Boston Coastal Storm Risk Management Study

Appendix F: Regional and Local Geology

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DRAFT

1 Contents

2 Introduction

This appendix provides an overview of the geology of the Boston area, with a focus on the bedrock framework, surficial materials, hydrogeology, and seismic setting. The subsurface conditions in Boston are composed of a complex sequence of crystalline bedrock, glacially derived sediments, and a surficial layer of anthropogenic fill.

The basement geology of eastern Massachusetts consists of the Avalonian terrane, a Late Proterozoic microcontinent that accreted to North America during the Paleozoic Era. The city of Boston is situated within the Boston Basin, a large structural depression filled with a thick sequence of metasedimentary rocks known as the Boston Bay Group. This group primarily consists of the Roxbury Conglomerate and the Cambridge Argillite. These formations were subsequently deformed by major orogenic events and intruded by igneous rocks, forming the bedrock that underlies the metropolitan area.

The modern topography and surficial geology are the direct result of Pleistocene glaciation. The Late Wisconsinan ice sheet eroded the bedrock surface and, upon retreat, deposited a complex stratigraphy of glacial and post-glacial materials. These deposits include dense glacial tills, glaciofluvial outwash sands and gravels, and extensive glaciomarine deposits, most notably the thick marine clay unit known as the Boston Blue Clay. These materials form the parent substrate for much of the city and control many of its geotechnical and hydrogeological properties.

The final major geologic unit is a thick layer of anthropogenic fill, placed over the last 400 years. This process of land-making has significantly altered the original topography and coastline, creating much of the city's modern land area. This report details each of these geologic components in sequence, beginning with the regional and local bedrock setting, followed by the surficial geology of the glacial, post-glacial, and urbanization periods, and a discussion of the region's hydrogeology and seismic hazards.

3 Bedrock Geology

3.1 Regional Geologic and Tectonic History

The bedrock of eastern Massachusetts primarily consists of the remnants of a microcontinent known as Avalonia. This landmass originated as a volcanic arc in the southern hemisphere, with its main phase of magmatism occurring between 630 and 590 million years ago (Ma). The landmass drifted northward and collided with the ancestral North American continent (Laurentia) at approximately 425 Ma, initiating the Acadian Orogeny.

Prior to this orogeny, around 595 Ma, regional tectonic forces shifted from subduction to extension. An east-west zone of normal faults was activated within Avalonia and formed a rift basin now known as the Boston Basin. The earliest deposits in this basin are related to the waning stages of volcanism, forming the Mattapan Volcanic Complex. These deposits were succeeded by a thick sequence of sediments as the land continued to subside: first, boulders and sand were deposited by submarine landslides, forming the Roxbury Conglomerate, and later, clay and silt accumulated in a quieter, deeper basin, forming the Cambridge Argillite. These formations are discussed in detail later in this appendix (Section 3.3 Bedrock Geology of Boston).

The Acadian orogeny (c. 425 Ma), caused by the collision of Avalonia with Laurentia, led to widespread regional metamorphism and granitic intrusions, primarily impacting the western margin of the terrane. The later Alleghenian Orogeny (c. 300 Ma) more significantly deformed the Boston Basin itself. This event, which resulted in the final assembly of the supercontinent Pangea, subjected the region to intense northwest-southeast compression. This created prominent folds and thrust faults and was responsible for the low-grade metamorphism that produced the characteristic slaty cleavage in the Cambridge Argillite. It also generated the intrusion of post-orogenic granites, such as the Quincy Granite.

By the Triassic Period (c. 235 Ma), Pangea began to rift apart. While the main rift that would eventually become the Atlantic Ocean formed to the east, many failed rifts developed along the continental margin. Although eastern Massachusetts does not contain a major onshore rift basin, it was impacted by the associated tensional stresses. These stresses resulted in the intrusion of numerous vertical mafic dikes that cut across the older folded and faulted bedrock, representing the final major bedrock-forming event in the region.

3.2 Regional Lithology and Structural Setting

The bedrock of Eastern Massachusetts consists of two geologic terranes: the Nashoba Zone to the west and the Milford-Dedham Zone to the east (Figure 1). These zones are separated by the Bloody Bluff fault zone, a major ductile shear zone.

The Nashoba Zone is bounded to the west by the Clinton-Newbury fault system, which separates it from the Merrimack belt (Figure 1). The Nashoba Zone generally consists of late Proterozoic and early Paleozoic gneisses and schists that are derived from sedimentary and volcanic protoliths. These deposits are intruded by granite and granodiorite. Structurally, the zone is interpreted as a complex synform, transected by numerous faults of varying age and displacement.

To the east of the Bloody Bluff Fault lies the Milford-Dedham Zone, which makes up the primary Avalonian basement rock of the region. The terrane is composed predominantly of late Proterozoic granite batholiths (Dedham Granodiorite) that intrude older metasedimentary and metavolcanic country rock. This crystalline basement material is overlain by unmetamorphosed to slightly metamorphosed sedimentary and volcanic sequences of late Proterozoic to Pennsylvanian age. The region has been faulted by numerous normal and reverse faults.

