CIVIL ENGINEERING PRACTICE · JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION / ASCE

Fall 1986 Volume 1, Number 2 ISSN: 0886-9685

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Reprinted from Civil Engineering Practice:
Journal of the Boston Society of Civil Engineers
Section / ASCE
Volume 1, Number 2
Fall 1986

CIVIL ENGINEERING PRACTICE: JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION / ASCE (ISSN: 0886-9685) is published twice yearly by the Boston Society of Civil Engineers Section / ASCE (founded 1848). Editorial, circulation and advertising activities are located at: Boston Society of Civil Engineers Section / ASCE, The Engineering Center, 236 Huntington Ave., Boston, MA 02115-4701; (617) 536-2576. Known as *The Journal of the Boston Society of Civil Engineers Section/ASCE* until 1985.

Back Bay Boston, Part II: Groundwater Levels

Man-made structures that permanently lower groundwater levels can have adverse effects on buildings with water table sensitive foundations.

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The temporary or permanent lowering of the groundwater table can adversely affect both natural and constructed environments, causing ground subsidence, flooding and damage to structures. The Back Bay section of Boston serves as an excellent site for the study of the causes and effects of groundwater level diminishment, and provides ample reasons for the need to monitor and maintain groundwater levels to preserve building foundations.

The second in a series of studies on Back Bay, this article summarizes groundwater levels in Back Bay since the area was filled more than 100 years ago, and traces the effects of construction of sewers and drains, subways and other transportation corridors, and buildings on the groundwater table. Part I described the geology of Back Bay as well as subsurface soil conditions and the topographic development of the area, concluding with a discussion of building foundation practice through the turn of the century, a practice based primarily on untreated wood piles.(1) Part III, now in preparation, will complete the series, documenting foundation design and construction practice from 1900 to the present.

Background

This study focused on the geographical area bounded by the Massachusetts Bay Transportation Authority's Southwest Corridor Project (south), Charles Street (east), Massachusetts Avenue (west) and the Charles River Basin (north). This area currently encompasses the Back Bay Historic District (primarily between Boylston Street and Beacon Street) and the central spine across Back Bay where major projects have been constructed during the past 30 years. The South End neighborhood, located to the south of the Southwest Corridor, was excluded, primarily because little data on groundwater levels exist for this area.

During the nineteenth century, a tidal estuary of the Charles River known to Boston residents as the Back Bay (see Figure 1) was filled 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 to bear in the underlying sand and gravel or clay stratum. For the most part, the tops of these piles were

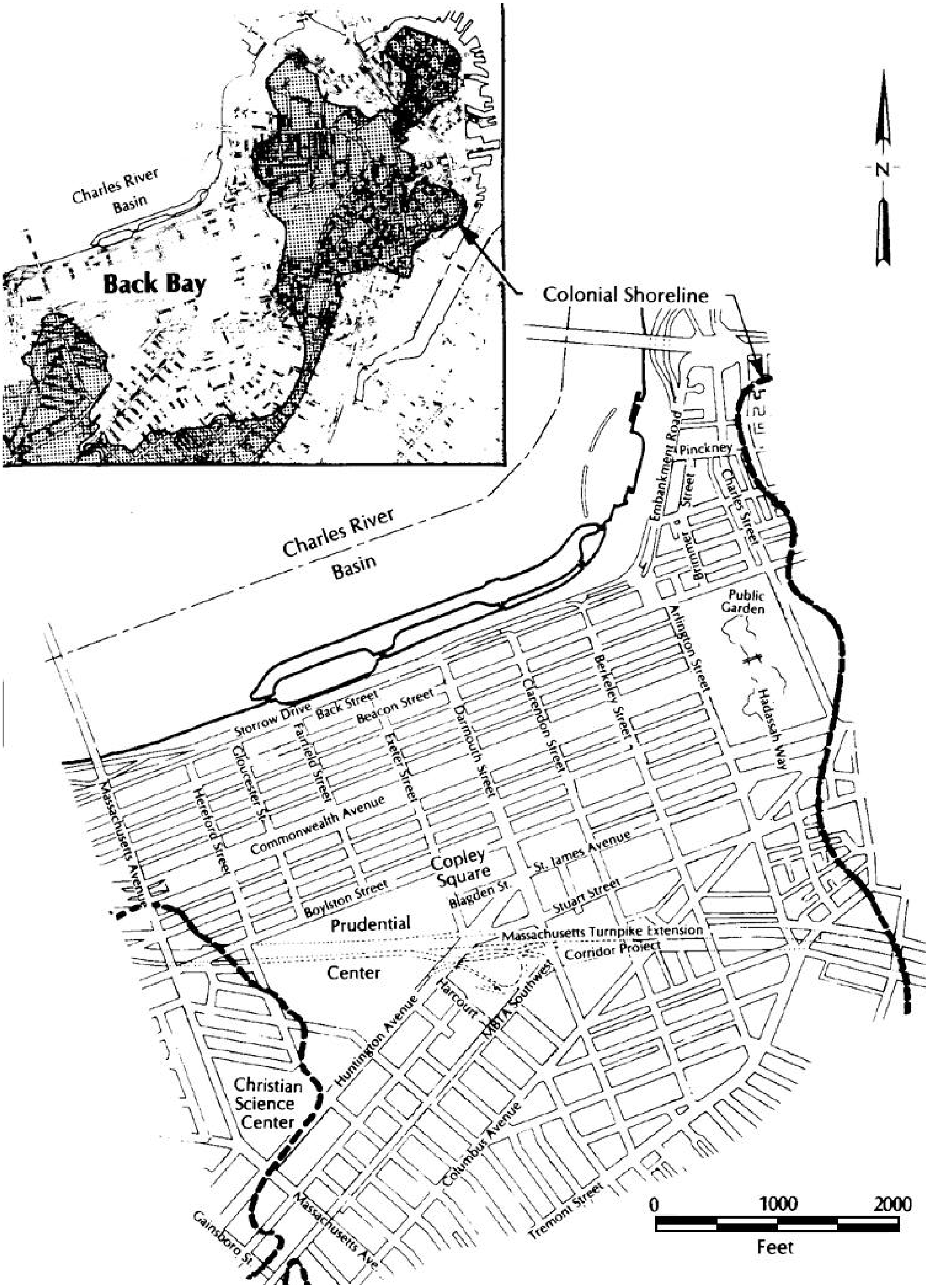


Figure 1. A map of Back Bay Boston showing the location of the colonial coastline.

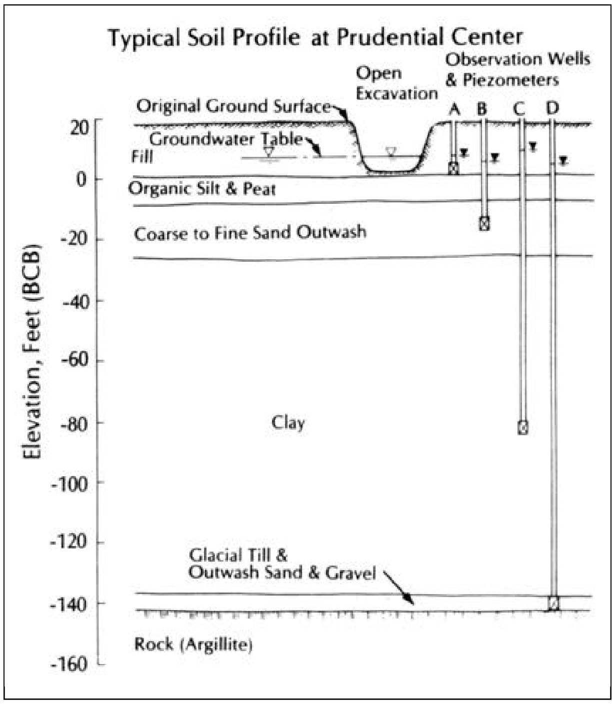


Figure 2. A typical soil profile, with groundwater table. Well A shows the static water level.

cut off below the water table at the time of construction with the expectation that they would be preserved if permanently immersed below the groundwater table.

With construction of sewers, drains, subways and the basements of buildings below the water table, some of which leak, the groundwater level has dropped in Back Bay. Where wood piles have been exposed to air for some time, the piles have rotted when attacked by fungi, borers and other organisms. A few buildings have settled and cracked, requiring owners to underpin their structures at great cost in order to restore the foundations.

The Groundwater Table

The Webster dictionary defines the groundwater table as the level below which the ground is saturated with water. In geotechnical engineering, it is the stabilized static water level in an open excavation, or in a shallow well or piezometer, as illustrated by well A in Figure 2. In Back Bay, the water table generally occurs within the fill stratum from 10 to 15 ft. below the ground surface.

Three principal water bearing aquifers occur in Back Bay, separated by impervious soils. The lowest aquifer, a relatively thin, but apparently continuous stratum of outwash sand and gravel or glacial till underlying the Boston blue clay, is relatively pervious. The middle aquifer is a compact gravelly sand stratum up to 20 ft. in thickness confined between the blue clay and a near continuous stratum of organic silt and peat. This pervious outwash material occurs primarily over the western and northern sections of Back Bay. It does not exist in the Copley Square area. The top aquifer is the artificial fill, commonly a silty coarse to fine sand, placed during the nineteenth century. The groundwater level in the fill, the top aquifer, is the principal concern in Back Bay.

In the westerly section of Back Bay, where the sand outwash stratum occurs below the relatively impervious organic soils, a second "water table" may be present - one that may differ from the water table in the fill. This situation is represented by well B in Figure 2. If the water level in all wells or piezometers in the figures were equal, then the groundwater would be hydrostatic with depth.

"Normal" Groundwater Levels. If there were no loss of groundwater by pumping and leakage into sewers and drains, and no additions to the groundwater from leaking water mains and other sources, the probable "normal" water table in Back Bay would be as shown in Table 1.

In colonial times, Back Bay was a tidal estuary that had a mean water level approximating the mean tide in Boston Harbor (el. 5.65 Boston City Base (2)). Following the completion of the Mill Dam along Beacon Street across Back Bay in 1821, and until 1880 when most of Back Bay was filled, water levels in the receiving basin east of Massachusetts Avenue were variable and generally below mean tide.

After Back Bay was filled, the groundwater table would have been expected to rise above mean tide level. The land mass was bounded on the north by the Charles River and on the south by South Boston Bay, both tidal. Surface water from rainfall and snowmelt that percolated into the ground would have been expected to raise the water table until a

TABLE 1

Probable "Normal" Groundwater Levels

Time Period	Probable Average Groundwater Level	Comments
Pre-1800; before Back Bay was filled	El. 5.7 (BCB) (mean tide level)	Back Bay was a tidal estuary of the Charles River
1880-1910; after filling	El. 5.8 at Charles River; el. 8± interior	Above mean tide level due to infiltration of rainfall & snowmelt
1910-present; after Charles River Dam completed	El. 8 at Charles River; el. 9.5± interior	Charles River Basin maintained at el. 8.0

Note: Assumes no loss of groundwater by pumping or by leakage into sewers, drains, foundations or basements; and no additions to groundwater from leaking water mains and other man-made sources.

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 Back Bay was, in fact, approximately el. 8.0 ft.(3)

The construction of the Charles River Dam in 1910 raised the mean water level in the Charles River Basin to el. 8.0. The Back Bay groundwater table would have then been expected to rise further, perhaps to el. 9.0 or higher along Boylston Street. Normal groundwater levels in the area between Charles Street and Storrow Drive would have then been from el. 10.0 down to 8.5, as a result of groundwater runoff from the west side of Beacon Hill.

Major sources of groundwater in Back Bay are infiltration of rainfall and snowmelt, leakage from water mains, and recharge from man-made groundwater recharge systems. The sand outwash receives water from the fill by seepage downward through the organic soil and by direct flow from the fill through holes, trenches and other manmade "openings" excavated through the organic stratum.

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 drains and sewers, the seasonal variations in the type, and level, of precipitation cause an annual fluctuation in groundwater levels up to about 2 ft. in some areas.

The Charles River may become a source of groundwater in the Back Bay when the water table falls. However, seepage through the fill is severely impeded by remnants of the Mill Dam and the West Side Interceptor along Beacon Street, and by the Boston Marginal Conduit under Storrow Drive. Because the river level is maintained at el. +7.5 to +8.0, its effect on groundwater levels is essentially constant. The river's influence on water levels in the fill decreases rapidly with distance from the river.

The relatively pervious sand outwash stratum also underlies the Charles River. The Mill Dam and Boston Marginal Conduit would not impede recharging in this stratum. However, since the river bottom is also blanketed by organic soils, its influence on piezometric water levels in the Back Bay outwash is uncertain.

Leaky pipes, particularly water mains, can be significant localized sources of groundwater. Cotton and Delaney provided groundwater contours that indicated several mounds where water levels were as much as 5 to 10 ft. above surrounding areas.(4) The overall contribution to the water table from leaking water mains may be about equal to that from precipitation. Cotton and Delaney reported that Boston Water Department data from the early 1940s indicated that water main leakage would have provided an equivalent recharge of 0.73 million gallons per day (gpd) per square mile. This amount is approximately equal to the recharge from 50 in. of precipitation per year, assuming a 30 percent infiltration rate. Storm and sanitary sewers located above the groundwater table can also leak and contribute to groundwater. Because they are not under pressure, their effect is probably minor.

In several areas, permanent recharge systems have been installed to help maintain groundwater levels. Notable examples are the recharge systems at Copley Square and Trinity Church. In these systems, surface drainage from precipitation is collected and directed to drywells or reverse drains. Water then seeps back into the ground through special piping systems. Temporary recharge systems have been used in areas adjacent to construction projects, notably the Prudential Center, to prevent or correct lowered groundwater levels caused by deep excavations and construction dewatering.

Loss of groundwater, and the resulting lowered water levels in Back Bay, occur primarily from leakage into sewers and drains, leakage through walls and floors of subway tunnels, underpasses, building foundations and other structures below the water table, and by pumping from sumps. In addition, water levels may be lowered temporarily by pumping from excavations in order to facilitate construction.

