is recommended here. It appears inadvisable to correct to a higher pH, since retention of bases from the effluent may lead to further increases in soil pH. The extent to which this may or may not occur will depend on exchange capacity and mineralogy of the soil and on the composition and properties of effluent from a specific source.

H. Proposed Rapid Infiltration for Treatment of Wastewater Effluents

The daily flood application of large volumes of wastewater effluent to a relatively small confined land area consisting of permeable stratified sands and gravels for the purpose of additional renovation or disposal of wastewater effluents has commonly been termed rapid infiltration. This mode of land treatment of wastewater has been used most extensively in arid climates to further renovate municipal and industrial wastewater effluent prior to recharging groundwater aquifers or for agricultural use. While much of our technical understanding of rapid infiltration for wastewater treatment has been gained in arid climates, this mode of wastewater has also been utilized in

New England for more than thirty years to provide final treatment/ disposal of domestic wastewater effluents. Sewage treatment facilities at Ft. Devens (44) and Otis Air Force Base, Massachusetts and Lake George, New York (5) have incorporated rapid infiltration as the final step for wastewater treatment.

Until recently, rapid infiltration was viewed as an "out-of-sight, out-of-mind" disposal mechanism for partially treated sewage effluents. Following the disposal concept, the design and operation criteria for the rapid infiltration system was based upon the hydraulic capacity of the site. Organic matter loading while often a consideration was important only as it pertained to hydraulics of the system. Management of the application rate and flooding cycle was only to prevent or correct capacity rather than achieving effective effluent renovation. Recent studies of rapid infiltration systems have shown effective renovations of applied sewage effluent is possible and with proper management, acceptable groundwater quality and a sustained infiltration rate can be maintained.

Investigations of the wastewater treatment facility at Ft. Devens, Massachusetts, which includes 22 rapid infiltration basins for final treatment of unchlorinated primary sewage effluent, have shown rapid infiltration system can renovate the applied primary effluent to a quality much better than conventional tertiary treatment at less cost. Groundwater quality at the Ft. Devens facility showed BOD_5, COD and total coliform bacteria levels of unchlorinated primary effluent were essentially removed after passing through the sand and gravel layers of the treatment basins. Organic nitrogen and ammonia-nitrogen were greatly reduced as well as the level of phosphorus (5).

Since rapid infiltration systems are operable throughout the year, there is no need for storage lagoons. The elimination of storage lagoons and the greater quantities of wastewater effluent which can be treated per unit of land area reduces the land requirements for rapid infiltration to less than ten percent of that needed for spray irrigation.

1. Effluent Quality

The degree of pretreatment given the wastewater applied to the treatment beds will greatly affect the quality of resulting renovated water and management practices followed. It was assumed wastewater effluent applied to rapid infiltration sites would be municipal wastewater which had received the equivalent of secondary treatment in conventional secondary facilities. All industrial wastewater discharging into municipal sewers were assumed to have been pretreated to remove toxic organics and trace nutrients (heavy metals). Oils and greases would be removed during pretreatment processes so none would be applied to the treatment basins. Characteristics of the effluent applied to the treatment beds was assumed to be that given in Table 17.

AD-A036 799 METCALF AND EDDY INC BOSTON MASS F/G 13/2

WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - --ETC(U)

OCT 75

UNCLASSIFIED NL

2 OF 4

AD A036799

2. Operational Cycle

Laboratory and field investigation of the effluent application has shown the importance of management procedures by which treatment basins are inundated for a period of time then allowed to dry before effluent is applied again. In arid climates of Arizona (9), California (32), and Israel (2, 3), investigation of rapid infiltration systems concluded that continuous or very long inundation periods would result in eventual clogging of treatment basin surface and negligible infiltration rate. Reduction of the infiltration rate has been directly related to accumulation of organic material and microbial growth on the filter medium which reduced soil porosity. Regeneration of infiltration rate is accomplished by aerobic microbial decomposition of organic matter during the recovery or drying period of the operation cycle. Recovery period is important not only to the infiltration rate but also is an important consideration when manipulating the length of the inundation and recovery periods to provide optimum conditions for non-structural methods of nitrogen removal.

Studies of the application drying cycle, have primarily been carried out in dry climates. Bouwer (9) found a 14-day effluent application period followed by seven days of drying would sustain the infiltration rate over the long term while improving the quality of effluent. Amramy (2, 3) investigated a number of application cycles and determined the ratio of wetting to drying periods should be in the range of 1:2 to 2:1. He observed good renovation of secondary effluent following seven-day wetting period and 14-day recovery cycle. Field studies and laboratory tests conducted by Lance (30, 31) and Bouwer (10) found two days of effluent application followed by five to 14 days recovery time was well suited for nitrification of the organic and ammonical forms of nitrogen but was not best for removing nitrogen by denitrification. Satterwhite (44) observed application of primary sewage effluent for two days followed by 14 days recovery, at Fort Devens, has maintained an acceptable infiltration rate while enhancing nitrification of organic and ammonia nitrogen. Although total nitrogen levels were reduced 40-60 percent, NO_3-N levels in the groundwater surrounding the infiltration area ranged from 10-20 mg/l. Where the purpose of rapid infiltration is to remove or reduce nitrogen in reclaimed water, short application periods in association with long recovery periods should be avoided. Since nitrogen removal was an integral consideration in formulating rapid infiltration systems, the operational cycle proposed would facilitate non-structural methods for nitrogen removal from secondary sewage effluent while maintaining adequate renovation of other wastewater constituents. The application cycle of 14 days inundation followed by seven days recovery was proposed.

3. Application Rate

Effluent loading rates, 0.3-0.8 ft/day (31, 60) together with system management have brought about considerable differences in effluent renovation. Lance and Whisler (31) observed 75-80 percent nitrogen removal when secondary effluent was applied to sand filters at approximately 0.5 ft/day for an annual total of 125-150 ft. Higher application rates, 1.1 ft/day, treated larger volumes of secondary effluent, 280 ft/yr, but nitrogen removed was only 30 percent of that added. The application rate selected for this study, 0.33 ft/day, was based on guidance from Massachusetts Department of Public Health (4). Using this loading rate and the operational cycle previously discussed, the acreage required to treat a wastewater flow of one million gallons per day (1 MGD) was calculated to be about 18.4 ac.

The amount of wastewater treated annually under this application rate and operation cycle would total about 83 feet. Compared to experiences at the Flushing Meadows project, this loading rate and volume of water effluent treated appear quite conservative. However, this may be warranted in view of the scarcity of available operation and performance data for rapid infiltration treatment facilities in New England.

As discussed previously, all rapid infiltration sites would not be operated continuously throughout the year. During the summer months, only about 62 mgd would be treated on the 3110 acres of rapid infiltration sites in the Bourne-Sandwich area.

To calculate annual nutrient addition to the rapid infiltration site, it was assumed that all 3110 acres in the Bourne-Sandwich area would be inundated about the same number of days during the year period.

Using an application rate comparable to that used in normal winter operation, the 3110 acres would receive about 32.3 ft secondary effluent during the summer months. An additional 64 feet would be applied during the winter operation for a total addition of about 95 feet of secondary effluent.

The 210 acres of rapid infiltration sites in the Freetown-Fall River area would be operated only during the winter half of the year and would receive about 63 ft/yr of secondary effluent.

4. Organic Material

Additions of organic material as expressed in terms of five-day bio-chemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are dependent as are other wastewater constituents upon concentration in the effluent, application rate, and operation cycle followed. BOD_5 and COD levels assumed here were 30 mg/l and 70 mg mg/l, respectively. Annual BOD_5 loading under the proposed application rate and application cycle would be about 5,130 lb/ac at Freetown and 7,760 at Bourne-Sandwich sites while COD loadings would be 11,770 lb/ac and 18,110 lb/ac in the two areas. Although these levels may appear high, studies of the infiltration-percolation which treat primary or secondary wastewater effluents have shown substantial amounts of material can be effectively treated without impairing renovation effectiveness of treatment basins. Investigations of the Ft. Devens, Massachusetts sewage treatment facility have found annual BOD_5 and COD loadings of 28,500 lb/ac and 47,600 lb/ac, respectively, did not reduce infiltration. After some 30 years operation, BOD_5 and COD levels in the groundwater were 2.5 and 19 mg/l, which represent about two percent and five percent, respectively, of the BOD_5 and COD levels of applied primary effluent. Organic matter inputs to the treatment beds at Ft. Devens plus the annual increment of plant material, growing naturally on the surface of the infiltration beds, has not clogged the filter surface so as to impair infiltration or continued removal of organic constituents (44). Other studies of treatment infiltration basins to renovate secondary effluents have shown similar results. Bouwer (9) found BOD_5 of secondary effluent applied to rapid infiltration basins was reduced to zero in groundwater. COD levels were reduced from 50 mg/l to 17 mg/l after percolating through sand and gravel to the groundwater.

Investigations of the infiltration basin operated for more than 30 years at Lake George, New York, revealed similar reductions in BOD_5 levels for secondary effluents passing through ten feet of permeable sand and gravel (5).

From these investigations, it seems reasonable that under proper management, the BOD_5 and COD levels assumed here can be adequately removed from wastewater effluent as it moves through permeable sand and gravel strata of the treatment basin. It is important to note industrial effluent with high levels of organic matter or effluents containing grease and oils should receive prior treatment to meet the assumed effluent quality in order to avoid clogging the treatment basins.

5. Nitrogen

Level of total nitrogen in the secondary quality effluent applied to the rapid infiltration basin was assumed to be about 20 mg/l; approximately 10 mg/l NH_4-N, 9 mg/l NO_3-N, 2 mg/l organic nitrogen and negligible NO_2-N. Under the proposed application rates and operation cycles, total quantities of nitrogen applied to the treatment area would be 342 and 518 lb/ac-yr for the Freetown-FallRiver and Bourne-Sandwich sites. Soil mechanisms for removing the applied nitrogen included crop uptake, soil fixation, and adsorption, ammonia volitalization and chemical denitrification, all of which have limited capacity or are short-lived removal mechanisms which eventually would return nitrogen to the infiltration system.

Biological fixation and accumulation of organic nitrogen compounds in the soil of the treatment basin could account for about ten percent of the nitrogen applied annually. Unless assimilated nitrogen is routinely removed through crop harvesting, the biologically-fixed nitrogen would eventually be released following microbial decay of organic matter.

Ammonia adsorption in the soil could remove substantial amounts of nitrogen. During the drying period adsorbed NH_4-N in the aerobic zone would be oxidized to NO_3-N which could be leached through the treatment basins during the next application period. Control of the mobile nitrogen may be accomplished under adequate and proper management practices facilitating both nitrification and denitirfication within the treatment basins.

Management practices which have been effective in reducing the nitrogen levels includes maintaining the proper carbon-nitrogen ratio in applied effluent.

Maintaining the proper C:N ratio is probably the key to nitrogen removal by denitrification, as nitrified water moves through the reduced zone in the treatment basins. NH_4-N and organic nitrogen applied to the treatment beds are adsorbed in the soil or oxidized to NO_3-N in aerobic zones of the treatment basin or water column above the soil surface. Because the soil adsorption capacity of the treatment bed is limited, the application rate must be adjusted so ammonia and organic nitrogen additions do not exceed adsorbtive capacity. During the recovery period, adsorbed ammonia nitrogen and organic nitrogen in the aerobic zone are oxidized to NO_3-N which in turn must undergo denitrification. At this point, the C:N ratio becomes very critical. The C:N ratio for secondary wastewater effluent varies from 0.5-1.0. The stoichiometric equation for denitrification indicates a minimum requirement of 0.7 mg of carbon per 1.0 mg NO_3-N, but in actual practice this ratio has shown to be somewhat greater due to the fact that some carbon is assimilated by other than just denitrifying bacteria. Denitrification of agricultural wastewater required about 1.3 mg methanol-carbon per 1.0 mg NO_3-N (29). Because organic carbon is necessary for the denitrification process, other readily available sources of carbon could be used. One source is the primary effluent which generally contains about 54-108 mg/l TOC. Bleeding primary sewage effluent into secondary treated sewage effluent, the C:N ratio could be effectively increased to facilitate biological denitrificatin, once mixing ratios for optimizing nitrogen removal have been determined. Economical benefits gained by this procedure would be those associated with expenditures for a carbon source such as methanol or glucose. Once a suitable C:N ratio has been achieved, the proper application rate and operation cycles can be employed in order to create aerobic condition for nitrification while at the same time creating anaerobic conditions at the soil-water interface of treatment beds to achieve denitrification.

Investigation at Flushing Meadows found that adjusting the application rate to 3.2-8.6 gal/ft/day, a 75-80 percent reduction in removal of nitrogen could be accomplished following nine days of effluent application followed by five days recovery (30, 31, 60).

Studies at Ft. Devens, Massachusetts sewage treatment facility counted total nitrogen reduction of 40-60 percent under a two-day application - 14 days recovery cycle.

In order to optimize nitrification-dennitrification pathways for nitrogen removal, specific management and operation practices will require field experience in the New England environment.

6. Phosphorus

Phosphorus level in secondary effluent treated by rapid infiltration was assumed here to be about 13 mg/l PO_4-P, which would result in annual phosphorus additions to the treatment area of 2220 lb/ac-yr at Freetown-Fall River and 3360 lb/ac-yr at Bourne-Sandwich. Under these application rates, capacity of sand and gravel medium to adsorb and fix phosphorus could be a short-term feature. Adsorptive capacity of sandy soils in the range 250-400 lb/ac/ft. Using these values to approximate adsorptive life of a treatment site with groundwater at 30 feet, the phosphorus adsorption capacity would be satisfied in one to eight years.

Recent studies have shown that phosphorus adsorption in a soil as approximated by the Langmuir Adsorption tends to underestimate adsorption capacity of the soil (16, 50). Soils tend to rejuvenate phosphorus adsorption capabilities upon drying which would extend the life of a soil to remove phosphorus. Studies of the rapid infiltration basin at Ft. Devens, Massachusetts tend to bear this out (44). Analysis of the soil samples taken from the treatment basins which have received primary effluent for over 30 years show phosphorus levels in the range 1,500-1,900 lb/ac-ft. Analysis of groundwater samples from observation wells located around the application area showed total phosphorus levels were generally less than 2 mg/l PO_4-P although phosphorus levels in the applied effluent averaged 11 mg/l PO_4P.

7. Chlorides

Chloride levels in effluent are not expected to be reduced substantially due to stability of chloride compounds and mobility of the ion. This should result in minimal chloride retention within the sand and gravel medium of the treatment beds. Studies of rapid infiltration sites operated over extended periods of time show chloride levels in percolate from these sites were approximately equivalent to that of the applied effluent.

8. Sulfate

Sulfate levels are not expected to increase significantly in the treatment beds due to chemical fixation. Field studies have shown increases are not large. Satterwhite (44) observed sulfate levels in percolate samples were approximate to those found in the effluent. There is the possibility some sulfate can combine chemically with iron to form a ferrous sulfide precipitate where anaerobic conditions exist in the treatment beds. This could result in decreased infiltration due to clogging if sufficient recovery time is not permitted to oxidize ferrous sulfide precipitate.

9. Pathogenic Organisms

Wastewater effluent receiving additional renovation by rapid infiltration was assumed at this time to have been disinfected prior to application to the land either by chlorination or ozonation. Health and economic impacts stemming from either process are discussed in other sections of this report. Studies of rapid infiltration systems which have renovated unchlorinated wastewater effluents have shown that total coliform bacteria and fecal coliform bacteria are effectively treated to acceptable levels for potable water supplies by physical, chemical and biological processes of land treatment sites. Satterwhite (44) found total coliform and fecal coliform bacteria levels in unchlorinated primary sewage effluent were essentially removed by the rapid infiltration system. Counts of total coliform bacteria in the primary effluent applied to rapid infiltration treatment area varied between 18×10^6 and 52×10^6 per 100 ml. Groundwater samples taken directly beneath the treatment site contained total coliform counts in a range 200-4,000 per 100 ml of sample while coliform counts in samples collected from observation wells 300 feet from the application area ranged from zero to 300 per 100 ml of sample.

Bouwer (9) found the number of fecal coliform bacteria in unchlorinated secondary effluent applied to rapid infiltration systems ranged between 1×10^5 to 1×10^6, but after percolating through 30 feet of stratified sand and gravel, fecal coliform counts beneath the application area were less than 10 per 100 ml and were absent in wells located 100-200 feet distance from the application area. Most coliform bacteria were believed removed in the upper three feet of the treatment basins. When long inundation periods were used, two-three weeks, total coliform bacteria MPN values were 200 per 100 ml; however, bacteria observed under short flooding period of two to three days were 5 per 100 ml.

Evaluation of the rapid infiltration system at Lake George, New York has shown total coliform bacteria were effectively treated by rapid infiltration of unchlorinated secondary sewage effluent (5). Total counts of coliform bacteria in the effluent numbered 600-2,400 per 100 ml of sample. Samples taken at five-foot showed coliform bacteria counts were reduced to 0.- 350 per 100 ml and after percolating through ten feet of sand and gravel the counts ranged 15-50/100 ml.

Disinfection of effluent applied to the land in spray irrigation systems may be a necessity because of unresolved concerns centered around hygienic effects of aerosols. However, disinfection of effluent applied to rapid infiltration sites may not be necessary due to the application method and renovation obtainable as effluent percolates to the water table.

Concerns of viruses applied to very permeable sand and gravels will require additional investigation as to their fate in rapid infiltration treatment system. Present data is inconclusive as to capacity of soils to remove viruses, thus, additional laboratory and field investigations are needed.

Further discussion of the possible hygienic and environmental impacts associated with the proposed land treatment of secondary effluent may be found in Volume 13C.

IV. PROPOSED SLUDGE MANAGEMENT

A. General

Table 9 gives design information related to the treatment and disposal of sludges produced at the regional treatment facilities affiliated with the land application system. Sludges produced at four of the five regional treatment plants will be thickened and stored prior to being pumped to the Dedham regional water pollution control facility where all sludges will be handled for ultimate disposal.

At each regional facility, the primary and secondary sludges will be kept separate until after thickening. The thickened sludges will be pumped to a central sludge handling and processing facility at the Dedham regional plant. Primary sludges will be thickened in gravity thickeners, and secondary or biological sludges, will be thickened in flotation thickeners. Both types of sludges will be blended and put into storage tanks at each regional treatment facility prior to being pumped to the Dedham plant. Sufficient closed storage for sludge will be provided at each regional plant, to hold 5 days of normal sludge production. Sludge storage facilities at the Dedham plant will be large enough to hold 10 days storage. Table 21 presents data regarding storage at all 5 regional plants.

Previous studies on sludge management which were made for the Metropolitan District Commission, Commonwealth of Massachusetts, by Havens and Emerson in 1973, were used as guidelines in preparing the sludge management plan (22). These studies, together with the gathering groundswell of emphasis on conservation of energy and fuel, indicate that all aspects of sludge management, as they relate to this plan's development, will probably be served best if the sludge is dewatered to as high a solids concentration as possible without any pretreatment by heat or chemicals, and then incinerated in multiple hearth furnaces with waste heat recovery. The complete sludge management plan consists of the following sequential operations:

(1) Primary Solids thickening and secondary solids thickening at each treatment plant,

(2) Storage at each plant,

(3) Pipeline conveyance of thickened sludges to storage at the Dedham plant,

(4) Chemical conditioning and vacuum filtration dewatering,

(5) Multiple hearth incineration with waste heat recovery,

(6) Ash disposal to lagoons, then truck haul to sanitary landfill.

TABLE 21

SLUDGE STORAGE CAPACITIES

AT REGIONAL TREATMENT PLANTS

PLANT LOCATION	SLUDGE STORAGE* GALLONS
Woburn	700,000
Medford	677,000
Watertown	1,000,000
Canton	677,000
Dedham	2,000,000**

*Based on blended sludge at 5.5 percent solids and 5 days average sludge production.

**10 days storage provided.

B. Sludge Conveyance System

The thickened sludges will be pumped from four of the regional treatment plants (Woburn, Medford, Watertown, and Canton) to the Dedham facility where they will be stored prior to dewatering and incineration. The sludge conveyance system will consist of force mains extending from Woburn to Dedham and from Canton to Dedham. Figure 14 shows a schematic diagram of the sludge conveyance system. Slude will be pumped by means of trash pumps to the Dedham plant. The sludge force mains will be placed in public rights-of-way in streets and roadways. Sufficient capacity has been provided in the conveyance piping system to enable each regional plant to pump sludge without restriction. Pumping capacity at each plant is adequate to pump down storage tanks within a 24-hour period.

C. Sludge Dewatering

At the Dedham WPCF, sludge will be pumped from storage facilities, as shown in Figure 14, to the sludge dewatering building where vacuum filters will dewater the sludge to produce a sludge cake having a moisture content ranging from 70 to 75 percent. Provision will be made to chemically condition the sludge with lime and ferric chloride, or organic polymers, as may be required. Table 9 presents some basic design criteria regarding sludge thickening and dewatering, however, because these facilities are highly sensitive to variations in sludge characteristics, no detailed or specific design can be presented. However, this in no way prevents determination of general facilities sizing and costing since provision will be made to handle the most difficult sludges.

The dewatered sludge will be stored in bins from which it will be drawn as required by a screw conveyor system, to be placed on a belt conveyor which will then conduct the sludge to the incinerator facility. All of the above facilities will be either housed in the sludge dewatering building or enclosed so that odors will be reduced and inclement weather will not cause any problems.

D. Sludge Incineration

The multiple hearth furnace has been widely used for incineration of sewage sludge for which it is well adapted. It can accept relatively large lumps of materials, is capable of handling and evaporating large amounts of moisture, and is designed to give good agitation and mixing of the burning mass. The size of the furnace, the spacing of the hearths, and the quantity of combustion air must be carefully selected for the problem at hand in order to provide efficient inceneration, but in general, the multiple hearth furnace is not an unduly sensitive combustion device because its large hot refractory area can absorb fairly large fluctuations in feed quantity and quality.

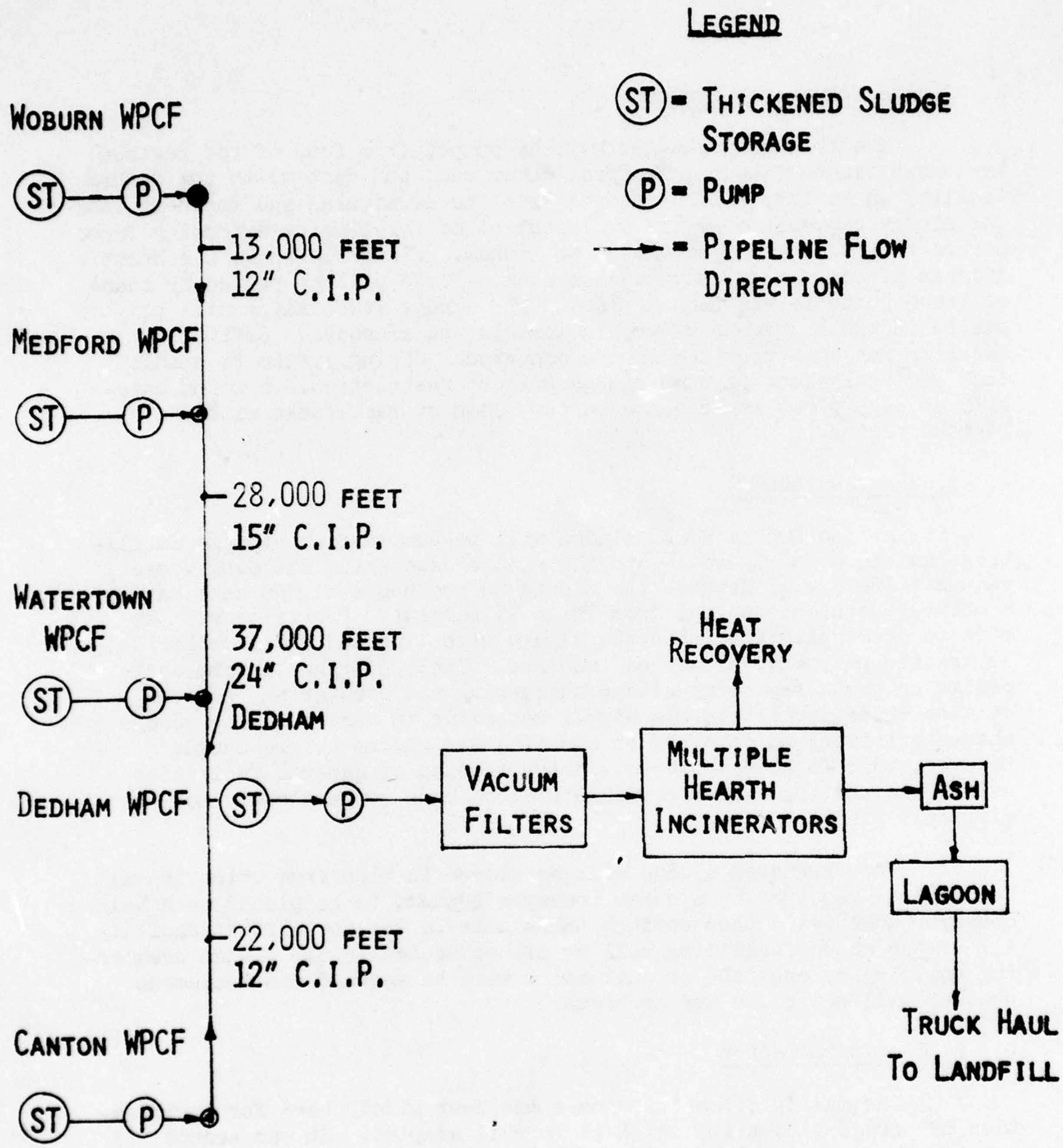


FIGURE 14 SCHEMATIC DIAGRAM OF SLUDGE CONVEYANCE SYSTEM

As an alternate, the fluidized bed incinerator has been used for the combustion of wastewater sludges since the early 1960's. This device consists of a vertical refractory lined cylindrical shell which contains a bed of sand at the bottom into which the waste material is fed. The sand bed is supported by a perforated grid plate through which heated compressed air passes upward from a bottom plenum chamber. The air lifts and expands the sand bed causing it to be "fluidized" during which condition intense agitation and mixing take place. Feed sludge, introduced into the fluidized bed, is rapidly distributed throughout the furnace and undergoes rapid drying and combustion. The hot flue gases leave the combustion zone near the top of the reactor and pass through cyclonic separators and scrubbers which remove fly ash. Like the multiple hearth incinerator, the fluidized bed can absorb fluctuations in feed quantity and volatile content because of its large heat reservoirs.

In recent years, incineration as a means of sludge disposal has been questioned on the grounds of environmental impact, namely, its contribution to air pollution problems and the destruction of a useful, recyclable resource. Based on studies made of air pollution control facilities placed at existing incinerator plants, it can be stated with complete assurance that sludge incinerators can be properly designed to meet the most vigorous standards for particulates emissions. Thus, from the standpoint of air pollution, sludge incineration is a practical and feasible alternative for sludge disposal.

The use of anaerobic digestion to recover gas for heat and plant operation does not offer a suitable economic alternative to the direct incineration of sewage solids. Capital costs and Operation and Maintenance Costs would each be almost 25 percent greater according to detailed studies made for the MDC. Anaerobic digestion requires a very large capital investment and high manpower costs; it has become less popular to control and it is highly sensitive to upset.

In an incineration flowsheet for sludge disposal, energy recovery in the form of digester gas is less efficient than recovery of heat energy from undigested solids. Incineration allows a portion of the heat generated in the combustion process to be utilized for beneficial purposes. Some of the heat is recycled to the incineration process while the excess heat can be recovered for power generation. The recovery of the waste heat allows partial recovery of the cost of sludge processing and disposal, and it reduces the need for fossil fuels.

Studies made for the MDC considered three feasible energy recovery systems: digester gas, digester gas and waste heat, and waste heat alone (22). For the same amounts of sludge, waste heat recovery employed alone was found to produce 14 percent more energy than from digester gas recovery alone. When both forms of energy recovery are employed, the total recoverable energy is greater than digester gas recovery by about 67 percent and greater than waste heat recovery alone by 47 percent. This comparison indicates the relative gross energy available from each of the systems but it does not show which system is more economical. When unit energy costs are compared, the waste heat recovery system is lower than either the digester gas system alone or the digester gas plus waste heat recovery system. However, all three systems can produce power cheaper than the current commercial rate, which was about 1.0¢/kwh in mid-1973.

The sludge disposal building at the Dedham WPCF will include chemical storage and conditioning equipment, sludge dewatering facilities, and some incineration equipment. Vacuum filters and incineratros will be sized so that two filters will serve one incinerator. Sludge cake movement from the vacuum filters to the incinerators will be by belt conveyors and/or screw conveyors. Standby vacuum filters and incinerators will be provided to insure continuous operation at the maximum daily sludge production rate. In general, standby units will be provided for all mechanical equipment to permit uninterrupted operation during equipment maintenance periods.

A high degree of automation will be incorporated to reduce manpower costs and to provide more exacting control of the unit processes. Centralized control will be provided by means of a detailed graphic panel which will indicate visually the status of all sludge handling processes.

Because site locations for each regional wastewater pollution control facility are only approximately known, details of soil conditions for determining foundation requirements for structures are not available. It is evident that heavy structures such as sludge holding tanks and the sludge disposal building will require pile foundations. Shallow tanks, such as gravity and flotation thickeners are not assumed to require pile foundations for their support. All thickeners and sludge storage tanks would be covered and provided with facilities for odor control.

E. Disposal of Screenings, Grit and Incinerator Ash

In addition to the sludge which must be disposed of at the regional waste treatment facility, other debris and solids must be handled and disposed.

Large screenings are normally removed by mechanical racks and stored in a bin or on a drained platform to dewater. These solids are then removed for burial or taken along with dewatered sludge to the incinerator to be burned. Smaller screenings will be comminuted and removed from the flow stream in the sedimentation units.

Grit from aerated grit removal facilities will be washed prior to disposal. Since it has a high inert fraction, it can be recycled for reuse as road fill. Excess amounts of grit will be buried in a sanitary landfill.

Incinerator ash will be discharged as a solids slurry to lagoons where it will settle and compact. Ash will be added to the lagoon to displace supernatant liquor, which will be recycled to the raw waste inflow point. After the lagoon has been filled with ash and allowed to stand and dewater to a low moisture content (30 to 40%), the lagoon contents will be removed by mechanical loaders and truck filled to burial sites.

V. COSTS

A. Methodology

Estimates for capital and operation and maintenance costs presented below were developed using the most recent cost information available from projects of comparable magnitude. Because much of the basic planning for Concept 5 is dependent upon assumptions regarding treatment sites and the plant design of various facilities in the absence of important criteria, particularly criteria related to waste flow rates, waste characteristics, sludge characteristics, and influences of industrial wastes, the costs submitted herein can only be described as being 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. Construction cost estimates do not provide for extraordinary costs related to rock excavation, site dewatering, or piling. Such costs cannot be reasonably included in average cost estimates for reasons previously cited.

Use was made of several guides and references in making cost estimates. The basic format established a contingency factor of 35 percent to be applied to the construction cost to cover construction contingencies, and engineering, legal, administrative, and supervisory fees. Construction cost data was selected from previous experience on projects of similar nature, Engineering News-Record (ENR) cost data and indexes, and several pertinent publications furnished by Federal agencies (10, 22, 20, 38, 54).

Wherever possible cost curve plots were developed or used directly from reliable sources. All costs were projected to reflect an ENR index of 2200. In the development of amortization and annual costs a life expectancy of 25 years for waste treatment plants and 50 years for pumping stations and pipelines and an interest rate of 5 5/8 percent were used.

B. Capital Costs

A summary of capital costs for this plan is presented in Table 22. The capital costs are subdivided into four major categories: (1) Waste Treatment Facilities Costs, (2) Effluent Conveyance System Costs, (3) Other Pumping Station and Piping Costs, and (4) Land Application Facilities Costs. The total capital costs for Concept 5 are estimated to be $1,263,106,000.

TABLE 22

SUMMARY OF CAPITAL COSTS FOR CONCEPT 5

Waste Treatment Facilities

1. WPCF's utilizing Land Application of Effluent (Includes Secondary Treatment with Sludge Thickening)

Woburn WPCF	31 MGD	$20,177,000	
Medford	30 "	19,525,000	
Watertown	45 "	29,218,000	
Dedham	41 "	26,809,000	
Canton	30 "	19,525,000	
Ipswich	2.4 "	2,600,000	
Hamilton	1.4 "	2,200,000	
Middleton	2.4 "	2,600,000	
	Subtotal		$122,654,000

2. Sludge Conveyance and Disposal System

Transmission Force Mains	$ 4,592,400	
Sludge Pumping Stations	1,844,600	
Vacuum Filters, Chem. Conditioning	5,650,000	
Incineration & Heat Recovery System Ash Lagoon	4,734,000	
Subtotal		$ 16,821,000

3. WPCF's not Utilizing Land Application (Ref: M&E)

Deer Island WPCF	285 MGD	$194,000,000
Nut Island	100 "	146,000,000
Lynn	24 "	33,000,000
Chelmsford	2.1 "	3,700,000
Scituate	5.5 "	5,600,000
Cohasset	2.0 "	4,600,000
SESD	47 "	26,100,000
Marshfield	3.0 "	5,900,000
Billerica	6.4 "	10,900,000
Swampscott	3.2 "	1,800,000
Manchester	1.6 "	2,100,000
Hudson	3.9 "	7,000,000
Milford	3.7 "	4,500,000
Rockland	1.7 "	3,400,000
Rockport	1.4 "	2,800,000

TABLE 22 (Cont.)

SUMMARY OF CAPITAL COSTS FOR CONCEPT 5

Gloucester	5.8 MGD	$ 12,800,000
Essex	0.4 "	1,300,000
Hull	1.0 "	2,900,000
Medfield	4.0 "	10,800,000
Medway	8.0 "	16,100,000
Concord	8.3 "	16,500,000
Sudbury	5.9 "	13,300,000
Marlboro (W)	9.3 "	14,200,000
Marlboro (E)	4.8 "	0

Subtotal $539,300,000

TOTAL COST OF WASTE TREATMENT FACILITIES

Effluent Conveyance System

1. Mole Tunnel, 10 ft. Dia., 100,000 ft., with Tunnel Lining and including 5 Drop Shafts — $ 88,898,000

2. Tunnel Lift Station, 250-MGD Capacity — 5,070,000

3. Transmission Pumping Station, 350 MGD Capacity, including Equalization Storage — 16,000,000

4. Pumping Stations at Ipswich, Hamilton and Middleton — 390,000

4. Transmission Force Mains:

From-To	Size	Length, ft.	
Canton-Pt. A	90"	116,000	$49,220,000
Pt. A-Freetown St.	54"	58,000	15,820,000
Pt. A-Pt. B	90"	85,000	36,070,000
Pt. B-Plymouth St.	48"	16,000	3,880,000
Pt. B-Pt. C	90"	42,000	17,820,000
Pt. C-Bourne St.	78"	37,000	14,000,000
Hamilton-Boxford (North)	12"	35,000	1,124,000

TABLE 22 (Cont.)

SUMMARY OF CAPITAL COSTS FOR CONCEPT 5

From-To	Size	Length, Ft.	
Ipswich-Ipswich, R.I.	12"	26,000	$ 674,000
Middleton-Boxford (South)	12"	12,000	386,000

Subtotal $138,994,000

TOTAL COST OF EFFLUENT CONVEYANCE SYSTEM $249,352,000

TOTAL COST ALL OTHER PUMPING STATIONS AND PIPING (Ref: M&E) $224,420,000

Land Application Facilities

1. Land Costs

Freetown:	7,130 Ac @ $1,000/Ac	$ 7,130,000	
Carver:	8,086 Ac @ $1,000/Ac	8,086,000	
Bourne:	3,475 Ac @ $2,000/Ac	6,950,000	
Ipswich:	60 Ac @ $2,000/Ac	120,000	
Hamilton:	47 Ac @ $2,000/Ac	94,000	
Middleton:	84 Ac @ $2,000/Ac	168,000	
		$22,548,000	
	Contingencies @ 25%	5,637,000	
	Subtotal		$ 28,185,000

2. Spray Irrigation Facilities including Storage Lagoons, Pumping Station, Piping and Valves, Monitoring Wells, and Sprinkling Devices

Freetown:	6,920 Ac @ $2,400/Ac	$16,650,000	
Carver:	8,086 Ac @ $2,400/Ac	19,400,000	
	Subtotal		$ 36,050,000

3. Rapid Infiltration Facilities including Storage Lagoons, Piping and Valves, Monitoring Wells, and Site Preparation

Freetown:	210 Ac @ $12,200/Ac	$ 2,562,000	
Bourne:	3,475 Ac A $12,200/Ac	42,395,000	
Ipswich:	44 Ac @ $12,200/Ac	537,000	
Hamilton:	24 Ac @ $12,200/Ac	295,000	
Middleton:	44 Ac @ $12,200/Ac	537,000	
	Subtotal		$ 46,324,000
TOTAL COST OF LAND APPLICATION FACILITIES			$ 110,559,000
TOTAL CAPITAL COSTS FOR CONCEPT 5			$1,263,106,000

1. Waste Treatment Facilities Costs

Waste treatment facilities costs for regional plants utilizing land application of effluent include costs for pretreatment, primary and secondary biological treatment, disinfection, sludge thickening and dewatering, sludge conveyance, sludge incineration with heat recovery, and ash disposal.

The basic construction costs for each WPCF were obtained by using the cost curve plots shown in Figures 15, 16, and 17. Sludge production was estimated at 1.0 tons of dry weight solids per million gallons of plant flow. No allowance for treatment plant land costs was included in the cost estimate.

Waste treatment facilities costs for plants not included in the land application scheme are presented as a separate item in Table 23. See Volume 4 for the development of these costs. The costs for these facilities is included so that the total capital costs for Concept 5 can be compared on an equal basis with the other concepts developed for the BH-EMMA.

As shown in Table 22, capital costs for the waste treatment facilities utilizing land application total $122,054,000 whereas costs for the regional water pollution control facilities not utilizing the land application scheme are estimated to be $539,300,000.

The cost of sludge conveyance and disposal facilities for the regional wastewater treatment plants utilizing the land application scheme total $16,821,000.

The total capital costs of all waste treatment facilities associated with Concept 5 is estimated to be $678,775,000 and constitutes about 57 percent of the total capital costs for Concept 5.

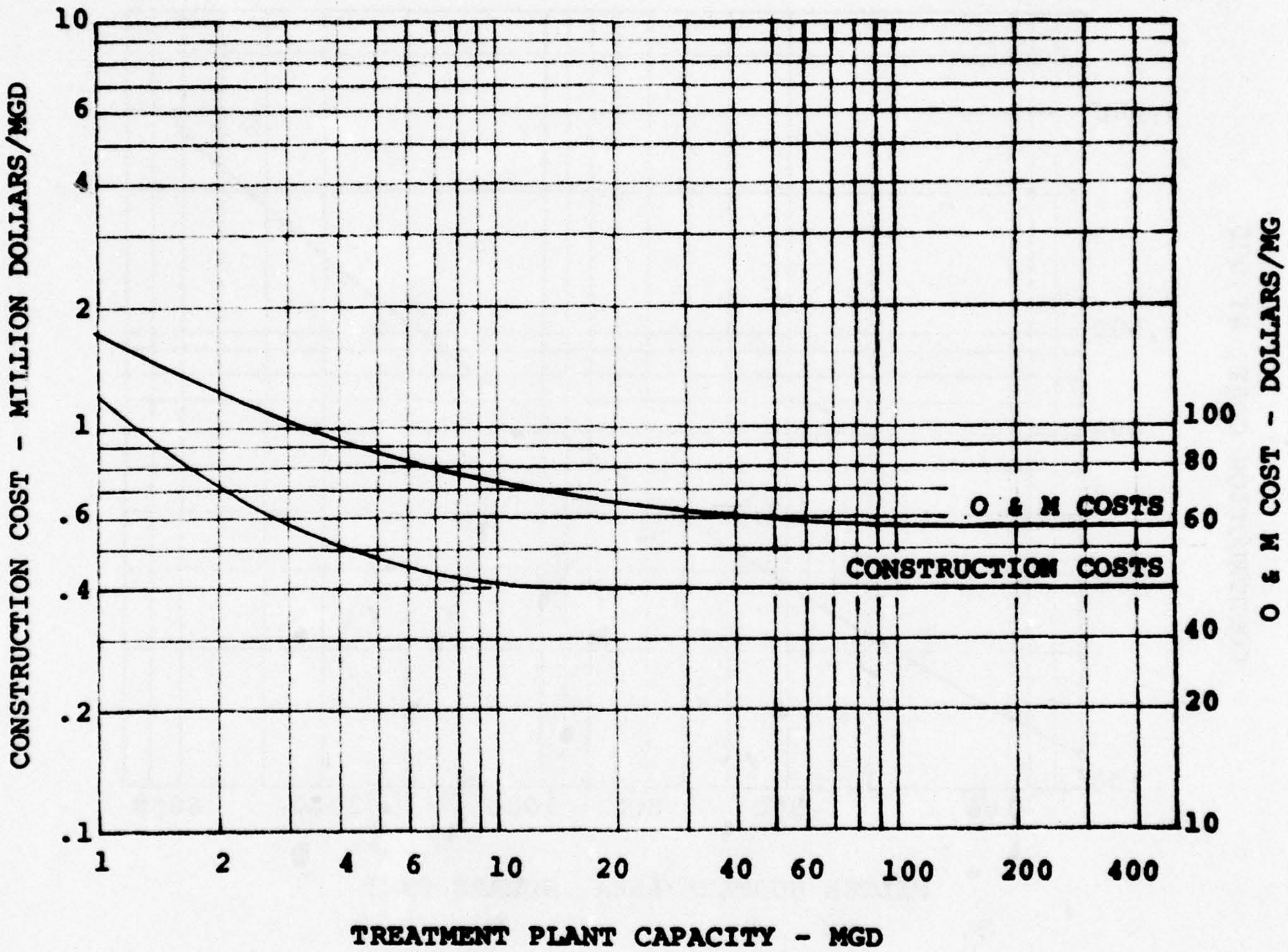


FIGURE 15. SECONDARY TREATMENT COST CURVES*

* After Bauer Engineering (6)

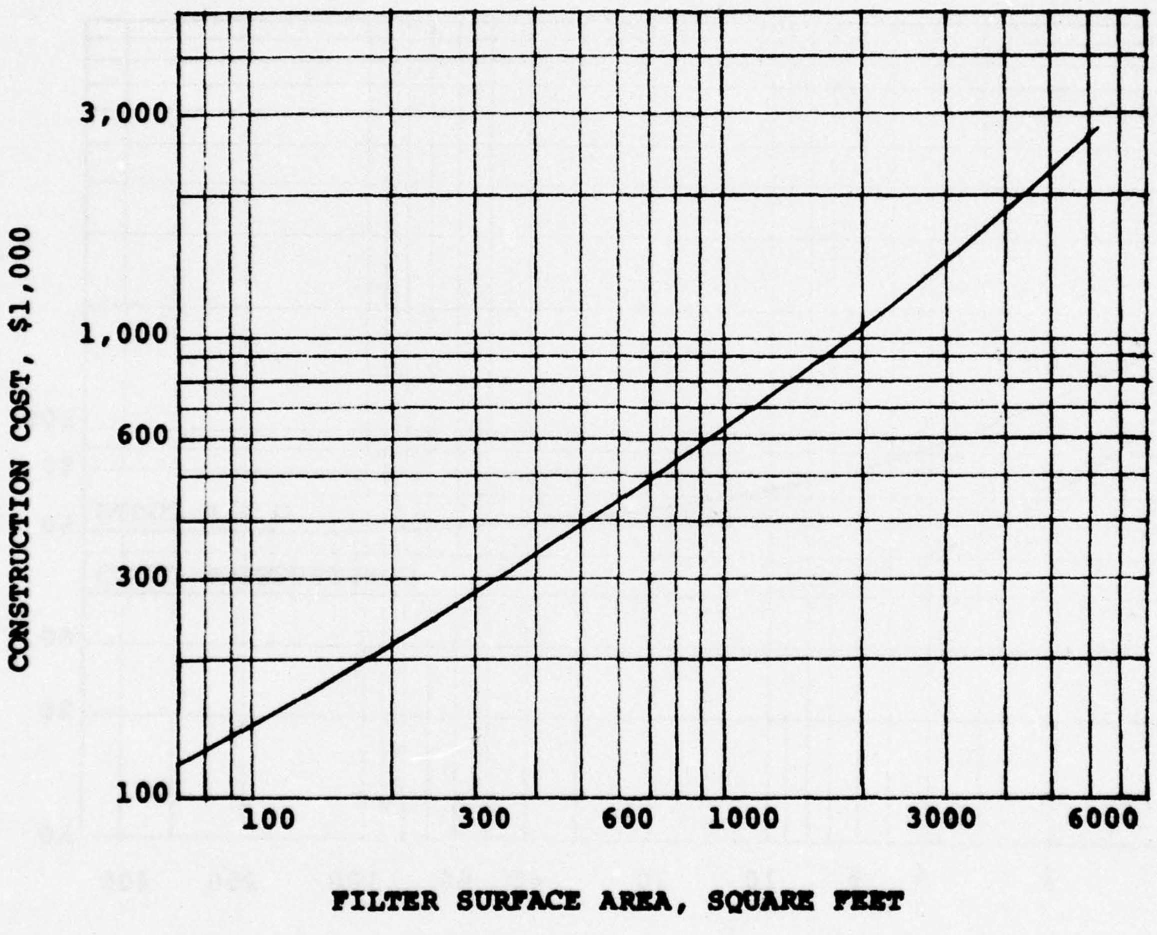


FIGURE 16. VACUUM FILTRATION CONSTRUCTION COSTS*

* After W. L. Patterson and R. F. Banker (38)

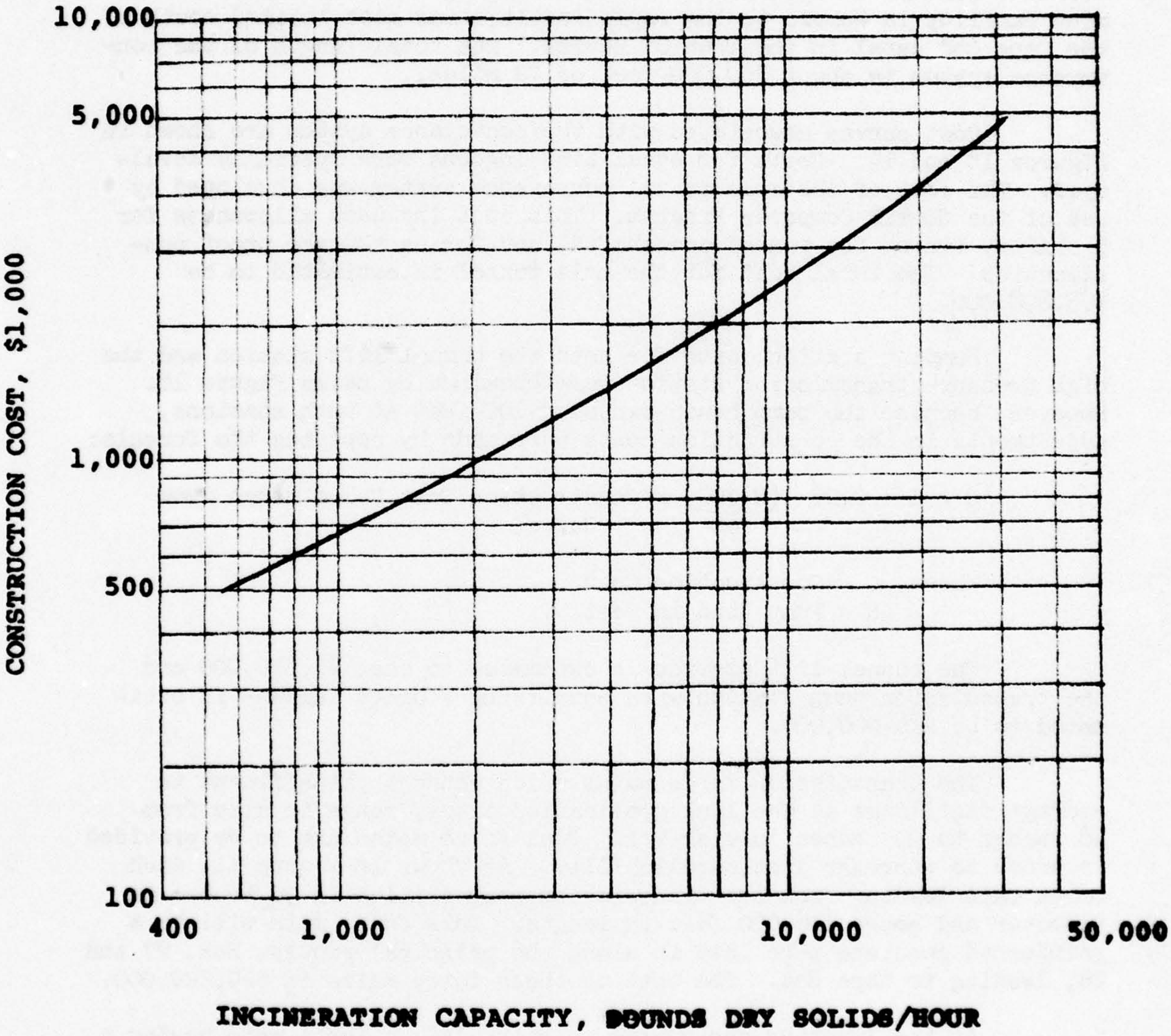


FIGURE 17. SLUDGE INCINERATION COSTS*

*After W.L. Patterson and R.F. Banker (38)

2. Effluent Conveyance System Costs

The effluent conveyance system includes the mole tunnel system, the tunnel life station, equalizing lagoons, a high pressure transmission pumping station, and force mains. As shown in Figure 10, the entire effluent conveyance system extends from the regional wastewater treatment facility in Woburn to the rapid infiltration site located south of the Cape Cod canal in the town of Bourne. The total length of the conveyance system is about 380,000 feet or 72 miles.

Cost curves associated with the conveyance system are shown in Figures 18 and 19. Costs for equalizing lagoons were specially developed. The cost of the mole tunnel conveyance system was developed by use of the COSTUN Computer Program. This cost includes allowances for 5 shafts, lining for tunnel and shafts, and for earthquake proof construction. The total cost for the mole tunnel is estimated to be $88,898,000.

Pumping station costs for both the tunnel lift station and the high pressure transmission station were obtained by using Figure 18. However, because the pump heads exceeded 100 feet at both stations, adjustments in the construction costs were made by applying the formula:

$$C = 1 + 0.25 \frac{(H-100)}{100} \times \text{Construction Cost Value taken from Curve}$$

Where, C = Construction Cost
H = Pump Head in Feet

The tunnel lift station is estimated to cost $5,070,000 and the transmission pump station with equalizing storage lagoons is estimated to be $16,000,000.

The transmission force mains which conduct the effluent to storage facilities at the land application sites, range in size from 48 inches to 90 inches in diameter. Dual force mains are to be provided in order to increase system reliability. As shown in Figure 11, each force main leading from the transmission pump station is 90 inches in diameter and about 116,000 feet in length. This force main will be a reinforced concrete pipe laid in along the principal routes, Nos. 27 and 24, leading to Cape Cod. The cost of these force mains is $49,220,000.

At the junction designated as Point "A", a force main having a diameter of 54 inches branches off to conduct flow to the storage lagoons at the Freetown-Fall River land application sites. The remaing portion of the flow is conveyed in an 90-inch diameter pipe some 85,000 feet further to the junction designated as Point "B" where a 48-inch line branches off to storage lagoons in the Carver-Plymouth region. The total cost of these force mains is $55,770,000.