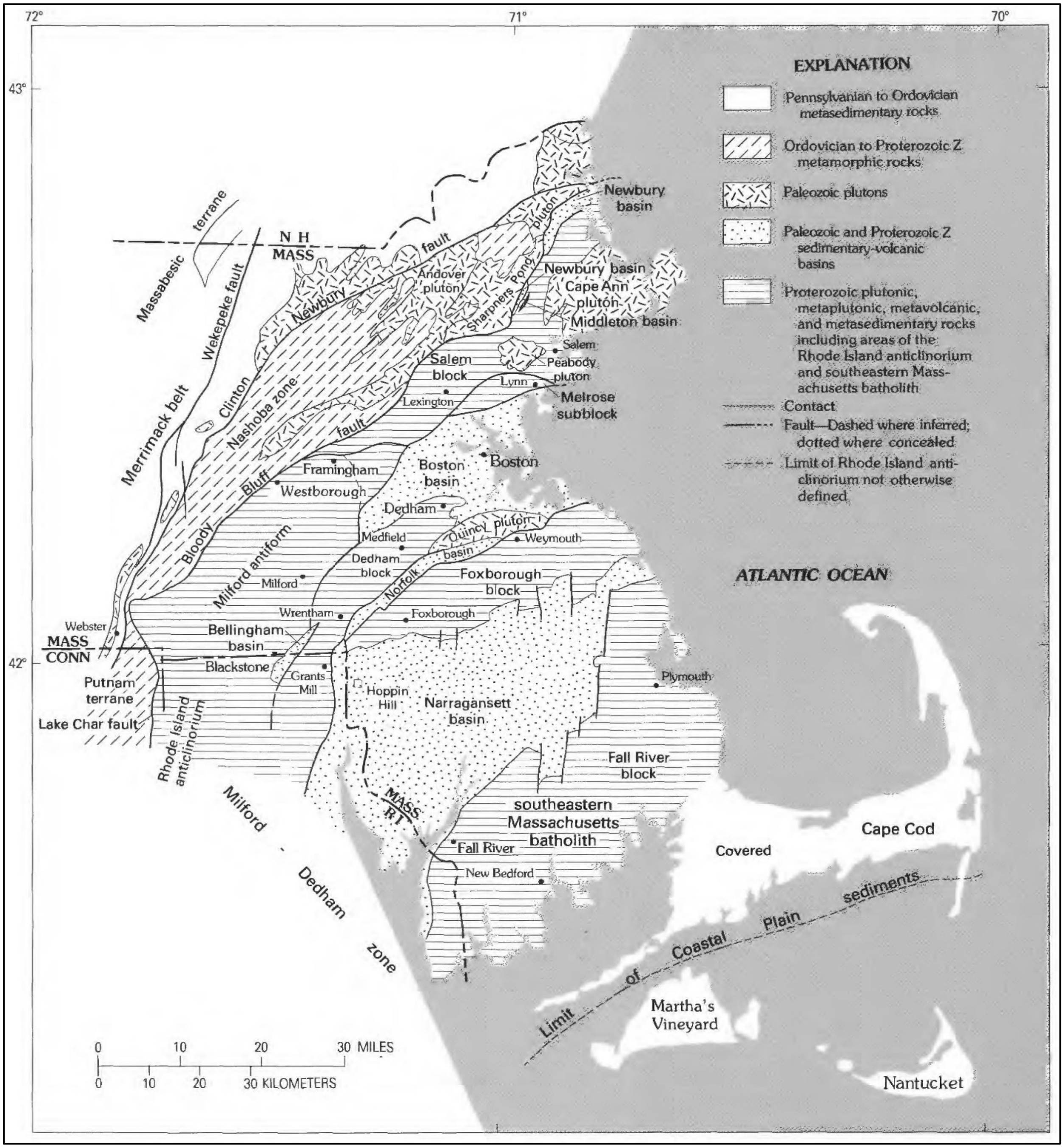


Figure 1. Map of major structural bedrock features in eastern Massachusetts (Goldsmith, 1991).

The Boston Basin lies within the Milford-Dedham Zone. The basin is filled with the Boston Bay Group, a thick sequence of low-grade metasedimentary and metavolcanic rocks (conglomerate, argillite, and minor volcanics) that unconformably overlies the Dedham Granodiorite batholith. The strata within the basin are broadly folded and highly faulted by a northeast-trending fault system that extends westward and ends at the Bloody Bluff fault zone (Figure 1). The basin itself is structurally bounded by the Northern Border thrust fault to the north and the Blue Hills and Ponkapoag faults to the south. The specific lithologies and stratigraphic relationships of the rocks contained within this basin are discussed in the following section.

3.3 Bedrock Geology of Boston

The bedrock of the Boston area consists primarily of the Late Proterozoic Boston Bay Group, which contains the Roxbury Conglomerate, the overlying Cambridge Argillite, and minor amount of various fine-grained intrusive and extrusive igneous rocks deposited over multiple intervals (Figure 2; Zen et al., 1983). These low-grade metasedimentary formations unconformably overlie a crystalline basement composed of the Mattapan Volcanic Complex and the Dedham Granodiorite (Figure 3).

The Dedham Granodiorite forms the batholithic basement of the region. The formation is typically medium to coarse grained and massive, and the mineralogy is dominated by quartz, plagioclase feldspar, and potassium feldspar. This is locally overlain by the Mattapan Volcanic Complex, which consists of shallow fine-grained intrusive rock and extrusive fine-grained flow and pyroclastic rock, including lava flows, explosion breccias, welded tuffs, and volcanic necks. The rocks range from rhyolite to sodic andesite. Sedimentary strata, predominantly consisting of reworked volcanic material, are locally interbedded with the volcanic rock. The complex represents several volcanic episodes and is found predominantly in the south, west, and central portions of the Boston Basin.

The Roxbury Conglomerate “Puddingstone” forms the basal unit of the Boston Bay Group (Figure 3). The formation consists of conglomerate, sandstone, argillite, and shale, with interbedded altered basalt and andesite in the upper portion. The formation is locally intruded by a porphyritic basalt (Brighton Basalt), often referred to as melaphyre (Figure 2). The conglomerate is generally a dark color, with clasts ranging from pebble to cobble in size, although boulders up to eight feet in diameter occur near the southern boundary. The rock is typically massive, with local thick gradational beds present, grading upward into sandstone or finer conglomerate. The Roxbury Conglomerate sits unconformably over both the Mattapan Volcanic Complex and the Dedham Granodiorite, depending on location.

The Roxbury Conglomerate is generally interpreted as a terrestrial fan deposit derived from ancient mountains to the south, that thins and interfingers to the north with sandstone and argillite. Previous historical interpretations identified a diamictite or “tillite” of glacial origin based upon the presence of drop stones. Thickness estimates range greatly due to uncertainties about fault repetitions, with estimates spanning 1,200 feet to over 3,000 feet (365 to 915 meters).

The Cambridge Argillite is the most widespread formation in the Boston area, underlying much of downtown Boston and overlying the Roxbury Conglomerate and Mattapan Volcanic Complex (Figure 3). The rock is generally covered by glacial deposits and is only exposed in a small area north of Beacon Hill and the harbor islands.