Adverse Effects of Lowered Groundwater Levels

Temporary or permanent lowering of the groundwater table from man-made or natural causes have been shown to adversely affect buildings, streets, underground utilities and other structures, as discussed by Aldrich.(5) Potential problems applicable to the Back Bay are illustrated in Figure 3 and include:

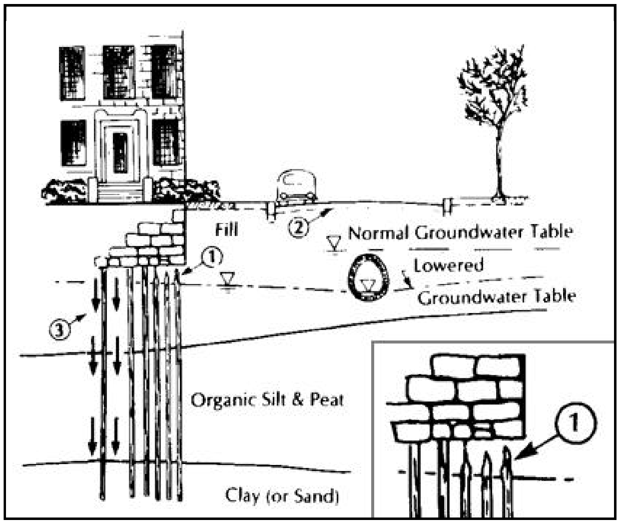


FIGURE 3. Principal adverse effects of lowered groundwater levels: (1) decay of wood piles when exposed to oxygen; (2) ground subsidence due to compression of organic silt and peat; and (3) negative friction (drag) on piles when the ground settles

- Deterioration of wood piles
- Ground subsidence
- Negative friction (drag) on piles

Deterioration or decay of wood piles is clearly the most serious potential problem associated with lowered water levels. As long as the water table remains above the tops of the piles, and the wood and surrounding soil remain saturated, the wood will not rot. Under these conditions, untreated wood piles can be considered to be permanent.

However, if the groundwater level drops below the tops of the piles, favorable conditions may be present for plant growth and insect attack. A greatly increased supply of oxygen, combined with moisture and moderate temperatures, facilitate the growth of fungi. Grubs or wood borers, termites and other insects may also attack the "exposed" wood.

The butts of piles that are surrounded by fill, in particular sand and gravel as well as ashes and cinders, are more prone to rotting than are piles that 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 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 the 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 3 to 10 years.

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

Most areas of the Back Bay have experienced one or more significant temporary groundwater drawdowns for the construction of sewers and drains, subways, foundations for buildings, and other excavations that have required pumping. For this reason, ground subsidence due to future temporary or nominal permanent lowering of the water table is not considered to be a serious concern.

Negative Friction. All buildings in Back Bay that are supported by piles driven through fill 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 the ground surrounding the piles settles. The building may settle as a result. The potential adverse effects are most pronounced for wood piles that derive their support by skin friction in the marine clay.

While significant negative friction undoubtedly developed in the nineteenth century from the compression of organic soils under the weight of overlying fill, and from temporary groundwater drawdowns, this factor is not likely to be a serious concern in the future.

Construction in Back Bay

The construction and maintenance of embankments, sewers and drains, transportation corridors and buildings throughout Back Bay have affected groundwater levels. The impact of this complex interconnected underground system, shown in Figure 4, on the water table cannot be appreciated without some knowledge of each component.

Mill Dam. The first significant filling in Back Bay took place in 1820 when the Mill Dam was constructed along Beacon Street from Charles Street to Sewall's Point in Brookline, near the present Kenmore Square. From a description given by Howe, a cross section of the dam can be developed as shown in Figure 5.

As a dam, the structure was relatively impervious to the flow of water from one side to the other, except where it has been breached locally by construction in the past 100 years. However, in a longitudinal direction along Beacon Street, the structure is probably very pervious.

Filling of Back Bay began in 1858 at the Public Garden, continuing westward to Massachusetts Avenue by 1880. From 10 to 20 ft. of sand and gravel fill were placed over soft organic soils that were underlain by a deep clay stratum. Considerable ground subsidence occurred over a long period of time from the compression of the organic soils and, to some extent, the clay.

Concurrent with the filling, a sea wall was constructed along the Charles River to create Back Street that parallels Beacon Street on the water side. The top of this wall is clearly visible from Storrow Drive. A similar wall was constructed in about 1865 behind homes on the water side of Brimmer Street on Beacon Hill. Both walls were composed of dry-laid granite placed on a timber platform and supported on wood piles (see Figure 6). It is probable the walls were ballasted with stone or gravel, similar to the Mill Dam walls.

Construction of buildings followed closely behind the Back Bay filling. All of these

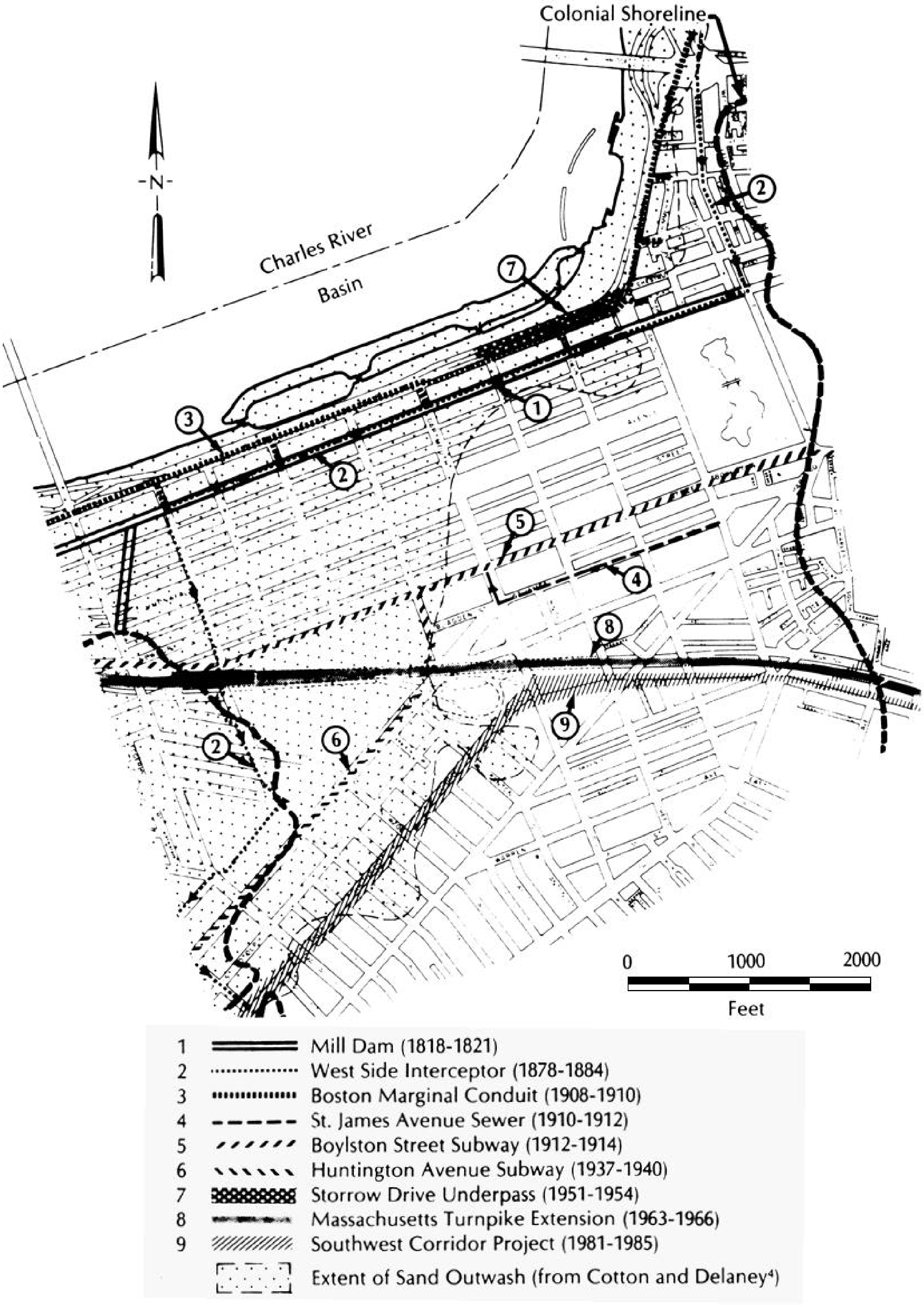
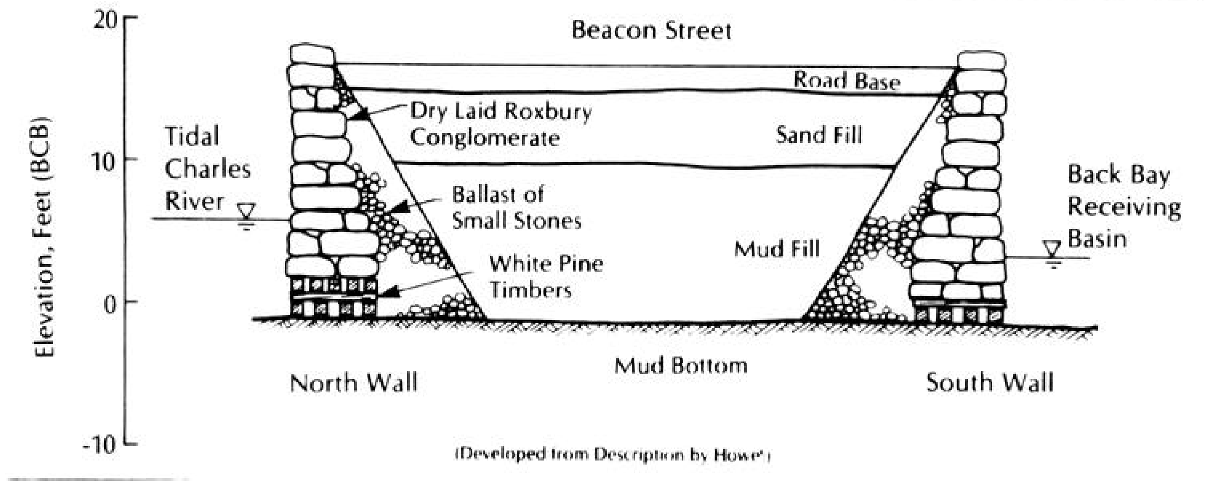


FIGURE 4. The locations of sewers and drains, and major transportation alignments.



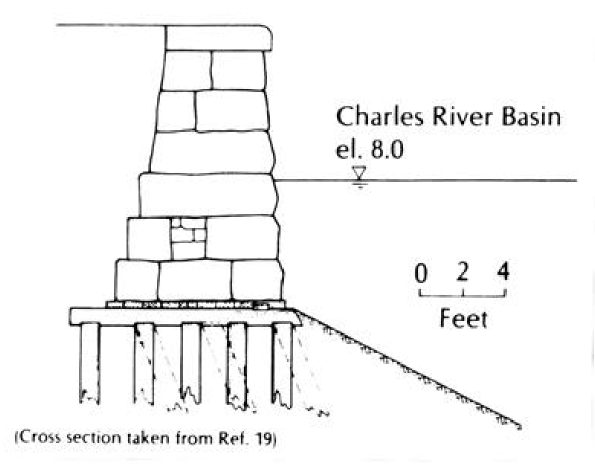
(Developed from Description by Howe*)

FIGURE 5. A typical cross section of the Mill Dam.

buildings were founded on untreated wood piles cut off typically at el. 5.0, approximately 2 to 3 ft. below the groundwater table.(1)

Sewers and drains in Back Bay have contributed to at least localized depressions in the groundwater table. Furthermore, dewatering for sewer construction undoubtedly caused extensive temporary lowering of the water table in some areas. Plans of the principal existing sewers and conduits in the Back Bay are shown in figures in a report by Camp, Dresser & McKee.(7)

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



(Cross section taken from Ref. 19)

FIGURE 6 The sea wall along Back Street.

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, the 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. Deposits of sludge and debris within the sewers and in tidal areas accumulated rapidly, with their 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 sewage system and to plan for future needs of the city. The plan adopted became the Boston Main Drainage System.

The Boston Main Drainage System, was constructed from 1877 to 1884. The principal feature of these works was a system of intercepting sewers along the margins of the city to receive the flow from the already existing sewers. These intercepting 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

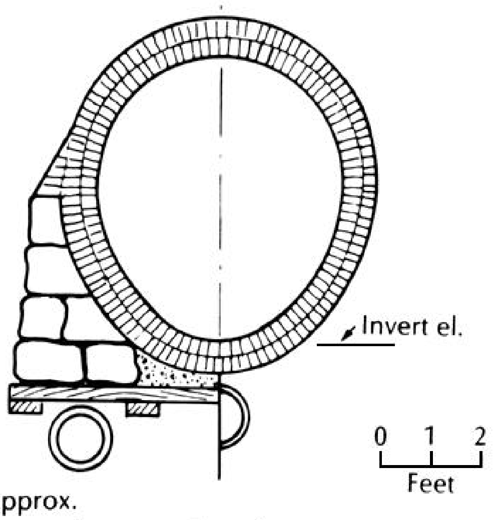
Island and discharged into Boston Harbor on outgoing tides.

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

Design and construction of the West Side Interceptor is of articular interest (see Figure 4). It travels down Charles Street to Beacon Street, where it turns westerly down Beacon to Hereford Street, then turns southerly down Hereford and Dalton Streets to Falmouth Street, and then westerly to Gainsborough Street. In the Beacon Street area, the invert grade varies from approximatel el. 0 at Beacon and Arlington Streets, to el. -2.4 at Beacon and Hereford Streets and to el. -4.7 at Huntington Avenue and Gainsborough Street.