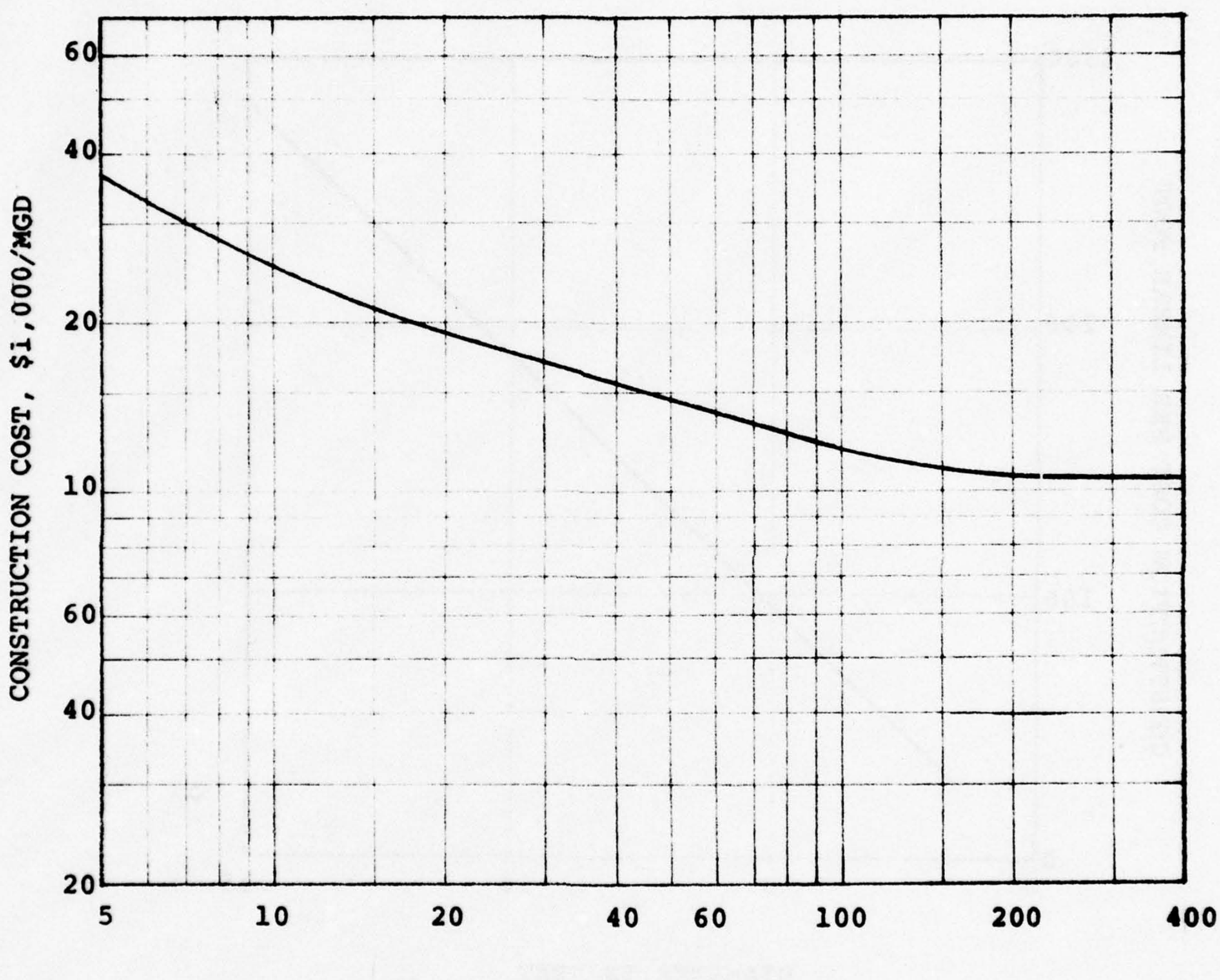


FIGURE 18 . PUMPING STATION COSTS*

*After Bauer Engineering, Inc., (6)

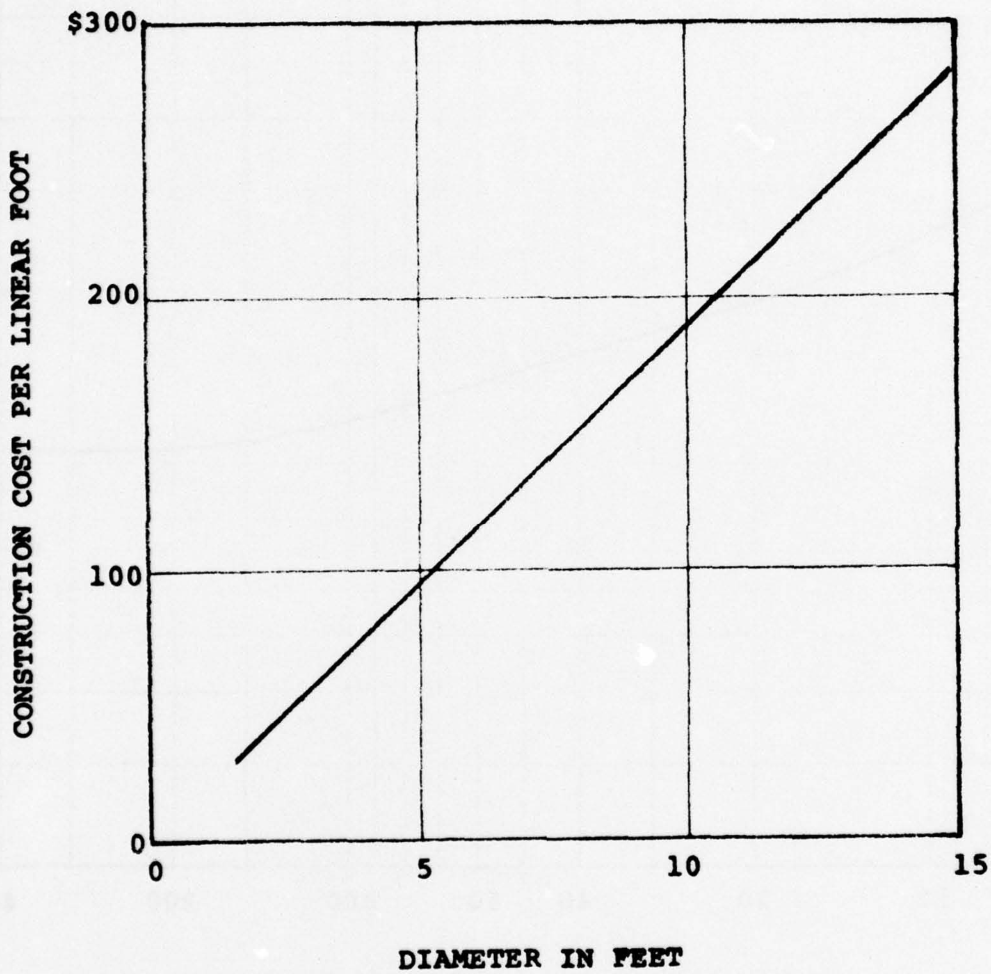


FIGURE 19. GRAVITY SEWER AND FORCE MAIN COSTS*

*After Bauer Engineering, Inc. (6)

From Point "B" to Point "C", a distance of 42,000 feet, the flow can enter storage lagoons at the rapid infiltration sites located in Bourne on the north side of the Cape Cod Canal. The remaining flow is to be carried across the canal in 78-inch diameter pipes. This crossing may be made by supporting the force mains on the understructure of the bridge or it may be done by constructing a siphon under the canal. The cost of these force mains is estimated to be $31,820,000 which includes an allowance of $500,000 over and above the cost of the pipe, in providing for the canal crossing.

As shown in Table 22, the total cost for all pressure force mains exceeds $138,994,000 and the total cost for the entire effluent conveyance system is $249,352,000.

3. Land Application Facilities Costs

Land application facilities will be located in three major areas: (1) Freetown-Fall River area, (2) Carver-Plymouth area, and (3) Bourne-Sandwich area. Typical facilities at each site include storage lagoons having sufficient capacity to hold 14 days of the average design flow rate, a pumping station, distribution piping, valves, and spraying devices. Land application will be done by spray irrigation in the summer and rapid infiltration in the winter at the sites indicated in Figure 11. Real estate costs for the application sites are estimated to be $28,185,000. The land costs were determined by utilizing unit acre costs developed from recent sales of comparable lands. The land costs also include an anticipated cost escalation factor of 25 percent.

Total costs for spray irrigation and rapid infiltration facilities are estimated to be $36,050,000 and $46,324,000, respectively. Unit costs for the development of spray irrigation and rapid infiltration sites were obtained by designing modular facilities for piping, storage lagoons, etc. The costs obtained from these studies showed that development costs were $2,400 per acre for spray irrigation sites and $12,200 per acre for rapid infiltration sites.

C. Operation & Maintenance Costs

A summary of annual operation and maintenance costs for Concept 5 is presented in Table 23. Operation and maintenance costs are divided into 3 main groups: (1) O & M costs for waste treatment facilities, (2) O & M costs for the effluent conveyance system, and (3) O & M costs for the land application facilities. The total annual operation and maintenance costs for Concept 5 are estimated to be $42,040,000.

In general, operation and maintenance costs consist of labor costs, and material and supply costs. While operation and maintenance costs can be related to the same design parameters that were used for determining construction costs, other parameters are often more appropriate.

TABLE 23

SUMMARY OF ANNUAL OPERATION & MAINTENANCE COSTS

FOR CONCEPT 5

Waste Treatment Facilities

1. WPCF' Utilizing Land Application of Effluent

Woburn	$ 980,000	
Medford	963,000	
Watertown	1,344,000	
Dedham	1,244,000	
Canton	963,000	
Hamilton	123,000	
Ipswich	210,000	
Middleton	210,000	
Subtotal		$6,037,000

2. WPCF's Not Utilizing Land Application (Ref: 35)

Deer Island & Nut Island	$14,000,000	
Lynn	2,004,000	
Chelmsford	277,000	
Scituate	525,000	
Cohasset	274,000	
SESD	3,572,000	
Marshfield	365,000	
Billerica	1,188,000	
Swampscott	365,000	
Manchester	219,000	
Hudson	855,000	
Milford	817,000	
Rockland	446,000	
Rockport	182,000	
Gloucester	765,000	
Essex	109,000	
Hull	146,000	
Medfield	855,000	
Medway	1,374,000	
Concord	1,449,000	
Marlborough (East)	965,000	
Sudbury	1,129,000	
Marlborough (West)	1,485,000	
Subtotal		$33,366,000

TABLE 23 (Cont.)

SUMMARY OF ANNUAL OPERATION & MAINTENANCE COSTS

FOR CONCEPT 5

3.	Sludge conveyance & Disposal System Sludge Pumping, Conveyance Force Mains, Vacuum Filtration, Chemical Conditioning, Incineration, Ash Disposal		$ 168,000
	TOTAL O & M COSTS FOR WASTE TREATMENT FACILITYS		$39,571,000
Effluent Conveyance System			
1.	Mole Tunnels	$ 89,000	
2.	Pumping Stations & Force Mains	1,556,000	
	TOTAL O & M COSTS FOR CONVEYANCE SYSTEM		$1,645,000
Land Application Facilities			
1.	Spray Irrigation	$ 697,000	
2.	Rapid Infiltration	127,000	
	TOTAL O & M COSTS FOR LAND APPLICATION		$ 824,000
	TOTAL ANNUAL OPERATION & MAINTENANCE COSTS FOR CONCEPT 5		$42,040,000

Labor costs indicate the total personnel requirement to adequately operate and maintain facilities. Material and supply costs include power, fuel, and chemicals.

A distinction between available man-power time and effective working time was not made in determining O & M costs, nor was any allowance included in material and supply costs for contract maintenance work.

1. Waste Treatment Facilities O & M Costs

Manpower requirements and costs for waste treatment facilities associated with the major land application scheme are shown in Table 24. These total $2,660,000.

Table 25 shows annual power requirements and costs for the major waste treatment facilities and Table 26 shows materials, chemicals, and other costs associated with these treatment plant operations. These costs total $1,077,000 and $1,757,000, respectively. Table 27 summarizes all O & M costs for Waste Treatment Facilities associated with land application.

2. Effluent Conveyance System O & M Costs

An allowance for effluent conveyance system O & M costs was taken as 0.1 percent of the capital costs. These costs total $1,645,000 and include the costs for the conveyance system from the Hamilton, Ipswich and Middleton Plants.

3. Land Application Facilities O & M Costs

An allowance for land application facilities O & M costs was taken as 1 percent of the capital cost of these facilities. These costs total $824,000.

4. Sludge Conveyance and Disposal System O & M Costs

An allowance for sludge conveyance and disposal system O & M costs was taken as 1 percent of capital costs. These costs total $168,000.

D. Capitalized Treatment Expense

In order to obtain comparative treatment cost values for Concept 5, a cost analysis of each regional waste treatment plant was made to determine its annual treatment expense. For this purpose the following factors were employed:

Annaul interest rate	5 5/8%
Waste treatment plant life	25 years
Life of Pumping Stations & Pipelines, etc.	50 years

TABLE 24

MANPOWER REQUIREMENTS & COSTS FOR WASTE TREATMENT FACILITIES

OCCUPATION	Annual Salary ($)	Woburn No.	Woburn Cost ($)	Medford No.	Medford Cost ($)	Watertown No.	Watertown Cost ($)	Canton No.	Canton Cost ($)	Dedham No.	Dedham Cost ($)
		TREATMENT FACILITY									
Superintendent	20	1	20	1	20	1	20	1	20	1	20
Asst. Superintendent	15	1	15	1	15	1	15	1	15	1	15
Clerk Typist	10	1	10	1	10	2	20	1	10	2	20
Operations Super.	15					1	15			1	15
Shift Foreman	15	1	15	1	15	2	30	1	15	2	30
Operator II	15	6	90	6	90	9	135	6	90	8	120
Operator I	10	10	100	10	100	12	120	10	100	12	120
Auto Equipment Oper.	10	4	40	4	40	4	40	4	40	4	40
Mech. Maintenance Foreman	15	1	15	1	15	1	15	1	15	1	15
Maint. Mechanic II	15	2	30	2	30	2	30	2	30	2	30
Maint. Mechanic I	10	2	20	2	20	2	20	2	20	2	20
Electrician II	15	1	15	1	15	1	15	1	15	1	15
Electrician I	10	1	10	1	10	1	10	1	10	1	10
Maint. Helper	10	3	30	3	30	4	40	3	30	4	40
Laborer	10	4	40	4	40	5	50	4	40	5	50
Custodian	10					1	10				
Lab. Technician	15	2	30	2	30	3	45	2	30	2	30
TOTALS		40	$480	40	$480	52	$630	40	$480	49	$590
MANPOWER COSTS PER MG			$42.00		$44.00		$38.00		$44.00		$39.00

Costs are in Thousands of Dollars except costs per MG

TABLE 25

POWER REQUIREMENTS & COSTS FOR
WASTEWATER TREATMENT FACILITIES

Plant Location	Design Flow, (MGD)	Annual Flow, (MG)	Required (H.P.*)	Annual Cost ($1000's)	Cost Per (MG)
Woburn	31	11,315	963	$ 189	$16.70
Medford	30	10,950	932	$ 182	$16.62
Watertown	45	16,425	1,398	$ 274	$16.68
Canton	30	10,950	932	$ 182	$16.62
Dedham	41	14,965	1,275	$ 250	$16.71
TOTALS	177	64,605	5,500	$1,077	$16.67

*Ref. (35)

TABLE 26

MATERIALS, **CHEMICALS** & SUPPLIES COSTS FOR MAJOR WASTE TREATMENT FACILITIES

Vacuum Filtration Costs

Plant Location	Design Flow, (MGD)	Annual Flow, (MG)	Annual Sludge Production (Dry tons)	Chem. (10^3)	Other Materials (10^3)	Annual** Chlorine Costs (10^3)	Cost*** of Supplies (10^3)	Total Annual Costs (10^3)	Cost Per MG
Woburn	31	11,315	8,260	59	29	19	204	311	$27.49
Medford	30	10,950	7,994	57	28	18	198	301	27.49
Watertown	45	16,425	11,990	80	37	27	296	440	26.79
Canton	30	10,950	7,994	57	28	18	198	301	27.49
Dedham	41	14,965	10,924	75	35	25	269	404	27.00
								1757	27.20

**Computed at $1,67/MG, Ref. (71)
***Computed at 1% of Capital Costs, Ref. (6)

TABLE 27

SUMMARY OF O & M COSTS FOR WASTE TREATMENT FACILITIES

ANNUAL COSTS*

Plant Location	Power	Chemicals & Supplies	Labor	Total
Woburn	189	311	480	980
Medford	182	301	480	963
Watertown	274	440	630	1,344
Canton	182	301	480	963
Dedham	250	404	590	1,244
Hamilton	23	38	62	123
Ipswich	40	65	105	210
Middleton	40	65	105	210
TOTALS	1,180	1,925	2,932	6,037

*Annual Costs given in thousands of dollars

Utilizing these factors the proposed regional treatment plants at Woburn, Medford, Watertown, Dedham and Canton each had capitalized treatment costs of 22¢/1000 gallons.

When the total capitalized expense for the land application portion of Concept 5 was determined it was found to be 57¢/1000 gallons. This cost does not reflect any financial return or gain from waste heat recovery, sale of crops, or benefit from renovated water. The total capitalized expense for Concept 5 is 42¢/1000 gallons.

E. Reuse Considerations

The reclaimed water from a land application system has excellent potential for a number of purposes. Depending upon the mode of application employed, relatively high removals of pollutants can be attained provided that optimum conditions are maintained. Table 28 shows the principal pollutant characteristics of a typical secondary treatment plant effluent and the removal percentages that would be obtained from the spray irrigation and rapid infiltration modes of land application. These removals would transform the quality of the secondary effluent to nearly meet selected drinking-irrigation water standards.

Perhaps the principal obstacle to the direct reuse of reclaimed water from land application is the persistent belief in the mind of the public that such waters pose a hazard to public health because of the possibility of disease transmission. It will be necessary for eminent authorities in the medical field to face the public and explain that uncontrolled reuse has been occurring for some time now in practically all of our surface water supplies before a majority of the public will accept reuse indirectly if not directly. It is interesting to note that attitudes surveys of 100 randomly-selected residents in each of ten Southern California communities revealed consumer acceptance of reclaimed wastewater for non-body contact uses and somewhat rejecting attitudes for direct human consumption uses. The strongest public objection to wastewater reuse was found to be psychological repugnance (48).

Aside from direct use as a potable water supply, reclaimed water from land application systems has a number of uses including water-contact recreation. Some communities are known to be planning to use the reclaimed water from a land application system to maintain a recreational lake for boating and swimming.

In the past, filtered effluents from activated sludge treatment plants have been found to be very useful in a number of industries such as: (1) primary metals (quenching, hot and cold rolling, and some rinse waters); (2) petroleum (cooling water); (3) lumber (cooling water); (4) paper (mechanical pulping); and (5) leather (tanning). Reclaimed land application effluent would be equally suitable, if not more so, for such industrial uses.

TABLE 28

REMOVALS OF CONSTITUENTS FROM SECONDARY EFFLUENT USING LAND TREATMENT METHODS

	Effluent mg/l	% Removal S.I.	R.I.
BOD	30	98+	90-95
COD	70	95+	90+
N	20	85+	75-80
P	10	99+	95+
Metals	-	95+	95+
Suspended Solids	30	99	99
Pathogens	-	99	99

Of course, the benefits to be obtained in using reclaimed land application waters must be weighed against the cost of installing a drainage or collection system. In some cases it may be necessary to install an underdrain system if the upper soil formations are to remain aerobic. The aerobic conditions are necessary, together with crop production and harvesting, in order for high removals of nitrogen and phosphorus to take place.

Reclaimed water may be stored in an open lagoon to be used for recreational purposes while it awaits use by industry. The lagoon will serve to "polish" the water during storage. Of course, such reclaimed water would make an excellent resource for watering vegetation, gardens, parks, etc., and thereby allow the water needed for potable purposes to be conserved.

VI. FUTURE REQUIREMENTS

Table 29 shows the average wastewater flow rates which are expected to occur at the respective regional water pollution control facilities during the years 2000, 2020, and 2050. The total average flows which would have to be accomodated by the land application system range from 183 MGD in the year 2000, to 235 MGD in the year 2050. This represents an increase of only 29 percent over a 50-year period.

Since the projected increase in flows is relatively low, there does not appear to be any need to consider purchasing additional real estate to complement the land application system's capacity.

Any additional increases in the flow rate can be taken care of easily by simply making a slight adjustment in the amount of water to be applied on the land daily. Such flow adjustments would have no significant effect on overall system performance.

The anticipated increased flows would also have little effect on the performance of the regional waste treatment facilities and conveyance systems since the initially designed facilities would be able to accomodate moderate increases in waste flows without difficulty.

TABLE 29

SUMMARY OF WASTEWATER FLOWS

Regional WPCF	Avg. Flow, MGD 2000	2020	2050
Canton	30	39	43
Dedham	41	53	59
Medford	30	34	32
Watertown	45	51	51
Woburn	31	36	34
Hamilton	1.4	6.5	5.3
Ipswich	2.4	3.6	4.6
Middleton	2.4	4.3	6.1
Totals	183.2	227.4	235.0

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

This study has shown that land application treatment of wastewater is a viable alternative for meeting the requirements of the Water Pollution Control Act Amendments of 1972. While the amount of real estate that is suitable for land application purposes is limited, sufficient land is available to serve the needs of the Boston Harbor-Eastern Massachusetts Metropolitan Area insofar as treatment of flows from designated areas is concerned.

Perhaps the most important facet of the land application system presented in Concept 5 is the total elimination of pollutant discharges to the ocean or to other receiving bodies of water. This means that adherence to the design features of Concept 5 would virtually transform existing rivers and streams into sparkling recreational waters, suitable for safe water contact recreation, and perhaps, use as potable water supplies.

The interlocking of the five regional waste pollution control facilities at Woburn, Medford, Watertown, Dedham and Canton, uniquely offers low development and treatment costs for sludge disposal as well as for land application treatment. By consolidating sludge dewatering and incineration in one location, economy is gained in operation and administration. Also, the greater installation size for sludge disposal enables employment of automation and computer control of sensitive unit processes. The use of a central incinerator facility for ultimate sludge disposal offers an opportunity to reduce the vast bulk of sludge that would have to be disposed of to a smaller, more compact and innocuous residue, while simultaneously extracting heat energy for power production. Thus, land costs for burial of sludge are reduced and a means is provided to conserve valuable fossil fuel supplies.

The reclamation of land applied wastewaters offers the opportunity of obtaining a low cost water that is highly suitable for a number of industrial and cultural uses. Thus, valuable water resources are conserved by saving potable water supplies for more important purposes.

The above described benefits and advantages would appear to make Concept 5 the first choice as the wastewater management scheme to serve the Boston Harbor-Eastern Massachusetts Metropolitan Area. Unfortunately, this may not be true or possible because of preconceived notions and prejudice among the general public. Some communities will stoutly oppose the concept because they judge as demeaning the idea of sending one community's wastes into another community for treatment and disposal. The mere thought that such wastes whould come from the metropolitan Boston area and be sent to some outer community which prides itself on its independence from a metropolitan problem is a source of irritation to many residents outside of Boston.

B. Recommendations

Because of possible strong resistance by the public to the scheme presented in Concept 5, and also because of the need to answer and clarify some questions as to operational feasibility of a land application system, the following recommendations are proposed:

1) Prior to offering Concept 5 for public scrutiny and serious consideration, it is advised that one or two areas be selected for land application demonstration projects. The performance data from these projects would provide suitable documentary evidence to support the validity of Concept 5 when questioned by those opposed to it.

2) The demonstration project should be suitably large in size, so that the reclaimed water can be used to maintain a recreational pond, or applied culturally and thereby enable the project's effects to be demonstrated visually.

3) Every effort should be made to grow crops of remunerative value. Nothing will do more to encourage amibitions venture in a project of this nature than the firmly established conviction that financial gain is an excellent prospect.

VIII. LITERATURE CITED

1. Allaway, W. H. 1968. Agronomic controls over the environmental cycling of trace elements. Advances Agron. 20:235-274.

2. Amramy, A. 1964. Waste treatment for groundwater recharge. Journ. Water Pollution Control Fed. 36:296-298.

3. Amramy, Aaron. 1964. Waste treatment for groundwater recharge. Second International Conference on Water Pollution Research. Tokyo, Japan. August. pp6-51619.

4. Anderson, Paul. 1974. Personal communication. Division of Environmental Health, Massachusetts Department of Public Health, 600 Washington Street, Boston, Massachusetts.

5. Aulenback, D. B., J. J. Ferris, N. L. Clesceri, and T. J. Tofflemire. 1973. Thirty-five years of use of natural sand bed for polishing a secondary treated effluent. Rural Environmental Engineering Conference, University of Vermont.

6. Bauer Engineering, Inc. 1973. Wastewater Management Study for Chicago South End Lake Michigan - Appendix B. Dept. of Army, Chicago District Corps of Engineers, Chicago, Illinois. July.

7. Beard, L. R. 1962. Statistical Methods in Hydrology. Civil Works Investigations Project CW-151. Dept. of the Army, Sacramento District Corps of Engineers, Sacramento, California.

8. Bouwer, H. 1970. Water quality aspects of intermittent systems using secondary sewage effluent. in. Artifical Groundwater Recharge Conference Proceedings Vol:1. Water Research Assoc., England.

9. Bouwer, H., R. C. Rice, E. D. Escarcega, and M. S. Riggs. 1972. Renovating secondary sewage by groundwater recharge with infiltration basins. U. S. E. P. A. Water Pollution Control Research Series 16060DRV.

10. Burd, R. S. 1968. "A Study of Sludge Handling and Disposal," U.S. Department of Interior, FWPCA Water Pollution Control Research Series, WP-20-4, May.

11. Chapman, H. D. 1966. In "Diagnostic Criteria for Plants and Soils" (H. D. Chapman ed.) Univ. of California, Div. of Agr. Sci., Riverside, California.

12. Cortell, Jason M. and Associates. 1974. A Study of Certain Industrial Wastes Eastern Massachusetts Metropolitan Area. U. S. Dept. of Army, New England Division, Corps of Engineers. Contract No. DACW33-73-C-0148.

13. Cox, W. J. and D. W. Rains. 1972. Effect of lime on lead uptake by five plant species. J. Environ. Qual. 1:167-169.

14. Dean, S. "Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study - Land Application Reconnaissance," Unpublished report dated February 12, 1974.

15. Deuel, E. L. and A. R. Swoboda. 1972. Arsenic solubility in a reduced environment. Soil Sci. Soc. Amer. Proc. 36:276-278.

16. Ellis, B. G., A. E. Erickson, B. D. Knezek, A. R. Wolcott. 1972. Impact of wastewater on soils. Instit. of Water Research, Michigan State Univ. Technical Report No. 30.

17. Ellis, B. G. and B. D. Knezek. 1972. In "Micronutrients in Agriculture" (J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (eds.), Soil Sci. Soc. Amer., Inc., Madison, Wisconsin.

18. Ellis, B. G., et. al. 1973. Land treatment of wastewater in southeastern Michigan. U. S. Army Corps of Engineers, Detroit District Contract Nos. DACW35-73-C-0163 to 0170.

19. Environmental Protection Agency. 1973. Proposed criteria for water quality, Volume 1. U. S. Environmental Protection Agency, Washington, D. C.

20. EPA, USDA. 1973. Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land, Champaign, Illinois, July.

21. Gray, J. F. 1968. Practical irrigation with sewage effluent. In C. W. Wilson and F. E. Becket (eds). Municipal Sewage Effluent for Irrigation. Agri. Engin. Dept., Louis, Polytech. Instit., Ruston, LA pp49-60.

22. Havens and Emerson Engineers. 1973. A Plan for Sludge Management, Metropolitan District Commission, The Commonwealth of Massachusetts, August.

23. Hunter, J. G. and O. Vergnano. 1952. Nickel toxicity in plants. Ann. Appl. Biol. 39:279-284.

24. John, M. K., H. H. Chuah, and C. J. Van Laerhoven. 1972. Cadmium contamination of soil and its uptake by oats. Environmental Science and Technology 6:555-557.

25. Kardos, L. T. 1968. Crop response to sewage effluent. In C. W. Wilson and F. E. Beckett (eds) Municipal Sewage Effluent for Irrigation. Agric. Engin. Dept., Louis. Polytech. Instit., Ruston LA pp21-29.

26. Kardos, L. T. 1967. Recycling sewage effluent through the soil and its associated biosystems. Instit. for Research on Land and Water Resources. Penn State University Reprint Series 29.

27. Kubota, J. and W. H. Allaway. 1972. Geographic distribution of trace element problems. In "Micronutrients in Agriculture." (J. J. Mortvedt, ed.) pp525-554. Soil Science Society of America, Inc., Madison, Wisconsin.

28. Lagerwerff, J. V. 1972. Lead, Mercury, and Cadmium as environmental contaminants. In "Micronutrients in Agriculture" (J. J. Mortvedt, ed.) pp593-642. Soil Sci. Soc. Amer. Inc., Madison, Wisconsin.

29. Lance, J. C. 1972. Nitrogen removal by soil mechanisms. Journ. Water Pollution Control Fed Vol 44:1353-1361.

30. Lance, J. C. and F. D. Whisler. 1972. Nitrogen balance in soil columns intermittently flooded with secondary sewage effluent.

31. Lance, J. C. and F. D. Whisler. 1973. Nitrogen removal during land filtration of sewage water. Proceedings, International Conferences on Land for Waste Management, Ottowa, Canada. October 1-3.

32. Lavery, F. B., R. Stone, and L. A. Meyerson. 1961. Reclaiming hyperion effluent. Proceedings American Soc. Civil Engineers, Journ. Sanitary Engineering Div., Vol 87.SA6.

33. Liebig, G. J. 1966. In "Diagnostic Criteria for plants and soils" (H. G. Chapman, ed.) pp13-23. University of California, Div. of Agric. Sci. Riverside, California.

34. McConnel, W. P. (In Progress) Remote sensing twenty years of change in the human environment in Massachusetts. 1951-1971. MA Agric. Exp. Stat. Dept. Forestry and Wildlife Management.

35. Metcalf & Eddy, Inc. 1972. Wastewater Engineering, McGraw-Hill, New York.

36. Morrison, F. B. 1961. Feeds and Feeding, Abridged (9th ed). The Morrison Pub. Co. Claremont, Ontario, Canada. 696p.

37. Murphy, H. R. 1939. The role of kaolinite in phosphate fixation Hilgardia 12(5):343-382.

38. Patterson, W. L. and R. F. Banker. 1971. Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities, Office of Research and Monitoring, EPA, October.

39. Reed, S. 1972. Wastewater management by disposal on the land. U.S. Army Corps of Engineers, CRREL Special Report 171.

40. Reuther, W. and C. K. Labanauskas. 1966. In "Diagnostic Criteria for Plants and Soils" (H. G. Chapman, ed.) pp157-179. Univ. of California, Div. of Agric. Sci., Riverside, California.

41. Richards, L. A. (ed.) 1954. Diagnosis and improvement of saline and alkali soils. USDA, Agric. Handbook No. 60.

42. Rhoades, J. D., R. D. Ingvalson, and J. T. Hatcher. 1970. Laboratory determination of leachable boron. Soil Sci. Soc. Am. 34:871-875.

43. Rhoades, J. D., R. D. Ingvalson, and J. T. Hatcher. 1970. Adsorption of boron by ferromagnesian minerals and magnesium hydroxide. Soil Sci. Soc. Amer. Proc 34:938-941.

44. Satterwhite, M. B., G. Stewart, B. Condike, and E. Vlach, (In Progress) Rapid infiltration of primary sewage effluent at Fort Devens, Massachusetts. U. S. Army, CRREL Report.

45. Squchelli, V. 1969. "Trace Elements in Agriculture." Van Nostrand Reinhold Company, New York, New York.

46. Sopper, W. E. 1971. Effects of trees and forests in new neutralizing waste. Instit. for Research on Land and Water Resources. Penn State Univer. Reprint Series 23.

47. Sopper, W. E. and C. J. Sagmuller. Forest vegetation growth response to irrigation with municipal sewage effluent. Institute for Research on land and water resources. Penn State Univ. Reprint Series No. 7.

48. Stone, (Ralph) and Co., Inc., Wastewater Reclamation: Socio-Economics, Technology, and Public Acceptance, Los Angeles, California.

49. Sullivan, R. H., M. M. Cohen, and S. S. Baxter. 1973. Survey of facilities using land application of wastewater. Office of Water Programs Operation, U. S. Environ. Protection Agency. EPA-430/9-73-066.

50. Tofflemire, T. J., M. Chen, F. E. Van Alstyne, L. J. Hetling, B. B. Aulenback. 1973. Phosphate removal by sands and soils. New York State Dept. Environ. Conserv. Tech. Paper 31.

51. Traynor, M. F. and B. D. Knezek. 1972. unpublished data (Cadmium).

52. Turner, M. A. and R. H. Rust. 1971. Effects of chromium on growth and mineral nutrition of soybeans. Soil Sci. Soc. Amer. Proc. 35:755-758.

53. Underwood, E. J. 1962. Trace elements in human and animal nutrition, Academic Press, New York.

54. U.S.D.A. (SCS). 1971. Planning for an Irrigation System, American Assoc. for Vocational Instructional Materials, June.

55. U. S. Dept. of Army Corps of Engineers and Commonwealth of Massachusetts. 1975. Merrimack Wastewater Management: A Key to a Clean River. Volume I, Background Information. U.S. Dept of Army, New England Division, Corps of Engineers.

56. Vanselow, A. P. 1966. In "Diaagnostic Criteria for Plants and Soils" (H. G. Chapman, ed.) pp142-156. Univ. of California, Div of Agric Sci, Riverside, California.

57. Vinande, R., B. Knezek, J. Davis, E. Doll and J. Melton. 1968. Field and Laboratory Studies with Zinc and Iron Fertilization of Pea Bean, Corn and Potatoes in 1967. Q. Bull., Mich. Agric. Expt. Sta. 50:625-636.

58. Wallihan, E. F. 1966. In "Diagnostic Criteria for Plants and Soils" (H. G. Chapman, ed.) pp203-212. Univ. of California, Div. of Agric. Sci., Riverside, California.

59. Walter, H., M. F. Traynor, and B. D. Knezek. 1972. unpublished data.

60. Whisler, F. D., J. C. Lance, and R. S. Linebarger. 1974. Redox potentials in soil columns intermittently flooded with sewage water Environ. Qualtiy Vol. 3:68-74.

61. Woolson, E. A., J. H. Azley and P. C. Kearney. 1971. Correlation between available soil arsenic, estimated by six methods and response of corn (Zea Mays L.) Maryland Agric. Exp. Sta., College Park, MD Soil Sci. Soc. Amer. Proc. 35:101-105.

62. Woolson, E. A., J. H. Azley, and P. C. Kearney. 1971. The chemistry and phytotoxicity of arsenic in soils: I. Contaminated field soils. ARS, USDA, Beltsville, Mr., and Univ. of Maryland, College Park. Soil Sci. Soc. Amer. Proc 35:938-943.

APPENDIX A

GEOLOGY AND SOILS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

Any planning of the feasibility and applicability of the treatment of wastewater by the alternative of land application requires that the geology and soils of the area under consideration be investigated thoroughly. When wastewater is applied to the land surface by any of the three modes which have historically proven feasible, i.e. spray irrigation, rapid infiltration, or overland flow, it infiltrates through the surface to one degree or another and becomes part of the complex hydrogeological system of soil, rock and water which underlies the surface. Knowledge of the effect of the added wastewater on this system and the manner in which the system assimilates the renovated water is necessary and vital to the planning and design of wastewater treatment system by land application methods.

When the make-up and complexities of the hydrogeological system in a certain area are known, it is then possible to make more valid predictions and assessments of the potential and capacility of that area to receive and adequately treat wastewater.

The effectiveness of the soil and underlying unconsolidated sediments and bedrock in treating the applied wastewater is of paramount importance. Geologic and hydrogeologic data regarding lithology, sedimentary properties such as porosity, permeability and sorting, thickness of the strata and depth to water table and thickness of the saturated zone all pertain to the evaluation of the renovative and treatment capabilities of a given area. It is also important to know what happens to the water once it infiltrates the soil surface. Questions regarding loading rates of effluent, length and direction of sub-surface migration of the applied water and the effect of the increased load on groundwater table levels (mounding) are all very important and must be considered in the total wastewater management planning study.

Investigations of the geology and soils of the Commonwealth of Massachusetts were undertaken to provide a broad base of information which could help provide answers to the above-mentioned questions within the scope of the planning effort. The investigations varied in detail from one part of the Commonwealth to another. The investigative results for the Merrimack River Basin are reported in Appendix I-A "Geologic-Hydrogeologic Investigations" to Merrimack Wastewater Management(1).

This appendix contains specific information on the bedrock and surficial geology and groundwater favorability of eastern Massachusetts exclusive of the Merrimack River Basin and generalized information on the western part of Massachusetts.

The geology of the Commonwealth is provided in the form of both maps and a narrative text. This information was used in the planning study to help select tracts of land which have potential for wastewater application. Close study of the geologic maps can also reveal areas which lack the type or sufficient thickness of subsurface material required for land application of wastewater effluent. These areas can then be immediately removed from further consideration. When examination of the maps and other geological information shows a certain area to have potential, it can be flagged as a possibility and set aside for further review and consideration.

The uses of the bedrock and surficial maps and their application to the study are apparent and are discussed further in the main body of this volume. The reasons for and applicability of groundwater information to the study, however, warrants further attention and is discussed at length below. Detailed groundwater information for a given area is difficult and time consuming to acquire. Thus, an in depth groundwater study of the Commonwealth of Massachusetts is beyond the scope of this study. A generalized description of the availability of groundwater complete with maps and texts is, however, included in this report and in a manner similar to the bedrock and surficial sections and provides useful background information.

Relationship of Groundwater to Land Application of Effluent

The occurrence and distribution of groundwater bears a direct relationship to the alternative of wastewater treatment by land application. This relationship hinges upon the three factors of depth to water table, seasonal variation in groundwater levels and the physical properties of the soils and rock material through which the groundwater flows.

Depth to Water Table

Effluent may be adequately treated only if it can percolate through a sufficient thickness of the proper type of unsaturated soil and unconsolidated sediment. Estimates of the necessary thickness depend on the mode of application and range from a minimum of 3 feet of loamy soil for spray irrigation to several tens of feet of free draining sandy material for rapid infiltration basins. If the water table in a given area is too high, effluent which infiltrates below the surface will not be properly treated when it enters the groundwater reservoir and extensive pollution of the groundwater may occur. Depth to water table varies with topography and type of sedimentary material. No application of effluent should be accomplished without a thorough investigation of the water table depth at and adjacent to the area being evaluated for potential use.

Seasonal Variation in Groundwater Levels

Groundwater levels fluctuate due mainly to the climate factors of precipitation and evapotranspiration. Substantial withdrawals due to pumping can also significantly change water table levels. Groundwater levels follow a general annual cycle upon which is superimposed the more immediate effect of high intensity rainfall and rapid snowmelt. The annual cycle was discussed in the main body of this volume. Planning for application loads of effluent must take into consideration this seasonal variation. Simply stated, the amount of moisture stored in the soil and the depth to the water table will be significantly lower in September than in May. A program of effluent application based only upon September levels will run into serious difficulties of implementation during other times of the year.

Type of Subsurface Material

Investigation of the lithology and physical properties of the soils and rock material underlying a given locality is important when considering land application of effluent. Especially significant is the permeability (hydraulic conductivity) of the material. Rates of permeability will influence planning as to kind and rates of application. Regardless of what application mode is used, the rate of initial effluent infiltration increases with permeability. Reliable estimates of permeability of the various layers of soil in the area under consideration will help in estimates of loading rates.

Recognition of the soil type and its hydrologic properties is also essential in planning for drainage systems and programs of groundwater management and control. Median grain size, sorting and permeability of the sediments must be measured and the depth to water table must be determined before a reliable under drainage system can be designed.

II. BEDROCK GEOLOGY OF EASTERN MASSACHUSETTS

A. Source Material and Mapping Procedure

The available literature concerning the bedrock of eastern Massachusetts dates back to the early nineteenth century. However, the more extensive and exacting mapping of the Massachusetts bedrock really began in the early twentieth century with the publication in 1917 of The Geology of Massachusetts and Rhode Island by B. K. Emerson(2). This monumental effort was of such quality that many of the more recent mapping efforts show little variance from those units mapped by Emerson. For this reason the map which accompanied Emerson's report was used as the primary source of data for this report's set of bedrock geology maps. In areas where more recent and more detailed mapping has been conducted the most recently published data were incorporated into this report.

Specifically, within the limits of this study area there have been two United States Geological Survey Quadrangle Reports completed. The first, The Brockton Quadrangle, GQ-5, was compiled by N. E. Chute(3) in 1950 and the second was the Blue Hills Quadrangle, GQ-796, compiled by N. E. Chute (4), in 1969. Two preliminary bedrock geology maps for the Natick and the Holliston Quadrangles are presently on Open File Report at the United States Geological Survey (U.S.G.S.) (5,6). These were done by A. E. Nelson and R. P. Volckman respectively.

The most recent revisions to the mapping of the bedrock geology for the remainder of the study area are found in the literature of four U.S.G.S. Bulletins (7,8,9,10) and one U.S.G.S. Professional Paper (11). These references are "The Geology of the Igneous Rocks of Essex County", U.S.G.S. Bulletin 704 by C. H. Clapp in 1921, "Geology of the Boston Area", U.S.G.S. Bulletin 839 by Laurence LaForge in 1932; "Bedrock Geology of the Salem Quadrangle", U.S.G.S. Bulletin 1163-A by P. Toulmin in 1964; "Geology of the Norwood Quadrangle", U.S.G.S. Bulletin 1163-B by N. E. Chute in 1966; and "Seismic Investigations on Cape Cod, Martha's Vineyard, and Nantucket, Massachusetts, and a Topographic Map of the Basement Surface From Cape Cod Bay to the Islands", U.S.G.S. Professional Paper 650-B by R. N. Oldale in 1969.

The information on the maps contained in these publications was redrawn at the 1 to 125,000 scale of our base map, which was a combination of the town and county boundaries of a map produced by the Massachusetts Department of Community Affairs and the coast lines taken from an enlargement of the U.S.G.S. 1 to 250,000 scale Boston and Providence Topographic maps. Due to the rescaling of the various sized geologic maps and the use of a combination of two maps to make up the base map the actual bedrock contacts could be slightly off in some areas. However, since the majority of these contacts are covered by surficial deposits, their specific locations are often speculative and any variance in contact becomes mostly academic.

The bedrock beneath the area southeast of a line roughly parallel to, and approximately 15 miles northwest of, the Cape Cod Canal including the Cape itself, Martha's Vineyard, Nantucket and the smaller islands of Nantucket Sound is overlain by such thick surficial deposits that few wells have encountered bedrock. For this reason little is known about the nature of the underlying rock. Where wells have penetrated the overlying cover and have reached bedrock they have been plotted in Figure A6 and the depth to bedrock (in feet below sea level) has been recorded. Interpretation of the cuttings has been recorded on the map for those wells for which there was available data. Otherwise, this area which appears on Figures A6, A7, and A8 has been shown with contour lines indicating depth to bedrock in feet below sea level. These contours were largely taken from the seismic study of Cape Cod and the Islands published by R. N. Oldale[11] in 1969. They have, however, been redrawn where shown to be inaccurate near the presently existing well sites.

B. Bedrock Units in Eastern Massachusetts

IGNEOUS ROCKS

ANDOVER GRANITE

The Andover Granite is found throughout the northern portion of the Town of North Andover and also in the southwestern portion of the Town of Middleton. Clapp (7, p. 28) states that:

> "The normal Andover Granite is typically a fairly coarse grained rock consisting of feldspar and abundant quartz...with biotite and muscovite as the chief mafic constituents."

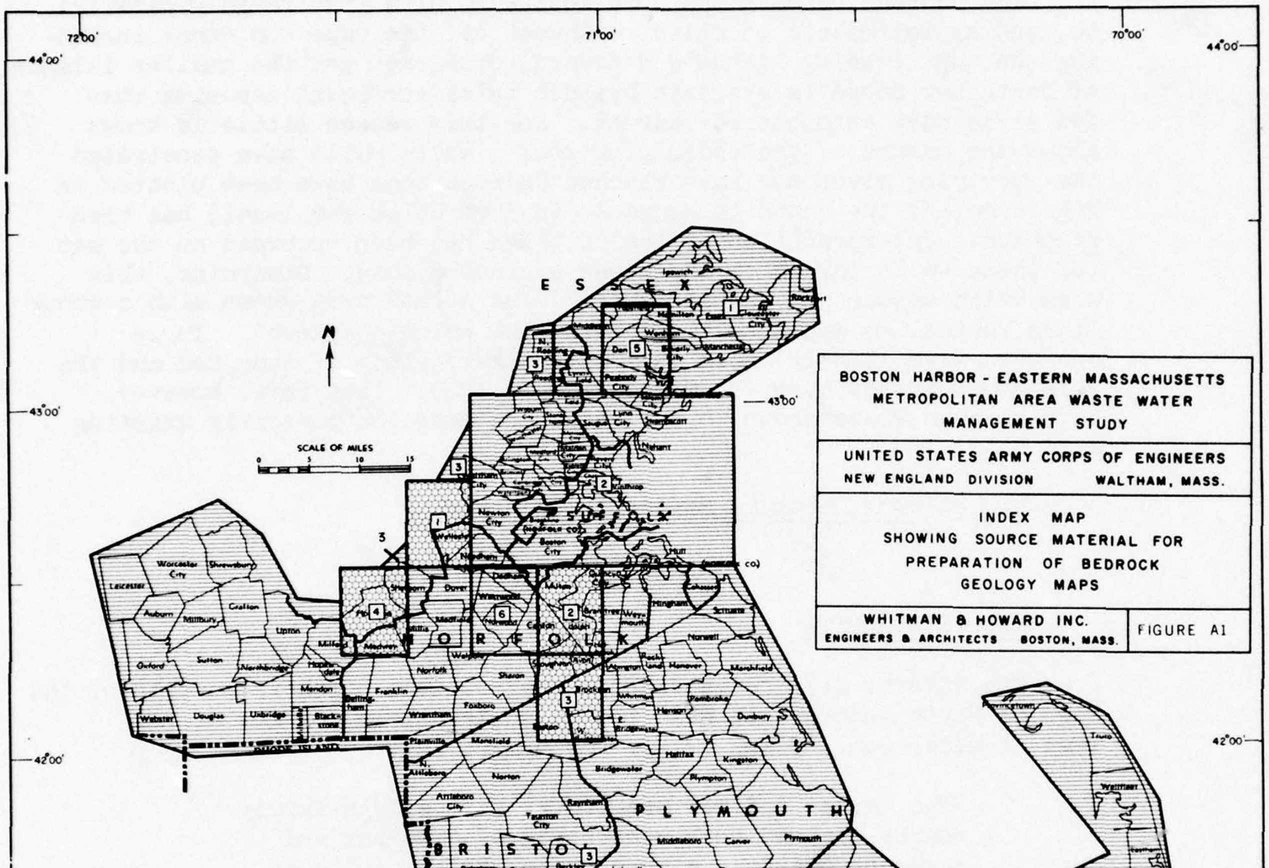
LaForge (8, p. 44) further declares:

> "It is intrusive into the Carboniferous strata of the Merrimack Basin but has been deformed with them. It is therefore regarded as of Late Carboniferous age...The rock is also generally foliated and in many places is rather strongly gneissic."

AYER GRANITE

The Ayer Granite forms a belt with a north-south orientation running from the Connecticut border north through the Towns of Webster, Oxford and Auburn.

The Ayer Granite also outcrops in the Town of Worcester where it has been extensively quarried. Emerson (2, p. 224) states:


BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.
INDEX MAP
SHOWING SOURCE MATERIAL FOR
PREPARATION OF BEDROCK
GEOLOGY MAPS
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.
FIGURE A1
SCALE OF MILES
0 5 10 15
N
ESSEX
SUFFOLK
NORFOLK
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
RHODE ISLAND
72°00'
71°00'
70°00'
44°00'
43°00'
42°00'
41°00'
40°00'
LEGEND
INFORMATION DERIVED FROM U.S.G.S. QUADRANGLE REPORTS
1. PRELIMINARY BEDROCK GEOLOGY - NATICK - QUADRANGLE; NELSON, 1973
2. BLUE HILLS QUADRANGLE GQ - 796; 1969
3. BROCKTON QUADRANGLE GQ - 5; 1950
4. PRELIMINARY BEDROCK GEOLOGY - HOLLISTON QUADRANGLE; VOLCKMAN, 1973
INFORMATION DERIVED FROM U.S.G.S. BULLETINS
1. GEOLOGY OF THE IGNEOUS ROCKS OF ESSEX COUNTY; GEOLOGICAL SURVEY BULLETIN 704; CLAPP; 1921
2. GEOLOGY OF THE BOSTON AREA; GEOLOGICAL SURVEY BULLETIN 839; LaFORGE, 1932
3. GEOLOGY OF MASSACHUSETTS AND RHODE ISLAND; GEOLOGICAL SURVEY BULLETIN 597; EMERSON; 1917
4. SEISMIC INVESTIGATIONS ON CAPE COD, MARTHA'S VINEYARD, AND NANTUCKET MASSACHUSETTS, AND A TOPOGRAPHIC MAP OF THE BASEMENT SURFACE FROM CAPE COD BAY TO THE ISLANDS; GEOLOGICAL SURVEY PROFESSIONAL PAPER 650-B, OLDALE; 1969
5. BEDROCK GEOLOGY OF SALEM QUADRANGLE; GEOLOGIAL SURVEY BULLETIN 1163-A, TOULMIN, 1964
6. GEOLOGY OF THE NORWOOD QUADRANGLE NORFOLK AND SUFFOLK COUNTIES, MASSACHUSETTS, GEOLOGICAL SURVEY BULLETIN 1163-B, CHUTE, 1966
INFORMATION PRIMARILY DERIVED FROM GEOLOGY OF MASSACHUSETTS AND RHODE ISLAND; EMERSON; U.S.G.S. BULLETIN 597; 1917

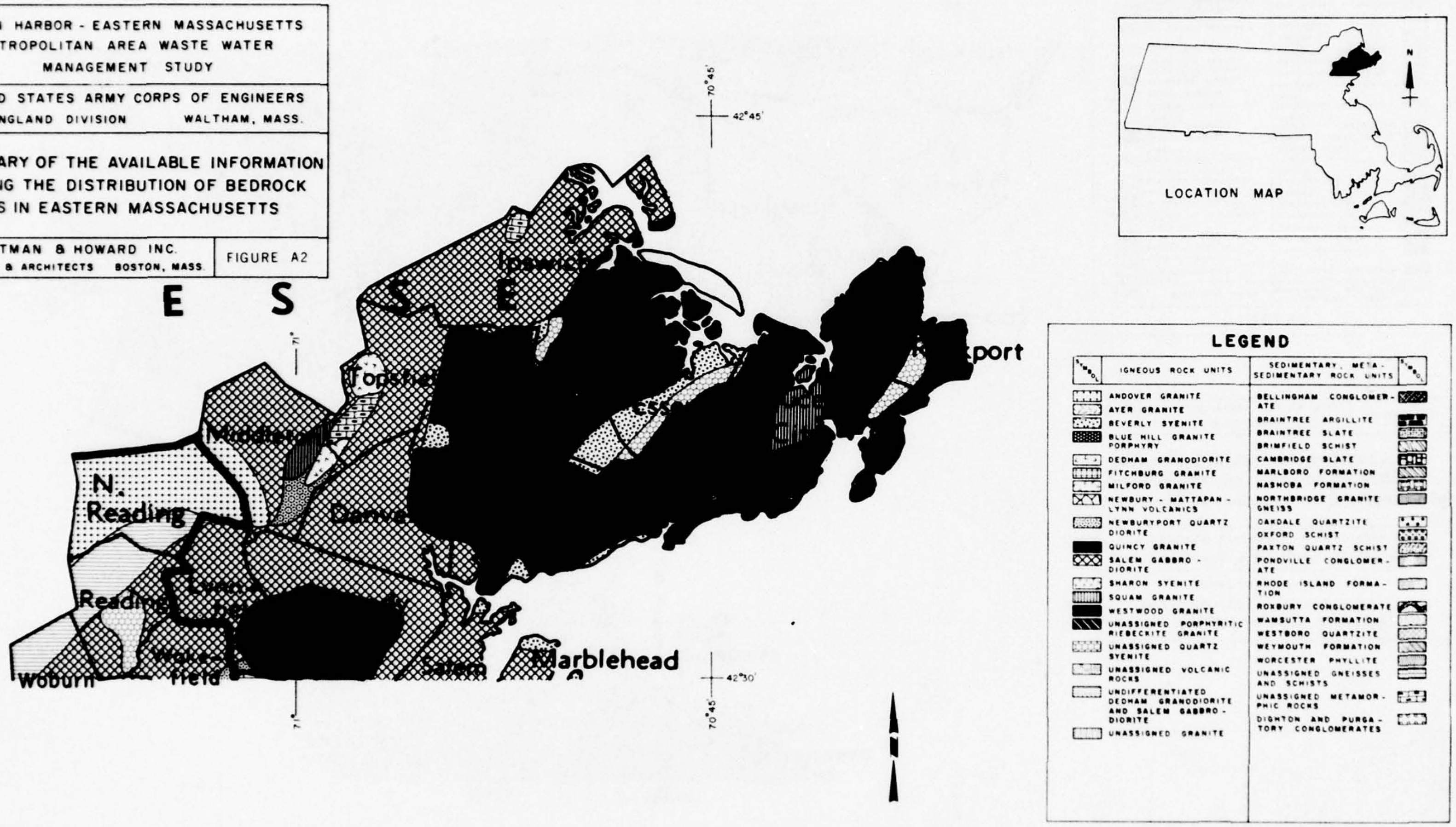
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

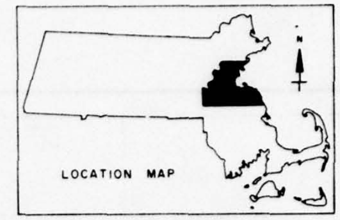
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