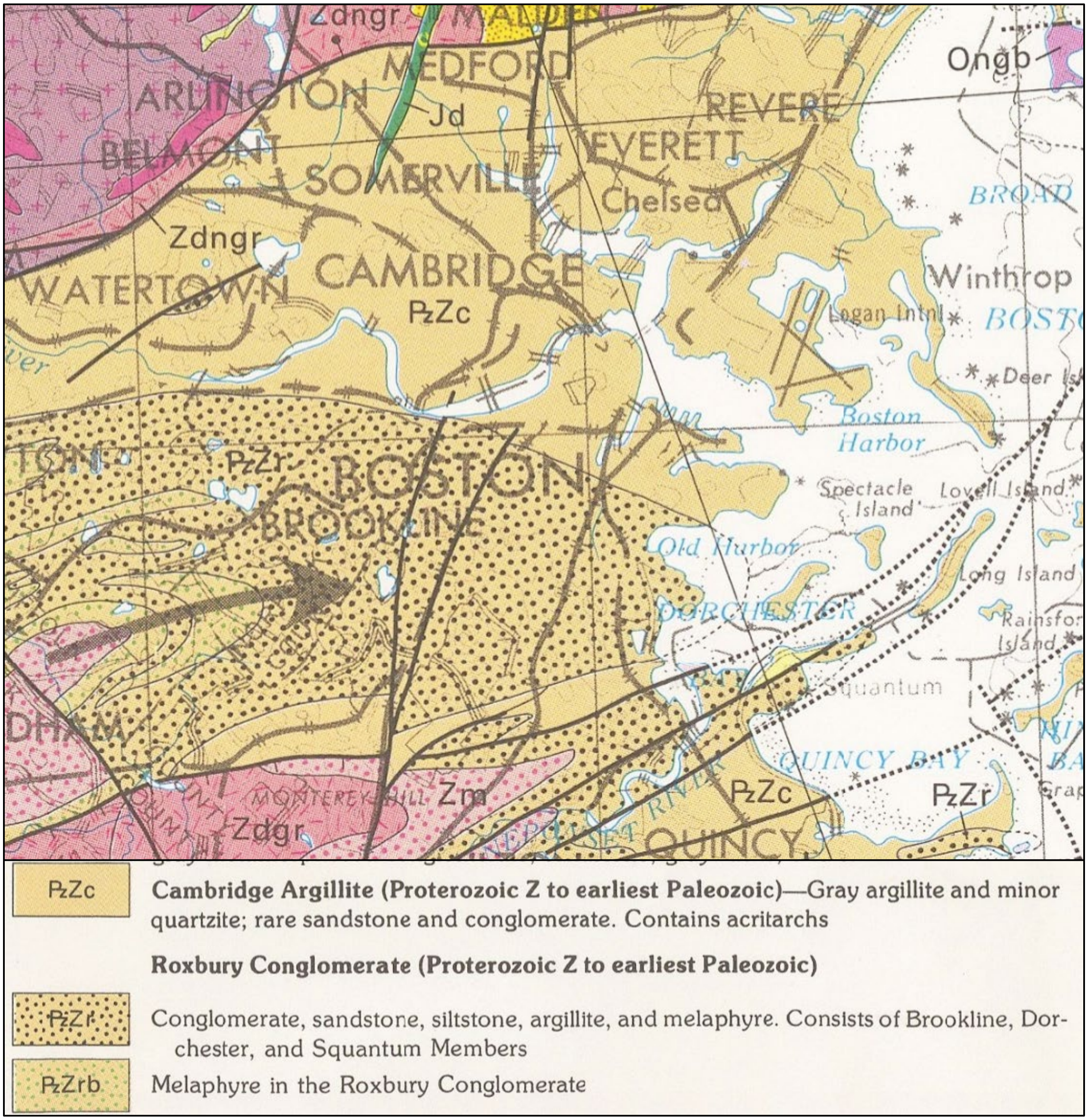


Figure 2. Bedrock geologic map of the Boston area (Zen et. al, 1983).

The formation is described as a massive to laminated siltstone, mudstone, and claystone that has been slightly metamorphosed to argillite, and varies locally, containing interbeds of thin limestone and locally abundant sandstone and tuffaceous beds. Higher stratigraphic levels of the argillite contain breccia, graded beds, and lenticular slumped masses of pebbly to bouldery mudstone, suggesting submarine sliding and turbidity currents. Estimated thickness of the formation exceeds 3,500 feet (1,067 meters) in some areas.

