REPORT ON GROUNDWATER IN BACK BAY BOSTON BOSTON, MASSACHUSETTS

HALEY & ALDRICH, INC.
Consulting Geotechnical Engineers and Geologists
Cambridge, Massachusetts

REPORT ON
GROUNDWATER IN BACK BAY BOSTON
BOSTON, MASSACHUSETTS

for
Boston Redevelopment Authority
Boston, Massachusetts

File No. 5381

March 1985

HALEY & ALDRICH, INC.

235 Main Street
P.O. Box 60
Cambridge, MA 02142
Tel. 617/492-6460

Consulting
Geotechnical Engineers
and Geologists

7 March 1985
File No. 5381

Boston Redevelopment Authority
1 City Hall Square
Boston, Massachusetts 02108

Attention: Mr. Stephen F. Coyle, Director

Subject: Study of Groundwater in Back Bay Boston

Gentlemen:

We are pleased to submit herewith five copies of our report entitled, "Groundwater in Back Bay Boston" in compliance with the terms of our contract with the BRA dated 14 May 1984.

In this report, compilations of available data on groundwater levels are presented in several Tables and Figures. The history of development and construction in Back Bay pertinent to an understanding of fluctuations of groundwater levels and their impact on the area is summarized. Portions of the study area which have experienced lowered groundwater levels and their probable causes are discussed in Section VIII, and the areas are identified in Figures 17, 18 and 19. Recommendations for action to monitor and preserve or restore groundwater levels are also made. The Summary of Investigation provides a synopsis of the studies.

Thank you for inviting us to undertake this interesting study. If you have any questions or comments regarding the content of this report, please do not hesitate to contact us.

Sincerely yours,
HALEY & ALDRICH, INC.

James R. Lambrechts
Senior Engineer

Deborah H. Gevalt
Senior Geologist

Harl Aldrich
Chairman

JRL:DHG:HPA:mk:0322A

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(continued)

SUMMARY OF INVESTIGATION

This study of groundwater levels in Back Bay Boston was prepared by Haley & Aldrich, Inc. for the Boston Redevelopment Authority in accordance with a contract dated 14 May 1984. The area of Back Bay under study is bounded by Storrow Drive, Massachusetts Avenue, Washington Street and Charles Street.

The objectives of the study were to collect and document available groundwater level data, identify areas where water levels have been lowered, evaluate probable causes of lowered groundwater, and determine if and where foundation problems, particularly rotted wood piles, have resulted from the lowered groundwater levels. Only data that were readily available from local sources were compiled and interpreted for this study. Haley & Aldrich performed no field work.

A separate "water table" exists for each of the three aquifers (pervious soil strata) which exist in Back Bay. However, the groundwater table in the near-surface layer of granular soil placed in the 1800's to fill the tidal flats is of greatest practical importance.

Low groundwater levels occur when water is withdrawn from the ground by leakage into sewers and drains, leaks into the basements of buildings, and by temporary and permanent pumping required to lower groundwater levels for construction and to prevent leakage into basements. Groundwater is replenished by infiltration from precipitation, lateral flow from the Charles and Muddy Rivers, Boston Harbor and Beacon Hill, leaky water pipes, and manmade recharge systems.

Long-term lowering of groundwater levels in the fill exposes the tops of untreated wood piles which support most of the nineteenth century buildings in Back Bay to air and subsequent decay. Many buildings in the lower Beacon Hill area, particularly along Brimmer Street, are experiencing wood pile rot due to recently lowered groundwater levels. Ground and building subsidence may also occur from long-term groundwater lowering.

A large volume of data on groundwater levels was compiled during this study. The sources of information and the methods by which the data are presented are discussed in Section VII. These data form an extremely important base for long-term future use in evaluating changes in groundwater levels in Back Bay.

Groundwater level data are available from hundreds of observation wells which have been installed throughout the study area in the past 50 years. Observation well locations are shown on drawings for each of seven zones in the study area, Figures 3 through 9. The data are presented in Figures 10 through 16 as ranges of water level elevation in each well.

The development of Back Bay and major construction projects are chronicled in Sections V and VI; Table V presents a chronology of major twentieth century building construction in Back Bay. Along the Charles River, three linear structures, the Mill Dam and the West Side Interceptor along Beacon St., and the Boston Marginal Conduit along Storrow Drive appear to hinder groundwater flow from the river into Back Bay. Similarly, the subway tunnel along Boylston Street also impedes groundwater movement.

However, buildings and other projects constructed within the past 40 years have not by their presence alone, caused permanently lowered or significantly changed groundwater levels, even where areas a city block or larger have been developed. Further development in Back Bay would similarly not be expected to cause permanent groundwater lowering provided that foundation walls and floors are watertight and there is no permanent pumping.

Areas which have experienced groundwater levels below El. +5, the usual pile cutoff level, for each of the monitoring periods, 1936 to 1940, 1967 to 1968 and 1970 to present, are indicated on Figures 17, 18 and 19. Many of these areas are a result of temporary groundwater lowering by nearby construction dewatering, as discussed in Section VIII.

Within the past 15 years, groundwater levels have been observed to be below El. +5 in the following major areas: around the John Hancock Clarendon and Berkeley buildings; within the area of the Prudential Complex that is enclosed by a permanent steel sheet pile cofferdam; in the Copley Square area which has experienced chronic problems with leaks into the St. James Avenue sewer; an area along Tremont St. where the historic data indicated widespread groundwater lowering; and recently in the lower Beacon Hill area, probably due to leakage into or along the Boston Marginal Conduit and adjacent sewers.

A major finding of this study has been the that there is a dearth of information on groundwater levels throughout most residential areas of Back Bay. However, it is in these areas, basically from Storrow Drive to Boylston Street and in the South End between Columbus Avenue and Washington Streets, where it is most critical to monitor groundwater levels since most of the buildings are founded on wood piles.

In Section XII, Haley & Aldrich recommends that the City of Boston undertake a groundwater level monitoring program. Immediate action to restore lowered groundwater levels in the lower Beacon Hill area is needed to halt further deterioration of wood piles. Studies to determine the extent and need for additional observation wells are needed. Also, legislation is necessary to restrict permanent lowering of the water table.

I. INTRODUCTION

1-01. General

During the nineteenth century, a tidal estuary of the Charles River known to Boston residents as the Back Bay, was filled in to create land for an expanding population. Most of the homes, churches and other buildings constructed prior to 1900 were founded on wood piles driven through fill materials and organic soils into the underlying sand and gravel or clay stratum.

Untreated wood piles will not rot if they remain permanently immersed below the groundwater table. For the most part, piles supporting the Back Bay buildings were cut off below the water table at the time, assuring the safety of the building foundations.

During the twentieth century, however, with construction of sewers, drains, subways and building basements below the water table, the groundwater level has dropped in some areas of the Back Bay. As wood piles have been exposed to air, some have been attacked by fungi, borers and other organisms. Numerous historic structures have settled and cracked requiring owners to underpin their buildings to restore the foundations at great cost.

The problem attracted the attention of public officials and residents in 1929 when alarming cracks appeared in walls of the Boston Public Library building and the stone platform facing Copley Square began to settle. Wood piles had rotted due to low water levels which were traced to leakage into a nearby sewer. A major part of the building was underpinned to repair the pile foundation.

In recent years, with construction of numerous new buildings in the City of Boston, the groundwater table has once again become a concern. Problems with deteriorated wood piles in the lower Beacon Hill area between Charles Street and Storrow Drive, have attracted further interest in groundwater levels. Investigations of lowered groundwater levels in the area are underway.

Responding to public concern, the Boston Redevelopment Authority contracted with Haley & Aldrich, Inc. to undertake a study of groundwater levels throughout the Back Bay. This report presents the results of investigations undertaken in accordance with a BRA contract dated 14 May 1984.

1-02. Purpose

The purpose of this study was to document groundwater levels throughout the Back Bay, to identify those areas which have experienced lowered levels and to determine, where possible, causes of these low water levels and the foundation problems which may have resulted.

1-03. Study Area

The area studied is bounded approximately by Storrow Drive, Massachusetts Avenue, Washington Street and Charles Street, as shown on Figure 1, Project Locus. The Back Bay Fens area was not included. Since relatively little information is currently available between Columbus Avenue and Washington Street, this area was not studied to the same extent as other areas of the Back Bay. To aid in the presentation of groundwater level data, the study area was divided into seven zones which are shown in Figure 2.

1-04. Scope

The scope of work under this contract included the following:

A. Compilation of readily available information on groundwater levels, soil stratigraphy, types of building foundations (in particular structures founded on wood piles) and records of wood pile deterioration and subsidence caused by lowered groundwater levels. Information from Haley & Aldrich files has been used along with data from the City of Boston, U.S. Geological Survey, MDC, Massachusetts Turnpike Authority, engineers, architects, contractors, and local property owners.

B. Analysis of information compiled to identify areas of lowered groundwater level, and determine probable causes. The analysis includes pertinent historical and technical aspects of the construction of major buildings, sewers, subways and roadway underpasses and the effects of construction dewatering on groundwater levels in surrounding areas.

C. Analysis of the effects of lowered groundwater levels on wood pile foundations and ground subsidence, identifying those areas where deteriorated wood piles have been found.

The scope of services did not include test borings, field surveys, installation of groundwater observation wells, measurements at existing wells, or examination of structures and foundations and related field work. Compilation and interpretation of only readily available data are included.

1-05. Datum for Elevations

All elevations used herein are referenced to the Boston City Base (BCB) Datum which is 5.65 ft. below the National Geodetic Vertical Datum (NGVD), formerly called U.S. Coast and Geodetic Survey Mean Sea Level datum of 1929. Elevation 0.0 BCB datum is El. -5.65 NGVD MSL datum.

Mean tide levels in Boston Harbor are:

High Tide: El. 10.54 BCB
Low Tide: El. 1.06 BCB

for a mean tide variation of 9.5 ft.

1-06. Acknowledgements

The assistance of Commissioner James Reid and Messrs. Connors, Folkins and Gurney of the City of Boston Department of Inspectional Services is gratefully acknowledged for providing access to and summaries of selected building permit records.

Special thanks are due to Mr. Richard Merrill of Trinity Church and Mr. Hugh Lacey of Muesser, Rutledge, Johnston & DeSimone for providing particularly useful data and information on groundwater levels and to Mr. David Delaney, formerly of the U.S. Geological Survey, for providing historical background on the earlier USGS groundwater study.

II. THE GROUNDWATER TABLE

2-01. Definition

The groundwater table is considered to be that level below which the soil is saturated. If an open excavation were made below the groundwater table, the excavation will fill with water in time and the equilibrium water level will be the elevation of the water table. The water level in a shallow well that is not being pumped is the groundwater level.

In the Back Bay, the water table is generally within fill material which was placed over organic soils of the former tidal flats. However, in the westerly section of the Back Bay, where pervious sand and gravel outwash occurs below the relatively impervious organic soil, a second "water table", different from that in the fill, may be present. Back Bay water tables are discussed in Section 4-03.

2-02. Normal Water Table Elevations

In colonial times, the Back Bay was tidal with adjacent areas that were tidal marsh. The colonial shoreline skirted around the south and east sides of the study area as shown in Figure 2. A part of the area known as Gravelly Point protruded into the western side of the study area between Commonwealth Avenue and Huntington Avenue. The average water level was approximately mean tide level in Boston Harbor, El. 5.65 Boston City Base. From the time of construction of the Mill Dam across the Back Bay in 1821 for tidal power generation until the time the Back Bay was filled, water levels in the receiving basin east of Massachusetts Avenue were generally below mean tide.

After the Back Bay was filled, the groundwater table would be expected to rise above mean tide level. The land was bounded on the north by the tidal Charles River and on the south by South Boston Bay. Surface water from rainfall and snowmelt which percolated into the ground would raise the water table until a horizontal gradient in the fill was established to conduct groundwater by seepage toward the adjacent bodies of open water. In the latter part of the nineteenth century, the groundwater level in the Back Bay was, in fact, approximately El. 8.

With construction of the Charles River Dam in 1910, raising the mean water level in the basin to El. 8, the Back Bay groundwater table would have been expected to rise further, perhaps to El. 8.5 or 9.0 north of Commonwealth Avenue. Normal groundwater levels in the area between Storrow Drive and Charles Street would have been even higher, perhaps from El. 8.5 to 10.0, as a result of groundwater runoff from the west side of Beacon Hill.

These "anticipated" groundwater levels assume no loss of groundwater by pumping or by leakage into sewers and drains, and no gain from leaking water mains. A brief discussion of groundwater levels actually measured in the late 1800's is presented in Section VIII.

III. ADVERSE EFFECTS OF LOWERED GROUNDWATER

3-01. General

Temporary or permanent lowering of the groundwater table from manmade or natural causes, can adversely affect buildings, streets, underground utilities and other structures. Potential problems, applicable to the Back Bay, include the following:

1. Deterioration of wood piles which support buildings.

2. Ground subsidence caused by increased overburden loads.

3. Negative friction (drag) loads on piling.

Each of the above is discussed by Aldrich (1979) and in the following paragraphs.

3-02. Deterioration of Wood Piles

Clearly, the most serious potential problem with lowered water levels is the deterioration or decay of wood piles which support most of the nineteenth century buildings in the Back Bay. As long as the water table remains above the tops of the piles, the wood and surrounding soil remain saturated and the wood will not rot. Under these conditions, the untreated wood piles are considered permanent.

However, if the groundwater level drops below the tops of the piles, favorable conditions may be present for plant growth and insect attack. Oxygen, combined with moisture and moderate temperatures, are required for the growth of fungi. Grubs or wood borers, termites and other insects may also attack the wood.

The butts of piles which are surrounded by fill, in particular sand and gravel as well as ashes and cinders, are more prone to rot than are piles which are embedded in organic silt, peat and other relatively impervious soils. When the water table drops, the fine-grained soils remain saturated for a time, thus protecting the piles from immediate deterioration.

The time required for significant deterioration of the wood to occur, following a drop in groundwater level below the tops of wood piles, is highly variable. It depends on the species of wood, the type of soil in which piles are embedded, the amount of moisture, temperature and other factors. Exposure for a few months is not considered serious. However, serious deterioration will probably occur after a drawdown period of from 3 to 10 years.

3-03. Ground Subsidence

When the groundwater level is lowered, the effective stress on soils which occur below the water table is increased. Buoyance in the zone of water drawdown is lost. If the soils are compressible organic soils or soft clays, these materials will consolidate as the soil structure adjusts to the increase in overburden stress. Settlement will also occur if the upper soils dry out and shrink when the water table is lowered.

Contrary to popular belief, ground subsidence when the water table is lowered is not usually caused by removal of soil particles by pumping or loss of soil fines into sewers and drains.

Compression of soft layers from groundwater lowering will result in the settlement of streets, sidewalks and other ground or structures not supported on piles, including underground utilities. The rate and magnitude of settlement will depend on the thickness and compressibility of soils affected, on the rate of consolidation and on the magnitude of groundwater drawdown. Furthermore, they will depend on whether the area has experienced one or more similar occurrences in the past.

On the first occasion when a compressible soil layer experiences an increase in effective stress, it will compress considerably more than on subsequent occasions. The soil fabric is not a spring; the stratum will not rebound to its original thickness when the water table returns to its original level. If the soil had fully consolidated under the increased stress from a low water table, it will recover about ten percent of its compression by swelling. If the water table is again lowered, the compression will be slightly greater than the

amount of swelling. In effect, compression of the layer, and resulting settlement of the ground surface will be perhaps ten to fifteen percent of that which occurred originally.

Most areas of the Back Bay have experienced one or more significant temporary groundwater drawdowns, with the construction of sewers and drains, subways, foundations for buildings, and other excavations which have required pumping.

For this reason, ground subsidence due to temporary or nominal permanent lowering of the water table is not considered to be a serious concern.

3-04. Negative Friction (Drag) on Piles

All buildings in the Back Bay which are supported by piles driven through fill materials and organic soils, whether they are wood piles bearing in the sand and gravel outwash or marine clay, or are long piles driven to bear in the glacial till or bedrock, will experience negative friction or drag loads when ground surrounding the piles settles. The subsiding earth will grip the pile and transfer load to the pile in addition to the load imposed by the building. The building may settle as a result. The potential adverse effects are most pronounced for wood piles which derive their support by skin friction in the marine clay.

Again, in the Back Bay, this factor is not considered as important as the potential for deterioration (rotting) of wood piles.

IV. GEOLOGY AND SUBSURFACE CONDITIONS

4-01. General

A majority of the Back Bay, as defined for this investigation, was a tidal estuary of the Charles River, land submerged at high tide and bordered by salt marsh. Subsurface soil conditions, and indeed the topography of nineteenth century Boston, owe their origin to events which took place during the Pleistocene, that period in geologic time when there were successive advances and retreats of glacial ice from the region followed by extreme variations in climate and sea level.

4-02. Soil and Rock

The sequence of soil and rock, from the oldest to the youngest formation, is as follows:

Bedrock
Glacial Till
Marine Clay
Sand and Gravel Outwash
Organic Silt and Peat
Fill

Each of the above units will be described briefly. More detailed descriptions and variations from the typical soil profile are described by Aldrich (1979).

Bedrock. Bedrock is Cambridge slate, frequently called "argillite", which is a fine-grained rock derived from siltstone, claystone or shale. In the Back Bay, the surface of the rock is relatively deep, generally from 100 to 200 ft. below ground surface.

Glacial Till. Glaciers overriding the bedrock during the Pleistocene deposited a layer of glacial till or hardpan, an unsorted, generally non-stratified mixture of rock fragments and mineral of all sizes, varying from cobbles and boulders to silt and clay-size particles. In the Back Bay, the till is relatively thin, varying from a few feet to perhaps 30 ft. in thickness. Relatively pervious outwash sand and gravel occur within the till stratum in places.

Marine Clay. A stratum known locally as Boston blue clay was deposited over the till. Silt and clay-size particles, sorted from the till by glacial meltwater streams, settled out in a relatively quiet marine environment in bays around the Boston peninsula. The clay stratum, typically from 50 to 125 ft. in thickness but thicker toward Massachusetts Avenue, is stiff to soft in consistency. Frequently, there are layers and lenses of sand.

Sand and Gravel Outwash. Following a re-advance of glacial ice perhaps 12,000 to 14,000 years ago, well-stratified sand and gravel outwash was deposited over the surface of the clay. The stratum is particularly well developed west of Copley Square. At Gravelly Point, the colonial marshy peninsular centered on Massachusetts Avenue from Huntington Avenue to about Commonwealth Avenue, the outwash is about 15 to 25 ft. in thickness. East of Copley Square the outwash is commonly absent.

Organic Silt and Peat. Following the last ice age, fresh water peat, organic silt and salt marsh peat formed in the tidal embayment. These soft compressible organic soils blanket the Back Bay continuously and vary in thickness generally from 5 to 25 ft. although lesser thicknesses have been encountered.

Fill. Finally, during the nineteenth century, the Back Bay was filled. The majority of fill was placed from 1858 through 1880. The fill today is commonly 15 to 20 ft. in thickness and consists largely of sand and gravel although many other materials were also used and intermixed including cinders and ashes, building rubble and other such materials.

The fill, organic soils and sand and gravel outwash are of especial importance to groundwater levels in the Back Bay.

4-03. Groundwater Level

The groundwater table is defined in Section 2-01 and normal water levels through the Back Bay, those anticipated in the absence of loss of makeup due to leakage and pumping, are described in Section 2-02.

The groundwater table in the Back Bay which is most commonly cited is the water level within the fill stratum. West of Copley Square, the sand and gravel outwash occurs as another aquifer, confined by the organic silt and underlying clay, both relatively impervious. Therefore, an observation well placed in the fill and one installed in the outwash may not rise to the same elevation. Further, pumping from the outwash may not affect the water table in the fill, and vice versa.

In fact, a third "water table" exists in the glacial till and sand-gravel stratum which occurs below the Boston blue clay. At one time, the water pressure was artesian in this aquifer. This "water table" is not a major concern to buildings in the Back Bay.

The presence of two aquifers west of Copley Square complicates an interpretation of groundwater levels measured in observation wells since some are located in the fill, above the organic soil, and some are in the outwash. Generally, east of Dartmouth Street, the observed water levels in shallow wells correctly represent the water table of concern to this study.

Actual groundwater levels measured throughout the Back Bay since the 1930's, locations where lowered water levels occur and their probable causes are discussed in Section VIII.

V. TOPOGRAPHIC DEVELOPMENT

5-01. General

The sequence of filling the Back Bay as well as materials used bear some significance to groundwater levels. Whitehill (1959) in his "Boston, A Topographical History" presents a detailed account of the city's development. The sequence of filling is illustrated by Aldrich (1970, Figure 2).

5-02. Mill Dam

While the earliest encroachment on the Back Bay occurred when fill was placed in 1794 at the foot of Boston Common, the first significant filling took place when a mill dam was constructed from Church Street westerly to Sewall's Point in Brookline, near the present Kenmore Square. The Mill Dam ran along what is now Beacon Street.

Begun in 1818 and completed in 1821, the dam consisted of two parallel rubble masonry walls about 50 ft. apart, placed on a grillage of timbers bearing on the organic silt. The dry-laid walls, about 15 ft. in height, were ballasted with small stones from the bottom to the top of the masonry. Thereafter, the remaining interior space between the walls was backfilled with mud, sand and road base. No wood piles were used.

The Mill Dam undoubtedly settled significantly during and following its construction. Furthermore, while it was undoubtedly relatively impervious to the flow of water across its width, until crossed by numerous excavations for utilities in later years, it was likely to have been very pervious along its length.

5-03. Public Garden and Railroads

By 1836, fill had been placed between Charles and Arlington Streets (later the Public Garden), from the colonial shoreline north of Washington Street to a line beyond Tremont Street and for two railroad embankments which criss-crossed the Back Bay.

An area bounded by Charles, Beacon, Brimmer and Mt. Vernon Streets at the foot of Beacon Hill had also been filled. Charles Street to approximately River Street was filled by 1805 using material excavated from Mt. Vernon Hill.

Subsequently, prior to about 1850, additional fill was placed to develop land on the water side of Beacon Street to approximately Clarendon Street and in other areas bordering the Back Bay.

5-04. Major Back Bay Filling

Beginning in 1858, sand and gravel fill was brought by rail from Needham to fill the Back Bay. Generally, filling began from Arlington Street and progressed westward reaching Massachusetts Avenue about 1880. In the following ten years, the Back Bay Fens was filled. The rate of filling can be traced by a series of maps, prepared at 10-year intervals by Fuller & Whitney, that are presented in Aldrich (1970). Generally, fill was placed to about El. 12 for building lots, and to approximately El. 18 for streets.

With the filling of the Back Bay, a granite sea wall was constructed immediately north of Back Street and along a line behind buildings on the water side of Brimmer Street.

5-05. Recent Filling

Subsequent events in the topographic development of the Back Bay area include the first Esplanade filling in 1893, which provided a 100-ft. wide promenade north of the sea wall adjacent to Back Street. In 1910, the original Charles River Dam was constructed, controlling water in the basin to approximately El. 8. In 1929-31, the Storrow embankment and ponds were constructed, and in 1951, Storrow Drive was built.

VI. CHRONOLOGY OF CONSTRUCTION

6-01. General

Construction within the Back Bay followed close behind the filling. Buildings were constructed, sewers and drains were built in city streets, and later, subways and major buildings with deep basements were constructed.

This section of the report summarizes the chronology of major construction having an effect, temporary or permanent, on the groundwater table. Foundation practice before the turn of the century is described by Aldrich (1970).

6-02. Nineteenth Century Buildings

Buildings constructed in the Back Bay were commonly supported by wood piles driven through fill and organic soil to a good bearing stratum. Piles were usually spruce and oak trees, trimmed of branches, turned upside down and driven into the ground. Safe loads on spruce piles were about 10 tons and piles were commonly spaced 2 to 3 ft. on centers. Piles were capped with dry-laid blocks of rock, usually granite, which supported the brick, stone or wood structure.

Many heavy buildings settled in spite of, or perhaps because of, a large number of closely-spaced piles. Trinity Church, for example, constructed in 1876, settled nearly one foot in the following 30 to 40 years. The towers of Old South Church on Boylston Street had to be dismantled and reassembled as a result of differential settlement. These settlements were not due to rotted wood piles or lowered groundwater levels. They were caused by consolidation of the Boston blue clay.

Before the turn of the century, it was common practice in the Back Bay to cut off wood piles at El. 5.0, approximately three feet below the groundwater table. As late as 1915, however, some engineers believed that piles could be cut at El. 7 or 8, with entire safety, especially with construction of the Charles River Dam in 1910. In fact, wood piles for foundations of many buildings in the Back Bay have been cut off higher than El. 5. Other buildings, because of physical requirements, have pile cutoffs below El. 5.

6-03. Sewers and Drains

A. General

There is little doubt that sewers and drains in the Back Bay have contributed to at least localized depressions in the groundwater table. Furthermore, dewatering for sewer construction undoubtedly caused extensive yet temporary lowering of the groundwater table in some areas. For these reasons, a discussion of sewers and sewer construction assumes some importance.

Plans of the principal existing sewers and conduits in the Back Bay are shown on figures in a report by Camp, Dresser & McKee. The report describes the entire system.

B. Early Sewerage and Drainage

The earliest sewers and drains in the city of Boston discharged by gravity from the hills to adjacent tidal areas. Flow velocities were high and there were few problems. With development of the low filled-land areas like the Back Bay, extension of sewers created serious drainage problems because of flat gradients and ground settlement.

Most house drains and sewers were below basement level, and when minimum slopes to street sewers and interceptors were provided, the outfalls were rarely above low tide. As a result, contents of the sewers were dammed up by the tide during the greater part of every day. (Tide gates were commonly adopted to prevent salt water from flooding the lower reaches of the sewers.) Settlement of the filled land caused numerous breaks in sewer connections and reversals of slope. Soon there were deposits of sludge and debris within the sewers and upon the tidal lands, with attendant health and odor problems.

By 1868, the State Board of Health recognized a serious public health problem and in 1875 the City Council authorized the Mayor to appoint a commission to study the sewerage system and to plan for future needs of the city. The plan adopted became the Boston Main Drainage System.

C. Boston Main Drainage System

A principal feature of the Boston Main Drainage System, constructed from 1877 to 1884, was a system of intercepting sewers along the margins of the city to receive the flow from the already existing sewers. These sewers drained to a pumping station located at Old Harbor Point on Dorchester Bay (Calf Pasture on Columbia Point) where sewage was pumped to Moon Island and discharged into the harbor on outgoing tides.

Existing combined sewers (storm water and domestic sewage) in the northerly section of the Back Bay which formerly discharged into the Charles River at Beaver, Berkeley, Dartmouth, Fairfield and Hereford Streets, were connected to the West Side Interceptor constructed along Beacon Street. Others located generally south of the railroads drained into the East Side Interceptor which follows Albany Street.

Design and construction of the West Side Interceptor is of particular interest. It travels down Charles Street to Beacon, where it turns westerly down Beacon to Hereford Street, turns southerly down Hereford and Dalton to Falmouth Street, then westerly to Gainsborough Street. In the Beacon Street area, the invert grade varies from approximately El. 0 at Beacon and Arlington Streets, to El. -2.5 at Beacon and Hereford Streets and to El. -5.5 at Huntington Avenue and Gainsborough Street. Excavation and dewatering for construction would have been required to at least 2 ft. below these grades, within fill and organic soil on Beacon Street; and to approximately El. -6 in the sand and gravel outwash stratum in Dalton and Falmouth Streets. So, 100 years ago, if not before, the outwash stratum experienced the first significant temporary drawdown.

The intercepting sewers and the main sewer, from the upper reaches to the pumping station at Calf Pasture, vary in size from 3 ft. to 10.5 ft. in diameter. The larger ones are circular and the smaller ones are generally egg-shaped. The West Side Interceptor is egg-shaped, 57 in. wide and 66 in. high. Sewers were constructed with a double or triple row of mortared

brick, and where piles were required, a timber platform was constructed and the sewer was cradled on mortared granite masonry.

It is of considerable importance to note that the intercepting sewers were constructed with an underdrain pipe varying from 8 in. to 12 in. in diameter and placed below the sewer to control groundwater during construction. The significance of the underdrain is discussed in a later section.