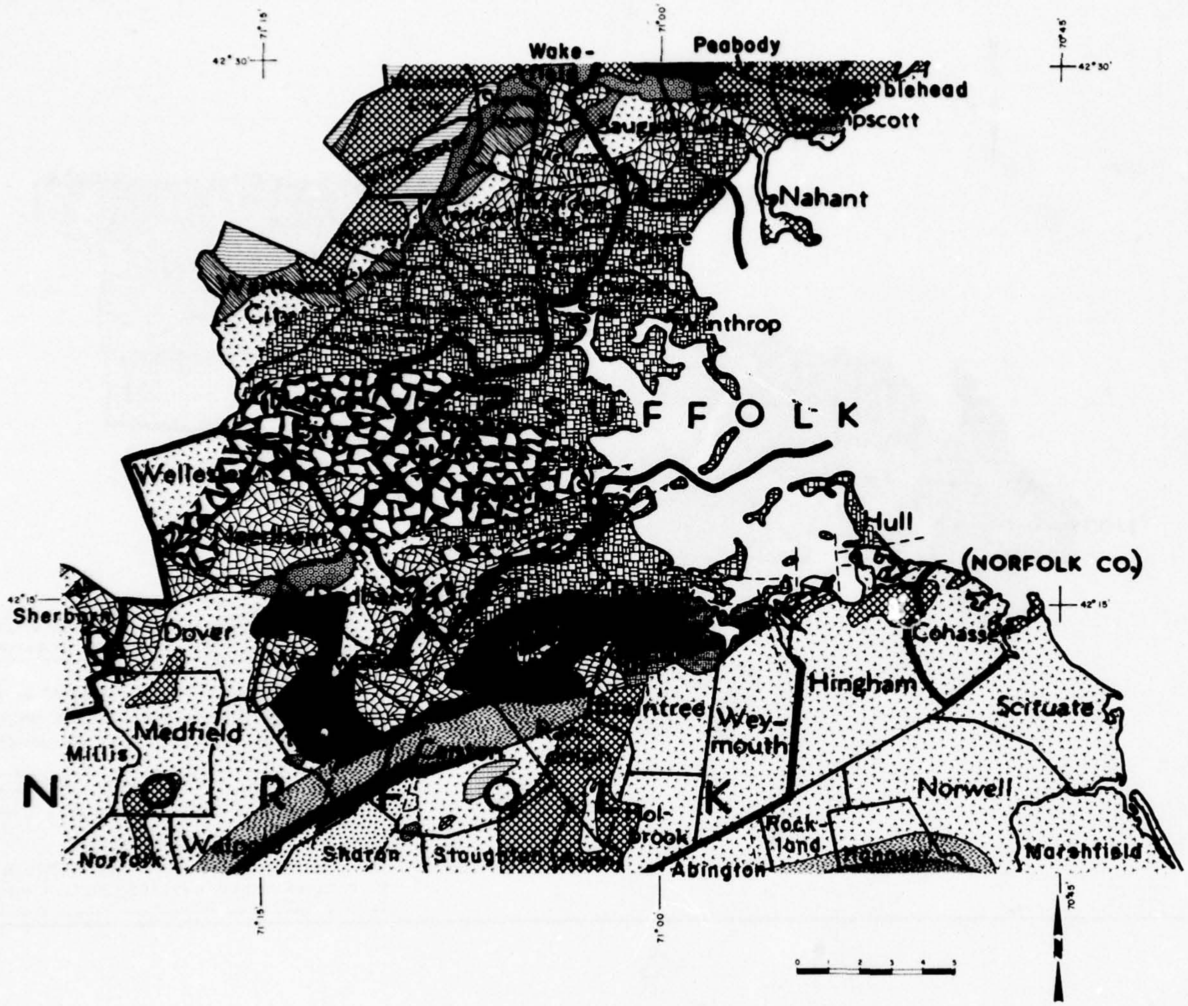
A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF BEDROCK UNITS IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A2







BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

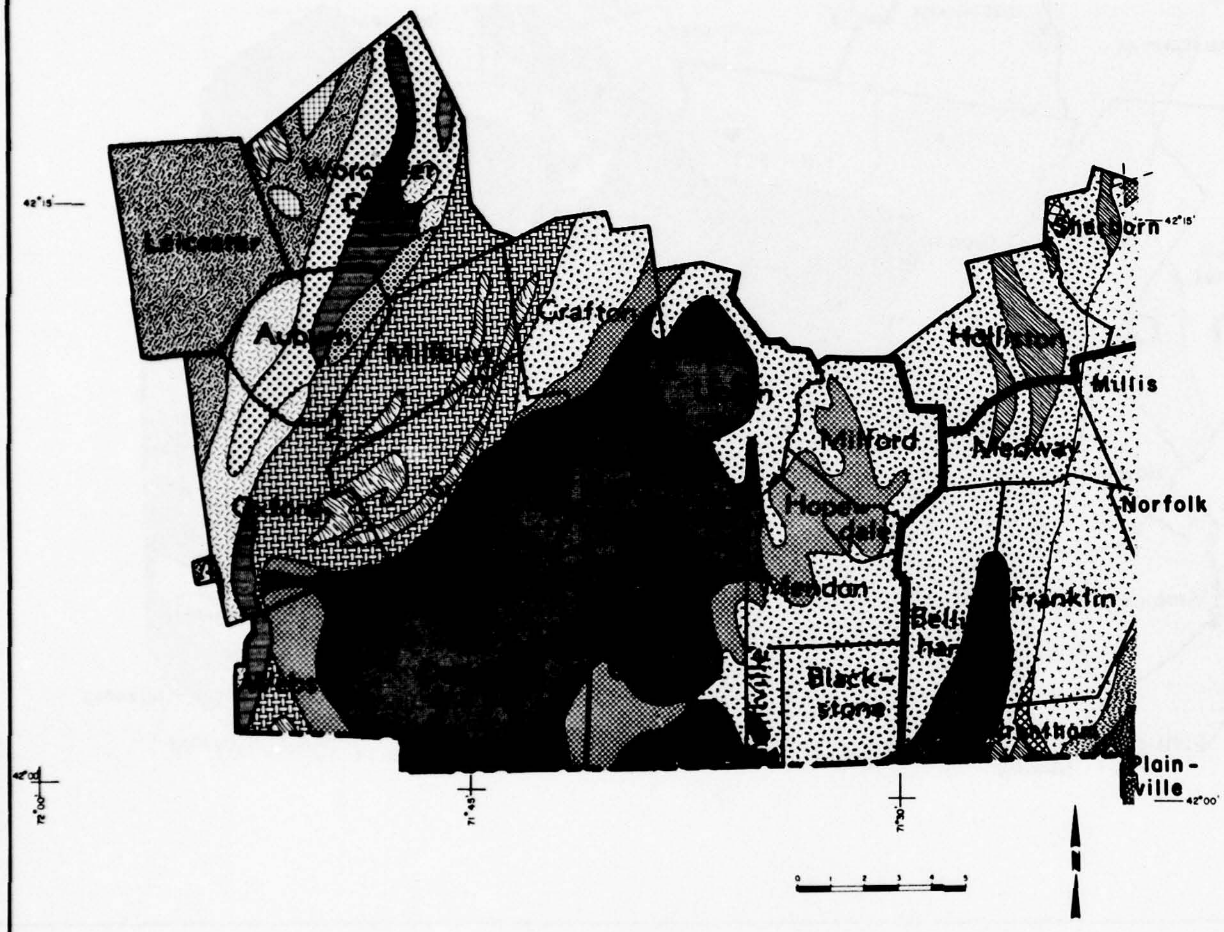
A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF BEDROCK UNITS IN EASTERN MASSACHUSETTS

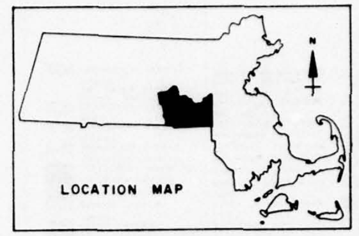
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A3

LEGEND

IGNEOUS ROCK UNITS	SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
ANDOVER GRANITE	BELLINGHAM CONGLOMERATE
AYER GRANITE	BRAINTREE ARGILLITE
BEVERLY SYENITE	BRAINTREE SLATE
BLUE HILL GRANITE PORPHYRY	BRIMFIELD SCHIST
DEDHAM GRANODIORITE	CAMBRIDGE SLATE
FITCHBURG GRANITE	MARLBORO FORMATION
MILFORD GRANITE	NASHOBA FORMATION
NEWBURY - MATTAPAN - LYNN VOLCANICS	NORTHBRIDGE GRANITE GNEISS
NEWBURYPORT QUARTZ DIORITE	OAKDALE QUARTZITE
QUINCY GRANITE	OXFORD SCHIST
SALEM GABBRO - DIORITE	PAXTON QUARTZ SCHIST
SHARON SYENITE	PONDVILLE CONGLOMERATE
SQUAM GRANITE	RHODE ISLAND FORMATION
WESTWOOD GRANITE	ROXBURY CONGLOMERATE
UNASSIGNED PORPHYRITIC RIEBECKITE GRANITE	WAMSUTTA FORMATION
UNASSIGNED QUARTZ SYENITE	WESTBORO QUARTZITE
UNASSIGNED VOLCANIC ROCKS	WEYMOUTH FORMATION
UNDIFFERENTIATED DEDHAM GRANODIORITE AND SALEM GABBRO-DIORITE	WORCESTER PHYLLITE
UNASSIGNED GRANITE	UNASSIGNED GNEISSES AND SCHISTS
	UNASSIGNED METAMORPHIC ROCKS
	DIGHTON AND PURGATORY CONGLOMERATES





BOSTON HARBOR - EASTERN MASSACHUSETTS METROPOLITAN AREA WASTE WATER MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

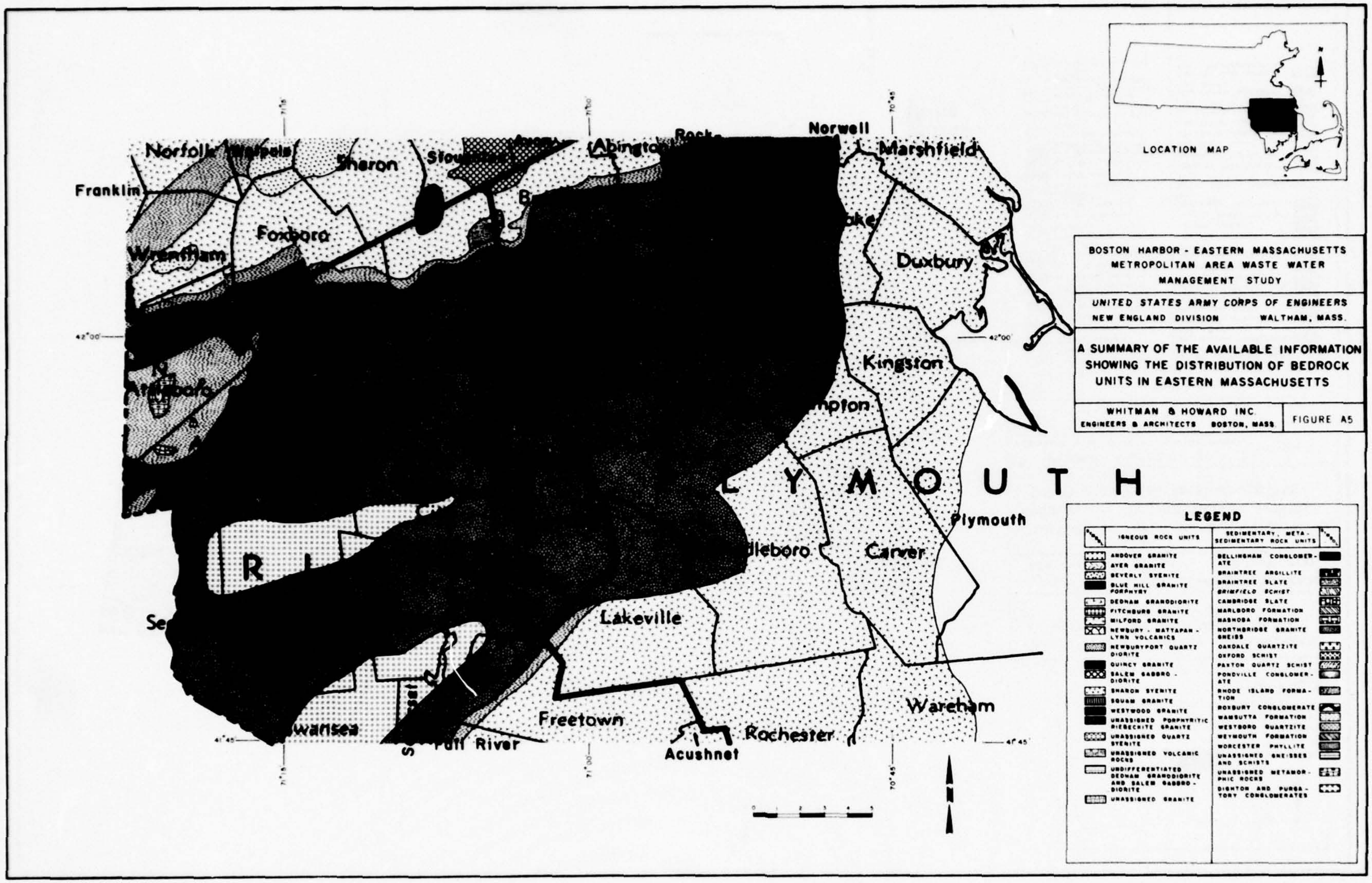
A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF BEDROCK UNITS IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

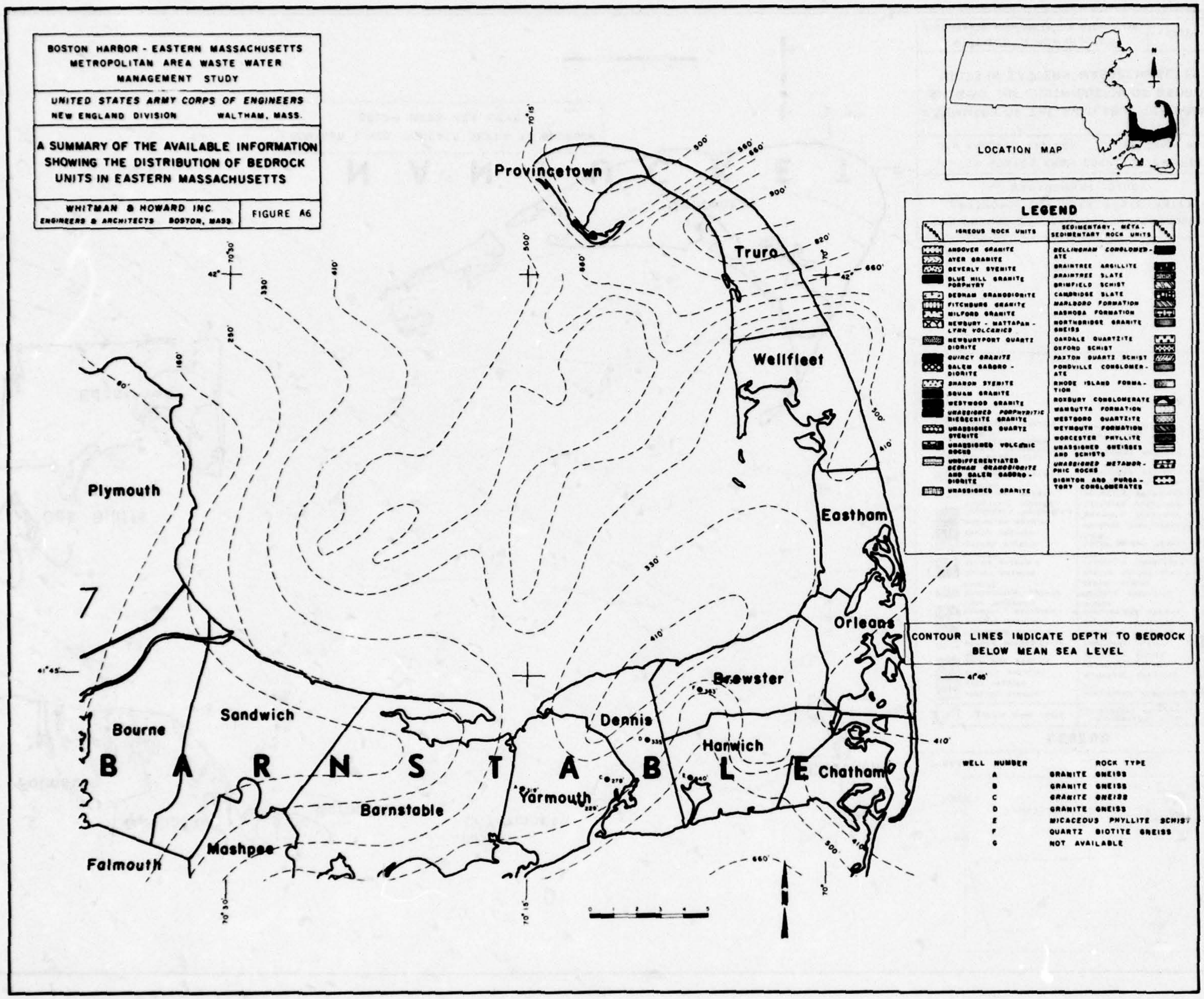
FIGURE A4

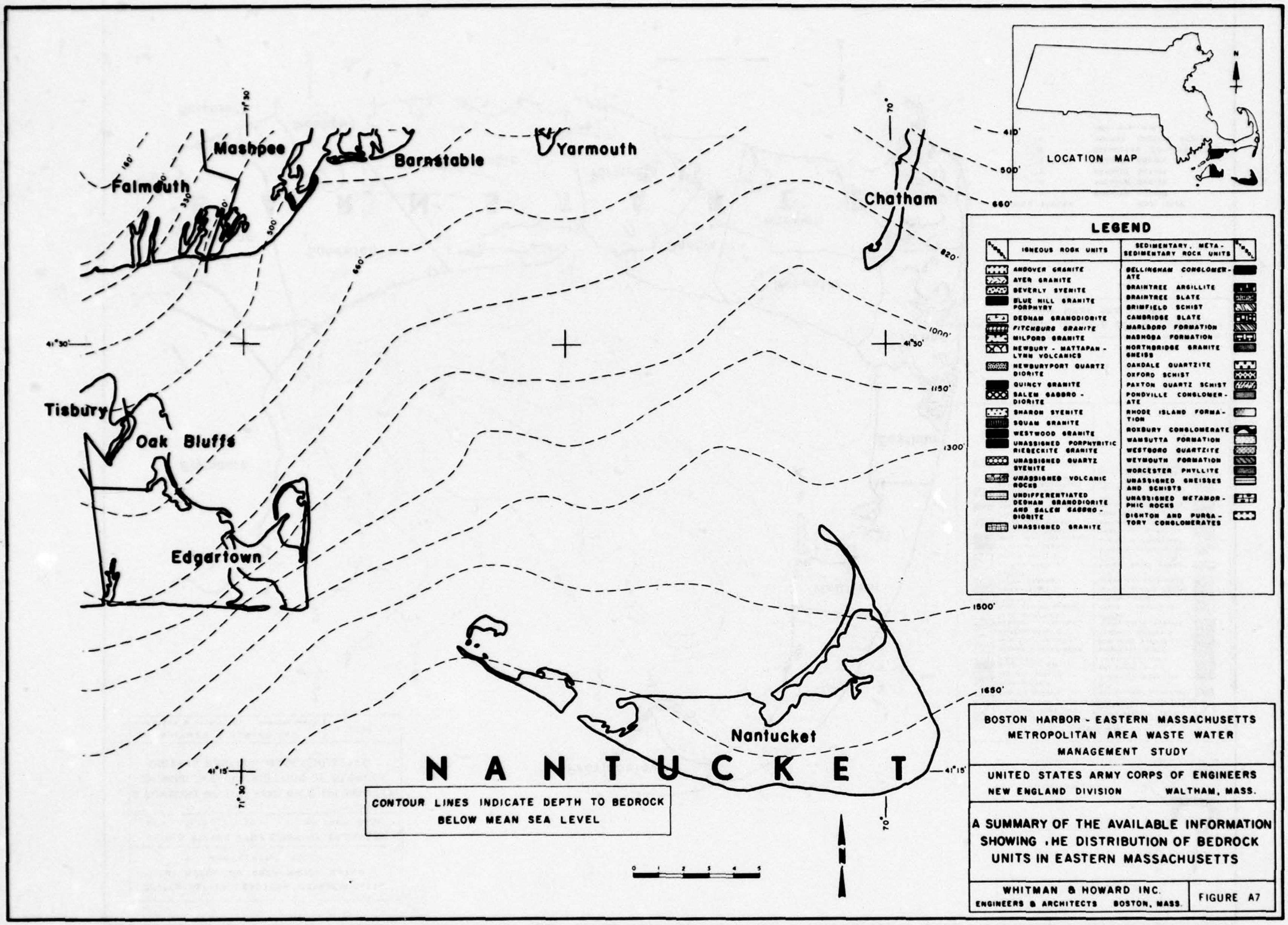
LEGEND

IGNEOUS ROCK UNITS	SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
ANDOVER GRANITE	BELLINGHAM CONGLOMERATE
AYER GRANITE	BRAINTREE ARGILLITE
BEVERLY SYENITE	BRAINTREE SLATE
BLUE HILL GRANITE PORPHYRY	BRIMFIELD SCHIST
DEDHAM GRANODIORITE	CAMBRIDGE SLATE
FITCHBURG GRANITE	MARLBORO FORMATION
MILFORD GRANITE	NASHOBA FORMATION
NEWBURY - MATTAPAN - LYNN VOLCANICS	NORTHBRIDGE GRANITE GNEISS
NEWBURYPORT QUARTZ DIORITE	OAKDALE QUARTZITE
QUINCY GRANITE	OXFORD SCHIST
SALEM GABBRO - DIORITE	PAXTON QUARTZ SCHIST
SHARON SYENITE	PONDVILLE CONGLOMERATE
SQUAM GRANITE	RHODE ISLAND FORMATION
WESTWOOD GRANITE	ROXBURY CONGLOMERATE
UNASSIGNED PORPHYRITIC RIEBECKITE GRANITE	WAMSUTTA FORMATION
UNASSIGNED QUARTZ SYENITE	WESTBORO QUARTZITE
UNASSIGNED VOLCANIC ROCKS	WEYMOUTH FORMATION
UNDIFFERENTIATED DEDHAM GRANODIORITE AND SALEM GABBRO-DIORITE	WORCESTER PHYLLITE
UNASSIGNED GRANITE	UNASSIGNED GNEISSES AND SCHISTS
	UNASSIGNED METAMORPHIC ROCKS
	DIGHTON AND PURGATORY CONGLOMERATES



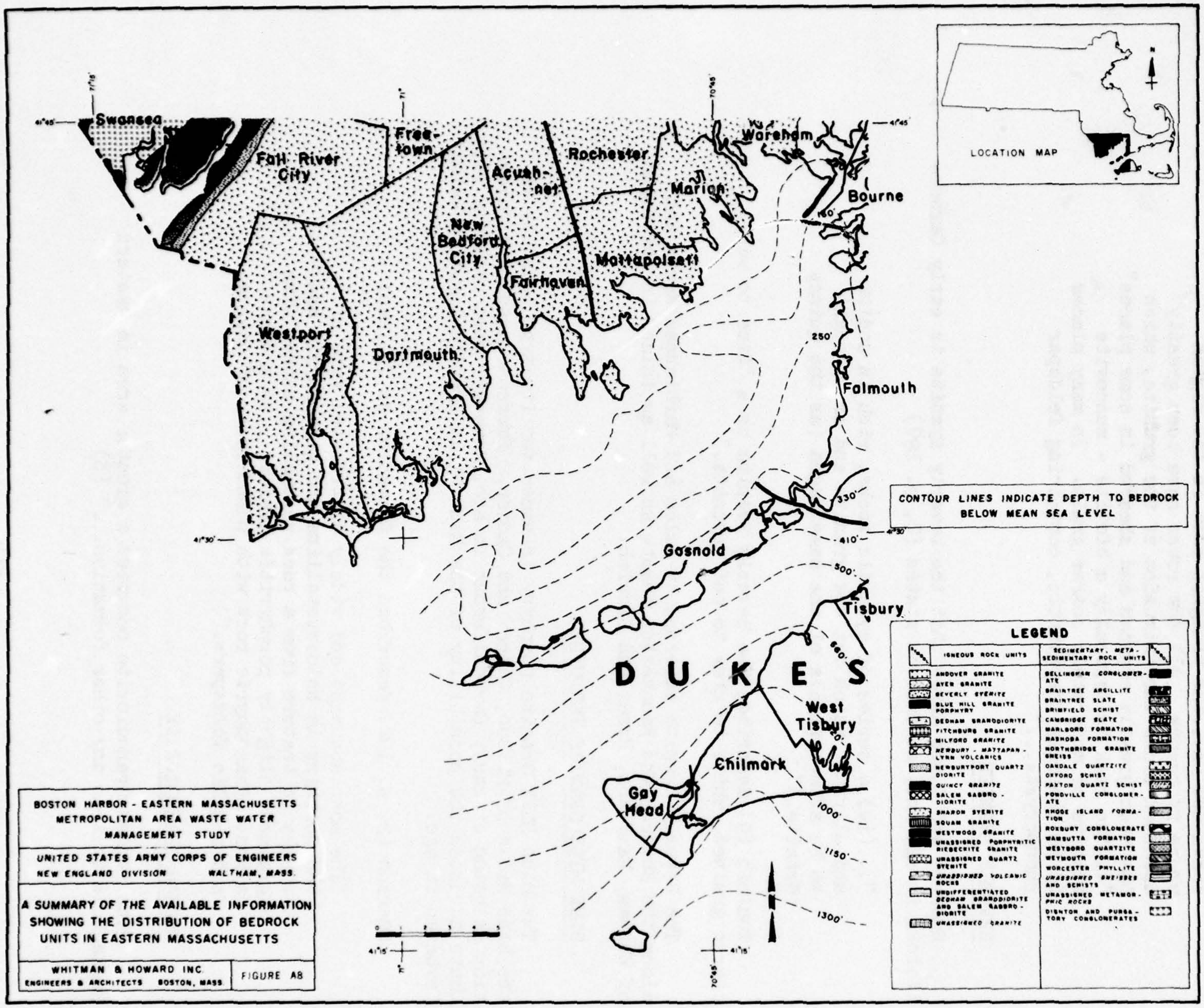
Franklin
Norfolk
Sharon
Foxboro
Wrentham
Attleboro
Abington
Norwell
Marshfield
Duxbury
Kingston
Plymouth
Carver
Lakeville
Freetown
Fall River
Acushnet
Rochester
Wareham
Swansea
PLYMOUTH
LOCATION MAP
42°00'
41°45'
71°15'
71°00'
70°45'
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.
A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF BEDROCK
UNITS IN EASTERN MASSACHUSETTS
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.
FIGURE A5
LEGEND
IGNEOUS ROCK UNITS
ANDOVER GRANITE
AYER GRANITE
BEVERLY SYENITE
BLUE HILL GRANITE PORPHYRY
DEDHAM GRANODIORITE
FITCHBURG GRANITE
MILFORD GRANITE
NEWBURY - MATTAPAN - LYNN VOLCANICS
NEWBURYPORT QUARTZ DIORITE
QUINCY GRANITE
SALEM GABBRO - DIORITE
SHARON SYENITE
SQUAM GRANITE
WESTWOOD GRANITE
UNASSIGNED PORPHYRITIC RIEBECKITE GRANITE
UNASSIGNED QUARTZ SYENITE
UNASSIGNED VOLCANIC ROCKS
UNDIFFERENTIATED DEDHAM GRANODIORITE AND SALEM GABBRO - DIORITE
UNASSIGNED GRANITE
SEDIMENTARY, META - SEDIMENTARY ROCK UNITS
BELLINGHAM CONGLOMERATE
BRAINTREE ARGILLITE
BRAINTREE SLATE
BRIMFIELD SCHIST
CAMBRIDGE SLATE
MARLBORO FORMATION
NASHOBA FORMATION
NORTHBRIDGE GRANITE GNEISS
OAKDALE QUARTZITE
OXFORD SCHIST
PAXTON QUARTZ SCHIST
PONDVILLE CONGLOMERATE
RHODE ISLAND FORMATION
ROXBURY CONGLOMERATE
WAMSUTTA FORMATION
WESTBORO QUARTZITE
WEYMOUTH FORMATION
WORCESTER PHYLLITE
UNASSIGNED GNEISSES AND SCHISTS
UNASSIGNED METAMORPHIC ROCKS
DIGHTON AND PURGATORY CONGLOMERATES


BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.
A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF BEDROCK
UNITS IN EASTERN MASSACHUSETTS
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.
FIGURE A6
LOCATION MAP
LEGEND
IGNEOUS ROCK UNITS
ANDOVER GRANITE
AYER GRANITE
BEVERLY SYENITE
BLUE HILL GRANITE PORPHYRY
DEDHAM GRANODIORITE
FITCHBURG GRANITE
MILFORD GRANITE
NEWBURY - MATTAPAN - LYNN VOLCANICS
NEWBURYPORT QUARTZ DIORITE
QUINCY GRANITE
SALEM GABBRO - DIORITE
SHARON SYENITE
SQUAM GRANITE
WESTWOOD GRANITE
UNASSIGNED PORPHYRITIC RIEBECKITE GRANITE
UNASSIGNED QUARTZ SYENITE
UNASSIGNED VOLCANIC ROCKS
UNDIFFERENTIATED DEDHAM GRANODIORITE AND SALEM GABBRO - DIORITE
UNASSIGNED GRANITE
SEDIMENTARY, META-SEDIMENTARY ROCK UNITS
BELLINGHAM CONGLOMERATE
BRAINTREE ARGILLITE
BRAINTREE SLATE
BRIMFIELD SCHIST
CAMBRIDGE SLATE
MARLBORO FORMATION
NASHOBA FORMATION
NORTHBRIDGE GRANITE GNEISS
OAKDALE QUARTZITE
OXFORD SCHIST
PAXTON QUARTZ SCHIST
PONDVILLE CONGLOMERATE
RHODE ISLAND FORMATION
ROXBURY CONGLOMERATE
WAMSUTTA FORMATION
WESTBORO QUARTZITE
WEYMOUTH FORMATION
WORCESTER PHYLLITE
UNASSIGNED GNEISSES AND SCHISTS
UNASSIGNED METAMORPHIC ROCKS
DIGHTON AND PURGATORY CONGLOMERATES
CONTOUR LINES INDICATE DEPTH TO BEDROCK
BELOW MEAN SEA LEVEL
WELL NUMBER ROCK TYPE
A GRANITE GNEISS
B GRANITE GNEISS
C GRANITE GNEISS
D GRANITE GNEISS
E MICACEOUS PHYLLITE SCHIST
F QUARTZ BIOTITE GNEISS
G NOT AVAILABLE
Provincetown
Truro
Wellfleet
Eastham
Orleans
Chatham
Brewster
Harwich
Dennis
Yarmouth
Barnstable
Mashpee
Sandwich
Bourne
Falmouth
Plymouth
B A R N S T A B L E



A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF BEDROCK UNITS IN EASTERN MASSACHUSETTS

FIGURE A7



BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF BEDROCK UNITS IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A8

"The Ayer Granite, like the Andover Granite, is intrusive into or against all the surrounding rocks and is...the youngest rock in the region where it occurs. All the rocks have been greatly deformed since the intrusion of the granite, which has been greatly crushed and sheared in some places" "...The rock is typically a biotite - muscovite granite of moderately coarse grain. In many places it is coarsely porphyritic, containing feldspar phenocrysts..."

BEVERLY SYENITE

Emerson and Clapp agree that the Beverly Syenite is early Carboniferous in age and, as Emerson states (2, p. 197)

"...(is) a series of syenitic rocks, rich in sodium and olivine, which cut the granite and are thought to be afterarrivals of the same magma (as the Quincy Granite.)"

Toulmin (9) describes the Beverly Syenite as a "fine to very coarse grained, white to gray to buff syenite."

The Beverly Syenite outcrops at Salem and Marblehead Necks and along the Beverly and Manchester coasts as well as inland in the Towns of Wenham, Hamilton, Essex and Ipswich.

BLUE HILL GRANITE PORPHYRY

The Blue Hill Granite porphyry is named for its type locality in the Blue Hills of Milton, Quincy and Canton. Emerson dated this formation as being of early Carboniferous in age, however, more recently (4) Chute advances the possibility of the Blue Hills Granite Porphyry being Devonian in age.

Emerson (2, p. 192) described the formation as follows:

"The most abundant and widely distributed type of the porphyry is holocrystalline and granophyric and ranges in texture from a rock resembling rather fine grained, slightly porphyritic granite...to a dense, almost aphanophyric rock with phenocrysts of quartz and alkalic feldspars."

DEDHAM GRANODIORITE

"The Dedham Granodiorite occupies a greater area in eastern Massachusetts than any other formation..." (8)

This is evident by the areas covered by this formation on the accompanying bedrock maps. (Figures A2 - A8).

Emerson's (2, p. 176) description of this formation reads as follows:

> "The most abundant and typical variety is a rather coarse biotitic granodiorite, composed essentially of microcline, plagioclase (generally andesine), quartz, and chlorite, and commonly more or less epidote and kaolin."

The Dedham formation has been dated as pre-Carboniferous by Chute (10) pre-Devonian by Nelson (5), Devonian by Emerson (2) and Clapp (7) and early Paleozoic by LaForge (8).

C. te (10) adds that it is a massive, medium to coarse grained, light pinkish grey (rock) which is high in quartz and low in ferro-magnesium minerals.

FITCHBURG GRANITE

Within the present study area the Fitchburg Granite outcrops only within the township of Worcester.

Emerson (2, p. 232) dates this formation as being either late or post Carboniferous and describes it as follows:

> "a fresh light-colored medium-grained muscovite-biotite-microcline granite."

MILFORD GRANITE

The Milford Granite underlies a large area near the junction of Norfolk, Middlesex and Worcester Counties and a smaller area to the west in the township of Grafton. This rock is extensively quarried for building stone.

Emerson (2, p. 165) describes its age and character as follows:

> "... it is apparently of the same age as the Dedham Granodiorite and it is therefore regarded as probably Devonian.

The commonest type of the granite is a pink, coarse-grained rock containing fairly abundant biotite in distinct black spots made up of minute scales. The quartz is in rounded blue grains and the feldspar in partly distinct crystals inclosed in a granulated quartz-feldspar groundmass."

NEWBURY-MATTAPAN-LYNN VOLCANICS

Due to the many similarities in the lithology, mode of origin and age of the Newbury, Mattapan and Lynn Volcanic Complexes in the Eastern Massachusetts area and the prevailing uncertainty concerning boundaries between these units, they have been grouped together as one formation for the purposes of this report.

Generally, the northern members of the complex underlying the lower Parker River basin to the north of the study area have been mapped by Emerson as the Newbury Volcanics. Clapp (7, p. 30) combined these with the members underlying lower Essex County and named them the Lynn Volcanics. In 1932 LaForge (8, p.35) indicates that the Lynn volcanics are probably the same as the more southerly Mattapan Complex.

These formations are thought to be Devonian or Early Carboniferous in age and are described by LaForge (8, p. 34) as follows:

> "Thick beds of volcanic ash and of coarse tuff, mud flows, and water laid sediments composed of reworked tuff with some extraneous pebbles...
> The sedimentary rocks of the complex are chiefly tuffs, tuff breccias, and mud flows, composed largely of andesitic material. Near the top are some interbedded lenses of conglomerate, sandstone, and slate."

NEWBURYPORT QUARTZ DIORITE

The Newburyport Quartz Diorite occurs as a belt running from Lynn westward to the town of Arlington, and as two smaller bodies in the Norwood Quadrangle.

Chute (10, p.8) and LaForge (8, p. 25) date the formation as being pre-Carboniferous and early Paleozoic respectively. Emerson (2, p. 178) and Clapp (7, p. 42) are more specific and have placed it in the Devonian.

There is general agreement that the Newburyport Quartz Diorite is as Clapp states "... The rock of the subalkaline group intermediate in composition between the Salem Gabbro-Diorite and the Dedham Granodiorite, into both of which types it is transitional."

The formation is described by Emerson (2, p. 178) as:

> "... a medium grained, somewhat gneissic rock, consisting essentially of andesine, labradorite, orthoclase, quartz, and hornblende, and accessory augite, ilmenite, magnetite, apatite, rutile and titanite."

Chute (10, p. B11) states:

> "The Newburyport Quartz Diorite of the Norwood quadrangle is a medium, to coarse-grained, dark-greenish-gray rock characterized by nearly equidimensional poikilitic hornblende crystals whose sections appear round or square."

QUINCY GRANITE

"The Quincy Granite forms a belt 10 miles long and 2.5 miles wide in the town of Quincy and Milton" (2, p. 188). Also, it forms a nearly circular stock in Peabody and Lynnfield and is the chief rock of Cape Ann (7, p. 25).

There is general agreement that the Quincy Granite is early Carboniferous in age. Emerson (2, p. 188) describes the formation as follows:

> "The normal Quincy Granite is a moderately coarse-grained rock composed of dominant quartz, feldspar, and hornblende and accessory aegirite, zircon, titanite and ores... The fresh rock, which takes a high polish, is prevailingly gray, but has scattered darker streaks and cloudy masses, due to abundant dark microlites in the feldspar crystals. At other places the rock is pinkish or reddish from surface oxidation, greenish from alteration along shear zones and near trap dikes, or from abundant microlites of hematite."

SALEM GABBRO-DIORITE

According to Emerson (2, p. 178) "The Principal area of the rocks mapped as Salem Gabbro-Diorite is in central and southern Essex County. It extends northeastward to the coast in Newburyport and Ipswich, southeastward to the coast from Salem to Swampscott, and southwestward into Arlington, Lexington, and Lincoln... In Norfolk and Plymouth Counties a number of masses of diorite, some of them of considerable size, are enclosed in the Dedham Granodiorite.

The Salem includes several types of rock. The most characteristic and most widely distributed is a rock containing quartz, labradorite, hornblende, augite, and biotite. It is a medium-grained dark gray granular rock, ranging to light gray with increase of quartz and feldspar and to greenish and brownish tones where considerably weathered."

Emerson and Clapp agree that the Salem is Devonian in age, with others using the broader "early Palezoic" (8, 9).

SHARON SYENITE

The Sharon Syenite forms a large body of rock in Walpole, Sharon and Foxboro, and smaller body in a town of Wrentham.

Estimates of this formation's age range from Precambrian (12) to possibly Carboniferous (10). No definite date has yet been determined.

Chute (10, p. B22) describes the formation as follows:

> "The Sharon Syenite is a medium-grained granitoid rock composed of 80-85 percent perthitic orthoclase in anhedral grains 3-6 mm in longest dimension; in addition it contains a samll amount of microcline-perthite, 1-5 percent oligoclase, 0-3 percent quartz, and 4-5 percent hornblende."

SQUAM GRANITE

The Squam Granite occurs as small bodies of granite which are intrusive into and slightly younger than the Quincy Granite. These bodies of Squam Granite are located in Gloucester and Middleton.

Clapp (7, p. 26), in describing the Squam, states:

> "Its feldspar is chiefly orthoclase, microcline, and albite, rarely intergrown. The little microperthite which is present is irregular, and in it orthoclase greatly predominates over albite. The total feldspars form only about 35 percent of the rock, which is correspondingly rich in mafic minerals, quartz forming about 25 percent, as in the normal granite."

WESTWOOD GRANITE

This formation outcrops in the Norwood, Blue Hills, Brockton and Medfield Quadrangles. Chute (10, p. B14) describes the formation as follows:

> "The Westwood Granite, like the Dedham Granodiorite, is a light-pinkish-gray, even-grained massive rock rich in quartz and low in dark minerals. The common variety is composed of 25-35 percent quartz, 25-45 percent orthoclase or microperthite, 15-35 percent albite or sodic oligoclase, and 0-5 percent microcline. A small amount of biotite, mostly altered to chlorite, is usually present. The principal accessory minerals are magnetite, sphene, and apatite."

Chute has placed the Westwood Granite in the pre-Carboniferous Paleozoic.

UNASSIGNED PORPHYRITIC RIEBECKITE

This porphyritic riebeckite granite occurs along the boundary between the Mansfield and Brockton Quadrangles. Chute (3) places this unassigned rock unit in the Devonian or early Carboniferous, and describes it as follows:

> "Light-gray granite with quartz and black phenocrysts of riebeckite in a medium-grained matrix of albite. This is the marginal phase of a riebeckite granite stock probably to be correlated with the Quincy Granite of adjacent areas."

UNASSIGNED QUARTZ SYENITE

These are those rocks of Carboniferous age in Essex County that Clapp (7, p. 89) has named "quartz syenite or nordmarkite." He describes them as follows:

> "The bulk of the nordmarkites of Essex County, clearly transitional into the Quincy Granite, are really quartz-poor granites. Like the granite, they occur as part of the main batholith and stocks. They are coarse-grained, usually greenish-gray rocks, which on exposure to the air turn darker green like the granite. They are granite in texture, having the same rectangular feldspars and virtually the same constituent minerals as the Quincy Granite."

UNASSIGNED VOLCANIC ROCKS

These occur as a body of rock centrally located in the Brockton Quadrangle. Chute (3) describes the volcanics as being:

> "Dark greenish-gray, dense, altered lavas with well developed flow banding. Hydrothermal alteration is so extensive that the original composition of the lavas is uncertain, but judging from the high percentage of quartz (15 to 20 percent) they may have been rhyolite or quartz latite."

UNDIFFERENTIATED DEDHAM GRANODIORITE AND SALEM GABBRODIORITE

These are areas within the Blue Hills and Norwood Quadrangles which are mapped by N. E. Chute (4, 10) in which these two formations occur together with such complexity that they are inseparable.

SEDIMENTARY, METASEDIMENTARY, AND METAMORPHIC ROCK UNITS

BELLINGHAM CONGLOMERATE

The Bellingham conglomerate is found in a finger-shaped outcrop extending northward into the towns of Bellingham, Franklin, and Wrentham from Rhode Island. This is its only exposure in the study area. Emerson (2, p. 56) describes the Bellingham conglomerate as:

> "... a coarse basal conglomerate composed of pebbles of granite, quartzite, and green scnist in a matrix of sericite schist. The pebbles are commonly drawn out by crushing into long bands and the whole mass is in places changed to coarse chloritoid (masonite) schist, furnishing great crystals of masonite, several inches square,..."

According to Emerson (2) the Bellingham conglomerate is regarded as the equivalent of the Pondville conglomerate and is Carboniferous in age.

BRAINTREE ARGILLITE

The Braintree argillite is found in the town of Braintree near the Old Quincy Reservoir and in the town of Milton to the west. Chute (4) describes the Braintree argillite as:

> "... (a) dark-gray slate with beds of light- and medium-gray siltstone... chief constituents are chlorite, epidote, sericite, quartz, untwinned feldspar, leucoxene and graphite. Away from the (Quincy) granite most of the Braintree is dark gray and distinctly thinly bedded. As metamorphism increases toward the granite contact, bedding becomes less distinct and color changes to greenish gray due to removal of graphite and the presence of chlorite and epidote."

Chute (4) puts the Braintree argillite in the Cambrian. The Braintree argillite is the same as the Braintree slate except that it is slightly less metamorphosed.

BRAINTREE SLATE

According to LaForge (8) the Braintree slate is not known except along the southern margin of the Boston Basin. It is exposed in the towns of Braintree, Quincy, and Weymouth. Emerson (2, p. 38) describes the Braintree slate as:

"... dark gray to black carbonaceous slates and dark gray lydite, with a few calcareous and epidotic layers and nodules."

LaForge (8, p. 21) adds that:

"... it has been altered by the contact of the intrusive Quincy granite, with induration and the development of considerable mica and garnet and some tourmaline in almost microscopic crystals."

Emerson (2, p. 38) continues:

"... the Braintree slate appears to overlie conformably and to be folded with the Weymouth formation in Weymouth. All its other contacts are with younger rocks - on the south it is faulted against, and possibly in one or two places intruded by, the Dedham granodiorite... and on the west it is extensively intruded by, and at places included in, the Quincy granite."

The age is well determined due to the presence of a characteristic fauna, (Paradoxides), a middle Cambrain fossil found in a classic locality of New England Geology, the former Hayward Creek Quarry.

BRIMFIELD SCHIST

The Brimfield schist is exposed in long narrow strips within the Nashoba formation in the towns of Oxford, Sutton, Middlebury, and Webster; and within the Paxton quartz schist in Worcester. Emerson (2, p. 69) describes the Brimfield schist as:

"... a uniform coarse red-brown muscovite schist containing much biotite, fibrolite (commonly derived from an antecedent anadalusite), and graphite, and so much pyrite that it is wholely rusted in many of the deepest openings. If forms deep brown soils and abundant efflorescence of copperas formerly used for dyeing."

The Brimfield schist is assigned by Emerson (1917, p. 69) to the Carboniferous. It is the most marked and widely distributed of the metamorphic formations of the Carboniferous according to Emerson.

CAMBRIDGE SLATE

The Cambridge slate occupies a large area north of Boston in the Boston Basin from Waltham northeast to Lynn. It also underlies much of Boston Harbor forming the islands in the bay, the Hull peninsula and extends southeastward into the towns of Quincy and Milton. LaForge (8, p. 43) describes the Cambridge slate as follows:

"... The formation consists chiefly of rock of generally fine-grained argillaceous character that has been called pelite, shale, argillite and slate, though none of those names is wholly satisfactory... The typical Cambridge slate is dark bluish gray or brownish gray, rather fine-grained and composed chiefly of argillaceous material. Some parts of it are well stratified and thin bedded; other parts are rather massive. Most of it splits easily parallel to the bedding; and nearly everywhere it has developed a fissility across the bedding, but only rarely is this secondary structure dominant, and practically nowhere in the basin is the rock a true slate... Coarse grained beds, some of them sandy, but most of them composed mainly of reworked tuff, are scattered through the formation, mainly in its lower part. Near its top it contains some red and green shale."

There is no direct internal evidence of the age of the Cambridge slate or any of the rocks in the Boston Bay group. Indirect evidence and external evidence such as structural relationships within the Boston Basin and relationships with adjacent formations such as the Norfolk Basin indicate the most probable age of the Cambridge slate as Carboniferous.

MARLBORO FORMATION

The Marlboro formation is a member of a group of rocks generally agreed to be Precambrian in age. This is due to their lack of fossils, volcanic nature, and highly metamorphosed character. Emerson (2) divided them into two general formations due to their occurrence in "small rather widely separated areas," and the consequent lack of detailed knowledge of them. LaForge (8) includes two more formations in his interpretation of these presumed Precambrian rocks.

The Marlboro formation is found in the towns of Medway, Holliston, Sherborn, Waltham, Belmont, and Woburn. LaForge (8, p. 17) describes the Marlboro formation as follows:

"... A considerable part of the formation consists of dark-green, dark-gray, or black schist and slate, in some places almost of hornstone, composed chiefly of biotite, chlorite, and epidote, with some quartz and hornblende. From its association with rocks that appear to be sheared and altered basaltic lavas this rock is believed to be largely of volcanic origin and to have consisted originally in the main of fine basaltic tuff. That it is not wholly volcanic and is in part perhaps a marine sediment is attested by the

> not uncommon occurrence in it, of thin beds of limestone, quartzite, and pebbly sandstone or even conglomerate."

NASHOBA FORMATION

The Nashoba formation is exposed in the towns of Webster, Oxford, Sutton, Auburn, Millbury, Grafton and Worcester City. It was described by Hansen (13, p. 31) as follows:

> "... The name Nashoba formation is proposed for a great mass of metamorphic rocks of Carboniferous age that extends north-eastward across east-central Massachusetts almost from Connecticut to New Hampshire. The name is proposed because of the occurrence and good exposure of these rocks in the valley of Nashoba Brook in the Maynard and Westford quadrangles. They are probably best exposed in the town of Bolton, and the name Bolton gneiss was originally applied to them by Emerson (2, p. 81); he abandoned this appropriate name, however, as it had been preoccupied for a different formation elsewhere."

Emerson (2, p. 81) describes his Bolton gneiss as follows:

> "... The Bolton gneiss is typically exposed in the town of Bolton and Berlin. It consists as a rule of well-banded mica gneiss, with layers made up of coarse muscovite, biotite, and quartz, alternating with more quartzose and feldspathic layers. The commonest type is a medium-grained to fine-grained quartzose biotite gneiss of gray or brown color, in some places containing graphite, fibrolite and garnet. The rock splits into layers 3 to 4 inches thick and makes good flagging. Layers and lenses of quartz and of several pegmatites are common and in places make up much of the rock. They include greisen as well as the more common feldspathic pegmatite, and some are much squeezed and schistose. Other intrusive rocks are numerous dikes and sheets of granite (chiefly Ayer and Andover) and of aplitic and dioritic rocks. The latter are generally more or less faulted."

NORTHBRIDGE GRANITE GNEISS

The Northbridge granite gneiss is found covering a wide area in the western section of the study area. This includes the towns of Webster, Douglas, Uxbridge, Northbridge, Sutton, Grafton, Mendon, and Upton. Emerson (2, p. 155) describes the Northbridge granite gneiss as follows:

"... The Northbridge granite gneiss occupies a broad area with a core of coarse slightly gneissoid, prophyritic microcline-biotite granite, and a broad border of completely mashed, stretched, and penciled, highly muscovitic gneiss. It is considered Archean because the Algonkian quartzite overlaps it normally and the Milford granite cuts both rocks. The gneiss is a monotonous rock of coarser grain than the Milford granite and the aplitic and hornblende varieties of that rock are absent."

OAKDALE QUARTZITE

The Oakdale quartzite is found in the towns of Oxford, Auburn, and Worcester City in the western region of the study area. The following description is given in Emerson (2, p. 61):

"... It is a fine, even-grained, flaggy quartzite, in many places greatly jointed, reddish-brown from the development of actinolite in small lenses or subordinate beds that were originally calcareous. It contains accessory menaccanite, offrelite, pyrite, and muscovite. The bedding and the quartz grains are in many places original. Near the granite intrusions the quartz grains are enlarged or wholly recrystallized, the whole mass is coarser grained, and the rock grades into the next type."

Emerson (2, p. 77) concludes that the Oakdale quartzite is Carboniferous in age because it grades into the overlying Worcester phyllite without visible unconformity. Emerson explains:

"... The Worcester phyllite is Carboniferous, for it contains Lepidodendron and several species of ferns at the Worcester "coal mine"... The conclusion that the Oakdale quarzite is of Carboniferous age is greatly strengthened by the fact that it and the Worcester phyllite are closely folded together and in pitching folds the Oakdale regularly passes under the Worcester. Another reason for believing that the two formations belong to the same geologic period is that they are cut by the same set of igneous rocks."

OXFORD SCHIST

The Oxford schist occupies a small finger-shaped area in Auburn and Worcester City in the Western portion of the study area. Emerson (2, p. 68) describes it as follows:

"... south of Worcester the Worcester phyllite grades along the strike into a lead-gray mica schist, full of large crystals of garnet and staurolite and containing tourmaline derived from the granite. In places it is silvery white from the absence of both graphite and biotite. Subordinate beds of this (Oxford) schist containing fine staurolite twins appear in the Boylston schist along the shore of the reservoir a mile west of Boylston Center. The main mass occupies a broad area extending south from Worcester across Auburn."

The Oxford schist is Carboniferous because of its gradational relationship with the Worcester phyllite known to be Carboniferous through fossil evidence.

PAXTON QUARTZ SCHIST

The Paxton quartz schist is found in the extreme western portion of the study area in the towns of Leicester, Oxford, and Worcester City. The Paxton quartz schist is described as follows in Emerson (2, p. 62):

"... Towards the west what I regard as the equivalent of the Oakdale quartzite is more flaggy, includes more abundant and visible biotite and, in the small green calcareous areas, distinct lenses of actinolite, some of them containing diopside, essonite, titanite, pyrite, and residual calcite. It includes small beds of mica schist and limestone, and some of it is slightly graphitic. This type of rock is called the Paxton quartz schist, from its development at Paxton, northwest of Worcester. Unlike the Brimfield schist it is distinctly quartzitic, less rusty, and lacks graphite, garnet, and the aluminous silicates. Though much intruded by granite, it maintains its type to the west edge of Worcester county, and at places farther west becomes completely gneissoid... This is the most widely extended type of the lower formation of the Carboniferous... The Paxton passes in pitching folds beneath the Brimfield, just as the Oakdale passes beneath the Worcester. For a great distance north and south of Worcester the boundary between the Paxton and the Oakdale is a zone rather than a line, and the transition is so gradual and over large areas the change is so slight that a new name was hardly needed."

Emerson (2, p. 62) gives the Paxton quartz schist an age of Carboniferous, along with the other schists described (Brimfield, and Oxford schists):

"... The progressive increase in the metamorphism of the sedimentary rocks from the areas of little, to those of extensive granite intrusion and the continuous and complete transition, without definite boundaries between the different phases of rocks, from the little altered rocks to the highly altered schists, are my reasons for correlating the schists with the Oakdale and Worcester and regarding them all as of Carboniferous age.

PONDVILLE CONGLOMERATE

The Pondville conglomerate runs in two long fingers in the towns of Walpole, Norwood, Sharon, Canton, Randolph, Milton, and Quincy City. Emerson (1917, p. 54) describes the Pondville conglomerate as follows:

"... The basal formation is generally a coarse conglomerate or arkose made up of material derived from adjacent granite. It is not a continuous formation but is well represented along the north and southeast borders of the basin. It was named from Pondville station, in the Norfolk basin, where it is well displayed."

Emerson assigns the Pondville conglomerate to the Carboniferous age.

Chute also describes the Pondville conglomerate in his work on the Norwood quadrangle, Chute (10, p. 30):

"... The Pondville conglomerate... is divisible into two members in the Norwood quadrangle. The lower member consists of cobble and boulder conglomerate; the upper member consists of gray coarse sandstone, gray granule conglomerate, and pebble conglomerate... The members of the Pondville conglomerate can be traced along both sides of the Norfolk basin in the southern part of the quadrangle. Along the northern edge of the basin, the lower member apparently terminates at the Stony Brook fault and is absent to the west. The upper member continues about 3 miles farther west to another north-east-trending fault. Along the southern edge of the basin the lower member seems to terminate at the Stony Brook fault and is absent east of the fault. These apparent terminations are interpreted by the author to be the result of thrust faulting, older rocks having been thrust over the Pondville conglomerate from the north and south."

RHODE ISLAND FORMATION

The Rhode Island formation covers a wide region running from the town of Hanover southwestward through Plymouth county into Bristol county and on into Rhode Island. Emerson describes the Rhode Island formation as a part of the strata of the Narragansett Basin. Following is Emerson's (2, p. 54) description:

"... The Rhode Island formation makes up the greater part of the rocks of the basin, both in thickness and extent. It is named for the fact that the graphite coal beds of the state of Rhode Island are a part of it. It is called the Pawtucket formation by Warren and Powers. It consists of shaly and slaty coal-bearing beds intercalcated with sandstones and conglomerates. It abounds in coal plants of Pennsylvanian age and contains the remains of a few ostracods and insects. The rocks along the western border of the basin are rather strongly metamorphosed.