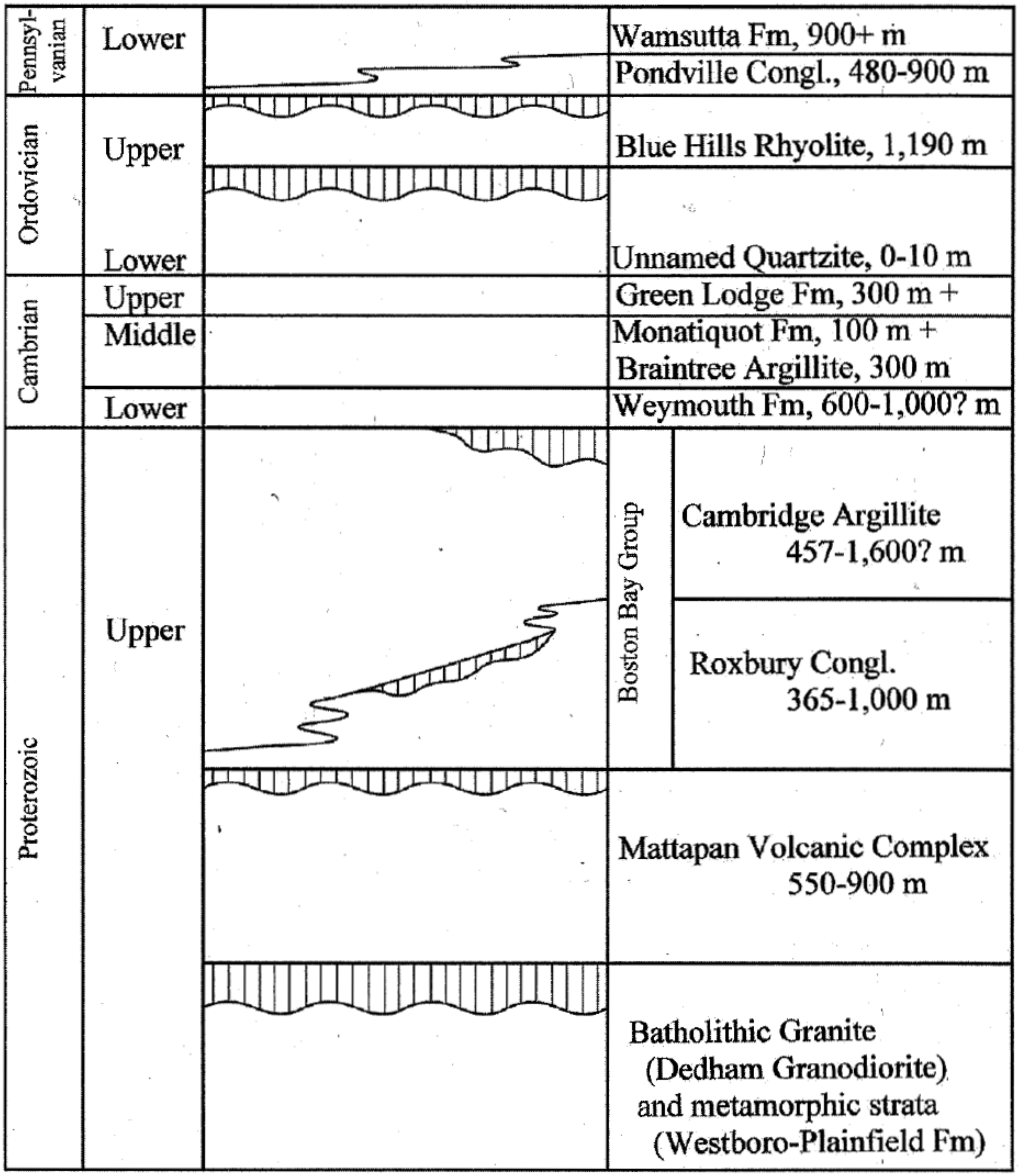


Figure 3. Simplified stratigraphic column of Proterozoic and Paleozoic-age bedrock in the Boston Basin and nearby Norfolk Basin (Barosh and Woodhouse, 2011).

The Cambridge Argillite generally conformably overlies the Roxbury Conglomerate, although the two are sometimes interfingered or have local unconformities. The boundary between the Roxbury and Cambridge formations is marked by a local transition from the coarser conglomerate below to finer material above; this division is not represented by a basin-wide horizon. Recent work indicates a slight angular unconformity at the base of the argillite, which helps to explain both the difficulty in local correlations in the units, and why the Brighton Basalt intrudes the Roxbury Conglomerate but not the Cambridge Argillite.

Scattered remnants of Cambrian-age strata, lithologically similar to the upper Cambridge Argillite, occur at the basin margins. These are divided into formations including the fossiliferous Braintree Argillite and the quartzite-bearing Green Lodge Formation (Figure 3). Ordovician deposits have been largely eroded, though a major Late Ordovician magmatic event associated with the Taconic Orogeny produced the Blue Hills Rhyolite and the granitic plutons that now form the core of the Blue Hills.

A major unconformity exists above these units, as Silurian through Mississippian strata are absent within the basin. Pennsylvanian rocks, such as the Pondville Conglomerate, are preserved in the adjacent Norfolk and Narragansett Basins but not within the Boston Basin itself.

The final phase of bedrock emplacement occurred during the Mesozoic Era (Triassic-Jurassic) and is associated with the tensional stress generated during Pangean rifting. This extensional tectonic event produced numerous, near-vertical mafic dikes. These dikes, predominantly composed of diabase, intruded along pre-existing faults and fracture systems. They typically occur in swarms with a preferred northwest-southeast orientation, reflecting the direction of crustal extension.

Modern bedrock topography has resulted from a combination of stream erosion in the Mesozoic and Tertiary, pre-Wisconsin Pleistocene ice movement, and stream erosion during interglacial periods. The seaward-sloping surface developed in the Mesozoic, with the shoreline shifting back and forth across Boston during the Mesozoic and Tertiary. In the late Tertiary, a river drainage system developed upland from the basin, eroding away many coastal plain deposits. During the Pleistocene, rising sea levels resulted in deposition of marine clay, which was later eroded and incorporated into the till deposits that followed the Wisconsin glacial advance.

Bedrock topography was modified further by Pleistocene glaciation, which produced an irregular bedrock surface with rock generally found at 75 feet to 175 feet (23 to 54 meters) below the surface. The low-lying areas in the basin tend to be underlain by the softer argillite, with the hilly areas in the western and southern portions of the basin underlain by more resistant conglomerate and volcanic rock. Dikes generate knobs and ridges, and faults create grooves and depressions.

Within the Boston Basin, much of the bedrock is covered by overlaying glacial deposits and artificial fill material. Most outcrop exposures occur in the southern part of the city near Roxbury and Dorchester (Figure 4; Kaye, 1980).