For a time, observation wells in the Back Bay indicated water levels similar to those measured before sewer construction but within 10 years, in 1894, areas were found where the groundwater was as low as El. 5 or lower, indicating that there was leakage into low-level sewers or that pumping was being done.

Along Beacon Street, the dry weather flow had been originally estimated to vary from El. 1.7 to -0.5 and in the section south to Gainsborough Street, this minimum flow was estimated at El. -0.5 to -2.5. It is understood, however, that these dry weather flow levels are no longer achieved and that the interceptor is generally full and surcharged.

The Boston Main Drainage System was designed with sufficient capacity to carry the estimated dry weather flow of sanitary sewage and a small volume of storm water. Excess storm flow and diluted sewage from the West Side Interceptor were discharged into the Charles River at numerous overflow outlets.

D. Boston Marginal Conduit

With construction of expensive homes along the Charles River, there were increasing demands to eliminate the odors and nuisance of the tidal basin. Under the Acts of 1903, a half-tide dam was completed in 1910 at the location of the former Craigie's bridge, where the Museum of Science is now located.

The dam was constructed with gates and a lock to maintain a water level in the Charles River basin at approximately El. 8.

As part of the project, a marginal conduit was constructed along the Boston side of the basin to collect flow from Stony Brook and mixed sewage and storm water overflows from the West Side Interceptor which formerly discharged into the river. Water was to be maintained at a low level in the conduit by means of tide gates constructed at the outfall below the Charles River dam.

The marginal conduit was constructed in a 100-ft. wide earth fill embankment placed immediately north of Back Street, beyond the old dry rubble retaining wall. Presently, the conduit is below Storrow Drive. Over most of its length, it is a reinforced concrete horseshoe-shaped section 76-in. wide by 92-in. high, supported on wood piles. The structure was constructed level with an invert grade estimated at El. -1.5. It was apparently built within a double row of tongue and groove wood sheeting which was driven into the organic silt and left in place. Again, a large diameter underdrain pipe was placed just below the marginal conduit to facilitate dewatering during construction.

When the Storrow Drive underpass was built in 1951, a portion of the conduit was relocated inland, away from the river. The relocated section, from Dartmouth Street to Mt. Vernon Street, is an 8-ft. diameter reinforced concrete pipe with an invert grade at El. -1.5. An underdrain pipe was placed below this new pipe. It was connected to the old underdrain when the relocated section was tied in.

The Mill Dam, West Side Interceptor and the Boston Marginal Conduit act as dams impeding the flow of groundwater from the Charles River basin into the Back Bay. Furthermore, while relatively impervious perpendicular to their axes, in a longitudinal direction, they can conduct groundwater with relative ease.

E. Present Low Level Sewers

Between 1910 and 1912, the present system of low level sewers was constructed throughout the Back Bay. Underdrain pipes again were commonly used.

By this time, nearly 75 years ago, there was little doubt that groundwater leaked into sewers, that the problem was very general and that groundwater levels in the Back Bay were controlled primarily by this leakage.

6-04. Subways

A. General

Two major subways have been constructed within the Back Bay by the Boston Transit Commission. Between 1912 and 1914, the Boylston Street subway tunnel was built and much later, from 1937 to 1940, the Huntington Avenue subway was added.

Construction for the Huntington Avenue subway required extensive and prolonged dewatering to levels below any known construction before or since. In addition, drains installed in the tunnels undoubtedly collect groundwater which leaks into the structure. These facts, plus records of soil conditions encountered during construction, contribute to our knowledge of Back Bay groundwater levels.

B. Boylston Street Subway

The Boylston Street subway crosses the Back Bay from Massachusetts Avenue to Charles Street. Within this section, the bottom of the subway varies from approximately El. +3 at Massachusetts Avenue, to El. -19 between Arlington and Church Streets (the low point) to El. -10 at Charles Street.

The structure is supported on a wide variety of soils including the fill, organic silt, and natural sand and gravel outwash. Wood piles were driven for support of the structure only between about Hadassah Way and Charles Street for a distance of 460 ft. where deep peat was encountered.

During construction, a temporary drawdown of water levels both in the fill and in the sand-gravel stratum would have occurred. Opposite the Prudential site, drawdown in the sand stratum to El. -10 is estimated.

C. Huntington Avenue Subway

Constructed between October 1937 and 1940, the Huntington Avenue subway crosses under Massachusetts Avenue as it enters the Back Bay and joins the Boylston Street subway at Exeter Street. Within this section, the bottom grade of the subway structure varies from El. -10 at Massachusetts Avenue to El. -19 where the structure passes below the railroad tracks (and under the Massachusetts Turnpike Extension).

The subway is founded on the outwash stratum which extends from 5 to 12 ft. below the bottom of the structure from Massachusetts Avenue to the Turnpike. North of the Turnpike to Boylston Street, the structure bears on clay and organic soils, without piling.

During construction, the pervious outwash stratum was dewatered for the entire length of the subway along Huntington Avenue to grades as low or even below El. -20. A very significant drawdown of water level occurred over a wide area, for a period of from 2 to 3 years, as discussed in Section VIII.

6-05. <u>Storrow Drive Underpass</u>

The construction of Storrow Drive in the early 1950's included an underpass and traffic interchange in the Berkeley Street area. The underpass is approximately 1300 ft. long between portals, with 300-ft. long approach ramps at either end. Road surface descends as low as about El. -4, being about 15 to 17 ft. below ground surface.

The underpass was designed to prevent groundwater lowering by extensive use of copper water stops in joints and combinations of cork, sponge, rubber, asphalt and caulk for joint fillers. The structure was designed as a boat with sufficient weight to resist uplift due to hydrostatic pressures; invert slabs were up to 2 ft. 8 in. thick. Precipitation and other surface water is collected in catch basins and cross drains which feed into pipes below the invert slab. These pipes carry water to wet wells near either portal. From these wet wells, water is pumped into the Charles River.

Soon after completion, leaks are reported to have developed in the reinforced concrete walls. To collect the infiltrating groundwater and improve appearances, gutters and false walls were installed, but the leaks were evidently never repaired. A significant volume of groundwater is apparently infiltrating into the underpass as recent dry weather pumping volumes have been reported to be about 20,000 gallons per day from each wet well.

During underpass construction, a portion of the original Boston Marginal Conduit between Dartmouth Street and Mt. Vernon Street had to be removed. Within this area, a new conduit was constructed inland of the underpass, as discussed above. It is not known, however, if either the underdrain and granular drainage materials that were below, or the granular backfill around the original conduit were sealed off to prevent groundwater flow to the underpass.

6-06. Massachusetts Turnpike Extension

The six-lane wide limited access highway crosses through the middle of the Back Bay study area. The turnpike extension was constructed between 1963 and 1966 and is just north of the Conrail (formerly Boston and Albany) railroad alignment. The highway is depressed 15 to 20 ft. below adjacent city streets and developed areas. The road surface descends from about El. 11 at Massachusetts Avenue to El. 6 at Tremont Street.

The turnpike was designed to prevent groundwater lowering below about El. 6.5 to 8.5, depending on location. West of Huntington Avenue, the thickness of the concrete pavement was minimized with an underdrain system to control groundwater uplift pressures beneath the slab. Through the Prudential Center site, a wall of steel sheetpiling, on either side of the turnpike, restricts water flow to the turnpike underdrain. The sheet piles were installed for Prudential Center construction. They were driven 5 ft. into the clay. Because the road surface east of Huntington Avenue is lower, underdrains were not used. This avoided groundwater lowering. Instead, the turnpike structure was designed as a boat section, with a thick slab to prevent flotation. The slab is more than 2-1/2 ft. thick in some areas. A drain was provided along the north wall to prevent groundwater levels from exceeding El. 8.5. Existing drains in the railroad alignment to the south keep water levels there below El. 7.

6-07. Southwest Corridor Project

The new corridor structure will have two tracks for the relocated Orange Line subway and three tracks for commuter rail and AMTRAK service. It occupies the former Penn Central alignment from Forest Hills to the South Cove area and follows parts of the two original railroad embankments that crossed the Back Bay. From Massachusetts Avenue to Dartmouth Street, the new concrete structure is below ground in a 3000 ft. long cut-and-cover tunnel. East of Dartmouth Street, the new structure extends about 10 ft. below former grade into the organic soils.

Reinforced concrete slurry walls were used for lateral support of the sides of about 2100 ft. of the tunnel excavation. The concrete walls are 3 ft. thick, penetrate 8 to 15 ft. into the clay stratum and are also being used as the tunnel's permanent outside walls. Steel sheetpiling was not used for lateral support because the concrete walls are: 1) more rigid and better able to restrain the adjacent soft soils, thereby limiting adjacent ground and rowhouse movement and 2) essentially watertight, thus preventing noticeable groundwater drawdown.

In other deep excavation areas where adjacent structures were further away from the excavation or absent, steel sheetpiling was used for temporary lateral support of excavation sides. East of Dartmouth Street, excavations were shallower and soldier piles with wood lagging were used. Water seepage into these excavations has lowered groundwater levels in adjacent areas as much as 12 ft.

Where concrete slurry walls were used, the tunnel is supported on a thick concrete invert slab bearing on compacted sand and gravel fill which was used to replace unsuitable organic soils. East of this portion of the tunnel, the structure is supported on precast-prestressed concrete piles driven through the clay to end bearing on glacial till or bedrock.

Throughout the Back Bay area, the new corridor structure forms a barrier to groundwater flow across the alignment through the fill. In some areas, a preconstruction groundwater gradient of 2 ft. in 100 ft. was inferred from observation well groundwater levels.

To allow groundwater movement across the corridor, a groundwater equalization underdrain system was installed. This system consisted of perforated longitudinal header pipes placed 2 to 4 ft. below preconstruction groundwater level on either side of the structure. The header pipes are surrounded with crushed stone which in turn was wrapped in filter fabric. A series of 8-in. diameter galvanized steel pipes was used to connect the header pipes on opposite sides of the excavation. Where slurry walls form the tunnel walls, the pipes were cast into the walls and later connected beneath invert slab level.

6-08. Major Buildings

There have been numerous major buildings constructed within the Back Bay study area in this century. Most of these buildings are listed in the Table V Chronology which summarizes dates of construction, location, foundation type and bearing stratum, elevation of the deepest basement, and other pertinent information about the construction.

VII. GROUNDWATER LEVEL DATA COLLECTED

7-01. General

Readily available information on past and current groundwater levels throughout the study area was collected, reviewed and prepared for graphical presentation, as discussed below.

Groundwater level data were obtained from various projects throughout the study area and included hundreds of observation wells that had been installed. Available pertinent details about each observation well are also presented.

7-02. Sources of Groundwater Observation Well Data

A. WPA Water Level Survey

The building department of the City of Boston conducted a groundwater level survey throughout the Boston Peninsula between 1936 and 1940. The project was funded by the Works Progress Administration under projects No. 5325 and No. 188868. Impetus for this study was a growing concern about groundwater levels in the City in the 1920's and 1930's. Concern was heighted by the discovery of rot in many of the wood piles that supported the Boston Public Library. Pile deterioration was caused by groundwater lowering which was eventually traced to leakage into a nearby sewer. This incident is discussed in more detail in Section IX.

Many observation wells were installed for this project. Wells previously installed by the Boston Sewer Department were also monitored. Throughout the Boston Peninsula, a total of approximately 700 observation wells were used in the WPA survey. About 300 of these wells were within the present study area. The number of wells within each study area zone is indicated in Table I.

Tables and plans which describe the location of each well and the highest and lowest water levels recorded during the four-year monitoring period were obtained

from the Boston Building Department. Data on the numerous actual water level readings made in each well and a location plan of wells installed in Ward 3 are no longer available.

B. USGS Water Level Survey

In 1967 and 1968, the United States Geological Survey made another survey of groundwater levels throughout the Boston Peninsula. This study was made in response to a request by the Massachusetts Department of Public Works which was concerned about the potential effects of construction of the then proposed Inner Belt expressway on groundwater levels.

The USGS used the observation wells extant from the WPA survey completed in 1940. Less than half of the original 700 observation wells were found to be usable. The number of WPA wells used by the USGS in each zone is indicated in Table I.

Water levels were only measured at two times, in September 1967 and March 1968. These levels were considered to represent low and high groundwater conditions, respectively. The results of the USGS study were published in 1975 as Hydrogeologic Investigation Atlas HA-513, Cotton and Delaney (1975). H&A obtained data collected for this study from the USGS Boston file. Mr. David F. Delaney, who was one of the authors of the USGS study, was interviewed to obtain additional information.

C. Haley & Aldrich Project Files

Groundwater level data were available for approximately 30 of the more than 150 projects with which Haley & Aldrich has been involved in the study area. These projects have generally been completed since 1970 although a few date back to 1960. Observation wells were installed for these projects and monitored over varying lengths of time, ranging from several months to many years. In several instances, the project files also contained data for observation wells installed and monitored by others at project sites prior to Haley & Aldrich involvement. Table II summarizes the projects for which groundwater observation

well data were available in the Haley & Aldrich files. The number of wells and years monitored are also tabulated. The results of Haley & Aldrich studies of the probable effects of the proposed 500 Boylston Street project on the nearby groundwater regime were also reviewed.

D. Other Sources

Groundwater observation well data were also obtained from the Massachusetts Turnpike Authority, Christian Science Center, and Trinity Church. Each organization maintains and periodically reads its own group of observation wells.

Other engineering firms also provided data for several projects in the study area. The numbers of observation wells for which data were provided by the other sources are also presented in Table II.

Additionally, requests for groundwater level data were made to (1) selected architects, engineers and contractors who have completed projects within the study area, (2) Back Bay and South End community groups and residents, and (3) subscribers to the Boston Society of Architects newsletter. Response to these requests was very limited.

7-03. Observation Wells

A. Components of an Observation Well

A typical observation well consists of a length of pipe installed in a hole drilled into the ground to some depth below the groundwater table. This pipe is generally called a riser. It is now usually plastic, however, metal pipes commonly were used in the past. The bottom portion of the riser is usually perforated, slotted or equipped with a porous element to permit entry of groundwater. This portion of the riser is generally called the tip. Water will rise in the riser to a level that balances the free water pressure in the soil at the tip.

To prevent the entry of soil particles, which can accumulate and eventually plug the well, the tip is usually surrounded with a graded sand. Filter materials such as plastic filter fabric or special porous stone or tubing can also be used.

In many instances, it is necessary to measure the groundwater level in a specific soil layer. This is accomplished by sealing the hole above the layer of interest with relatively impermeable material, such as clay or grout. Without seals, the water level in the observation well will generally reflect the dominant groundwater level of the various soil layers through which the hole was drilled.

B. Observation Well Details

Available information on the details of each observation well used in this study are presented in Table III for wells installed for the WPA study and in Table IV for wells from H&A and other sources. Details tabulated include depth from ground surface and elevation of well tips (bottom), the soil stratum in which the tip was placed, and whether or not the well was sealed in a particular soil stratum.

In many instances, these details are not known, particularly for the WPA observation wells. Most were installed to depths of 15 to 20 ft. below ground surface and therefore have tip elevations around El. 0. As a result, the water levels monitored generally reflect groundwater levels in the fill stratum. Some of the wells penetrated into the deeper sand stratum. Records do not indicate if the WPA wells were sealed into particular strata, however, it is strongly suspected that they were not. The holes into which they were installed were probably backfilled with granular fill material removed when the holes were drilled. The periods over which the WPA wells were monitored and the condition of each at these time is also indicated in Table III.

C. Locations

The location of each observation well used in this study is indicated by zone in Figures 3 through 9.

The locations of the wells monitored by the WPA were generally taken from location plans provided by the Boston Building Department but were cross-checked with the plans prepared by the USGS and with the written descriptions on the original data summary sheets. Where discrepancies existed, the written location description was generally used. Locations of the observation wells from H&A project files were established with greater confidences.

7-04. Groundwater Level Data

Data on groundwater levels collected for this study are presented graphically, by zone, in Figures 10 through 16. The data collected were reduced to ranges of groundwater levels measured in each observation well over each of several five-year intervals, as indicated by the bars in the figures. Only the high and low groundwater levels were available from the WPA data (1936 through 1940). The USGS measured groundwater levels in September 1967 and March 1968 and used these data as the lows and highs, respectively.

Data from other sources were generally available as series plots of groundwater levels versus time. However, because it was not possible within the scope of this study to present and evaluate this voluminous amount of data, it was also reduced to ranges of high and low levels within each applicable (usually five-year) period.

Ranges, such as presented in Figures 10 through 16, generally provide a reasonable representation of groundwater levels at observation wells but can be misleading with regard to the extremes. Proper interpretation and use of the range data requires an understanding of observation well details, particularly the stratum in which the well tip was placed and whether or not it was sealed in specific stratum. The groundwater levels in the sand outwash often vary from those in the fill and are generally more significantly affected by dewatering for construction or other pumping.

The high end of a range is probably less reliable as an indicator of groundwater levels than is the low because some wells are prone to flooding by heavy rainfall near the time of the reading or other flooding if the well is in a low

spot. Wells can remain flooded for quite some time if they are partially plugged. During normal monitoring, it may not be apparent that a well is partially flooded or plugged.

Unusually low levels do not occur as frequently. They can often be related to temporary drawdown caused by nearby construction, particularly for large construction projects. When using the data, frequent references should be made to Tables V and VI which contain information about construction in Back Bay that may have had an effect on observation well water levels.

Also, groundwater levels from observation wells that were monitored for only a few months are probably biased, either high or low, depending on the season. Notes relative to short monitoring periods are provided in Table IV. When using the data presented, it is important to understand the factors that may have influenced water levels in particular wells.

The groundwater level data presented in Figures 10 through 16 were checked to assure that it is properly presented but it is obviously not possible to verify the accuracy of the readings obtained from the various sources.

VIII. EVALUATION OF GROUNDWATER LEVELS

8-01. General

Groundwater levels in the Back Bay are influenced by the natural process of precipitation and infiltration and the levels of the Charles River, the Muddy River and Boston Harbor. It is man's activities, however, that govern the groundwater level. His structures often impede, divert or withdraw groundwater although they are sometimes sources. These effects and the seasonal climatic variations combine to produce a groundwater regime that varies from place to place and with the time of year.

This section discusses the sources of groundwater in the Back Bay and groundwater level changes that have occurred in the last 50 to 100 years. The available data on groundwater levels that were collected for this study formed the basis for assessing areas having low groundwater levels. Summaries of historical concerns about lowered groundwater levels and the temporary effects of construction on groundwater levels are also presented.

8-02. Sources of Groundwater

The major sources of groundwater to the fill stratum in the Back Bay are infiltration from precipitation, the Charles River, adjacent areas such as Beacon Hill and the Fens; leaky water pipes; and recharge systems. The effect of each on groundwater levels is different and can vary with time. The sand and gravel outwash receives water by infiltration from the fill through the overlying organic soils, by direct seepage from the fill through holes and trenches excavated through the organic soils, and from nearby bodies of water that may communicate directly with the outwash, such as the Muddy River in the Fens and the Charles River.

Only a fraction of the annual precipitation actually enters the ground because more than 80 percent of the Back Bay is covered by impervious surfaces such as streets, sidewalks and buildings. Even in open, unpaved areas, only part of the precipitation enters the ground. Although most of the precipitation in Back Bay becomes runoff and is carried away by

storm drain and sewers, the seasonal variation in quantity causes an annual fluctuation in groundwater levels up to about 2 ft.

The Charles River is also a source of groundwater in the Back Bay. However, flow from the river is impeded by remnants of the Mill Dam and the later West Side Interceptor along Beacon Street and the Boston Marginal Conduit under Storrow Drive. Because the river level is maintained at from El. +7.5 to +8.0, its effect on groundwater levels is essentially constant. The river's relative influence decreases with distance. Plans of contours of equal groundwater levels prepared by the USGS (1975) indicate appreciable declines of 1 to 3 ft. in Back Bay areas near the river. These lowered groundwater levels are probably due to the interference of the Mill Dam, Interceptor and Conduit to the horizontal flow of groundwater, or possibly leakage into the two drains.

Leaky pipes, particularly water mains, can be significant localized sources of groundwater. The USGS groundwater level contours indicate several mounds where groundwater levels are as much as 5 to 10 ft. above surrounding areas. The overall contribution of water leaking from water mains may be about the same as that due to precipitation. The USGS (1975) reports that Boston Water Department data from the early 1940's indicated that water main leakage would provide an equivalent recharge of 0.73 million gallons per day (gpd) per square mile. This is approximately equal to the recharge due to 50 inches of precipitation per year assuming a 30 percent infiltration rate. Storm and sanitary sewers that are above the groundwater table can also leak and contribute to groundwater, but because they are usually not under pressure, they probably provide only minor amounts of water.

In several areas, special permanent recharge systems have been installed to help maintain the groundwater at certain levels. Notable examples are the recharge systems at Copley Square and Trinity Church. In these systems, surface drainage and precipitation runoff is collected and directed to drywells or reverse drains from which it seeps back into the ground through special piping systems. Details of each of these systems are discussed in Section X. Temporary recharge systems have been employed in areas adjacent to several construction projects to prevent or correct lowered groundwater levels caused by deep excavations and construction dewatering. These systems are also discussed in Section X.

8-03. Historical Reports and Studies of Groundwater Levels

A. General

Concern for groundwater levels in the Back Bay has prompted sporadic action in the past century. The available records and literature indicate that area-wide studies were made before and after construction of the main drainage works in the 1880's, during the 1890's studies for the Charles River Dam, in the late 1903's by the WPA, and by the USGS in 1967 and 1968. Numerous localized studies have been made around construction sites. In the 1930's, Trinity Church undertook a comprehensive study of the Copley Square area. Several of these studies are discussed below.

B. 1880's Main Drainage Works

Stearns (1894) reports that groundwater levels in wells installed in 1878 before construction of the main drainage works were practically the same in 1885, one year after construction. At that time, water levels were "nearly level at Grade 7.7 over the whole district". The data indicate levels between El. 6.7 and 8.5. Apparently engineers at that time realized the importance of maintaining groundwater levels and were concerned about the effects of the new main drainage works on these levels.

C. 1894 Charles River Dam Study

Water levels were measured in wells installed for a study for a proposed Charles River Dam and for the earlier main drainage works studies. Generally, groundwater levels continued to be about the same levels as in 1878 and 1885. Stearns blamed leaky sewers for some low levels, below El. 5, but considered these to be isolated. He recommended that El. 8 be established as the water level for the new Charles River Basin. This level would maintain the present water levels, except near the river where the tides had an effect, and in areas where newly constructed drains caused groundwater withdrawal.

Stearns also indicated that by existing law, wood pile cutoff was set at El. 5 and that basement grade for structures was established no lower than El. 12.

D. 1914

Snow (1936) reported that Gow and Stearns, in a 1914 BSCE Journal article, cited leaky sewers as a cause for local groundwater depressions.

E. 1932 Trinity Church Study

The discovery of rotted wood piles under a substantial portion of the Boston Public Library in 1929, sparked renewed interest in groundwater levels, particular at nearby Trinity Church, because of its wood pile foundation. Many observation wells were installed in the Copley Square area. When subsequent installation of a partial dam in the sewer caused observation well water levels to rise, it was concluded that the sewer was the cause of the depressed groundwater levels. The exact source of the leak was never identified, nor was it established if leakage was at service connections or through the pipe's underdrain to leaky joints or other breaks. The church has continued to monitor groundwater levels for the past 50 years.

F. Late 1930's WPA Study

The increased public and municipal concern that was generated by the studies in the Trinity Church/Copley Square study led to a city-wide program that was funded by the Works Progress Administration (WPA). Several hundred observation wells were installed throughout the Boston Peninsula. These wells were monitored from 1936 to 1940 when the program was discontinued. Unfortunately, the original records were destroyed in a fire at City Hall. All that survived were location plans and tabulations of well locations and the highest and lowest of the numerous readings made in each well during the four-year period.

G. 1967-1968 USGS Study

Not until the late 1960's was another comprehensive program undertaken to monitor observation well ground-

water levels throughout Boston. Concern about the potential effects of proposed freeway construction through Boston provided impetus for the study. As described in Section 7-02, water levels were measured in the WPA wells that were still usable. The USGS subsequently published contour plans of high and low groundwater levels for both the WPA 1930's data and the data collected for 1967-68 study. The USGS took readings on only two occasions, in September 1967 and March 1968.

H. Individual Project Studies

Groundwater levels have been monitored and studied for most of the larger building projects constructed in Bay Bay in the last 25 years. However, groundwater level studies have generally been restricted to the areas immediately surrounding each site.

In most cases, monitoring continued only until below-ground construction was completed. Because water levels are important to the preservation of their wood pile foundations, the Christian Science Church and Prudential Center have continued to monitor and evaluate on-site groundwater levels. The Boston Public Library, Trinity Church and Massachusetts Turnpike Extension also have continuing, independent groundwater monitoring programs. Individual wells at other locations such as the Church of the Advent on Brimmer Street have also been monitored.

A recent, extensive study of groundwater levels around the proposed New England Mutual Life development at 500 Boylston Street did examine a nine city block area around the proposed site, Haley & Aldrich (1985). In this study contours of the existing groundwater table were developed, probable off-site effects of temporary construction-related pumping were examined, and the effects of the building's proposed deep basements on the long-term, steady-state groundwater levels in the site area were extensively modeled and analyzed. The study concludes that the proposed 500 Boylston Street development will have little impact on long-term off-site groundwater levels.

8-04. Low Groundwater Levels and Changes

A. Method of Evaluation

The low ends of the groundwater level range data were used in part to evaluate changes in groundwater levels. The low readings are less likely to have been affected by heavy rains or observation well plugging than are the high readings. The low of the range though is the lowest reading made over each monitoring period. It may be significantly below the predominant range of readings for a well. Extremely low levels can, in many cases, be related to temporary groundwater lowering due to nearby construction.

B. Low Groundwater Levels, 1936-1940

When evaluating the WPA data, it is important to remember that the ranges indicate the highest and lowest water levels observed in each well over a 4-year monitoring period. These levels are extremes from perhaps 20, 30 or more individual water level readings and, as such, they are probably not representative of the "usual" low groundwater. However, the highest and lowest levels are all that remain from the 1936 to 1940 period.

Areas in which groundwater levels below El. +5 were observed during the WPA monitoring program in the late 1930's are shown on Figure 17. These areas cover much of the Back Bay study area. Low groundwater levels were not due to particularly dry weather. Precipitation in Boston in the 1930's was about average, with yearly deviations of up to about 6 inches.

The areas shown on Figure 17 were determined from the USGS contour plan of low groundwater levels between 1936 and 1940 and by a separate, conservative evaluation of the same WPA data available to this study that is presented in Figures 10 through 16. As indicated on Figure 17, the re-evaluation of the WPA data showed somewhat smaller areas in which low water levels were below El. +5 than did the USGS contour plan although the shapes of the areas were similar. This would be expected since the contours often include adjacent

areas where there were no observation wells. Also, some of the data used by the USGS is no longer available. No attempt was made to verify the USGS groundwater level contours. In re-evaluating the WPA data, only those areas around the observation wells that had low groundwater levels below El. +5 were included, not the extended areas that may be included in the contours.

The low groundwater levels were apparently due to several causes, including several construction projects, particularly the Huntington Avenue subway and Massachusetts Avenue underpass, leaky sewers and pumping from sumps. Dewatering of the pervious outwash stratum for subway construction was probably responsible for the lowered groundwater levels north of the Southwest Corridor alignment from Massachusetts Avenue to Clarendon Street. Groundwater drawdown immediately adjacent to the Huntington Avenue excavation is not known because data are not available for wells there during the construction period, Cotton and Delaney (1975). Throughout much of this area, the outwash stratum is particularly well developed and is separated from the fill by a relatively thin layer (as little as 3 ft.) of organic soils and/or peat. However, in many locations, where trenches and holes have been excavated, the outwash and fill strata are connected and lowered water levels in the outwash can directly effect the fill. Some of the WPA observation wells may have been installed into the outwash stratum. Water levels observed in some wells may, therefore, be lower than the groundwater levels in the fill.

In the Copley Square area, south of Boylston Street between Dartmouth and Berkeley Streets, the low groundwater levels may have been caused by leakage into sewers and drains and pumping from sumps in building basements. Because the outwash stratum generally does not extend into this area and the Boylston Street subway structure essentially forms a barrier to groundwater seepage across the street, low groundwater levels in this area were probably not related to dewatering and drawdown due to Huntington Avenue subway construction. The St. James Avenue sewer has a

history of causing local groundwater lowering. Groundwater levels have also been lowered by drainage from a deep crawl space along the easterly side of the John Hancock Clarendon building which reduces hydrostatic pressures on basement floors and walls. Sump pumping has also been done in the YWCA building at Stuart and Clarendon Streets.