Excavation and dewatering for the construction would have been required to at least 2 ft. below these grades, into the fill and organic soil on Beacon Street; and to approximately el. -6.0 in the sand outwash stratum in Dalton and Falmouth Streets. So, over 100 years ago, if not before, the outwash stratum experienced its first significant temporary drawdown. Significant ground subsidence and negative friction on wood piles undoubtedly occurred.

The intercepting sewers and the main sewer, from the upper reaches to the pumping station at Calf Pasture, varied in size fro 3 to 10.5 ft. in diameter. The larger ones were circular and the smaller ones were generally egg-shaped. The West Side Interceptor was egg-shaped, 57 in. wide and 66 in. high (see Figure 7). Sewers were constructed with double or triple rows 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 to 12 in. in diameter that was placed below the sewer to control groundwater during construction.

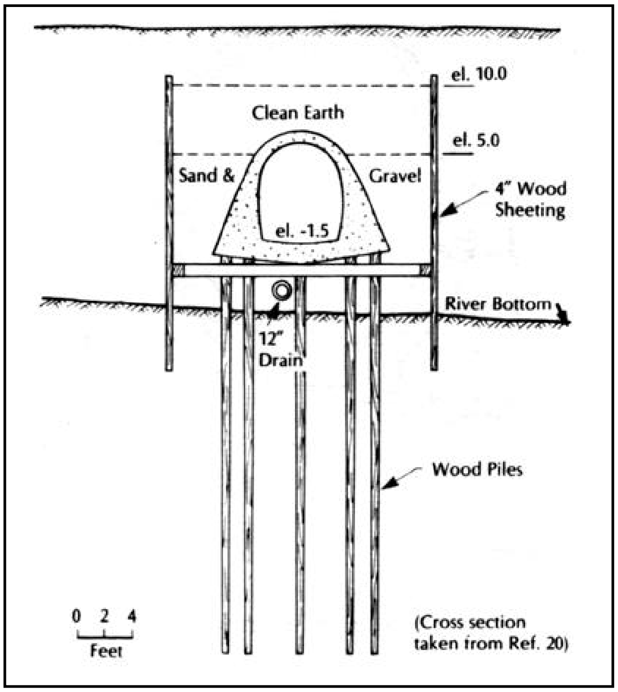


Approx. Invert el.	Location
0.7	Charles St. at Pinckney St.
0.4	Charles St. & Beacon St.
-0.6	Beacon St. at Berkeley St.
-1.2	Beacon St. at Dartmouth St.
-2.4	Beacon St. & Hereford St.
-3.0	Hereford St. at Boylston St.
-3.9	Falmouth St. at Mass Ave.
-4.7	Gainsborough St. at Huntington Ave.

FIGURE 7. A typical cross section of the West Side Interceptor. Invert elevations at selected locations are noted.

Observation wells in Back Bay at that time 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 groundwater was being pumped.

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. Boston Marginal Conduit. With the 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



(Cross section taken from Ref. 20)

FIGURE 8 A typical cross section of the Boston Marginal Conduit.

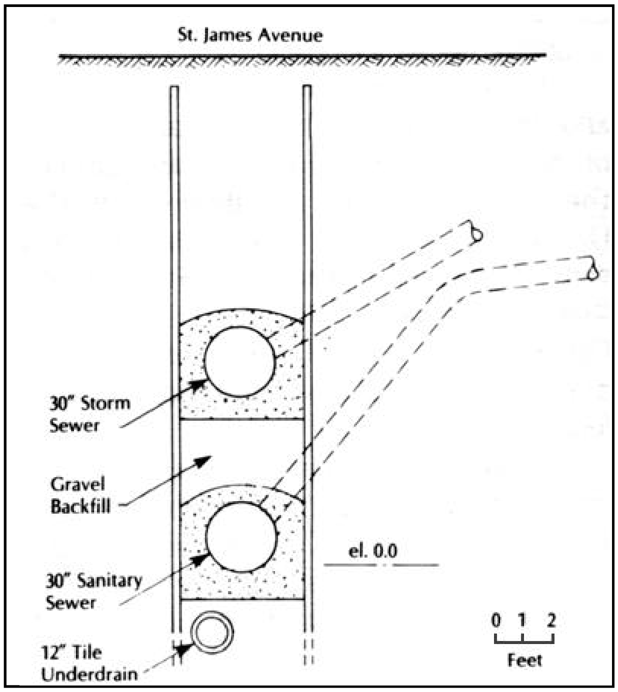


FIGURE 9 A typical cross section of the St. James Avenue sewer.

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 the water level in the Charles River basin at approximately el. 8.0.

As part of the dam project, the Boston Marginal Conduit was constructed along the Boston side of the basin to collect flows from Stony Brook, and mixed sewage and storm water overflows from the West Side Interceptor that formerly discharged into the river at the sea wall (see Figure 4). 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 lies beneath 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, as shown in Figure 8.

The structure was constructed level with an invert grade estimated at el. -1.5. Drawings indicated that it was built within a double row of tongue and groove wood sheeting that 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, was an 8-ft. diameter reinforced concrete pipe with an invert grade at el. -1.5. An underdrain pipe was placed beneath this new pipe, and it was apparently 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, they can conduct groundwater with relative ease in a longitudinal direction.

The present system of low level sewers was constructed throughout Back Bay between 1910 and 1912. Underdrain pipes again were used as shown in Figure 9, which presents a section through the St. James Avenue storm and sanitary sewers. By that time, nearly 75 years ago, there was little doubt that groundwater leaked into sewers, that the problem was widespread and that groundwater levels in Back Bay were controlled primarily by this leakage.

Two major subways have been constructed across Back Bay by the Boston Transit Commission (now known as the Massachusetts Bay Transportation Authority). Between 1912 and 1914, the BoyIston Street subway tunnel was built, and from 1937 to 1940 the Huntington Avenue subway was added. Their locations are shown on Figure 4 on page 37.

The Boylston Street subway crosses Back Bay from Massachusetts Avenue to Charles Street. Within this area, the bottom of the subway varies from approximately el. +3.0 at Massachusetts Avenue, to el. -19.0 between Arlington Street and Hadassah Way (its lowest point) to el. -10.0 at Charles Street. Table 2 presents elevation and soil condition data for the subway. A cross-section through the structure between Berkeley and Clarendon Streets is shown in Figure 10.

The structure was supported on a wide variety of soils including the fill, organic silt, and natural sand and gravel outwash. Where peat was encountered, approximately between Hadassah Way and Charles Street (a distance of 460 ft.), wood piles were driven to support the structure.

L.B. Manley, Asst. Engineer for the Transit Commission at the time, reported on soil conditions:(8)

> "As is well known, the land reclaimed from the Back Bay consists of sand and gravel filling resting on a bed of silt whose upper surface lies at about grade 0, Boston City base, or grade 100, Boston Transit Commission base. This layer of silt is continuous throughout the length of the subway, and attains a thickness of about 17 ft. at Dartmouth Street, and over 20 ft. in the Fens. Between Exeter Street and Charlesgate East and between Clarendon Street and Charles Street, where it finally disappears, it averages about 8 ft. in thickness. Below the silt between Massachusetts Avenue and Hereford Street, and at Exeter Street, are pockets of peat from 2 to 4 ft. in thickness. Another extensive body of peat occurs between Arlington and Charles Streets, where it attains a great depth.
>
> "Below the silt and peat is a stratum of sand and gravel which also extends throughout the length of the subway excavation except for a length of about 1,600 ft. between Exeter and Clarendon Streets. This sand and gravel carries large quantities of water laden with sulphurated hydrogen, which has been offensive to passersby and injurious to the health of those working in it. This gas, as it leaves the surface of the water, is particularly destructive to metal, and copper floats in several of the temporary pump wells have been corroded through at the surface of the water in a few weeks' time by the action of this gas. It is supposed that this layer of gravel is the same as that which appears in the bed of the Charles River and affords an underground water course which tends to equalize the level of the groundwater in the Back Bay."

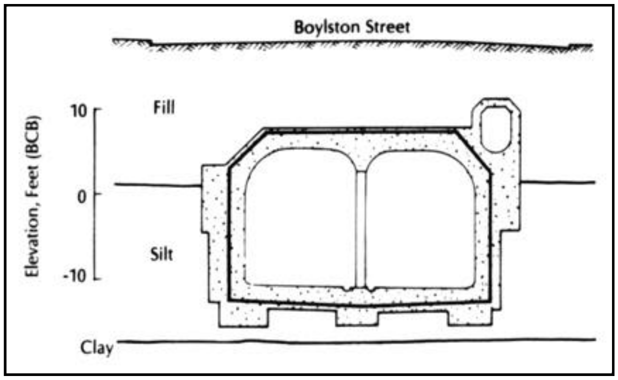


FIGURE 10. A cross section of the Boylston Street Subway at Sta. 58+00 between Berkeley and Clarendon Streets. (Ref. 21).

During construction, a temporary drawdown of water levels both in the fill and in the sand-gravel stratum would have occurred. Where the subway route passed opposite to what is now the Prudential site, drawdown in the sand stratum to el. -10.0 is estimated.

Constructed between October 1937 and 1940, the Huntington Avenue subway crosses under Massachusetts Avenue as it enters Back Bay and joins the BoyIston Street subway at Exeter Street (see Figure 4). Within this area, the bottom grade of the subway structure

TABLE 2

Boylston Street Subway

Location	Approximate Station	El. Top of Rail	Soil Conditions at Bottom of Subway
Kenmore Street (at Commonwealth)	0+00	16.2	Sand & gravel fill underlain by silt
Charlesgate West (at Commonwealth)	6+00	-8.7	Silt underlain by sand & gravel
Charlesgate East (at Newbury St.)	10+00	-18.9	Sand & gravel; short section of clay
Massachusetts Ave. (at Newbury St.)	19+32	7.5	Sand & gravel fill underlain by silt
Hereford Street	27+15	7.7	Silt over sand & gravel
Gloucester Street	31+55	1.9	Sand & gravel
Fairfield Street	37+15	-4.8	Sand & gravel
Exeter Street	43+75	-6.4	Silt over sand & gravel
Dartmouth Street	49+80	-6.5	Silt over thin peat over thin sand & gravel
Clarendon Street	56+05	-8.8	Silt over thin peat
Berkeley Street	62+25	-13.0	Sand & gravel
Arlington Street	69+10	-14.5	Clay
Hadassah Way	73+35	N -14.0 S -11.5	Fairly hard blue clay (peat between Hadassah Way & Charles Street)
Charles Street	78+00	N -4.2 S -5.0	Blue clay & gravel

Notes: Information was obtained from Boston Transit Commission Plans No. 10219, 10386, 10091, 10418, 11157, 11159,11161 and 11162 of "Boylston Street Subway." The bottom of subway structure varies from 4 to 5.5 ft. below top of rail. The subway is supported on wood piles from Station 71+82 to Station 76+41.

varies from el. -10.0 at Massachusetts Avenue down to el. -19.0 where the structure passes below the railroad tracks (and under the Massachusetts Turnpike Extension). Table 3 presents elevation and soil condition data.

The subway was founded on the outwash stratum that extends from 5 to 12 ft. below the bottom of concrete 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 outwash stratum was dewatered for the entire length of the subway along Huntington Avenue to grades as low as, or even below, el. -20.0. A very significant drawdown of water level occurred over a wide area, for a period of 2 to 3 years. An observation well at Massachusetts and Commonwealth Avenues, 0.4 miles away, was reported to have dropped from el. 7.0 to el. 0 in 1939.

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 of both subway lines have undoubtedly collected groundwater that leaked into the structure.

Construction of Storrow Drive in the early 1950s included an underpass and traffic interchange in the Berkeley Street area. This underpass is approximately 1,300 ft. long between

TABLE 3
Huntington Avenue Subway

Location	Approximate Station	El. Top of Rail	Soil Conditions at Bottom of Subway
Massachusetts Ave.	13+85	-6.0	12 ft. hard packed coarse sand
Cumberland Street	21+50	-10.9	11 ft. hard packed coarse sand & gravel
West Newton Street	26+65	-13.0	7 ft. hard packed sand & gravel
Garrison Street	32+00	-13.1	4 ft. hard packed coarse sand
B&A Railroad Tracks (Mass. Turnpike Extension)	37+50	-13.6	Hard yellow clay (sand pinches out at Station 37+50±)
Blagden Street (& Exeter Street)	41+30	-10.7	4 ft. silt over medium blue clay & sand
Boylston Street (& Exeter Street)	44+50	-6.9	4 ft. peat over 8 ft. fine sand over stiff blue clay

Notes: information was obtained from City of Boston Transit Department Plans No. 17947, 17943, 17936,17933 and 17914 of "Huntington Ave. Subway, Plan & Profile." The bottom of the subway structure varies from 3.5 to 6 ft. below top of rail. Footings, pedestrian passageway (Mass. Ave.) and bottoms of catch basins are deeper.

portals, with 300-ft. long approach ramps at either end. The road surface descends as low as about el. -4.0, about 15 to 17 ft. below the ground surface.

The underpass was designed to prevent groundwater lowering by the extensive use of waterstops. The structure was designed as a boat with sufficient weight to resist hydrostatic uplift pressure. Invert slabs were up to 2-ft. 8-in. thick. Precipitation and other surface water is collected in catch basins and cross drains that feed into pipes below the slab. These pipes transport water to wet wells near each portal where the water is then pumped into the Charles River.

Soon after completion, leaks were reported in the reinforced concrete walls. In order to collect the infiltrating groundwater and improve the appearance, gutters and false walls were installed. 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.

The Massachusetts Turnpike Extension, a six-lane limited access highway, crosses the Back Bay. The highway was constructed between 1963 and 1966, and is located just north of the Conrail (formerly Boston and Albany) railroad alignment (see Figure 4). The roadway was depressed 15 to 20 ft. below adjacent city streets and developed areas. The road surface descends from about el. 11.0 at Massachusetts

Avenue down to el. 6.0 at Tremont Street.