Coal was mined from the formation about the middle of the last century but apparently without profit. The coal beds are much crushed by the folding and include considerable infiltrated foreign material, so that the coal contains much ash. The coal is very anthracitic and apparently partly graphitic - indeed, the more altered rocks south of Providence are still Mined for graphite."

The age of the Rhode Island formation is given by both Emerson (2, p. 54) and Chute (3) as Pennsylvanian.

ROXBURY CONGLOMERATE

The Roxbury conglomerate has been studied by numerous geologists including the following published studies: Chute (10), Nelson (5), Emerson (2), and LaForge (8).

It is found in Boston City, Newton, Wellesley, Needham, Sherborn, and Dover. Emerson (2, p. 56) described its occurrence in the Boston Basin Carboniferous strata:

"... The lower formation, named for the Roxbury district of Boston, where it is conspicuously exposed, consists of a thick conglomerate and some sandstone and slate. In at least the southern part of the basin it may be divided into three members - the Brookline conglomerate at the base, the Dorchester slate in the middle, and the Squantum tillite at the top. The later flows of the Mattapan volcanic complex, chiefly amygdaloidal melphyre, are at several places interstratified with the Brookline and Dorchester members, but they are not known to occur in the Squantum member. It is impossible to distinguish everywhere between some of the earlier beds of the Brookline member and some of the volcanic conglomerates of the Mattapan complex, but clearly the volcanic activity began before the deposition of the Brookline and it appears to have ceased, at least in so far as surface extrusion is concerned, before the glacial conditions that marked the close of Roxbury time."

According to later work by LaForge (8, p. 39):

"... Later knowledge gained from recent excavations has shown that this threefold division does not persist throughout the area occupied by the formation with sufficient definiteness to warrent mapping the units separately... The threefold division is herein retained for convenience in description, but no attempt is made to represent the members on the map or in the sections and they are not regarded as clearly distinguishable stratigraphic subdivisions throughout the area...

The Brookline conglomerate member consists mainly of massive conglomerate... In a few places it is well stratified, but in much of its outcrop area it shows no bedding. Its base where exposed is generally coarse and heterogenous, containing cobbles and small boulders, many of which are of the same rock as the underlying formation, which in a few places is the Dedham granodiorite but elsewhere is some part of the Mattapan volcanic complex...

The Dorchester slate member is characterized by beds of red and purple sandy slate, purplish sandstone and grit, and small-pebble conglomerate. Much of the slate is composed of rather coarse material, apparently reworked balsatic or andesitic tuff...

The Squantum member consists mainly of a peculiar breccia now regarded as tillite or glacial conglomerate interbedded with a few thin layers that are regarded as water laid drift. The tillite contains striated and faceted pebbles and other indications of its glacial origin, including angular boulders of granite and other rocks 3 to 4 feet long...

The interpretation of the Roxbury formation has always been difficult... The discovery that the upper part of the formation is tillite has shed much light on the problem, and it is now regarded as mainly of glacial origin and as consisting chiefly of outwash deposits that were later overridden by the ice and covered with a deposit of till."

WAMSUTTA FORMATION

The Wamsutta formation is found in the towns of Attleboro, Fall River, Wrentham, Norfolk, and Walpole. A long sinuous band extends from Plainville, northeastward to Abington. Emerson (2, p.54) gives the following description of the Wamsutta formation:

"... Overlying the Pondville conglomerate, or resting on the older rocks where the Pondville is absent, is a group of characteristically red beds, composed of sandstones, felsite, agglomerates, arkose, and shales which Woodworth called the Wamsutta group, from Wamsutta, an Indian name proposed, but not adopted, for North Attleboro, where it is typically developed. The sediments, which include both felsite and melaphyres, are interbedded with some tuffs and flows of volcanic rocks."

The Wamsutta formation is Carboniferous in age according to Emerson (2).

WESTBORO QUARTZITE

The Westboro quartzite outcrops in the towns of Webster, Oxford, Douglas, Uxbridge, Mendon, Hopedale, and Milford, in the western region of the study area. Also in the Boston area it is found in Saugus and Medford. Emerson (2, p. 24) grouped the Westboro quartzite along with the Marlboro formation as an Algonkian rock. His description follows:

"... The Westboro quartzite, the lower of the two Algonkian formations, is a shoreward bed of sugary quartzite, in places actinolitic or biotitic. Across Uxbridge it is stretched into ligniform masses. It occupies nearly the whole town of Hopedale as a pure massive quartzite, and another area of this type extends from Grafton northward into Westboro, where much of it contains many minute needles of tremolite."

LaForge (8, p. 17) describes the Westboro quartzite in the Boston area:

"In the Boston area the formation occurs in several small lenses and narrow strips chiefly in Waltham, Belmont, Arlington, Melrose and Saugus. Probably the best as well as the most extensive development is that in Melrose and Saugus, where it crops out in many places. It is not a particularly resistant formation, and much of the area occupied by it is low ground, although it is found here and there on hills.

The formation consists almost wholly of white, light-yellow, cream-colored, or light-gray quartzite, in some places containing feldspathic material, in others considerable muscovite, and in still others some biotite or other dark mineral. It is as a rule thin bedded and differs slightly in composition and weathering from bed to bed, so that many outcrops have fluted surfaces parallel to the bedding."

WEYMOUTH FORMATION

The Weymouth slate is found in the town of Weymouth on the southern shore of Boston Harbor. Also a very small outcrop exists on East Point in Nahant. Emerson (2, p. 37) describes the Weymouth formation as follows:

"... At Weymouth the formation consists of reddish brownish, and greenish cherty slate, with greenish epidotic and calcareous lenses and nodules and thin beds of white limestone. At Nahant the beds are cherty greenish slate and gray lydite and a few layers of white limestone. Only a few feet of the formation is exposed at Nahant, the strata apparently being large inclusions in the great mass of gabbro that makes up the peninsula, though possibly that mass is a deformed sill or laccolith, of which the Cambrian strata exposed are the remnants of the floor and roof. At Weymouth the strata appear to be folded with the overlying Braintree slate, but the drift cover is so general that the relations are concealed and the thickness of the beds can not be determined.

According to LaForge (8, p. 20) the Weymouth formation contains, "fossils (which) belong to the Olenellus fauna and fix the age of the formation as Lower Cambrian."

WORCESTER PHYLLITE

The Worcester phyllite outcrops in small sinuous bands through the towns of Webster, Oxford, Auburn, and Worcester City. Emerson (2, p.62) describes the general character of the Worcester phyllite as follows:

> "...In its least changed or typical phase the Worcester phyllite ranges from soft black slate or phyllite, partly carbonaceous and partly graphitic, to light greasy sericite schist. The prevailing rock is thinly fissile, lead gray, with a corrugated satiny surface, generally splitting on the original lamination and not on a secondary cleavage... Its satiny surface is produced by the recrystallization of its clayey material into fine scales of mica, and as these scales grow coarser the rock grades into mica schist. The accessory minerals are biotite, ottrelite, garnet, pyrite, and minute chiastolite.
>
> In the Worcester "coal mine" and in the more metamorphosed western part of the Narragansett Basin a greenish-white satiny fibrous mineral occurs, filling fissures with its transverse needles. It was originally a prochlorite, possibly made fibrous by pressure, and is now changed in part to silica by the action of the acids formed on the oxidation of the pyrite."

UNASSIGNED GNEISSES AND SCHISTS

Within the limits of the study area in the towns of Worcester, Woburn, Reading, North Reading, Winchester and Arlington is an area of unassigned gneisses and schists. Emerson (2, p. 79) describes these undated rocks as follows:

> "... In all the areas the rocks have been closely folded, crushed and sheared, and greatly altered. The sedimentary rocks in particular have nearly everywhere been completely recrystallized. Nevertheless, the original bedding of the sedimentary rocks is preserved in many places, and in other places it is reasonably clear that the foliation of igneous rocks is due largely to original flow banding...

> The greater part of the area, however, is occupied by a complex mica gneiss, chiefly biotitic but in places containing muscovite, with which is associated some hornblende gneiss. It has been closely folded and greatly squeezed, and much of it closely and intricately plicated. It is certainly in part sedimentary and almost certainly in part igneous, but the two sorts of rock are so complexly interbedded and folded that in many places they can be distinguished with difficulty, it at all, and in most places to map them separately is out of the question."

UNASSIGNED METAMORPHIC ROCKS

The unassigned metamorphic rocks in the study area are in the towns of Topsfield and Ipswich, both small rounded areas surrounded for the most part by Salem gabbrodiorite. Clapp (7, p. 17) describes the rocks under the heading "Cambrian and Algondian Metamorphic Rocks" as follows:

> "... The oldest rocks of Essex County are clearly a series of metamorphic rocks of widely varying composition. They occur in relatively small areas usually in the form of elongate lenses entirely surrounded by intrusive granitic rocks throughout the greater part of the county. The larger areas are shown on the map (Pl. I, in pocket). Small areas occur in Georgetown, Newbury, West Newbury, and Newburyport, the Highfield ridge being composed chiefly of quartz-hornblende schists. Another relatively large area of quartzites, slates, and limestones occurs in Topsfield and northwest of Middleton...
>
> The metamorphic rocks are of both sedimentary and volcanic origin, although, as in the hornblende schists, it is not everywhere possible to determine the true nature of the original rock. The sedimentary rocks, all highly metamorphosed, range from quartzites to marbles, with many schistose varieties. The quartzites have been entirely recrystallized and are usually fairly coarse grained. However, some of them are extremely fine grained, in fact cherty, and are hard to distinguish from silicified felsites. They are closely associated with slaty beds, usually more or less schistose."

DIGHTON AND PURGATORY CONGLOMERATES

These conglomerates outcrop in Swansea, Seekonk, Rehoboth, Dighton, Taunton, Somerset, and Berkley. Emerson (2, p. 55) describes them as follows:

> "... Infolded in the Rhode Island formation are long lenses of a peculiar conglomerate, mentioned above as the Dighton conglomerate. It is named from Dighton, Massachusetts, near which it is well exposed. It contains Obolus-bearing quartzite pebbles of Upper Camrian age and pebbles of muscovite granite, both rocks being of unknown origin. The pebbles are commonly more than a foot long and are well rounded, suggesting beach action. Their size indicates more violent currents than those that existed during the earlier stages of Carboniferous deposition. Farther south what is regarded as the same formation is called the Purgatory conglomerate from a well-known cliff near Newport, where the conglomerate is much metamorphosed, the matrix is mica schist and the large pebbles indent each other. The whole is perfectly sheared by great joints."

According to Emerson (2) these conglomerates were laid down during the Carboniferous age.

C. ENGINEERING CHARACTERISTICS OF BEDROCK UNITS

The previously described bedrock units have been grouped into eight catagories, each of which has its own engineering characteristics. The source of information used in determining these characteristics was Engineering Geology of the Northeast Corridor, Washington, D. C., to Boston, Massachusetts, Bedrock Geology, 1967, U.S.G.S. Miscellaneous Geologic Investigations Map I-514-A, Sheet 6. (14)

The following are the bedrock units of the eight catagories and their respective engineering characteristics.

MAP UNIT #1	Andover Granite	Quincy Granite
	Ayer Granite	Salem Gabbrodiorite
	Beverly Syenite	Sharon Syenite
	Blue Hill Granite Prophyry	Squam Granite
	Dedham Granodiorite	Westwood Granite

	Fitchburg Granite	Unassigned Prophyritic Riebeckite Granite
	Milford Granite	Undifferentiated Dedham Granodiorite and Salem Gabbrodiorite
	Newburyport Quartz Diorite	
	Northbridge Granite Gneiss	Unassigned Granite
MAP UNIT # 2	Oakdale Quartzite	
	Westboro Quartzite	
MAP UNIT # 3	Brimfield Schist	Paxton Quartz Schist
	Marlboro Formation	Unassigned Gneisses and Schists
	Nashoba Formation	
	Oxford Schist	
MAP UNIT # 4	Worcester Phyllite	
MAP UNIT # 5	Braintree Argillite	
	Braintree Slate	
	Cambridge Slate	
	Weymouth Formation	
MAP UNIT # 6	Newbury-Mattapan-Lynn Volcanics	
	Unassigned Volcanic Rocks	
MAP UNIT # 7	Rhode Island Formation	
	Wamsutta Formation	
MPA UNIT # 8	Bellingham Conglomerate	
	Pondville Conglomerate	
	Roxbury Conglomerate	
	Dighton and Prugatory Conglomerates	

TABLE A1 ENGINEERING CHARACTERISTICS OF BEDROCK UNITS

	PHYSICAL PROPERTIES[1]				EVALUATION OF ROCK FOR CONSTRUCTION[2]
Map Unit	Dry unit weight (pounds per cubic foot)	Compressive strength[3]	Young's modulus of elasticity[4]	Relative drillability[5]	Excavation Characteristics
1. **Granitic rocks.**	162-173	**Medium to very high.**	**Low to medium.**	4	**Overbreak and rock load generally minimal. Rock locally in high state of compression; popping and spalling increased with depth. Very high stress may deform deep underground openings. Open joint water bearing locally and persistent with depth. Fibrous rock will slow excavation by boring machine.**
2. Quartzite with interbedded conglomerate, schist, and gneiss.	165-172	Medium to high.	Mostly high; schist low.	3	Overbreak and rock loads mostly moderate; excessive in crushed zones. Scaling excessive and hazardous in very blocky to crushed zones. Massive zones may be highly stressed; possible popping and spalling.
3. Coarse mica schist and mica gneiss.	166-176	Low to medium.	Low (schist) to high (gneiss).	5-6	Moderately easy to excavate. Machine boring slowed by quartz pods and other hard inclusions. Overbreak generally slight but depends partly on orientation of excavation to foliation partings. Rock load variable; moderate in altered rock; excessive in shear zones. Squeezing ground in wet shear zones probable.
4. Fine-grained mica schist, chlorite schist, and phyllite with interbedded quartzose rocks.	165-181	Very low to medium.	Mostly low, quartzite high.	3-5	Relatively easy to excavate. Machine boring slowed by quartz pods and other hard inclusions. Overbreak and rock loads mostly slight except in large fault and shear zones and in highly altered rock; squeezing ground common in wet shear zones. Scaling slight to moderate, increasing in more brittle rocks.

TABLE A1 (cont.)

Map Unit	Dry unit weight (pounds per cubic foot)	Compressive strength[3]	Young's modulus of elasticity[4]	Relative drillability[5]	Excavation characteristics
	PHYSICAL PROPERTIES[1]				EVALUATION OF ROCK FOR CONSTRUCTION[2]
5. Argillite, siliceous shale, slaty shale, slate, phyllite, and fine-grained schist.	148-177	Very low (phyllite) to high (slate).	Low to high.	5	Moderately easy to excavate. Overbreak and rock loads mostly slight, but excessive where rock altered or faulted. Scaling moderate.
6. Volcanic rocks, commonly altered and slightly metamorphosed.	164-172	High.	High.	1	Overbreak slight to moderate. Rock load mostly slight, increases near major faults. Thin dikes (some similar to map unit 23) generally give moderate to extreme overbreak and rock loads. Generally very wet. Scaling excessive.
7. Sandstone and shale	135-162	Very low (shale) to high (sandstone).	Very low to low.	6	Stability and rock loads variable, depending on frequency and attitude of bedding and jointing. Slight air slaking in shales.
8. Conglomerate	165-168	Medium to high.	High (conglomerate) to low (sandstone).	3-4	Overbreak and rock loads minimal. Popping and slabbing may result from high state of stress.

1. Physical data available only for some rock units; where data are lacking, the physical properties are inferred from comparisons with those of rock elsewhere that possess similar composition, structure, and geologic histories.

2. Reported construction characteristics are limited in number. Evaluations of rock units, for the most part, are inferred from generalized conditions of structure, alteration, hydrology, and state-of-stress. Specific conditions can change within short distance. More refined engineering evaluations must be based on more detailed knowledge of geologic conditions.

3. Classification is for uniaxial compressive strength of intact rock. Strength is reduced by physical defects and chemical alteration in rock; it may differ with respect to bedding, foliation, or direction of principal residual stress.

Strength class	Range of compressive strength (psi)
Very high	>32,000
High	16,000-32,000
Medium	8,000-16,000
Low	4,000- 8,000
Very low	<4,000

4. Inferred for intact rock. Modulus is reduced by physical defects and chemical alteration in rock; it differs with respect to bedding, foliation, or direction of principal residual stress.

Modulus class	Range of static modulus of elasticity (psi)
Very high	$>12 \times 10^6$
High	$8 \times 10^6 - 12 \times 10^6$
Medium	$4 \times 10^6 - 8 \times 10^6$
Low	$1 \times 10^6 - 4 \times 10^6$
Very low	$<10^6$

5. Number "1" indicates rock most difficult to drill. Numbers increase with ease of drilling.

III. SURFICIAL GEOLOGY OF EASTERN MASSACHUSETTS

A. Source Material and Mapping Procedure

The source material used to prepare the surficial geology maps can be divided into four categories.

These four source categories were:

a. Information derived from United States Geological Survey (U.S.G.S.) Bulletins. These included The Geology of the Boston Area (8) and Geology of the Norwood Quadrangle (10).

b. Information derived from United States Geological Survey Quadrangle Reports. There were twenty quadrangle reports which were used for this study. The names of the quadrangles and their corresponding Geologic Quadrangle (GQ) numbers are given here.

1.	GEORGETWON	GQ - 850	11.	HANOVER	GQ - 633
2.	IPSWICH	GQ - 189	12.	DUXBURY	GQ - 466
3.	WILMINGTON	GQ - 122	13.	NORTH TRURO	GQ - 599
4.	READING	GQ - 186	14.	BRIDGEWATER	GQ - 127
5.	SALEM	GQ - 271	15.	WELLFLEET	GQ - 750
6.	CONCORD	GQ - 331	16.	ASSAWOMPSET POND	GQ - 265
7.	BLUE HILLS	GQ - 463	17.	ORLEANS	GQ - 931
8.	SCITUATE	GQ - 467	18.	HARWICH	GQ - 786
9.	BROCKTON	GQ - 5	19.	CHATHAM	GQ - 911
10.	WHITMAN	GQ - 632	20.	MONOMOY POINT	GQ - 787

c. Information derived from United States Department of Agriculture (U.S.D.A.) soil survey publications. The most recent soils reports were used where available, however, for most areas only the series of reports made in the 1920's were available. The exception to this was the recent detailed soil survey of Plymouth County. Those U.S.D.A. publications that were used in the compliation of this report are as follows:

1. Soil survey of Essex County; Latimer, Lanphear; 1925

2. Soil survey of Middlesex County; Latimer, Lanphear; 1924

3. Soil survey of Worcester County; Latimer, Lanphear; Martin 1922

4. Soil survey of Norfolk, Bristol, and Barnstable Counties; Latimer, Maxon, Smith, Mallory, Roberts; 1920

5. Soil survey of Norfolk, Bristol, and Barnstable Counties; Latimer, Maxon, Smith, Mallory, Roberts; 1920

6. Soil survey Plymouth County; Upham; 1969

d. Information derived from publications other than U.S.G.S. Bulletins or Quadrangle Reports, or U.S.D.A. Soil Reports. There were two such publications used, one was The Geography and Geology of the Region Including Cape Cod, the Elizabeth Islands, Nantucket, Martha's Vineyard, No Man's Land, and Block Island by J. B. Woodworth and E. Wigglesworth in 1934. (15) This was published in 1934 as Volume 52 of The Memoirs of the Museum of Comparative Zoology at Harvard College. The other publication was a United States Geological Survey Open File Report on the Preliminary Surficial Geology of the Natick Quadrangle by A. E. Nelson in 1972. (5)

When available the maps of the U.S.G.S. Bulletins, Quadrangle Reports and Open File Reports were regarded as the most accurate description of the surficial deposits and were therefore used without alteration. The maps contained in the Woodworth and Wigglesworth publication were used to describe those areas of the Cape and the Islands where no U.S.G.S. maps were available. Lastly, where no other source of information was available the soils of eastern Massachusetts were grouped together into categories determined by the type of surficial sediment which they most likely overlie. Then, using the various county soils maps and U.S.G.S. topographic maps (for swamp and marsh determination) the surficial deposits were plotted on the same base map as was used for the bedrock maps.

In all instances, those maps from which information was obtained were of a different scale than that of the maps prepared for this report. Due to this fact, all source maps had to receive various degrees of reduction before their information could be transferred to the base maps of this report.

B. Legend Explanation

The surficial sediments were first divided into two main groups. These were: 1. coarse-grained soils 2. fine-grained and/or organic soils. The first of these groups, the coarse-grained soils, was further divided into four sections, each with a different mode of origin. These four sections were as follows. First, those stratified sediments derived from ice contact features and the outwash resulting from the melting of the glaciers. Sands and gravels are the dominant grain sizes with minor quantities of silts and clays sometimes encountered. On the maps these sediments appear as white areas and smaller, hard to recognize deposits are given the letter symbol Qsc.

Secondly are those sediments which are derived from marine beaches and windblown dunes. These deposits are generally strictly sands with very minor gravels or clays. On the maps these deposits are represented by northeast-southwest diagonal lines and the symbol Qmc where necessary.

The third group is the alluvium and river terrace deposits. These are sediments from recent rivers which generally are composed of sands and silts with minor clay and gravel content. This group is represented by a stippled pattern and Qac where necessary. The fourth and last group of the coarse-grained soils is the glacial till. This group, represented by horizontal lines and the letters Qtc where necessary, is composed of unsorted clayey or silty sands and gravels. The sediments are primarily derived from subglacial ground moraine, terminal moraines and lateral moraines. The deposits are unstratified and frequently contain rocks from cobble size to boulders as large as a small house.

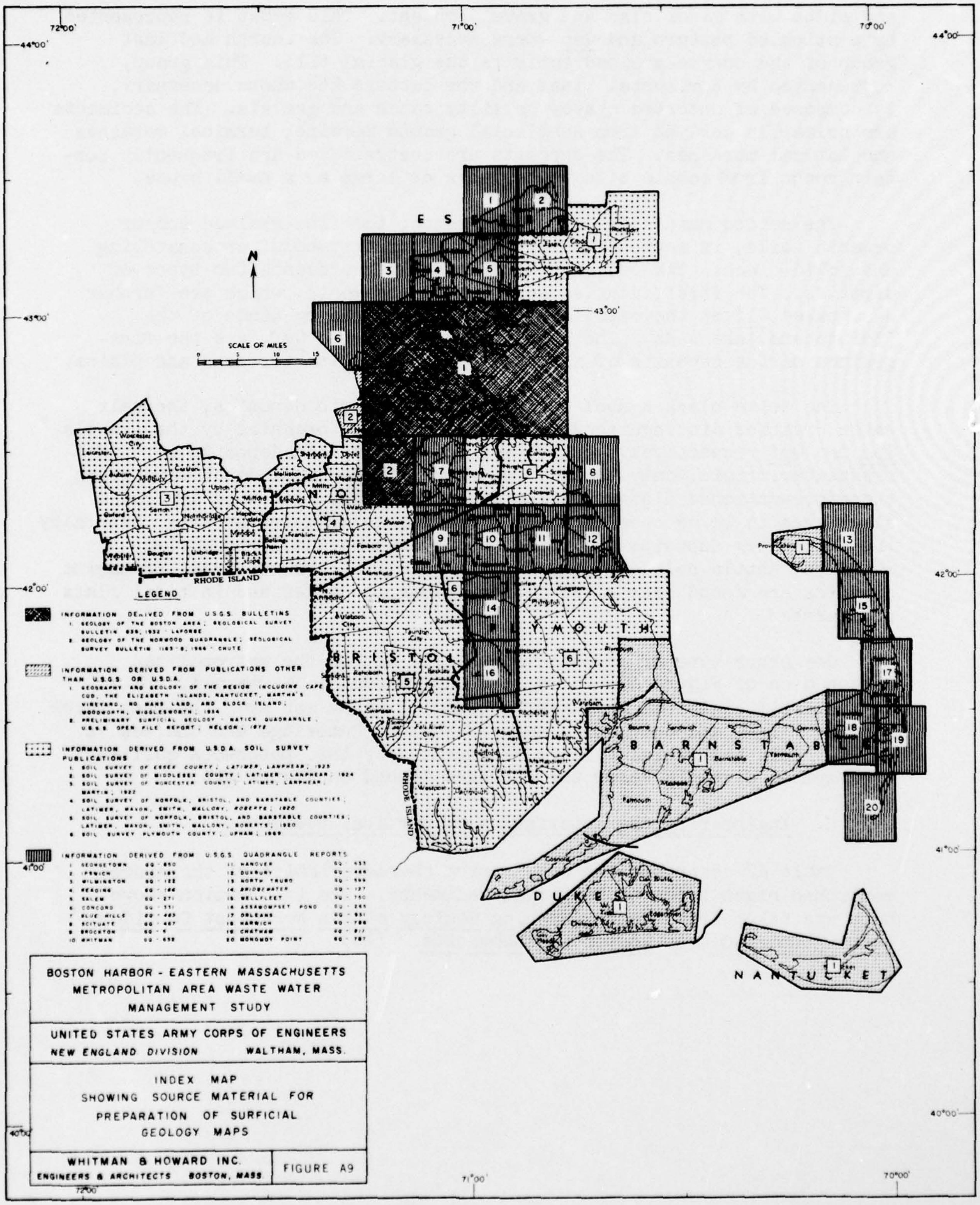
The second main category of sediments, the fine-grained and/or organic soils, is represented by two different symbols, crosshatching and solid black. The crosshatching actually represents two types of deposits. The first, glacial lake bottom sediments, which are further designated Qlf on the maps, are the silty and clayey sands of the Pleistocene lake beds. The second type designated Qmf, are the fine-grained marine deposits of the once offshore marine terraces and plains.

The solid black symbol represents the organic deposits, the salt water organics distinguished from the freshwater organics by the symbols Qom and Qof respectively. Since most of the organic deposits were of freshwater origin, only those areas where there may be doubt were given the aforementioned distinguishing letter symbols, otherwise any solid black area is to be considered as a freshwater organic deposit. Generally the freshwater deposits are found in old lake basins, cutoff river meanders, kettle holes or dammed off glacial valleys, whereas the marine organics are found near river mouths, along estuaries and in tidal flats and marshes.

One other type of deposit occurs only within the metropolitan Boston area of Figure A11 in large enough extent to be mapped. This is the artificial fill that has been hauled in by man over the past three hundred years, and upon which much of Boston, Cambridge and Chelsea is built. This artificial fill is represented by the "patchwork quilting" type symbol directly below the standard Legend on Figure A11.

C. Engineering Characteristics of Surfical Sediments

Table A2 describes the engineering characteristics of the aforementioned eight types of surficial sediments. The information shown here was taken from the Engineering Geology of the Northeast Corridor, Washington, D.C., to Boston Massachusetts. (14)


LEGEND
INFORMATION DERIVED FROM U.S.G.S. BULLETINS
1. GEOLOGY OF THE BOSTON AREA; GEOLOGICAL SURVEY BULLETIN 839, 1932 - LAFORGE
2. GEOLOGY OF THE NORWOOD QUADRANGLE; GEOLOGICAL SURVEY BULLETIN 1163-B, 1966 - CHUTE
INFORMATION DERIVED FROM PUBLICATIONS OTHER THAN U.S.G.S. OR U.S.D.A.
1. GEOGRAPHY AND GEOLOGY OF THE REGION INCLUDING CAPE COD, THE ELIZABETH ISLANDS, NANTUCKET, MARTHA'S VINEYARD, NO MANS LAND, AND BLOCK ISLAND; WOODWORTH, WIGGLESWORTH, 1934
2. PRELIMINARY SURFICIAL GEOLOGY - NATICK QUADRANGLE, U.S.G.S. OPEN FILE REPORT, NELSON, 1972
INFORMATION DERIVED FROM U.S.D.A. SOIL SURVEY PUBLICATIONS
1. SOIL SURVEY OF ESSEX COUNTY, LATIMER, LANPHEAR, 1925
2. SOIL SURVEY OF MIDDLESEX COUNTY, LATIMER, LANPHEAR, 1924
3. SOIL SURVEY OF WORCESTER COUNTY, LATIMER, LANPHEAR, MARTIN, 1922
4. SOIL SURVEY OF NORFOLK, BRISTOL, AND BARSTABLE COUNTIES; LATIMER, MAXON, SMITH, MALLORY, ROBERTS; 1920
5. SOIL SURVEY OF NORFOLK, BRISTOL, AND BARSTABLE COUNTIES; LATIMER, MAXON, SMITH, MALLORY, ROBERTS, 1920
6. SOIL SURVEY PLYMOUTH COUNTY, UPHAM, 1969
INFORMATION DERIVED FROM U.S.G.S. QUADRANGLE REPORTS
1. GEORGETOWN GQ - 850
2. IPSWICH GQ - 189
3. WILMINGTON GQ - 122
4. READING GQ - 166
5. SALEM GQ - 271
6. CONCORD GQ - 331
7. BLUE HILLS GQ - 463
8. SCITUATE GQ - 467
9. BROCKTON GQ - 5
10. WHITMAN GQ - 632
11. HANOVER GQ - 633
12. DUXBURY GQ - 466
13. NORTH TRURO GQ - 599
14. BRIDGEWATER GQ - 127
15. WELLFLEET GQ - 750
16. ASSAWOMPSET POND GQ - 265
17. ORLEANS GQ - 931
18. HARWICH GQ - 786
19. CHATHAM GQ - 911
20. MONOMOY POINT GQ - 787
SCALE OF MILES
ESSEX
NORFOLK
BRISTOL
PLYMOUTH
BARNSTABLE
DUKES
NANTUCKET
RHODE ISLAND
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.
INDEX MAP
SHOWING SOURCE MATERIAL FOR
PREPARATION OF SURFICIAL
GEOLOGY MAPS
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.
FIGURE A9

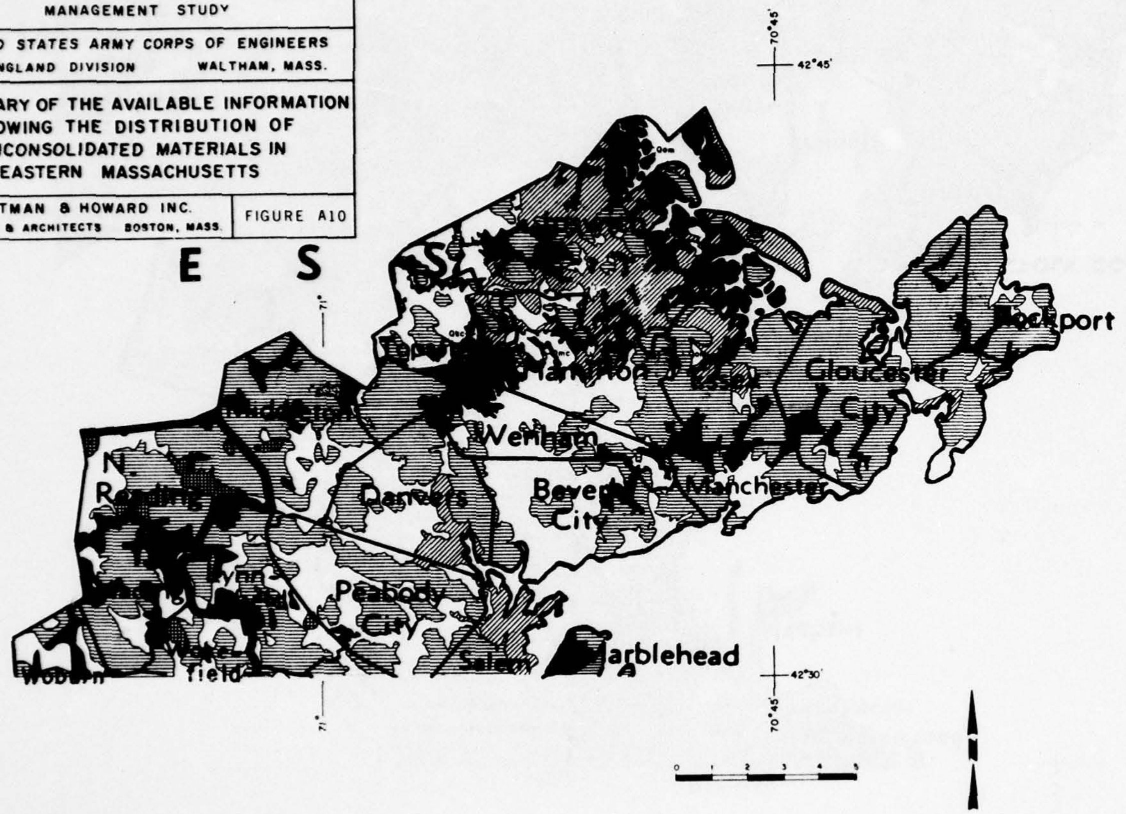
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

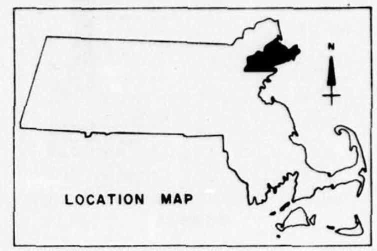
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF UNCONSOLIDATED MATERIALS IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

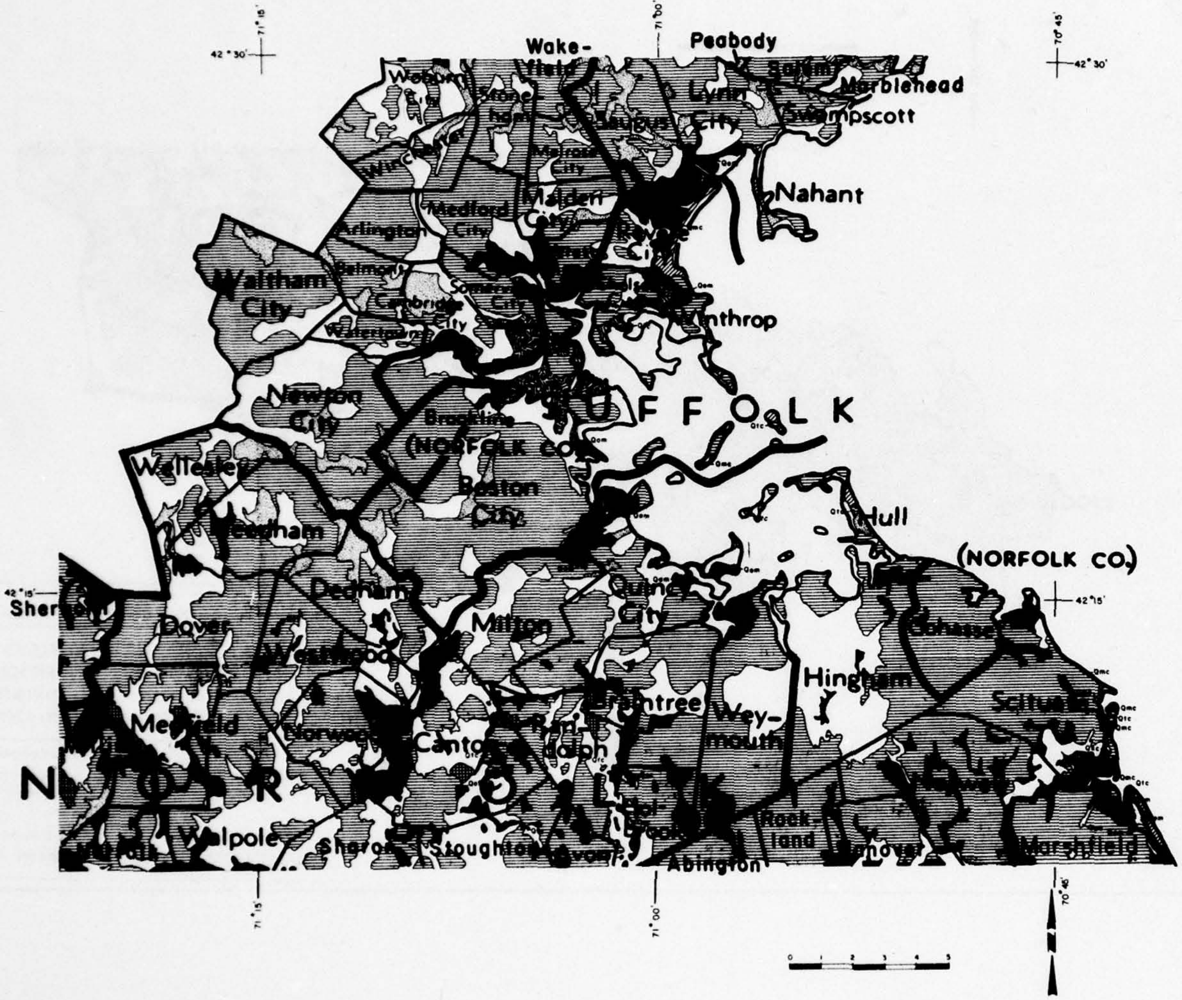
FIGURE A10

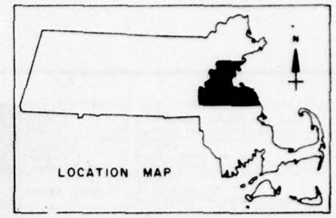




LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE-GRAINED SOILS	Qsc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross-bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS, Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"





BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS

A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF
UNCONSOLIDATED MATERIALS IN
EASTERN MASSACHUSETTS

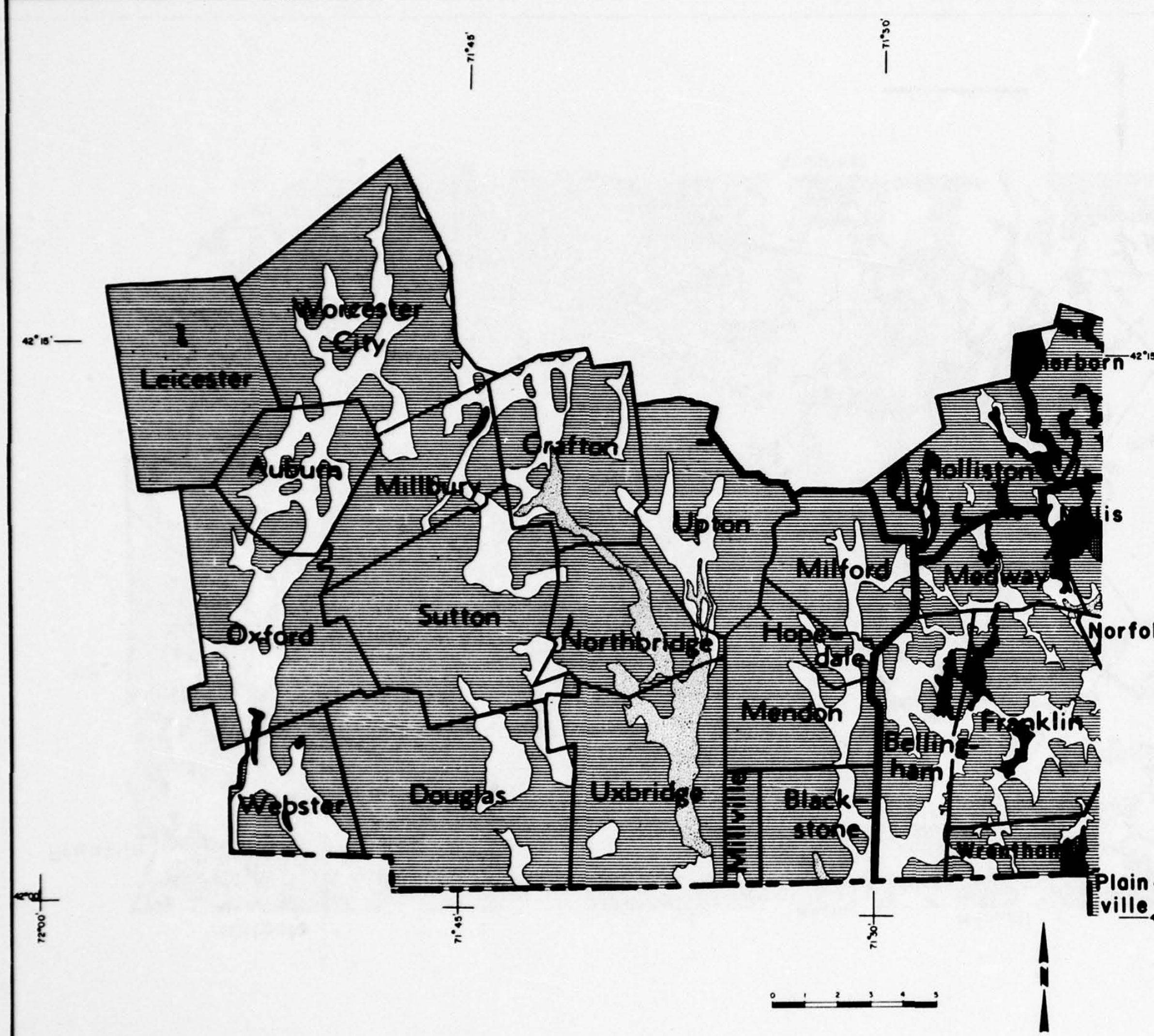
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

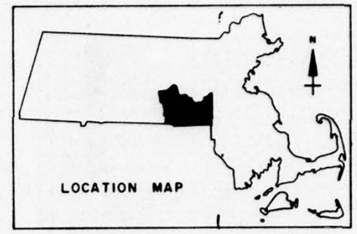
FIGURE A11

LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE-GRAINED SOILS	Qsc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross-bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"

ARTIFICIAL FILL





BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

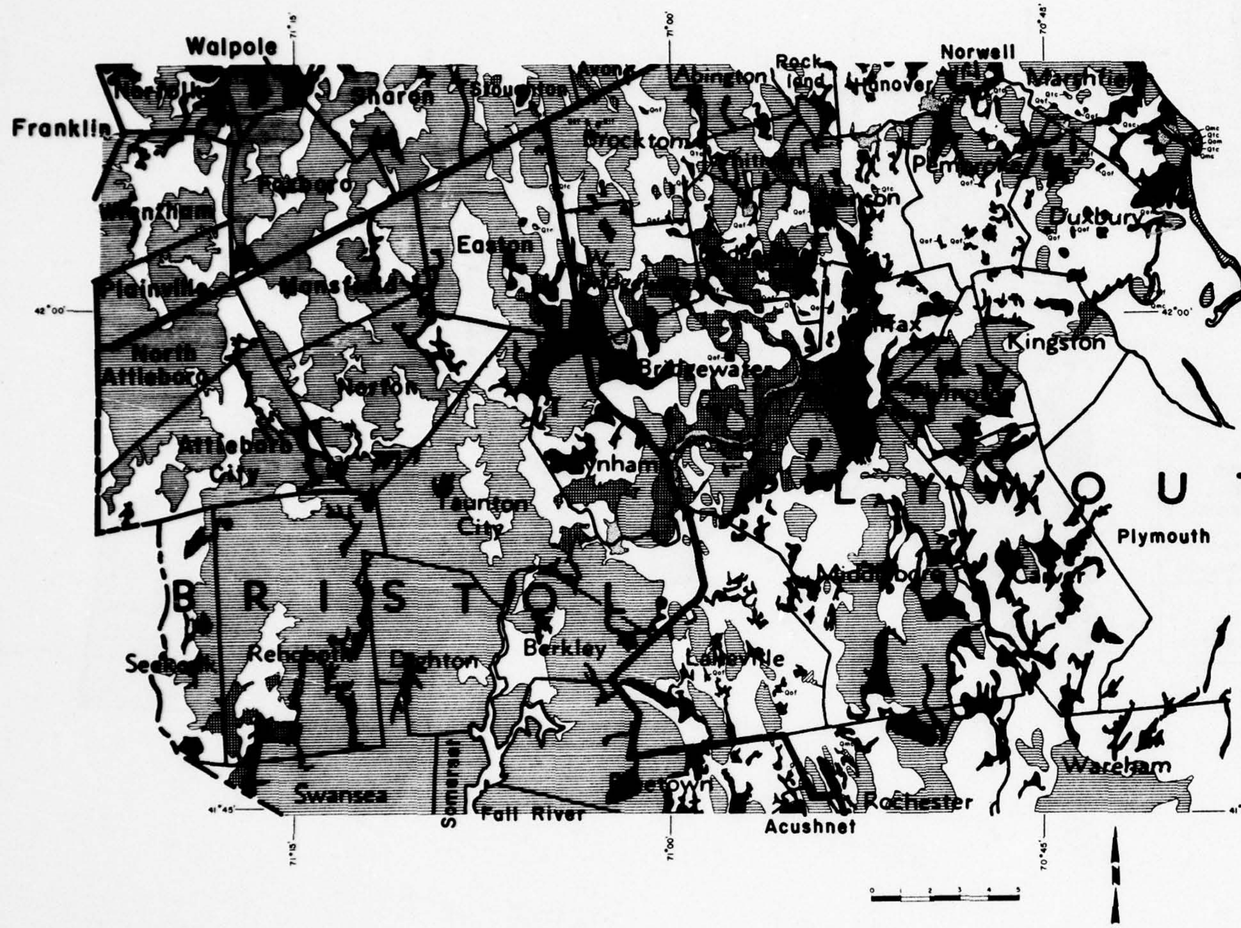
A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF UNCONSOLIDATED MATERIALS IN EASTERN MASSACHUSETTS

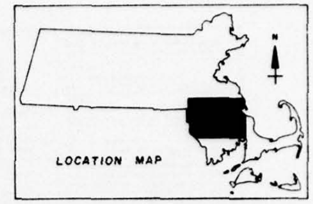
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A12

LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE-GRAINED SOILS	Qoc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross-bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"





BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

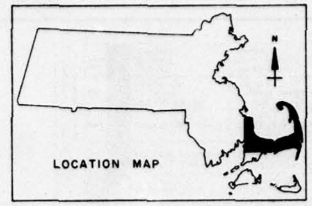
A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF
UNCONSOLIDATED MATERIALS IN
EASTERN MASSACHUSETTS

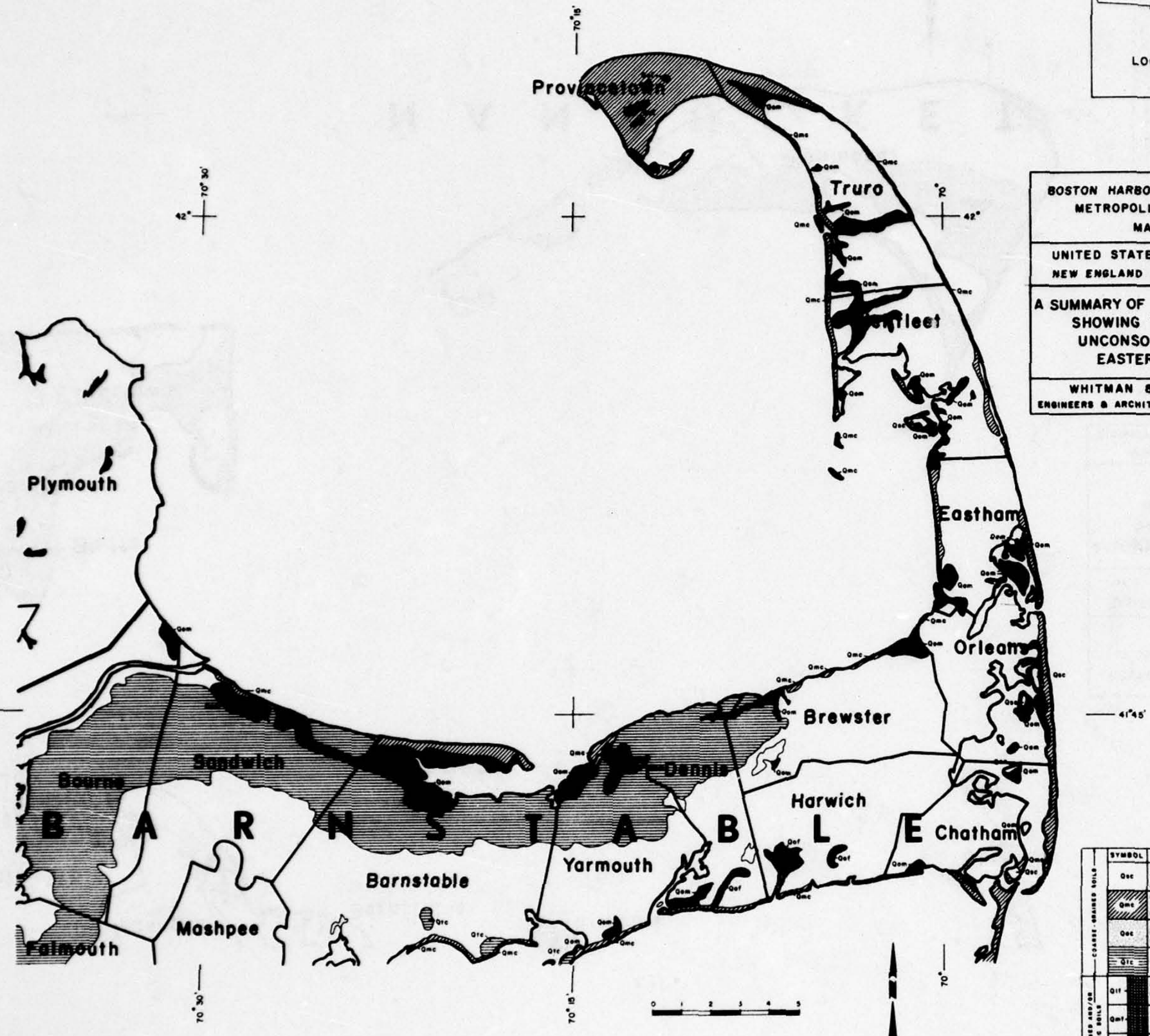
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A13

LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE - GRAINED SOILS	Qsc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross-bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"





BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

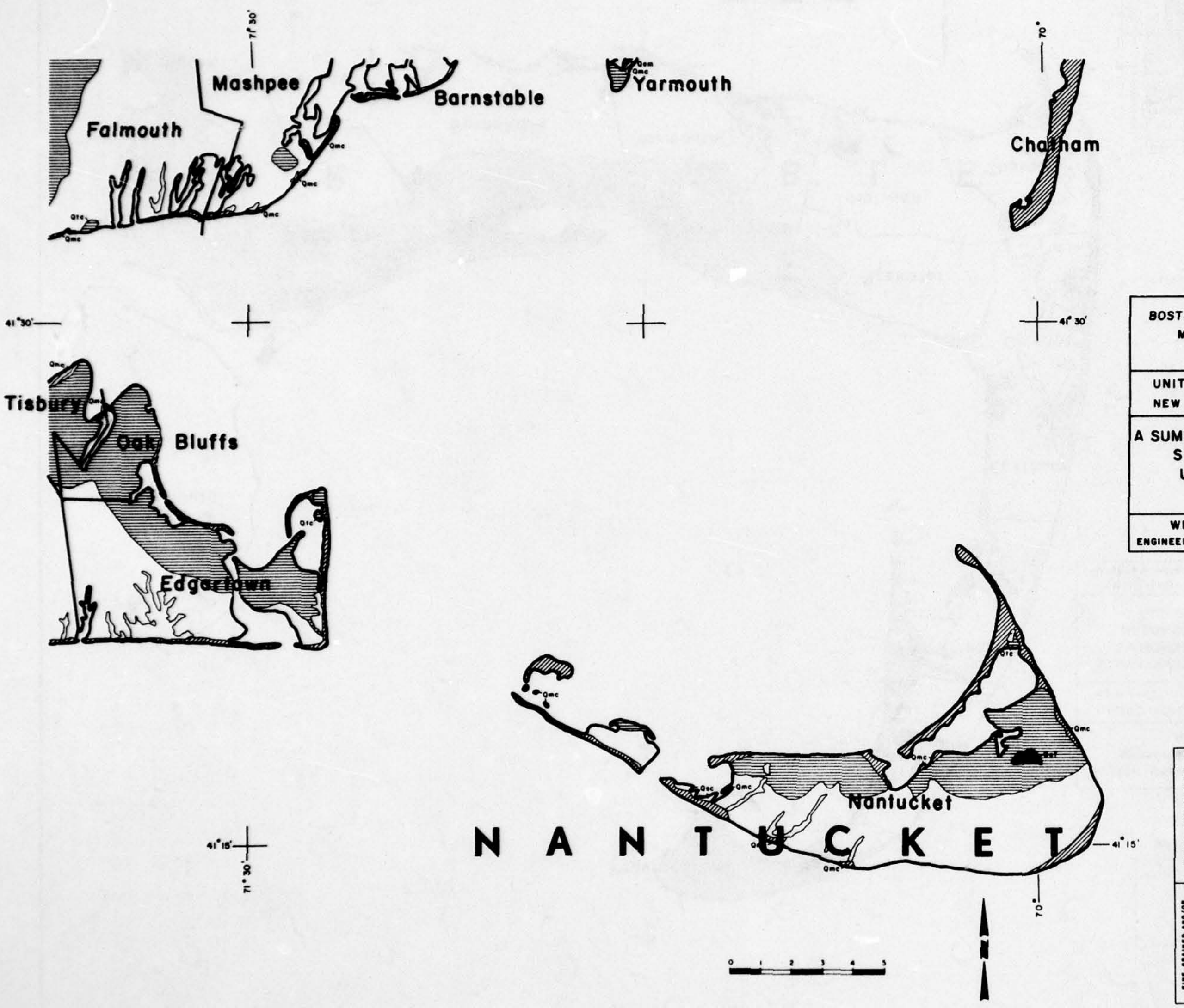
A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF
UNCONSOLIDATED MATERIALS IN
EASTERN MASSACHUSETTS

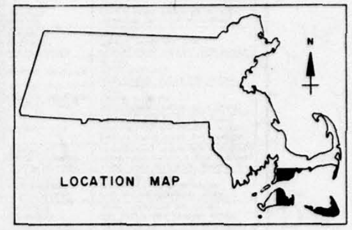
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A14

LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE-GRAINED SOILS	Qoc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross-bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS, Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"





BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF UNCONSOLIDATED MATERIALS IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A15