In other areas, low groundwater levels were probably due to leakage into sewers. The West Side Interceptor beneath Beacon and Charles Streets may have been responsible for low groundwater levels in that area. Low groundwater levels along Tremont Street in the South End were probably caused by leakage into the sewer beneath Tremont Street. Some water levels there were as low as El. 0 to -3. In this area, there were also several groundwater mounds, probably due to water main leaks. These local recharges intermittently interrupted the drawdown pattern toward Tremont Street.

C. Low Groundwater Levels, 1967 to 1968

The areas in which groundwater levels were below El. +5 in the 1967-1968 USGS survey are shown on Figure 18. These areas are much reduced from those areas observed between 1936 and 1940. Low groundwater levels were generally 1 to 3 ft. higher than the lows of the 1936 to 1940 data. The limited number of observation wells used by the USGS and the lone September and March monitoring periods undoubtedly bias this data away from particularly low levels. Precipitation in 1967 was more than 6 inches above normal which may also have caused the observed September "low" levels to be somewhat higher than would otherwise be expected.

Groundwater levels were again below El. +5 in the Copley Square/John Hancock area, along Tremont Street in the South End, and in an isolated area on Charles Street. Additionally, low levels were observed in wells around the Christian Science Center. Some of those data may not have been available to the USGS and would, therefore, not have been reflected in the USGS contours.

Low groundwater levels in the Copley Square/John Hancock area are again probably due to leakage into sewers and drawdown to a drain in a deep crawl space between the John Hancock Clarendon and Berkeley buildings. The crawl space and drain were installed across the entire width of the buildings from St. James Avenue to Stuart Street to reduce hydrostatic pressures on floors and walls. Local effects of construction of the Lord & Taylor store and the Southeast Tower at the north corner of the Prudential Center may also have caused some temporary drawdown.

Low water levels along Tremont Street were again below El. +5. If sewer leaks had been the cause of lowered levels in the 1930's, then they were probably still causing lowered levels during the 1967-68 readings.

Again, it must be remembered that the data from which Figure 18 was derived were much more limited than those used in Figure 17. The low groundwater levels may have been below El. +5 in areas other than those indicated but were not detected because there were no observation well readings in those areas.

Major construction within the study area between 1940 and 1967 does not appear to have permanently lowered groundwater levels below El. +5 by 1967. Major projects completed during this period included the Prudential Center, which is surrounded by a cofferdam of interlocking steel sheetpiling and the Massachusetts Turnpike Extension, which has a partial relieving underdrain system. Observation well data within the Prudential Center in the late 1960's showed levels above El. +5, even though the area was essentially cut off from outside sources.

D. Low Groundwater Levels, 1970 to Present

Data on post-1970 groundwater levels were available for only limited portions of the study area, as indicated on Figure 19. The figure shows the areas where low groundwater levels have been below El. +5 and other areas where observed groundwater levels were not below El. +5. There are large areas where no data were available.

Data were generally available only around major construction projects which have been located primarily in the center of the study area, Zones IV-E and III-W. Monitoring periods for many of the projects were only a few months. In many cases, excavation dewatering caused temporary groundwater level lowering which does not reflect long-term conditions.

Groundwater levels substantially below El. +5 in the area of the Christian Science Center and in the Park Square area were due to construction excavation dewatering. Observed low groundwater levels around Hadasaah Way are due to sump pumping from a basement in that area.

Low groundwater levels below El. 5 have been observed throughout the Prudential Center. Leakage into the underground parking garage is suspected to be the primary cause of lowered groundwater levels. The effect of these low levels on groundwater in adjacent areas is mitigated by the wall of steel sheetpiling that encloses the Prudential Center. The sheetpiling is reported to have been driven 5 ft. into the clay stratum to form a relatively impermeable barrier. Limited data from adjacent areas indicates the wall is effective in preventing off-site groundwater lowering in the fill stratum.

Other Zone III areas where low groundwater levels have been below El. 5 include the area bounded by the Prudential Center, Dartmouth Street, Boylston Street, and the Massachusetts Turnpike, and the block occupied by the John Hancock Clarendon and Berkeley buildings. The drain between the two older John Hancock buildings continues to cause lowered groundwater levels in the latter area. During subsurface investigations for the Copley Place project, the low groundwater levels between the Boston Public Library and the Massachusetts Turnpike were concluded to be due largely to leakage into the St. James Avenue sewer. The Prudential Center, the subway tunnel beneath Exeter Street and Conrail railroad alignment may also be lowering groundwater levels in this area.

East of the Back Bay railroad station, groundwater levels 1 to 2 ft. below El. 5 have been observed on both sides of the right-of-way occupied by the Massachusetts Turnpike and Southwest Corridor Project. The groundwater levels presented in Figure 16 for observation wells in this area were observed for several years before Southwest Corridor construction began and therefore do not reflect the construction-related groundwater lowering that has occurred there. Drains in the former railroad right-of-way were probably responsible for the lowered groundwater levels. Massachusetts Turnpike drains are probably not the cause of the low groundwater levels because they are above the observed low groundwater levels.

Along Tremont Street in the South End, where groundwater levels had been below El. 5 in the two previous monitoring periods, data were available for only one observation well. Low groundwater levels in this well, near the intersection of Berkeley and Tremont Streets, were below El. 5. This could indicate that the lowered levels along Tremont Street still exist.

Lowered groundwater levels have recently been discovered in the lower Beacon Hill area, as indicated in Figure 19. The Boston Water and Sewer Commission and the MDC are conducting investigations to establish whether or not the West Side Interceptor, sewers and drains in streets or the Boston Marginal Conduit is the cause of the groundwater lowering. The Storrow Drive underpass is also being investigated. The lowered groundwater levels are believed to have occurred within the past 5 to 10 years and may be related to new Prison Point pumping station which maintains low water levels in the Marginal Conduit. The conduit had previously been subject to tidal fluctuation. The lowered groundwater levels have led to rotting of wood piles that support many of the buildings in the area.

In major portions of the Back Bay study area, no data were available on groundwater levels since 1970. However, in these areas, maintenance of groundwater levels should be of greatest concern because most of the buildings are supported on untreated wood piles which will rot if exposed to air for a significant

length of time. Most of the available data was for areas in Zone III where "recent" Back Bay commercial development has been concentrated.

8-05. Temporary Effects of Construction on Groundwater Levels

Many construction projects in the Back Bay have caused significant temporary lowering of local groundwater levels. Some of the effects which major projects have had on groundwater levels are presented in Table VI. Included in this summary are the levels to which excavations were dewatered, the type of lateral earth support and its depth of installation, and the off-site drawdown of groundwater levels. Information on the effects of major construction projects on groundwater levels was gathered from available literature, design reports and construction records.

A brief review of the information indicates the following conclusions relative to the hydraulic performance of the fill and sand outwash strata when subjected to construction-related dewatering:

- The depth to which groundwater is lowered decreases with distance from the excavation.
- In the fill, groundwater levels were generally lowered less than 1 ft. at distances beyond 400 ft. from excavations. Significant groundwater drawdown generally occurred within an even smaller radius.
- In the sand, significant lowering of groundwater levels has often occurred at distances 1000 ft. or more from the excavations. On two projects, significant lowering was observed 1400 to over 2000 ft. away.
- As the duration of excavation dewatering increases, so do the depths of off-site groundwater lowering and the area affected.
- Recharging has been successfully used in limiting drawdown in the fill but has generally not been effective in the outwash stratum.

Groundwater drawdown due to construction-related dewatering generally extends 5 to 10 times further in the outwash stratum than in the fill. This is due to the high permeability of the outwash and in part to the outwash being in most areas an essentially trapped aquifer. The relatively impervious organic silt above and clay below severely restrict natural recharge to the outwash. The fill is more readily recharged by surface water and precipitation infiltration and water main leaks, among other sources.

Groundwater level lowering in the outwash is generally not detrimental to wood piles. Because the outwash generally occurs at some depth below the fill, drawdown in the outwash is rarely great enough to cause it to dry out. Rather, drawdown in the outwash usually results only in decreased porewater pressures. For example, if the outwash stratum occurred from El. -10 to -20, and the pre-construction groundwater level were at El. 5, then a 12-ft. drawdown would leave the groundwater level at El. -7 or 3 ft. above the top of the stratum. There are some areas, however, particularly around Gravelly Point, where the top of the outwash is high and long-term dewatering may lower groundwater levels below the top of the stratum.

IX. DISTRESS CAUSED BY LOWERED GROUNDWATER

9-01. General

Deterioration of wood piles caused by lowered groundwater levels has occurred sporadically throughout the Back Bay. In some cases, the decay problem has been well publicized, either because of the structure or the size of the area affected. But for the most part, records of wood pile distress are buried in the building department records or do not exist at all. Occurrences of wood pile deterioration for which information was readily available are summarized below. References are not made to specific structures unless knowledge of their problem is already widely known.

Ground and building subsidence caused by groundwater lowering has been observed in Back Bay but has generally been small enough in the last 30 to 40 years to go unnoticed unless precise measurements were being made. Examples cited below illustrate the insignificance of the problem.

No reports of distress due to negative friction (drag) on piles caused by lowered groundwater levels in the Back Bay were found during this study. Drag has occurred due to other causes and has resulted in substantial building damage. Discussion of these other causes of negative friction on piles is beyond the scope of this study.

9-02. Wood Pile Deterioration

A. Known Occurrences

Records of wood pile deterioration available from the Boston Building Department and local engineers and architects were collected. The primary source of information was the city records. A search was made through the building permit applications filed since 1979 to identify structures which had undergone foundation repairs. Bound volumes of building permit data recorded on Daily Entry Sheets were also examined for the years 1967-1972 and 1976-1979. These several years were considered to be a representative sample of the distribution of foundation problems throughout the Back Bay study area. A further search through permits issued in earlier years was beyond the scope of this study.

In the approximately 6000 permit applications reviewed, only two were for repair of decayed wood piles. This would indicate that the problems of wood pile deterioration is relatively minor. However, it is probable that some foundation repairs have been made without building permits and that numerous problems had been corrected prior to 1979.

In an independent search, Mr. Paul Folkins, Supervising Structural Engineer in the Boston Inspectional Services Department, found records of decayed wood piles at 32 buildings in the lower Beacon Hill area (in general, Study Area Zone I). His search examined all available records for this area. Foundation problems in the area west of Charles Street are not new, as some buildings required wood pile repairs as early as 1927.

Little additional information was available from H&A files, or those of other local engineers and architects. These limited data indicate that within the last 20 years or so, three buildings in Zone II-E between Boylston Street and Newbury Street and one in Zone II-W on Marlboro Street have had deteriorated wood piles repaired. Except for the well-known problems experienced at the Boston Public Library in 1929 and 1930 and two occurrences reported in the 1945 J.R. Worcester & Co. report, no other records or reports of wood pile decay were found. It is likely, however, that other structures have required foundation repair, particularly in areas where groundwater levels have historically been low.

B. Boston Public Library Problems

A major part of the library was underpinned in 1929 and 1930. In about 40 percent of the building area, the tops of many wood piles were completely rotted away or badly decayed. These piles had been originally cut off at approximately El. 5. The groundwater levels was found to be at El. 4 at the time of underpinning. Subsequent investigations indicated that the St. James Avenue sewer or its underdrain were the probable cause for lowered groundwater levels in the Copley Square area. The subsequent installation of a "dam" in the sewer caused nearby groundwater levels to

rise back to acceptable levels. The dam requires periodic maintenance and is often wasted away causing local groundwater levels to fall.

C. Lower Beacon Hill Area

Recently, attention has focused on foundation problems and lowered groundwater levels in the area of Zone I near Storrow Drive. As noted above, the area has a history of wood pile deterioration. This is due in part to widespread use of El. 7 as pile cutoff grade. But some buildings with piles cut off as low as El. 5 have also experienced rotted piles due to lowered groundwater levels. Water levels are presently lowest along Storrow Drive and rise both toward Charles Street and toward the Charles River Basin.

The Boston Water and Sewer Commission and the MDC are conducting investigations in an attempt to establish the cause of the groundwater lowering and to rectify the problem. However, the wood piles supporting many structures in the area are suffering irreversible decay. In some cases, significant portions of the tops of the piles have rotted, but in others, the decay is less severe. The deterioration will continue as long as the lowered groundwater levels persist. Further decay can be halted if groundwater levels are restored so that the piles are again submerged and saturated. Damaged piles can be repaired, in fact underpinning is currently underway at three houses on Brimmer Street.

9-03. Subsidence

Only a few cases of minor ground or building subsidence due to groundwater lowering have been reported in the Back Bay area. The physical process by which subsidence would occur is discussed in Section III.

During construction of the John Hancock Berkeley Building in 1946 and 1947, a 10-ft. drawdown was observed at the nearby Liberty Mutual Building. Up to 1/2 in. of building settlement or subsidence was attributed to this groundwater lowering. About half of the subsidence was recovered in rebound after construction when groundwater levels returned to normal preconstruction levels.

Dewatering of the deep sand stratum between the clay and bedrock for construction of deep caissons for the Boston Herald Traveler Building in 1957 was thought to be the cause of about 1/2 in. of settlement at the Liberty Mutual Building. Drawdown in the sand was significant, 30 ft. at one mile, because the layer is trapped between two impervious strata. Although no drawdown measurements were made at the Liberty Mutual Building, it would be expected that drawdown in the deep sand there would be greater because it is only 1/2 mile from the Herald Building. Most of the subsidence at Liberty Mutual was recovered as rebound after dewatering.

Groundwater lowering in the sand and gravel outwash during construction of the Prudential entrance to the Huntington Avenue subway caused as much as 1/2 in. of settlement of the Prudential Center Garage. Here again, most of the subsidence was recovered after dewatering when groundwater levels returned to preconstruction levels.

The three cases of subsidence due to groundwater lowering discussed above occurred within the last 40 years, after much of the area had experienced at least one episode of groundwater lowering associated with construction of early sewers, drains and subways. Undoubtedly, significant amounts of ground subsidence occurred as a result of the first major drawdown. Buildings probably experienced substantially less settlement than adjacent ground areas because they were generally supported on strata below the compressible organic silt.

There have probably been many other instances of subsidence due to groundwater lowering caused by nearby temporary construction dewatering. However, the magnitude of settlement has probably also been small and gone, for the most part, unnoticed. Similar subsidence due to groundwater lowering to levels customarily associated with building construction in Back Bay is expected to be similarly small.

X. PRECAUTIONS TAKEN TO PRESERVE GROUNDWATER LEVELS

10-01. General

The importance of maintaining groundwater levels in Back Bay has been recognized since the late 1800's. Positive measures were incorporated into early sewer and subway construction in certain areas to mitigate their impact on groundwater movement and levels. In several areas, permanent recharge systems have been installed to replenish the groundwater, particularly around historic structures founded on wood piles. Temporary recharging around excavations for building construction projects has not always been successful. Several of the measures that have been taken to preserve groundwater levels in the Back Bay are discussed below.

10-02. Siphons to Maintain Groundwater

A. Boston Marginal Conduit Siphon Pipes

Siphon pipes were reported to have been "placed under the conduit from the Basin to the Back Bay intended to carry groundwater from one side to the other", Worcester (1945). These pipes, if actually installed and working as intended, would mitigate some of the damming effect of the nearly 8-ft. high concrete conduit and the wood sheeting installed and left in place on either side. Worcester questioned the long-term effectiveness of these siphons because they would probably fill with silt and would be only locally effective. No other information has been found to verify that these siphons were actually installed.

B. Boylston Street Subway Siphons

Four 12-inch diameter tile siphon pipes were placed under the concrete subway tunnel in the vicinity of Copley Square to carry groundwater from one side to the other. These pipes were probably considered necessary here because the bottom of the tunnel is in the clay and its top is at about El. 6, thus forming a virtual dam along Boylston Street. West of Copley Square, the tunnel rises and is founded in the sand outwash.

The effectiveness of these siphons has never been verified although over the years, a distinct difference in groundwater levels has been observed in opposite sides of Boylston Street. This difference was not apparent in the early 1920's, but was noted in 1930, Paine (1935), and has been confirmed by several projects in the past several years.

C. Southwest Corridor Project

A special groundwater equalization system was included in corridor structure design to prevent cross-alignment water flow from being interrupted by the concrete structure. Maintenance of cross-corridor groundwater flow was a particular concern between Massachusetts Avenue and Dartmouth Street where the concrete slurry walls used for permanent tunnel walls penetrate 8 to 15 ft. into the clay and the structure roof extends several feet above groundwater level. Unlike other earlier siphon systems, this groundwater equalization system provides longitudinal perforated header pipes along most of both sides of the structure. To protect the system from becoming clogged with soil particles, the header pipes are surrounded with crushed stone and filter fabric. The header pipes on each side of the structure are connected by underdrain pipes spaced at about 300-ft. intervals.

10-03. Permanent Recharge Systems

A. Early "Inadvertent" Recharging

Although not indicated by available records, recharging was undoubtedly done at many locations by drywells which were commonly used to dispose of precipitation runoff from roofs. These systems were probably not intended to replenish groundwater, and were probably not installed frequently enough to have a significant widespread impact on groundwater levels.

B. Trinity Church

In 1930, the first reported recharge system intended to raise groundwater levels to protect wood piles was installed. Preservation of wood piles was of particular concern to the church since only a year before

severely rotted wood piles were found at the nearby Boston Public Library and newly-installed observation wells at the church indicated water levels at about El. 4. The large conductors from the church's roof gutters were disconnected from the city sewers and redirected into long, stone-filled drywells outside the church and to a brick-lined pit in the basement. Although groundwater levels around Trinity Church during dry periods remained below El. 4 to 5 for many years, the intermittent rises in water levels and periodic inundation of the wood piles due to the recharge system was probably responsible for the preservation of the church's foundations.

C. Copley Square Plaza

In the mid-1950's, a recharge system was constructed in the triangular grass plot across Dartmouth Street from the Boston Public Library. Water was supplied by diverting surface drainage from a 3'-8" by 5'-10" concrete drain beneath Boylston Street, between Berkeley and Clarendon Streets. Water was distributed through twin 12-in. perforated Armco pipes about 280 ft. long that were installed in a 4-1/2 ft. wide trench in a 3-ft. thick bed of washed gravel. The bottom of the trench was at El. 4 to 5.

In 1968, when Copley Square was redeveloped with its sunken plaza and fountain, another recharge system was installed below the plaza to carry storm water runoff, collected in catch basins, into the fill. Perforated pipes, 8 and 12-inch diameter, were installed on a deep bed of screened stone, 3-ft. wide and as much as 5-ft. thick. Drains were laid at grades from El. +7.5 to +14 for a combined length of 350 ft. Voids in the stone alone were calculated to take 80 percent of the design 24-hour runoff to the catch basins.

D. Christian Science Center Parking Garage

The underdrain system below the slab-on-grade floor of the parking garage can be reversed to recharge groundwater. The system consists of perforated pipes in an 8-in. thick drainage course over a 24-in. thick

layer of granular soil. Its normal function is to prevent groundwater levels from rising above El. 6'-8"; higher levels would cause uplift pressures on the concrete slab. However, should water levels in the fill ever fall to levels that would threaten to expose the wood piles that support the Mother Church, the underdrain system could be reversed by introducing city water to maintain groundwater levels.

E. Proposed Storrow Drive/Brimmer Street System

To raise water levels in a section of lower Beacon Hill along Storrow Drive, it has been proposed that a recharge system be installed just east of the road between Pinckney and Mt. Vernon Streets. Recently observed groundwater levels along Storrow Drive have been as low as El. 2.3. The MDC is continuing to investigate the cause of the problem. It has been suggested that the lowered levels have been caused by the Boston Marginal Conduit, its underdrain system, or other connecting sewers and drains. It is hoped that design studies for a system that would return groundwater levels to El. 7 or higher will soon be undertaken.

10-04. Temporary Recharging during Building Construction

Groundwater recharging to minimize temporary drawdown outside of construction sites has generally not been practical in the Back Bay. Notable exceptions include projects at the Christian Science Center and Prudential Center project near Exeter Street, where there was particular concerns for wood pile foundations of existing structures. Specific projects where recharging has been done are indicated on Table VI.

Recharging usually involves injecting water, under pressure, into the fill or sand outwash stratum through pipes, screened or slotted at the bottom. The pipes are driven or drilled into the ground. In some cases, recharge is accomplished by simply pumping water into open ditches and allowing it to percolate into the ground.

It has been possible to recharge the fill stratum and successfully limit drawdown. However, recharging in the sand outwash to limit hydrostatic pressure decreases has generally been unsuccessful.

10-05. Other Measures

Studies done for Trinity Church in the early 1930's indicated that the St. James Avenue sewer was lowering groundwater levels along much of its length. As a test, a dam was installed in the sewer. When the dam was closed and the level of sewage rose, water levels in nearby observation wells also rose, thus confirming that the sewer was lowering groundwater levels. Because the dam was so successful in raising groundwater levels back to "normal" levels, it was left in place and forms a sort of recharge system. It mitigates the effects of leakage into the sewer. Over the years, the original butterfly valves deteriorated and have been replaced. A sand bag dam which requires periodic repair is now used.

In the early 1980's, a study was conducted for John Hancock to determine the effect of the crawl space drain between the Clarendon and Berkeley buildings on groundwater levels. As a result of the study, the water level maintained in the crawl space was raised somewhat. Although there is still an area-wide drawdown toward this drain, its magnitude has been reduced by this adjustment.

XI. CONCLUSIONS

Long-term lowering of groundwater levels and the subsequent deterioration of wood piles that support many of the nineteenth century structures in the Back Bay would be a disaster that can and must be prevented. In certain areas, rotted wood piles have been found below numerous buildings due to locally lowered groundwater levels. In some of these structures, pile foundations have been restored by underpinning at great cost. Work will be required in many others. It is imperative that groundwater levels be kept permanently above the tops of wood piles.

Ground subsidence has sometimes occurred due to temporarily lowered groundwater levels during construction. Significant settlement undoubtedly occurred in the late 1800's and/or early 1900's due to dewatering for sewers, drains, subways and other in-ground construction. However, in the future, such settlements are expected to be small because the compressible soils have already experienced one or more episodes of consolidation.

It is difficult to assess long-term changes in groundwater levels particularly between the 1930's and 1960's because the available data do not reflect similar monitoring efforts. In particular, the available WPA data from the late 1930's provide only the highest and lowest water levels observed in each well over the 4-year monitoring period, whereas the USGS groundwater levels were only measured once in September 1967 and once again in March 1968, presumably representing low and high levels, respectively. Although groundwater level readings for specific building projects are usually made at frequent intervals, the duration of monitoring is often too short to adequately define either normal yearly ranges or long-term trends in the absence of temporary pumping at the site.

Since the USGS groundwater level survey in 1967-1968, there has been little or no monitoring of groundwater levels throughout most of the Back Bay, particularly in Zones II-E, II-W, IV and V. However, it is in these areas that most buildings are supported on untreated timber piles. Only within the past few months have groundwater levels been systematically monitored throughout the lower Beacon Hill area, Zone I.

The bulk of the available data were for construction projects and other sites within the central commercial spine of Back Bay, between Boylston Street and Huntington Avenue and the Massachusetts Turnpike, Zones III-E and III-W. Most of the buildings constructed in this area in the last 40 years have foundations that would not be affected by lowering of groundwater levels in the fill.

Within the limitations of the available data, the following can be concluded regarding areas which have or had low groundwater levels below El. 5:

- A wide area west of Dartmouth Street experienced low groundwater levels below El. 5 in the late 1930's apparently due to dewatering for construction of the Huntington Avenue subway. Available data indicate that since that time, water levels have generally recovered.

- The Copley Square area has historically experienced lowered groundwater levels due to leaks in the St. James Avenue sewer. Recharging and other measures have been taken to maintain groundwater levels. Recent data indicate lowered groundwater levels in portions of the area that may be due to the sewer, other structures which maintain lowered water levels, such as the nearby Prudential Center garage, or the Exeter Street segment of the Huntington Avenue subway.

- Groundwater levels within much of the Prudential Center area have been lowered below El. 5. However, the lowered water levels generally do not extend off-site because of the cofferdam of steel sheetpiling which encloses most of the Prudential Center.

- In the immediate vicinity of the John Hancock Berkeley and Clarendon buildings, groundwater levels have been and continue to be lowered due to a drain in a crawl space between the two buildings.

- In areas along Tremont Street in Zone V, low groundwater levels were observed to be below El. 5 by both the WPA and USGS. Sewer leaks are suspected as being the cause. Very limited data in this area since the USGS study indicate that low water levels may still exist.

- In the lower Beacon Hill area, particularly near Storrow Drive, groundwater levels are significantly below "normal". These lowered levels are apparently recent, within the last 10 years, and are probably due to leakage into or along the Boston Marginal Conduit, nearby sewers and drains or the Storrow Drive underpass. Significant deterioration of wood piles that support residential buildings on Brimmer Street adjacent to Storrow Drive has recently been discovered, requiring costly repairs. There is little double that pile rot has been caused by lowered water levels. Immediate action is required to restore groundwater levels to stop further deterioration of building foundations.

Temporary groundwater lowering has often occurred around dewatered excavations for building projects. Significant drawdown in the fill stratum has generally not extended far from the excavation. However, water levels in wells located in the sand outwash have been lowered significantly at distances 5 to 10 times as far as in the fill. When pumping is discontinued, groundwater levels usually return to preconstruction levels in a short time.

Buildings and other projects constructed in the Back Bay within the last 40 years have not, by their presence alone, caused permanently lowered groundwater levels. Some groundwater lowering has occurred where there is pumping from or leakage into basement areas. Further development in the Back Bay, such as the 500 Boylston Street project proposed by G.D. Hines Interests, is not expected to cause permanent groundwater lowering. These projects should provide for foundation walls and floors which are watertight.

Long "dams" with the potential to impede groundwater flow have been created by the 1820 Mill Dam along Beacon Street, the Boston Marginal Conduit, the Boylston Street and Huntington Avenue subways and the MBTA Southwest Corridor project. The conduit, Boylston Street subway and Southwest Corridor structure tunnel provided siphons to allow groundwater to pass across portions of their alignments. However, lower groundwater levels have developed on the south sides of both the Marginal Conduit and the Boylston Street subway, indicating that the siphons have been ineffective. The groundwater

equalization system that has been installed along the Southwest Corridor project in Back Bay is a considerable improvement over the siphons used in previous projects. Groundwater levels in the fill stratum along the tunnel portion of the corridor where concrete slurry walls were used have thus far remained approximately at preconstruction levels.

The large volume of data compiled for this study and presented in the tables and figures of this report forms an extremely important base for long-term future use in evaluating changes in groundwater levels. As data are collected in future years, it should be added to that compiled for this report so as to produce an ever expanding data base. A significant amount of the work effort expended in this study was in the compilation and summation of data from previous studies and projects. The data should be made available to all interested parties.

XII. RECOMMENDATIONS FOR ACTION BY OTHERS

It is imperative that groundwater levels throughout Back Bay be monitored and evaluated to provide a forewarning against long-term lowering of the water table. Low water levels must be identified before the discovery of cracks in buildings and rotted wood piles. There are large sections of the Back Bay study area where no measurements of groundwater levels have been made for 15 years or more, see Figure 20. It is ironic that these sections coincide with the areas where the preservation of groundwater levels is most crucial, that is the areas where most of the buildings are founded on untreated wood piles.

The City of Boston should undertake a groundwater level monitoring program that would, as a minimum, provide for the following:

- A network of groundwater observation wells throughout the Back Bay. The density of wells should be at least equal to that provided under the WPA program. Existing observation wells which are in proper working condition should be used wherever possible. New wells should be installed according to the typical observation well detail shown in Figure 21.

- Qualified personnel to monitor the observation wells in the network at least four times a year. The data should be tabulated and plotted promptly after each series of readings. At least yearly, the data should be added to that compiled for this study to produce an ever-increasing data base.

- Review and interpretation of the data once a year by a geotechnical engineer who is knowledgeable about the history and problems with groundwater levels in the Back Bay. After this review, the engineer should submit a report which summarizes conclusions and lists recommendations for further study of areas where groundwater levels were observed to be particularly low.