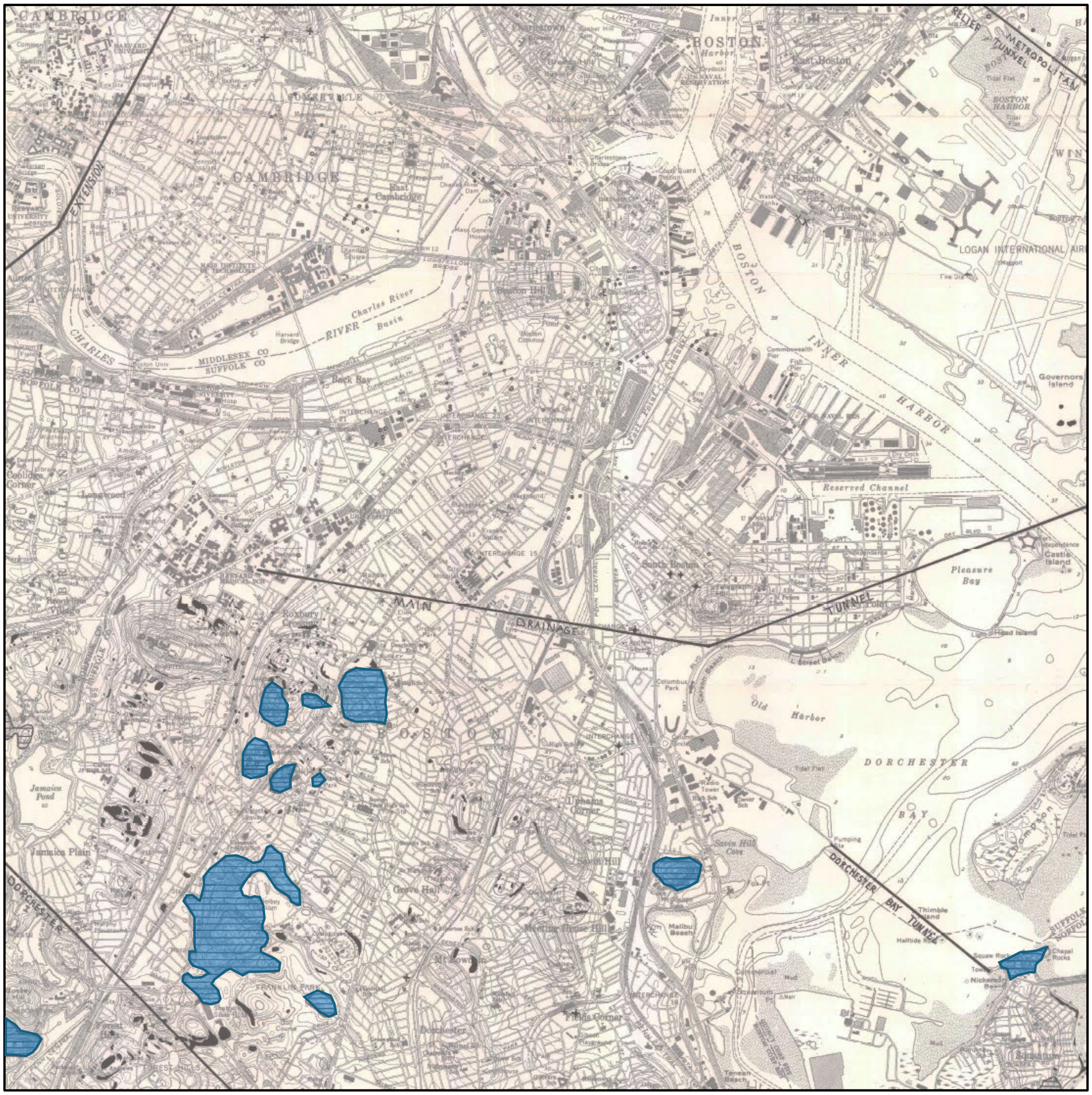


Figure 4. Bedrock exposures (blue highlighted regions) in the Boston area (Kaye, 1980).

4 Surficial Geology

4.1 Regional Surficial Geology

The surficial geology of eastern Massachusetts is dominated by landforms and deposits from the Late Wisconsinan glaciation. During the Last Glacial Maximum (LGM), the region was covered by the Laurentide Ice Sheet. Glacial movement scoured the underlying bedrock and imparted a strong southeasterly orientation to the landscape, reflecting the direction of ice flow and retreat. Modern topography and surficial deposits are almost entirely the result of this glaciation and subsequent post-glacial processes.

Figure 5. Digital elevation model of the Boston area showing modern topography and remaining glacial landforms (1-meter resolution; USGS 3D Elevation Program (3DEP), 2026).

As deglaciation occurred and the ice sheet retreated northward, a suite of distinct glacial and postglacial landforms were deposited, including ground moraines, drumlins, end moraines, kame terraces and glaciofluvial, glaciolacustrine, and glaciomarine sediments.

Some of these glacial landforms are still prominent features of Boston's topography, including drumlin hills (e.g., Bunker Hill, Breeds Hill, Telegraph Hill, Orient Heights, Meeting House Hill, Mount Bowdoin, Popes Hill, Copps Hill, and many of the Boston Harbor Islands) (Figure 5). The Southwest Uplands contain a dense concentration of northwest-southeast trending drumlins, including Corey Hill, Aspinwall Hill, Fisher Hill, and Parker Hill. Jamaica Pond and Hammond Pond are the result of kettles, formed when isolated blocks of glacial ice are buried by sediment and eventually melt, leaving steep sided depressions. Kame terraces, composed of stratified sand and gravel deposited by glacial meltwater, are also present in the region (e.g., Mount Auburn). The undulating, irregular high ground in the southwest corner of Figure 5 illustrates a thick blanket of ground moraine placed over bedrock.

The post-glacial landscape has been further shaped by isostatic and eustatic adjustment. Retreat of the ice sheet resulted in isostatic rebound, with differential uplift across the region resulting in a regional down-tilting to the southeast. Concurrently, melting of ice sheets caused eustatic sea-level rise. The relative rates of these two processes controlled the paleo-shoreline position, leading to periods of marine transgression and regression across low-lying coastal regions.

Finally, centuries of anthropogenic activity, including grading, terracing, filling, and excavation, have heavily modified the original glacial and post-glacial landforms. Consequently, much of Boston's nearly-flat topography is the result of urban landscape modification.

4.2 Surficial Geology of Boston

The surficial geology of Boston is largely characterized by glacial reworking and deposition during the Pleistocene epoch, topped by Holocene deposits and 400 years of anthropogenic filling and land modification (Figure 6). Repeated glaciations during the Pleistocene (approximately 2 million years ago to 11,000 years ago) stripped pre-existing surficial materials from the bedrock, then later deposited a variety of glacial deposits as the glaciers retreated. Fluctuations in sea level as glaciers advanced and retreated, combined with isostatic fluctuations, resulted in a complex depositional environment. In Boston, this often leads to intricate stratigraphic relationships that change abruptly over short distances.

Thick glacial deposits, predominantly late Wisconsin deposits from two major advances and one lesser advance, cover nearly all the bedrock in the Boston area and attain a maximum thickness of nearly 300 feet (91 m) (Figure 7). Glacial till was often deposited as drumlins; the Boston Basin has more than 100 drumlin features including the Harbor Islands, Bunker Hill, and Breed's Hill. The two major glacial advances crossed the entire city and harbor (Beacon Hill and Boston Substages), while the lesser glacial advance extended only to the northern and western sides of the basin (Lexington Substage). Evidence of glaciations prior to the Wisconsin was erased by this most recent glacial period.