The turnpike was designed to prevent a permanent lowering of groundwater levels below about el. 6.5 to 8.5, depending on the location. West of Huntington Avenue, an underdrain system was used to limit uplift pressures on the slab, Through the Prudential Center site, two lines of steel sheetpiling driven 5 ft. into the clay inhibit the flow of groundwater to the turnpike underdrain.

Because the road surface east of Huntington Avenue was lower, underdrains were not used. The turnpikestructure was designed for uplift as a boat section, using a thick concrete slab to prevent flotation. 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 maintain water levels at about el. 7.0.

Southwest Corridor Project. This new transportation structure was constructed between 1981 and 1985. It has two tracks for the relocated Massachusetts Bay Transportation Authority Orange Line subway and three tracks for commuter rail and Amtrak service. Through Back Bay, the alignment followed parts of two original railroad embankments that were constructed across the Receiving Basin in the mid-1830s (see Figure 4 on page 37). From Massachusetts Avenue to Dartmouth Street, the new concrete structure was below ground in a 3,000-ft. Icing cut-and-cover tunnel that required excavations as deep as 38 ft.- East of Dartmouth Street, the structure extended about 10 ft. below former grade. Depths of excavations and other data are summarized in Table 4 on page 46.

Reinforced concrete slurry walls were used for lateral support of the sides for about 2,100 ft. of the tunnel excavation (see Figure 11). The concrete walls were 3-ft. thick and penetrated 8 to 15 ft. into the clay stratum. They were used as the tunnel's permanent outside walls. Although water leakage did occur through some of the vertical joints between wall panels, there was no appreciable lowering of groundwater levels in adjacent areas.

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

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

In order to allow groundwater movement across the corridor structure, a groundwater equalization underdrain system was installed. This system consisted of longitudinal drains placed 2 to 4 ft. below the pre-construction groundwater level on either side of the structure. Where slurry walls formed the tunnel walls, 8-in. diameter header pipes surrounded by crushed stone were connected to 8-in. galvanized steel pipes cast into the walls and connected beneath the invert slab. In other areas, rectangular drains of crushed stone wrapped in filter fabric were constructed beneath the invert slab and up the outside of each wall in order to allow water to flow between longitudinal drains on tither side.

Major Buildings. The first major buildings with deep basements in Back Bay were the Liberty Mutual and New England Life buildings, constructed in the late 1930s. Since that time, other buildings requiring excavation well below the groundwater table have been erected.

Temporary Effects of Building Construction Dewatering

Where excavations have been carried below the water table for building construction in Back Bay, the water table in nearby areas has been lowered, in some cases by a significant amount. Table 5 on page 48 summarizes pertinent information - dates of construction, location, foundation type, elevation of the deepest excavation, dewatering and drawdown - for major construction projects gathered from the available literature, reports

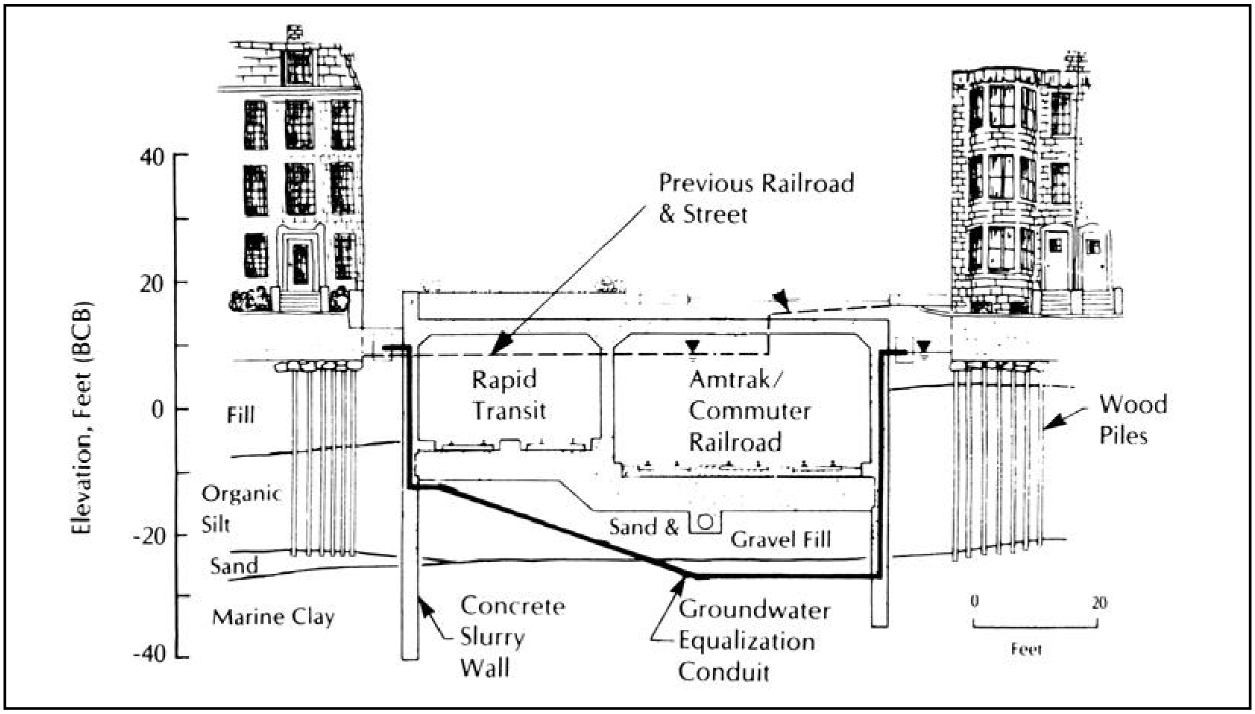


FIGURE 11. A cross section of the Southwest Corridor Project tunnel, taken at Follen Street.

and construction records. The locations of major deep excavations for both buildings and sewer and transportation projects, and the approximate elevations of the bottoms of these excavations are shown in Figure 12 on page 50.

Copley Square Area. The sand Outwash is shown in Figure 4 on page 37 to be absent around and for some distance north, east and south of Copley Square, which is generally near the intersection of Dartmouth and Boylston Streets. Therefore, the principal source of water to excavations in the area is by seepage from the fill. Drawdown in the fill is limited to the distance between normal groundwater level and the top Of tile underlying organic silt, generally less than 7 to 10 ft. Drawdowns of this magnitude were usually confined to areas near the excavation. The volume of water entering excavations has been small and temporary recharging has generally not been practiced.

Excavations for deep foundations have advanced from the early use of unsupported slopes, often combined with deeper laterally supported soldier piles and wood lagging, to the more recent use of steel sheetpiling and concrete diaphragm walls installed in slurry trenches.

In the case of the New England Mutual Life Insurance Co. building, a nearly 40-ft. deep excavation was opened in 1939 Over the western two-thirds of the block bounded by Clarendon and Berkeley Streets, and Boylston and Newbury Streets. Steel soldier piles and wood lagging were used to support the sides of the excavation in the organic silt stratum, and the overlying fill was cut back to a stable slope. Surface water and groundwater were collected in troughs cut into the top of the organic silt stratum at the toe of slope behind the sheeting, and sumps were used to dewater the excavation, The building was founded on large spread footings and mats bearing on the stiff crust of the clay at el. -17.0 to -22.0, in early classic example of a "floating" foundation. Adjacent to the excavation, groundwater levels in the fill would have been lowered to the top of the underlying organic silt, about el. 0. Water levels in observation wells located immediately west of the site, at Clarendon Street, dropped 4 to 6 ft. to about el. 2.0. There were no reports of adverse effects to surrounding buildings.

The excavation, in 1947, for the John Hancock Berkeley building was very

Table 4

Southwest Corridor Project

	Elevation of Bottom of Structure		Elevation of Bottom of Deepest Excavation
	Subway	Amtrak	
Gainsborough Street	6.0	3.3	3.6
Massachusetts Avenue	6.0	-6.0	-7.5
Blackwood Street	-8.2	-14.4	-23.0*
West Newton Street	-10.4	-16.7	-24.5*
Harcourt Street	-10.4	-16.4	-24.5*
Yarmouth Street	-4.7	-12.4	-14.4 -18.4**
Dartmouth Street	3.6	-4.0	-5.6 -12.4**
Clarendon Street	3.6	-5.0	-6.4 -9.6**
Berkeley Street	1.6	-5.0	-6.4 -8.4**
Chandler Street (to east end)	-2.1	-3.0	-4.4

Notes: Information was obtained from 1981 and 1982 Massachusetts Bay Transportation Authorit plans for Contracts No. 097-115 and 097-120.
*Removed organic silt to top of clay stratum.
**Lower elevation for trench excavated for track drain pipe.

similar to that for the New England Mutual building. The excavation was opened on Berkeley Street between St. James Avenue and Stuart Street. Again, soldier piles and wood lagging were used to support the sides of the excavation in the organic silt, while the overlying fill was cut to a slope of about 1.5 horizontal to 1 vertical. In order to intercept groundwater and surface runoff, an 8-in. pipe was installed around the sides of the excavation in a sand-filled trench located just above the organic silt. The excavation was dewatered using three caisson wells.

During construction, groundwater levels in the fill adjacent to the excavation would have been lowered to the top of the organic silt, as they were during the construction at the New England Mutual building. A 10-ft.

Lateral Earth Support System	Type of Foundation
None, excavation sloped	Belled caissons bearing on clay crust
Steel sheet piling	Rectangular pedestals bearing on clay crust
Concrete diaphragm wall	Slab on compacted gravel borrow replacement fill
Concrete diaphragm wall	Slab on compacted gravel borrow replacement fill
Concrete diaphragm wall	Slab on compacted gravel borrow replacement fill
Steel sheet piling	Precast-prestressed concrete piles to glacial till/bedrock
Soldier piles & lagging to south (Amtrak) side. None to north side.	Precast-prestressed concrete piles to glacial till/bedrock
Soldier piles & lagging to south side. None to north side.	Precast-prestressed concrete piles to glacial till/bedrock
Soldier piles & lagging to south side. None to north side.	Precast-prestressed concrete piles to glacial till/bedrock
Soldier piles & lagging to south side. None to north side.	Precast-prestressed concrete piles to glacial till/bedrock

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drawdown, to about el. -2.0 on St. James Avenue, would have occurred. Casagrande reported a 10-ft. drawdown in 1947 across Berkeley Street at the Liberty Mutual Building.(9) To the west of the excavation, groundwater levels in the fill were also lowered by 4.5 and 2.5 ft. at distances of 125 and 300 ft., respectively.

An increase in the rate of settlement of the Liberty Mutual building, located across from the site at Berkeley Street, was attributed to an increase in the effective stress in the clay stratum caused by lowered groundwater levels, and to the effects of disturbance to the structure of the clay from the driving of steel H-piles.(10) The building settled an additional 0.5 in., about half of which was recovered in rebound when the groundwater returned to

Table 5
Temporary Effects of Major Back Bay Construction on Groundwater Levels

Construction Project	Location	Years of Dewatering	Site Dewatering Probable Lowest Elevation	Method or Remark
Sewers & Drains				
West Side Interceptor	Charles St. to Beacon to Hereford to Falmouth to Gainsborough St	1877-1884 to el. -7.5	Varied el. -2.0 & sumps	Underdrains sheeting
Low Level Sewers	Throughout Back Bay	1910-1912		Underdrains & sumps
West Side Interceptor Relocation	At Christian Science Church Center	1968-1969	el. -7.5	Wellpoints in sand
Subways				
Boylston Street Subway	Boylston St. from Arlington St. to beyond Mass. Ave.	1912-1914	el. -19.0	Deepest between Arlington St. & Copley Square
Huntington Avenue Subway	Beneath Exeter St. & Huntington Ave to beyond Mass. Ave.	1937-1940	el. -20.0	Lowest under Mass. Turnpike & railroad
Huntington Avenue Subway Prudential Entrance	Huntington Ave. near West Newton St.	1969-1970	el. -15.0	
Southwest Corridor Project	Mass. Ave. to Harcourt St.	1981-1985	el. -15.0 to el. -28.0	None required
	Harcourt St. to Berkeley St.	1982-1985	el. -28.0 el -4.0	Sumps in excavation
Buildings				
Christian Science Publ. House	Norway St.	1931-1934	el. -3.0 to el. -6.0	Wellpoints in Sand
New England Mutual Life Ins. Co. Bldg.	Clarendon St. between Newbury & Berkeley Sts.	1939-1940	el. -21.0	Sumps in excavation
John Hancock Berkeley Bldg.	Berkeley St. between St. James & Stuart Sts.	1946-1947	el. -25.0	Sumps in excavation
Boston Herald Traveler Bldg.	Harrison Ave. between Herald & Traveler Sts.	1957	Deep in sand above bedrock	
Christian Science Publ. House Underground Equip. Rm.	Norway St. adjacent to Mother Church	1958	el. -3.0	Wellpoints in Sand
Prudential Center Tower	Center of Prudential Center Complex	1959-1960	el. -12.0	Wellpoints in Sand
Sheraton Hotel at Prudential Center	Dalton & Belvidere Sts.	1962-1963	el. -4.0	Wellpoints in Sand
180 Beacon St. Apart. Bldg.	Beacon & Clarendon Sts.	1964-1966	el. -14.0	Unknown
Christian Science Admin. Bldg.	Huntington Ave. between Belvidere & Cumberland Sts.	1967-1968	el. -5.0	Open pumping in excavation
Christian Science Colonnade Bldg.	Clearway & Belvidere Sts.	1968-1969	el. 0.0	Shallow, probably by sumps
John Hancock Tower	Clarendon, between St. James & Stuart Sts.	1968-1974	el. -28.0	Sumps within site
Christian Science Church New Portico	West Side of Mother Church	1973	el. -4.0	Wellpoints in Sand
Symphony Plaza Apartments	Mass. Ave. at St. Botolph St.	1977	el. +4.0 to el. -3.0	Sumps in pile cap pits
Greenhouse Apartments	Huntington Ave. at W. Newton St.	1981	el. -2.0	Sumps in pile cap & elevator pits
Copley Place	Huntington Ave between Harcourt & Dartmouth Sts.	1981-1982	el. -4.0	Sumps in pile cap excavations
One Exeter Place	Boylston & Exeter Sts.	1982-1983	el. 0.0	Sumps in excavation