Other recommendations follow:

1. In the lower Beacon Hill area, Zone I, the Boston Water and Sewer Commission and the MDC should continue investigations to determine the cause of lowered groundwater levels, in particular those observed along Storrow Drive at the foot of Pinckney, Mt. Vernon and Chestnut Streets. A temporary groundwater recharge system should be installed without delay to raise the water table until the problem is corrected and the water table is restored permanently.

2. Owners of buildings supported on wood piles who suspect that their piles may have suffered decay should seek the opinion of a civil engineer who is familiar with area groundwater and foundation conditions. On the basis of existing building conditions, the engineer may recommend test pits to allow visual examination of the condition of several piles.

3. Other investigations of the causes and extent of lowered groundwater levels along Tremont Street in the South End and along the Southwest Corridor Project from Columbus Avenue to Arlington Street should be undertaken. Necessary measures should be taken to restore the water table.

4. A specific monitoring program should be undertaken outside the Prudential Center to watch for lowering of groundwater levels in either the fill or outwash strata which may occur due to the lowered water levels within the cofferdam.

5. Legislation and/or revisions to the Massachusetts Building Code should be undertaken which specifically address requirements for preserving the groundwater level. The following provisions should be considered:

    - Restrictions on permanent lowering of the water table, except within privately owned project sites where there is no potential for deterioration of wood piles or other adverse effects. Where surrounding structures are supported by wood piles, pumping from sumps, deep basements, etc. that lowers groundwater levels should be prohibited.

- Requirements for recharging to maintain groundwater levels adjacent to construction sites where temporary pumping is required, unless the extent and duration of drawdown can be shown to have no adverse effects on adjacent property.

- Requirements to install observation wells and monitor groundwater levels before, during and for some time after construction which requires pumping.

6. In time, significant leakage of groundwater into sewers, drains, sumps in buildings, tunnels and other structures below grade should be eliminated. It will be very costly to accomplish this objective, but each new construction project, repair or renovation, and building permit should incorporate provisions to eliminate or reduce the loss of groundwater.

XIII. REFERENCES

1. Aldrich, H. P., 1970, Back Bay Boston - Part I, Journal of the Boston Society of Civil Engineers, Vol. 57, No. 1, January, pp. 1-33.

2. Aldrich, H. P., 1979, Preserving the Foundations of Older Buildings, Technology & Conservation, Summer, 6 pp.

3. Cotton, J. E. and Delaney, D. F., 1975, Groundwater Levels on Boston Peninsula, Massachusetts, Hydrologic Investigations Atlas HA-513, U.S. Geological Survey, Reston, VA, 4 sheets.

4. Haley & Aldrich, Inc., 1985, Draft Report on Subsurface Investigations and Foundation Design Recommendations, Proposed Development, 500 Boylston Street, Boston, Massachusetts, for Gerald D. Hines Interests, February, 57 pp.

5. Paine, R. T., 1935, Trinity Church - The Church Endangered by the Low Level of the Ground Water - How the Danger has been Temporarily Averted, April, 20 pp.

6. Snow, B. F., 1936, Tracing Loss of Groundwater, Engineering News-Record, July 2, pp. 1-6.

7. Stearns, F. P., 1894, Report of the Engineer, Report of the Joint Board upon the Improvements of Charles River, April, pp. 1-32.

8. Whitehill, W.M., 1959, Boston, A Topographic History, The Belknap Press of Harvard University Press, Cambridge, Mass.

9. Worcester, J. R., & Co., 1945, Report on Pile Foundations and Ground Water Levels at Trinity Church - Boston Public Library - S.S. Pierce Bldgs., Copley Square, Boston, Mass., December 31, 10 pp.

TABLE I

NUMBER OF WPA OBSERVATION WELLS INSTALLED OR MONITORED

ZONE	NO. OF WELLS INSTALLED IN 1930's	NO. OF ORIGINAL WELLS FOUND TO BE FUNCTIONAL BY U.S.G.S IN 1960's	NO. OF WELLS MONITORED BY OTHERS SINCE 1956 (1)
I	14	5	2
II-E	31	15	3
II-W	56	28	11
III-E	41	20	5
III-W	42	15	22
IV	16	4	0
V	68	32	1

Notes

1. See Table III for details of monitoring by others.
2. See Figure 2 for location of each zone.

TABLE I

NUMBER OF WPA OBSERVATION WELLS INSTALLED OR MONITORED

ZONE	NO. OF WELLS INSTALLED IN 1930's	NO. OF ORIGINAL WELLS FOUND TO BE FUNCTIONAL BY U.S.G.S IN 1960's	NO. OF WELLS MONITORED BY OTHERS SINCE 1956 (1)
I	14	5	2
II-E	31	15	3
II-W	56	28	11
III-E	41	20	5
III-W	42	15	22
IV	16	4	0
V	68	32	1

Notes

1. See Table III for details of monitoring by others.

2. See Figure 2 for location of each zone.

TABLE II

SUMMARY OF OBSERVATION WELL DATA SOURCES OTHER THAN WPA AND USGS

SITE REFERENCE NUMBER	DATA SOURCE	PROJECT NAME & LOCATION	NUMBER OF WELLS	YEAR(S) INSTALLED	MONITORING PERIOD	REMARKS
I-A	Gilbert Small & Co., Inc.	Church of the Advent 30 Brimmer St.	4	1974	1974-1984	
I-B	Boston Water and Sewer Commission	Lower Beacon Hill Groundwater Study	6	1984	1984	Wells installed (10/84)
II-E-A	H&A Files	N.E. Life Development 500 Boylston St.	5	1984	1984	Installation date for well II-E-A-1 unknown
II-E-B	H&A Files	Ritz-Carlton Addition 15 Arlington St.	4	1978 (2 Wells) 1979 (2 Wells)	1978-1979	
II-E-C	H&A Files	First Unitarian Church of Boston Marlborough & Berkeley Sts.	2	1970	1970	
II-E-D	H&A Files	Ritz-Carlton Garage Newbury St.	1	1978	1978-1979	
II-W-A	H&A Files	Exeter Place Exeter & Boylston Sts.	5	1981 (2) 1982 (3)	1981-1983	
II-W-B	H&A Files	Ingalls Building 857 Boylston St.	2	1984	1984	
III-E-A	H&A Files & Massachusetts Turnpike Authority Archives	Massachusetts Turnpike Extension	5	-	1960's - 1970's	Not all wells monitored during all periods
III-E-B	H&A Files	N.E. Life Development 500 Boylston St.	12	1984	1984	Installation date for well III-E-B-11 unknown
III-E-C	H&A Files	Four Seasons Hotel Boylston St.	21	1969, 1980 1981, 1982	1969-1970 1980-1981 1982-1983	Not all wells monitored during all periods
III-E-D	H&A Files	South Cove Plaza 230-246 Stuart St.	2	1979	1979	
III-E-E	H&A Files	John Hancock Garage 100 Clarendon St.	4	1968	1968	
III-E-F	H&A Files	John Hancock Clarendon Building, Clarendon St.	11	1982	1982	
III-E-G	H&A Files	State Transportation Building Park Plaza	10	1977, 1981	1977-1978 1977-1979 1981-1982	Not all wells monitored during all periods
III-E-H	H&A Files	Copley Place Dartmouth St. & Huntington Ave.	2	1980	1980-1981	
III-E-I	H&A Files & Trinity Church Archives	Trinity Church Copley Square	15	1930's 1975	1940-1961 1968-1983	Not all wells monitored during all periods
III-E-J	H&A Files	Arlington/Hadassah Development	7	1984	1984	Wells installed (11/84)

TABLE II (continued)

SUMMARY OF OBSERVATION WELL DATA SOURCES OTHER THAN WPA AND USGS

SITE REFERENCE NUMBER	DATA SOURCE	PROJECT NAME & LOCATION	NUMBER OF WELLS	YEAR(S) INSTALLED	MONITORING PERIOD	REMARKS
III-W-A	H&A Files	Copley Place Dartmouth St. & Huntington Ave.	10	1980	1980-1981	
III-W-B	H&A Files	MBTA Southwest Corridor Project	20	1977, 1979 1981	1977-1980 1981-1984	Not all wells monitored during all periods
III-W-C	H&A Files	Hynes Auditorium Expansion 900 Boylston St.	2	1984	1984	
III-W-D	H&A Files	Horticultural Hall 300 Massachusetts Ave.	2	1983	1983	
III-W-E	H&A Files	Greenhouse Apartments 150 Huntington Ave.	2	1980	1980-1981	
III-W-F	Metcalf & Eddy Inc. Reports	Prudential Center	31	1957-1970	1957-1982	Not all wells monitored for entire period
III-W-G	H&A Files & Archives of Christian Science Center	Christian Science Center	18	1937-1980	1934-1982	Not all wells monitored for entire period
III-W-H	Gilbert Small & Co., Inc.	Hotel Lenox 710 Boylston St.	1	1981	1981-1984	
II-W-I	H&A Files & Archives of Massachusetts Turnpike Authority	Massachusetts Turnpike Extension	7	-	1963-1964 1971-1972 1977-1979 1980-1981	Not all wells monitored during all periods
III-W-J	Gilbert Small & Co., Inc.	Copley Square Hotel 47 Huntington Ave.	1	1980	1980-1984	
IV-A	H&A Files	MBTA Southwest Corridor Project	1	1977	1977-1979	
IV-B	H&A Files	South Cove Extended Care Facility Shawmut Avenue	2	1979	1979	
IV-C	H&A Files	Franklin Institute 41 Berkeley St.	1	1979	1979	
IV-D	H&A Files & Archives of Massachusetts Turnpike Authority	Massachusetts Turnpike Extension	1	-	1971-1972	
V-A	H&A Files	MBTA Southwest Corridor Project	19	1977,1979 1981	1977-1980 1981-1984	Not all wells monitored during all periods
V-B	H&A Files of Archives of the Massachusetts Turnpike Authority	Massachusetts Turnpike Extension	4	-	1963-1964 1971-1972 1977-1979 1980-1981	Not all wells monitored during all periods

TABLE III

DETAILS OF WPA AND USGS OBSERVATION WELLS

WELL NUMBER		TIP LOCATION			WELL	WELL MONITORING/CONDITION			
CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM	INSTALLED BY	1936-1940	1967-1968	1968-PRESENT	REMARKS
I-1	5-16	15.5	1.41	FILL*	WPA	M	M	I(1984)	
I-2	S5-18	-	U	-	SD	M	D		
I-3	5-158	15.0	3.1	FILL*	WPA	M	P	D(1984)	
I-4	5-160	15.0	4.9	FILL*	WPA	M	M	P(1984)	
I-5	S5-17	-	U	-	SD	M	D		
I-6	5-82	15.5	-1.3	SILTY SAND	WPA	M	D		
I-7	5-161	15.0	3.1	FILL*	WPA	M	M	P(1984)	
I-8	S5-16	-	U	-	SD	M	D		
I-9	5-06	15.5	0.9	ORGANIC SILT*	WPA	M	D		
I-10	S5-15	-	U	-	SD	M	D		
I-11	5-81	15.5	-0.8	ORGANIC SILT*	WPA	M	M	M(10/84-12/84)	Monitored by BWSC
I-12	5-159	15.0	1.2	FILL*	WPA	M	M	M(10/84-12/84)	Monitored by BWSC
I-13	S5-19	-	U	-	SD	M	D		
I-14	5-102	15.0	-0.1	ORGANIC SILT*	WPA	M	P		
II-E-1	S5-41	-	U	-	SD	M	M		
II-E-2	S5-12	-	U	-	SD	M	D		
II-E-3	5-62	15.5	-0.5	FILL*	WPA	M	D		
II-E-4	S5-13	-	U	-	SD	M	D		
II-E-5	5-118	20.0	-7.1	FILL*	WPA	M	P		
II-E-6	5-162	-	U	-	WPA	-	P		Not monitored 1936-40
II-E-7	5-79	20.5	-3.7	FILL*	WPA	M	D		
II-E-8	5-163	-	U	-	WPA	-	P		Not monitored 1936-40
II-E-9	5-80	20.5	-3.7	FILL*	WPA	M	D		
II-E-10	5-27	15.5	0.9	FILL*	WPA	M	D		
II-E-11	D5-28	15.5	1.9	-	WPA	M(1)	D		
II-E-12	5-29	15.5	1.7	FILL*	WPA	M	M		
II-E-13	5-135	20.0	-5.6	ORGANIC SILT & FINE SAND*	WPA	M	P		
II-E-14	5-128	20.0	-4.2	FILL*	WPA	M	M		
II-E-15	5-126; BBD2	20.0	-4.5	FILL*	WPA	M	M	M(9/79-4/80)	Monitored for site II-E-B construction
II-E-16	S5-34	-	U	-	SD	M	D		
II-E-17	S5-35	-	U	-	SD	M	M		
II-E-18	S5-37	-	U	-	SD	M	M		
II-E-19	S5-42	-	U	-	SD	M	M		
II-E-20	5-138	20.0	-5.9	ORGANIC SILT/FINE SAND*	WPA	M	M		
II-E-21	5-127	20.0	-5.1	ORGANIC SILT/FINE SAND*	WPA	M	M(2)		
II-E-22	5-154; BBD1	15.0	0.7	FILL*	WPA	M	M	M(9/79-4/80)	Monitored for site II-E-B construction
II-E-23	5-75	20.5	-4.3	FILL*	WPA	M	M		
II-E-24	5-123	20.0	-2.5	FILL*	WPA	M	M		
II-E-25	5-40	15.5	2.2	FILL*	WPA	M	D		
II-E-26	5-141	20.0	-5.7	FILL*	WPA	M	M		Not monitored (3/68)
II-E-27	S5-55	-	U	-	SD	M	-	Dry(84)	Monitored for site II-E-A
II-E-28	S5-59	-	U	-	SD	M	M		
II-E-29	DS5-62	-	U	-	SD	M(1)	M		
II-E-30	S5-207	-	U	-	SD	M	D		
II-E-31	D5-65	17.5	-0.1	FILL*	WPA	M	D		
II-W-1	S-5-06	-	U	-	SD	M	D		
II-W-2	S-5-07	-	U	-	SD	M	D		
II-W-3	5-14	15.8	-1.6	FILL*	WPA	M	D		
II-W-4	S-5-08	-	U	-	SD	M	D		
II-W-5	S-5-09	-	U	-	SD	M	D		
II-W-6	5-15	17.5	-4.5	FILL*	WPA	M	D		
II-W-7	S-5-10	-	U	-	SD	M	D		
II-W-8	S-5-11	-	U	-	SD	M	D		

TABLE III
(Continued)

DETAILS OF WPA AND USGS OBSERVATION WELLS

WELL NUMBER		TIP LOCATION			WELL INSTALLED BY	WELL MONITORING/CONDITION			REMARKS
CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM		1936-1940	1967-1968	1968-PRESENT	
II-W-8a	5-78	15.5	-2.6	FILL*	WPA	M	D		
II-W-9	5-109	20.0	-2.9	ORGANIC SILT*	WPA	M	M(2)		
II-W-10	5-59	15.5	0.6	FILL*	WPA	M	M		
II-W-11	5-60	15.5	0.2	FILL*	WPA	M	M		
II-W-12	5-61	15.0	0.3	ORGANIC SILT*	WPA	M	M		
II-W-13	5-107	20.0	-5.3	ORGANIC SILT*	WPA	M	P		
II-W-14	5-106	20.0	-4.2	FILL*	WPA	M	M		
II-W-15	5-108	20.0	-3.6	FILL*	WPA	M	M		Not monitored (3/68)
II-W-16	5-110	20.0	-4.7	FILL*	WPA	M	M(2)		
II-W-17	5-115	20.0	-6.0	ORGANIC SILT*	WPA	M	M		
II-W-18	5-120	-	U	-	WPA	M	P		
II-W-19	5-21	18.0	-0.4	FILL*	WPA	M	M		
II-W-20	5-22	17.5	0.2	FILL*	WPA	M	P		
II-W-21	5-23	15.5	2.0	FILL*	WPA	M	M(2)		
II-W-22	5-24	17.5	-0.4	-	WPA	M	M		
II-W-23	5-25	15.5	0.3	ORGANIC SILT/FILL*	WPA	M	M		
II-W-24	5-26	15.5	0.3	FILL*	WPA	M	D		
II-W-25	5-150	20.0	-5.2	FILL*	WPA	M	D		
II-W-26	5-151	20.0	-4.2	FILL*	WPA	M	P		
II-W-27	5-134	20.0	-5.7	FILL*	WPA	M	M		
II-W-28	5-143	-	U	-	WPA	M	M		
II-W-29	5-139	20.0	-7.1	ORGANIC SILT*	WPA	M	M		
II-W-30	5-99	25.0	-2.9	FILL*	WPA	M	M		
II-W-31	S-5-26	-	U	-	SD	M	D		
II-W-32	S-5-31	-	U	-	SD	M	D		
II-W-33	S-5-32	-	U	-	SD	-	D		Not monitored 1936-40
II-W-34	S-5-24	-	U	-	SD	M	M		
II-W-35	DS-5-25	-	U	-	SD	M(1)	D		
II-W-36	S-5-28	-	U	-	SD	M	M		
II-W-37	S-5-30	-	U	-	SD	M	M		
II-W-38	5-130	20.0	-7.1	FILL*	WPA	M	D		
II-W-39	5-153	15.0	-2.0	FILL*	WPA	M	M		
II-W-40	5-132	15.0	-0.6	FILL*	WPA	M	D		
II-W-41	5-145	20.0	-5.3	FILL*	WPA	M	M		
II-W-42	5-148	20.0	-5.2	FILL*	WPA	M	D		
II-W-43	5-72	25.5	-3.0	-	WPA	M	M		
II-W-44	5-117	20.0	-1.7	FILL*	WPA	M	D		Note 1
II-W-45	5-73	20.5	-2.8	FILL*	WPA	M	M		Note 1
II-W-46	5-131	25.0	-7.1	FILL*	WPA	M	M		Note 1a
II-W-47	5-74	20.5	-2.9	FILL*	WPA	M	D		Note 1
II-W-48	5-140	15.0	-0.9	FILL*	WPA	M	D		
II-W-49	DS-5-49	-	U	-	SD	M(1)	D		Note 1
II-W-50	5-152	20.0	-6.3	FILL*	WPA	M	M		Note 1; Not monitored (9/67)
II-W-51	5-147	20.0	-6.3	FILL*	WPA	M	M		Note 1a
II-W-52	5-146; BBD2	20.0	-5.5	FILL*	WPA	M	M	M(10/82-4/83)	Note 1a; Monitored for site II-W-A construction
II-W-53	S-5-53	-	U	-	SD	M	D		Note 1
II-W-54	S-5-54	-	U	-	SD	M	M(2)		Note 1a
II-W-55	S-5-58	-	U	-	SD	M	D		Note 1a
III-E-1	S-4-60	-	U	-	SD	M	M(Dry)		
III-E-2	S-4-61;48	-	U	-	SD	M	-	P(8/84)	Monitored for site III-E-B
III-E-3	5-124	20.0	-1.2	FILL*	WPA	M	D		
III-E-4	S-4-200	-	U	-	SD	M	D		
III-E-5	S-5-104	-	U	-	SD	M	D		
III-E-6	S-5-105	-	U	-	SD	M	M(2)		
III-E-7	S-4-67	-	U	-	SD	M	D		
III-E-8	S-4-68	-	U	-	SD	M	D		
III-E-9	S-4-69	-	U	-	SD	M	D		
III-E-10	S-4-85	-	U	-	SD	M	M		

TABLE III
(Continued)

DETAILS OF WPA AND USGS OBSERVATION WELLS

WELL NUMBER		TIP LOCATION			WELL	WELL MONITORING/CONDITION			
CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM	INSTALLED BY	1936-1940	1967-1968	1968-PRESENT	REMARKS
III-E-11	S-4-99;58	-	U	-	SD	M	M	M(8/84-9/84)	Monitored for site III-E-B
III-E-12	4-65	15.5	2.1	FILL*	WPA	M	M		Not monitored 9/67
III-E-13	S-4-100	-	U	-	SD	M	D		
III-E-14	S-4-101	-	U	-	SD	M	M		
III-E-15	S-5-103	-	U	-	SD	M	D		
III-E-16	D5-149	-	U	-	WPA	Dry	P		
III-E-17	S-4-83;56	-	U	-	SD	M	M(Dry)	I(8/84)	Monitored for site III-E-B
III-E-18	S-4-98	-	U	-	SD	M	D		
III-E-19	4-66	20.5	-3.3	FILL*	WPA	M	M		
III-E-20	S-4-107	-	U	-	SD	M	M		
III-E-21	5-51	15.5	2.1	FILL*	WPA	M	M		
III-E-22	S-4-82	-	U	-	SD	M	D		
III-E-23	S-4-106	-	U	-	SD	M	D		
III-E-24	4-63	20.5	-2.8	FILL*	WPA	M	M		
III-E-25	5-92	20.5	-3.0	SAND	WPA	M	M		
III-E-26	5-94	18.0	-0.6	FILL*	WPA	M	M		
III-E-27	5-98	20.5	0.1	SAND, CLAY	WPA	M	M		
III-E-28	4-62;B	20.5	-3.9	FILL	WPA	M	M	M(6/84-9/84)	Not monitored (9/67). Monitored for site III-E-B
III-E-29	5-84	25.5	-2.1	FILL*	WPA	M	D		
III-E-30	S-5-112	-	U	-	SD	M	D		
III-E-31	PS-5-187	-	U	-	SD	P	P		
III-E-32	S-4-109	-	U	-	SD	M	D		
III-E-33	4-61	20.5	-0.4	FILL*	WPA	M	M	M(8/68-11/68)	Monitored for site III-E-E
III-E-34	D4-117	15.0	2.3	-	WPA	M(1)	P		
III-E-35	S-5-111	-	U	-	SD	M	M		
III-E-36	5-95	20.5	-1.1	FILL*	WPA	M	M		
III-E-37	5-93	20.5	-2.9	FILL*	WPA	M	D		
III-E-38	S4-84	-	U	-	SD	M	D		
III-E-39	P4-64	10.5	2.3	FILL*	WPA	M(1)	D		
III-E-40	5-56	15.5	2.9	SAND/CLAY	WPA	M	M		
III-E-41	5-97	20.5	-3.4	FILL*	WPA	M	M		
III-W-1	D-5-4-50	-	U	-	SD	M(1)	D		
III-W-2	5-4-55	-	U	-	SD	M	D		Note 1
III-W-3	5-4-57	-	U	-	SD	M	D		
III-W-4	4-104	-	U	-	WPA	M	M		Note 1a
III-W-5	4-102	25.0	-8.7	SAND	WPA	M	M		Note 1a
III-W-6	5-4-194	-	U	-	SD	M	M		Note 1a
III-W-7	5-4-195	-	U	-	SD	M	M		Note 1
III-W-8	4-109	25.0	-0.3	CLAY/SAND	WPA	M	M		Note 1a
III-W-9	P4-78	-	U	-	WPA	M(1)	P		
III-W-10	DS-4-204	-	U	-	SD	M(1)	D		
III-W-11	4-103; BBD1	-	U	FILL*	WPA	M	M	M(10/82-8/83)	Note 1a; Monitored for site II-W-B
III-W-12	S-4-81;38	-	U	-	SD	M	M(2)	M(3/80-3/83)	Note 1a; Monitored for site III-W-A
III-W-13	4-39	20.0	-2.7	ORGANIC SILT*	WPA	M	M		Note 1a
III-W-14	4-40	15.5	2.0	ORGANIC SILT*	WPA	M	D		Note 1
III-W-15	4-67	25.5	-2.2	FILL*	WPA	M	D		Note 1
III-W-16	S-4-118	-	U	-	SD	M	P		
III-W-17	4-77	-	U	-	WPA	M	M		Note 1a
III-W-18	S-4-205	-	U	-	SD	M	D		
III-W-19	4-47	20.5	-2.0	ORGANIC SILT*	WPA	M	P		
III-W-20	4-124	-	U	-	WPA	M	D		
III-W-21	S-4-185	-	U	-	SD	M	D		
III-W-22	S-4-121	-	U	-	SD	M	P		
III-W-23	S-4-119	-	U	-	SD	M	M		Note 1; Not monitored (3/68)
III-W-24	S-4-120	-	U	-	SD	M	M		Not monitored (9/67)
III-W-25	4-46	15.5	2.3	FILL*	WPA	M	P		Note 1
III-W-26	4-123	-	U	-	WPA	M	D		
III-W-27	4-48	15.5	2.1	FILL*	WPA	M	D		Note 1

TABLE III
(Continued)

DETAILS OF WPA AND USGS OBSERVATION WELLS

WELL NUMBER		TIP LOCATION			WELL INSTALLED BY	WELL MONITORING/CONDITION			REMARKS
CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM		1936-1940	1967-1968	1968-PRESENT	
III-W-28	S-4-122	-	U	-	SD	M	P		
III-W-29	4-138	-	U	-	WPA	M	M		Note 1a
III-W-30	4-139	-	U	-	WPA	M	M		Note 1a
III-W-31	4-136	-	U	-	WPA	M	M		
III-W-32	4-121	-	U	-	WPA	M	D		
III-W-33	4-45	15.5	1.4	ORGANIC SILT/FILL*	WPA	M	M		Note 1a
III-W-34	4-122	-	U	-	WPA	M	P		Note 1
III-W-35	S-4-206	-	U	-	SD	M	M		
III-W-36	S-4-184	-	U	-	SD	M	D		
III-W-37	4-111	15.0	3.6	FILL*	WPA	M	P		
III-W-38	4-148	-	U	-	WPA	-	-		Note 1
III-W-39	P4-49	15.5	1.2	FILL*	WPA	M,P	P		Note 1
III-W-40	4-107	-	U	-	WPA	M	D		
III-W-41	4-147	-	U	-	WPA	M	P		
III-W-42	S-4-82	-	U	-	SD	M	D		Note 1
IV-1	5-56	15.5	2.9	FILL*	WPA	M	M		
IV-2	5-97	20.5	-3.4	FILL*	WPA	M	M		
IV-3	5-77	20.5	-2.6	FILL*	WPA	M	M		
IV-4	5-156	20.0	1.3	FILL	WPA	M	D		
IV-5	S-5-188	-	U	-	SD	M	M		
IV-6	5-55	18.0	3.0	FILL*	WPA	M	D		
IV-7	S-5-139	-	U	-	SD	-	D		Not monitored 1936-40
IV-8	5-96	18.0	4.3	FILL*	WPA	M	P		
IV-9	5-165	15.0	3.0	ORGANIC SILT*	WPA	M	D		
IV-10	S-54	20.5	-3.4	FILL*	WPA	M	D		
IV-11	5-85	25.5	-8.3	SAND/CLAY	WPA	M	D		
IV-12	5-164	15.5	-1.3	FILL*	WPA	M	D		
IV-13	5-105	17.5	-0.2	FILL*	WPA	M	D		
IV-14	5-86	25.5	-7.6	CLAY/SAND	WPA	M	D		
IV-15	5-58	15.5	7.5	FILL*	WPA	M	D		
IV-16	5-57	15.5	2.0	FILL*	WPA	M	D		
V-1	9-39	-	U	-	WPA	M	P		
V-2	4-144	-	U	-	WPA	M	M		
V-3	4-116	15.0	2.4	FILL*	WPA	M	P		
V-4	4-51;32	15.5	0.6	FILL*	WPA	M	M	M(1/80-4/81)	Monitored for site III-W-A
V-5	4-150	17.5	0.7	FILL	WPA	M	-		
V-6	S-4-128	-	U	-	SD	M	M(2)		
V-7	S-4-129	-	U	-	SD	M	P		
V-8	4-75	15.0	2.4	FILL*	WPA	M	M		
V-9	4-74	20.0	-1.3	FILL*	WPA	M	M		
V-10	4-106	20.0	-3.3	FILL*	WPA	M	P		
V-11	4-132	20.0	-1.9	FILL*	WPA	M	M		
V-12	4-113	15.0	2.0	FILL*	WPA	M	M		
V-13	4-118	15.0	2.3	FILL*	WPA	M	M		
V-14	4-140	-	U	-	WPA	M	M		
V-15	5-83	20.5	0.4	FILL*	WPA	M	M		Not monitored (3/68)
V-16	S-5-133	-	U	-	SD	M	P		
V-17	9-53	20.0	-1.8	FILL	WPA	M	M		
V-18	9-37	15.0	2.7	FILL*	WPA	M	D		
V-19	4-54	15.5	2.2	FILL*	WPA	M	M		
V-20	4-115	20.0	-2.5	FILL*	WPA	M	P		
V-21	4-55	15.5	2.7	FILL*	WPA	M	P		
V-22	P4-143	17.5	0.3	-	WPA	M(1)	P		
V-23	4-142	-	U	-	WPA	M	M(2)		
V-24	4-58	20.5	-3.1	FILL*	WPA	M	P		
V-25	4-60	15.5	1.0	FILL*	WPA	M	P		
V-26	4-69	17.5	0.1	ORGANIC SILT/FILL*	WPA	M	M		
V-27	5-157	-	U	-	WPA	M	D		Not monitored 1936-40