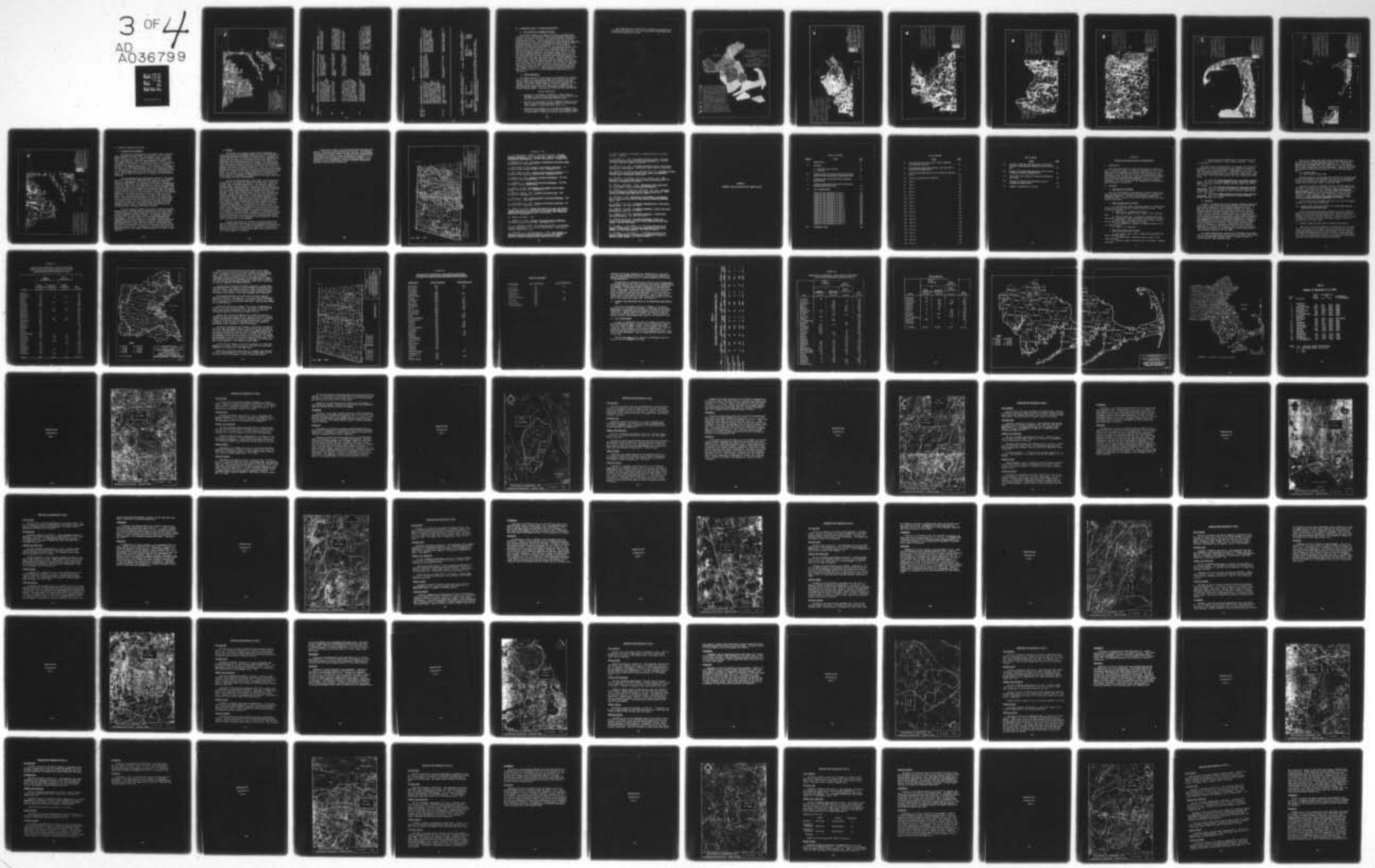
LEGEND

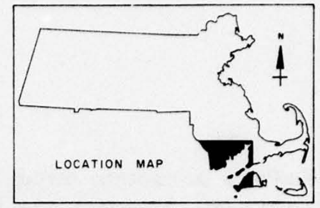
	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE-GRAINED SOILS	Qsc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross-bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS, Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"

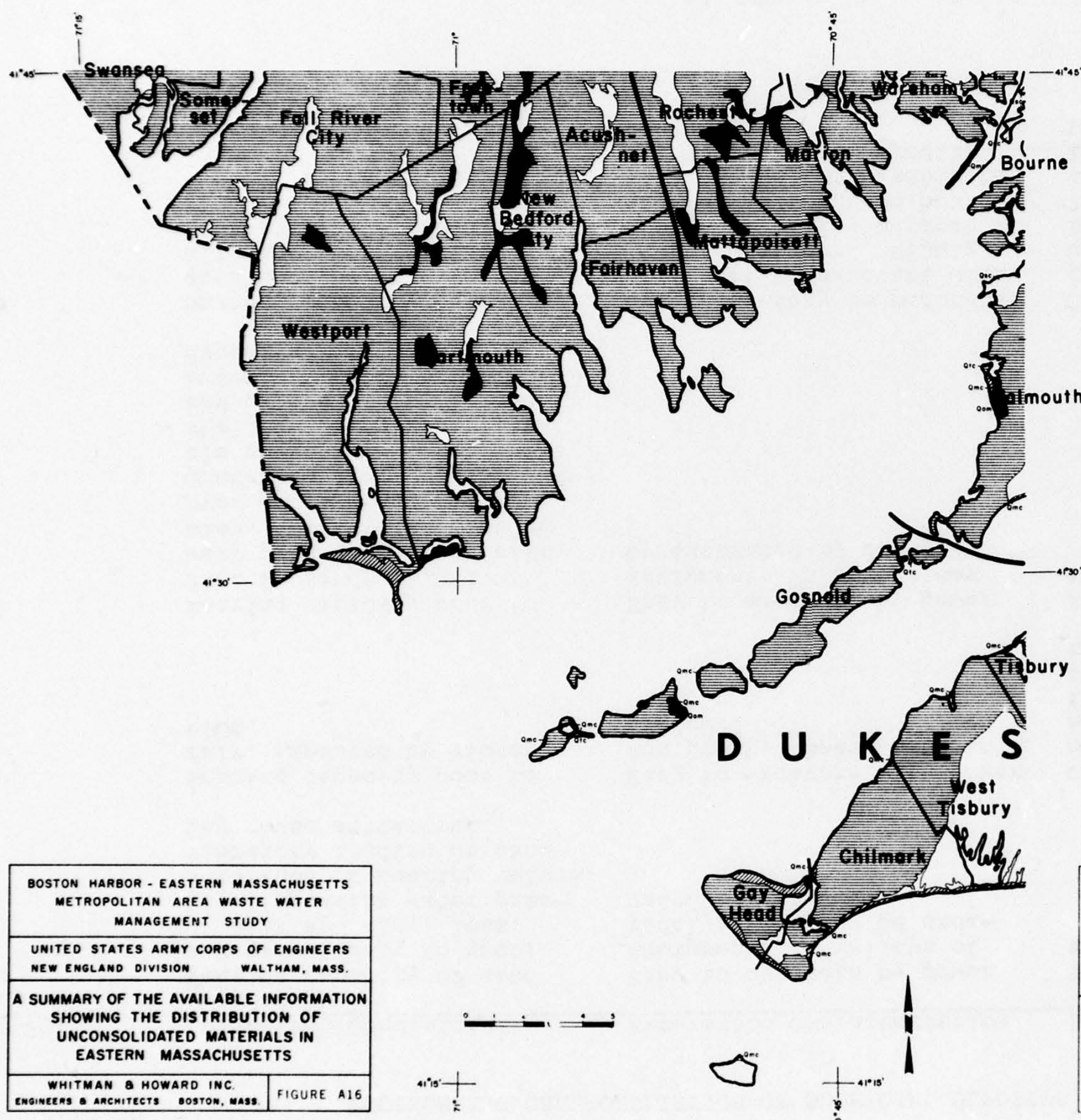
AD-A036 799 METCALF AND EDDY INC BOSTON MASS F/G 13/2
WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - --ETC(U)
OCT 75

UNCLASSIFIED NL

3 OF 4
AD
A036799







LEGEND

	SYMBOL	GEOLOGIC UNIT	CHARACTERISTICS OF MATERIAL
COARSE-GRAINED SOILS	Qsc	OUTWASH AND ICE CONTACT DEPOSITS	SANDS or SANDS and GRAVELS Silt and/or clay portions usually minor - stratified and sorted
	Qmc	BEACH, DUNE AND MARINE DEPOSITS	Fine or Fine to medium SANDS well sorted - often stratified and cross bedded
	Qac	ALLUVIUM AND RIVER TERRACE DEPOSITS	SAND, SILT with minor amounts of Gravel, Clay and/or Organics - poorly to moderately sorted and stratified
	Qtc	GLACIAL TILL	Silty or Clayey SAND and GRAVEL with Cobbles and boulders - dense, non-stratified unsorted mixture
FINE-GRAINED AND/OR ORGANIC SOILS	Qlf	GLACIAL LAKE BOTTOM DEPOSITS	SILTS, Clayey SILTS, Silty SANDS, Varved Silts and Clays
	Qmf	MARINE DEPOSITS	Silty CLAYS, SILTS and CLAYS SILTS Silty fine SANDS
	Qof	FRESH-WATER ORGANIC DEPOSITS	PEATS, Sandy PEATS, Silty PEATS, Organic Sands and Silts, "MUCK"
	Qom	MARINE ORGANIC DEPOSITS	ORGANIC SILT, Clayey Organic Silts, Organic Sands Marsh Mats, "Ooze"

BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF THE AVAILABLE INFORMATION SHOWING THE DISTRIBUTION OF UNCONSOLIDATED MATERIALS IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A16

TABLE A2

ENGINEERING CHARACTERISTICS OF SURFICIAL DEPOSITS

Map Unit	Foundation Conditions[1]	Excavation Characteristics	Slope Stability[2]
Qsc	Bearing capacity of sand and gravel fair to good; of silt and clay, less. Local artesian water pressure reduces bearing values. Vibratory loading on sand may cause settlement.	Easy to excavate by power equipment; in valleys of tidal rivers may be excavated by dredge.	Excavations below water table require support.
Qmc	Bearing capacity poor to fair; improved by vibration.	Easy to excavate with power equipment. Beach sand to dredge.	Cut slopes stable to angle of repose; steeper slopes need lagging because sand is free running when dry; readily flows into excavations below water table.
Qal	Bearing capacity poor to fair in sandy alluvium; very poor to poor on silt, clay. Structures founded over small lenses of compressible clay or silt settle unevenly. Water table shallow. Compressibility and expansion negligible except in thick organic deposits.	Easy to excavate by power equipment; in rivers may by excavated by dredge.	Excavations below water table require support.
Qtc	Bearing capacity generally good because of high density and poor sorting. Expansion negligible.	Generally easy to moderately difficult to excavate with power equipment. Highly compacted till ("hardpan"), and very strong and bouldery till can be troublesome to excavate without special equipment.	Cuts higher than 40 ft. generally require individual stability analysis. For lower slopes, 1 1/2 on 1 to 2 on 1 generally considered safe. Vertical slopes up to 15 ft. common, particularly in more cohesive clayey till.

TABLE A2 (cont.)

Map Unit	Foundation Conditions[1]	Excavation Characteristics	Slope Stability[2]
Qlf, Qmf	Bearing capacity generally poor. Where oxidized and preconsolidated, capacity fair. When confined and loaded, pore-water pressure increases and shearing strength decreases. Where saturated, dewatering may cause consolidation over large area. Compressibility high to low; expansion negligible to moderate.	Easy to excavate; wet conditions hamper construction equipment. "Quick" reaction to vibration in silt.	Generally unstable except in shallow dewatered cuts with gentle slopes. Support usually required. Clay is somewhat fissured and may fail along vertical joints. Sensitivity low.
Qof, Qom	Bearing capacity very poor. Compressibility high.	Easy to excavate by dredge or dragline.	Unstable; flows readily into underwater excavations.

[1]Bearing capacity - numerical values (tons per square foot) applied to qualifying adjectives:

Very poor	less than 1
Poor	1-4
Fair	4-8
Good	8-32
Excellent	greater than 32

[2]Cut slopes - numerical values, in degress, applied to qualifying adjectives:

Vertical	90
Near vertical	80-89
Steep	45-80
Moderate	30-45
Gentle	0-30

Compressibility - volume decrease in a soil mass in response to an external load.
Expansion - volume increase that is a function of load, time, density, water content, and type of clay minerals.

IV. GROUNDWATER GEOLOGY OF EASTERN MASSACHUSETTS

A. Source Material and Mapping Procedure

Two different agencies and number of different individuals have conducted or are in the process of conducting groundwater favorability studies in the area of this study. The studies have been conducted on a drainage basin basis. Involved with those studies are the United States Geological Survey, and the Massachusetts Water Resources Commission. Published material included two Groundwater Favorability Maps by the Massachusetts Water Resources Commission, (16, 17) two U.S.G.S. Hydrologic Investigation Atlases (18, 19), two Massachusetts Basic Data Reports (20,21), and an Availability of Groundwater Study (22). Unpublished material included six U.S.G.S. open files reports; of which four were Groundwater Management River Basin Studies (23, 24, 25, 26) and two were Water Resources of the Coastal Drainage Basins, (27, 28). The larger scale maps of these individual study areas were reduced to produce maps of the same scale as this study. The three mapping units of favorability were then superimposed upon a screened copy of the surficial maps. These drainage basin maps were obtained for the whole study area except for the Cape Cod region. For the Cape Cod region the data on well yields was used to produce a favorability map. Presently existing high production wells (300 G.P.M.) were enclosed within the unit number 1 (300 G.P.M.). Areas with wells producing 100-300 g.p.m. were enclosed in unit 2. All other areas were considered as unit 3 (100 g.p.m.).

B. Legend Explanation

The legend produced for this study for the favorability of groundwater is based on U.S.G.S. mapping legends which describe the aquifer and the potential groundwater yield that can be expected from that aquifer. This study's legend defines 3 categories of aquifers and the expected yields to be obtained from them. It is a compilation of descriptions that appear on U.S.G.S. groundwater favorability maps of various drainage basins. Below are the 3 units and their descriptions:

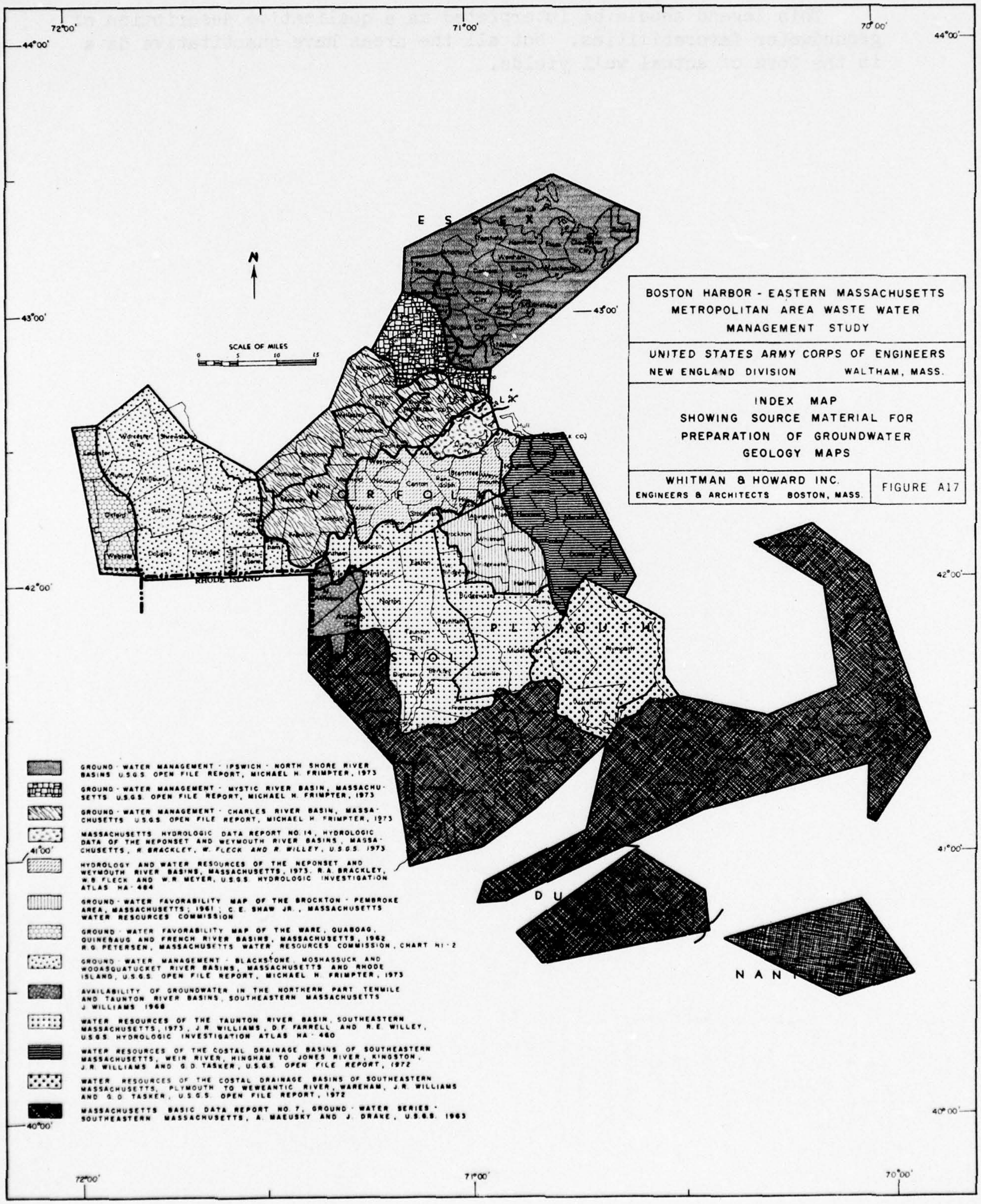
Aquifer Description

1. Favorable for development of moderate to large volumes of groundwater; saturated thickness generally larger than 40 feet; generally capable of yielding more than 300 g.p.m.

2. Favorable for development of low to moderate volumes of groundwater; saturated thickness generally from 20 to 40 feet; generally capable of yields from 100 to 300 g. p. m.

3. Favorable for development of low volumes of groundwater; saturated thickness generally less than 20 feet; generally capable of yields from 0 to 100 g.p.m. with the lowest yields in till.

This legend should be interpreted as a qualitative description of groundwater favorabilities. Not all the areas have quantitative data in the form of actual well yields.


BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY
UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.
INDEX MAP
SHOWING SOURCE MATERIAL FOR
PREPARATION OF GROUNDWATER
GEOLOGY MAPS
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.
FIGURE A17
SCALE OF MILES
0 5 10 15
N
ESSEX
NORFOLK
PLYMOUTH
RHODE ISLAND
72°00'
71°00'
70°00'
44°00'
43°00'
42°00'
41°00'
40°00'
GROUND - WATER MANAGEMENT - IPSWICH - NORTH SHORE RIVER BASINS U.S.G.S. OPEN FILE REPORT, MICHAEL H. FRIMPTER, 1973
GROUND - WATER MANAGEMENT - MYSTIC RIVER BASIN, MASSACHUSETTS U.S.G.S. OPEN FILE REPORT, MICHAEL H. FRIMPTER, 1973
GROUND - WATER MANAGEMENT - CHARLES RIVER BASIN, MASSACHUSETTS U.S.G.S. OPEN FILE REPORT, MICHAEL H. FRIMPTER, 1973
MASSACHUSETTS HYDROLOGIC DATA REPORT NO. 14, HYDROLOGIC DATA OF THE NEPONSET AND WEYMOUTH RIVER BASINS, MASSACHUSETTS, R. BRACKLEY, W. FLECK AND R. WILLEY, U.S.G.S. 1973
HYDROLOGY AND WATER RESOURCES OF THE NEPONSET AND WEYMOUTH RIVER BASINS, MASSACHUSETTS, 1973. R.A. BRACKLEY, W.B. FLECK AND W.R. MEYER, U.S.G.S. HYDROLOGIC INVESTIGATION ATLAS HA - 484
GROUND - WATER FAVORABILITY MAP OF THE BROCKTON - PEMBROKE AREA, MASSACHUSETTS; 1961; C.E. SHAW JR., MASSACHUSETTS WATER RESOURCES COMMISSION
GROUND - WATER FAVORABILITY MAP OF THE WARE, QUABOAG, QUINEBAUG AND FRENCH RIVER BASINS, MASSACHUSETTS, 1962 R.G. PETERSEN, MASSACHUSETTS WATER RESOURCES COMMISSION, CHART HI - 2
GROUND - WATER MANAGEMENT - BLACKSTONE, MOSHASSUCK AND WOOASQUATUCKET RIVER BASINS, MASSACHUSETTS AND RHODE ISLAND, U.S.G.S. OPEN FILE REPORT, MICHAEL H. FRIMPTER, 1973
AVAILABILITY OF GROUNDWATER IN THE NORTHERN PART TENMILE AND TAUNTON RIVER BASINS, SOUTHEASTERN MASSACHUSETTS J. WILLIAMS 1968
WATER RESOURCES OF THE TAUNTON RIVER BASIN, SOUTHEASTERN MASSACHUSETTS, 1973, J.R. WILLIAMS, D.F. FARRELL AND R.E. WILLEY, U.S.G.S. HYDROLOGIC INVESTIGATION ATLAS HA - 460
WATER RESOURCES OF THE COSTAL DRAINAGE BASINS OF SOUTHEASTERN MASSACHUSETTS, WEIR RIVER, HINGHAM TO JONES RIVER, KINGSTON, J.R. WILLIAMS AND G.D. TASKER, U.S.G.S. OPEN FILE REPORT, 1972
WATER RESOURCES OF THE COSTAL DRAINAGE BASINS OF SOUTHEASTERN MASSACHUSETTS, PLYMOUTH TO WEWEANTIC RIVER, WAREHAM, J.R. WILLIAMS AND G.D. TASKER, U.S.G.S. OPEN FILE REPORT, 1972
MASSACHUSETTS BASIC DATA REPORT NO. 7, GROUND - WATER SERIES - SOUTHEASTERN MASSACHUSETTS, A. MAEUSKY AND J. DRAKE, U.S.G.S. 1963

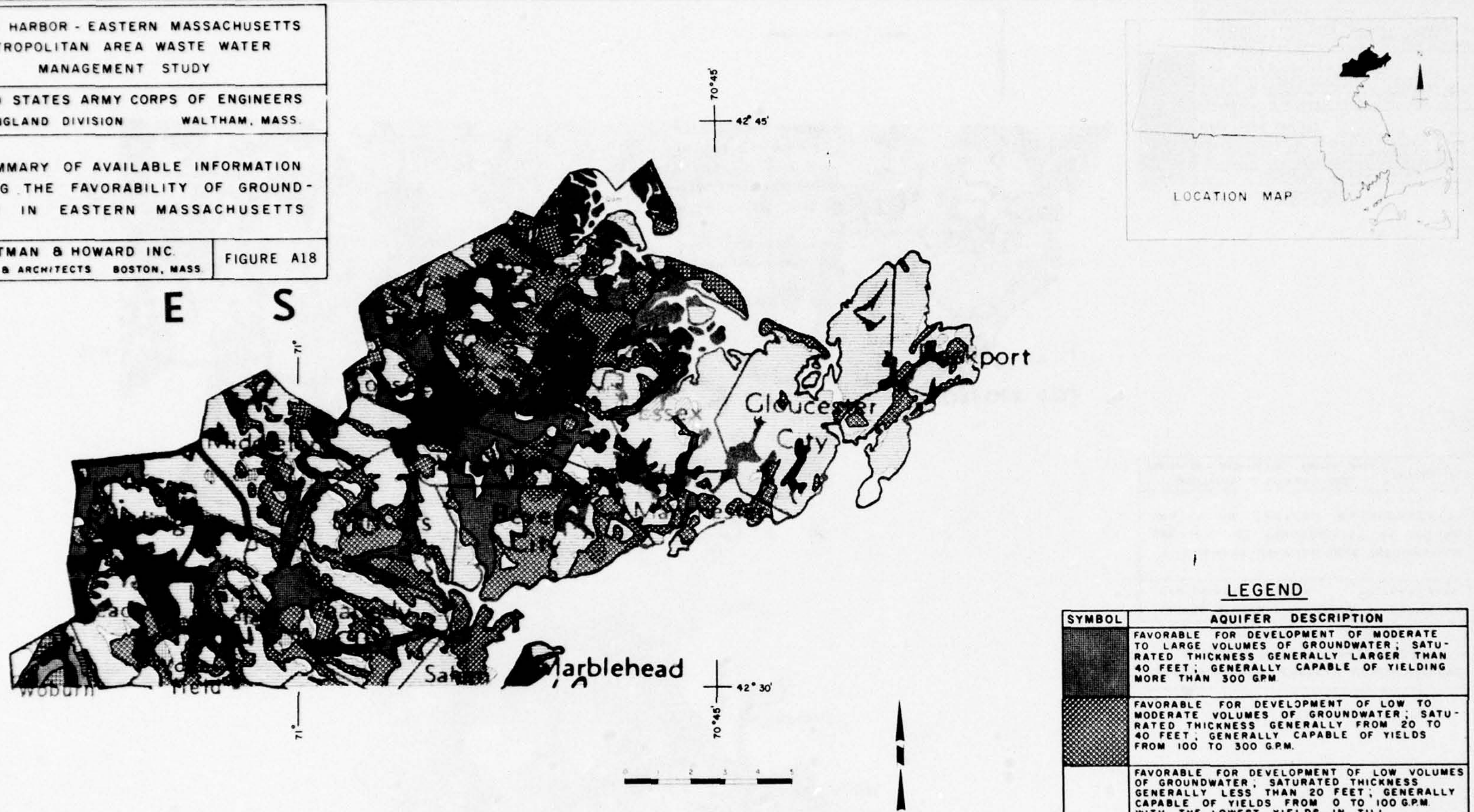
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUND-WATER IN EASTERN MASSACHUSETTS

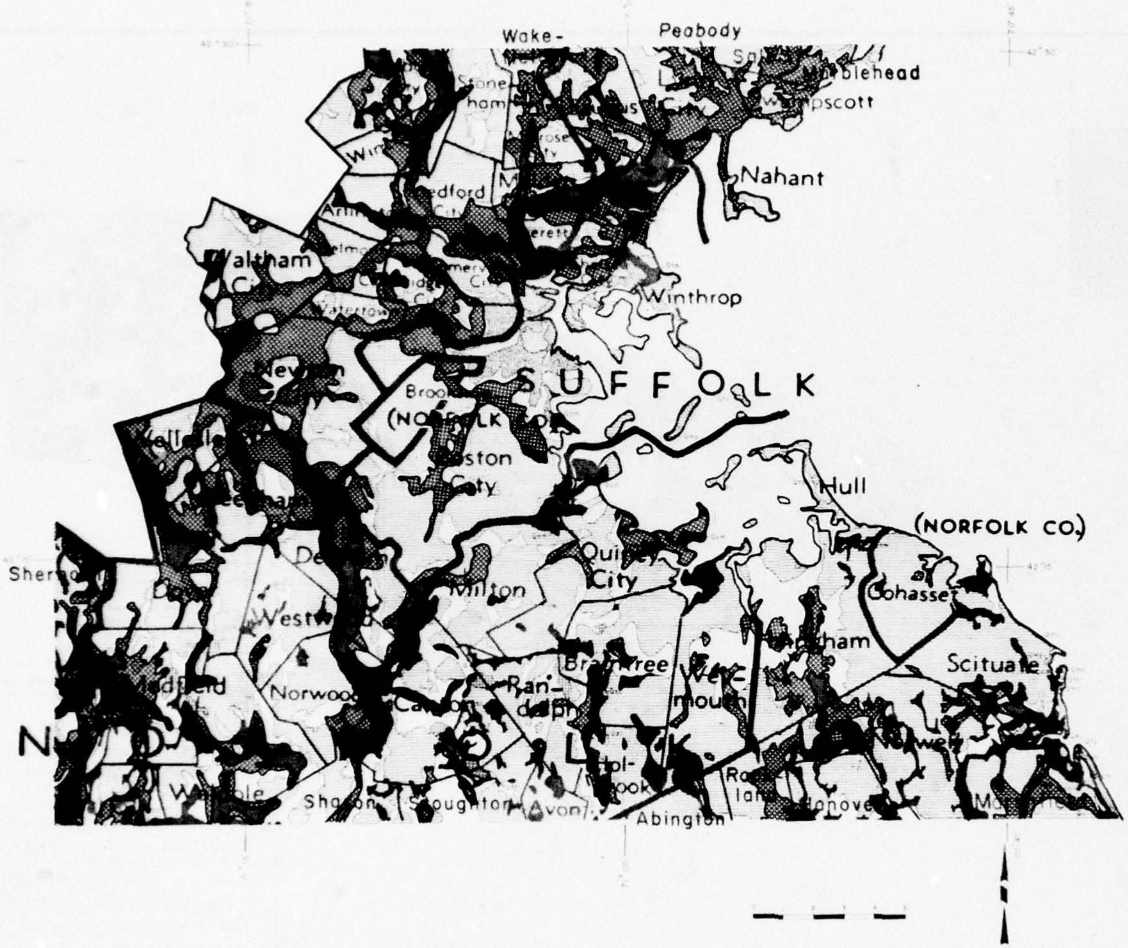
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A18



LEGEND

SYMBOL	AQUIFER DESCRIPTION
	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET; GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM
	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET; GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 G.P.M.
	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER, SATURATED THICKNESS GENERALLY LESS THAN 20 FEET; GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 G.P.M. WITH THE LOWEST YIELDS IN TILL



BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS

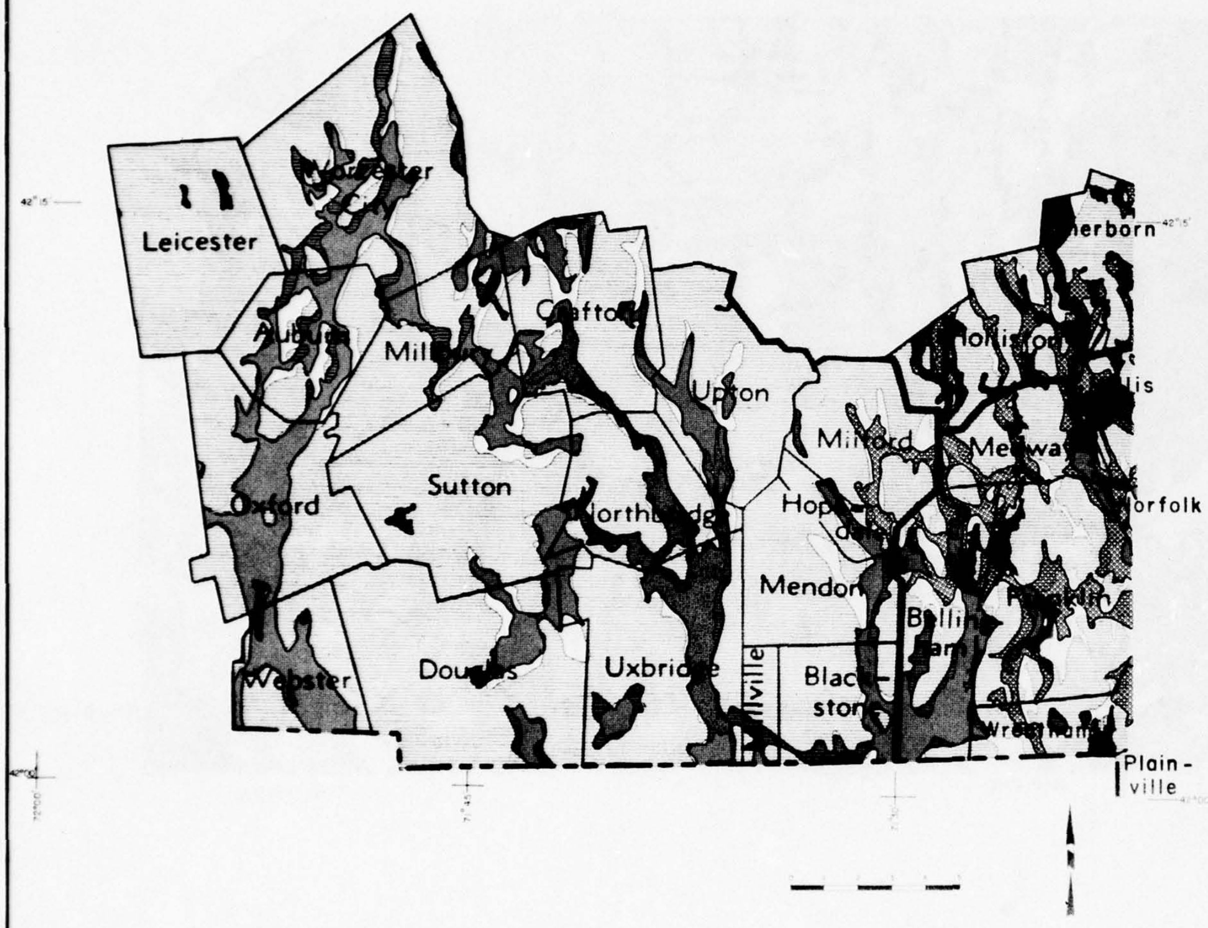
A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUND-WATER IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS

FIGURE A19

LEGEND

SYMBOL	AQUIFER DESCRIPTION
(dark)	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET; GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM
(stippled)	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET; GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 GPM
(blank)	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER, SATURATED THICKNESS GENERALLY LESS THAN 20 FEET; GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 GPM WITH THE LOWEST YIELDS IN TILL



BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUND-WATER IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A20

LEGEND

SYMBOL	AQUIFER DESCRIPTION
(dark shading)	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET, GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM
(crosshatch)	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET, GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 GPM
(light)	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER, SATURATED THICKNESS GENERALLY LESS THAN 20 FEET, GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 GPM WITH THE LOWEST YIELDS IN TILL

BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

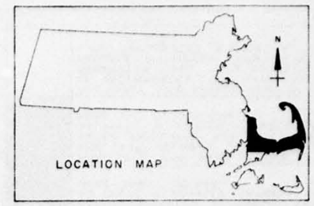
A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUNDWATER IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A21

LEGEND

SYMBOL	AQUIFER DESCRIPTION
	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET, GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM
	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER, SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET, GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 GPM
	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER, SATURATED THICKNESS GENERALLY LESS THAN 20 FEET, GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 GPM WITH THE LOWEST YIELDS IN TILL



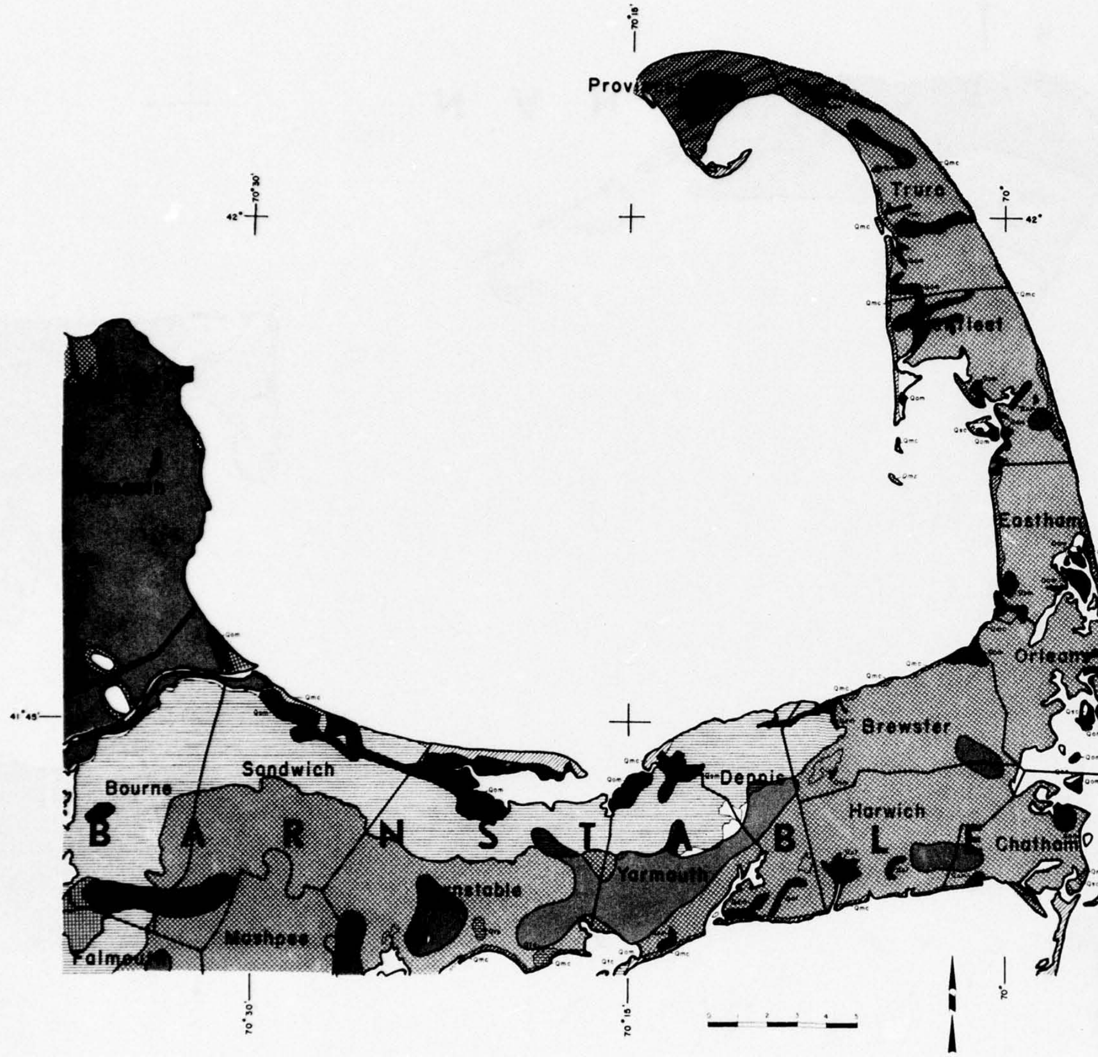
BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUND-WATER IN EASTERN MASSACHUSETTS

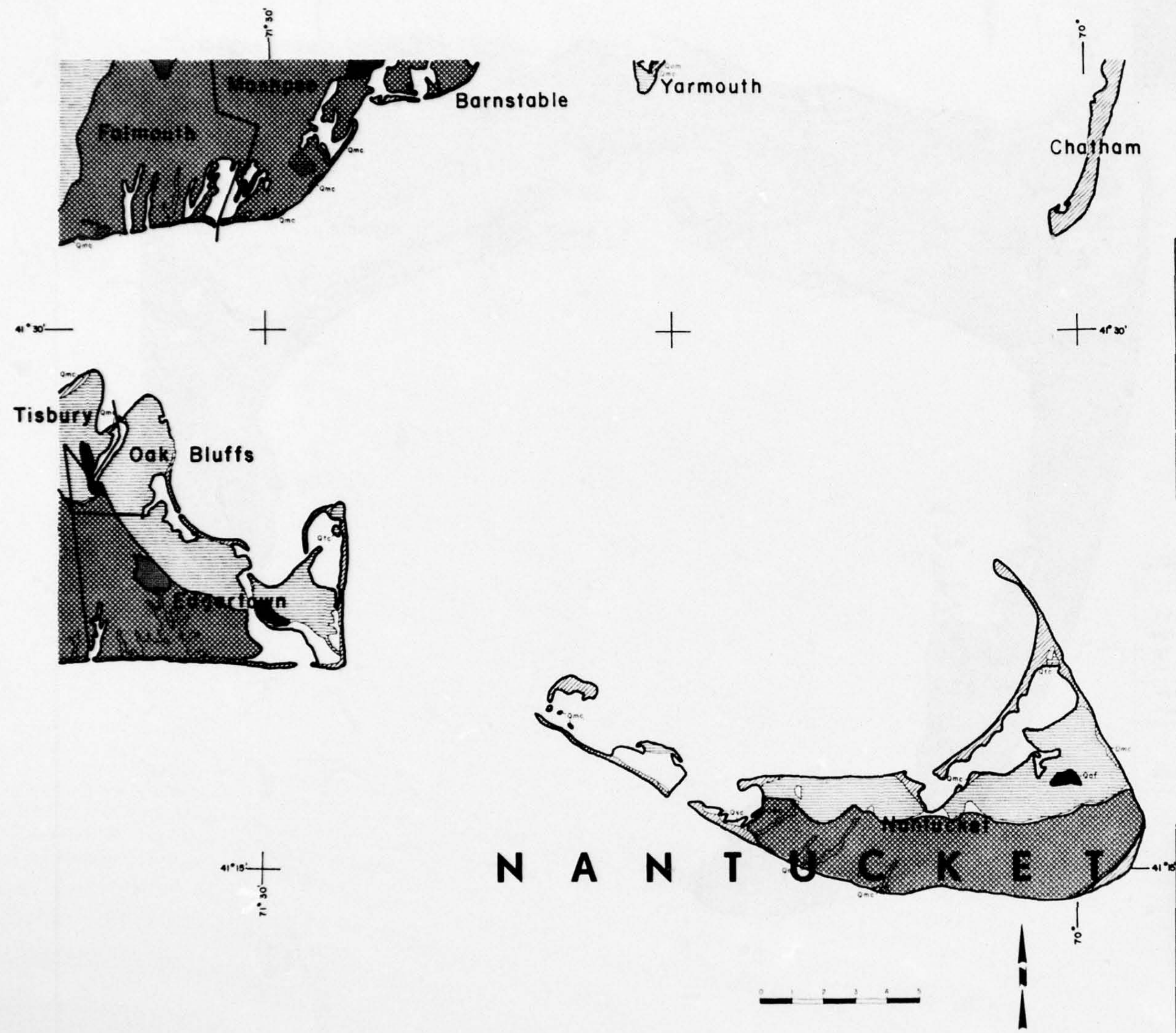
WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

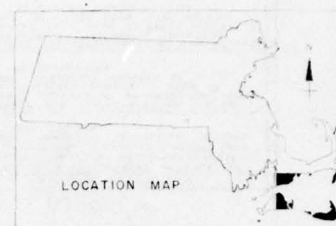
FIGURE A22



LEGEND

SYMBOL	AQUIFER DESCRIPTION
	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET; GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM
	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET; GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 GPM
	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LESS THAN 20 FEET, GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 GPM WITH THE LOWEST YIELDS IN TILL





BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

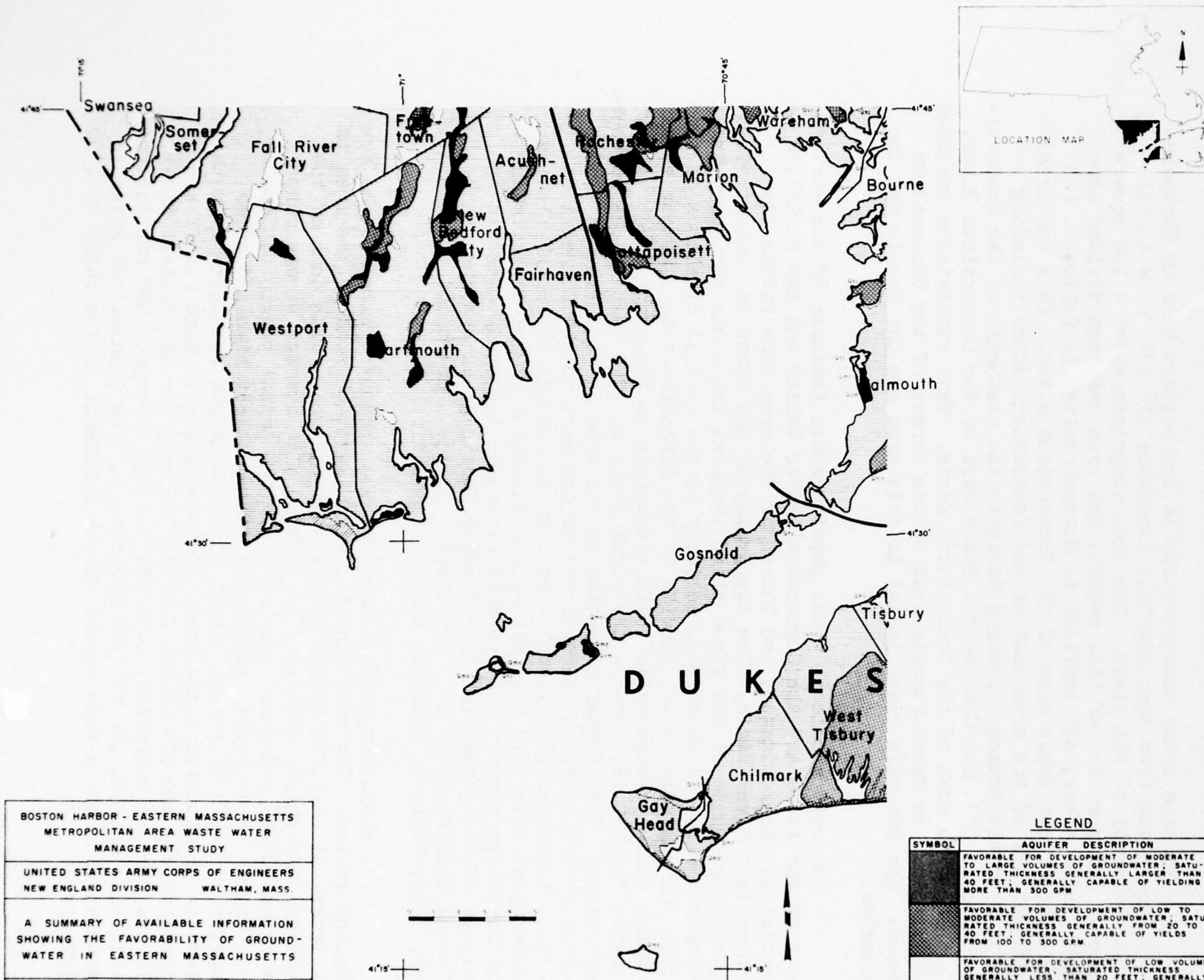
A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUND-WATER IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE A23

LEGEND

SYMBOL	AQUIFER DESCRIPTION
(black)	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET; GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM.
(cross-hatched)	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET; GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 G.P.M.
(blank)	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LESS THAN 20 FEET; GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 G.P.M. WITH THE LOWEST YIELDS IN TILL



BOSTON HARBOR - EASTERN MASSACHUSETTS
METROPOLITAN AREA WASTE WATER
MANAGEMENT STUDY

UNITED STATES ARMY CORPS OF ENGINEERS
NEW ENGLAND DIVISION WALTHAM, MASS.

A SUMMARY OF AVAILABLE INFORMATION SHOWING THE FAVORABILITY OF GROUND-WATER IN EASTERN MASSACHUSETTS

WHITMAN & HOWARD INC.
ENGINEERS & ARCHITECTS BOSTON, MASS

FIGURE A24

LEGEND

SYMBOL	AQUIFER DESCRIPTION
(dark)	FAVORABLE FOR DEVELOPMENT OF MODERATE TO LARGE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY LARGER THAN 40 FEET; GENERALLY CAPABLE OF YIELDING MORE THAN 300 GPM
(cross-hatched)	FAVORABLE FOR DEVELOPMENT OF LOW TO MODERATE VOLUMES OF GROUNDWATER; SATURATED THICKNESS GENERALLY FROM 20 TO 40 FEET; GENERALLY CAPABLE OF YIELDS FROM 100 TO 300 GPM.
(light)	FAVORABLE FOR DEVELOPMENT OF LOW VOLUMES OF GROUNDWATER, SATURATED THICKNESS GENERALLY LESS THAN 20 FEET; GENERALLY CAPABLE OF YIELDS FROM 0 TO 100 GPM WITH THE LOWEST YIELDS IN TILL

V. GEOLOGY OF WESTERN MASSACHUSETTS

A. Location and Physiography

The area under consideration is the western half of Massachusetts extending from approximately longitude 71° 52' 30" W to the western border of the state. The area comprises about 4,100 square miles. For purposes of this report, the area has been divided into three major areas, all confined to Massachusetts, as follows: (1) the Connecticut Basin east of the Connecticut River. This subdivision includes all of the area east of the Connecticut River including a portion of the French-Quinebaug Basin to the southeast of the Connecticut River. (2) The Connecticut Basin west of the Connecticut River. (3) The area west of the Connecticut Basin. This subdivision includes all the land in Massachusetts west of the border of the Connecticut Basin. The two main river basins in this area are the Hoosic and the Housatonic.

The most prominent gross physiographic features of the western part of the state are the Connecticut River Valley and the Berkshire mountains. Approximately two thirds of the area lies within the Connecticut River Basin. The topography of the basin is characterized by the flat lands of the flood plain (wide at the south and narrowing towards the north) which rise easterly to the central highlands of the state and westerly to the summits of the Berkshire range. The area as a whole exhibits high relief with elevations in the Connecticut Valley ranging from 50-120 feet in the flood plain to 2700 feet in the northern Berkshires. The highest elevation in the area is 3487 feet at the summit of Mt. Graylock which stands to the west of the Connecticut Basin. A pronounced regional linearity is seen by the south flowing Connecticut River and the north-south direction of the divide along the Berkshire range. West of this divide in the study area are the valleys of the generally north flowing Hoosic River and the south flowing Housatonic River. Tributaries to the Connecticut are the Deerfield, Millers, Chicopee and Westfield Rivers.

The humid temperate climate of the area is typical of the New England region. The mean annual precipitation of most of the area is 44 inches distributed rather evenly over the year, with some of the Northern Berkshires receiving 48 inches. The average stream runoff is about 20-24" per year, about half of the annual precipitation. This figure is exceeded slightly in the northwest highland areas. Representative mean annual stream flow discharges resulting from this abundant precipitation and conditions conducive to high runoff are approximately 600 cfs (cubic foot per second) for the Millers River, 870 cfs for the Deerfield, 1050 cfs for the Chicopee, 920 cfs for the Westfield, and 520 cfs for the Housatonic. The Connecticut River in Massachusetts has a mean annual stream discharge in the range of 1300-1500 cfs.

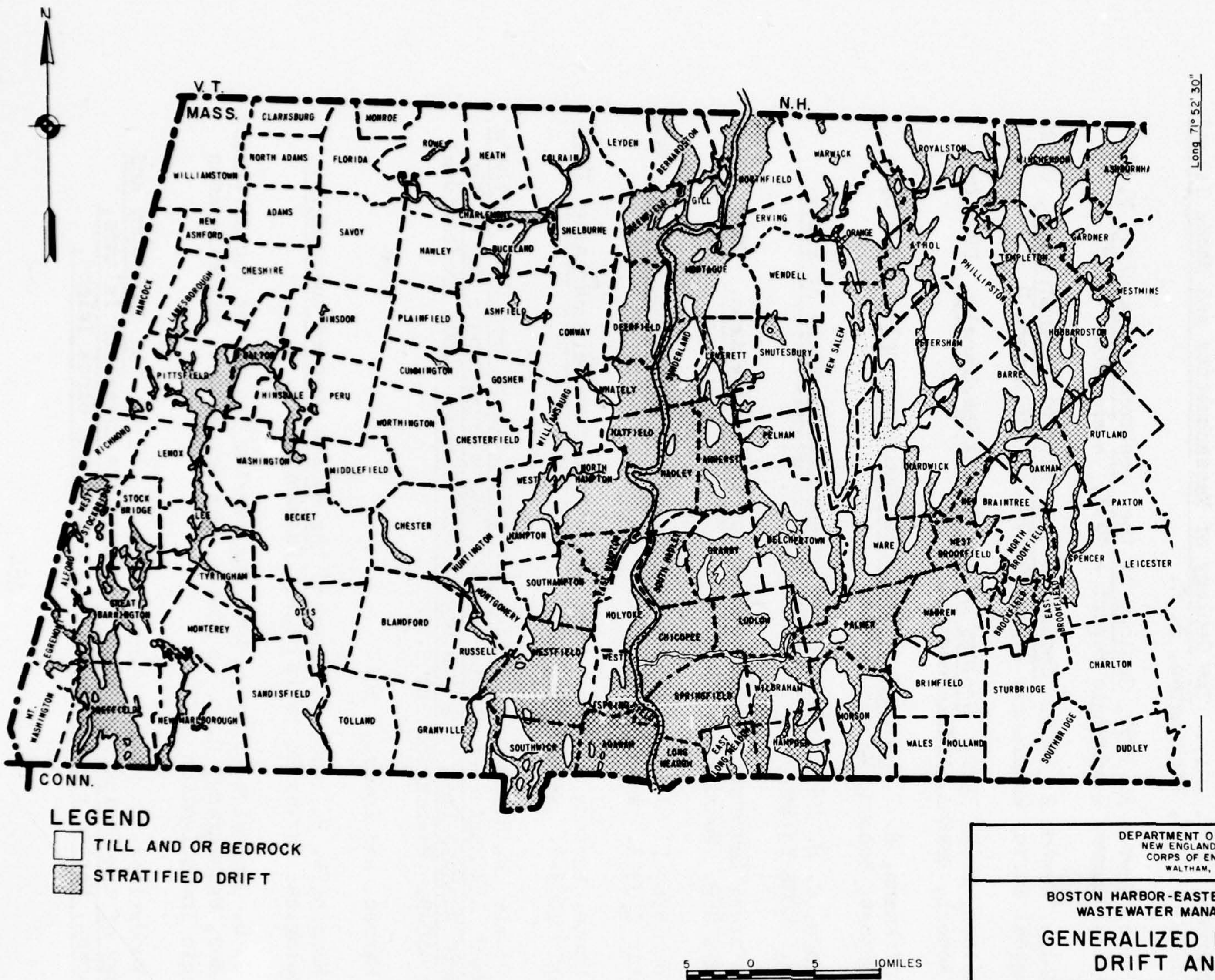
B. Geology

The geology of the region consists of both sedimentary and crystalline igneous and metamorphic bedrock mantled discontinuously by unconsolidated material of glacial and fluvial origin. Crystalline bedrock underlies most of the area and outcrops in the highlands while sedimentary rock underlies the vicinities of the main stems of the Connecticut, Hoosic and Housatonic River Valleys. The sandstone and shale into which the Connecticut River is cutting were formed approximately 200 million years ago, during the Triassic Period, and are the youngest rock found in the entire study area. There is no evidence remaining of any intense geologic activity in the area during the interval between the Triassic and the advent of glaciation during the Pleistocene Epoch. This interval of the time was characterized by weathering and erosion by which the summits of highland areas were worn down and a thick blanket of eroded material accumulated over the region especially in the valleys and other low-lying areas.