Lateral Earth Support System		Effect of Pumping on Groundwater Levels		
Type	Lowest Stratum Penetrated	Distance from Excavation	Drawdown	Other Remarks
Probably wood & Sand	Organic Silt	No records available		Significant drawdown in adjacent areas probably occurred. See Figure 4.
		No records available		Significant drawdown in adjacent areas probably occurred.
Steel sheet piles	Clay	100 ft.	8 to 10 ft. in Sand	Recharge around Christian Science Church eliminated drawdown in Fill.
		700 ft.	none in Sand	
		100 ft.	3 ft. in Fill	
Steel sheet pile	Clay	No reports available		Siphon pipes installed to allow structure. groundwater movement across See Table 2.
Steel sheet piles	Clay	200 ft.	13 ft. in Sand	Dewatered for 3 yrs. WPA data indicated large area affected (Mass. Ave. to Dartmouth St.). See Table 3.
		800 ft.	12 ft. (after 2 yrs.)	
		1100 ft.	8 ft. in Sand	
		0.4 mi.	7 ft. in Sand	
Steel sheet piles		300 ft.	18 ft. in Sand	Dewatering for 5 months. No drawdown observed in Fill.
		400 ft.	4 ft. in Sand	
		800 ft.	6 ft. in Sand	
		1000 ft.	8 ft. in Sand	
		1200 ft.	6 ft. in Sand	
		1400 ft.	4 ft. in Sand	
Concrete diaphragm walls	Top of Clay	None observed that was attributable to corridor tunnel construction.		Excavation open 1-2 yrs. Observ. wells at each street. See Table 4.
Sheet piles, soldier beams & lagging	Organic Silt			Rises to el. -4.0 east of Dartmouth St.
Unknown	Sand	300 ft.	8 ft. in Sand	
		300 ft.	2.5 ft. in Fill	
		1000 ft.	4-5 ft. (in Sand?)	
Soldier piles & lagging	Clay	Nearby	4-6 ft. in Fill	No Sand at site.
Soldier piles & lagging		90 ft.	10 ft.	No Sand at site.
		140 ft.	7 ft. in Fill	
	Unknown	1 mi.	30 ft. in deep sand	Dewatering for caissons to rock.
Steel sheet piles	Sand, halfway through	At excavation	11 ft. in Sand	Little drawdown in Fill.
		500 ft.	8 ft. in Sand	
		1200 ft.	4 ft. in Sand	
Steel sheet piles	Clay	Nearby	16 ft. in Sand 1-2 ft. in Fill	Recharged Fill & Sand outside sheeting.
Steel sheet piles	Clay	400 ft.	Initially, 3.5 ft. in Sand	Recharge system correction eliminated drawdown.
Concrete slurry walls	Unknown	Nearby	12-15 ft. in Sand	Slurry wall leaked. Recharged Sand outwash unsuccessful.
	Unknown	200 ft.	“Some” in Fill	
		500 ft.	0 ft. in Fill	
	Unknown		“Minor” in Fill	No data available on off-site drawdown.
Steel sheet piles	Clay	Near	Negligible in Fill	No Sand at site.
Partially sheeted	Sand	40 ft.	8 ft. in Sand	No drawdown observed in Fill.
		90 ft.	4.5 ft. in Sand	
		230 ft.	5.5 ft. in Sand	
	Unknown	Nearby	3 ft. in Fill	
Soldier pile & lagging	Organic Silt	40 ft.	3 ft. in Fill	
Soldier pile & lagging	Organic Silt	Near	Minor in Fill	Only pile cap excavations went below groundwater.
Steel sheet piles	Clay	Nearby	Negligible in Fill	

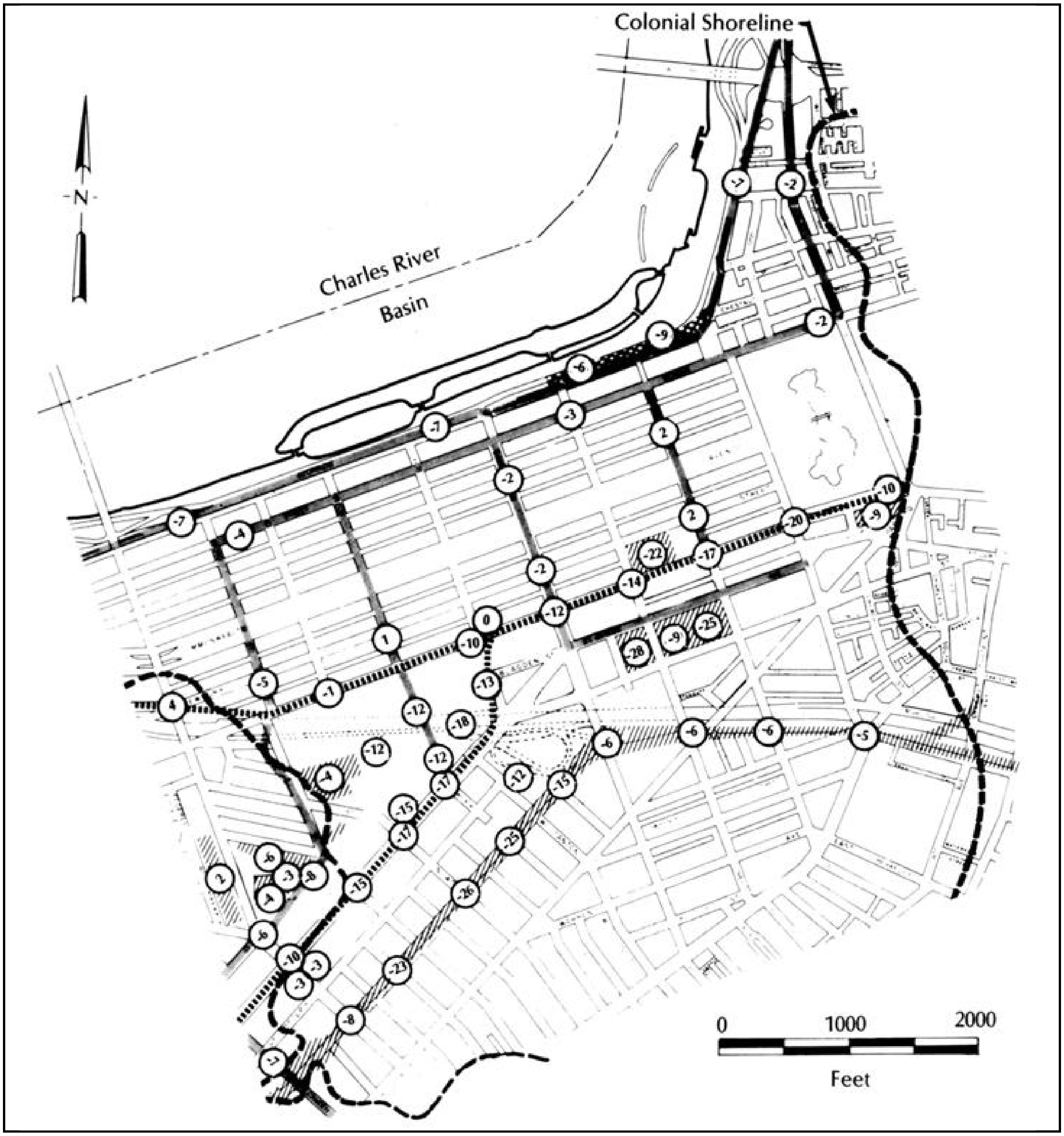


FIGURE 12. The locations and elevations of major deep excavations in Back Bay.

pre-construction levels.

Construction of the John Hancock Tower, begun in late 1968, required excavation to el. -28.0 (45 ft. below ground surface).(11) Interlocking steel sheetpiling was driven approximately 5 ft. into the clay to form a cofferdam around the site. The sheeting extended to ground surface, unlike excavations at the New England Mutual and the Hancock Berkeley buildings where the fill was sloped down to the laterally-supported organic silt. Prior to construction, during October and November 1967, water levels at the site varied between el. 4.5 and 6.0, with an average of el. 5.0.

Contrary to experience at the Prudential Center, there was no significant drawdown of the water table beneath the streets surrounding the site. Water levels measured in the fill during construction were generally from el. 4.0 to 5.0. Immediately behind the steel sheeting, a local drawdown exceeding 10 ft. was measured in a piezometer installed in the organic silt. Very little pumping was required inside the sheeting and no recharging was performed. Drawdown at the John Hancock Tower was insignificant because steel sheet piling was used and the sand outwash stratum was absent.

Foundation construction for Copley Place began in 1981 on a 10-acre site bounded by Huntington Avenue, the Southwest Corridor, Harcourt and Dartmouth Streets. The lowest floor level was established at el. 6.6, somewhat above the pre-construction groundwater table. Dewatering was required only for the construction of pile caps and a deep water main. Excavation and dewatering for one large pile cap below the Westin Hotel was carried to approximately el. -5.0, using steel sheeting for lateral support. Elsewhere, the sides of the excavation were either unsupported slopes or supported with soldier piles and wood lagging.

The impact of dewatering on groundwater levels adjacent to the site was minor. An observation well on Blagden Street adjacent to the Boston Public Library dropped temporarily about 3 ft. However, there was no observable drawdown at Trinity Church.

A quarter-mile north of Copley Square, at the corner of Beacon and Clarendon Streets, significant construction was required for a 17-story apartment building constructed in 1964-1966 at 180 Beacon Street. Here, soil conditions were much like those in Copley Square. Concrete diaphragm walls installed in slurry trenches were used both for lateral support of the sides of excavation and as permanent basement walls, the first such use in Boston. The 2-ft. thick reinforced concrete walls were internally braced and surrounded the site. These walls penetrated about seven feet into the clay stratum, which is overlain at this location by 5 ft. of sand outwash. The site was excavated down to about el. -20.0 for the 3-1/2 basement levels required (12 to 14 ft. above the outwash stratum).

Leakage through the concrete wall was apparently the cause of a 12 to 15-ft. draw down in observation wells installed in the outwash on adjacent property. Water from city mains was pumped into the outwash through five 2-inch diameter recharge wells, but with only moderate success in raising the piezometric head. The extent to which the perched water level in the fill was affected is not known. Some minor settlement of an adjacent wood pile-supported 10-story apartment building was attributed to the construction, but the cause was never clearly established.

The Christian Science Church Center is southwest of Copley Square. In this area, the pervious sand outwash stratum is fully developed to a thickness of 12 to 20 ft. Most of the structures built in the Christian Science complex have been founded, in one way or another, on this outwash. The Mother Church was founded on untreated wood piles. Dewatering of the confined outwash aquifer had been required during construction of several buildings constructed in the last 55 years in this complex.

In 1932, excavation for the 100 by 630 ft. Christian Science Publishing House building on the former Norway Street was carried as low as el. -6.0 for spread footing construction on the sand outwash. Dewatering by wellpoints in the outwash dropped the piezometric head an estimated 10 to 15 ft. for approximately eight months. The lateral earth support system used for this excavation is not known.

Water levels in the confined outwash aquifer responded quickly to the dewatering over a large area. The water level in an observation well located 1,200 ft. Southwest of the site dropped 4 to 5 ft. in two weeks, while at the Mother Church, the water level was lowered 8 ft. The effects of construction dewatering in the fill were much less, with the water table dropping only 2.5 ft. at the Mother Church.

Drawdown in 1958 for the excavation of the Christian Science Publishing House Underground Equipment Room adjacent to the Mother Church was similar to that experienced in 1932 during Publishing House construction. Excavation extended to el -3.0 in the sand outwash. Lateral earth support was provided by steel sheet piling that penetrated part way through the sand. Wellpoints were used inside the sheeting to dewater the outwash to approximately el. -4.0. Water levels in observation wells in the outwash 500 and 1,200 ft. from the site were lowered to el. -1.0 and 3.0, respectively.

As part of a major construction program at the Christian Science Church between 1969 and 1972, an approximately 1,000-ft. long section of the West Side Interceptor was relocated into a gallery. Construction was carried out between two rows of steel sheet piling, 16 ft. apart, and driven 5 ft. into the clay stratum. The bottom of the foundation for the gallery was el. -7.5 in the sand outwash. Dewatering was accomplished by wellpoints installed inside the cofferdam. Drawdown in the sand stratum at the nearby Mother Church was initially to el. -2.0. Six large-diameter recharge wells installed around the Mother Church raised piezometric levels to about el. 3.0. Later, as recharge became ineffective, outwash water levels fell back to el. -2.0 and -3.0. In the fill stratum, the initial drawdown to el. 3.0 was successfully recharged to el. 6.0.

For the 1973 construction of a new portico for the Mother Church, the last major project at the Christian Science complex, foundations at the front of the Mother Church were underpinned with six concrete piers bearing on the outwash at el. -3.5. Dewatering by wellpoints lowered water levels in the outwash by 8 and -5.5 ft. at distances of 40 and 230 ft. from the excavation, respectively. There was no observable drawdown in the fill.

The Prudential Center is immediately west of Copley Square. Construction began in 1959 with a 52-story tower. The entire development, the largest in Boston at the time, was enclosed within a wall of interlocking steel sheeting that was reported to have been driven 5 ft. into the clay stratum to form a relatively impermeable cofferdam. Internally, the area was divided by sheet pile walls into several cells.

A parking garage was constructed beneath most of the Prudential Center, with the lowest floor level at el. 3.0. A portion of the slab was supported on compacted sand and gravel fill that was placed after the organic soils were excavated. This excavation and backfill operation, and other excavations requiring dewatering, were accomplished with wellpoints.