TABLE III
(Continued)

DETAILS OF WPA AND USGS OBSERVATION WELLS

WELL NUMBER CURRENT STUDY	ORIGINALLY	TIP LOCATION DEPTH	ELEVATION	STRATUM	WELL INSTALLED BY	WELL MONITORING/CONDITION 1936-1940	1967-1968	1968-PRESENT	REMARKS
V-28	S-9-140	-	U	-	SD	M	M		
V-29	4-114	20.0	-2.3	CLAY*	WPA	M	P		
V-30	4-73	20.0	-2.4	ORGANIC SILT/FILL*	WPA	M	M		
V-31	4-105	-	U	-	WPA	M	M		
V-32	4-72	20.0	-4.1	ORGANIC SILT/FILL*	WPA	M	M		
V-33	4-133	-	U	-	WPA	M	D		
V-34	4-71	20.0	-2.3	-	WPA	M	M		
V-35	4-131	20.0	-2.5	-	WPA	M	M		
V-36	4-130	20.0	-3.0	-	WPA	M	P		
V-37	S-4-136	-	U	-	SD	M	D		
V-38	4-101	15.0	4.1	FILL*	WPA	M	M		
V-39	4-141	15.0	1.5	FILL*	WPA	M	M		
V-40	4-149	20.5	-4.1	FILL*	WPA	M	M		
V-41	D5-103	20.0	-3.3	FILL*	WPA	M(1)	P		
V-42	5-53	15.0	1.5	FILL*	WPA	M	M		Not monitored (3/68)
V-43	5-90	20.5	-3.3	FILL*	WPA	M	M		
V-44	9-93	15.0	3.3	ORGANIC SILT*	WPA	M	M		Not monitored (3/68)
V-45	S-9-141	-	U	-	SD	M	M		
V-46	9-113	15.5	0.2	FILL*	WPA	M	M(2)		
V-47	9-114	-	U	-	WPA	M	P		
V-48	S-4-136	-	U	-	SD	M	P		
V-49	9-42	-	U	-	WPA	M	M		
V-50	4-59	15.5	0.3	FILL*	WPA	M	M		
V-51	4-70	20.0	-3.2	-	WPA	M	D		
V-52	5-104	20.0	-4.7	FILL*	WPA	M	D		
V-53	9-97	15.0	1.3	CLAY	WPA	M	D		
V-54	S-9-142	-	U	-	SD	M	P		
V-55	9-91	20.0	-3.8	CLAY	WPA	M	P		
V-56	S-9-146	-	U	-	SD	M	D		
V-57	9-111	15.0	2.1	CLAY	WPA	M	M		
V-58	9-99	20.0	-4.0	CLAY	WPA	M	P		
V-59	S-9-147	-	U	-	SD	M	P		
V-60	S-9-150	-	U	-	SD	M	P		
V-61	9-96	15.0	2.5	CLAY	WPA	M	P		
V-62	DS4-135	-	U	-	SD	M(1)	D		
V-63	4-50	15.5	2.1	FILL*	WPA	M	D		
V-64	S4-130	-	U	-	SD	M	M		
V-65	4-100	15.0	3.3	FILL*	WPA	M	D		
V-66	S4-131	-	U	-	SD	M	D		
V-67	S3-153	-	U	-	SD	M	D		
V-68	S3-190	-	U	-	SD	M	D		

NOTES:

1. Refer to Figures 3 through 9 for observation well locations.
2. Information on Observation Well Locations, Tip Locations, and 1936-40 conditions is from available City of Boston records.
3. Where WPA data do not indicate stratum, it was inferred from data from nearby soil borings and noted with *. Tip Location stratum was taken as indicated on available WPA records. In some instances, data were insufficient to determine stratum.
4. Wells installed by Boston Sewer Department (SD) or Works Progress Administration (WPA).

NOTES FOR WELL MONITORING/CONDITION:

M Observation well water level monitored during the periods indicated. Monitoring between 1936 and 1940 was periodic and done by WPA. USGS monitor water levels twice, once in Sept. 1967 and again in March 1968.
D Observation well destroyed.
P Observation well plugged.
I Observation well inoperative.
(1) WPA data lists high and low water levels but also indicates well was at some time dry.
(2) USGS data indicates well was plugged but also lists high and low water levels.

NOTES FOR REMARKS:

Note 1: Well monitored by Metcalf & Eddy, 1957-58.
Note 1a: Well monitored by Metcalf & Eddy, 1957-58 and 1966-67.

TABLE IV

DETAILS OF OBSERVATION WELLS OTHER THAN THOSE BY WPA AND USGS

SITE REFERENCE NUMBER	WELL NUMBER CURRENT STUDY	WELL NUMBER ORIGINALLY	TIP LOCATION DEPTH	TIP LOCATION ELEVATION	TIP LOCATION STRATUM	TYPE OF WELL (2)	REMARKS (3)
I-A	I-A-1	1	20.0	--	FILL	--	
	I-A-2	2	20.0	--	FILL	--	
	I-A-3	3	20.0	--	FILL	--	
	I-A-4	4	20.0	--	FILL	--	
I-B	I-B-1	OW-1	19.0	-1.0	FILL	A	Monitored only (10/84 - 12/84)
	I-B-2	OW-2	19.0	-4.8	FILL	A	
	I-B-3	OW-3	19.0	-4.7	FILL	A	
	I-B-4	OW-8	20.0	-4.9	FILL	A	
	I-B-5	OW-5	19.0	-3.6	FILL/ORGANIC SILT	A	
	I-B-6	OW-6	19.0	-2.6	FILL	A	
II-E-A	II-E-A-1	C	--	--	--	--	Monitored only (8/84 & 9/84)
	II-E-A-2	84-6	18	-0.4	FILL	S	Monitored only (5/84 - 9/84)
	II-E-A-3	84-7	19.0	-1.9	FILL	S	Monitored only (5/84 - 9/84)
	II-E-A-4	84-8	23.0	-5.5	FILL	S	Monitored only (4/84 - 9/84)
	II-E-A-5	84-9	13.5	4.5	FILL	S	Monitored only (5/84 - 9/84)
II-E-B	II-E-B-1	H2-OW	20.0	-0.6	FILL	A	Monitored (10/78 - 8/79)
	II-E-B-2	H3-OW	20.0	-4.2	FILL	A	Monitored (10/78 - 9/79)
	II-E-B-3	B101	19.0	0.6	FILL	S	Monitored (9/79 - 7/80)
	II-E-B-4	B102	20.0	-0.3	FILL	S	Monitored (9/79 - 7/80)
II-E-C	II-E-C-1	B1-OW	21.3	-1.8	ORGANIC SILT	A	Monitored only (2/70 - 4/70)
	II-E-C-2	B2-OW	19.0	-6.1	FILL	A	Monitored only (2/70 - 4/70)
II-E-D	II-E-D-1	G1-OW	20.0	-2.8	FILL	A	Monitored (10/78 - 9/79)
II-W-A	II-W-A-1	B203-OW	20.1	-3.6	ORGANIC SILT	A	Monitored only (6/81 & 7/81)
	II-W-A-2	B202-OW	20.0	-5.7	FILL	A	Monitored only (6/81 & 7/81)
	II-W-A-3	OW-1	19.0	-2.1	FILL	A	Monitored only (10/82 - 4/83) for site III-W-A
	II-W-A-4	OW-3	18.4	-0.6	FILL	A	
	II-W-A-5	OW-2	18.0	-1.3	FILL	A	
II-W-B	II-W-B-1	B-104 (OW)	20.4	-0.7	SAND	A	Monitored only (2/84 and 3/84). No ORGANIC SILT stratum present
	II-W-B-2	B-101 (OW)	20.8	-5.9	SAND	A	
III-E-A	III-E-A-1	5H, 12	--	--	--	--	Also Monitored for site III-E-H. Plugged 5/80
	III-E-A-2	6H, 13	--	--	--	--	Also Monitored for site III-E-H.
	III-E-A-3	16H, 3E, 1	--	--	--	--	Also Monitored for sites III-E-H and III-W-B
	III-E-A-4	21H	--	--	--	--	Also Monitored for site III-W-B
	III-E-A-5	31AH	--	--	--	--	

TABLE IV
(Continued)

DETAILS OF OBSERVATION WELLS OTHER THAN THOSE BY WPA AND USGS

SITE REFERENCE NUMBER	WELL NUMBER		TIP LOCATION			TYPE OF WELL (2)	REMARKS (3)
	CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM		
III-E-B	III-E-B-1	84-1 (OW)	21.0	-3.5	FILL	S	
	III-E-B-2	84-2 (OW)	23.0	-4.9	FILL	S	
	III-E-B-3	84-3 (OW)	12.5	1.7	FILL	S	
	III-E-B-4	84-5 (OW)	22.0	-3.4	FILL	S	
	III-E-B-5	84-11 (OW)	15.5	1.9	FILL	S	
	III-E-B-6	84-13 (OW)	20.0	-2.9	FILL	S	Wells monitored only (4/84 - 9/84)
	III-E-B-7	84-10 (OW)	20.0	-2.0	FILL	S	
	III-E-B-8	84-14 (OW)	19.0	-1.9	FILL	S	
	III-E-B-9	84-4 (OW)	17.0	0.2	FILL	S	
	III-E-B-10	84-15 (OW)	18.0	0.9	FILL	S	
	III-E-B-11	A	--	U	--	--	
	III-E-B-12	84-16 (OW)	19.5	0.3	FILL	S	
III-E-C	III-E-C-1	W1	48.0	-33.3	SAND	S	Monitored only (12/69 - 3/70)
	III-E-C-2	B106	34.1	-17.3	SAND/GRAVEL	--	Monitored only (9/69 - 3/70)
	III-E-C-3	B105	34.8	-18.6	SAND/CLAY	--	Monitored only (9/69 - 3/70)
	III-E-C-4	W2	15.5	-0.1	FILL.	A	Monitored only (12/69 - 3/70)
	III-E-C-5	B204	34.5	-19.9	SAND/CLAY	S	Monitored only (7/80 & 8/80)
	III-E-C-6	B202	25.0	-10.5	SAND/CLAY	S	
	III-E-C-7	B201	20.4	-7.0	ORGANIC SILT	S	
	III-E-C-8	B203	19.9	-6.1	FILL	S	
	III-E-C-9	326	30.2	-14.3	ORGANIC SILT	A	
	III-E-C-10	327	31.7	-16.0	CLAY	A	
	III-E-C-11	328	32.5	-15.3	SAND/SILT/GRAVEL	A	Wells for site III-E-C not installed in FILL or ORGANIC SILT strata are in near shore deposits not typical of most of Back Bay.
	III-E-C-12	329	31.9	-15.5	SAND/GRAVEL/CLAY	A	
	III-E-C-13	330	31.8	-16.1	CLAY	A	
	III-E-C-14	331	29.5	-15.2	SAND/CLAY	A	
	III-E-C-15	332	29.5	-13.8	CLAY	A	
	III-E-C-16	333	28.5	-14.9	PEAT	A	
	III-E-C-17	334	28 5	-14.8	ORGANIC SILT	A	
	III-E-C-18	335	30.5	-16.0	ORGANIC SILT	A	
	III-E-C-19	336	31.5	-16.4	ORGANIC SILT	A	
	III-E-C-20	208	20.2	-3.2	SAND/GRAVEL	--	Monitored only (7/81)
	III-E-C-21	216	20.5	-3.4	ORGANIC SILT	--	Monitored only (7/81)
III-E-D	III-E-D-1	B-1 OW	20.4	-2.1	CLAY/SILT	A	Monitored only (5/79 - 9/79)
	III-E-D-2	B-3 OW	20.1	-2.1	CLAY	S	
III-E-E	III-E-E-1	68-14 (OW4)	22.3	-2.3	FILL	A	
	III-E-E-2	68-7 (OW2)	10.5	-1.0	FILL	A	
	III-E-E-3	68-1 (OW1)	12.0	-3.7	FILL	A	Monitored only (8/68 - 11/68)
	III-E-E-4	68-9 (OW3)	--	--	FILL		
III-E-F	III-E-F-1	OW-1	3.2	-3.6	ORGANIC SILT	S	
	III-E-F-2	OW-2	2.9	-3.2	ORGANIC SILT	S	
	III-E-F-3	OW-3	2.8	-3.0	ORGANIC SILT	S	Monitored only (11/82 and 12/82)
	III-E-F-4	OW-4	2.9	-3.1	ORGANIC SILT	S	
	III-E-F-5	OW-5	3.1	-3.4	ORGANIC SILT	S	For site III-E-F wells lowest water level was observed in Nov. 1982 when water level in crawl space below subbasement was controlled at El. -6.0 for a period of 4 days. Highest level was observed in Dec. 1982 with water level controlled at El. +1.0
	III-E-F-6	OW-6	2.9	-3.1	ORGANIC SILT	S	
	III-E-F-7	OW-7	2.9	-3.2	ORGANIC SILT	S	
	III-E-F-8	OW-8	3.2	-3.3	ORGANIC SILT	S	
	III-E-F-9	OW-9	3.2	-3.5	ORGANIC SILT	S	
	III-E-F-10	OW-10	3.2	-3.4	ORGANIC SILT	S	
	III-E-F-11	OW-11	2.2	-2.3	ORGANIC SILT	S	

TABLE IV
(Continued)

DETAILS OF OBSERVATION WELLS OTHER THAN THOSE BY WPA AND USGS

SITE REFERENCE NUMBER	WELL NUMBER		TIP LOCATION			TYPE OF WELL (2)	REMARKS (3)
	CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM		
III-E-G	III-E-G-1	B201 OW	25.0	-7.8	SAND	A	Monitored only (3/77 - 2/78).
	III-E-G-2	B216 OW	30.0	-8.3	SAND	A	
	III-E-G-3	B104 OW	21.5	-3.4	SAND	A	Wells for site III-E-G were installed in near shore deposits not typical of most of Back Bay
	III-E-G-4	OW-401	37.0	-20.0	SAND/GRAVEL	A	
	III-E-G-5	OW-402	37.0	-21.0	FINE SAND/SILT	A	
	III-E-G-6	OW-403	36.5	-20.2	CLAY	A	
	III-E-G-7	OW-404	39.0	-20.8	CLAY	A	
	III-E-G-8	OW-405	42.5	-20.3	--	A	
	III-E-G-9	OW-406	40.6	-20.0	--	A	
	III-E-G-10	OW-407	45.0	-20.6	--	A	
III-E-H	III-E-H-1	203	25.0	-3.9	ORGANIC SILT	A	
	III-E-H-2	204	25.0	-7.7	ORGANIC SILT	A	
III-E-I	III-E-I-1	75-3	--	--	--	--	Also Monitored for site III-E-H (1980-81) and site III-E-B (5/84 - 9/84).
	III-E-I-2	75-2	--	--	--	--	
	III-E-I-3	MH	--	--	--	--	Installed prior to 1935. Also monitored for site III-E-B (8/84 - 9/84)
	III-E-I-4	75-1	--	--	--	--	Also monitored for site III-E-H (1980-84) and site III-E-B (5/84 - 9/84).
	III-E-I-5	75-4	--	--	--	--	
	III-E-I-6	TH	--	--	--	--	Installed prior to 1935. Also monitored for site III-E-B (8/84 - 9/84).
	III-E-I-7	1	--	--	--		
	III-E-I-8	2	--	--	--		
	III-E-I-9	3	--	--	--		Installed prior to 1940.
	III-E-I-10	4	--	--	--		
	III-E-I-11	5	--	--	--		
	III-E-I-12	6	--	--	--		
	III-E-I-13	7	--	--	--		
	III-E-I-14	9	--	--	--		
	III-E-I-15	10	--	--	--		
III-E-J	III-E-J-1	B101 (OW)	20.7	-7.1	ORGANIC SILT	A	Monitored only (11/84)
	III-E-J-2	B102 (OW)	20.2	-6.6	ORGANIC SILT	A	
	III-E-J-3	B104A (OW)	20.9	-4.8	FILL	A	
	III-E-J-4	B106 (OW)	45.0	-27.8	SILT AND CLAY	A	
	III-E-J-5	B108A (OW)	20.4	4.6	ORGANIC SILT	A	
	III-E-J-6	B109 (OW)	30.0	--	SAND	S	
	III-E-J-7	B110 (OW)	33.0	15.4	SAND	A	
III-W-A	III-W-A-1	205	25.0	-7.5	ORGANIC SILT	A	
	III-W-A-2	WH8	22.0	-4.3	FILL	A	
	III-W-A-3	WH9	25.7	-4.5	FILL	A	
	III-W-A-4	WH10	28.0	-4.4	FILL	A	
	III-W-A-5	CA19	20.0	-1.0	FILL	A	Monitored only (7/80 - 3/81)
	III-W-A-6	CA20	20.4	-7.0	ORGANIC SILT	A	Monitored only (7/80 - 1/81)
	III-W-A-7	MH12	25.2	-8.1	ORGANIC SILT	A	Monitored only (8/80 - 2/81)
	III-W-A-8	MH11	35.5	-7.6	ORGANIC SILT	A	
	III-W-A-9	201	25.0	-1.6	ORGANIC SILT	A	
	III-W-A-10	202	23.0	-6.4	FILL	A	

TABLE IV
(Continued)

DETAILS OF OBSERVATION WELLS OTHER THAN THOSE BY WPA AND USGS

SITE REFERENCE NUMBER	WELL NUMBER CURRENT STUDY	WELL NUMBER ORIGINALLY	TIP LOCATION DEPTH	TIP LOCATION ELEVATION	TIP LOCATION STRATUM	TYPE OF WELL (2)	REMARKS (3)
III-W-B	III-W-B-1	I-12-OW	15.0	-2.7	FILL	A	Also monitored for site III-W-B
	III-W-B-2	I-100-OW (S), 4S	20.0	-3.2	FILL	S	
	III-W-B-2a	I-100-OW (D); 4D	38.3	-21.5	SAND	S	
	III-W-B-3	I-105-OW (S)	12.5	-0.7	FILL	S	
	III-W-B-3a	I-105-OW (D)	37.0	-25.2	SAND	S	
	III-W-B-4	I-98-OW (S)	17.0	0.2	FILL	S	
	III-W-B-4a	I-98-OW (D)	35.0	-17.9	SAND	S	
	III-W-B-5	I-19-OW	30.3	-12.7	ORGANIC SILT	A	
	III-W-B-6	I-96A-OW (S)	18.0	-1.3	FILL	S	
	III-W-B-6a	I-96-OW (D)	34.9	-18.1	SAND	S	
	III-W-B-7	I-94-OW (S)	15.0	2.1	FILL	S	
	III-W-B-7a	I-94-OW (D)	34.8	-17.8	SAND	S	
	III-W-B-8	I-104-OW (S)	24.9	-0.8	FILL	S	
	III-W-B-8a	I-104-OW (D)	37.3	-13.2	SAND	S	
	III-W-B-9	OW-1900	33.0	-3.8	FILL	S	
	III-W-B-10	OW-1954	15.0	1.7	FILL	S	
	III-W-B-10a	OW-1954	36.0	-25.0	SAND	S	
	III-W-B-11	OW-2036	36.0	-8.6	FILL	S	
	III-W-B-12	OW-2076	19.0	-7.4	FILL	S	
	III-W-B-13	OW-2104	20.0	-3.2	FILL	S	Also monitored for Site III-W-B
	III-W-B-14	I-OW-4E;2	20.3	-3.2	FILL	A	
III-W-C	III-W-C-1	B84-1 (OW)	34.9	-5.8	FILL	S	Monitored only (4/84 - 5/84)
	III-W-C-2	B84-2 (OW)	49.0	-18.2	SAND	S	Monitored only (4/84 - 9/84)
III-W-D	III-W-D-1	B2-OW	23.6	-4.6	SAND	A	Well plugged
	III-W-D-2	B3-OW	25.2	-6.3	SAND	A	Monitored only (4/83)
III-W-E	III-W-E-1	OW-1	13.0	-0.7	FILL	A	Monitored only during construction (11/80 - 2/81)
	III-W-E-2	OW-2	13.0	0.2	FILL	A	
III-W-F	III-W-F-1	H3	--	--	ORGANIC SILT/FILL	A	
	III-W-F-2	H2	--	--	ORGANIC SILT/FILL	A	
	III-W-F-3	H1	--	--	ORGANIC SILT/FILL	A	
	III-W-F-4	P-1	--	--	--	--	
	III-W-F-5	P-5	--	--	--	--	
	III-W-F-6	P-20	--	--	--	--	
	III-W-F-7	P-24	--	--	--	--	
	III-W-F-8	P-25	--	--	--	--	
	III-W-F-9	P-31	--	--	--	--	
	III-W-F-10	P-35	--	--	--	--	
	III-W-F-11	P-41	--	--	--	--	
	III-W-F-12	H-1	--	--	SAND	--	Wells III-W-F-12 - III-W-F-31 are in the floor slabs within the sheeted section of the Prudential Center. They are in or reflect groundwater levels of the natural SAND OUTWASH stratum
	III-W-F-13	H-2	--	--	SAND	--	
	III-W-F-14	H-3	--	--	SAND	--	
	III-W-F-15	SC-1	--	--	SAND	--	
	III-W-F-16	SC-2	--	--	SAND	--	
	III-W-F-17	SC-3	--	--	SAND	--	
	III-W-F-18	SC-4	--	--	SAND	--	
	III-W-F-19	SE-3	--	--	SAND	--	
	III-W-F-20	SE-5	--	--	SAND	--	
	III-W-F-21	SE-11	--	--	SAND	--	
	III-W-F-22	NC-1	--	--	SAND	--	
	III-W-F-23	NC-2	--	--	SAND	--	
	III-W-F-24	NE-3	--	--	SAND	--	
	III-W-F-25	NE-5	--	--	SAND	--	
	III-W-F-26	NE-7	--	--	SAND	--	
	III-W-F-27	FE-11	--	--	SAND	--	
	III-W-F-28	FE-14	--	--	SAND	--	
	III-W-F-29	FE-18	--	--	SAND	--	
	III-W-F-30	FE-19	--	--	SAND	--	
	III-W-F-31	FE-20	--	--	SAND	--	

TABLE IV
(Continued)

DETAILS OF OBSERVATION WELLS OTHER THAN THOSE BY WPA AND USGS

SITE REFERENCE NUMBER	WELL NUMBER		TIP LOCATION			TYPE OF WELL (2)	REMARKS (3)
	CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM		
III-W-G	III-W-G-1	4	20.4	-3.0	ORGANIC SILT	A	
	III-W-G-2	5	14.7	2.8	ORGANIC SILT	A	
	III-W-G-3	7	6.1	4.6	FILL	A	
	III-W-G-4	8A	6.1	4.1	ORGANIC SILT	A	
	III-W-G-5	9	6.2	2.3	FILL	A	
	III-W-G-6	TP-1	6.2	2.3	ORGANIC SILT	A	
	III-W-G-7	TP-2	9.6	1.1	ORGANIC SILT	A	
	III-W-G-8	TP-3	10.0	-0.3	ORGANIC SILT	A	
	III-W-G-9	TP-4	9.2	1.5	ORGANIC SILT	A	
	III-W-G-10	TP-5	8.7	2.1	ORGANIC SILT	A	
	III-W-G-11	1	23.6	-6.0	--	A	
	III-W-G-12	2	19.7	-2.5	SAND	A	
	III-W-G-13	3	22.1	-4.4	SAND	A	
	III-W-G-14	8	17.4	-7.2	SAND	A	
	III-W-G-15	10	14.2	-4.5	SAND	A	
	III-W-G-16	T1	16.7	-6.3	SAND	A	
	III-W-G-17	T2	14.7	-4.4	SAND	A	
	III-W-G-18	T3	13.5	-3.7	SAND	A	
III-W-H	III-W-H-1	NONE	20	--	FILL	--	
III-W-I	III-W-I-1	1H	--	--	--	--	
	III-W-I-2	2H;10	--	--	--	--	
	III-W-I-3	3H;11	--	--	--	--	Also monitored for site III-W-A (1980-81)
	III-W-I-4	4H	--	--	--	--	
	III-W-I-5	135H	--	--	--	--	Also monitored for site III-W-B (1977-80)
	III-W-I-6	OWH1;8	--	--	--	--	Also monitored for site III-W-A (5/80-2/81)
	III-W-I-7	136H	--	--	--	--	
III-W-J	III-W-J-1	NONE	20	--	FILL	--	
IV-A	IV-A-1	I-OW-1	21.2	-15.0	ORGANIC SILT	A	
IV-B	IV-B-1	BE1-OW1	15.0	6.7	ORGANIC SILT	A	Monitored only (11/79)
	IV-B-2	BE5-OW2	15.0	4.4	FILL/CLAY	A	Monitored only (11/79 & 12/79)
IV-C	IV-C-1	B2-OW	20.0	-9.7	ORGANIC SILT	A	Monitored only (11/79)
IV-D	IV-D-1	OW #5	18.4	-2.0	ORGANIC SILT	A	

TABLE IV
(Continued)

DETAILS OF OBSERVATION WELLS OTHER THAN THOSE BY WPA AND USGS

SITE REFERENCE NUMBER	WELL NUMBER		TIP LOCATION			TYPE OF WELL (2)	REMARKS (3)
	CURRENT STUDY	ORIGINALLY	DEPTH	ELEVATION	STRATUM		
V-A	V-A-1	I-OW-6	22.0	-13.3	ORGANIC SILT	A	
	V-A-2	I-OW-5	25.7	-17.1	ORGANIC SILT	A	
	V-A-3	I-106A-OW (S); 5S	17.8	-0.4	FILL	S	Also monitored for site III-W-A (1/80 - 3/83)
	V-A-3a	I-106A-OW (D); 5D	36.3	-18.9	SAND	S	
	V-A-4	I-7-OW	18.2	-2.8	ORGANIC SILT	A	
	V-A-5	I-OW-2	33.5	-10.8	ORGANIC SILT	A	
	V-A-6	I-107 OW (S)	25.5	-3.4	FILL	S	
	V-A-6a	I-107-OW (D)	39.0	-16.9	ORGANIC SILT	S	
	V-A-7	I-99A-OW (S)	19.3	-1.6	FILL	S	
	V-A-7a	I-99A-OW (D)	30.1	-12.4	ORGANIC SILT	S	
	V-A-8	I-97-OW (S)	20.0	-2.3	FILL	S	
	V-A-8a	I-97-OW (D)	31.8	-14.1	ORGANIC SILT	S	
	V-A-9	I-95-OW (S)	18.0	0.2	FILL	S	
	V-A-9a	I-95-OW (D)	27.8	-9.7	ORGANIC SILT	S	
	V-A-10	I-93-OW (S)	20.0	-2.0	FILL	S	
	V-A-10a	I-93-OW (D)	29.0	-5.4	ORGANIC SILT	S	
	V-A-11	OW-1947	21.0	-9.8	FILL	S	
	V-A-12	OW-2042	12.5	-5.5	FILL	S	
	V-A-13	OW-2063	20.5	-8.5	FILL	S	
V-B	V-B-1	138;18	--	--	--	--	Well V-B-1 often reported to flooded Monitored for site III-W-A (1/80 - 7/81)
	V-B-2	13H	--	--	--	--	
	V-B-3	14H	--	--	--	--	
	V-B-4	22H	--	--	--	--	

NOTES:

(1) See Table II for sources of data on observation well details, project names, and years wells were installed and monitored.

(2) Type of Well: A : Averaging - not sealed in a particular stratum. Probably influenced most by groundwater levels in Fill Stratum.
S : Sealed in a particular stratum or zone.