During the Pleistocene Epoch, which began 1 million years ago, large sheets of ice spread over the land from the north. There were at least four such advances separated by inter-glacial intervals of varying length. The last advance of ice over the area, termed the Wisconsin stage, began approximately 80,000 years ago and the area was free of ice about 10,000 years ago. The moving ice further eroded the land and picked up and transported the weathered and broken rock material. As the climate turned warmer, the ice front retreated back and water flowing from the melting ice distributed and deposited the enormous quantities of sand, silt, clay and gravel carried by the wasting ice. Glacial deposits fall into two broad categories; till and stratified drift. Till (hard pan) consists of unsorted, unstratified deposits of unconsolidated material which commonly contains a high percentage of clay. The texture and clay content of till make it relatively impermeable. Stratified drift of glacial origin is usually well bedded and well to moderately well sorted with the individual bed being composed predominantly of one grain size such as sand, silt or gravel. Stratified material is usually permeable especially if the grain size is large enough. Subsequent to the formation of the glacial deposits, much of the till and drift was eroded and redeposited by later streams and is now found as alluvial deposits along present stream courses. Much of this alluvium with the exception of clay and silty clay deposits, is also permeable.

The main distribution of sediments by glacial meltwater and other streams determine the pattern of the unconsolidated surficial material in the area. Till is relatively impermeable; stratified sands, gravels and coarse silty sand allow for high rates of infiltration; clays and silts have a low infiltration capacity and ponding will result if that capacity is exceeded.

Figure A25 is a map of the study area showing the generalized pattern of distribution of stratified drift and till. This information was gained from publications and maps concerning the groundwater favorability of the area. The map is general and is intended to show broad depositional patterns rather than specific locations. It is interesting to note the general linear and branching aspects of the patterns of drift reflecting their origin as deposits from glacial meltwater flows and other stream flows.



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

BOSTON HARBOR-EASTERN MASSACHUSETTS
WASTEWATER MANAGEMENT STUDY

GENERALIZED PATTERN OF
DRIFT AND TILL
WESTERN MASSACHUSETTS

FIGURE A25

References Cited

1. U. S. Army Corps of Engineers, New England Division. Merrimack Wastewater Management, Key to a Clean River. Appendix I-A, Geologic-Hydrogeologic Investigations. Waltham, Massachusetts. November 1974.

2. Emerson, B. K. 1917. The Geology of Massachusetts and Rhode Island. USGS Bulletin 597, Washington, D. C.

3. Chute, Newton E. 1950, Geology of the Brockton Quadrangle. U. S. Geological Survey Quadrangle Report - GQ-5. Washington, D. C.

4. Chute, Newton E. 1969. Geology of the Blue Hills Quadrangle. U. S. Geological Survey Quadrangle Report-GQ-796. Washington, D. C.

5. Nelson, A. E. 1972. Geology of the Natick Quadrangle. USGS Open File Report, Boston, Massachusetts.

6. Volckmann, R. P. Geology of the Holliston Quadrangle. USGS Open File Report, Boston, Massachusetts.

7. Clapp, C. H. 1921. The Geology of the Ingeous Rocks of Essex County. USGS Bulletin 704. Washington, D. C.

8. LaForge, Laurence. 1932. Geology of the Boston Area. USGS Bulletin 839. Washington, D. C.

9. Joulinin, P. 1964. Bedrock Geology of the Salem Quadrangle. USGS Bulletin 1163-A. Washington, D. C.

10. Chute, Newton, E. 1966. Geology of the Norwood Quadrangle. USGS Bulletin 1163-B. Washington, D. C.

11. Oldale, R. N. 1969. Siesmic Investigations on Cape Cod, Martha's Vineyard, and Nantucket, Massachusetts, and a Topographic Map of the Basement Surface from Cape Cod Bay to the Islands. USGS Professional Paper 650-B. Washington, D. C.

12. Warren, and Powers. 1914.

13. Hansen, W. R. 1956. Geology of the Hudson Maynard Quadrangle. US Geological Survey Bulletin 1038. Washington, D. C.

14. U. S. Geological Survey, 1967 Engineering Geology of the Northeast Corridor, Washington, D. C. to Boston, Massachusetts. Miscellaneous Geologic Investigation 1-514.

15. Woodwriter, J. B. and Wigglesworth E., 1934. The Geography and Geology of the Region Including Cape Cod, the Elizabeth Islands, Nantucket, Martha's Vineyard, No Man's Land and Block Island.

15. (cont.) Memoirs of the Museum of Comparative Zoology at Harvard College. Volume 52.

16. Peterson, R. G. 1962. Groundwater Favorability Map of the Ware, Quagoag, Quinebaug and French River Basins, Massachusetts. Massachusetts Water Resources Commission Chart H1-2.

17. Shaw, C. E. Jr. 1961. Groundwater Favorability Map of the Brockton Pembroke Area, Massachusetts. Massachusetts Water Resources Commission.

18. Brackley, R. A., Fleck, W.B., and Meyer W.R., 1973. Hydrology and Water Resources of the Neponset and Weymouth River Basins, Massachusetts. USGS Hydrologic Investigation Atlas HA-484.

19. Williams, J. R., Farrell, D.F. and R. E. Willey, 1973. Water Resources of the Taunton River Basin, Southeastern Massachusetts, USGS. Hydrologic Investigation Atlas HA-460.

20. Maeusky, A and Drake, J.,1963. Massachusetts Basic Data Report No. 7, Groundwater Series - Southeastern Massachusetts.

21. Brackley, R. A., Fleck, W.B., and Willey, R.E., 1973. Hydrologic Data of the Neponset and Weymouth River Basins, Massachusetts. Massachusetts Hydrologic Data Report No. 14. USGS.

22. Williams, J. 1968. Availability of Groundwater in the Northern Part of the Ten Mile and Taunton River Basins, Southeastern Massachusetts. USGS.

23. Frimpter, N. H. 1973. Groundwater Management-Mystic River Basin, Massachusetts. USGS Open File Report.

24. Frimpter, M. H. 1973. Groundwater Management - Mystic River Basin, Massachusetts. USGS Open File Report.

25. Frimpter, M. H. 1973. Groundwater Management - Charles River Basin, Massachusetts. USGS Open File Report.

26. Frimpter, M. H. 1973. Groundwater Management, Blackstone, Moshassuck and Woonasquatucket River Basins, Massachusetts and Rhode Island. USGS Open File Report.

27. Williams, J. R. and Tasker, G. D.,1972 Water Resources of the Coastal Drainage Basins of Southeastern Massachusetts, Wier River, Hingham, to Jones River, Kingston. USGS Open File Report.

28. Williams, J. R. and Tasker, G. D.,1972 Water Resources of the Coastal Drainage Basins of Southeastern Massachusetts, Plymouth to Weweantic River, Wareham. USGS Open File Report.

APPENDIX B

POTENTIAL LAND APPLICATION SITE IDENTIFICATION

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX B

Potential Land Application Site Identification

I. INTRODUCTION

Since land application in a humid area requires the addition of water to the soil in excess of vegetative requirements, it is critical that factors of topography, soils and groundwater be given due consideration in the site selection process. This Appendix sets forth the procedures and criteria used in the Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study to identify and select potential sites for the application of secondarily treated wastewater. Only the land areas in the Commonwealth of Massachusetts were considered in this effort.

II. PROCEDURE

A. Land Application Methods

Two of the three modes of land application, spray irrigation and rapid infiltration were determined to be applicable in treating the wastewaters generated in the Boston Harbor-Eastern Massachusetts Metropolitan Area. Selection criteria for potential sites were established for each mode.

1. Spray Irrigation Site Criteria

a. Soil Textural Class - fine sandy loam to silt loam surface horizons with similar textures throughout underlying strata. Soils with few or no stones.

b. Depth of Soil - minimum of five feet.

c. Infiltration Capacity of Soil Surface - 0.25 inches per hour.

d. Aerosol buffer zone - continuously forested strip with width equal to distance of throw of sprinkler times height of delivery.

e. Water Table - not within three feet of the soil surface for more than four consecutive months of the year.

f. Soil Permeability - moderate to moderately-rapid - 0.63-6.3 inches per hour.

g. Slope - 0 to 15 percent.

2. Rapid Infiltration Site Criteria

a. Soil Texture Class - sand or sandy gravel throughout the path of effluent travel.

b. Percolation Rate - moderately rapid to rapid - 2-6.3 inches per hour.

c. Effective length of vertical travel of effluent - minimum of 20 feet.

d. Total vertical plus lateral travel - minimum of 320 feet.

e. Lateral distance to potable water supply well - minimum of 1,000 feet.

The general areas of Massachusetts to be examined were identified by examination of the surficial geology maps prepared as discussed in Appendix A. For finer delineations, it was necessary to utilize the soil delineations prepared by the U. S. Department of Agriculture. The soil types that were considered to be suitable for either spray irrigation or rapid infiltration were grouped into three categories as shown below:

(1) Soils with slight limitations for use as spray irrigation sites. This group includes the Agawam, Belgrade, Brookfield, Canton, Charlton, Enfield, Gloucester, Hartland, Melrose, Newport and Suffield soil series.

(2) Soils with moderate limitations for use as spray irrigation sites. This group includes the Bernardston, Broadbrook, Carver, Colona, Essex, Millis, Narragansett, Paxton, Plymouth, Poquonnock and Warwick soil series.

(3) Soils with slight limitations for use as rapid infiltration sites. This group includes the Enfield, Hinckley, Merrimac, Quonset and Windsor soil series.

B. Procedure

Initially, evaluations of soil and geologic information pertaining to the lands in the Boston Harbor-Eastern Massachusetts Metropolitan Area, western Massachusetts and southeastern Massachusetts were made for sites suitable for land treatment systems. As a result of evaluating spacial distribution and acreage of potential sites and distance from the wastewater treatment facilities to the land sites, it was concluded quite early that the general area of Massachusetts with the greatest potential for developing a land treatment alternative for the Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study was in southeastern Massachusetts. Because of this determination, more intensive study of potential land treatment sites was carried out in this area. Considerable land area, well suited for treatment of wastewater effluents, was found in western Massachusetts. However, the distance of these sites and the size of individual areas prohibited the development of western Massachusetts land treatment alternatives for this study.

For eastern Massachusetts, exclusive of the Merrimack River Basin, the soil types discussed above were delineated on copies of the U.S.D.A. county soils maps which had been reduced or enlarged to match the 1:24,000 scale of USGS topographic maps.

Next, land use maps drawn from vertical aerial photos and set to the 1:24,000 scale of USGS topographic maps for the study area, were obtained from the Massachusetts Map Down Project (1). Those areas whose present land usage would allow them to be utilized as land application sites at some future date were delineated. Generally those land use categories permitting the possibility of future land application were:

(1) Forested Areas
(2) Agricultural and Open Areas

Whenever possible, a one thousand foot "buffer zone" was maintained between each designated land application area and any surrounding land use type which would not be compatible with land application methodologies such as residential areas or industrial sites.

The actual selection of potential sites for land application was now enabled by overlaying the selected soil types by the selected land use types. Areas where the soils indicated slight limitations for spray irrigation, and at the same time where shown to be situated in a land use type compatible with a land application system, were then delineated on USGS topographic maps. Similarly, acceptable areas suitable for spray irrigation with moderate limitations and rapid infiltration sites with slight limitations were indicated.

The delineated USGS topographic maps are in file with New England Division, U. S. Army Corps of Engineers.

III. POTENTIAL LAND APPLICATION SITES IN THE BOSTON HARBOR-EASTERN MASSACHUSETTS METROPOLITAN AREA

Using the procedures described in Chapter II, the 109 community area of the Boston Harbor-Eastern Massachusetts Metropolitan Area was examined for potential land application sites. Table B1 shows the acreages by application mode and suitability identified within the area by community. Figure B1 indicates the general location, size and application mode of these sites.

IV. POTENTIAL LAND APPLICATION SITES IN WESTERN MASSACHUSETTS

Land sites, with a high probability of satisfying the site selection criteria set forth in Chapter II, were delineated upon close and careful examination of the United States Geological Survey $7\frac{1}{2}$ minute topographic quadrangle maps which cover the area. Further supportive and background information was supplied by the various geologic maps and geologic and water supply reports of the area and discussions with personnel from the USGS and other interested workers.

TABLE B 1

ACREAGE OF POTENTIAL LAND APPLICATION SITES WITHIN THE BOSTON HARBOR-EASTERN MASSACHUSETTS METROPOLITAN AREA

Town	Spray Irrigation		Rapid Infiltration	
	Slight Limitations (Acres)	Moderate Limitations (Acres)	Slight Limitations (Acres)	TOTAL (Acres)
Ashland	13			13
Bellingham	235			235
Boxford	131	71	110	312
Danvers	40			40
Dover	82			82
Duxbury	94	103	111	308
Franklin	1488			1488
Hamilton	69			69
Hanover	3	5	93	101
Hingham	201	256	43	500
Holbrook	50			50
Holliston	696			696
Hopkinton	171			171
Ipswich	39	215	103	357
Marshfield	539	99	103	741
Medfield	213			213
Medway	262			262
Middleton	79			79
Milford	14			14
Millis	36			36
Norfolk	392			392
North Reading	227			227
Norwell	290	364	129	783
Pembroke	175	28	112	315
Rockland		4	10	14
Scituate	27	251	9	287
Sharon	1416		26	1442
Sherborn	70			70
Stoughton	318			318
Topsfield	23	134	5	162
Walpole	351			351
Wrentham	579	109	5	693
TOTAL	8823	1639	859	10,821

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

BOSTON HARBOR-EASTERN MASSACHUSETTS
METROPOLITAN AREA
WASTEWATER MANAGEMENT STUDY

POTENTIAL LAND APPLICATION SITES
EASTERN MASSACHUSETTS METROPOLITAN AREA

FIGURE B1

Using the criteria and methods described above, sites judged suitable for rapid infiltration or spray irrigation were outlined on a set of topographic sheets covering the entire western Massachusetts area. The entire set of maps were bound into a folio entitled, "Topographic Map Folio-Potential Sites for Land Application of Wastewater-Western Massachusetts Quadrangles Boston Harbor-Eastern Massachusetts Metropolitan Area Wastewater Management Study" and is on file at the Corps of Engineers, New England Division.

A total of 421 sites with an inclusive land area of 34,285 acres considered potentially suitable for land treatment of wastewater effluents were located. The general locations of these sites are shown in Figure B2. The acreages of lands suited for spray irrigation or rapid infiltration were totaled for each USGS quadrangle sheet (Table B2).

The area was subdivided into three units for better ease and handling of the data. The areas are: (1) the Connecticut River Basin - east of the river; (2) the Connecticut River Basin - west of the river; (3) the area west of the Connecticut River Basin. Each area was treated as an individual unit.

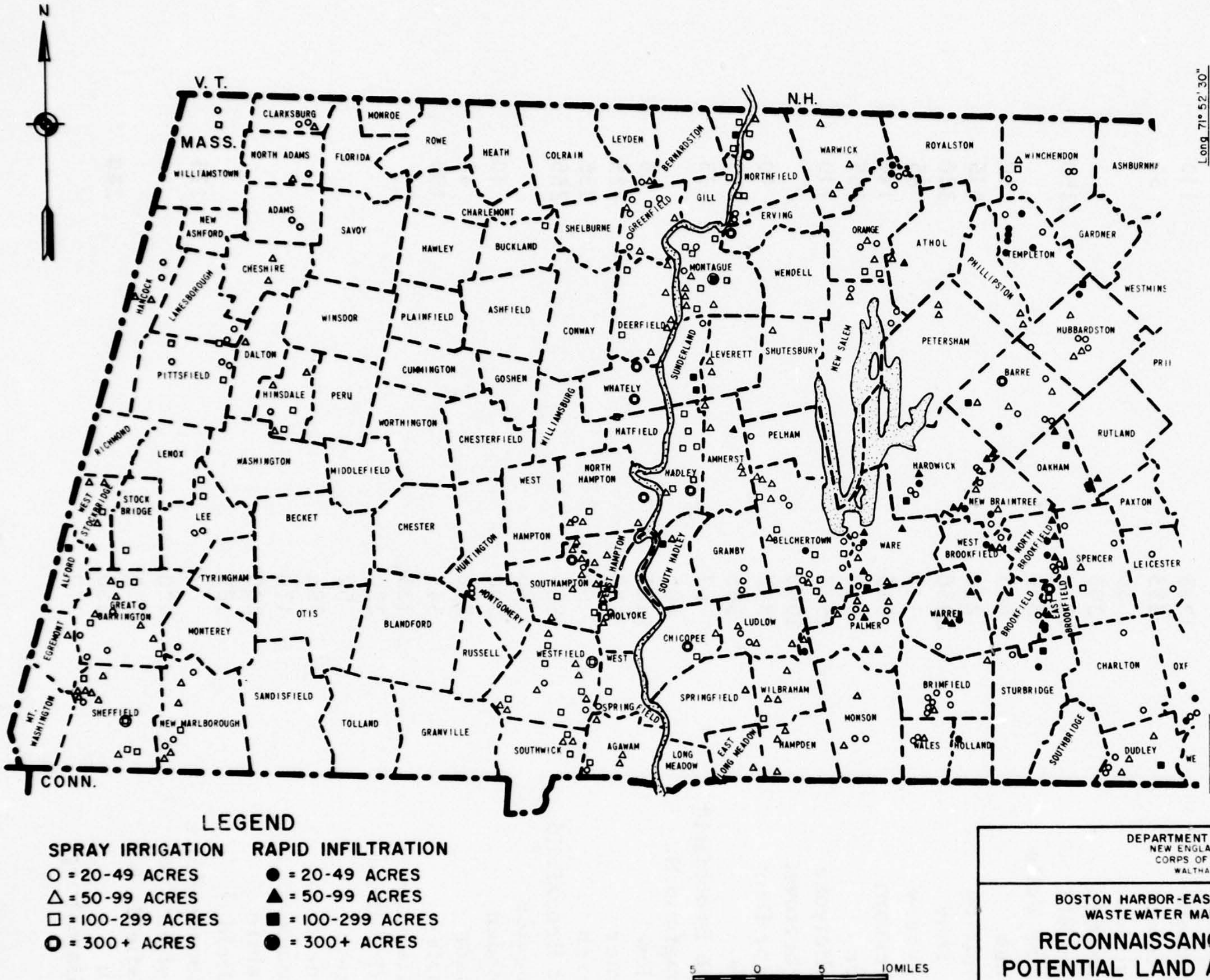
During the latter part of August 1973, a field reconnaissance of several of the selected sites was made. The purpose of the field work was to check current availability of the sites and to confirm the inferred hydrogeologic conditions at a number of sites.

Several bits of data were gathered and recorded for each site. Judgments of open space versus structure type and density was recorded. Various hydrogeological parameters were examined and noted. An on-site estimate of suitability for land treatment was made and if possible, an estimate of the best mode of land application, which should be implemented; spray irrigation or rapid infiltration.

The field reconnaissance was confined to sites within the Connecticut River Basin and examined areas in the basin both east and west of the river. The availability of sites equal to or greater than 50 acres in size was noted and this data was used to extrapolate availability and loading at other sites not visited in the field. The sites in the size grouping of 0-49 acres were ignored in this analysis. All figures and percentages discussed in this section pertain to those areas in the east and west portions of the Connecticut River Basin, but do not pertain to the areas west of the Connecticut River Basin.

Of the 135 sites ranging in size from 50-99 acres, 12 (8.9%) were examined in the field. Ten of the twelve, or 83.3% of the sites were determined to be suitable for land application.

There were 69 sites which were equal to or greater than 100 acres in size. Field examination of 24 of the plots (34.8%) showed that 22, or 91.6% of these sites appeared suitable for land application.



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

BOSTON HARBOR-EASTERN MASSACHUSETTS
WASTEWATER MANAGEMENT STUDY

RECONNAISSANCE SURVEY MAP
POTENTIAL LAND APPLICATION SITES
WESTERN MASSACHUSETTS

FIGURE B2

TABLE B 2

ACREAGE OF POTENTIAL LAND APPLICATION SITES BY MODE OF APPLICATION-WESTERN MASSACHUSETTS

Quadrangle	Spray Irrigation	Rapid Infiltration
Northfield	1385	110
Mt. Grace	335	50
Royalston	30	
Wichenden	295	
Greenfield	1680	1250
Millers Falls	390	
Orange	845	50
Templeton	290	415
Mt. Toby	2130	320
Shutesbury	115	85
Petersham	545	110
Barre	510	265
Mt. Holyoke	1585	110
Belchertown	1090	
Winsor Dam	300	90
Ware	565	595
North Brookfield	67	423
Springfield N.	605	
Ludlow	1125	25
Palmer	575	435
Warren	100	235
East Brookfield	805	255
Leicester	125	
Hampden	400	40
Manson	140	40
Webster	345	195
Williamstown	135	
North Adams	220	
Colrain	50	
Bernardston	385	
Hancock	170	
Cheshire	220	
Ashfield	125	
Shelburne Falls		175
Pittsfield, W.	120	
Pittsfield, E.	810	
Peru	280	240
Williamsburg	170	

TABLE B2 (contiuned)

Quadrangle	Spray Irrigation	Rapid Infiltration
State Line	410	55
Stockbridge	340	
East Lee	485	
Easthampton	920	345
Egrement	980	
Great Barrington	1045	
Woronoco	665	165
Mt. Tom	1655	275
Ashley Falls	960	
West Springfield	1055	

Combining the two site categories, the figures show 36 or 204 sites (or 17.6%) were examined in the field. Of the 36 sites examined, 32 appeared suitable and available for treating wastewater by the method of land application.

Extrapolating the information derived from the field reconnaissance to the total area of land in the Connecticut River Basin in Massachusetts, the appearant suitable and available acreage for land application may be estimated. In the group of land sites ranging in size from 50-99 acres, a total area of 9,130 acres was identified and for the 100+ acre group, 14,480 acres. Field survey data revealed 83.3% of the 50-99 acre size group or 7,600 acres were available. In the 100+ acres size group, 91.6% or 13,260 acres were available. Thus, a total of about 21,000 acres in plot sizes of 50 acres or more were available as of the date of the field survey, August 1973. (See Table B3)

V. POTENTIAL LAND APPLICATION SITES IN THE SOUTHEASTERN MASSACHUSETTS AREA

Utilizing the procedures described in Chapter II, the area of Massachusetts to the south and southeast of the Boston Harbor-Eastern Massachusetts Metropolitan Area was examined for potential land application sites. Table B4 shows the acreages by application mode and suitability identified within the area by town. Figure B3 shows the general location, size and application mode for the identified sites.

VI. SITE RECONNAISSANCE

In order to confirm the site selection procedure utilized in the eastern Massachusetts area, 19 typical sites in southeastern Massachusetts were studied in greater detail. Figure B4 shows the general location of these 19 sites. At each site, the general site conditions, bedrock and surficial geology and groundwater were examined. An evaluation was made of the site as to its suitability for spray irrigation or rapid infiltration. Table B5 summarizes the evaluation of each of the sites.

The following pages are the Inspection and Evaluation Reports of each site with an accompanying site map.

Table B3

Total Number and Acreage of Potential Land Application Sites

Area	0-49 Acres		50-99 Acres			100+ Acres			Totals		
	# Sites	Acreage	# Sites	Acreage	Sites Examined	# Sites	Acreage	Sites Examined	# Sites	Acreage	Sites Examine
astern Connecticut iver Basin	117	3670	100	6725	10+ 2-	46	9405	19+ 1-	263	19800	29+ 3-
estern Connecticut River Basin	16	545	35	2405	0 0	23	5075	3+ 1-	74	8025	3+ 1-
est of Connecticut iver Basin	31	980	32	2135	0 0	21	3345	0 0	84	6460	0 0
GRAND TOTALS	164	5195	167	11265	10+ 2-	90	17825	22+ 2-	421	34285	32+ 4-

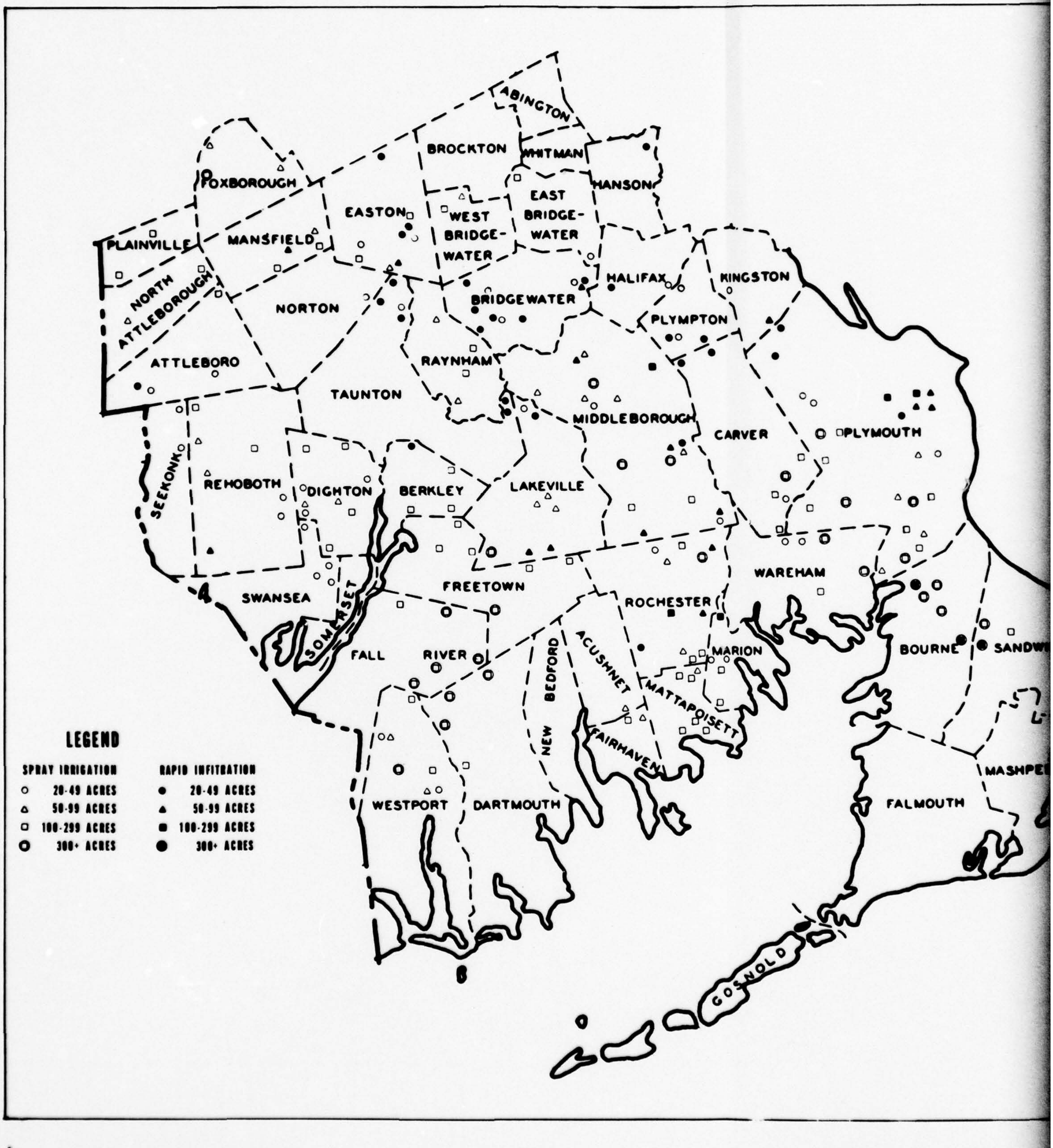
TABLE B4

ACREAGE OF POTENTIAL LAND APPLICATION SITES
SITES IN SOUTHEASTERN MASSACHUSETTS

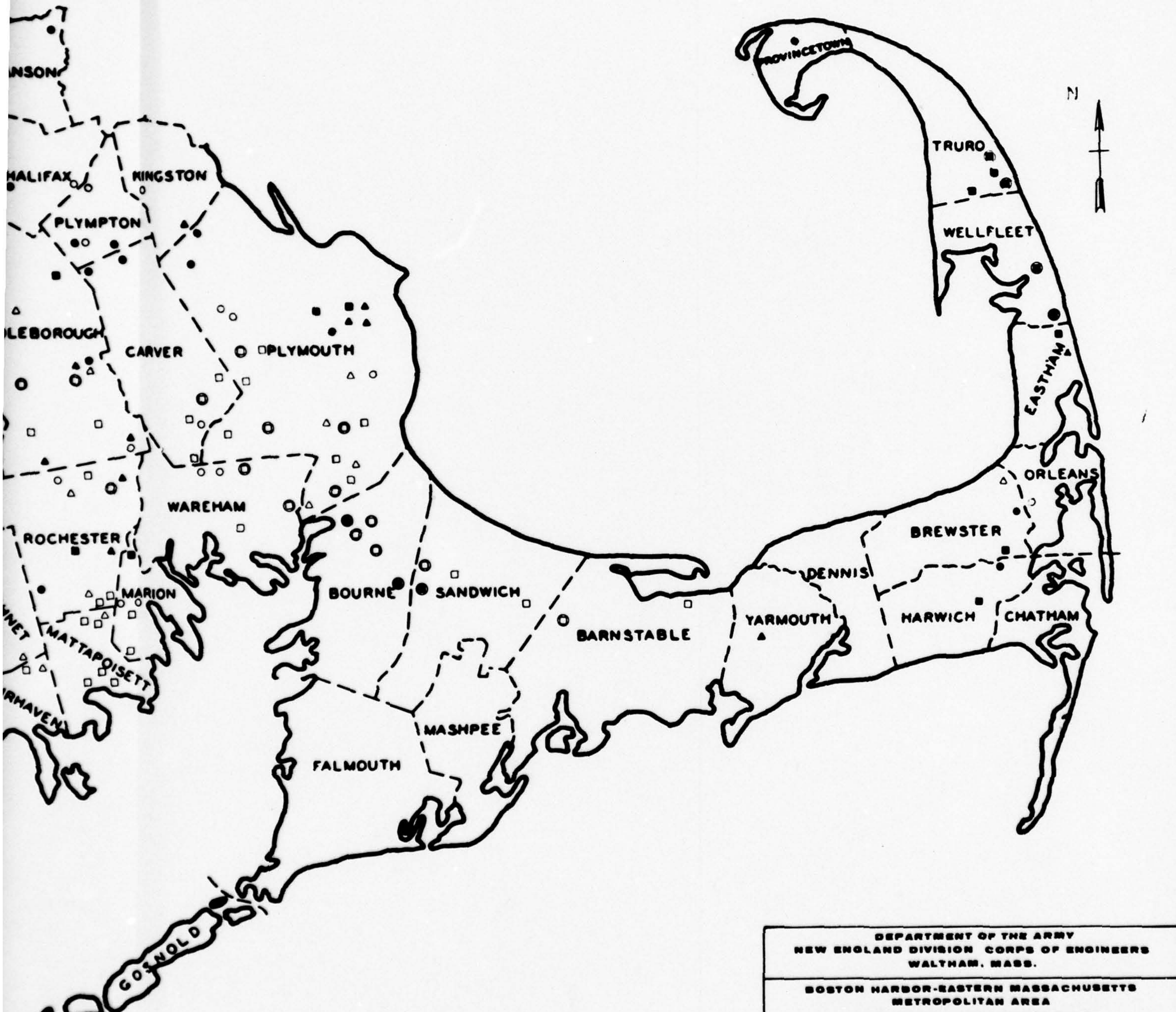
Town	Spray Irrigation		Rapid Infiltration	
	Slight Limitations (Acres)	Moderate Limitations (Acres)	Slight Limitations (Acres)	TOTAL (Acres)
Acushnet	56			56
Attleboro		354	39	393
Barnstable		978		978
Berkley		630	13	643
Bourne		4279	863	5142
Brewster		193	237	430
Bridgewater	107	82	306	495
Brockton	6	6		12
Carver		1408	156	1564
Darmouth	507			507
Dighton		1072		1072
E. Bridgewater	32	133		165
Eastham			288	288
Easton	417	200	233	850
Fairhaven	244			244
Fall River	4412			4412
Foxboro	703		20	723
Freetown	869	526	55	1450
Halifax	5	45	50	100
Hanson		4	54	58
Harwich			176	176
Kingston		43	83	126
Lakeville	458	573	324	1355
Mansfield	733	69	113	915
Marion	311	133	107	551
Mattapoisett	1114	157	13	1284
Middleborough	1592	691	865	3148
North Attleboro	18	451	42	511
Norton	58	10	14	82
Orleans		44		44
Plainville	19	345		364
Plymouth	3	6190	2304.	8497
Plympton	6	100	126	232
Provincetown			33	33

Table 4 (Cont'd)

Town	Spray Irrigation Slight Limitations (Acres)	Spray Irrigation Moderate Limitations (Acres)	Rapid Infiltration Slight Limitations (Acres)	TOTAL (Acres)
Raynham	475			475
Rehoboth	5	949	57	1011
Rochester	1263	141	398	1802
Sandwich		1188	2247	3435
Seekonk	35	54		89
Swansea		281		281
Taunton	32	47	304	383
Truro			1345	1345
Wareham	44	1036	88	1168
Wellfleet			1642	1642
W. Bridgewater	9	276	12	297
Westport	286			286
Whitman	7			7
Yarmouth			96	96
TOTAL	13,826	22,688	12,703	49,217



ABINGTON
BROCKTON
WHITMAN
HANSON
FOXBOROUGH
EASTON
WEST BRIDGE-WATER
EAST BRIDGE-WATER
PLAINVILLE
MANSFIELD
NORTH ATTLEBOROUGH
NORTON
HALIFAX
KINGSTON
BRIDGEWATER
PLYMPTON
ATTLEBORO
RAYNHAM
TAUNTON
MIDDLEBOROUGH
CARVER
PLYMOUTH
SEEKONK
REHOBOTH
DIGHTON
BERKLEY
LAKEVILLE
SWANSEA
SOMERSET
FREETOWN
WAREHAM
ROCHESTER
FALL RIVER
NEW BEDFORD
ACUSHNET
MARION
MATTAPOISETT
BOURNE
SANDW
FAIRHAVEN
WESTPORT
DARTMOUTH
MASHPEE
FALMOUTH
GOSNOLD
LEGEND
SPRAY IRRIGATION
20-49 ACRES
50-99 ACRES
100-299 ACRES
300+ ACRES
RAPID INFILTRATION
20-49 ACRES
50-99 ACRES
100-299 ACRES
300+ ACRES



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

BOSTON HARBOR-EASTERN MASSACHUSETTS
METROPOLITAN AREA
WASTEWATER MANAGEMENT STUDY

POTENTIAL LAND APPLICATION SITES
SOUTHEASTERN MASSACHUSETTS

FIGURE B3

FIGURE B4. Location of typical sites

TABLE B5

SUMMARY OF EVALUATION OF 19 SITES

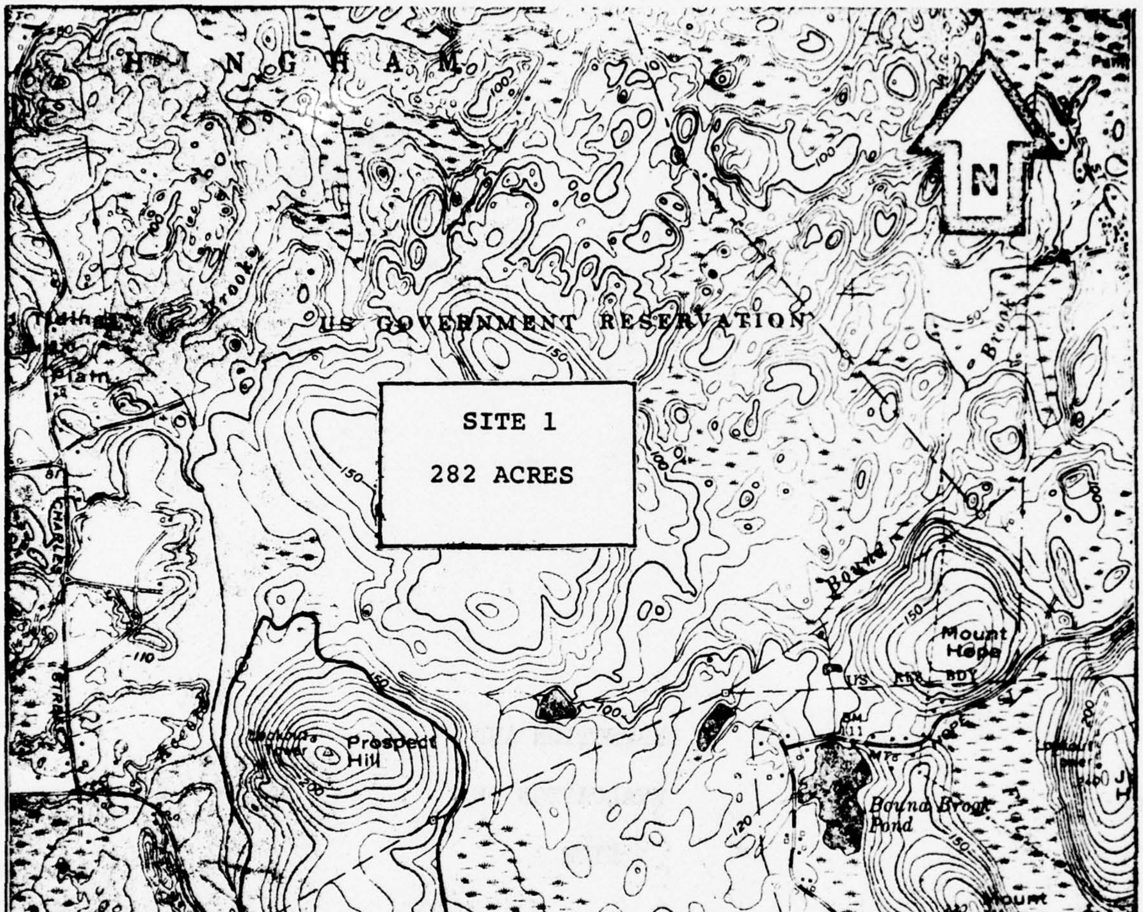
Site No.	Location	Total Area Acres	Suitability for S.I.	Suitability for R.I.	Confidence In Evaluation
1	Hingham & Norwell	282	F/G	Poor	High
2	Middleborough	1010	F/G	Poor	High
3	Plymouth	637	Fair	Good	High
4	Mattapoisett	411	Good	Poor	High
5	Plymouth	835	Fair	Good	High
6	W. Bridgewater	200	F/G	Poor	High
7	Sandwich	1873	F/G	Good	High
8	Foxboro & Wrentham	900	Good	Poor	Mod./High
9	Truro	702	F/G	Good	Mod.
10	Brewster	160	F/G	Good	Mod.
11	Yarmouth	399	Poor	Poor	High
12	Barnstable	356	F/G	Good	Mod.
13	Rochester	471	Good	Poor	High
14	Sharon	1081	Good	Poor	Mod.
15	Raynham	295	Good	Poor	Mod.
16	Freetown & Lakeville	643	F/G	Poor	High
17	Franklin	723	Good	Poor	Mod.
18	Marshfield	168	Good	Poor	High
19	E. Bridgewater	80	F/G	Poor	High

NOTE: R.I. indicates Rapid Infiltration
S.I. indicates Spray Irrigation
F - Fair
G - Good

INSPECTION AND

EVALUATION OF

SITE 1



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B5

INSPECTION AND EVALUATION OF SITE 1

SITE LOCATION

The site lies in the Towns of Hingham and Norwell in Plymouth County. The site is bounded on the west by Accord Brook, on the southwest by Prospect Street and on the east by Bound Brook. It lies mainly within the U. S. Government Reservation in Hingham and Norwell. The nearest Town is Assinippi, 2 miles to the south.

AVAILABLE DATA

Available information consisted of: U.S.G.S. Topographic Map Cohasset quadrangle, 1961; Bedrock Geology Map for Massachusetts B. K. Emerson, 1917,(2) USDA soil survey of Plymouth County-Upham, 1969;(3) 1971 Massachusetts Land Use and Vegetative Cover Mapping.(1)

GENERAL SITE CONDITIONS

The site encompasses approximately 280 acres including Prospect Hill and the area to the south, to Prospect Street. Elevation ranges from 240 feet on Prospect Hill to 110 feet along Prospect Street. Prospect Hill is one of a number of hills in this low swampy area.

Vegetation consists mainly of soft woods 40 - 60' high, of a density of 80 - 100 percent. In the northern and southern limits of the area hardwoods predominate. Slopes over the whole area are a gentle 3 to 8 percent, steeper in the north portion and flatter to the south.

BEDROCK GEOLOGY

According to B. K. Emerson (2), the site lies within the Dedham granodiorite formation, a chlorite, biotite, granodiorite. Chute, (4), describes it as a massive, medium to coarse grained, highly fractured rock. Depth to bedrock ranges from 5 - 30 + feet.

SURFICIAL GEOLOGY

According to the USDA Soil Survey of Plymouth County, (3) half of the site is covered by Essex very stony coarse sandy loam. The remaining half is covered by Scituate very stony loam and Gloucester extremely stony loamy sand. The Essex profile formed mainly in firm glacial till occupying ground moraines and drumlins. A slowly permeable fragipan of sandy loam is found at a depth of 2 - 2.5 feet. The Scituate profile formed in compact glacial till derived mainly from granitic material. A moderately slowly permeable fragipan of loamy sand is found at a depth of 1 - 1.5 feet.

The Gloucester profile formed from glacial till derived chiefly from granite. It occurs mostly on the higher part of rolling ground moraines. The degree of stoniness of the Gloucester soils at this site and others may limit the use of these soils to some degree.

Permeability of the Essex profile is rapid above the fragipan but slow through the fragipan. The Gloucester profile has rapid permeability above the fragipan and slow through the fragipan.

GROUNDWATER

According to the U.S.D.A. Plymouth County Soil Survey the seasonal high water level of the Essex and Gloucester soils is 3 to 5+ feet. The seasonal high water level of the Scituate soil is 1.5 - 3 feet. General direction of groundwater flow is probably from the center of the site to the perimeters. Test borings would be needed to confirm groundwater levels on the site.

EVALUATION

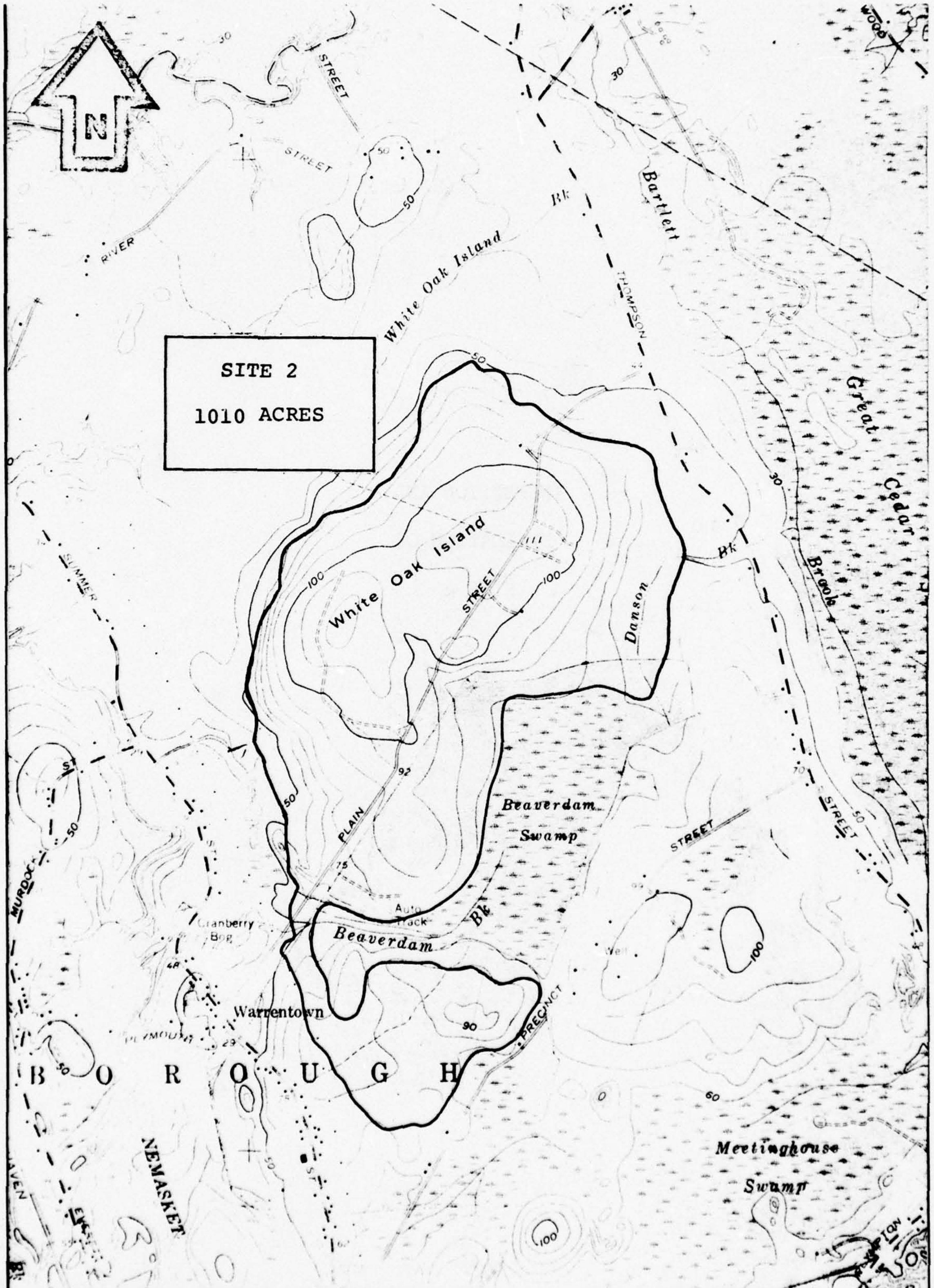
The properties of the soils on this site make them suitable for spray irrigation application of wastewater with only slight to moderate limitations. Site number 1 contains no soils suitable for rapid infiltration of wastewater without severe limitations.

Examination of the site revealed that there is no new development within the boundaries of the U. S. Government Reservation. There are new houses along the southwest side of Prospect Street but they are at the very edge of the site and pose no problem. There were no other cultural limitations noted except a lookout tower on the top of Prospect Hill. There was very little underbrush development as the site is covered by mature forest. Therefore the site can be considered as suitable for spray irrigation application with slight to moderate limitations, and as unsuitable for rapid infiltration of wastewater due to severe limitations. This analysis is subject to confirmation or rejection by more detailed site analysis, including exploration and boring with respect to groundwater depth to bedrock, and permeability of soils.

INSPECTION AND

EVALUATION OF

SITE 2



WHITMAN & HOWARD, INC.

ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B6

INSPECTION AND EVALUATION OF SITE 2

SITE LOCATION

The site is located in the Town of Middleborough in Plymouth County. The site is bounded on the west by Summer Street, the east by Thompson Street, the southeast by Precinct Street, and the north by River Street. Plain Street bisects the site from northeast to southwest. The principal topographic relief is White Oak Island. The nearest Town is Middleboro, 2 miles to the south.

AVAILABLE DATA

Available information consisted of: U.S.G.S. Topographic Map Bridgewater quadrangle, 1962; Bedrock Geology Map for Massachusetts (2) U.S.G.S. quadrangle Report, Bridgewater, 1971 Massachusetts Land Use and Vegetative Cover Mapping.(1)

GENERAL SITE CONDITIONS

The site encompasses approximately 1010 acres. Elevation ranges from 110 feet in the area of White Oak Island to 40 feet near Summer Street in the west.

Vegetation is mainly mixed hardwoods and softwoods with alternately hardwoods and softwoods dominating. Heights range quite widely from 20 - 80 feet. Crown closure is of a high density of 80 - 100 percent. Slopes over the area are slight with approximately half the area less than 3 percent slope and the other half 3 - 8 percent slope.

BEDROCK GEOLOGY

According to the Bedrock Geology Map for Massachusetts(2) site 2 lies within the Rhode Island formation, a black shale, conglomerate, and sandstone with beds of coal. The Plymouth County Soil Survey(3) gives ranges of depth to bedrock of 5 - 30 + feet.

SURFICIAL GEOLOGY

According to information derived from the U.S.G.S. Quadrangle Report GQ-127 on Bridgewater, and the county soil survey, the site is approximately half covered by Essex soils; the remaining half composed of mainly Gloucester, Agawam and Scituate soils and some Norwell soils. The Essex soils are mainly coarse sandy loams with small areas of very stony coarse sandy loam formed from glacial till. The Gloucester soil is a very stony loamy sand formed from glacial till derived chiefly from granite. The Agawam soil is a fine sandy loam formed in thick deposits of water-sorted sandy material found on terraces along major tributaries.

Permeabilities range from rapid in the Gloucester and Agawam soils to moderately rapid in the upper layers of the Essex and Scituate soils. The Essex and Scituate soils have a slowly permeable impervious zone at a depth of 1.5 - 3.0 feet. Norwell soils which run in a strip across the southern extent of the site are unsuitable for wastewater application because they have a high water table for 7 months or more each year, and a fragipan restricts downward movement of water.

GROUNDWATER

According to the Plymouth County Soil Survey(3) the seasonal high water level of the Essex, Agawam, and Gloucester soils is 3 - 5+ feet. The seasonal high water level of the Scituate soil is 1.5 - 3 feet. The Norwell soil has a depth to seasonal high water level of 0 - 1 feet. Groundwater flow is probably from the center of White Oak Island to the perimeters of the site. The groundwater of the southern tip most likely runs north to Beaverdam Brook then follows the stream course to the west. Groundwater is likely to be at or near the surface in Beaverdam Swamp and along Beaverdam Brook. These levels are speculative and detailed test borings or geophysical exploration would be required to determine actual groundwater levels.

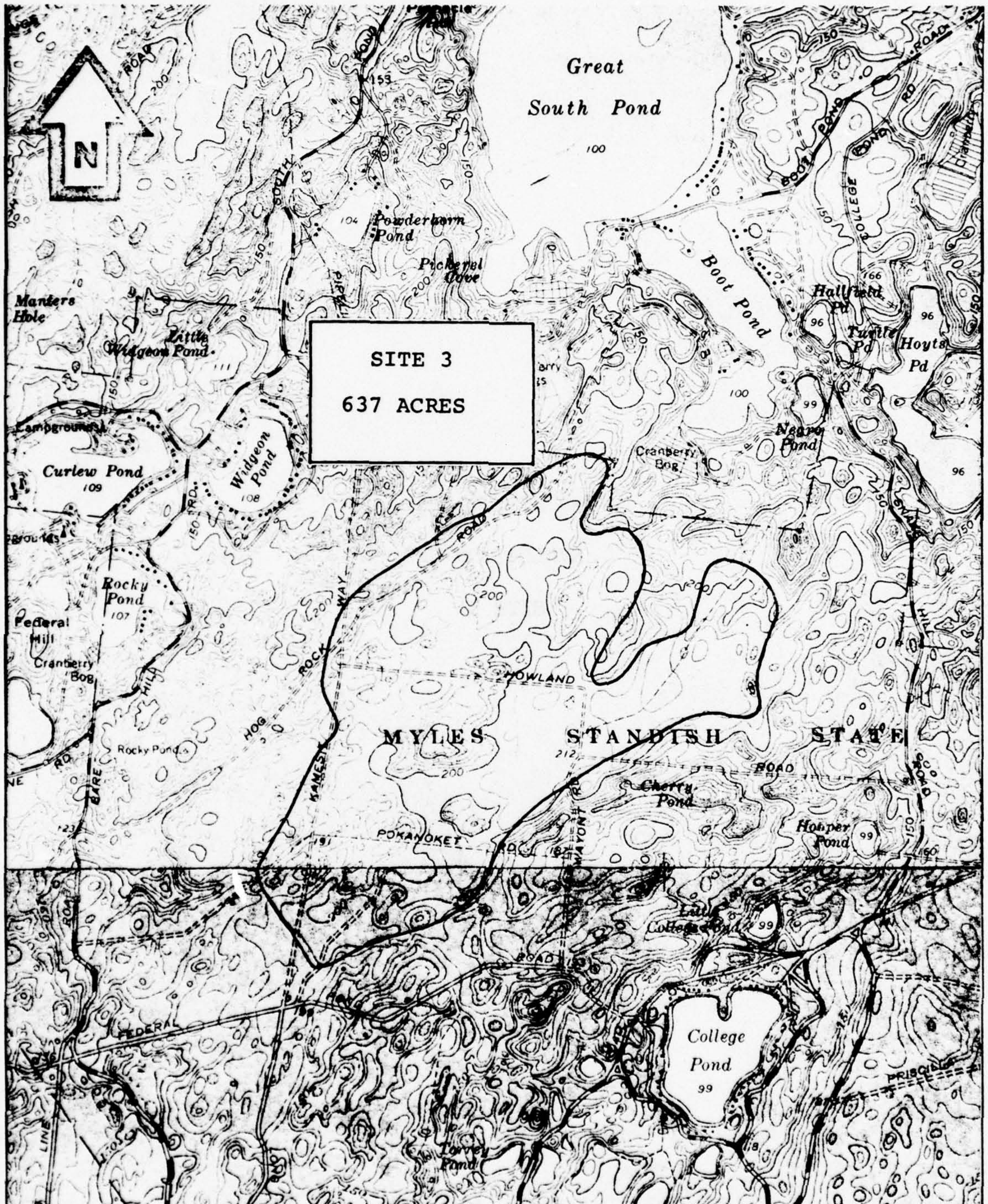
EVALUATION

An examination of the site revealed no new development on the site. Present cultural limitations are Plain Street and an auto track near Beaverdam Brook. Underbrush development is low. The properties of the soils on the site make them suitable for spray irrigation application of wastewater with slight to moderate limitations. There are no soils suitable for rapid infiltration of wastewater. The Norwell soil in the area of Beaver Brook has severe limitations for both spray irrigation and rapid infiltration applications. Considering all the information that portion of site 2 not underlain by Norwell soils can be used for spray irrigation application of wastewater if further site investigations, including test borings, and explorations, confirm the above information.