Drawdown in the outwash sand just outside the sheet piles was reported to have been to as low as el. -12.0. Construction specifications required recharging outside the sheeting to maintain groundwater levels at or above el. 5.0. There were considerable problems with recharging the sand outwash, and it was only moderately successful. However, there were no significant problems in maintaining water levels outside the sheeting in the fill.

In 1969 and 1970, an area at the edge of the Prudential Center was dewatered for the construction of a new entrance to the Huntington Avenue subway. Excavation and dewatering were carried out to el. -15.0 in the sand outwash. Dewatering lowered water levels in wells at the Mother Church and Massachusetts Avenue to el. -7.0 and 0.0 (1,000 and 1,200 ft. away, respectively). Drawdown in the sand outwash was reported to have caused the Prudential Center garage to settle 0.5 in. Here again, most of the subsidence was recovered after dewatering when water levels returned to pre-construction levels.(9,12)

Effects from Outside Back Bay. In 1957, the Boston Herald Traveler Corporation started construction of a new building at 300 Harrison Avenue, well outside of the fill area to the east of Copley Square. Dewatering of the glacial till/outwash strata occurring below the clay was required for construction of deep caissons. Because these materials are relatively pervious, piezometric levels in the till and outwash were lowered significantly in Back Bay. Water levels in deep observation wells at the Prudential Center, approximately one mile away, dropped as much as 30 ft. within a month of the start of pumping.(9) This drawdown over a period of five months caused about 0.1 and 0.3 in. of settlement at the New England Mutual Building and the Liberty Mutual Building, respectively, located about 0.8 and 0.6 miles from the Herald Traveler Building.(10) Most of the subsidence was recovered by rebound after dewatering.

Overall, for sites where the sand outwash stratum was absent, for example in the Copley Square area, deep excavations have been successfully accomplished within steel sheet pile cofferdams without significant groundwater drawdown in the fill and without having to install recharge systems. Where the outwash occurred to the west, even the use of steel sheeting had not prevented drawdown in the pervious sand stratum because of leakage through untensioned interlocks.

Drawdown in the sand outwash stratum generally extended 5 to 10 times further from a deep excavation than groundwater drawdown in the fill. Water levels in the outwash were lowered significantly at distances of 1,000 ft. or more from an excavation. In the fill, however, drawdown greater than one foot did not usually occur at distances beyond 400 ft. Drawdown in the fill was limited by the depth to the organic silt stratum. Groundwater recharge systems have been successfully used to limit lowered water levels in the fill. Similar systems have not been effective in the outwash stratum.

Historical Groundwater Levels in Back Bay

Groundwater levels in Back Bay are influenced by the natural process of precipitation and infiltration, and by water levels in adjacent bodies of water. If there were no man-made structures, the water table would be relatively uniform across Back Bay and would vary little with time, being affected only by the amount of precipitation and local infiltration.

Construction over the past 100 years - sewers and drains, dams, transportation corridors and building foundations described above - have diverted or withdrawn groundwater, have impeded its flow and, in other respects, have influenced the water table. Groundwater levels are non-uniform, complex and have varied substantially in localized areas over time. Therefore, the interpretation of groundwater data can be confusing, frustrating and misleading.

Concern for groundwater levels in Back Bay has prompted sporadic action during the past 100 years. Area-wide studies were made before and after construction of the Boston Main Drainage System in the late 1800s, during the 1890s for the Charles River Dam, in the late 1930s under a WPA program, by the USGS in 1967 and 1968, and in 1985 for the BRA." In the past 25 years, numerous studies have been undertaken in local areas for building construction, most recently in 1985. 18 However, there has been no long-term study.

1880s Study. Stearns reported that groundwater levels in wells installed in 1878 before construction of the main drainage system were practically the same in 1885, one year after construction, with water levels "nearly level at Grade 7.7 over the whole district" (P. 26)."(3) The data indicated levels between el. 6.7 and 8.5. Engineers of that time realized the importance of maintaining groundwater levels and were concerned about the effects of the new main drainage works on the water table.

1894 Charles River Dam Study. Water levels were measured in wells installed for an 1890s study of the proposed Charles River Dam as reported by Stearns.(3) Generally, groundwater levels were similar to those measured between 1878 and 1885. Stearns blamed leaky sewers for some levels below el. 5.0, but considered these instances to be local and isolated. He recommended that el. 8.0 be established as the water level for the new Charles River Basin. In discussions to Worcester's 1914 paper, Gow and Stearns cited leaky sewers as a cause of local groundwater depressions.(8)

1930s Copley Square Study. In 1929, public officials and residents noticed several alarming cracks in the Boston Public Library Building, and settlement of the stone platform in front of the library facing Copley Square on Dartmouth Street. Investigations by the Building Department and consulting engineers found that the tops of many wood piles supporting the building were completely rotted away or badly decayed.(14,15) Piles were originally cut off at approximately el. 5.0 and groundwater was found to average el. 4.0 at the time of underpinning.

Rotted piles below approximately 40 percent of the building area were cut off to sound wood and were posted with 6-in. steel H-sections bearing on steel plates and wedged against the underside of the stone foundation. The cost of this underpinning in 1929-30 was reported to be "nearly $200,000."

The discovery of rotted wood piles under the Library sparked renewed interest in groundwater levels, especially among the Trustees of the nearby Trinity Church that was constructed in 1876 on 4,500 wood piles. Numerous observation wells were installed in the Copley Square area, showing water levels as low as el. 2.0.

When contours of equal water level were analyzed (see Figure 13), the loss of groundwater was traced to leakage into a 30-in. diameter sewer on St. James Avenue (see Figure 9). Construction of a partial dam in the sewer on Dartmouth Street, where it joins the Boylston Street sewer in front of the Public Library, caused observation wells to rise immediately, proving without a doubt the source of the lost groundwater.

Fortunately, Trinity Church was spared. Excavations to examine the condition of wood piles, originally cut off from el. 5.0 to 5.5, showed no significant deterioration. The structure had settled nearly one foot in 50 years and pile butts were now lower. This case history was documented by Robert Treat Paine in 1935.11, In addition, Snow traced the loss of groundwater in the area.(14)

1936-1940 WPA Surveys. The city of Boston measured groundwater levels throughout the Boston Peninsula between 1936 and 1940. The project was funded by the Works Progress Administration under projects No. 5325 and No. 188868. The impetus for this study was the growing concern about groundwater levels in the city during the 1920s and 1930s, heightened by the discovery of the rotted wood piles at the Boston Public Library.

Observation wells installed for the WPA project and wells previously installed by the Boston Sewer Department were monitored. Throughout the Boston Peninsula, a total of approximately 700 observation wells were used in the WPA survey. Approximately 300 of these wells were located in Back Bay. A report prepared for the Boston Redevelopment Authority (BRA) contains tables and plans that describe the location of each well, and the highest and lowest water levels recorded during the four-year monitoring period." Unfortunately, complete records of all water levels recorded during the program are not available, since they were destroyed in a fire at Boston City Hall. Figure 14, on page 56, prepared from contour plans by Cotton and Delaney, shows areas in Back Bay having water levels below el. 5.0 during that 4-year period.(4)

Most wells in Back Bay experienced a water level below el. 5.0, and, in seven wells, the highest water level measured was also below el 5.0. Local drawdowns from leaking sewers are the most probable cause for the low water levels in the seven wells. Precipitation during the period was about average for Boston, with yearly deviations up to 6 in.

Significant construction projects during 1936-1940 included the Huntington Avenue subway that dewatered the sand outwash to el. -20.0 or below; the Liberty Mutual building, with excavation below el. 0; and the New England Mutual building where excavation extended to el. -21.0. These projects cannot, however, account for the broad extent of low water levels in Back Bay. Leaking sewers and pumping from sumps in basements of buildings undoubtedly were major contributors.

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.(4)

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 silt 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 affect water level in the fill. Some of the WPA observation wells may have been installed into the outwash stratum. Water levels observed in some wells may, therefore, have been lower than groundwater levels in the fill.

In the Copley Square area, south of Boylston Street between Dartmouth and Berkeley Streets, the low groundwater levels

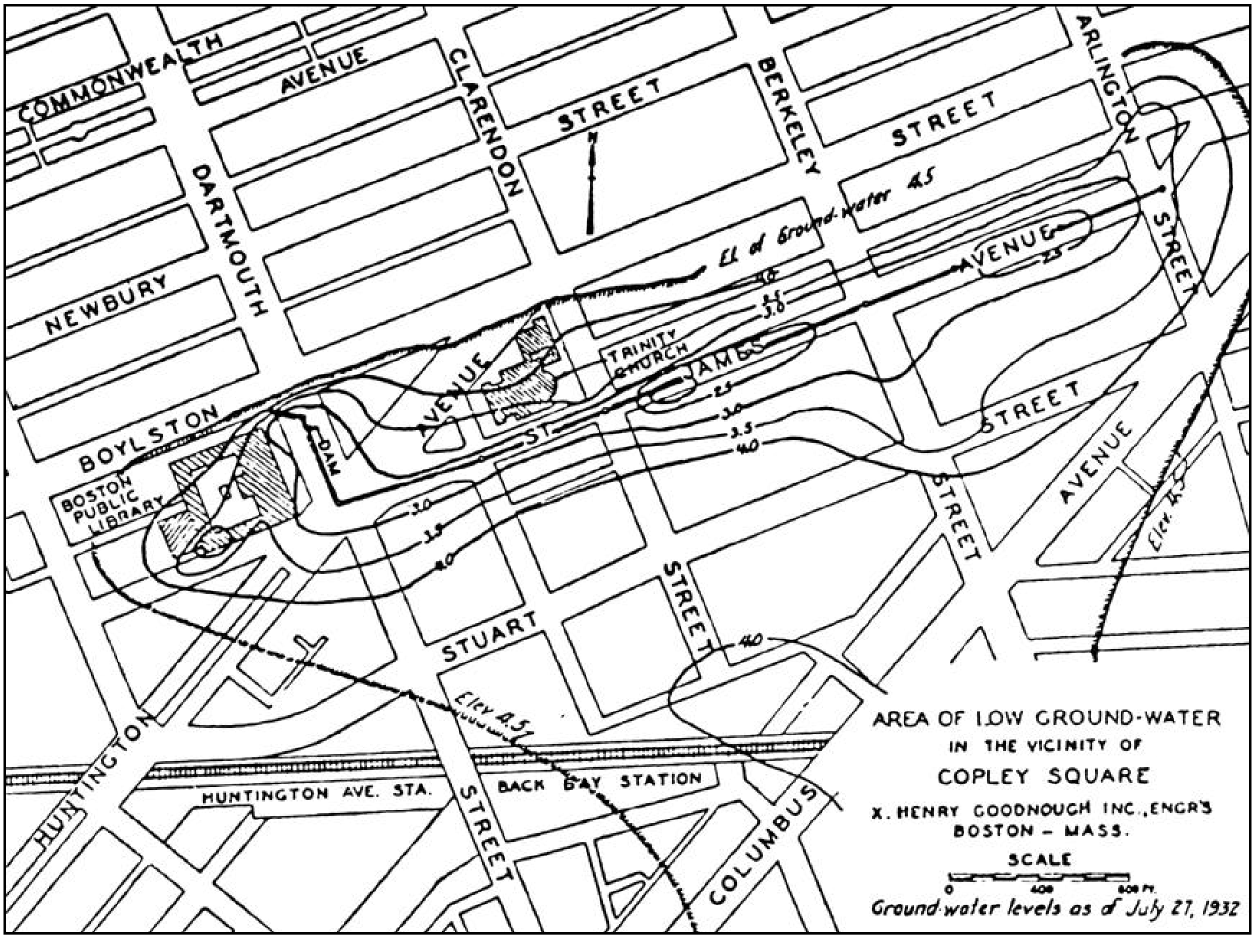


FIGURE 13. Water level contours along St. James Avenue in 1932. (16)

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 forms a barrier to groundwater seepage from across the street, low groundwater levels in this area were probably not related to construction dewatering and drawdown.

The St. James Avenue sewer has a history of causing local groundwater lowering. Groundwater levels have also been lowered by drainage in a crawl space along the easterly side of the John Hancock Clarendon building that reduces hydrostatic pressures on basement floors and walls. Until 1984, the water level had been held at el. -0.5. It has been raised somewhat with recent renovations to the structure. Sump pumping has also been performed at 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 major sewers that join in that area. Some water levels there were as low as el. 0 to -3.0. In this area, there were also several groundwater mounds, probably due to water main leaks. These local recharges intermittently interrupt the drawdown pattern toward Tremont Street.