(3) Monitoring periods indicated where water levels were monitored less than one year. Water levels in the other wells were monitored for at least one year, see Table II for years monitored.

TABLE V

CHRONOLOGY OF MAJOR BUILDING CONSTRUCTION IN BACK BAY

PROJECT	LOCATION	ZONE	YEARS OF CONSTRUCTION	FOUNDATION TYPE	FOUNDATION BEARING STRATUM	ELEVATION OF DEEPEST BASEMENT	EFFECTS OF CONSTRUCTION ON ADJACENT AREAS
Copley Plaza Hotel	St. James Ave. and Dartmouth St.	III-E	1912				
John Hancock Clarendon Building	Clarendon St. between St. James Ave and Stuart St.	III-E	1920	Wood Piles	Clay	El. 0 to -12	
Heath Building	Columbus Ave. and Clarendon St.	IV	1925	Belled Caissons	Clay	El. 9	
Ritz Carlton Hotel	Arlington and Newbury Sts.	II-E	1927				
Y.W.C.A. Building	Clarendon and Stuart Sts.	III-E	1928				
Professional Arts Building			1930				
Christian Science Publishing House	Clearway St.	III-W	1931 - 1934	Spread Footings	Sand Outwash		Groundwater drawdown in Sand and Fill.
Liberty Mutual Insurance Company Building	Berkeley St. between St. James Ave. and Stuart St.	III-E	1936 - 1937	Belled Piers	Clay		
New England Mutual Life Insurance Co. Building	Clarendon St. between Newbury and Boylston Sts.	III-E	1939 - 1940	Spread Footings and Mats	Clay		Groundwater drawdown in Fill.
John Hancock Berkeley Building	Berkeley St. between St. James Ave. and Stuart St.	III-E	1946 - 1947	Steel H-Piles	Bedrock	El. -24	Groundwater drawdown in Fill. Major settlements of adjacent streets.
Liberty Mutual Ins. Co. Building Addition	Between St. James Ave. and Stuart St.	III-E	1958	Belled Piers	Clay		
Christian Science Publishing House Underground Equipment Room	Between Mother Church and Publishing House	III-W	1958	Spread Footings	Sand Outwash		Significant groundwater drawdown in SAND.
Prudential Center Tower	Between Boylston St. and Huntington Ave.	III-W	1959 - 1960	Steel H-Piles & Drilled Caissons	Bedrock		Groundwater drawdown in Fill and Sand.
Prudential Center Central Area Parking Garage	Between Boylston St. and Huntington Ave.	III-W	1959 - 1961	Soil-Supported Slab	Sand Outwash	El. 3	
Hynes Auditorium	Dalton and Boylston Sts.	III-W	1962 - 1963	Steel Pipe and H-Piles	Glacial Till		
Sheraton Hotel at Prudential Center	Dalton and Belvidere Sts.	III-W	1962 - 1963	Steel Pipe and H-Piles	Glacial Till	El. -2	Groundwater drawdown in Sand.

TABLE V
(continued)

CHRONOLOGY OF MAJOR BUILDING CONSTRUCTION IN BACK BAY

PROJECT	LOCATION	ZONE	YEARS OF CONSTRUCTION	FOUNDATION TYPE	FOUNDATION BEARING STRATUM	ELEVATION OF DEEPEST BASEMENT	EFFECTS OF CONSTRUCTION ON ADJACENT AREAS
Prudential Center Southeast Tower	Between Boylston St. and Huntington Ave.	III-W	1962	Concrete-Filled Pipe Piles	Glacial Till		Minor heave due to pile driving.
Prudential Center Apartment Building 5	Between Boylston St. and Huntington Ave.	III-W	1962	Concrete-Filled Pipe Piles	Glacial Till		
Prudential Center Apartment Buildings 1 and 3	Between Boylston St. and Huntington Ave.	III-W	1963	Drilled-In Caissons	Bedrock		
180 Beacon Street	Beacon St.	II-E	1964 - 1965	Concrete-Filled Pipe and Shell Piles	Glacial Till	El. -14	Groundwater drawdown in Sand. Minor structure settlement.
Prudential Center Lord & Taylor Retail Store	Boylston St. near Exeter St.	III-W	1966 - 1967	Concrete-Filled Pipe Piles	Bedrock		
Prudential Center North Area Parking Garage	Between Boylston St. and Huntington Ave.	III-W	1964 - 1967	Wood Piles	Sand Outwash	El. 3	
Christian Science Administration Tower	Huntington Ave. between Cumberland and West Newton St.	III-W	1967 - 1968	Concrete-Filled Pipe Piles	Glacial Till	El. 5	Groundwater drawdown in Fill.
John Hancock Tower	Clarendon St. between St. James Ave. and Stuart St.	III-E	1968 - 1972	Steel H-Piles	Bedrock	El. -24	Major settlement of adjacent streets due to sheet pile movements.
John Hancock Parking Garage	Over Mass. Turnpike between Clarendon and Dartmouth Sts.	III-E	1968 - 1969	Drilled-In Caissons	Bedrock		
Christian Science Underground Parking Garage, Sunday School and Colonnade Buildings	Huntington Ave. between Belvidere St. and Mass. Ave.	III-W	1968 - 1972	Pressure Injected Footings	Sand Outwash	El. 7	
Prudential Center Sak's Fifth Avenue Retail Store	Between Boylston St. and Huntington Ave.	III-W	1970	Pressure Injected Footings	Sand Outwash		
Boston Public Library Addition	Exeter St. between Boylston and Bladgen Sts.	III-W	1972	Mat	Sand Outwash and Clay		
Christian Science - New Portico for Mother Church	Mass. Ave. and Norway St.	III-W	1973	Pressure Injected Footings	Sand Outwash		Groundwater drawdown in Sand.
Colonnade Hotel	Huntington Ave. between West Newton and Garrison Sts.	III-W	1975	Pressure Injected Footings	Sand Outwash		

TABLE V
(continued)

CHRONOLOGY OF MAJOR BUILDING CONSTRUCTION IN BACK BAY

PROJECT	LOCATION	ZONE	YEARS OF CONSTRUCTION	FOUNDATION TYPE	FOUNDATION BEARING STRATUM	ELEVATION OF DEEPEST BASEMENT	EFFECTS OF CONSTRUCTION ON ADJACENT AREAS
Symphony Towers	Mass. Ave. and Huntington Ave.	III-W	1977	Pressure Injected Footings	Sand Outwash	El. 5	Groundwater drawdown in Sand and Fill.
Exeter Towers	Exeter and Newbury Sts.	III-W	1980	Pressure Injected Footings	Sand Outwash		
Copley Place	Huntington Ave. between Dartmouth and Harcourt Sts.	III-W	1980 - 1983	Precast Concrete Piles	Bedrock		Groundwater drawdown in Fill and Sand.
Ritz Carlton Addition	Newbury and Arlington Sts.	II-E	1980 - 1981	Pressure Injected Footings	Sand and Gravel	El. 10	
Ritz Carlton Garage	Newbury and Arlington Sts.	II-E	1981	Precast Concrete Piles	Clay/Sand	El. 16	
Greenhouse Apartments	Huntington Ave. between West Newton and Cumberland Sts.	III-W	1981	Pressure Injected Footings	Sand Outwash	El. -2 Elevator Pits	Groundwater drawdown in Fill
Back Bay Hilton Hotel	Dalton and Belvidere Sts.	III-W	1981 - 1982	Precast Concrete Piles	Glacial Till		
South Cove Plaza, East and West	Tremont St.; Stuart and Church Sts.	III-E	1981	Belled Caissons	Clay	El. 6	
Transportation Building	Park Ave. and Stuart St.	III-E	1981 - 1982	Concrete Mat	Sand and Gravel		
Four Seasons Hotel	Boylston St. and Park Ave.	III-E	1982 - 1983	Pressure Injected Footings	Sand and Gravel		
Zero Newbury St.	Newbury and Arlington St.	II-E	1983	Root-Piles			
199 Boylston St.	Boylston St.	III-E	1983	Precast Concrete Piles	Glacial Till		
One Exeter Place	Boylston and Exeter Sts.	III-W	1983	Precast Concrete Piles	Bedrock	El. 3.5	

TABLE VI

TEMPORARY EFFECTS OF SELECTED MAJOR BACK BAY CONSTRUCTION ON GROUNDWATER LEVELS

	PROJECT OR DEVELOPMENT	YEARS OF DEWATERING	SITE DEWATERING: PROBABLE LOWEST ELEVATION	SITE DEWATERING: METHOD OR REMARK	LATERAL EARTH SUPPORT: TYPE	LATERAL EARTH SUPPORT: LOWEST STRATUM PENETRATED	GROUNDWATER LOWERING IN ADJACENT AREAS CAUSED BY SITE DEWATERING: DISTANCE FROM EXCAVATION	GROUNDWATER LOWERING IN ADJACENT AREAS CAUSED BY SITE DEWATERING: DRAWDOWN	OTHER REMARKS
SUBWAYS	BOYLSTON STREET SUBWAY	1912 - 1914	El. -19	Deepest between Arlington St. and Copley Sq.	Steel Sheet Piles	CLAY	No reports available		o Siphon piles installed to allow groundwater movement across structure
SUBWAYS	HUNTINGTON AVENUE SUBWAY	1937 - 1940	El. -20	Lowest under Mass. Pike and railroad	Steel Sheet Piles	CLAY	200 ft. 800 ft. 1100 ft. 0.4 mi.	13 ft. 12 ft. (after 2 yrs) 8 ft. 7 ft.	o Dewatered for 3 years o WPA data indicates large area affected (Mass. Ave. to Dartmouth St.)
SUBWAYS	HUNTINGTON AVENUE SUBWAY: PRUDENTIAL ENTRANCE	1969 - 1970	El. -15				300 ft. 400 ft. 800 ft. 1000 ft. 1200 ft. 1400 ft.	18 ft. 4 ft. 6 ft. 8 ft. 6 ft. 4 ft.	o Dewatering for 5 months o No drawdown observed in FILL
SEWERS and DRAINS	BOSTON MAIN DRAINAGE SYSTEM	1877 - 1884	Varied; El. -2 to El. -7.5	Underdrains and sumps	Probably wood sheeting	ORGANIC SILT and SAND	No records available		o Significant drawdown in adjacent areas
SEWERS and DRAINS	LOW LEVEL SEWERS	1910 - 1912		Underdrains and sumps			No records available		o Significant drawdown in adjacent areas
SEWERS and DRAINS	SEWER SIPHON THROUGH PRUDENTIAL CENTER	1959 - 1961	El. -4	Intermittent Wellpoint Pumping	Unknown		None at 100 ft. from excavation		o Prudential recharge system apparently maintained groundwater levels
SEWERS and DRAINS	WEST SIDE INTERCEPTOR RELOCATION AT CHRISTIAN SCIENCE	1968 - 1969	El. -7.5	Wellpoints in SAND	Steel Sheet Piles	CLAY	100 ft. 700 ft. 100 ft.	8 to 10 ft. in SAND none in SAND 3 ft. in FILL	o Recharge around Christian Science Church eliminated drawdown in FILL
BUILDINGS	CHRISTIAN SCIENCE PUBLISHING HOUSE	1931 - 1934	El. - 3 to -6	Wellpoints in SAND	Unknown	SAND	300 ft. 300 ft. 1000 ft.	8 ft. in SAND 2 1/2 ft. in FILL 4-5 ft. (in SAND?)	
BUILDINGS	CHRISTIAN SCIENCE PUBLISHING HOUSE UNDERGROUND EQUIPMENT ROOM	1958	El. -3	Wellpoints in SAND	Steel Sheet Piles	SAND, halfway through	At excavation 500 ft. 1200 ft.	11 ft. in SAND 8 ft. in SAND 4 ft. in SAND	o Little drawdown in FILL
BUILDINGS	CHRISTIAN SCIENCE ADMINISTRATION BUILDING	1967 - 1968	El. -5	Open pumping in excavation	Unknown		200 ft. 500 ft.	"Some" in FILL 0 ft. in FILL	

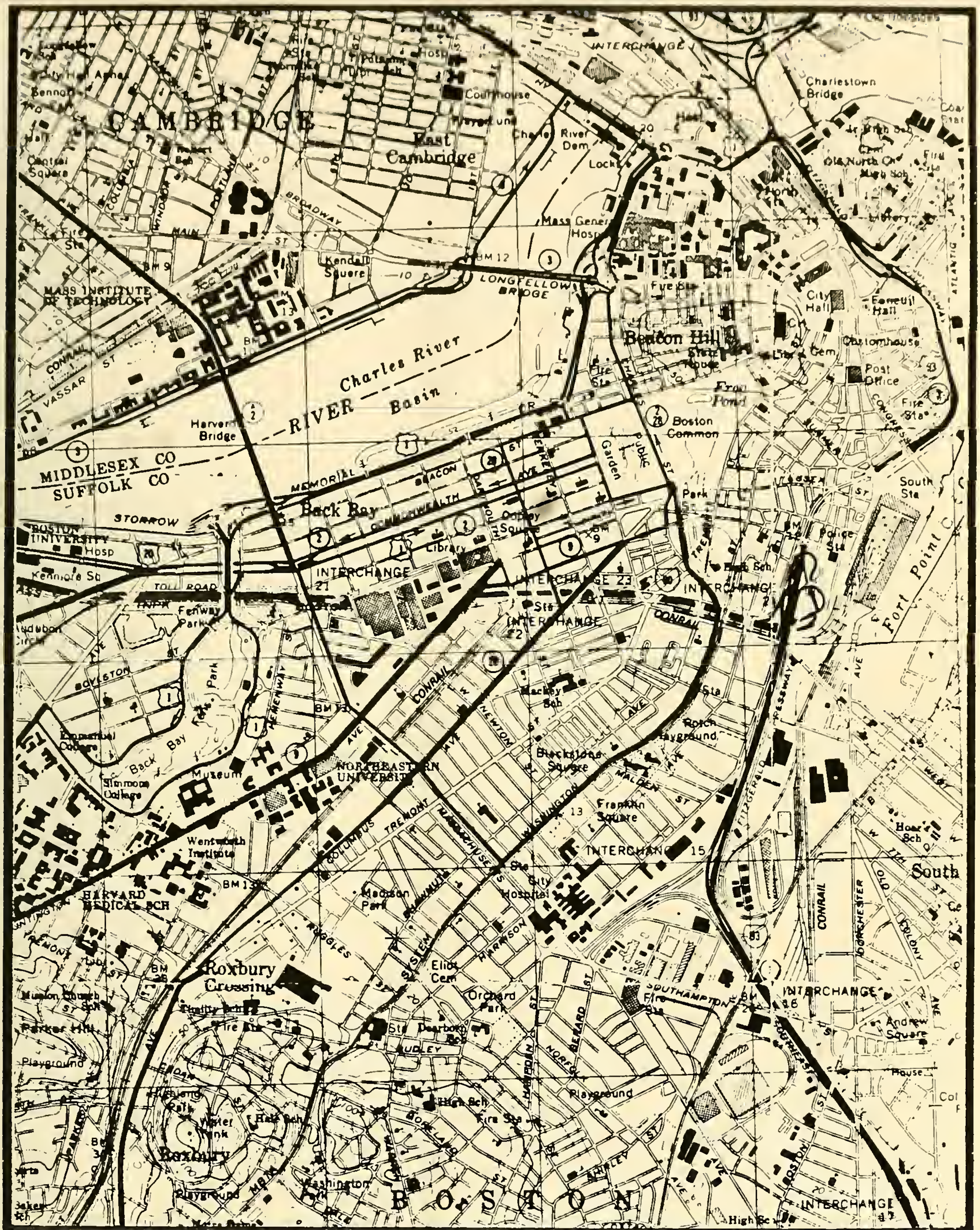
TABLE VI
(continued)

TEMPORARY EFFECTS OF SELECTED MAJOR BACK BAY CONSTRUCTION ON GROUNDWATER LEVELS

	PROJECT OR DEVELOPMENT	YEARS OF DEWATERING	SITE DEWATERING: PROBABLE LOWEST ELEVATION	SITE DEWATERING: METHOD OR REMARK	LATERAL EARTH SUPPORT: TYPE	LATERAL EARTH SUPPORT: LOWEST STRATUM PENETRATED	GROUNDWATER LOWERING IN ADJACENT AREAS CAUSED BY SITE DEWATERING: DISTANCE FROM EXCAVATION	GROUNDWATER LOWERING IN ADJACENT AREAS CAUSED BY SITE DEWATERING: DRAWDOWN	OTHER REMARKS
BUILDINGS	CHRISTIAN SCIENCE COLANNADE BUILDING	1968 - 1969	El. 0	Shallow, probably by sumps	Unknown			"Minor" in FILL	o No data available on off-site drawdown
BUILDINGS	CHRISTIAN SCIENCE NEW PORTICO, MOTHER CHURCH	1973	El. -4	Wellpoints in SAND	Partially sheeted	SAND	40 ft. 90 ft. 230 ft.	8 ft. in SAND 4 1/2 in SAND 5 1/2 in SAND	o No drawdown observed in FILL
BUILDINGS	JOHN HANCOCK BERKELEY BLDG.	1946 - 1947	El. -25	Sumps in excavation	Unknown		90 ft. 140 ft.	10 ft. 7 ft. in FILL	
BUILDINGS	JOHN HANCOCK TOWER	1968 - 1970	El. -28	Deep wells within site	Steel Sheet Piles	CLAY	Near	Negligible in FILL	o No SAND at site
BUILDINGS	PRUDENTIAL CENTER TOWER	1959 - 1960	El. -12	Wellpoints in SAND	Steel Sheet Piles	CLAY	Nearby	1-2 ft. in FILL	o Recharged FILL and SAND outside sheeting
BUILDINGS	SHERATON HOTEL AT PRUDENTIAL CENTER	1962 - 1963	El. -4	Wellpoints in SAND	Steel Sheet Piles	CLAY	400 ft.	Initially 3 1/2 ft. in SAND	o Recharge system correction eliminated drawdown
BUILDINGS	NEW ENGLAND MUTUAL LIFE INS. CO. BLDG.	1939 - 1940	El. -12	Sumps in excavation	Steel Sheet Piles	CLAY	Nearby	4 to 6 ft. in FILL	o No SAND at site
BUILDINGS	BOSTON HERALD TRAVELER BLDG.	1957	Deep in sand above bedrock		Unknown		1 mile	30 ft. in deep sand	o Dewatering for caissons to rock
BUILDINGS	180 BEACON ST. APARTMENT BLDG.	1964 - 1966	El. -14	Unknown	Concrete Slurry Walls	Unknown	Nearby	12-15 ft. in SAND	o Slurry wall leaked o SAND recharge unsuccessful
BUILDINGS	SYMPHONY PLAZA APARTMENTS	1977	El. +4 to -3	Sumps in pile cap pits	Unknown		Nearby	3 ft. in FILL	
BUILDINGS	GREENHOUSE APARTMENTS	1981	El. -2	Sumps in elevator pits	Soldier Pile and Wood Lagging	ORGANIC SILT	40 ft.	3 ft. in FILL	
BUILDINGS	ONE EXETER	1982-1983	El. 0	Sumps in excavation	Steel Sheet Piles	CLAY	Nearby	Negligible in FILL	

NOTICE !

THIS IS YOUR MASTER LOCUS COPY. KEEP IN YOUR PROJECT FILE FOR FUTURE COPIES AS NEEDED.



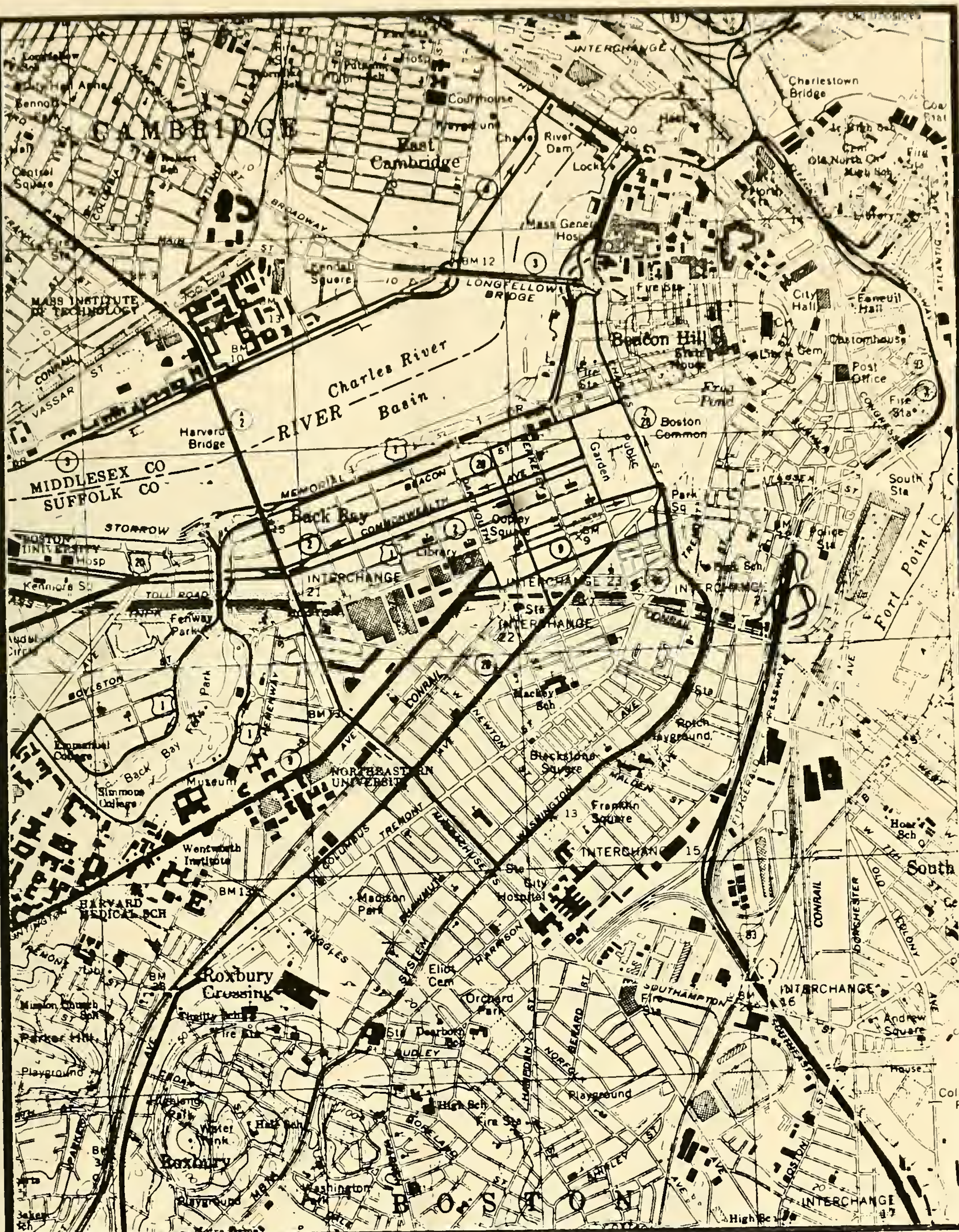
HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS

N

PROJECT LOCUS
U.S.G.S. QUADRANGLE
BOSTON SOUTH, MA
APPROXIMATE SCALE 1:25,000

FILE NO. 5381 AI

FIGURE 1



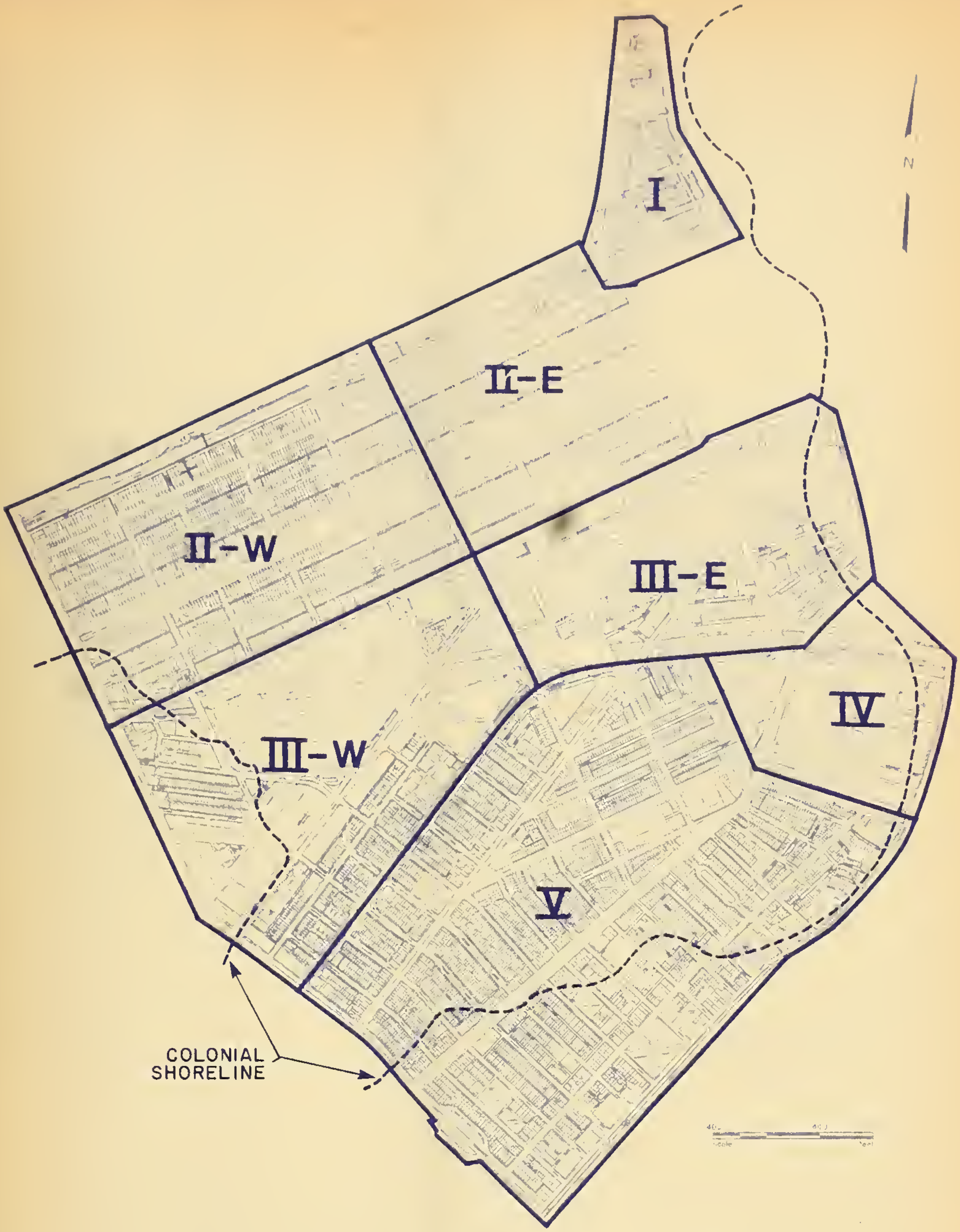
HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS

N

PROJECT LOCUS
U.S.G.S. QUADRANGLE
BOSTON SOUTH, MA
APPROXIMATE SCALE 1:25,000

FILE NO. 5381 AI

FIGURE 1



HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

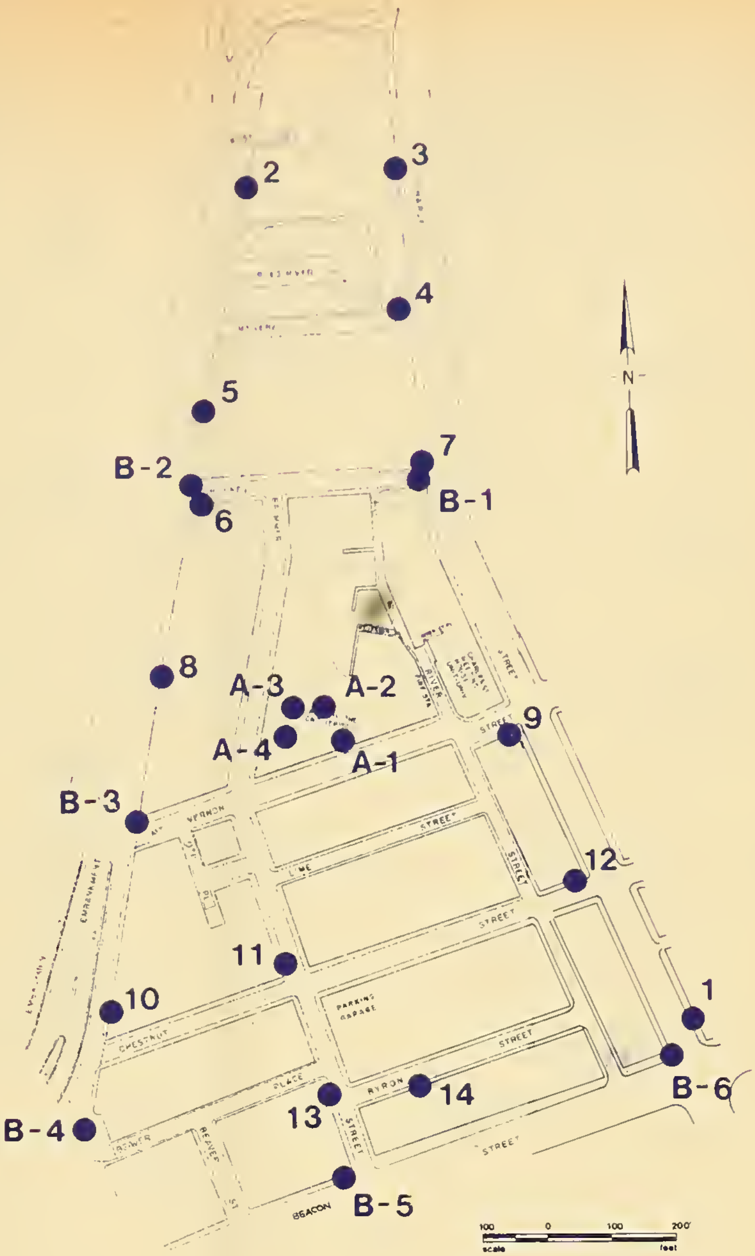
DELINEATION OF
STUDY AREA ZONES

SCALE: AS SHOWN

MARCH 1985

FILE NO. 8351 A16

FIGURE 2



LEGEND:

● 6 — LOCATION OF WPA OBSERVATION WELL

● C-2 — LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.
2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

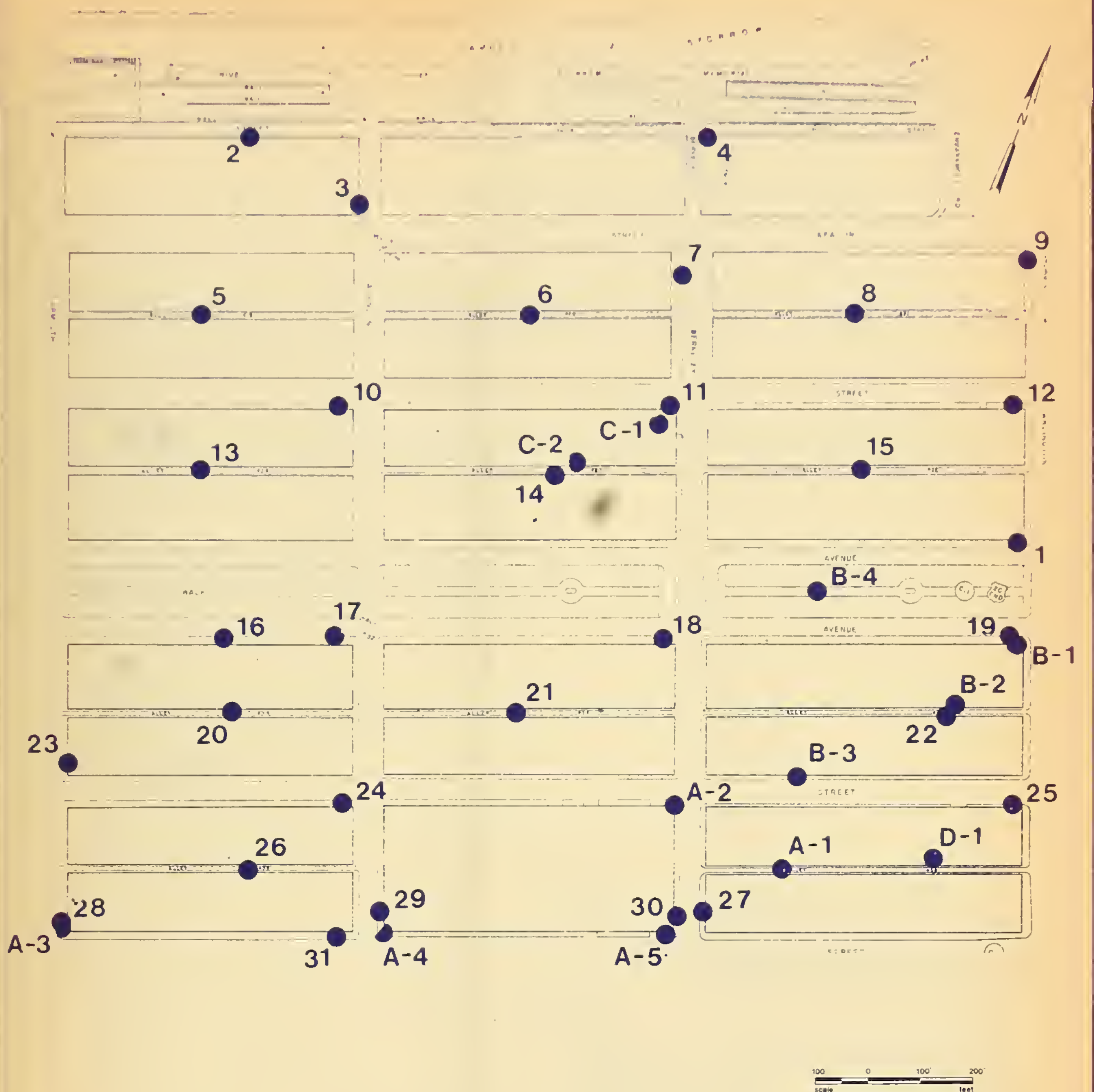
HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE I

NOVEMBER 1984

FIGURE 3



LEGEND:

- ●6 LOCATION OF WPA OBSERVATION WELL
- ●C-2 LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.
2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

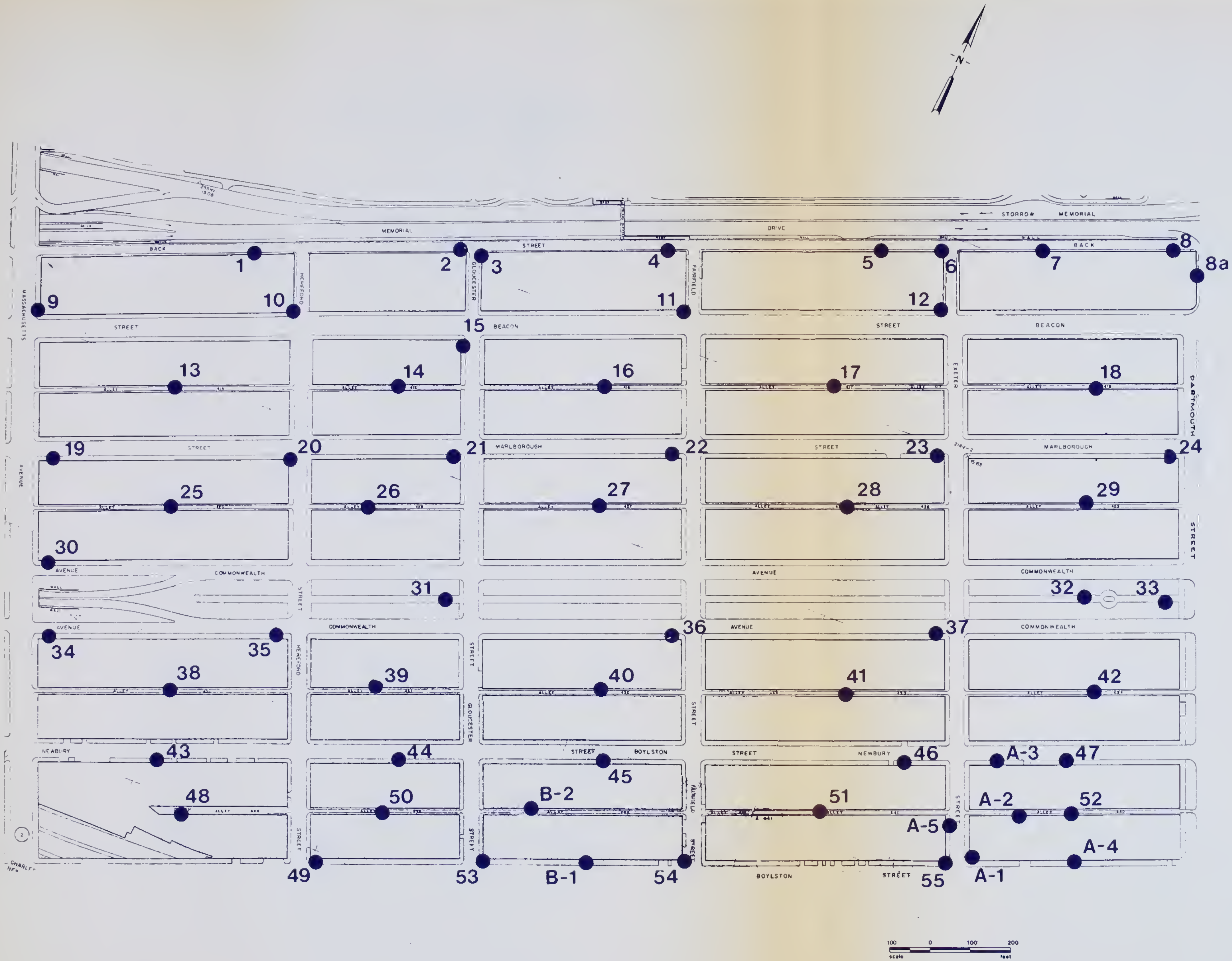
HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE II-E

NOVEMBER 1984

FIGURE 4



LEGEND:

● 6 LOCATION OF WPA OBSERVATION WELL

● C-2 LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.

2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

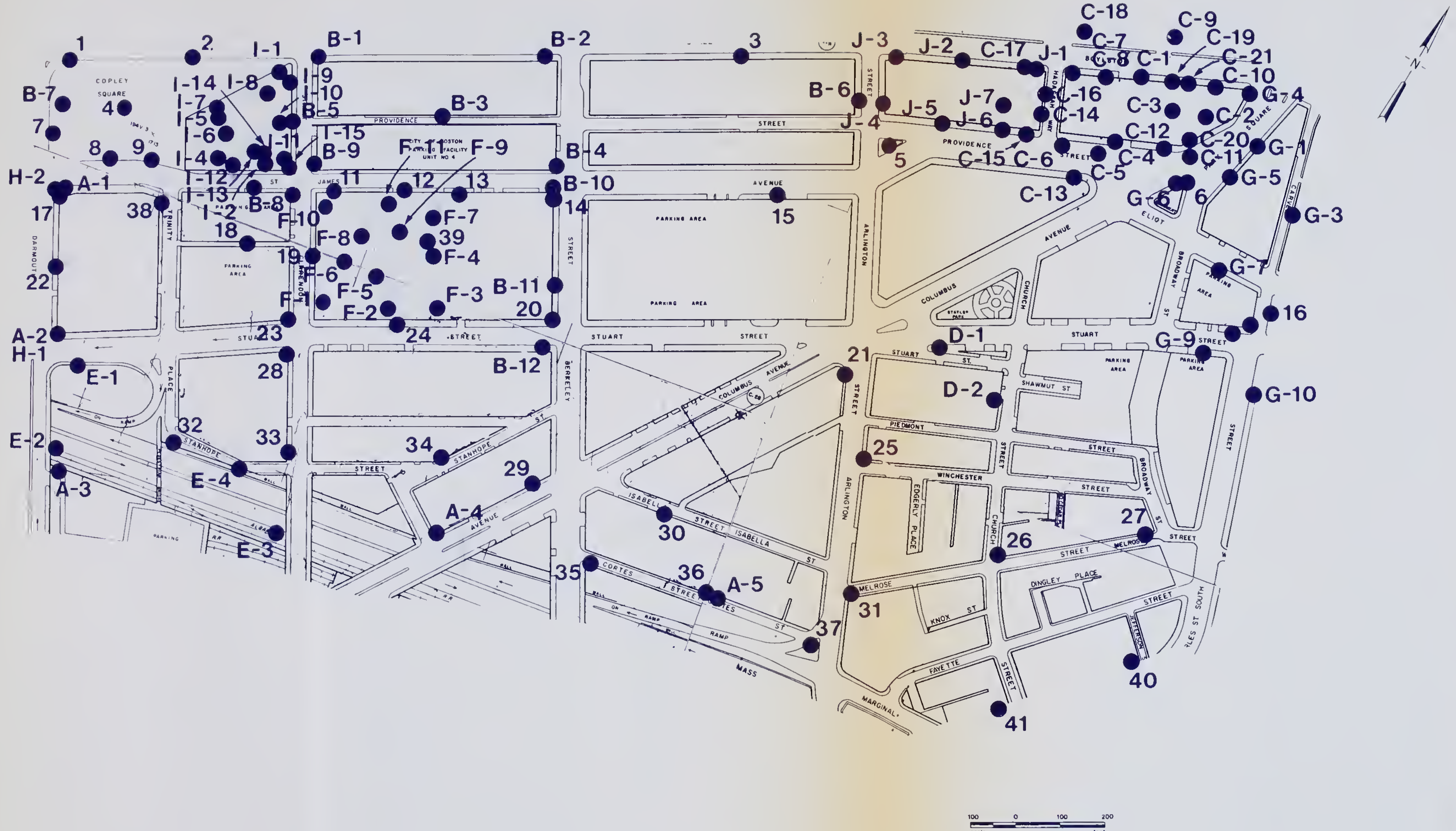
BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE II-W

NOVEMBER 1984

FIGURE 5

FILE NO. 5381 B11



LEGEND:

● 6 LOCATION OF WPA OBSERVATION WELL

● C-2 LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.

2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

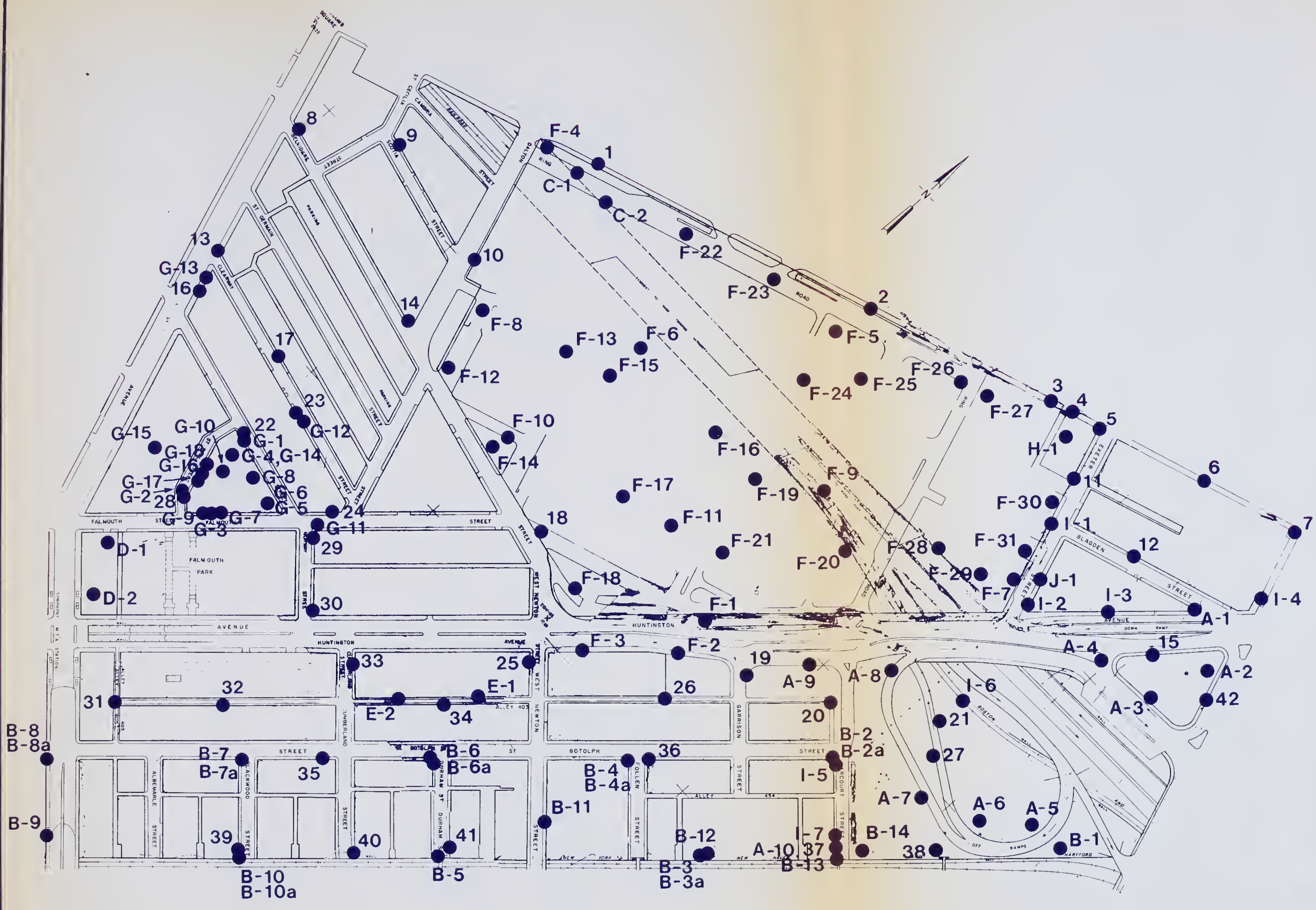
HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE III-E

NOVEMBER 1984

FIGURE 6



LEGEND:

- •6 LOCATION OF WPA OBSERVATION WELL
- •C-2 LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.
2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

100 0 100 200
scale feet

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE III-W

NOVEMBER 1984

FIGURE 7

LEGEND:

● 6 — LOCATION OF WPA OBSERVATION WELL

● C-2 — LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.

2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE IV

NOVEMBER 1984

FILE NO. 5381 B14

FIGURE 8

LEGEND:

● 6 — LOCATION OF WPA OBSERVATION WELL

● C-2 — LOCATION OF OBSERVATION WELL INSTALLED AND MONITORED FOR OTHER PROJECTS.

NOTES:

1. OBSERVATION WELL ZONE PREFIXES HAVE BEEN DELETED FOR CLARITY.

2. LOCATIONS INDICATED ARE FROM AVAILABLE RECORDS AND PLANS. WHERE TWO DIFFERENT LOCATIONS WERE INDICATED FOR A WPA OBSERVATION WELL, WRITTEN LOCATION DESCRIPTIONS WERE USED.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

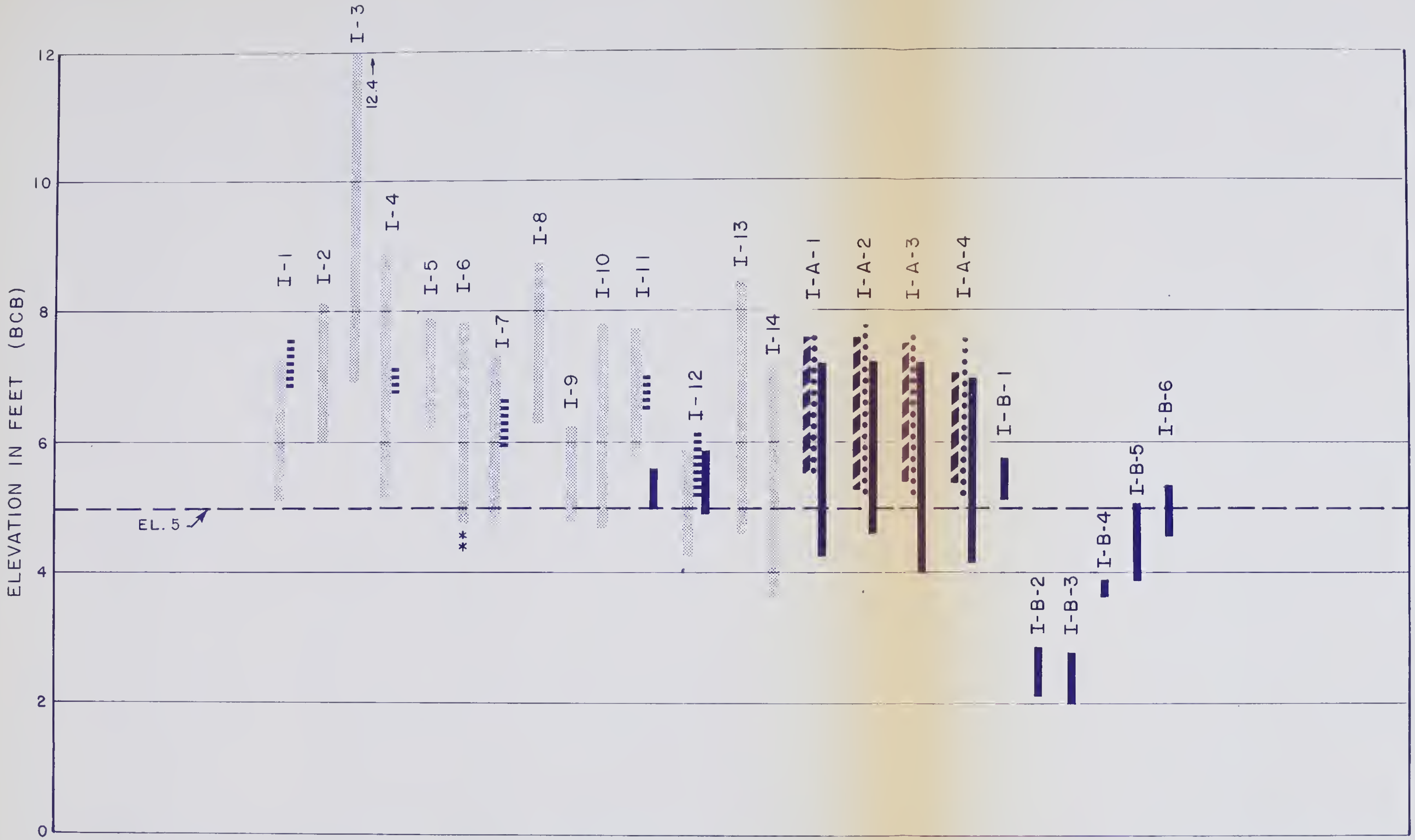
BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

OBSERVATION WELL LOCATIONS
IN ZONE V

NOVEMBER 1984

FIGURE 9

FILE NO. 5381 B15



NOTES:

1. SEE FIGURE 3 FOR ZONE I OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1936 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

LEGEND:

SYMBOL	(stippled)	(dashed)	(hatched)	(dotted)	(solid)
YEARS OF MONITORING	1935-1940	1965-1970	1971-1975	1976-1979	1980-1984

SPECIFIC REFERENCE NOTES:

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

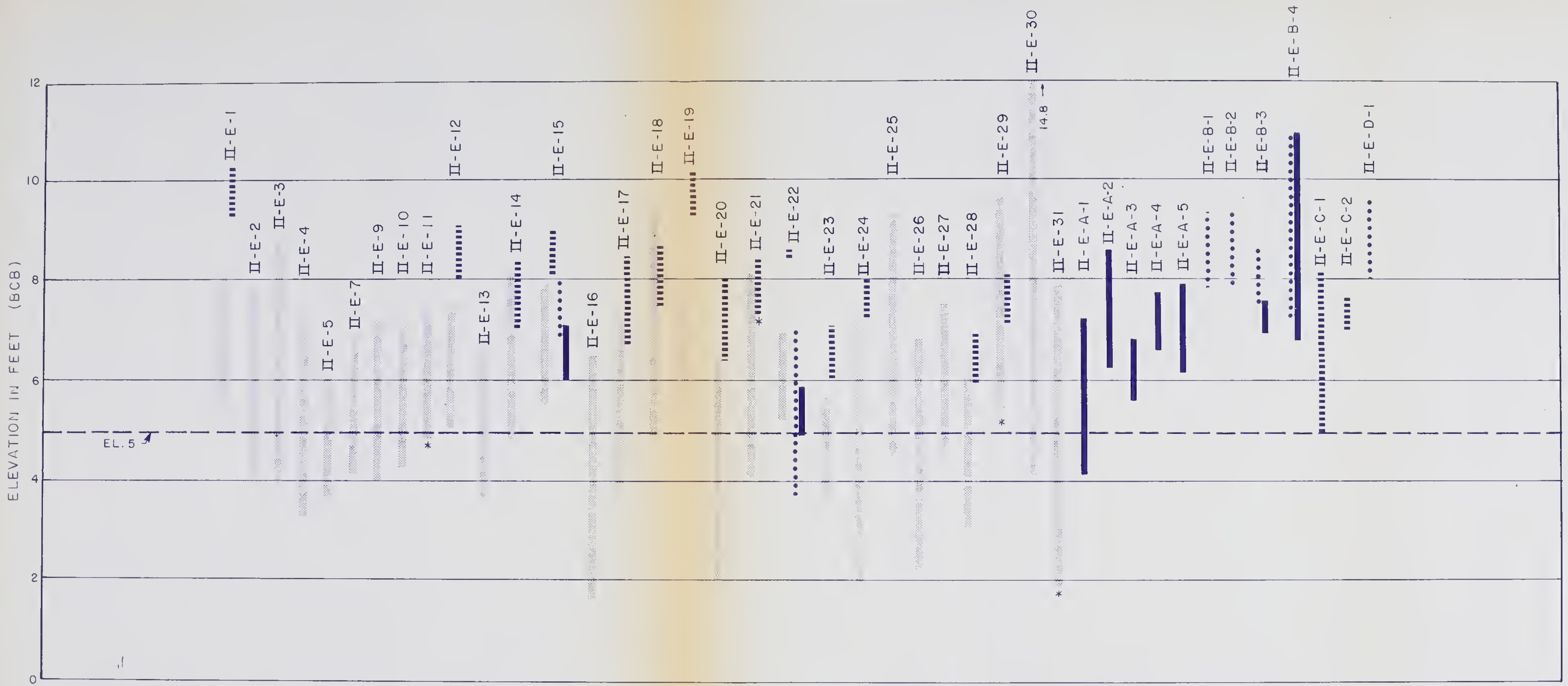
BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE I OBSERVATION WELLS

NOVEMBER 1984

FIGURE 10

FILE NO. 5381 B2



LEGEND:

SYMBOL					
YEARS OF MONITORING	1935-1940	1965-1970	1971-1975	1976-1979	1980-1984

SPECIFIC REFERENCE NOTES:

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA.

NOTES.