INSPECTION AND

EVALUATION OF

SITE 3



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B7

INSPECTION AND EVALUATION OF SITE 3

SITE LOCATION

The site lies in the Town of Plymouth in Plymouth County. The site is bounded on the east by Snake Hill Road, on the west by Bare Hill Road, and on the south by Federal Pond Road. It lies within the Myles Standish State Forest. The nearest Town is Plymouth 3 miles to the north.

AVAILABLE DATA

Available information consisted of: USGS Topographic Maps Wareham quadrangle 1957, and Plymouth quadrangle 1962; Bedrock Geology Map for Massachusetts[2]; 1971 Massachusetts Land Use and Vegetative Cover Mapping [1]; Seismic Investigations on Cape Cod - Geological Survey Professional Paper 650-B.[5]

GENERAL SITE CONDITIONS

The site encompasses approximately 637 acres. Elevation varies from 200 feet over wide areas of the site, to 130 feet in a depression in the central portion of the site.

Vegetation consists mainly of softwoods from 10 - 60 feet in height with 30 - 80 percent crown closure. The northern extremes have some mixed hardwoods and softwoods. There is very little underbrush evident on the site.

Slopes are generally 3 - 8 percent with some small areas of 8 - 15 percent. The depression in the center of the site has slopes of 15 - 35 percent.

BEDROCK GEOLOGY

Using information from B. K. Emerson's Bedrock Geology of Massachusetts,[2] and Oldale's Seismic Investigations on Cape Cod[5] bedrock beneath this site is believed to be granite and at a depth of approximately 80 feet.

SURFICIAL GEOLOGY

According to the Plymouth County Soil Survey[3] this site is completely composed of Carver soils of various slope phases. This series consists of excessively drained sandy soils, which formed in thick deposits of coarse, pebbly quartz sand deposited in outwash deposits from the last glaciation. Permeability is rapid through the soil and the substratum beneath. Depth to bedrock is given as greater than 100 feet.

GROUNDWATER

According to the Plymouth County Soil Survey(3) the depth to seasonal high water table is greater than 5 feet. The lack of water in the depression in Site 3 indicated that groundwater is possibly at a depth greater than 50 feet in this area for at least part of the year. Topography indicates that groundwater may move to the west from the southwestern portion of the site. From the eastern portion of the site groundwater movement may be to the southeast, towards College Pond. Test borings would be required to determine the actual depth to the groundwater table on the site.

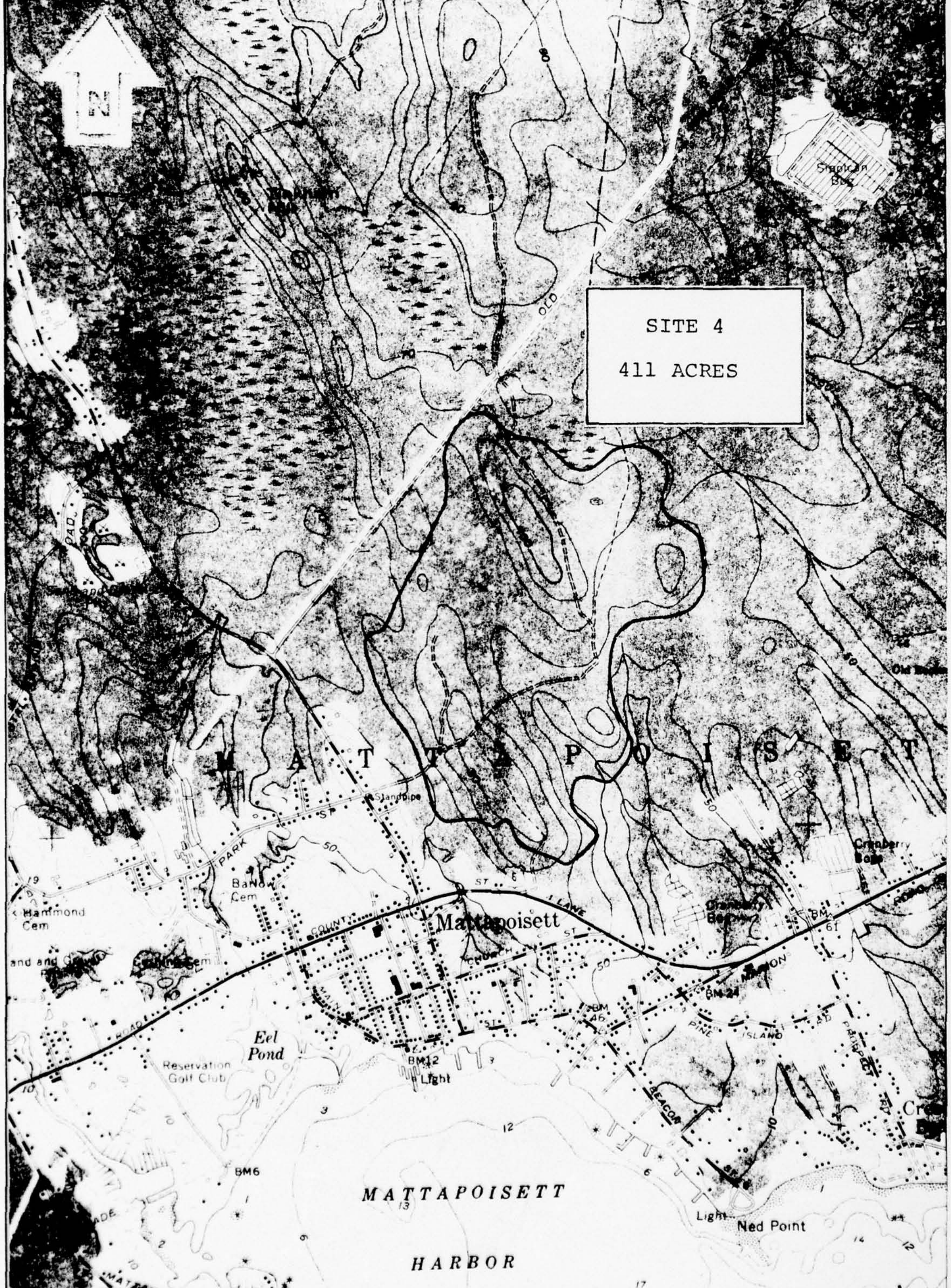
EVALUATION

An examination of the site revealed no new development which is logical as the site lies within a state forest area. Cultural features present, pose no problems, as only 3 unimproved roads cross portions of the site. There are some steep slopes but they are depressions which are generally fully enclosed within the site, thus creating no problems of movement of effluent off the site down steep slopes. The properties of the soils on the site make them suitable with moderate limitations for rapid infiltration application of wastewater. The potential of this site for rapid infiltration of wastewater may preclude its use for spray irrigation application as spray irrigation is less efficient in terms of volume of wastewater treated. Therefore it is concluded from available information that Site 3 is suitable for rapid infiltration with moderate limitations. This is subject to confirmation by more detailed site analysis. Including test borings, and geophysical exploration, for groundwater levels, permeabilities, and depth to bedrock.

INSPECTION AND

EVALUATION OF

SITE 4



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B8

INSPECTION AND EVALUATION OF SITE 4

SITE LOCATION

The site lies in the Town of Mattapoisett in Plymouth County. The site is bounded on the west by North Street on the south by County Street and on the northwest by an old railroad grade. The nearest town is Mattapoisett one half mile to the south.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Marion Quadrangle, 1962; Bedrock Geology Map for Massachusetts[2]; Soil Survey of Plymouth County[3]; 1971 Massachusetts Land Use and Vegetative Cover Mapping[1]; Southeastern Massachusetts Basic-Data Report No. 7, Groundwater Series[6].

GENERAL SITE CONDITIONS

The site encompasses approximately 411 acres. Elevation ranges from 100 feet near the north center of the site to 50 feet in the southern extremes near County Street. The topography gently slopes down to the ocean 1 mile to the south.

Softwoods dominate in a mixed softwood, hardwood vegetation in the east central portion of the site. Height ranges from 20 - 60 feet with mainly dense crown closure of 80 - 100 percent. To the south and west hardwoods tend to dominate the vegetation, with heights ranging from 40 - 80 feet and high density crown cover of 80 - 100 percent. Underbrush development is low over the site.

BEDROCK GEOLOGY

According to B. K. Emerson[2], Site 4 lies completely within the Dedham Granodiorite formation, a chloritic, biotite, granodiorite. Chute (4) describes it as a massive medium to coarse grained, highly fractured rock. The Plymouth County Soil Survey (3) gives a range of depth to bedrock of 5 - 30 + feet.

SURFICIAL GEOLOGY

According to the Plymouth County Coil Survey[3] the site is covered mainly by Gloucester soils and a small amount of Essex and Scituate soils. The Gloucester soil is an extremely stony loamy sand derived from granite glacial tills. The Gloucester soil has rapid permeability throughout the profile. The small areas of Scituate and Essex soils have good permeabilities in the upper layers but both contain slowly permeable fragipans at a depth of from 1-2.5 feet. A strip of unsuitable Brockton soils runs northwest to southeast splitting the Gloucester soils in two. The

Brockton soils are poorly drained in nature, and the high water table make it unsuitable for wastewater application.

GROUNDWATER

According to the Plymouth County Soil Survey[3], Gloucester and Essex soils have seasonal high water tables of 3 - 5 + feet. Brockton soil has a seasonal high water table of 0 feet. Groundwater movement in the area is probably generally away from the 100 foot contour in all directions and also towards the southeast along with the surface drainage pattern. A well located very near the site had a recorded level of 5 feet according to the Southeastern Massachusetts Basic - Data Report No. 7,[6].

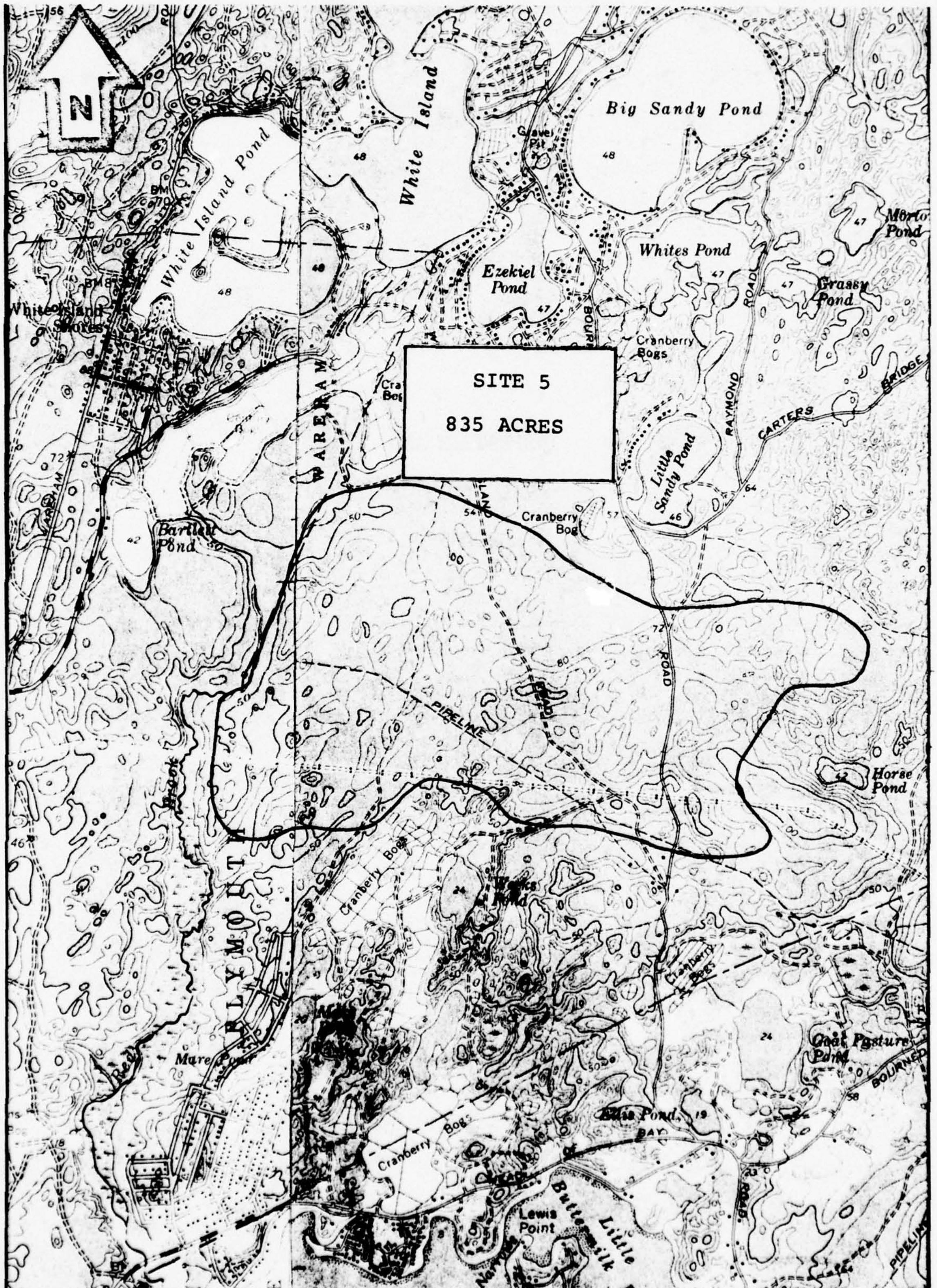
EVALUATION

An examination of the site revealed no new development within the site. Present cultural limitations are insignificant. There is one unimproved road which crosses the site. Underbrush development is low due to the presence of a large amount of mature softwood cover. The properties of the Gloucester, Scituate, and Essex soils on the site make them suitable for spray irrigation application of wastewater with slight, (Gloucester), to moderate, (Essex, Scituate), limitations. The Brockton soil is unsuitable for wastewater application by either method. Therefore, Site 4 is recommended for spray irrigation excluding the strip of Brockton soils. This conclusion is subject to confirmation or rejection based on more detailed site investigations. This would include test borings, and exploration to determine groundwater levels, depth to bedrock and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 5



WHITMAN & HOWARD, INC. ENGINEERS & ARCHITECTS BOSTON, MASS.	FIGURE B9

INSPECTION AND EVALUATION OF SITE 5

SITE LOCATION

The site lies in the Town of Plymouth in Plymouth County. The site is bounded on the west by Red Brook, on the south by Head of Bay Road, and on the east by Valley Road. To the south and north lie a number of cranberry bogs and small ponds of various sizes. The site is cut by a pipeline, a power line, and two roads. White Island Road, and Bourne Road. The nearest Town is Buzzards Bay, 2 miles to the south.

AVAILABLE DATA

Available information consisted of: USGS Topographic Maps, Sagamore Quadrangle 1967, and Wareham Quadrangle 1957; Bedrock Geology Map for Massachusetts [2]; Plymouth County Soil Survey [3]; 1971 Massachusetts Land Use and Vegetative Cover Mapping [1]; Southeastern Massachusetts Basic - Data Report[6].

GENERAL SITE CONDITIONS

The site encompasses approximately 835 acres. Elevation ranges from 100 feet in the eastern section of the site to 30 feet in the southwestern corner near Red Brook.

Vegetation consists mainly of mixed softwoods and hardwoods with softwoods dominating the western portions and hardwoods the eastern portion of the site. Heights range from 20 - 60 feet. Crown cover is of a high density 80 - 100 percent, underbrush development is low.

Slopes over the site range from 3 - 15 percent. Steeper slopes are found in the western section and in the northeast, and southeast corners of the site.

BEDROCK GEOLOGY

According to Oldale[5] bedrock in this area is at a depth of approximately 80 feet. Bedrock is assumed to be granite if B. K. Emerson's[2] data is extended to the east slightly.

SURFICIAL GEOLOGY

According to Woodworth and Wigglesworth,[7] and the USDA Plymouth County Soil Survey[3] the site is covered with Carver soil. This series consists of excessively drained sandy soils, formed in thick quartz sand deposits. It occupies an outwash plain deposit in the southeastern part of Plymouth County. Permeability is rapid through the soil and the substratum beneath. Depth to bedrock is given as greater than 100 feet.

GROUNDWATER

According to the Plymouth County Soil Survey[3] the depth to seasonal high water table is greater than 5 feet. Topography indicates a possible general movement of groundwater from north to south. Of 2 wells at the same elevation as the site 2 miles to the northeast, one had a depth to groundwater of 60 feet, the other 50 feet. To determine the actual depth of groundwater at Site 5 test borings would be required.

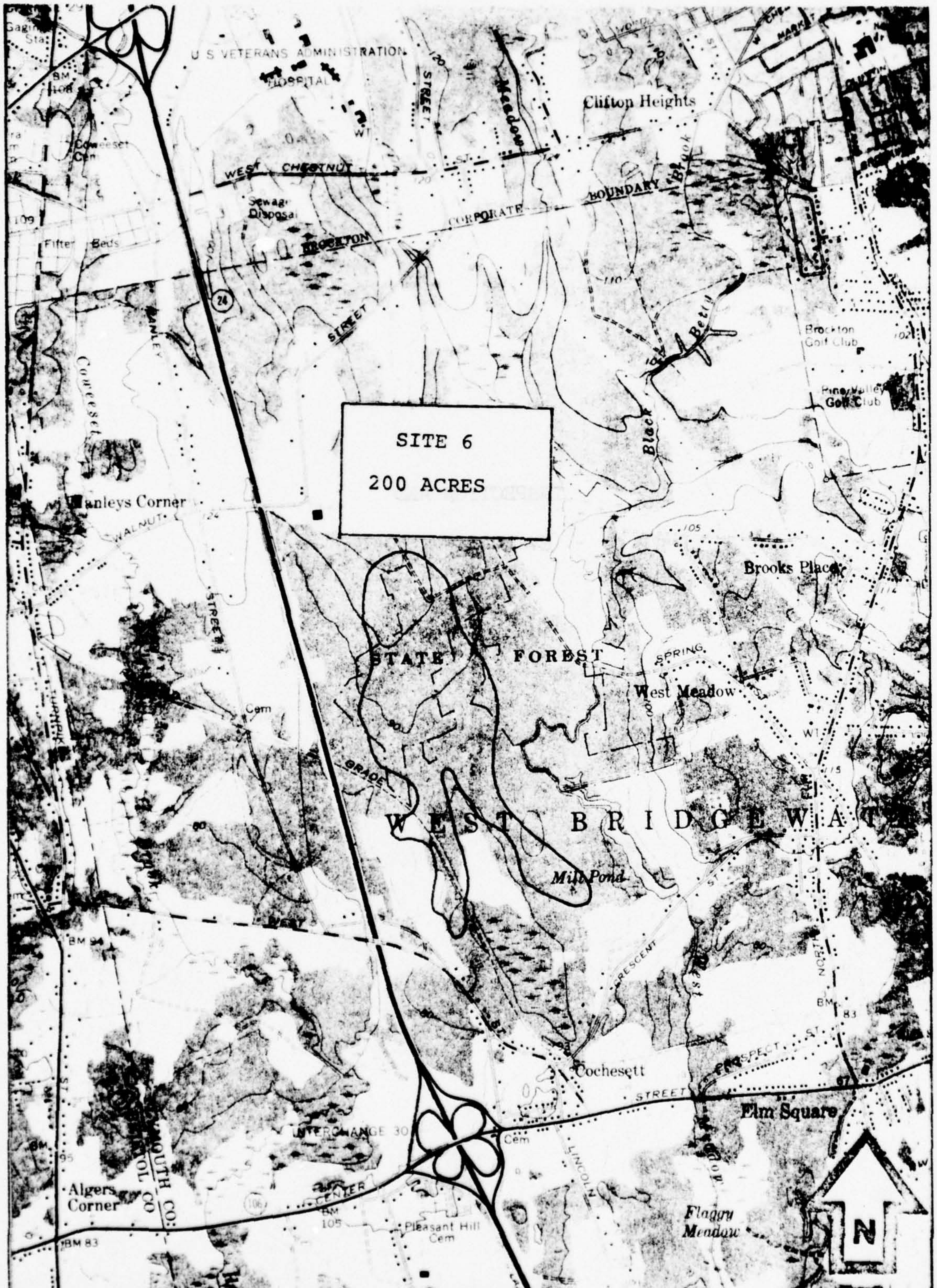
EVALUATION

An examination of Site 5 revealed no new development within the boundaries. Present cultural features produce no significant problems. They include a powerline, pipeline and two roads. A number of cranberry bogs around the perimeter of the site would have to be taken into account in a detailed survey. Underbrush development is low on the site. The properties of the soil on this site make it suitable for rapid infiltration application of wastewater with moderate limitations. The potential of this site for rapid infiltration may preclude the use of spray irrigation, as spray irrigation is less efficient in terms of volume of wastewater treated. Therefore according to data available and preliminary site investigation, Site 5 is suitable for rapid infiltration application of wastewater. This conclusion is subject to reconsideration following detail site investigation including test boring, and exploration to determine depth to groundwater table and bedrock, and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 6



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B10

INSPECTION AND EVALUATION OF SITE 6

SITE LOCATION

The site is located in the Town of West Bridgewater in Plymouth County. The site is bounded on the west by Highway 24, on the north by Walnut Street, and on the east by Spring Street. The site lies partially within a state forest in West Bridgewater. The nearest Town is Brockton 2 miles to the northeast.

AVAILABLE DATA

Available data consisted of: USGS Topographic Map Brockton Quadrangle 1963; Brockton Quadrangle, GQ-5 1950; Bedrock Geology Map for Massachusetts (2);Plymouth County Soil Survey (3);1971 Massachusetts Land Use and Vegetative Cover Mapping (1).

GENERAL SITE CONDITIONS

The site encompasses approximately 200 acres. Elevation ranges from 110 feet in the northern section to 80 feet in the southeastern corner of the site. There has been no new development on the site since the 1971 Land Use Mapping.

Vegetation is mixed hardwoods and softwoods. Softwoods 40 - 60 feet in height dominate in the northeast central portion of the site. 40 - 60 foot high hardwoods dominate the west central and southern extremes of the site. Crown cover is of a high density of 80 - 100 percent. Underbrush is moderately dense in hardwood areas around outside edges of site. In the center where softwoods dominate underbrush is light.

BEDROCK GEOLOGY

According to the USGS Brockton quadrangle GQ-5 1950, and B. K. Emerson's Bedrock Geology Map for Massachusetts (2),the site lies completely within the Rhode Island formation, a black shale, conglomerate, sandstone with beds of coal. Chute (4) describes the Rhode Island formation as an interbedded gray feldspathic sandstone, conglomerate and nonmarine gray to black slaty shale. Depth to bedrock given by the Plymouth County Soil Survey (3) ranges from 5 - 30+ feet. To determine the actual depth to bedrock at site 6, a more detailed test boring or seismic survey would be required.

SURFICIAL GEOLOGY

According to the USGS Brockton quadrangle GQ-5, 1950, and the Plymouth County Soil Survey (3), the soils on this site are of the Scituate series. Ninety percent is Scituate very stony, sandy loam.

The remaining 10 percent is Scituate sandy loam in the extreme south-west corner of the site. Permeability in the Scituate soils is moderately rapid in the upper layers but a slowly permeable imperivous zone lies at a depth of 1.5-3.0 feet.

GROUNDWATER

According to the Plymouth County Soil Survey(3) the seasonal high water level of the Scituate series is 1.5 - 3.0 feet. Groundwater flow is probably from the north to the south towards a swampy area to the south of site number 6. Test borings would be advisable to determine actual depths to groundwater.

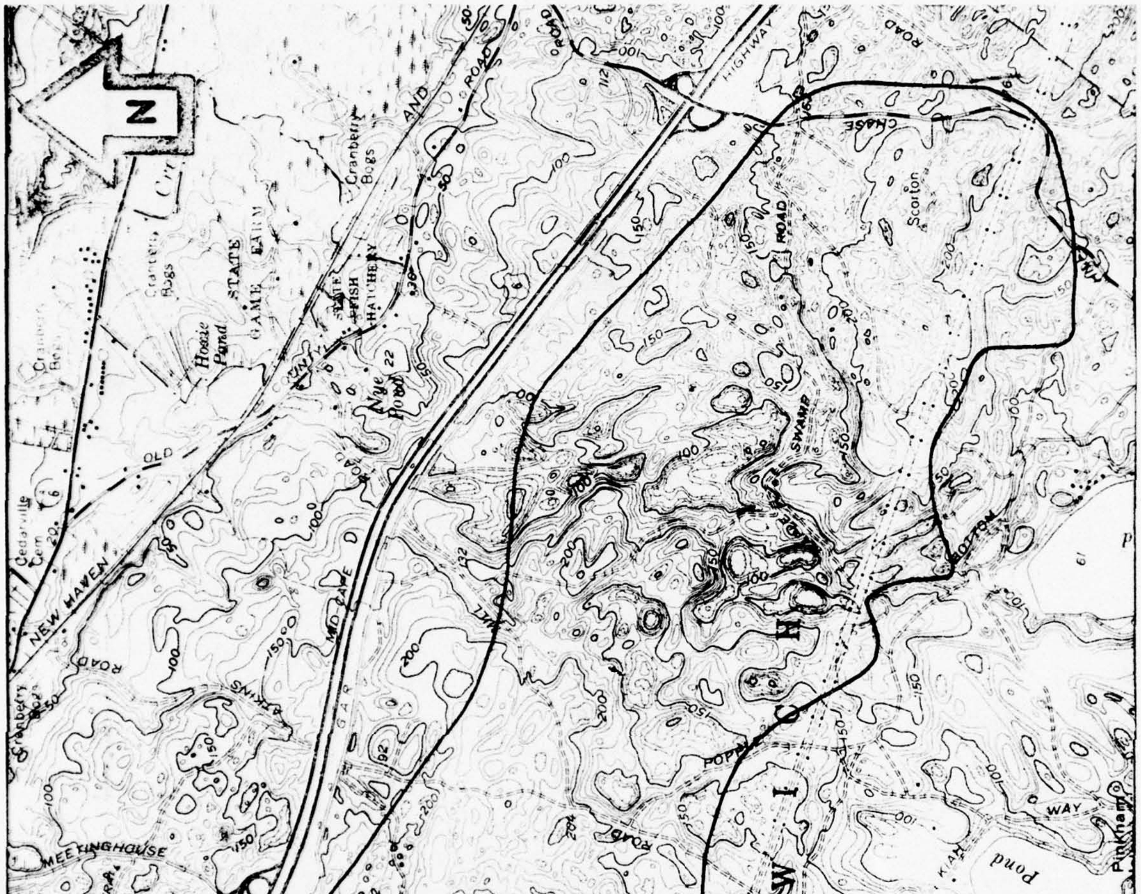
EVALUATION

Examination of site 6 revealed no new development on site. There are no interfering cultural features presently on site. The site contains very little underbrush because of the dense softwood vegetation. The properties of the Scituate soil on Site 6 make it suitable for spray irrigation of wastewater with moderate limitations. Here one of the limitations may be a higher than normal groundwater table in the Scituate soil. The site was frozen when viewed but numerous low swampy areas were noted to the south and east. The actual level of groundwater on the site is speculative but is probably slightly deeper as the elevation of the site is 10 - 30 feet higher than the surrounding swamps. Test borings would be required to confirm this. Taking into consideration the available data this site is recommended for spray irrigation of wastewater with the usual reservations for more detailed study.

INSPECTION AND

EVALUATION OF

SITE 7



WHITMAN & HOWARD, INC. ENGINEERS & ARCHITECTS BOSTON, MASS.	FIGURE B11

INSPECTION AND EVALUATION OF SITE 7

SITE LOCATION

The site is located in the Town of Sandwich in Barnstable County. The site is bounded on the north by the Mid-Cape Highway, on the west by Sandwich - Cotuit Road, on the east by Great Hill Road and Chase Road. A number of roads traverse the site: Discovery Hill Road, Quaker Meetinghouse Road. A power line cuts the southeast corner of the site. The nearest town is Sandwich, 2 miles to the northwest.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map, Sandwich Quadrangle, 1957; Geography and Geology of the Region including Cape Cod (7);Seismic Investigation on Cape Cod (5);1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Massachusetts Basic-Data Report No. 7, groundwater series (6).

GENERAL SITE CONDITIONS

The site encompasses approximately 1873 acres running parallel to the Mid-Cape Highway. The topography is hummocky with numerous depressions and irregularities. Elevation varies erratically but ranges from 260 feet to 40 feet.

Vegetation on the site is mixed softwoods and hardwoods. Heights range from 200 - 60 feet. Densities are irregular, low and high density distributed randomly over the site. There is little underbrush on Site 7.

SURFICIAL GEOLOGY

According to the soil survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8) the soil on this site is Plymouth sandy loam, light phase. The subsoil below 6" grades to loamy sand to loose sand which extends below 3 feet. Rounded gravel, masses of granite, and angular fragments occur in and on the soil. This soil is confined to hilly land occupying the rough morainic areas in southwestern Barnstable County. This phase is characterized as well to excessively well drained.

GROUNDWATER

Information from the Southeastern Massachusetts Basic Data Report No. 7(6) on a number of wells within 1 mile of Site 7 indicates that the groundwater level remains relatively flat, not following the land surface topography. Because elevation on the site varies from 260 to 40 feet, it is probable that the depth to groundwater varies from 200 to 20 feet, the greater depths under the higher elevations the lesser depths under the lower elevations. This is speculative and test borings would be needed to determine the actual depths to groundwater. But is is very likely that the depth to groundwater is everywhere greater than 10 feet, and in most areas greater than 30 feet. The existance of numerous dry depressions up to 50 feet deep confirms this.

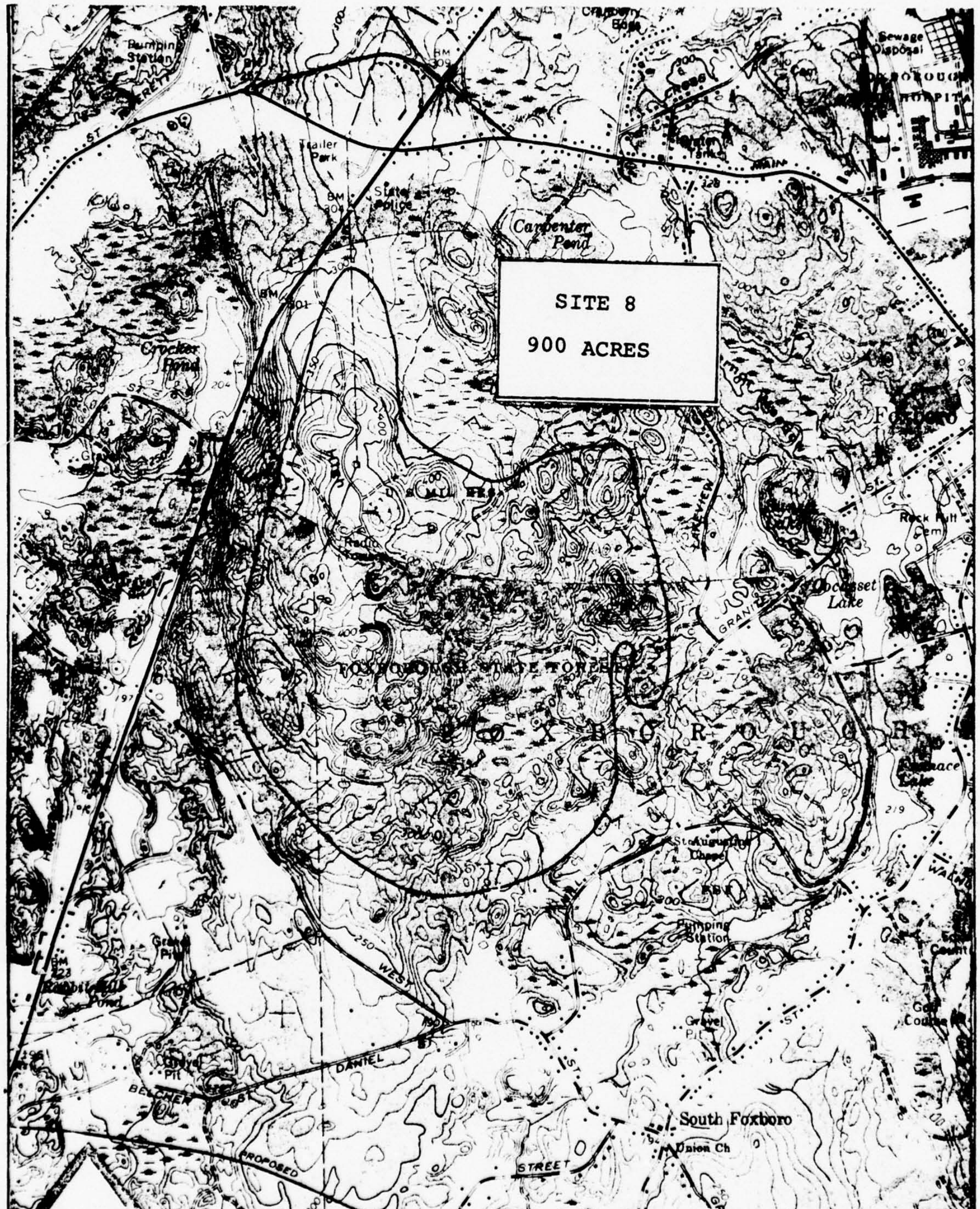
EVALUATION

Examination of Site 7 revealed no new development. This is the largest of the sites and a number of unimproved roads and a power line cut the site. The properties of the Plymouth soil make it suitable for rapid infiltration of wastewater. The potential of this site for rapid infiltration of wastewater may preclude its use for spray irrigation as spray irrigation is less efficient in terms of volume of wastewater treated. Therefore according to the above data Site 7 is recommended for application of wastewater by the rapid infiltration method. A more detailed survey would be required particularly into the rates of infiltration and permeability of the Plymouth soil as little is known about this old soil.

INSPECTION AND

EVALUATION OF

SITE 8



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B12

INSPECTION AND EVALUATION OF SITE 8

SITE LOCATION

The site lies in the Towns of Foxborough and Wrentham in Norfolk County. It is bounded on the west by U. S. Route 1, on the south by West Street, on the east by Lakeview Road, and on the north by Main Street. The site lies for the most part within Foxborough State Forest. The nearest town is Foxboro, 2 miles to the east.

AVAILABLE DATA

Available information consisted of: U.S.G.S. Topographic Map Wrentham Quadrangle, 1964; Bedrock Geology Map for Massachusetts (2); Soil Survey of Norfolk, Bristol, and Barnstable Counties (8); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Massachusetts Basic-Data Report No. 10 Groundwater Series (9).

GENERAL SITE CONDITIONS

The site encompasses approximately 900 acres. Elevation ranges from 430+ feet at High Rock in the west central section of the site to 190 feet in the southeast corner of the site. A radio tower with access roads is located just north of High Rock. Topography is hilly and erratic. Some swampy areas are in evidence in the northern and southern limits of the site.

Vegetation consists mainly of hardwoods 20-80 feet in height, with a crown density of generally 80-100 percent. Some small scattered areas, mostly to the south, have lower densities of 30-80 percent. There is very little underbrush on Site 8 because of the fairly dense forest cover. Slopes are erratic but generally are 0-10 percent. Approximately 20 percent of the site has slopes from 10-20 percent.

BEDROCK GEOLOGY

According to Bedrock Geology Map for Massachusetts (2) the bedrock at Site 8 is Dedham granodiorite, a chloritic biotite, granodiorite. Chute (4) describes it as a massive, medium to coarse grained, highly fractured rock. Depth to bedrock ranges from 5-30+ feet, according to the Plymouth County Soil Survey (3).

SURFICIAL GEOLOGY

According to the Soil Survey of Norfolk, Bristol, and Barnstable Counties (8) the soils on Site 8 are 95 percent Gloucester very stony loam and 5 percent Gloucester stony loam. The Gloucester stony loam consists of a heavy fine sandy loam, relatively high in silt. The substratum is stony and gravelly till from granite gneiss and schist. The stones consist of subangular and rounded glacial boulders and various sizes of small stones. These occur on the surface, in the soil, and in the till deposit beneath. The deposit ranges from 3 to 25 feet in depth to bedrock. The Gloucester very stony loam is a "stonier" phase of the stony loam.

GROUNDWATER

According to the Massachusetts Basic-Data Report No. 10, Groundwater Series (9) a well on Site 7 had a depth to groundwater of 60 feet. Groundwater movement in the area should be generally outward from the center of the site from the higher elevations to the lower elevations.

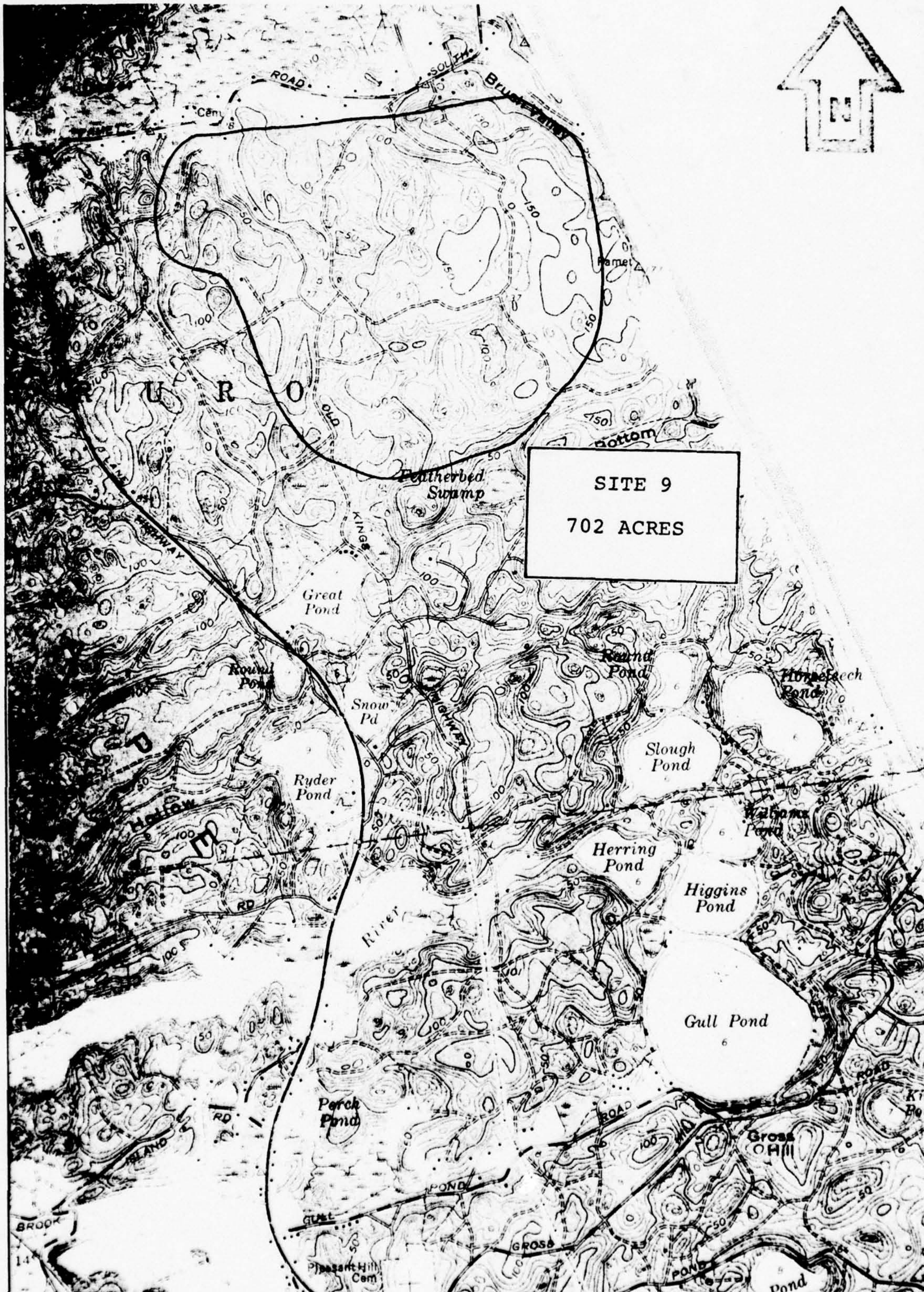
EVALUATION

Examination of Site 8 revealed no new development. This site is not likely to be developed because it lies within a U. S. Military Reservation and Foxborough State Forest. Underbrush development on the site is low. The properties of the Gloucester soil make it suitable for spray irrigation with only slight limitations. This soil is not suitable for rapid infiltration application of wastewater. Therefore, the site can be recommended as suitable for spray irrigation application of wastewater. This conclusion is subject to confirmation or rejection based on detailed site analysis, including exploration and test boring to evaluate groundwater levels, depth to bedrock, and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 9



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B13

INSPECTION AND EVALUATION OF SITE 9

SITE LOCATION

The site lies in the Town of Truro in Barnstable County. The site is bounded on the north by Pamet Road, on the west by the Mid-Cape Highway and on the east by the Atlantic Ocean. The nearest Town is Truro 1 mile to the west.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Wellfleet Quadrangle, 1958; Geography and Geology of the Region Including Cape Cod (7); Seismic Investigation on Cape Cod (5); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8); USGS Quadrangle Report - Wellfleet GQ-750; Massachusetts Basic-Data Report No. 7 Groundwater Series (6).

GENERAL SITE CONDITIONS

The site encompasses approximately 702 acres along the eastern shore of Cape Cod in the Truro township. Elevation ranges from 150 feet on the eastern edge of the site to 10 feet on the northwestern corner of the site. A network of unimproved dirt roads exists on the site.

Vegetation consists mainly of hardwoods and some mixed hardwood and softwoods. Heights range from 20 - 40 feet with dense crown cover of 80 - 100 percent over 60 percent of the area. The remaining 40 percent has crown cover of 30 - 80 percent density. Underbrush was of a low density. Vegetation was "scrubby." Slopes over the area range from 0 - 10 percent, steeper slopes exist to the west and north near the Pament River channel. To the east gentle slopes prevail to the edge of the escarpment.

BEDROCK GEOLOGY

According to Seismic Investigation on Cape Cod (5) bedrock is at a depth of approximately 400 feet below mean sea level. This would put bedrock between 410 and 550 feet below the surface.

SURFICIAL GEOLOGY

According to the U.S.G.S. Quadrangle Report for Wellfleet, GQ-750 this site is composed of older Wellfleet plain deposits derived from gravelly fine to very coarse sand with many quarzite stones. This is a highly permeable surficial material. According to the Soil Survey for Norfolk, Bristol, and Barnstable County[8] the soil on this site is Hinckley coarse sand. This soil consists of a light brown loose coarse sand grading to bright yellow coarse sand, becoming lighter with depth. Some areas approach the texture of very fine gravel. The open structure of the soil makes it well to excessively well drained.

GROUNDWATER

Information from the Massachusetts Basic-Data Report No. 7 Groundwater Series[6] indicates that groundwater in the area on Site 9 is at or just above sea level. Therefore groundwater should range from 10 to 150 feet below the surface. Test borings would have to be run in order to confirm these depths.

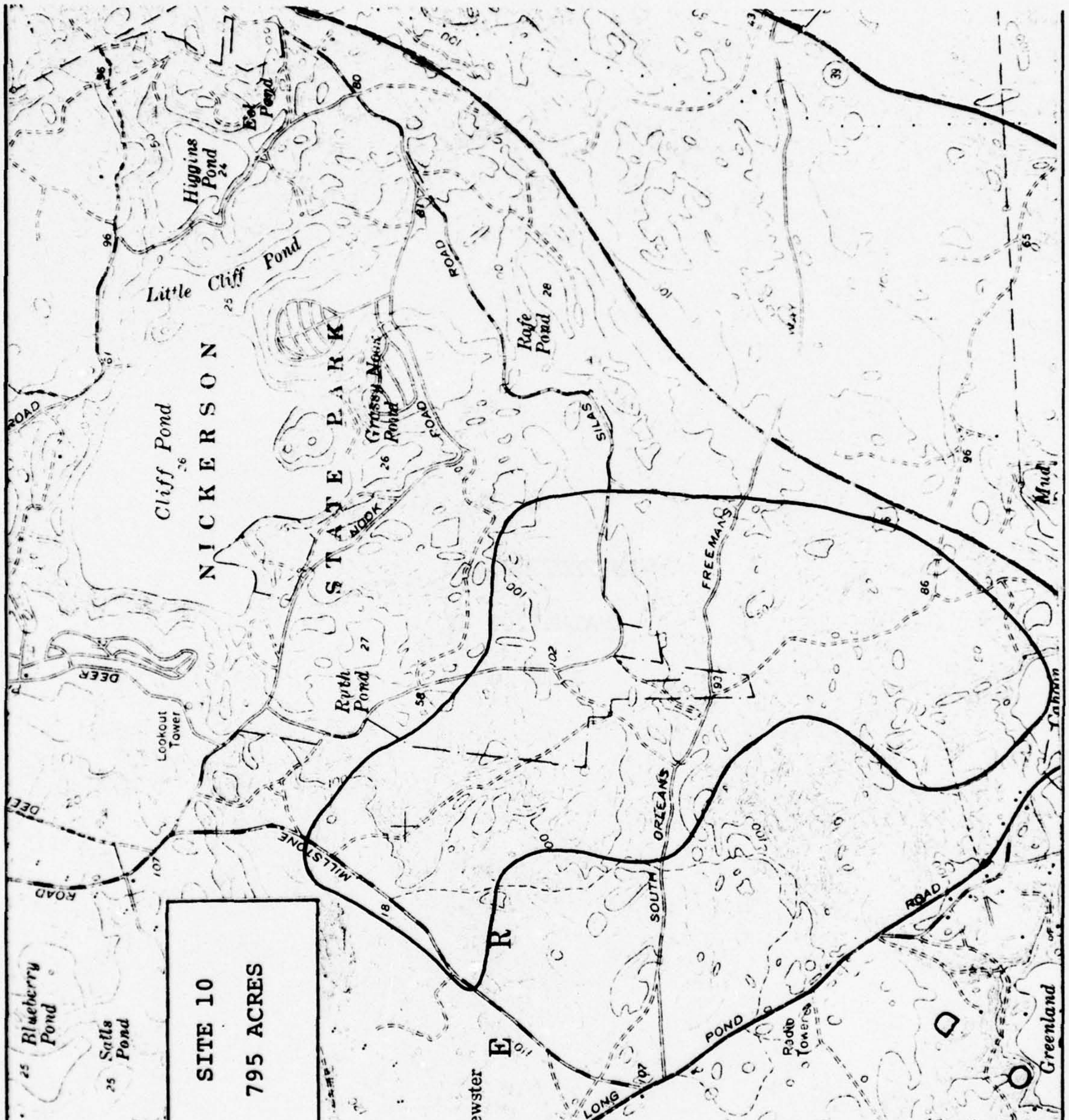
EVALUATION

Examination of the site revealed no new development. Present cultural features include a network of small unimproved dirt roads, that would present no problem to a wastewater application program. Some consideration would have to be made of the proximity of the beach cliffs and shore on the eastern edge of the site. The properties of the Hinckley soil make it suitable for rapid infiltration of wastewater. The potential of the soil for rapid infiltration may preclude the use of spray irrigation on this site as spray irrigation is less efficient in terms of volume treated. Based on the data available this site is recommended for rapid infiltration application of wastewater.

INSPECTION AND

EVALUATION OF

SITE 10



WHITMAN & HOWARD, INC.

ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B14

INSPECTION AND EVALUATION OF SITE 10

SITE LOCATION

The site is located in the Town of Brewster in Barnstable County. The site is bordered on the southwest by Long Pond Road, on the southeast by the Mid-Cape Highway, and on the north by Nook Road. The northeast corner extends into Nickerson State Park. The nearest Town is East Brewster. South Orleans Freemans Way bisects the site from west to east.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map, Harwich Quadrangle; Geography and Geology of the Region Including Cape Cod (7); Seismic Investigation on Cape Cod (5); 1971 Massachusetts Land Use and Vegetation Cover Mapping (1); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8); USGS Quandrangle Report - Harwich GQ - 786.

GENERAL SITE CONDITIONS

The site encompasses approximately 795 acres. Elevation ranges from 120 feet in the central portion of the site to 40 feet in some small depressions in the southern section of the site.

Vegetation consists of hardwoods and mixed hardwoods and softwoods. Heights range from 20 - 60 feet. Crown cover is mainly dense; 80 - 100 percent. Approximately 20 percent of the area has a crown cover density of 30 - 80 percent.

Slopes are gentle probably not over 10 percent anywhere on the site.

BEDROCK GEOLOGY

According to Seismic Investigation on Cape Cod[5] bedrock is at a depth of approximately 330' below mean sea level.

SURFICIAL GEOLOGY

According to the U.S.G.S. Quadrangle Report for Harwich, GQ - 786, surficial deposits on this site are Harwich outwash plain sands and gravels. These deposits have very high permeabilities and low moisture holding capacilities. According to the soil survey for Norfolk, Bristol, and Barnstable County[8] the soil on this site is Hinckley coarse sand. This soil consists of a light-brown loose coarse sand, grading to bright yellow coarse sand, becoming lighter with depth, some areas approach the texture of very find gravel. The open structure of the soil and the great depth of the coarse material beneath makes this soil well to excessively well drained.

GROUNDWATER

According to the Massachusetts Basic-Data Report No. 7 Groundwater Series(6), groundwater is at or just above sea level. This varies somewhat with topography. Therefore the depth to groundwater table should range from approximately 10 - 50 feet depending on the elevation of the site. Test borings would have to run on the site in order to confirm this.

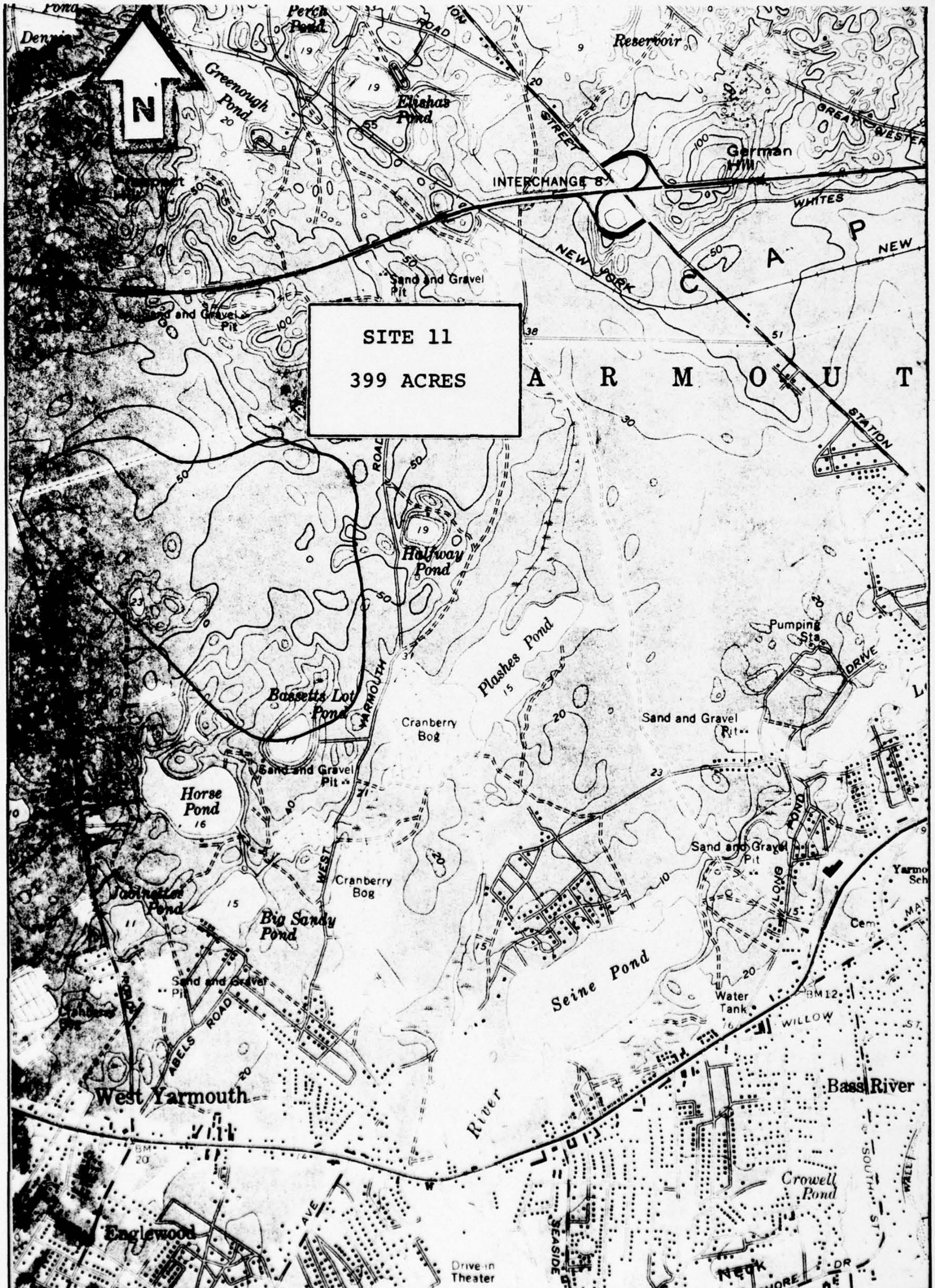
EVALUATION

Examination of Site 10 revealed that new development has reduced the usable size of the site considerably. The Brewster Watershed and Conservation Area now occupies approximately the northern 4/5 of the site leaving approximately 160 usable areas bordering on Cahoon Pond to the south. The properties of the Hinckley soil on this site make it suitable for rapid infiltration application of wastewater. This potential for rapid infiltration may preclude the use of spray irrigation on the site as spray irrigation is less efficient in terms of volume treated. Based on the above data this site is recommended for rapid infiltration application of wastewater. This evaluation is subject to further study on the usable 160 acres including test boring, and exploration, to determine groundwater levels and particularly soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 11



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B15

INSPECTION AND EVALUATION OF SITE 11

SITE LOCATION

The site is located in the Town of Yarmouth in Barnstable County. The site is bounded on the north by the Mid-Cape Highway, on the west by Higgins Crowell Road, on the east by West Yarmouth Road and on the south by Horse Pond. The nearest Town is West Yarmouth to the south.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Dennis Quadrangle, 1961; Geography and Geology of the Region Including Cape Cod (7); Seismic Investigation on Cape Cod (5); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8).