1967-1968 USGS Measurements. On two occasions, in September 1967 and March 1968, the United States Geological Survey (USGS) measured 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 adverse effects of construction for the then proposed Inner

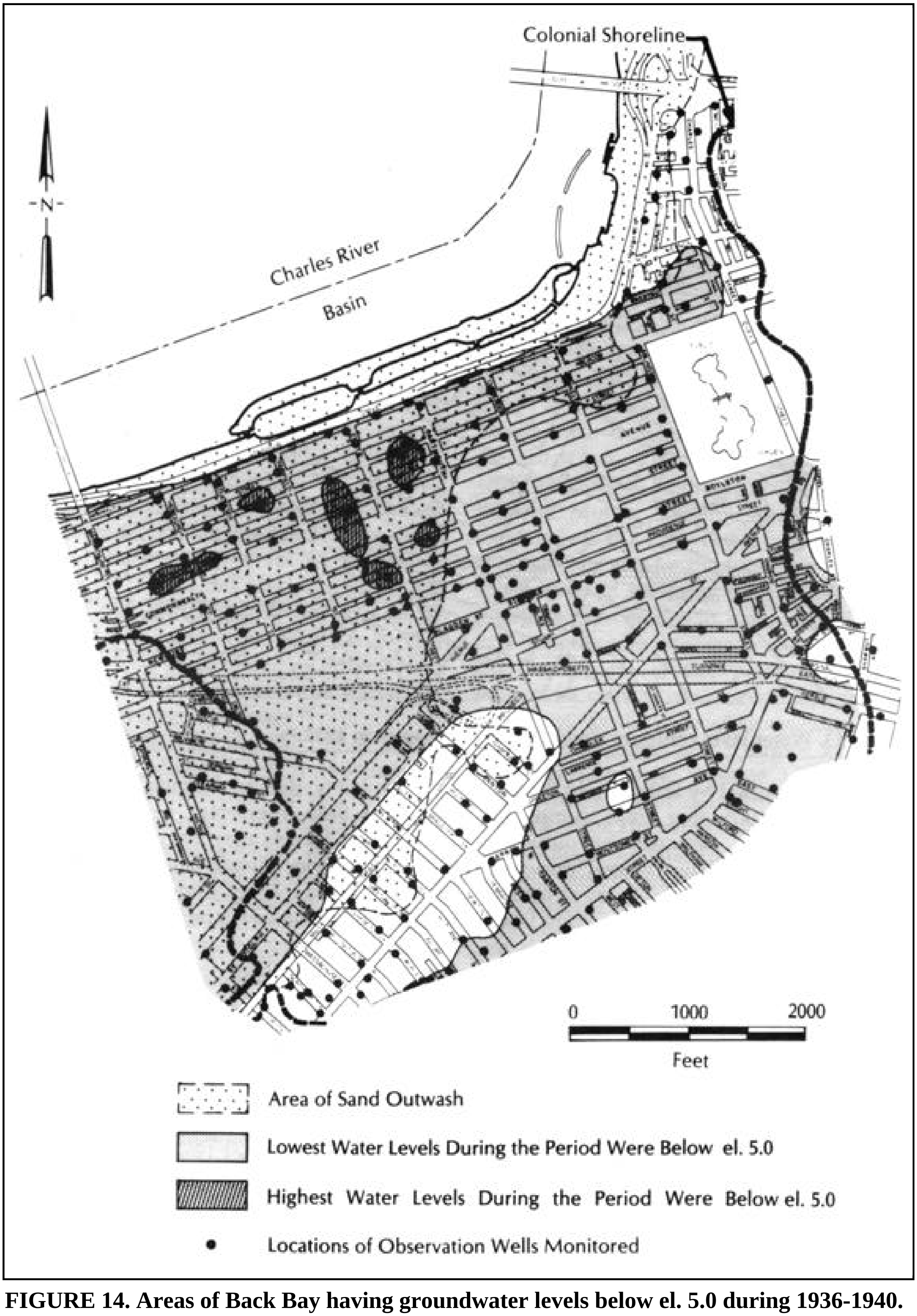


FIGURE 14. Areas of Back Bay having groundwater levels below el. 5.0 during 1936-1940.

Belt expressway on groundwater levels. The USGS used observation wells extant from the WPA survey completed in 1940. Less than half of the original wells were found to be usable. Results of the USGS study were published in 1975 as Hydrogeologic Investigation Atlas HA-513.(4) Figure 15 has been prepared from the groundwater contours presented therein.

Areas in Back Bay where the September 20-21, 1967, water levels were below el. 5.0 are shown in Figure 15. Areas where both readings, the second on March 20-22, 1968, were below el. 5.0 are also indicated. In addition to the areas shown, low levels were observed in wells around the Christian Science Center; however, those data may not have been available to the USGS.

It would appear, by comparison of Figure 15 with Figure 14, that water levels throughout Back Bay were higher in the 1960s than in the 1930s. Note, however, that Figure 15 was based on two isolated readings while the 1930s data represent extreme lows from numerous readings over a four-year period. Furthermore, the 1960s readings were taken during a wet period; precipitation in 1967 was 6 in. above normal and 5 in. of rain fell on March 17-18, 1968. On the other hand, looking at the high water level readings, two of the seven wells that were never above el. 5.0 in the 1930s, were above that level in the 1960s. No significant construction dewatering during the 1967-68 period has been reported. Groundwater levels were again below el. 5.0 in the John Hancock area and along Tremont Street in the South End.

Construction within the study area between 1940 and 1967, which includes the Prudential Center, does not appear to have permanently lowered groundwater levels below el. 5.0 by 1967.

1970-1985 Groundwater Levels. The BRA report summarized available groundwater data from numerous building projects.(13) Water level observations were generally made at the building sites and at immediately adjacent areas before, during and shortly after construction. Table 5 lists major projects constructed both before and during the period.

In addition, data were collected from other sources where monitoring is ongoing, for example, at the Christian Science Church, Prudential Center, Boston Public Library, Trinity Church, Massachusetts Turnpike Extension and Church of the Advent. Primarily, data were available for the area along the central spine across Back Bay. Essentially, no recent groundwater data are available for the Back Bay Historic District and other important areas having buildings founded on wood piles.

Figure 16 shows the location of most of the observation wells monitored at some point during the 15-year period from 1970 to 1985 and the area where the lowest water level observed was below el. 5.0. The monitoring period often lasted less than a year, since the purpose of the monitoring was to monitor the effects of construction and dewatering that caused the temporary lowering of water levels in areas adjacent to sites. Some data in Figure 16 were affected by construction dewatering while the two readings in 1967-68 (see Figure 15) were not affected.

Groundwater levels substantially below el. 5.0 in the area of the Christian Science Center and in the Park Square area south of the Public Garden were due to construction-related dewatering. Observed low groundwater levels around Hadassah Way were due to sump pumping from a basement in that area. Groundwater levels of approximately el. 3.0 were observed within the Prudential Center, probably caused by leakage into the underground parking garage. The effect of these low levels on groundwater in adjacent areas is mitigated by a wall of steel sheetpiling that encloses the Prudential Center site. (Note that the USGS observations shown in Figure 15 did not include the Prudential Center.)

Other areas of low groundwater 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 Hancock buildings continues to cause lowered groundwater levels in that area. During subsurface investigations for the Copley Place project, low groundwater levels between the Boston Public Library and the Massachusetts Turnpike were concluded to have largely been due to leakage into the

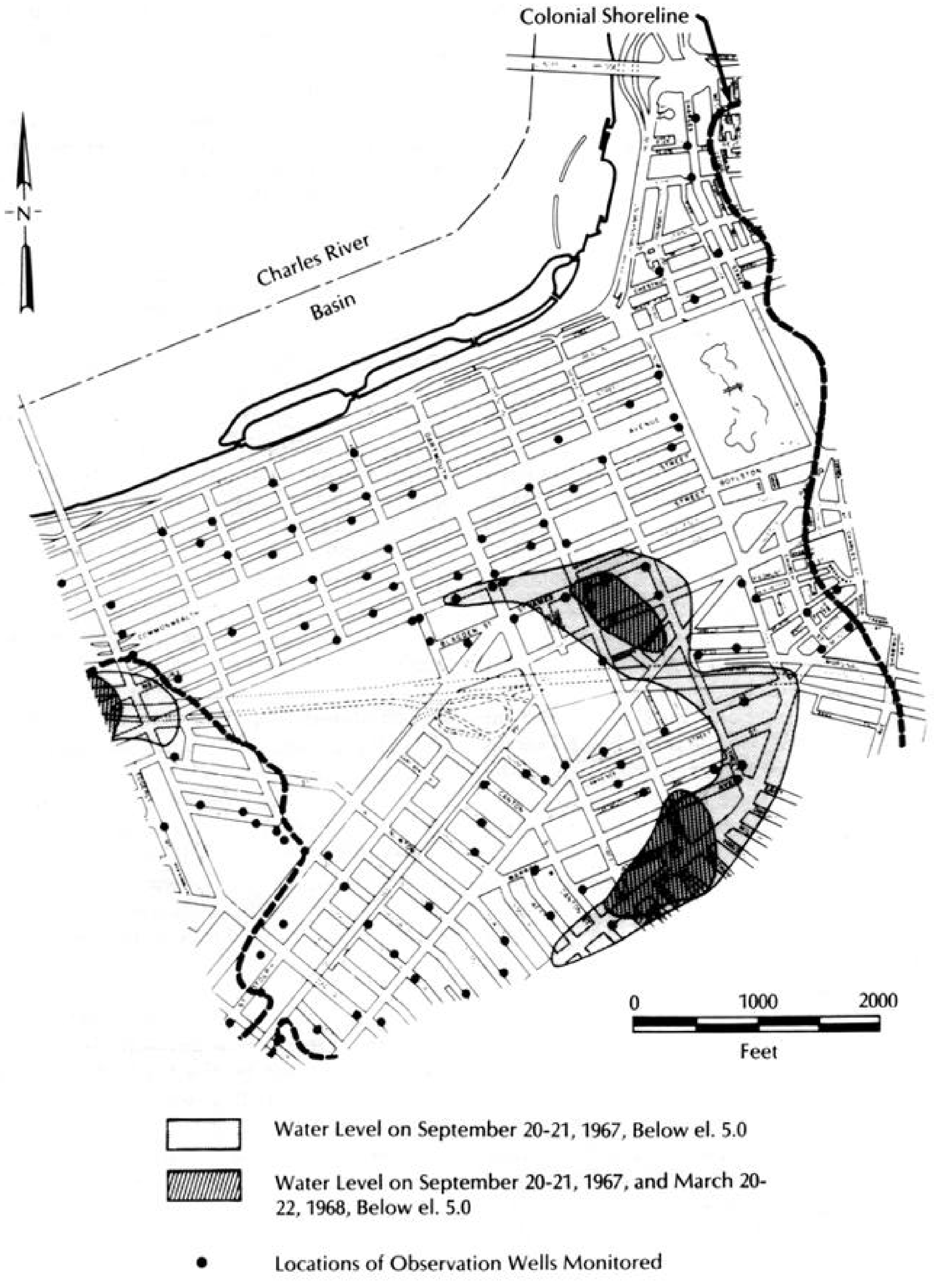


FIGURE 15. Areas of Back Bay having groundwater levels below el. 5.0 during 1967-1968.

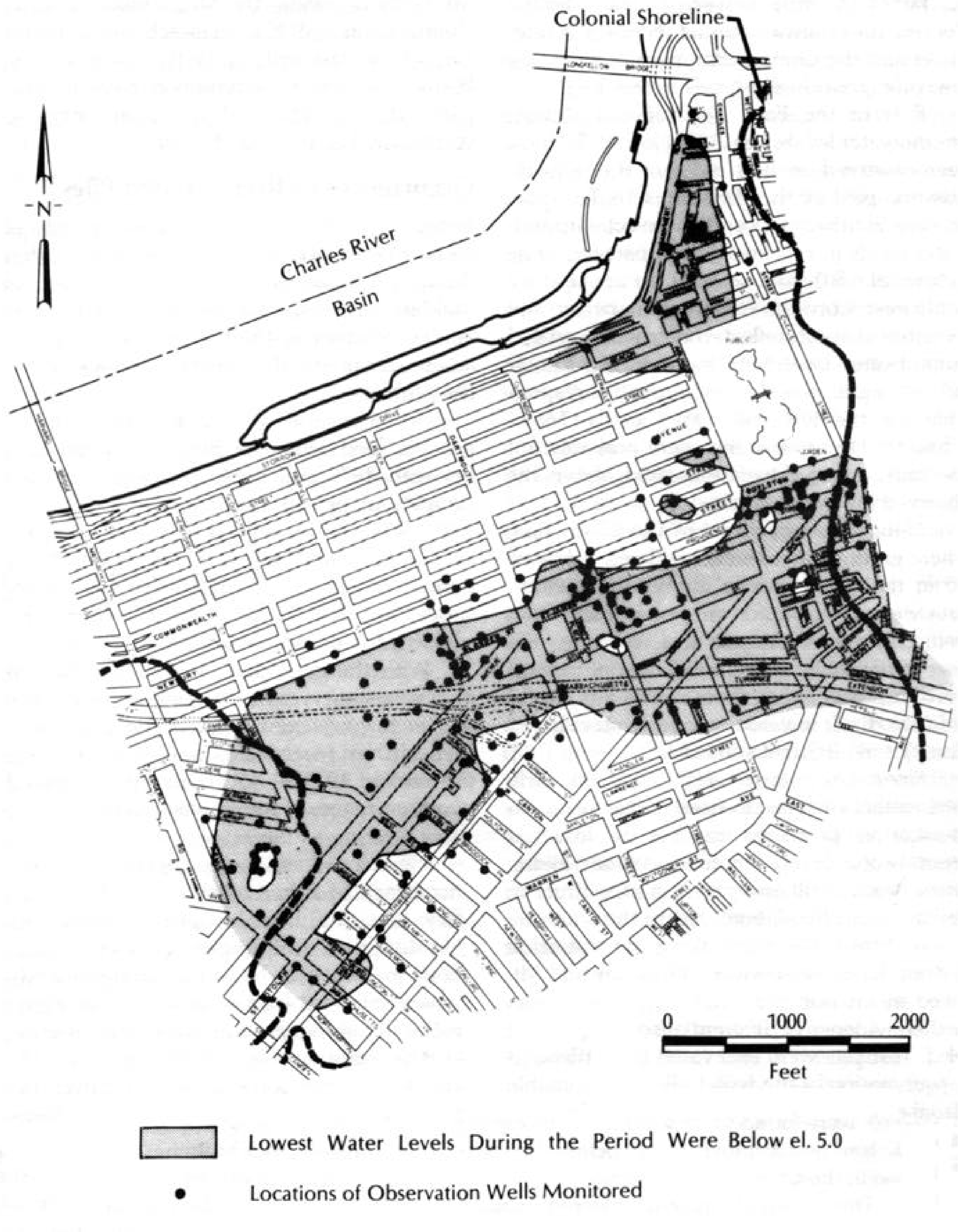


FIGURE 16. Areas of Back Bay having groundwater levels below el. 5.0 during 1970-1985.

St. James Avenue sewer. The Prudential Center, the subway tunnel beneath Exeter Street and the Conrail alignment may also be lowering groundwater levels in this area.