1. SEE FIGURE 4 FOR ZONE II-E OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1936 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

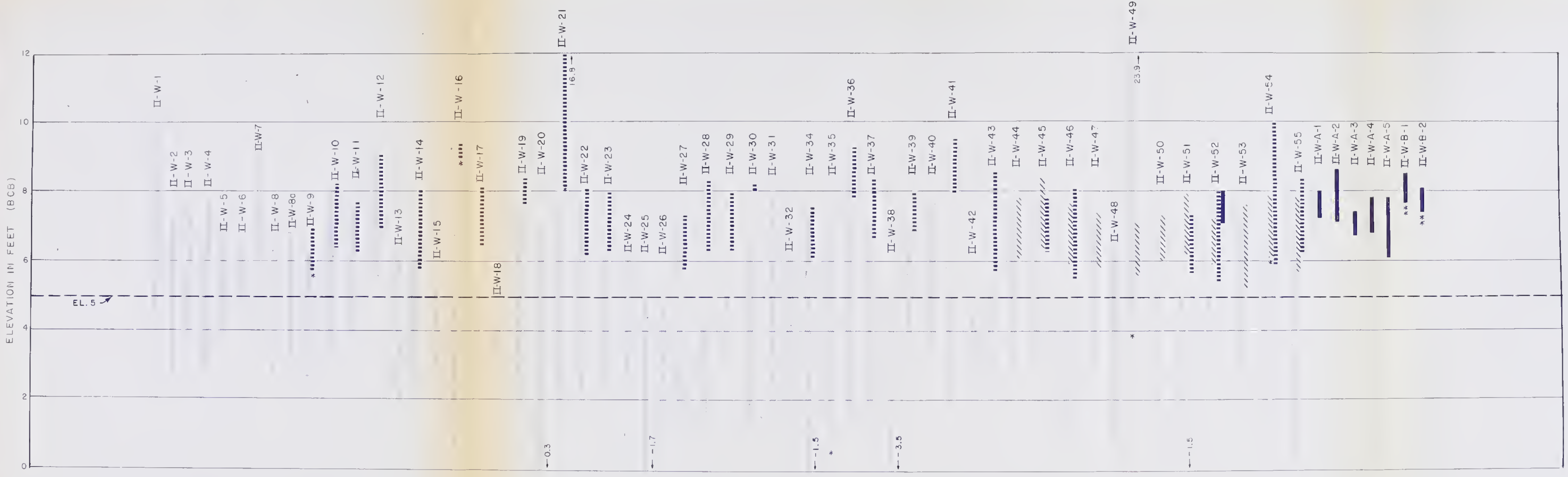
HALEY & ALDRICH INC

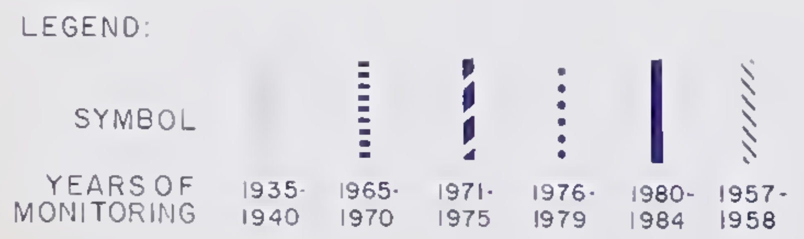
BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE II-E OBSERVATION WELLS

NOVEMBER 1984

FIGURE 11





SPECIFIC REFERENCE NOTES:

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA.

NOTES:

1. SEE FIGURE 5 FOR ZONE II-W OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1936 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

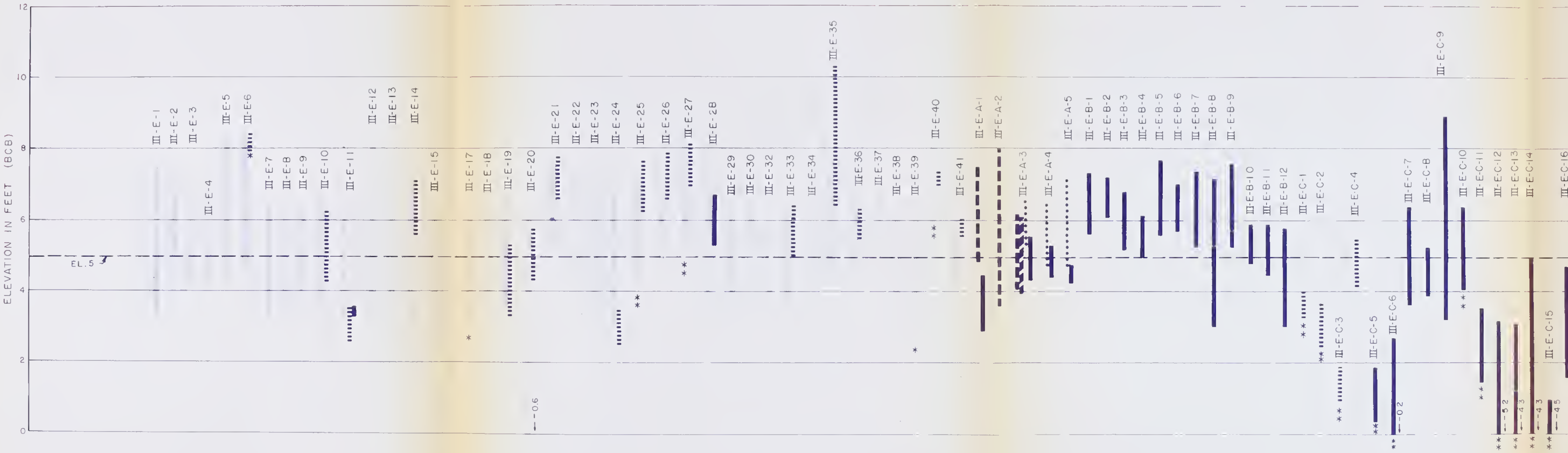
HALEY & ALDRICH, INC.

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE II-W OBSERVATION WELLS

NOVEMBER 1984

FIGURE 12



LEGEND:

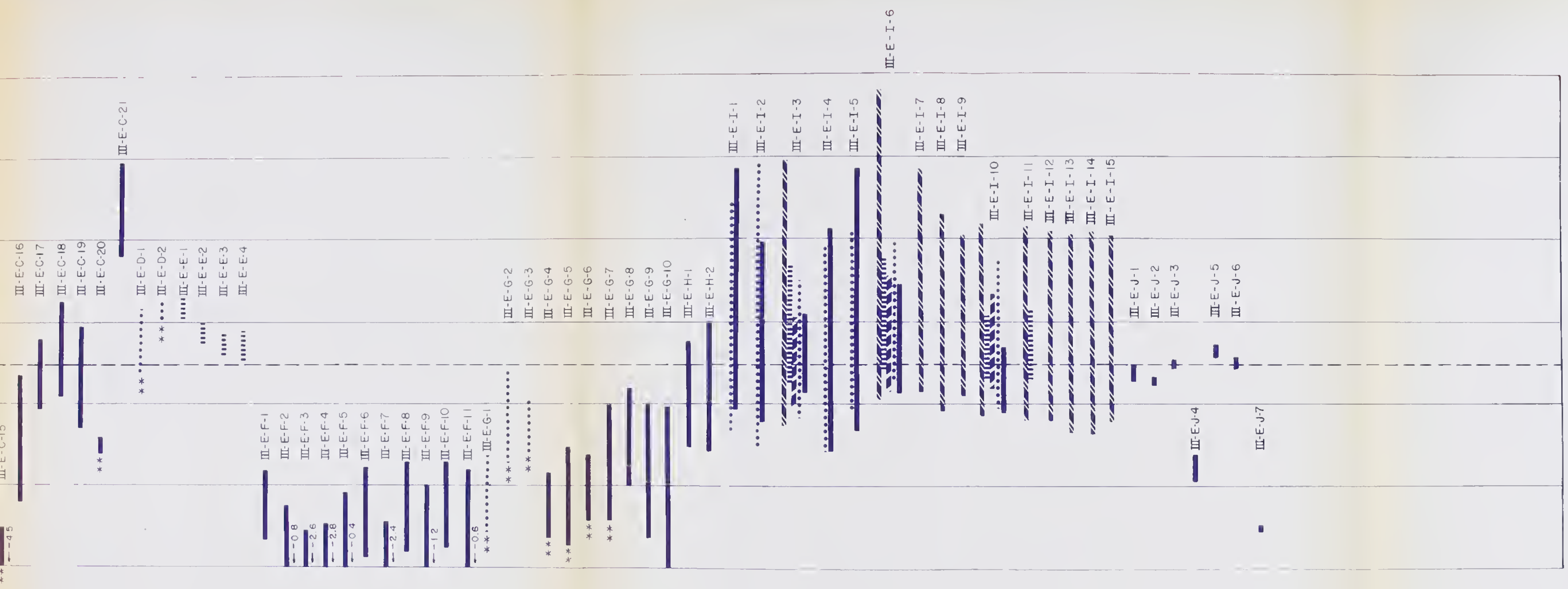
SYMBOL						
YEARS OF MONITORING	1935-1940	1965-1970	1971-1975	1976-1979	1980-1984	1963-1964	1940-1961

SPECIFIC REFERENCE NOTES

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA

FILE NO. 53BI B5



NOTES.

1. SEE FIGURE 6 FOR ZONE III-E OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1936 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE III-E OBSERVATION WELLS

NOVEMBER 1984

FIGURE 13

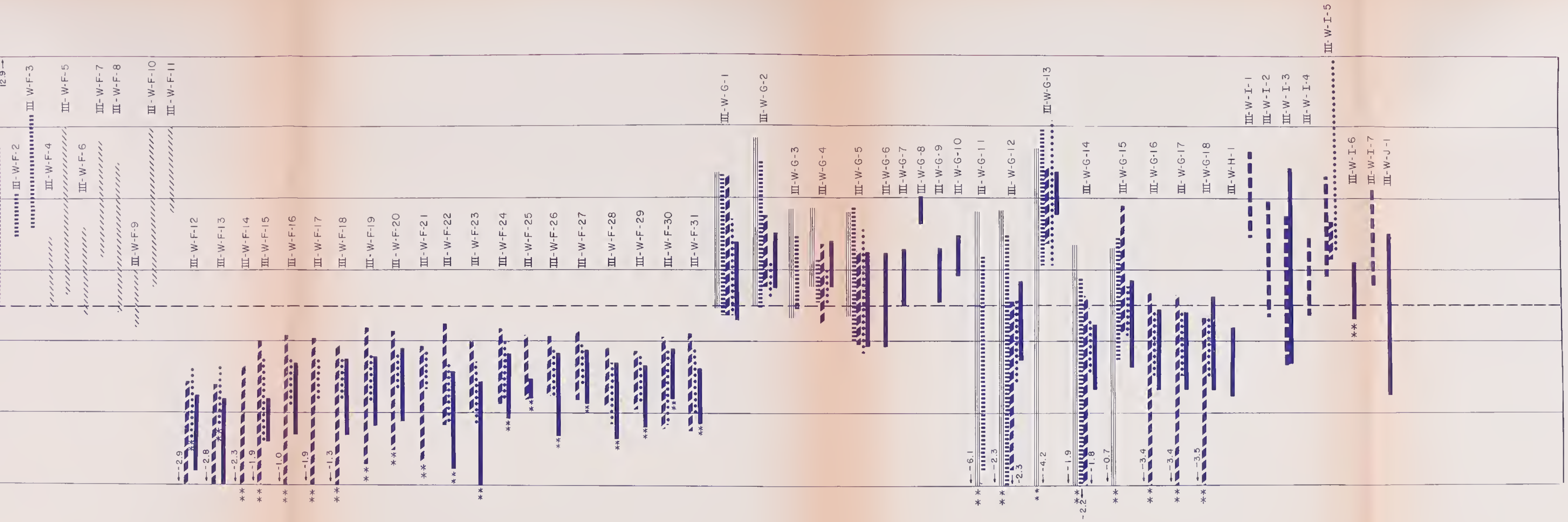
LEGEND:

SYMBOL							
YEARS OF MONITORING	1935-1940	1965-1970	1971-1975	1976-1979	1980-1984	1934-1964	1957-1958	1963-1964

SPECIFIC REFERENCE NOTES:

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA.



NOTES:

1. SEE FIGURE 7 FOR ZONE III-W OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1936 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

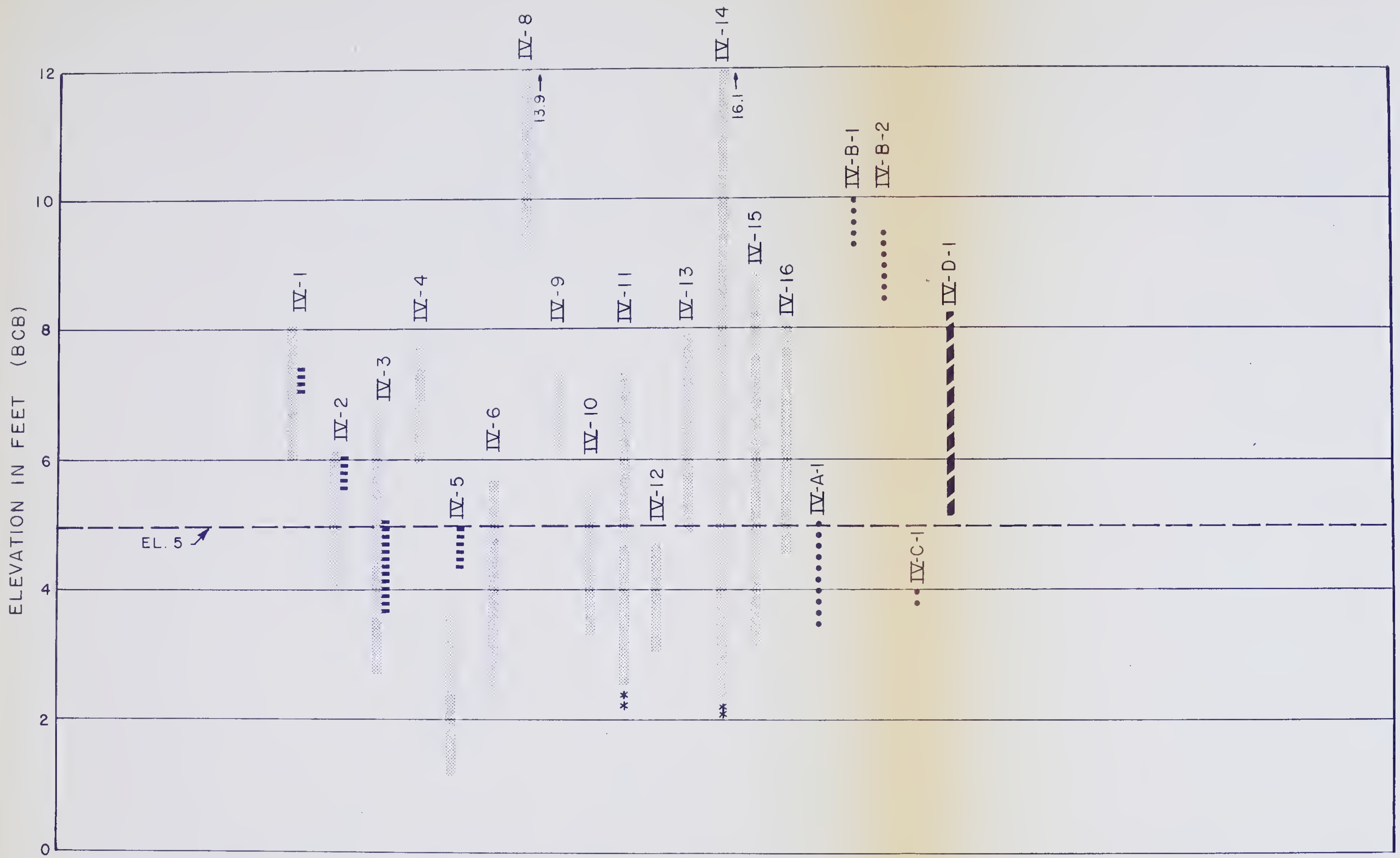
HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE III-W OBSERVATION WELLS

NOVEMBER 1984

FIGURE 14



NOTES:

1. SEE FIGURE 8 FOR ZONE IV OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1936 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

LEGEND:

SYMBOL					
YEARS OF MONITORING	1935-1940	1965-1970	1971-1975	1976-1979	1980-1984

SPECIFIC REFERENCE NOTES:

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE IV OBSERVATION WELLS

NOVEMBER 1984

FILE NO. 5381 B6

FIGURE 15

LEGEND:

SYMBOL

YEARS OF MONITORING	1935-1940	1965-1970	1971-1975	1976-1979	1980-1984	1963-1964

SPECIFIC REFERENCE NOTES:

* REFER TO REMARKS IN TABLES III OR IV FOR PARTICULAR COMMENTS.

** INDICATES OBSERVATION WELL TIP NOT IN EITHER THE FILL OR ORGANIC SILT STRATUM. SEE TABLE III OR IV FOR OTHER STRATUM. OTHER OBSERVATION WELLS WERE GENERALLY INSTALLED IN THE FILL OR ORGANIC SILT STRATA.

NOTES.

1. SEE FIGURE 9 FOR ZONE V OBSERVATION WELL LOCATIONS.
2. RANGES OF WATER LEVELS MONITORED IN OBSERVATION WELLS ARE FROM HIGHEST TO LOWEST LEVELS WITHIN EACH MONITORING PERIOD. PREDOMINANT RANGE OF LEVELS MEASURED MAY BE MUCH SMALLER THAN RANGES INDICATED.
3. OBSERVATION WELLS WERE GENERALLY NOT MONITORED FOR EACH YEAR OF THE INDICATED MONITORING PERIODS. WPA OBSERVATION WELLS WERE GENERALLY MONITORED PERIODICALLY FROM 1935 TO 1940, AND IN SEPTEMBER 1967 AND MARCH 1968 BY THE USGS. MONITORING PERIODS FOR "OTHER" WELLS ARE INDICATED ON TABLES II AND IV.
4. REFER TO TABLES III AND IV FOR DETAILS OF EACH OBSERVATION WELL INCLUDING DEPTH, STRATUM, AND WELL TYPE.

HALEY & ALDRICH, INC
CAMBRIDGE MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RANGES OF WATER LEVELS MONITORED IN ZONE V OBSERVATION WELLS

NOVEMBER 1984

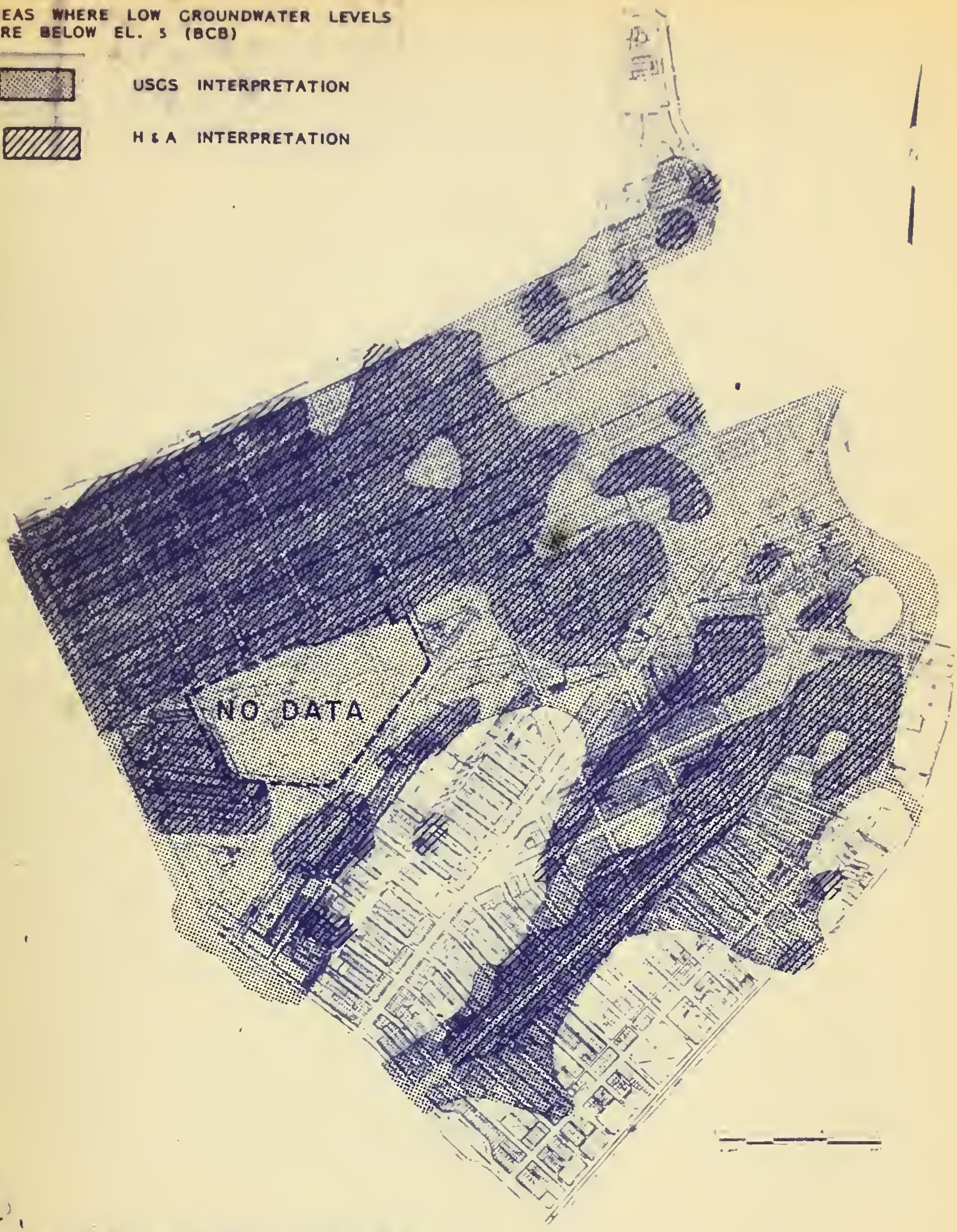
FIGURE 16

LEGEND:

AREAS WHERE LOW GROUNDWATER LEVELS WERE BELOW EL. 5 (BCB)

USGS INTERPRETATION

H & A INTERPRETATION



NOTES:

1. DATA USED TO DEVELOP THIS FIGURE WERE PRIMARILY FROM SEPT. 1967 AND MARCH 1968 USGS READINGS IN SURVIVING WPA OW'S. LIMITED DATA FROM OTHER PROJECTS IN ZONE III-W WERE ALSO USED.

2. USGS INTERPRETATION WAS PUBLISHED AS CONTOURS OF SEPT. 1967 GROUNDWATER LEVELS. CONTOURS SPAN BETWEEN WIDELY SPACED OW'S AND CAN ENCOMPASS LARGE AREAS.

3. H & A INTERPRETATION INCLUDED ONLY AREAS BETWEEN NEARBY OW'S OR IMMEDIATELY AROUND MORE ISOLATED OW'S. SOME DATA USED WERE NOT AVAILABLE TO USGS.

4. "NO DATA" INDICATES FORMER RAILROAD YARD WHERE NO WPA OW'S WERE INSTALLED.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

AREAS HAVING GROUNDWATER LEVELS BELOW EL. 5
1936 - 1940

MARCH 1985

FILE NO. 5381 A17

FIGURE 17

LEGEND:

AREAS WHERE LOW GROUNDWATER LEVELS WERE BELOW EL. 5 (BCB)

USGS INTERPRETATION

H & A INTERPRETATION

NOTES:

1. DATA USED TO DEVELOP THIS FIGURE WERE PRIMARILY FROM SEPT. 1967 AND MARCH 1968 USGS READINGS IN SURVIVING WPA OW'S. LIMITED DATA FROM OTHER PROJECTS IN ZONE III-W WERE ALSO USED.

2. USGS INTERPRETATION WAS PUBLISHED AS CONTOURS OF SEPT. 1967 GROUNDWATER LEVELS. CONTOURS SPAN BETWEEN WIDELY SPACED OW'S AND CAN ENCOMPASS LARGE AREAS.

3. H & A INTERPRETATION INCLUDED ONLY AREAS BETWEEN NEARBY OW'S OR IMMEDIATELY AROUND MORE ISOLATED OW'S. SOME DATA USED WERE NOT AVAILABLE TO USGS.

4. "NO DATA" INDICATES FORMER RAILROAD YARD WHERE NO WPA OW'S WERE INSTALLED.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

AREAS HAVING GROUNDWATER LEVELS BELOW EL. 5
1967 - 1968

MARCH 1985

FIGURE 18

NOTES:

1. THIS FIGURE WAS DEVELOPED USING AVAILABLE DATA PRIMARILY FROM CONSTRUCTION PROJECTS WITHIN THE STUDY AREA SINCE 1970.
2. DATA WERE NOT AVAILABLE IN AREAS THAT ARE NOT CROSS-HATCHED.
3. SOME OW DATA WERE AFFECTED BY DURATION OF MONITORING PERIOD AND/OR NEARBY CONSTRUCTION DEWATERING. SEE REPORT TEXT FOR FURTHER DISCUSSION.

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

AREAS HAVING GROUNDWATER LEVELS BELOW EL.5 1970 - PRESENT

MARCH 1985

FILE NO. 5381 A19

FIGURE 19

LEGEND:

- STRUCTURES PREDOMINANTLY SUPPORTED ON WOOD PILES
- GROUNDWATER DATA AVAILABLE FOR SOME TIME PERIODS SINCE 1970

HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

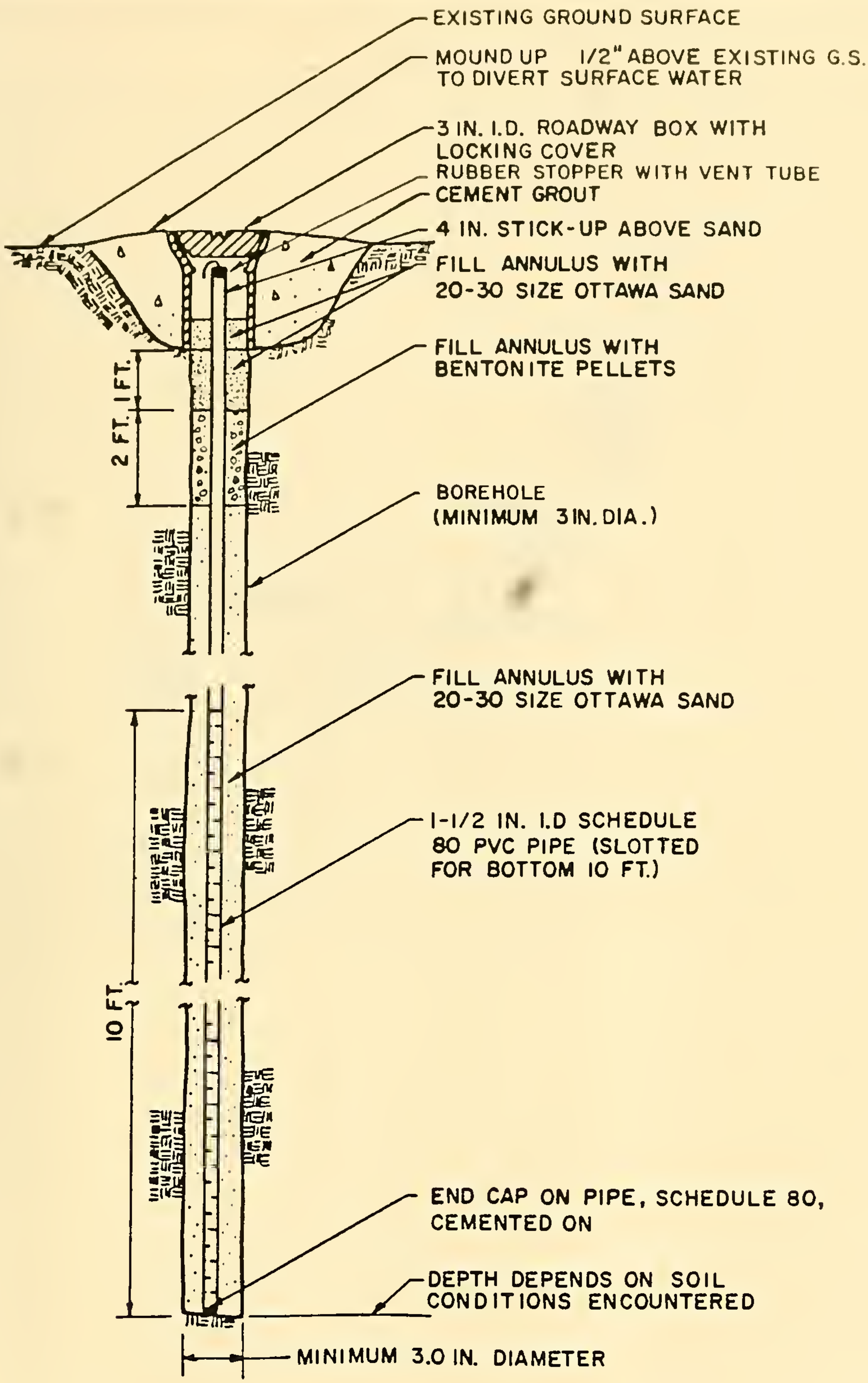
BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

AREAS OF WOOD PILE SUPPORTED BUILDINGS AND AVAILABLE POST-1970 GROUNDWATER LEVEL DATA

MARCH 1985

FILE NO. 5381 A20

FIGURE 20



HALEY & ALDRICH, INC.
CAMBRIDGE, MASSACHUSETTS
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

BOSTON REDEVELOPMENT AUTHORITY
GROUNDWATER IN BACK BAY BOSTON

RECOMMENDED TYPICAL
OBSERVATION WELL DETAIL

NO SCALE | NOVEMBER 1984

FIGURE 21

AUTHOR

TITLE Report On Groundwater...

DATE LOANED	BORROWER'S NAME