4.2.1 Pleistocene Deposition

The earliest preserved Pleistocene deposits exist as small, scattered sand and gravel deposits, that are found under the lower-most till deposits ("Pre-Till Sand and Gravel", Figure 7). These stratified sand deposits may be up to six feet thick and have been interpreted as under-melt deposits or remnants of an earlier glacial retreat deposit. A particularly thick section of sand, situated between argillite and till, is found near South Station.

Artificial fill—Earth materials and manmade materials that have been artificially emplaced, primarily in highway and railroad embankments and in dams; unit may also include landfills, urban-development areas, and filled coastal wetlands	**Marine regressive deposits**—Sand and minor gravel deposited along former, higher shorelines in northeastern Massachusetts by waves and currents, and by wind action on beaches and spits. These deposits are shown where they overlie glaciomarine fine deposits. Regressive beach and nearshore deposits are composed of moderately sorted, very coarse to fine sand, commonly laminated. Coarser layers may contain some fine gravel particles; finer layers may contain some very fine sand and silt. Regressive beach and nearshore deposits are rarely more than a few feet thick. Regressive spit deposits are 10 to 30 ft thick
Glaciomarine fine deposits include clay, silty clay, fine sand, and some fine gravel deposited in a higher-level sea in environments of low wave energy along the coast and in river estuaries. Fine to very fine sand, massive and laminated, commonly is present at the surface and grades downward into interbedded very fine sand, silt, silty clay, and clay. The lower silty clay and clay is massive and thinly laminated. Total thickness is generally a few feet to 75 ft	**Thin till**—Nonsorted, nonstratified matrix of sand, some silt, and little clay containing scattered pebble, cobble, and boulder clasts; large surface boulders are common; unit was mapped where till is generally less than 10 to 15 ft thick including areas of shallow bedrock. Predominantly consists of upper till of the last glaciation; loose to moderately compact, generally sandy, commonly stony. Two facies are present in some places: a looser, coarser grained ablation facies, melted out from supraglacial position; and an underlying more compact, finer grained lodgement facies deposited subglacially. In general, both ablation and lodgement facies of upper till derived from fine-grained bedrock are finer grained, more compact, less stony and have fewer surface boulders than upper till derived from coarse-grained crystalline rocks. Across Massachusetts, fine-grained bedrock sources include the red Mesozoic sedimentary rocks of the Connecticut Valley lowland, marble in the western river valleys, and fine-grained schists in upland areas
Salt-marsh and estuarine deposits—Peat and organic muck interbedded with sand and silt, deposited in saltwater or brackish-water environments of low wave energy along the coast and in river estuaries. Salt-marsh deposits are dominantly peat and muck, generally a few feet to 25 ft thick. In the major estuaries, these deposits locally overlie estuarine deposits (not mapped), which are sand and silt with minor organic material and are as much as 30 to 80 ft thick. Salt-marsh and estuarine deposits generally are underlain by adjacent glacial material, consisting of till, coarse stratified deposits, or glaciomarine fine deposits	**Thick till**—Nonsorted, nonstratified matrix of sand, some silt, and little clay containing scattered pebbles, cobbles, and boulders in the shallow subsurface; at greater depths consists of compact, nonsorted matrix of silt, very fine sand, and some clay containing scattered small gravel clasts. Mapped in areas where till is greater than 10 to 15 ft thick, mostly in drumlin landforms in which till thickness commonly exceeds 100 ft (maximum recorded thickness is 230 ft). Although upper till of late Wisconsinan age is the surface deposit, lower till of probable Illinoian age constitutes the bulk of the material in thick-till areas. Lower till is moderately to very compact and is commonly finer grained and less stony than upper till. An oxidized zone, the lower part of a soil profile formed during a period of interglacial weathering, is generally present in the upper part of the lower till. This zone commonly shows closely spaced joints that are stained with iron and manganese oxides
Coarse deposits consist of *gravel deposits*, *sand and gravel deposits*, and *sand deposits*, not differentiated in this report. *Gravel deposits* are composed of at least 50 percent gravel-size clasts; cobbles and boulders predominate; minor amounts of sand occur within gravel beds, and sand comprises a few separate layers. Gravel layers generally are poorly sorted, and bedding commonly is distorted and faulted due to postdepositional collapse related to melting of ice. *Sand and gravel deposits* occur as mixtures of gravel and sand within individual layers and as layers of sand alternating with layers of gravel. Sand and gravel layers generally range between 25 and 50 percent gravel particles and between 50 and 75 percent sand particles. Layers are well sorted to poorly sorted; bedding may be distorted and faulted due to postdepositional collapse. *Sand deposits* are composed mainly of very coarse to fine sand, commonly in well-sorted layers. Coarser layers may contain up to 25 percent gravel particles, generally granules and pebbles; finer layers may contain some very fine sand, silt, and clay	

Figure 6. Surficial geology of Boston (Stone and DiGiacomo-Cohen, 2018a-2018d).

Pleistocene deposition is predominantly divided among three sub-stages: the Beacon Hill Substage, the Boston Substage, and the Lexington Substage (Figure 7). The earliest well-preserved stage is the Beacon Hill Substage, which is stratigraphically preceded by the Pleistocene pre-till sand and gravels. Following the Beacon Hill substage, the Boston Substage shaped Beacon Hill and formed the drumlins that comprise the Harbor Islands. Glacial retreat during this substage was not uniform, and fluctuations in the ice front generated local re-advances; the terminal readvance is known as the Lexington Substage. This substage, which coincides with a brief cool period known as the Younger Dryas, only extended into the valleys north and west of Boston.