Fast of the Back Bay railroad station, groundwater levels 1 to 2 ft. below el. 5.0 have been observed on both sides of the right-of-way occupied by the Massachusetts Turnpike and the Southwest Corridor Project. Groundwater levels in this area were observed to be below el. 5.0 for several years before Southwest Corridor construction began and therefore do not reflect construction-related groundwater lowering. Drains in the former railroad right-of-way were probably responsible for the lowered water levels. Massachusetts Turnpike drains were probably not the cause since they are located above the observed low water levels.

Along Tremont Street in the South End, where groundwater levels had been below el. 5.0 in the two previous monitoring periods, data were available for only one observation well. Low water levels in this well, near the intersection of Berkeley and Tremont Streets, were below el. 5.0. These findings could indicate that lowered groundwater levels along Tremont Street still exist.

Recent Lower Beacon Hill Study In early 1984, attention was focused once again on foundation problems caused by lowered groundwater levels, on this occasion in the lower Beacon Hill area from Charles Street to Embankment Road, bounded to the south by Beacon Street. Residents along the waterside of Brimmer Street, between Pinckney and Mt. Vernon Streets, became alarmed when cracks developed in interior and exterior walls and when other evidence of differential settlement appeared. Test pits were excavated to enable visual examination of the wood piles. In most cases, the wood in the top 1 to 3 ft. of the piles was severely decayed. Groundwater levels were found to be several feet below the pile tops and as much as 6 ft. below the water level in the Charles River Basin.

The principal cause of lowered groundwater has been determined to be leakage through cracks and joints in combined sewer overflows, where they join the Boston Marginal Conduit at the foot of Pinckney and Mt. Vernon Streets. The Metropolitan District Commission (MDC), Massachusetts Water Resources Authority (MWRA) and Boston Water and Sewer Commission have investigated the problem and are taking steps to correct the loss of groundwater.

Occurrences of Rotted Wood Piles

Except for well-publicized cases, records of wood pile deterioration are buried in Boston Building Department files, in the files of building owners, their architects, engineers and contractors, or they do not exist. Owners are understandingly reluctant to talk about the problem.

Six thousand applications for building permits filed with the building department between 1979 and 1984, and representative samples of permit data from 1967-1972 and 1976-1979 were examined in the preparation of the 1985 BRA report.(13), Only two of the permits issued were for repairs to wood piles, suggesting that the problem in recent years (to 1984) has been minor or not reported.

With the exception of the lower Beacon Hill area, other cases throughout Back Bay appear to have been isolated and infrequent. In addition to the Boston Public Library problem in 1929-30, J.R. Worcester identified two occurrences of rotted wood piles:(15)

> "Such extensive repair work has been necessary in other localities in the Back Bay; e.g., the Fire Insurance Protective Headquarters at 4 Appleton Street (South End) in July 1921 had to be underpinned where piles cut as low as elev. 3.96 were rotted off above ground water level found at the time at elev. 3.30; again at 12 Hereford Street, corner of Beacon Street, in June 1933, piles cut at elev. 8.13 were rotted to within 3" of ground water level found to be at elev. 6.50."

Additionally, four buildings between Boylston and Beacon Streets are known to have had deteriorated wood piles that required repair.

The lower Beacon Hill area from Charles Street to Embankment Road has had a history of problems related to rotted wood piles dating back to 1927. The Boston Inspectional

Services Department (formerly the Building Department) reported that repairs to wood piles had been made at 38 of the 188 houses and buildings in this 10-block area, some having been made in each decade since the 1920s.(17) The Brimmer Street problem described earlier is the most recent example.

Problems in the lower Beacon Hill area appear to be related to both a lowered water table caused primarily by leakage into sewers and drains, and an original wood pile cutoff level at el. 7.0, 2 ft. above the el. 5.0 that was commonly used throughout Back Bay. The area is outside of the Mill Dam and West Side Interceptor and, until 1910, groundwater was readily recharged by the nearby and then tidal Charles River. Construction of the Boston Marginal Conduit and embankment appeared to have impeded groundwater recharge.

Effect of Contemporary Buildings on the Water Table

From the available groundwater data, it is difficult to assess long-term changes in groundwater levels that may have resulted from the construction of buildings in Back Bay. While temporary drawdown has occurred during construction, groundwater has shown that it will return to preconstruction levels unless there is continued pumping from foundation drains or leakage into basements. There is no evidence that buildings constructed in Back Bay within the last 50 years have caused significant permanent adverse effects to groundwater levels. However, older buildings are known to have foundation walls and floors that leak, requiring sump pumping.

Recent heightened public interest in Back Bay groundwater levels prompted an extensive study of existing and probable post-construction groundwater levels around the proposed Hines/New England Mutual Life development at 500 Boylston Street.(18) The study concluded that the building's proposed deep basements would have little impact on long-term off-site groundwater levels.

Preserving Groundwater Levels

The importance of maintaining groundwater levels in Back Bay has been recognized since the late 1800s. Pipes were placed to act as siphons beneath an early sewer and subway tunnel to mitigate their impact on groundwater movement and levels. In several areas, permanent recharge systems have been installed to replenish groundwater, particularly around historic structures founded on wood piles. Temporary recharging around excavations for building construction projects has also been used.

Siphons. In order to lessen the damming effect of the 8-ft. high Boston Marginal Conduit and the wood sheeting that was left in place, Worcester reported that siphon pipes were "placed under the conduit from the Basin to the Back Bay intended to carry groundwater from one side to the other."(15) Worcester questioned the long-term effectiveness of these siphons because they would probably have filled with silt and would have been only locally effective.

Four 12-inch diameter tile siphon pipes were placed under the Boylston Street subway tunnel in the vicinity of Copley Square to transport groundwater from one side to the other. These pipes were probably considered necessary because the bottom of the tunnel was in the clay and its top was at about el. 6.0, thus forming a virtual dam along Boylston Street. The distinct difference in groundwater levels observed on opposite sides of Boylston Street since 1930, confirmed by studies for several projects in recent years, raises doubts about the effectiveness of these siphons.

Siphon pipes were also used in the groundwater equalization system of the recently constructed Southwest Corridor structure to connect perforated header pipes placed on either side of the tunnel.

Recharging. Early inadvertent recharging was undoubtedly performed at many locations by drywells that were used to dispose of precipitation from roofs. These systems were probably not installed frequently enough to have a significant impact on groundwater levels.

In 1930, the first reported recharge system intended to raise groundwater levels in order to protect wood piles was installed at Trinity Church. Only a year before, severely rotted wood piles were found at the nearby Boston Public Library. Large conductors from the Church's roof gutters were connected into long, stone-filled drywells outside the Church and into a brick-lined pit in the basement. Although dry weather groundwater levels around Trinity Church were below el. 4.0 to 5.0, the intermittent rise in water level and wetting of wood piles due to the recharge system were probably responsible for the preservation of the Church's foundations.

Other recharge systems have since been installed in Copley Square. In the mid-1950s, a recharge system was constructed at a triangular grass plot across Dartmouth Street from the Boston Public Library. In 1968, when Copley Square was redeveloped with its current sunken plaza and fountain, another recharge system was installed below the plaza. Both systems conveyed surface water runoff into the fill through perforated pipes laid in 3 to 5-ft. thick beds of gravel or screened stone.

An underdrain system was provided below the slab-on-grade floor of the Christian Science Church Center parking garage. This system was designed to function only when water levels rose above approximately el. 6.7. The underdrains could be reversed to recharge groundwater should water levels in the fill fall to levels that would threaten wood piles that support the Mother Church. Again, a system of perforated pipes in a thick granular drainage blanket were used.

Recharging to minimize temporary drawdown outside of construction sites had been undertaken for several building projects where there was particular concern for wood piles supporting nearby structures. In these instances, recharging usually involved injecting water, under pressure, into the fill or sand outwash stratum through wellpoints. In some cases, water was pumped into open ditches and large diameter recharge wells and then allowed to percolate into the ground.

Sewer Dams. In the early 1930s, the St. James Avenue sewer was found to be the cause of lowered groundwater levels along most of its length. It was found that when sewage was backed up behind a dam installed in the sewer, groundwater levels rose to "normal" levels, thereby mitigating the effects of leakage into the sewer. Over the years, the original butterfly valves deteriorated and were replaced by a sand bag dam that requires periodic repair.

Since 1985 the MWRA has maintained raised water levels in the Boston Marginal Conduit in order to minimize the impact of local leaking sewers that lower groundwater levels. A permanent solution is still being sought.

Summary

Pumping from water supply wells, accompanied by lowered groundwater levels, has caused subsidence of major cities around the world - including Mexico City, Venice, Taipei and Bangkok. While Boston has not experienced a comparable problem, areas of the Back Bay have suffered damage from lowered groundwater levels. The groundwater table should be restored to levels that preserve the integrity of foundations for the city's historic nineteenth century buildings.

If there were no loss of groundwater by pumping and by leakage into sewers, drains and foundations, and no additions to groundwater from leaking water mains and other man-made sources, the probable groundwater table throughout Back Bay would be expected to vary from el. 8.0 to 10.0. Actual groundwater levels in the fill are lower, except for local groundwater mounds probably caused by leaking water mains. In some areas, the water table is below el. 5.0, a common level at which wood piles were cut off in the nineteenth century.

The principal cause of lowered water levels is leakage into sewers and drains. Groundwater loss through the walls and floors of the Storrow Drive underpass, into subways and the basements of older buildings below the water table also occurs.

With the available data, it is virtually impossible to determine if "permanent" water levels have changed significantly during the past 50 years, except in one or two local areas - for example, the Brimmer Street area and westward along the Boston Marginal Conduit where low water levels have been discovered in the past two years. Little or no water level data have been available over the past 20 years for major sections of Back Bay, notably the Back Bay Historic District where most buildings are supported on wood piles. A long-term groundwater monitoring program should be established in this and other areas.

The Charles River Basin cannot effectively recharge the groundwater table in the fill because the Mill Dam and Boston Marginal Conduit act as dams. However, some recharging to the sand outwash may occur, but the overall effect throughout the entire Back Bay area is not very significant.

Of the three principal adverse effects of lowered groundwater levels, temporary or permanent, the major future concern in Back Bay is for the deterioration, or rotting, of untreated wood piles. Numerous buildings in Back Bay have suffered damage during the past 60 years from differential settlement caused by rotted wood piles. Problems have been reported in the lower Beacon Hill area in the past two years. Underpinning is currently underway to restore foundations. Future ground subsidence and negative friction on pile foundations are not likely to be significant because of extensive and prolonged dewatering for construction projects over the past 100 years.

There is no evidence that buildings constructed during the past 50 years have caused permanently lowered or significant changes in groundwater levels. Future development in Back Bay would similarly not be expected to cause permanent adverse effects on water levels, provided foundation walls and basement floors are watertight.

Dewatering for the construction of sewers and drains, subways and other transportation corridors, and many buildings has temporarily lowered the groundwater table in the fill and, in particular, the piezometric head in the sand outwash over a large area of Back Bay, in some cases for a period of several years.

Temporary drawdown of piezometric levels in the sand outwash are not likely to cause deterioration of wood piles. There is no evidence of failure or settlement attributed to rotting at the tips of wood piles that commonly bear on the outwash stratum a few feet below the organic silt. Nevertheless, it must be assumed that the sand outwash and fill are connected where construction has penetrated the organic soils. Therefore, dewatering in the sand stratum may affect the groundwater levels in the fill at localized areas that lie a considerable distance from the source of pumping.

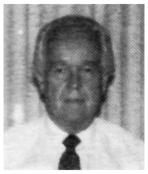
Recommendations

In situations where buildings have been constructed with groundwater level sensitive foundations, special emphasis must be given to:

1. An extensive and continuing water table monitoring plan.
2. A thorough review of the temporary and permanent effects of all construction projects on the water table, with construction plans and/or methods altered to minimize their effects on, or replenish, the water table.
3. Rapid response by appropriate agencies to correct lowered groundwater levels found in the monitoring program.

The consequences of repairing and improving water distribution and the sewerage drainage systems throughout Back Bay must be considered. Unless the work is undertaken in the correct sequence, these improvements may adversely affect groundwater levels. For example, since leaking water mains recharge the water table and leaking sewers deplete it, it seems obvious that sewers should be repaired before water mains are fixed. Furthermore, improvements in the sewer system or changes in operations that facilitate drainage and lower fluid levels in pipes will exacerbate the groundwater problem unless leaking pipes are repaired prior to the improvements.

ACKNOWLEDGEMENTS - *This article was originally presented at a meeting of the BSCES Geotechnical Group on March 10, 1986. The authors wish to thank the Boston Redevelopment Authority and Gerald D. Hines Interests for funding the Haley & Aldrich, Inc., study on groundwater in Back Bay Boston, for which the authors were* *principal investigators and upon which much of this article is based.(13) Local organizations providing data on groundwater levels and information on construction included: Christian Science Church, Trinity Church, Church of the Advent, Boston Public Library, Prudential Center, and the Massachusetts Turnpike Authority. The illustrations were drawn by Ms. Acey Welch and the text was prepared by Ms. Marion Keegan, whose assistance is gratefully acknowledged.*



HARL P. ALDRICH is Chairman of the Board and a founding principal of Haley & Aldrich, Inc. He received an Sc.D. in civil engineering from MIT in 1951. Dr. Aldrich has over 30 years of experience in solving foundation problems in Back Bay Boston, including recent work on the study of "Groundwater in Back Bay Boston "for the Boston Redevelopment Authority.

JAMES R. LAMBRECHTS is a Senior Engineer with Haley & Aldrich, Inc. He received his B.S.C.E. from the University of Maryland in 1973 and an M.S.C.E. from Purdue University in 1976. His experience with the geotechnical problems in Back Bay Boston have been principally associated with the MBTA Southwest Corridor Project. He was also primary investigator for the study of "Groundwater in Back Bay Boston" for the Boston Redevelopment Authority.

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