GENERAL SITE CONDITIONS

The site encompasses approximately 399 acres. Elevation ranges from 60 feet in the northeast corner of the site to 20 feet near Bassetts Lot Pond.

Vegetation consists of softwoods; heights ranging from 20 - 40 feet. Approximately 70 percent of the site is mixed hardwoods and softwoods from 20 - 60 feet in height. Crown cover: 50 percent high density (80-100 percent) and 50 percent low density (30-80 percent).

Slopes over the site are very gentle; 0 - 3 percent.

BEDROCK GEOLOGY

According to the Seismic Investigation on Cape Cod[5] bedrock is a depth of approximately 400 feet below mean sea level. This would put bedrock at 440-520 feet below the surface on Site 11.

SURFICIAL GEOLOGY

According to the Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts[8] Site 11 is covered by Merrimack sandy loam, light phase. The soil is a medium textured loamy sand to 8 inches, underlain by loamy sand or sticky sand to 24 inches. Small gravel in small amounts is encountered in places in the subsoil. The Merrimack sandy loam occupies gently undulating plains composed of materials derived chiefly from crystaline rocks and laid down as terrace, outwash, or delta deposits. The phase is characteristically well drained.

GROUNDWATER

According to the Southeastern Massachusetts Basic Data Report No. 7 Groundwater Series(6) there are a number of borings near the site that were dry to depths of 30 - 40 feet. These borings are at the same elevations as the average site elevation. It is therefore likely that the depth to groundwater on the site is at least 30 feet.

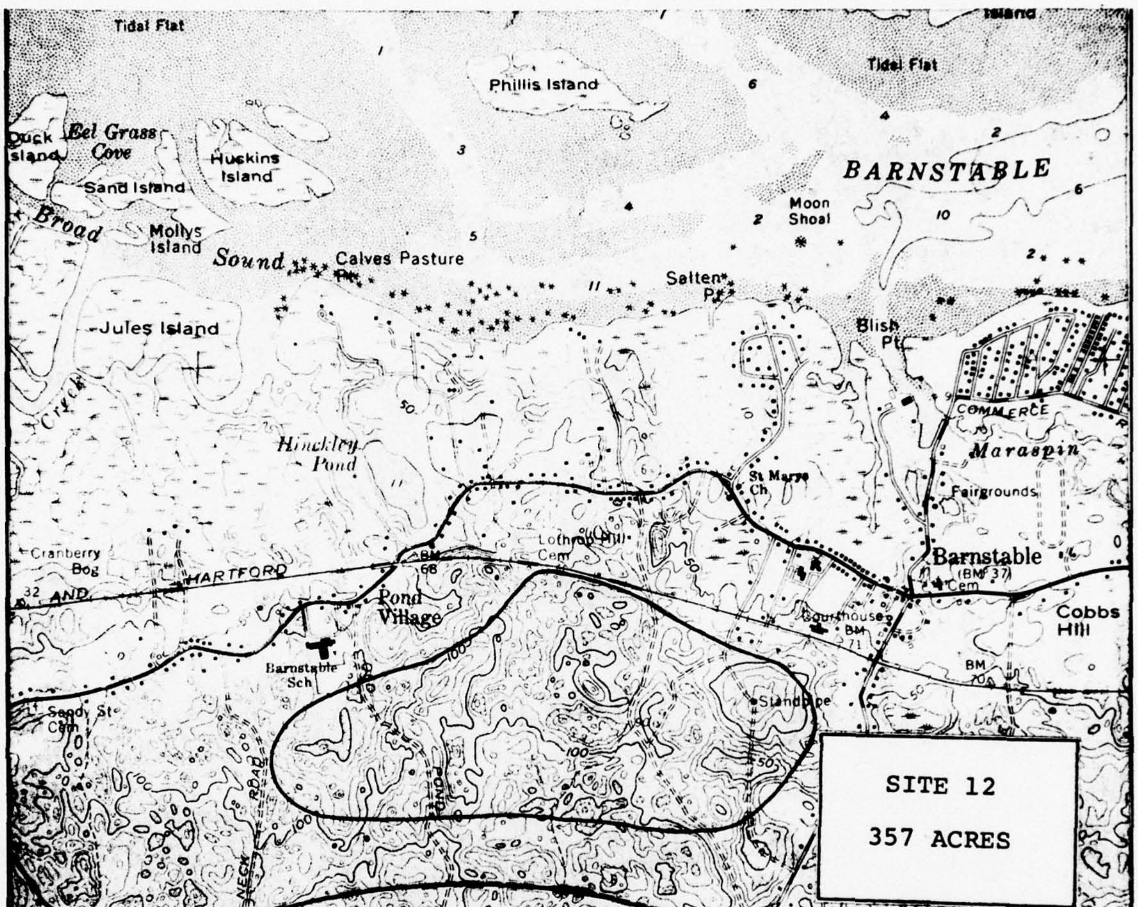
EVALUATION

Examination of Site 11 revealed that extensive new development on and around the site has rendered the site unuseable for wastewater application. The eastern portion of the site has new condominiums and the western portion has a new school built on the site. There are also municipal wells on this site.

INSPECTION AND

EVALUATION OF

SITE 12



WHITMAN & HOWARD, INC.

ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B16

INSPECTION AND EVALUATION OF SITE 12

SITE LOCATION

The site is located in the town of Barnstable in Barnstable County. The site is bounded on the north by the New York, New Haven and Hartford R.R., on the south by U.S. Route 6, on the east by Phinneys Lane on the west by Old Neck Road. The nearest town is Hyannis to the southeast.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Hyannis Quadrangle, 1961; Geography and Geology of the Region Including Cape Cod (7); Seismic Investigation on Cape Cod (5); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8); Southeastern Massachusetts Basic-Data Report No. 7, Ground-Water Series (6).

GENERAL SITE CONDITIONS

The site encompasses approximately 357 acres. Elevation ranges from 140 feet to 40 feet. Vegetation varies considerably over the site. Approximately 50 percent is mixed hardwoods and softwoods, with hardwoods dominating. The other half is mixed with softwoods dominating. There are a few small areas of softwoods alone. Heights range from 40 - 60 feet with an area in the west of hardwoods and softwoods from 20 - 40 high. Crown cover density is mainly high from 80 - 100 percent. Slopes range from approximately 0 -10 percent. The topography is slightly hummocky with scattered shallow depressions.

BEDROCK GEOLOGY

According to Seismic Investigation on Cape Cod[5] bedrock in the area lies at a depth of approximately 200 feet below mean sea level. This would put bedrock at a depth of 240 to 340 feet below the surface.

SURFICIAL GEOLOGY

According to the Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts[8] the soil on this site is Plymouth sandy loam, light phase. The surface soil consists of medium - textured, light sandy loam. The subsoil below 6" grades to loamy sand to loose sand which extends below 3 feet in depth. Rounded gravel, masses of granite, and angular fragments occur in and on the soil. This soil is confined to hilly land occupying the rough morainic areas in southwestern Barnstable County. This phase is characterized as well to excessively well drained.

GROUNDWATER

According to the Southeastern Massachusetts Basic-Data Report No. 7 Ground-Water Series (6) groundwater levels in two wells within 1/2 mile of the site are 21 and 29 feet above sea level at elevations of 50 and 40 feet respectively. Site elevations range from 140 to 40 feet. Therefore it is probably safe to assume that depths to groundwater on the site are at least 11 feet below the surface and in most cases more. This would have to be confirmed using test borings if the site were to be chosen for more detailed study.

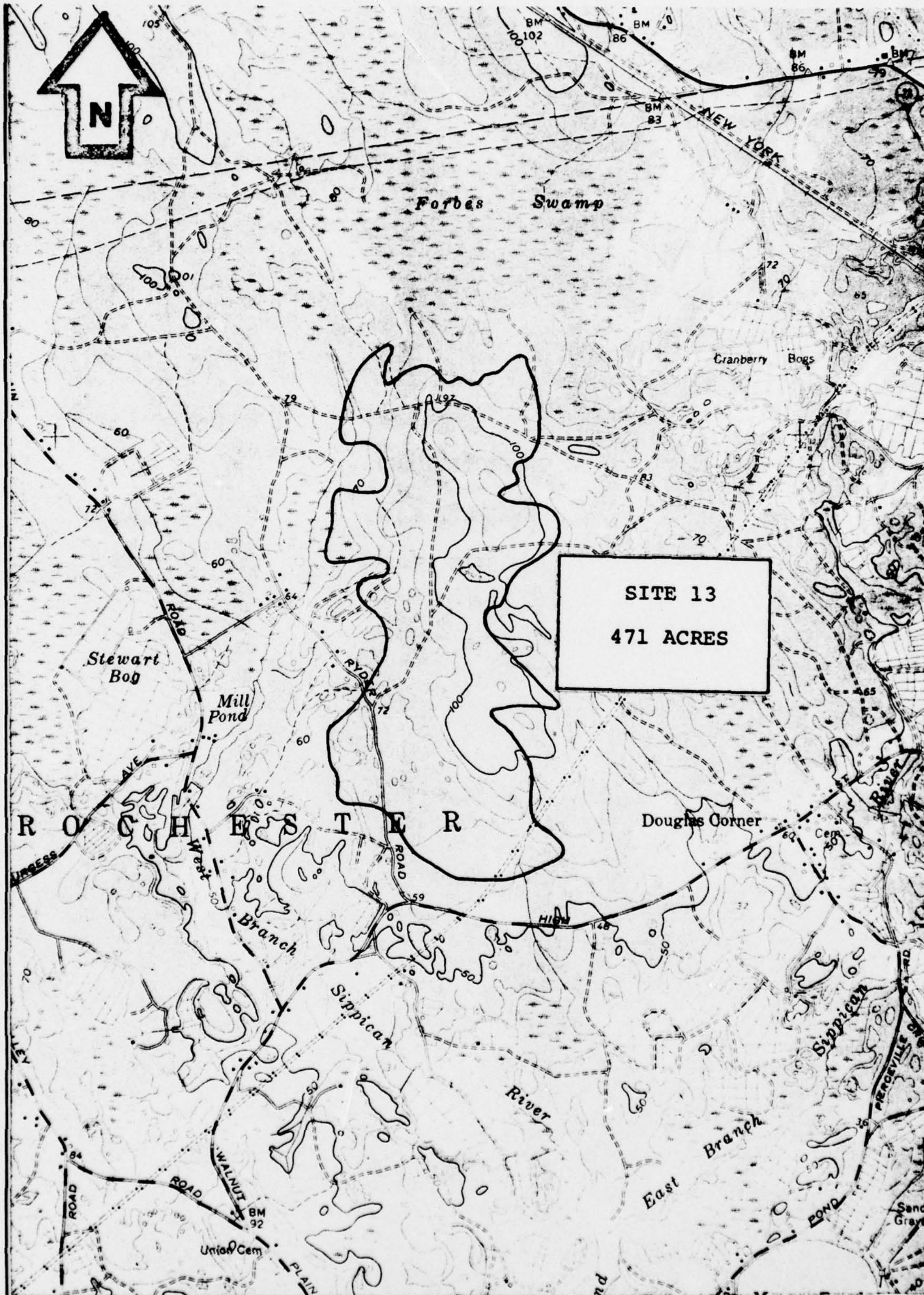
EVALUATION

Examination of site 12 revealed no new development in the area. Presently there are only 4 unimproved roads that cross site 12. Underbrush development is low in a scrubby forest vegetation. The properties of the Plymouth soil on this site make it suitable for rapid infiltration of wastewater. This potential for rapid infiltration may preclude the use of spray irrigation on the site as spray irrigation is less efficient in terms of volume of wastewater treated. Based on the above information this site is recommended for rapid infiltration application of wastewater. This evaluation is subject to confirmation or rejection based on further study, including test boring, and exploration, to determine groundwater levels, and particularly soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 13



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B17

INSPECTION AND EVALUATION OF SITE 13

SITE LOCATION

The site is located in the town of Rochester in Plymouth County. The site is bounded on the west by Walnut Plain Road, on the south by High Street, on the east by a power line, and on the north by Forbes Street. The nearest town is the West Wareham area.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Sniptuit Pond quadrangle, 1962; Bedrock Geology Map for Massachusetts (2); Soil Survey of Plymouth County (3); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Southeastern Massachusetts Basic-Data Report No. 7, Ground-Water Series (6).

GENERAL SITE CONDITIONS

The site encompasses approximately 471 acres. The elevation ranges from 120 feet in the northeast section to 60 feet in the western and southern sections of the site. The site is traversed by 3 unimproved dirt roads. The site is on a small rise just south of Forbes Swamp and approximately 1/2 mile east of Cedar Swamp. The area to the east and south is used extensively for cranberry production.

Vegetation on the site:

	Height	Density	Percentage
Softwoods	40-80 feet	80-100 percent	25
*Softwoods & Hardwoods	20-80 feet	80-100 percent	50
*Hardwoods & Softwoods	20-60 feet	30-80 percent	25

*Dominant

Slopes on the site are gentle, mainly 3-8 percent.

BEDROCK GEOLOGY

According to Bedrock Geology Map for Massachusetts (2) the site lies within the Dedham granodiorite . Chute[4] describes it as a massive, medium to coarse grained, highly fractured rock. Depth to bedrock ranges from 5-30+ feet, according to the Plymouth County Soil Survey (3).

SURFICIAL GEOLOGY

According to the Plymouth County Soil Survey(3) the soils on this site are mainly Gloucester soils with 2 small sections of Brockton soils. The Gloucester soils are very stony loamy sand formed in glacial till derived chiefly from granite. They occur mainly on the higher parts of rolling ground maraines. The Gloucester soil has a high permeability rate in the profile and the substratum. Brockton soils are very poorly drained, with high water tables throughout the year. For this reason they are not suitable for wastewater application.

GROUNDWATER

According to the Plymouth County Soil Survey(3) the seasonal high-water table is 3 to 5+ feet in the Gloucester soils. According to the Southeastern Massachusetts Basic-Data Report No. 7 Ground-Water Series(6) a well within 1/2 mile of site 13 at an elevation of 70 feet had a groundwater level 12 feet below the surface. Site elevations range from 60-120 feet, therefore the figure of 12 feet to groundwater table is likely approximation for depth to groundwater table at site 13. Test borings on the site would be required to confirm this approximation in a detailed site survey. Groundwater movement is probably from east to west downslope towards Ryder Road.

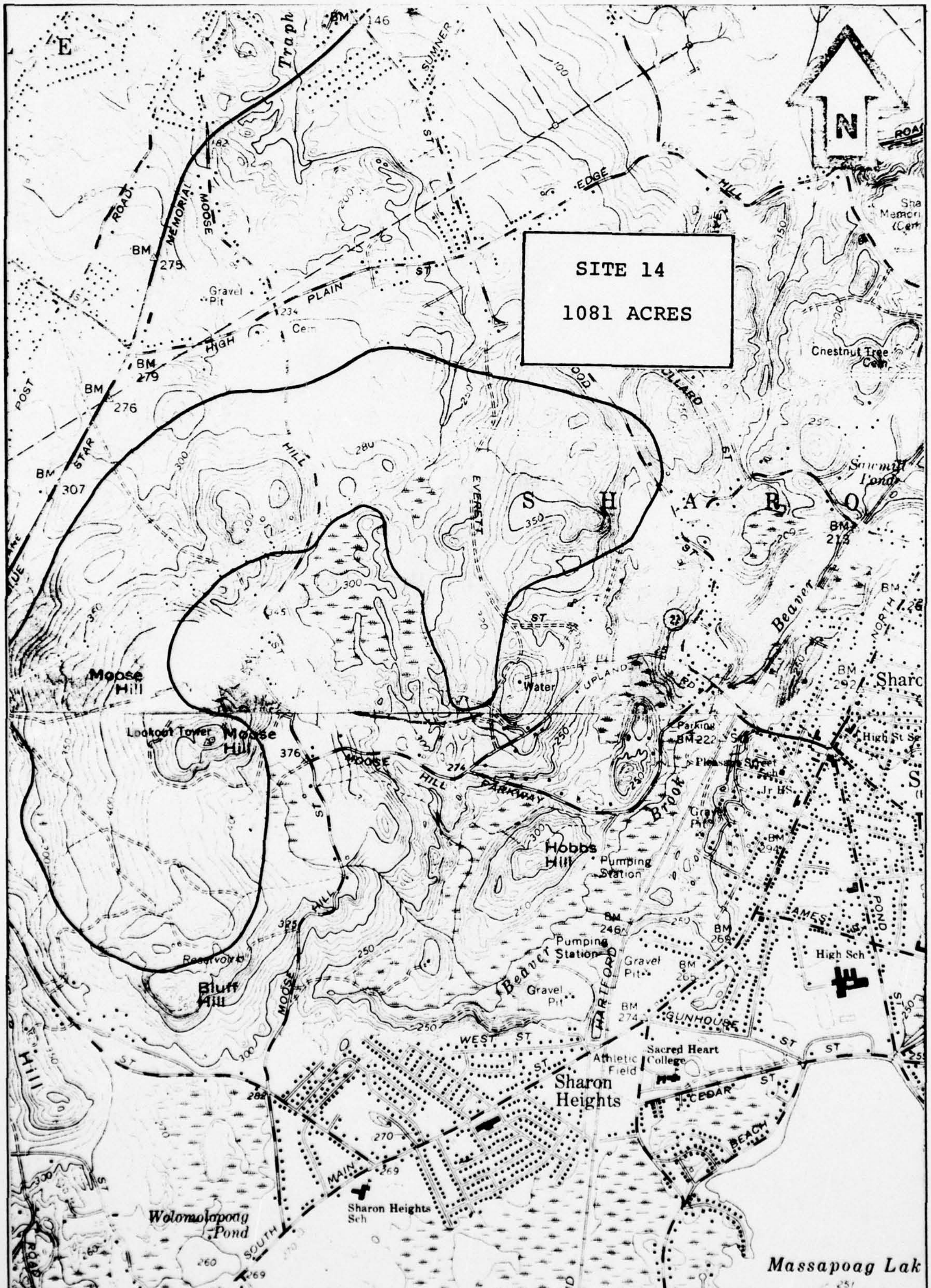
EVALUATION

Examination of the site revealed no new development. Present cultural development is minor. Three unimproved roads cut the site. A power line passes through the extreme southeast corner of the site. Underbrush is no problem on this site because of the relatively dense softwood and hardwood vegetation screen above. The properties of the Gloucester soil on site 13 makes it suitable for spray irrigation with only slight limitations. The Gloucester soil is not suitable for rapid infiltration application of wastewater. The area of Brockton soils on site 13 is not suitable for either application method because of its high water table throughout the year. Taking the above information into account it is felt that this site is suitable for spray irrigation excluding the Brockton soil areas, pending further study. This should include test boring, and exploration to confirm groundwater levels, depth to bedrock and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 14



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B18

INSPECTION AND EVALUATION OF SITE 14

SITE LOCATION

The site lies in the town of Sharon in Norfolk County. The site is bounded on the north by High Plain Street, on the west by Blue Star Memorial Highway and Interstate 95, on the northeast by Norwood Street, on the southeast by Moose Hill Street, and on the southwest by Walpole Street. The nearest town in Sharon, 1 mile to the east.

AVAILABLE DATA

Available information consisted of: USGS Topographic Maps, Norwood quadrangle 1958, and Mansfield quadrangle, 1964; Bedrock Geology Map for Massachusetts (2); Geology of the Norwood Quadrangle (4); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8).

GENERAL SITE CONDITIONS

.The site encompasses approximately 1081 acres. Elevation varies from 530 feet on the top of Moose Hill to 260 feet in the northern section of the site. Traversing the site are 5 roads, 4 of which are unimproved dirt roads. A power line runs from southwest to northeast through the site.

Vegetation consists of hardwood and softwoods, with hardwoods dominant over approximately 80 percent of the area. Softwoods are dominant over approximately 20 percent of the site. Density of crown cover varies widely but is approximately 50 percent high density (80-100 percent) and 50 percent high density (30-80 percent).

Slopes on the site range widely (0-20 percent) but most of the area, (90%), is under 10 percent slope. The area of steep slopes is located on the south flank of Moose Hill near the perimeter of the site.

BEDROCK GEOLOGY

According to Bedrock Geology Map for Massachusetts (2); and the Geology of the Norwood Quadrangle (4); the bedrock under this site is Sharon Syenite, a medium grained syenite.

SURFICIAL GEOLOGY

According to Geology of the Norwood Quadrangle[4] the surficial material on site 14 is ground moraine and kame terraces. The ground moraine consists mainly of sedimentary material derived from volcanic, granitic, and dioritic igneous rocks that produce gray sandy till. The kame terraces are composed of pebble and cobble gravel containing some interbedded sand. A large gravel pit 1/2 mile northwest of site 14 has exposed horizontal beds of pebble and cobble gravel containing some interbedded pebbly sand and a few boulders. According to the Soil Survey of Norfolk, Bristol, and Barnstable Counties[8] the soils on site 14 are Gloucester stony loam, Gloucester very stony loam and Gloucester sandy loam. The Gloucester stony loam consists of a heavy fine sandy loam, relatively high in silt. The substrata is stony and gravelly till from granite gneiss and schist. The stones consist of subangular and rounded glacial boulders and various sized smaller stones. These occur on the surface, in the soil, and in the till deposit beneath. The Gloucester very stony loam is a "stonier" phase of the stony loam. The sandy loam is a less stony phase of the stony loam. The Gloucester soils are rated as well drained soils.

GROUNDWATER

There is no direct information concerning the groundwater levels on site 14. A seasonal high water level of 3-5+ feet for the Gloucester soil series can however be taken from the Plymouth County Soil Survey[3] and extended to the Gloucester soils in Norfolk county with some degree of confidence.

EVALUATION

Examination of site 14 revealed that no new development had occured in the area. There is presently a Dept. of Public Works water reservoir just outside the southern boundary of the site. The site is large enough, however, to avoid placing any treatment areas that might cause contamination near this area. Underbrush is moderate to heavy on the hill to the west of Moose Hill Road. This might create some problem in implementation of a spray irrigation system. The rest of the site has little or no underbrush due to the mature forest cover screen above. A number of small unimproved roads traverses the site along with one power line. A lookout tower sits on top of Moose Hill. The properties of the Gloucester soil on site 14 make it suitable for spray irrigation application of wastewater with slight limitations. The Gloucester soil is not suitable for rapid infiltration application of wastewater. Therefore, it is concluded that site 14 is adaptable for spray irrigation application of wastewater pending further confirming study. This would include the usual: test boring and geophysical exploration to determine groundwater levels, depth to bedrock, and soil permeabilities.

AD-A036 799 METCALF AND EDDY INC BOSTON MASS F/G 13/2
WASTEWATER ENGINEERING AND MANAGEMENT PLAN FOR BOSTON HARBOR - --ETC(U)
OCT 75

UNCLASSIFIED NL

4 OF 4
AD
A036799

END
DATE
FILMED
4-77

INSPECTION AND
EVALUATION OF
SITE 15

INSPECTION AND EVALUATION OF SITE 15

SITE LOCATION

The site is located in the town of Raynham in Bristol County. The site is bounded on the northwest by Route 24, on the northeast by Locust Street, on the north by King Street, and on the south by Judson Street. The nearest town is Taunton 3 miles to the west.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Taunton quadrangle, 1962; Bedrock Geology Map for Massachusetts (2); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8); Plymouth County Soil Survey (3).

GENERAL SITE CONDITIONS

The site encompasses approximately 295 acres. Elevation ranges from 110 feet in the northeast corner to 30 feet in the western sections of the site.

Vegetation on the site is an extremely erratic mixture of hardwoods and softwoods. Heights range from 20 feet to 80 feet. The crown cover density is high, 80-100 percent.

Slopes on the site are even and gentle, usually less than 5 percent.

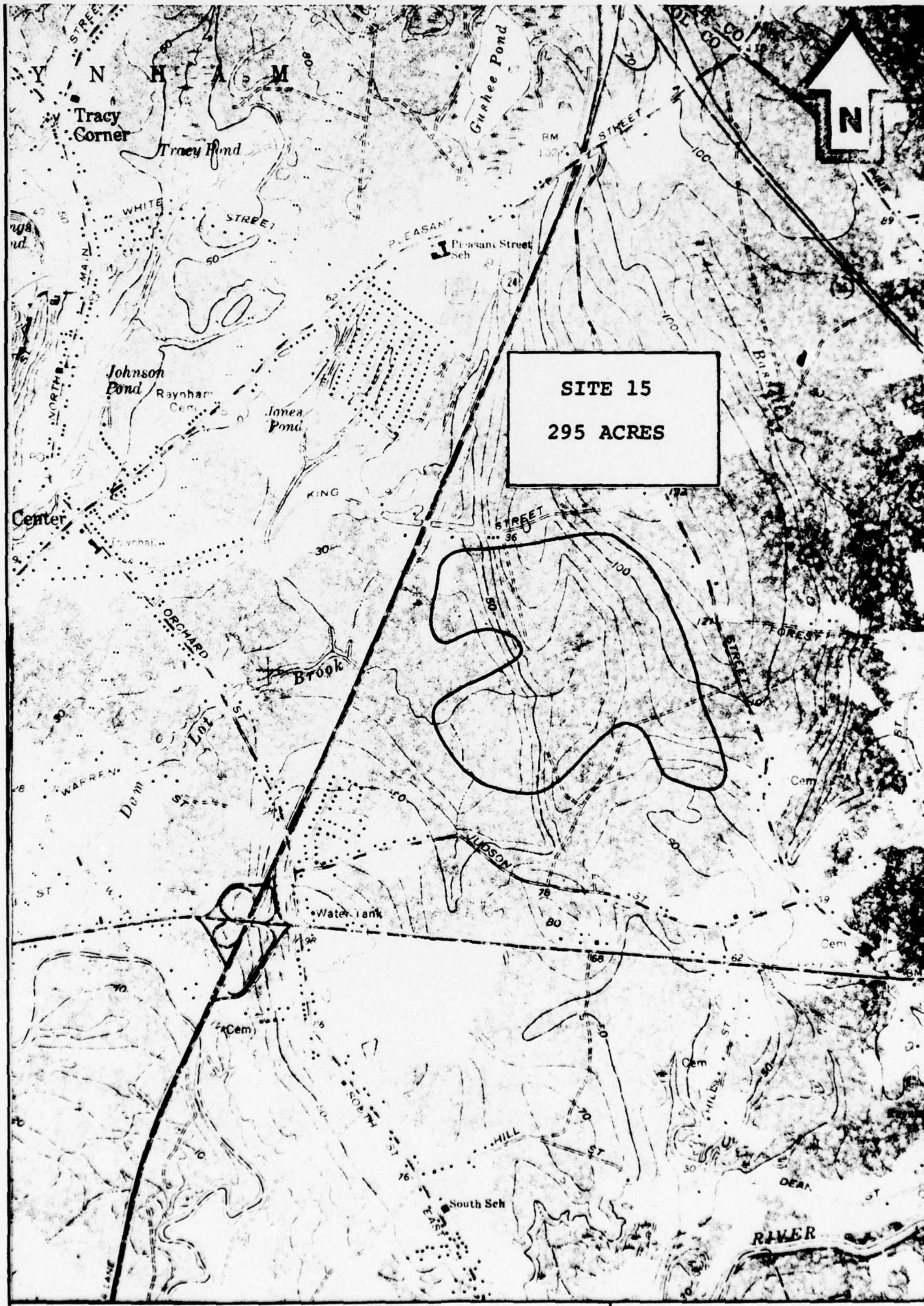
BEDROCK GEOLOGY

According to the Bedrock Geology Map for Massachusetts(2) bedrock in this area is the Rhode Island Formation, a black shale, conglomerate, and sandstone with beds of coal. Depth to bedrock ranges from 5 to 30+ feet. Test boring would be required to determine actual depths of bedrock on the site.

SURFICIAL GEOLOGY

According to the Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts(8) the surficial materials on the site are Gloucester series covers approximately 80 percent of the site. The Mansfield series covers a small strip in the northwest arm of the site.

The Gloucester sandy loam is derived from sandy till of mixed origin; from granite, gneiss, with some sandstone and slate. The Mansfield sandy loam occupies depressed positions in uplands and along smaller streams. It is derived from glacial till and is differentiated



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B19

from Coloma sandy loam by its poor drainage. Permeability rates are high in the Gloucester sandy loam. The Mansfield sandy loam would have a lower rate of permeability due to its poor drainage characteristics.

GROUNDWATER

According to the Plymouth County Soil Survey(3) and the Soil Survey of Norfolk, Bristol and Barnstable Counties, Massachusetts(8) the seasonal high groundwater level for the Gloucester sandy loam is 3 to 5+ feet. The Mansfield sandy loam has a high water table, usually within 3 feet of the surface. Groundwater movement on the site may be from northeast to southwest and south, flowing downslope and following the drainage pattern towards Dam Lot Brook.

EVALUATION

Examination of the site revealed no new development except along Locust Street along the edge of the site. Present development includes only 2 small unimproved roads that cut portions of the site. There is very little underbrush due to the extensive softwood forests on the site. The properties of the Gloucester soils on the site make them suitable for spray irrigation application of wastewater with slight limitations. The Gloucester soil is unsuitable for rapid infiltration application of wastewater. Therefore site 15 is recommended for spray irrigation application of wastewater. This recommendation is subject to confirmation or rejection based on further study of the area including, test boring and exploration, to determine groundwater levels, depth to bedrock, and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 16

WHITMAN & HOWARD, INC.

ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B20

INSPECTION AND EVALUATION OF SITE 16

SITE LOCATION

The site is located in the towns of Freetown and Lakeville in Plymouth and Bristol Counties. The site is bounded on the north by Howland Street, on the west by a cranberry bog and pond, and on the south by the Plymouth-Bristol County border. The nearest Town is Assonet.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Assonet Quadrangle, 1963; Bedrock Geology Map for Massachusetts (2); Plymouth County Soil Survey (3); Soil Survey of Norfolk, Bristol, and Barnstable Counties, Massachusetts (8); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Southeastern Massachusetts Basic-Data Report No. 7 Groundwater Series (6).

GENERAL SITE CONDITIONS

The site encompasses approximately 643 acres. Elevation ranges from 240 feet on the top of a hill in the central portion of the site to 120 along the western perimeter of the site.

Vegetation consists of hardwoods and mixed hardwoods and softwoods with hardwoods dominant over 90 percent of the site. The remaining 10 percent is mixed with softwoods dominant. Heights range from 20-80 feet. Crown cover density is high, (80-100 percent).

Slopes over the site are a gentle 3-8 percent, with the steeper slopes to the west towards the cranberry bog. The top of the hill has the most gentle slopes.

BEDROCK GEOLOGY

According to Bedrock Geology Map for Massachusetts(2) the site lies within the Dedham Granodiorite formation, a chloritic, biotitic, granodiorite. Chute(4) describes it as a massive, medium to coarse grained, highly fractured rock. Depth to bedrock ranges from 5-30+ feet according to the Plymouth County Soil Survey(3). A well located on Site 16 had a depth to bedrock of 42 feet according to the Southeastern Massachusetts Basic-Data Report No. 7.(6)

SURFICIAL GEOLOGY

According to the Plymouth County Soil Survey(3) the soils on this site are the Essex, and Gloucester soils. The Essex soil is a very stony coarse sandy loam, and the Gloucester is a very stony fine sandy loam, with firm substratum.

The Essex series is a well-drained soil formed in firm glacial till, occupying ground moraines and smooth rounded hills. At a depth of 2-2.5 feet is a fragipan of sandy loam. Permeability is rapid above the fragipan, but slow through the fragipan.

The Gloucester series is a well drained soil, derived chiefly from granite, occurring mainly on the higher parts of rolling ground moraines. Permeability rates are high through the soil profile and substratum.

GROUNDWATER

According to the Plymouth County Soil Survey(3) the groundwater seasonal high levels are approximately 3-5+ feet below the surface for both the Gloucester and Essex soils.

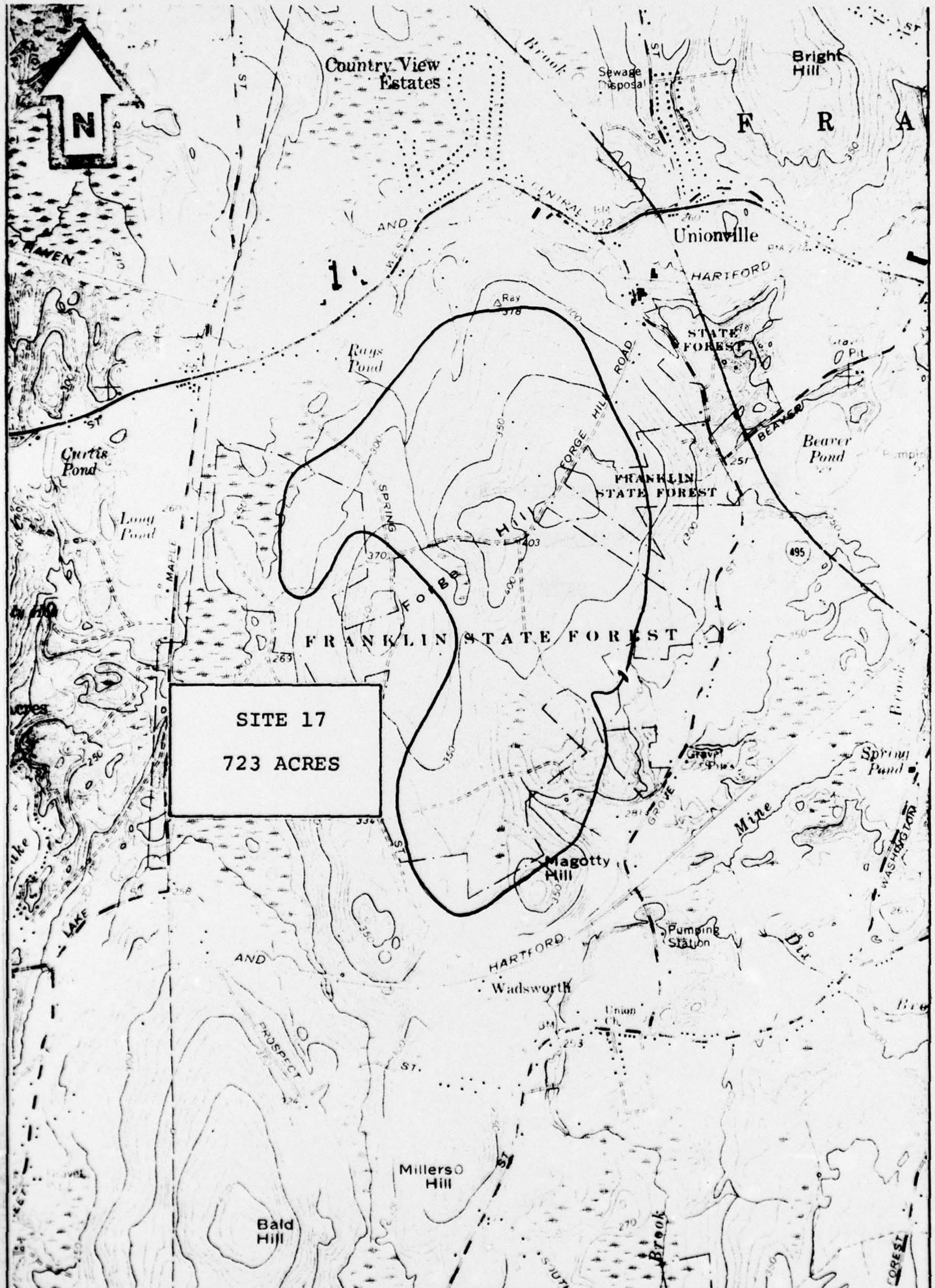
EVALUATION

Examination of Site 16 revealed no new development. Present cultural development includes a cranberry bog adjacent to the western boundary of the site. Possible contamination of this cranberry bog would have to be considered before the site could be utilized for wastewater treatment. There is little underbrush on the site because of the forest cover. The properties of the Gloucester and Essex soils make them suitable for spray irrigation application of wastewater with slight, (Gloucester), to moderate, (Essex), limitations. These soils are not suitable for rapid infiltration. Site 16 is therefore recommended for further study to confirm or reject its tentative suitability for spray irrigation. Recommended further study includes test boring and exploration for groundwater level, depth to bedrock, and soil permeability.

INSPECTION AND

EVALUATION OF

SITE 17



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B21

INSPECTION AND EVALUATION OF SITE 17

SITE LOCATION

The site is located in the town of Franklin in Norfolk County. The site is bounded on the north by West Central Street, on the west by Maple Street, on the south by the New Haven and Hartford Railroad, and on the east by Grove Street. It lies mainly within the Franklin State Forest. The nearest Town is Franklin approximately 1 mile to the east.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map Franklin Quadrangle, 1964; Bedrock Geology Map for Massachusetts (2); Soil Survey of Norfolk, Bristol, and Barnstable Counties (8); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1); Plymouth County Soil Survey (3).

GENERAL SITE CONDITIONS

The site encompasses approximately 723 acres. Elevation ranges from 410 feet Forge Hill in the center of the site to 250 feet in the northwest corner of the site. Forge Hill Road traverses the site directly over the top of Forge Hill, running from northeast to the west. Spring Street cuts the northwest corner of the site. A power line cuts across the northeast corner.

Vegetation consists of mixed hardwoods and softwoods (50 percent of the site) and hardwoods alone (50 percent). The hardwoods range in height from 20-60 feet with a crown closure density of 80-100 percent. The mixed hardwoods and softwoods range in height from 20-60 feet with a crown closure density of 30-80 percent.

BEDROCK GEOLOGY

According to the Bedrock Geology Map for Massachusetts[2] bedrock in this area is part of the Bellingham conglomerate, a mashed granitic conglomerate, and the Milford Granite, a biotitic granite with blue quartz.

SURFICIAL GEOLOGY

According to the Soil Survey of Norfolk, Bristol, and Barnstable Counties[8] the surficial material on this site is composed of Gloucester very stony loam and Gloucester stony fine sandy loam. The Gloucester very stony loam is composed of a shallow glacial deposit occupying hills and ridges. Here it covers the slopes and top of Forge Hill. The Gloucester stony fine sandy loam is a well drained soil formed from light stony sandy till.

Both these phases of the Gloucester series are highly permeable.

GROUNDWATER

Groundwater in the Gloucester soils can be found at a depth of 3-5+ feet during seasonal high water, according to the Plymouth County Soil Survey[3]. Groundwater flow on the site should be north and south away from Forge Hill.

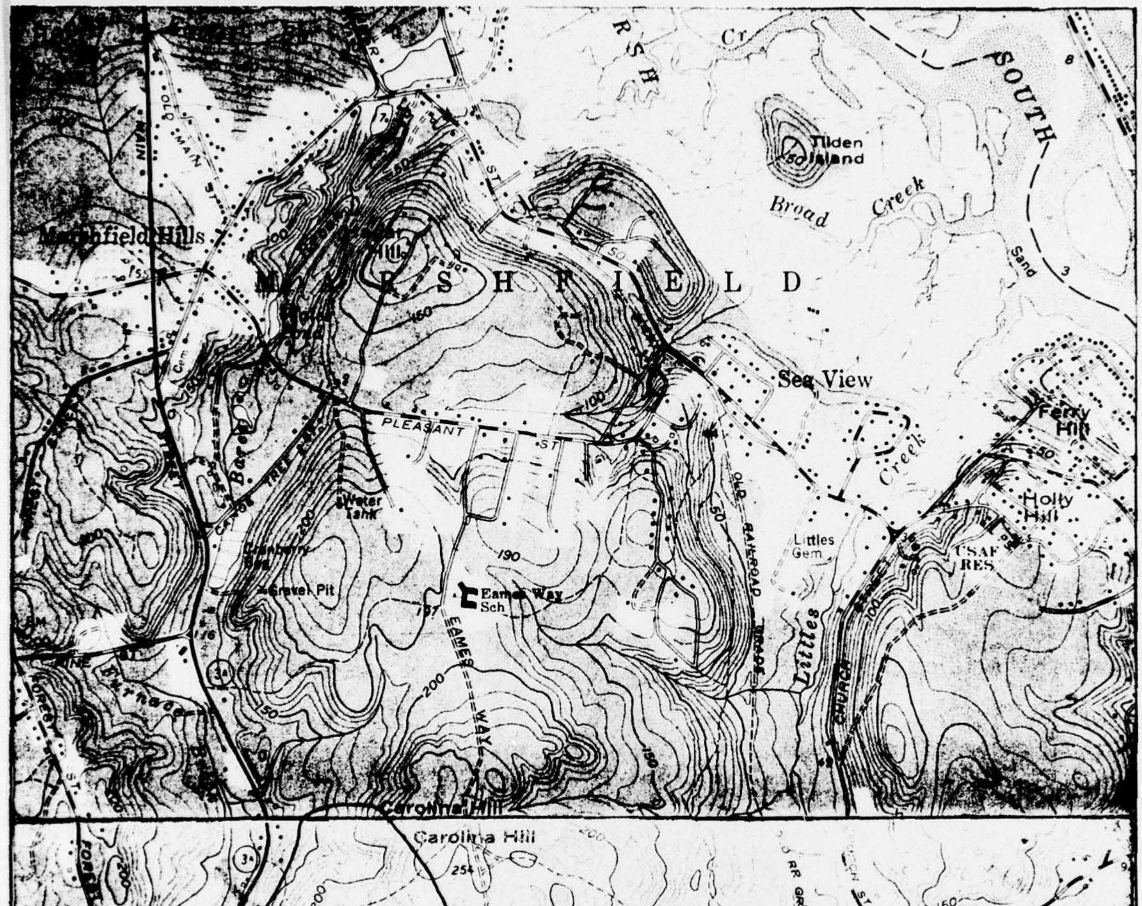
EVALUATION

Examination of Site 17 revealed no new development of the site. The site will probably remain undeveloped because it lies mainly within the Franklin State Forest. Presently there are 3 small unimproved roads and a power line which cut the site. Underbrush development is low because of the canopy provided by the forest vegetation cover above. The properties of the Gloucester soil make it suitable for spray irrigation application of wastewater. The Gloucester soil is unsuitable for rapid infiltration application of wastewater. Therefore Site 17 is recommended for spray irrigation, subject to confirmation or rejection by more detailed study including test boring, and exploration to determine groundwater levels, depth to bedrock, and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 18



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B22

INSPECTION AND EVALUATION OF SITE 18

SITE LOCATION

The site is located in the Town of Marshfield in Plymouth County. The site is bounded on the west by Main Street, on the east by Eames Way, and on the south by Furnace Street. The nearest Town is Marshfield 1.5 miles to the southeast.

AVAILABLE DATA

Available information consisted of: USGS Topographis Map, Duxbury Quadrangle, 1961; Bedrock Geology Map for Massachusetts (2); Plymouth County Soil Survey (3); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1).

GENERAL SITE CONDITIONS

The site encompasses approximately 168 acres. Elevation ranges from 240 feet at the southern perimeter to 100 feet in the southeast corner.

Vegetation on the site is composed of mixed hardwoods and softwoods, with hardwoods dominating. The heights range from 40-60 feet and crown closure density is 80-100 percent.

Slopes over the site are moderate, from 3-8 percent in the eastern half of the site, and from 8-15 percent in the western half of the site.

BEDROCK GEOLOGY

According to Bedrock Geology Map for Massachusetts[2] the bedrock in this area is part of the Dedham granodiorite formation, a chloritic, biotitic, granodiorite. Chute[4] describes it as a massive, medium to coarse grained, highly fractured rock. Depth to bedrock ranges from 5-30+ feet according to the Plymouth County Soil Survey[3].

SURFICIAL GEOLOGY

According to the Plymouth County Soil Survey[3] the surficial material is Gloucester very stony loamy sand. This material has a high rate of permeability through the profile and the substratum beneath. Gloucester soils are well-drained soils, formed in granitic glacial tills. They occur mainly on uplands in parts of the rolling ground moraine.

GROUNDWATER

The depth to seasonal high water level of the Gloucester soils is 3-5+ feet. Groundwater in this site probably moves from east to west downslope towards Main Street.

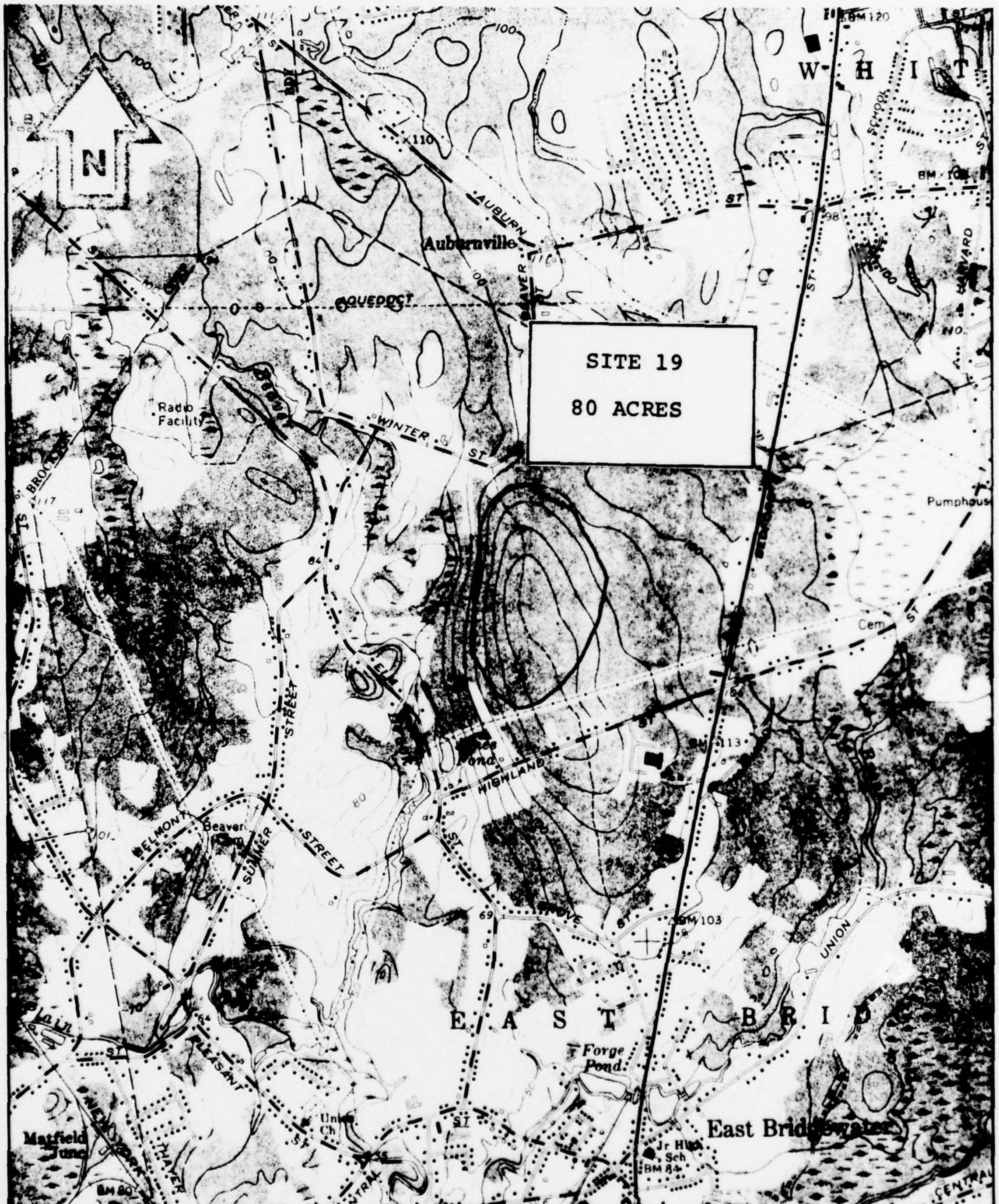
EVALUATION

Examination of this site revealed no new development on the site. There is no cultural development evident on the topographic quadrangle sheet. Underbrush is very low as a mature forest covers the site. The properties of the Gloucester soil make it suitable for spray irrigation application of wastewater. The Gloucester soil is not suitable for the rapid infiltration method. The site is recommended for spray irrigation application with consideration for further study to confirm or reject the data available for the site. Further study should include detailed test boring and exploration to determine groundwater levels, depth to bedrock, and soil permeabilities.

INSPECTION AND

EVALUATION OF

SITE 19



WHITMAN & HOWARD, INC.
ENGINEERS & ARCHITECTS BOSTON, MASS.

FIGURE B23

INSPECTION AND EVALUATION OF SITE 19

SITE LOCATION

The site lies in the Town of East Bridgewater in Plymouth County. The site is bounded on the east by Bedford Street, on the south by Highland Street, on the northwest by Winter Street, and on the west by Elm Street. The nearest Town in East Bridgewater, one mile to the south.

AVAILABLE DATA

Available information consisted of: USGS Topographic Map, Whitman Quadrangle, 1962; Bedrock Geology Map for Massachusetts (2); Plymouth County Soil Survey (3); 1971 Massachusetts Land Use and Vegetative Cover Mapping (1).

GENERAL SITE CONDITIONS

The site encompasses approximately 80 acres. Elevation ranges from 190 to 150 feet.

Vegetation on Site 19 is composed of mixed hardwoods and softwoods with hardwoods dominating. Heights range from 20 to 60 feet and crown cover density is 80-100 percent.

Slopes over the site are low, 3-8 percent. Site 19 lies on a small gentle rise surrounded by a number of small swamps.

BEDROCK GEOLOGY

According to the Bedrock Geology Map for Massachusetts[2] the bedrock in this area is part of the Rhode Island formation, a black shale, conglomerate, sandstone with beds of coal. Depth to bedrock ranges from 5-30+ feet according to the Plymouth County Soil Survey[3].

SURFICIAL GEOLOGY

According to the Plymouth County Soil Survey[3] the soil on Site 19 is Essex very stony coarse sandy loam. The Essex profile formed mainly in firm glacial till occupying ground moraines and drumlins. A slowly permeable fragipan of sandy loam is found at a depth of 2-2.5 feet. Permeability of the Essex profile is rapid above the fragipan but slow through the fragipan.

GROUNDWATER

According to the Plymouth County Soil Survey(3) the seasonal high water level of the Essex soil is 3 to 5+ feet. Groundwater movement on the site is likely to be from the center outward towards the perimeter.

EVALUATION

Examination of Site 19 revealed no new development. There is presently no evidence of cultrual development anywhere on the site. Underbrush is moderate on the site. The properties of the Essex soils make them suitable for spray irrigation application of wastewater with moderate limitations. They are not suitable for rapid infiltration application of wastewater. Site 19 is recommended for spray irrigation application of wastewater. However the usual detailed survey should be made of the site, including test boring, and exploration to determine groundwater level, depth to bedrock and soil permeabilities.

VII. REFERENCES CITED

1. Massachusetts Agricultural Experiment Station. 1971. Remote Sensing Twenty Years of Change in the Human Environment in Massachusetts, 1951-1971. University of Massachusetts, Amherst.

2. Emerson, B. K. 1917. The Geology of Massachusetts and Rhode Island.

3. U. S. Department of Agriculture. 1969. Soil Survey, Plymouth County, Massachusetts. U. S. Government Printing Office, Washington D. C.

4. Chute, M. E. 1966. Geology of the Norwood Quadrangle. USGS Bulletin 1163-B.

5. Oldale, R. N. 1969. Seismic Investigations on Cape Cod, Martha's Vineyard, and Nantucket, Massachusetts, and a Topographic Map of the Basement Surface from Cape Cod Bay to the Islands. USGS Professional Paper 650-B.

6. Maseusky, A. and J. Drake. 1963. Massachusetts Basic Data Report No. 7, Groundwater Series - Southeastern Massachusetts. USGS.

7. Woodworth, J. B. and E. Wigglesworth. 1934. The Geography and Geology of the Region Including Cape Cod, the Elizabeth Islands, No Man's Land, and Block Island. Volume 52, the Memoirs of the Museum of Comparative Zoology, Harvard College, Cambridge, Massachusetts.

8. Latimer, Maxon, Smith, Mallory, and Roberts. 1920. Soil Survey of Norfolk, Bristol, and Barnstable Counties. U. S. Department of Agriculture.

9. Williams, J. R. and R. E. Willey. 1967. Massachusetts Basic Data Report No. 10 Groundwater Series. USGS.