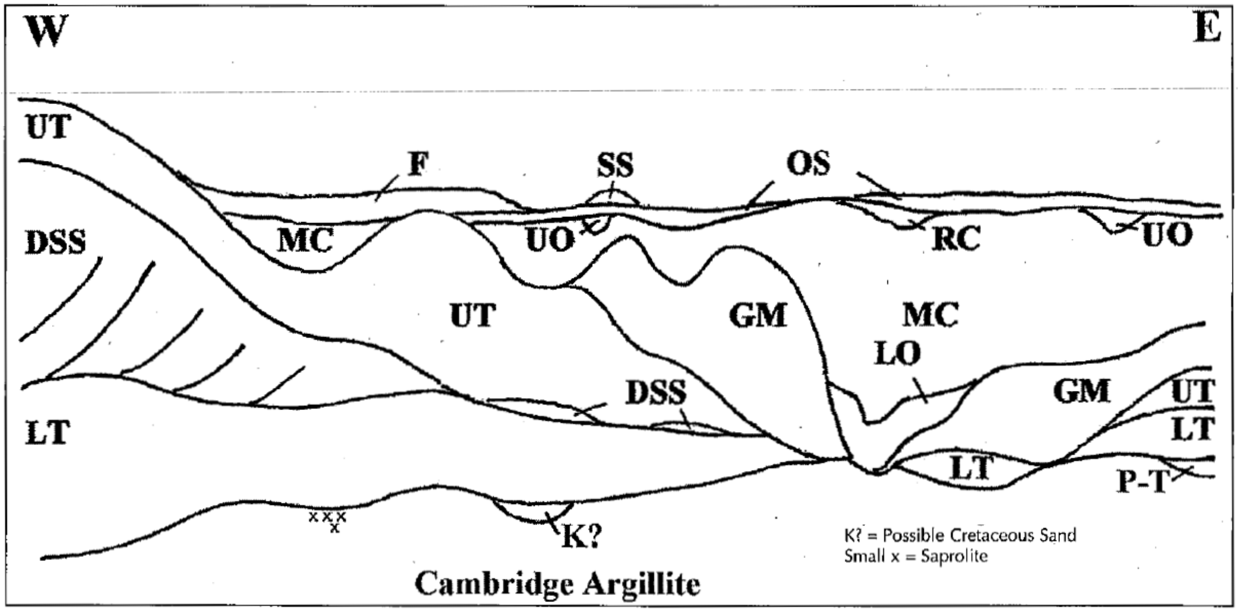
The Beacon Hill Substage deposits are characterized by a till deposit ("Lower Till", Figure 7) from glacial advance that is sometimes overlain by retreat deposits of deltaic sand, gravel, and clay. Many of these retreat deposits were later scoured by the Boston Substage, excluding those that were reworked and amassed beneath Beacon Hill ("Deformed Stratified Sediment", Figure 7).

The Boston Substage, the last advance that covered all of Boston, is characterized by a widespread till deposit ("Upper Till", Figure 7) that forms the drumlins in the Boston area. The retreating front during this substage discharged material into the ocean, forming poorly sorted glaciomarine sediment that was later incised by channels. These channels would later fill with outwash sand and gravel ("Lower Outwash", Figure 7) as the glaciers retreated landward. Local sea level rise resulted in the deposition of marine clay in submerged areas.

The upper and lower tills are generally dense, unsorted and nonstratified mix of all particle sizes, ranging from clay and silt to cobbles and boulders. Both tills are generally gray to olive gray, and buff to brown where oxidized. Because the rock fragments are often composed of the underlying bedrock, the bedrock composition influences the composition of the till – where argillite is the underlying rock, the till is often siltier and more clayey. The color ranges from gray to brown, depending on oxidation. The till tends to have low plasticity.

The thickness of the lower till varies locally, with a maximum thickness of nearly 50 feet (15 m) near South Station. The unit thins to approximately 30 feet (9 m) thick underneath the Boston Common, is thinner elsewhere in the city (i.e. Back Bay area) and is absent in some areas, such as near North Station. The lower till is thought to be of Early Wisconsin or Illinoian age, while the upper is interpreted as Late Wisconsin (approximately 25,000 to 15,000 years ago). In Boston Harbor, including the Reserved Channel, the lower till has been observed to be a very dense, over-consolidated lodgment/basal till.

The upper till is largely similar to the lower till, although it is less dense and has larger clasts. Local areas of varved clay and silts are sometimes found incorporated into the till. This till is more than 30 feet (9 m) thick at the Common and even thicker at Beacon Hill, but thins or is absent north of Beacon Hill. Borings and geophysical information indicate bedrock depths of greater than 100 feet (30.5 m) underneath some drumlins.



QUATERNARY STRATIGRAPHY OF BOSTON

AGE	GLACI-TION	SYMBOL	STRATIGRAPHIC UNIT
HOLOCENE		F	Fill
		^^^	
		SS	Shore Sediment
		^^^	
		OS	Organic Sediment
		^^^	
PLEISTOCENE UPPER	___	RMC	Reworked Marine Clay
		^^^	
		LC	Lake Clay & Capping Outwash
	L		
		UO	Upper Outwash
	___	MD	Moraine Deposit/
		^^^	
		MC	Marine Clay

	B	LO	Lower Outwash
		^^^	
		GM	Glaciomarine Sediment

	___	UT	Upper Till
		^^^	
LOWER	BH	DSS	Deformed Stratified Sediment

	___	LT	Lower Till
		^^^	
	?	P-T	Pre-Till Sand and Gravel

BH = Beacon Hill Substage
B = Boston Substage
L = Lexington Substage

Figure 7. Diagrammatic sketch and stratigraphic column of Quaternary deposits of the Boston Area (Barosh and Woodhouse, 2011).

Drilling investigations have exposed various units that separate the two tills, including the presence of a zone of very compact, thickly stratified clay and silt in many drumlins, and a lens of stratified material that thickens to the west appears to form a separating unit between the two at Beacon Hill ("Deformed Stratified Sediment" in Figure 7). Relatively undisturbed sand and gravel, bracketed between basal and capping clay layers, occur between Beacon Hill and Boston Common, with the basal clay ranging from 0 to 25 feet (7.5 m) thick and the entire unit reaching a maximum thickness of 65 feet (20 m). However, some exposures do not indicate significant deposits between the two layers, the two tills are often undistinguished on boring logs. The inclusion of shells in the lower till also helps to distinguish between the lower and upper tills in some locations.

Following glacial retreat and deposition of the upper till in the Late Wisconsin, a local sea level rise resulted in deposition of glaciomarine sediments, where sand, silt and clay-sized particles were discharged by glacial meltwater streams directly into the shallow ocean ("Glaciomarine Sediment", Figure 7). This resulted in a complex deposit of interfingering layers of fine sand, silt, and clay overlying the upper till for much of the Boston area before it thins out seaward. These deposits are variable throughout the Boston area, ranging from dense, fine- to coarse-grained sand with minor silt and clay to hard, plastic brown clay with minor silt, sand and gravel.

As isostatic rebound began to outpace local sea level rise, the glaciomarine sediments were subsequently overlain by outwash sand and gravel ("Lower Outwash", Figure 7). Outwash from the north and the west was carried through channels that established the river system that was a precursor to the modern river system. The outwash sediments occur as local deposits that infill channels that had cut through the top portion of till, or in some cases, down to bedrock, and as thin, discontinuous capping layers. The deposits are primarily dense, olive-gray fluvial sand and gravel, with local, thin clay lenses. The channel fills reach up to 55 feet (17 m) in thickness, while the lenses outside of channels rarely exceed 10 feet (3 m) in thickness.

Rising sea levels subsequently inundated many low-lying areas, resulting in deposition of a thick layer of marine clay known as the Boston Blue Clay ("Marine Clay", Figure 7). This deposit is found in areas of low topography and extends eastward beyond the harbor; the clay is thickest in the lower valley of the Charles River and Boston Harbor, reaching up to 250 feet (76 m) in thickness, and thins to the north, east, and south. The clay is typically light greenish-gray to medium gray, and weathers yellowish in the upper portion that has been subaerially exposed, where it is often stiff and overconsolidated. The material is generally soft and plastic, but less so in the upper, weathered zone where it may also contain partings of fine sand or silt. Where the upper portion was overlain by peat, iron reduction has occurred, resulting in a zone of softened blue clay. The occasional gravel or boulder-sized clasts were deposited as iceberg dropstones. The clay may be found overlying any preceding deposit, including bedrock, and is generally overlain by outwash from the Lexington Substage, Holocene organic deposits, or fill.

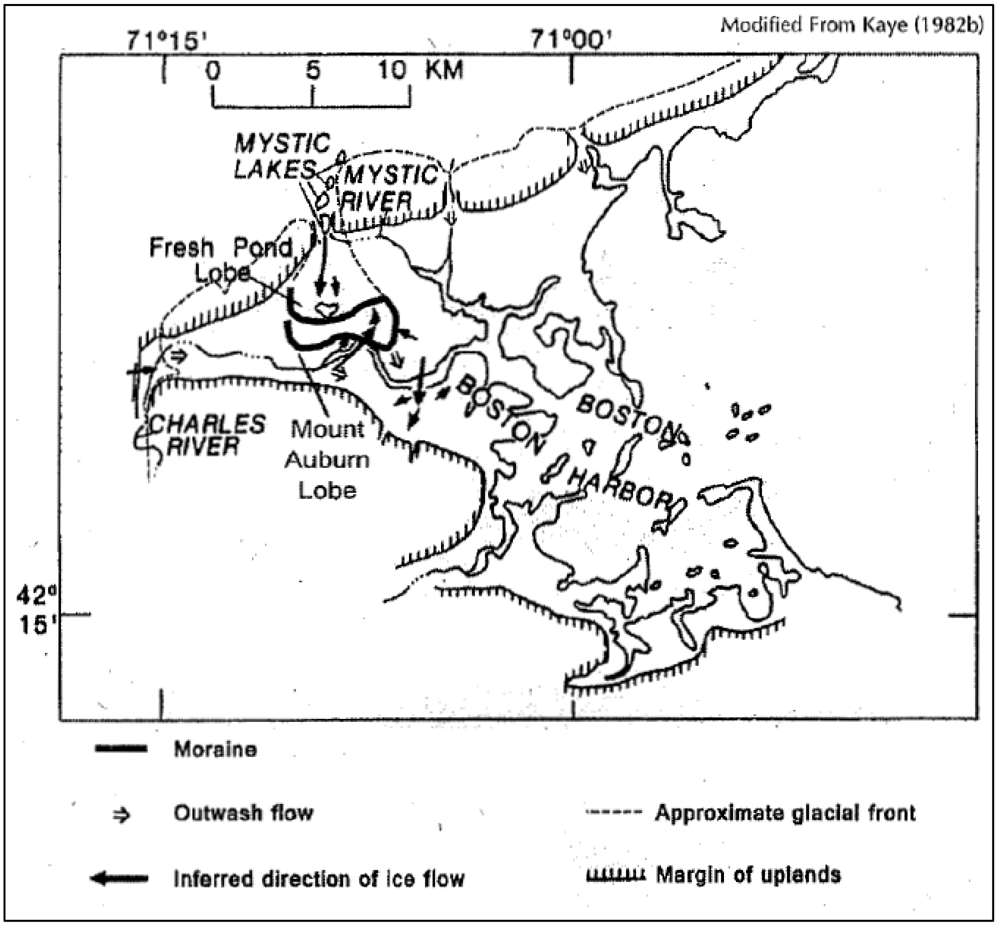


Figure 8. Extent of glacial front and moraine deposits from the Lexington Substage (Barosh and Woodhouse, 2011).

The Lexington Substage glacial advance extended only into the western and northern edges of the Boston Basin, resulting in deposition of two moraine deposits near Fresh Pond and the upper outwash sequence in river valleys and other topographic lows ("Moraine Deposit" and "Upper Outwash", Figure 7). The moraine extends through the Mystic Lakes/Fresh Pond area, then veers southeast near Mount Auburn Cemetery, producing a prominent moraine ridge known as the Fresh Pond Lobe (Figure 8). The moraine generally consists of very clayey till, reworked from glacially eroded Boston Blue Clay.

Following retreat of the last stage of glaciation, outwash sand and gravel were deposited outward from the glacial front, forming an upper outwash deposit. A co-occurring drop in sea level exposed the top of the marine clay, into which new channels were cut. Outwash sand and gravel were primarily deposited in these channels and into the western side of the harbor, where they spread into thin fans. The outwash deposits had multiple sources from nearly all directions with deposition guided by preexisting river and stream channels and is generally absent between channels. The channel fills pinch out seaward as a result of both original deposition and subsequent erosion. Thickness can range from 1 foot up to 100 feet (30.5 m).

Finally, Pleistocene deposition concluded with lacustrine clay infilling local ponds and a capping outwash sand and gravel (“Lake Clay & Capping Outwash”, Figure 7) . A clay deposit formed when the region behind the Fresh Pond moraine filled, with the deposit spanning between the Fresh Pond moraine to the Mystic Lakes. The clay is greenish gray, similar to the older Boston Blue Clay, and lacks varves but contains few sandy interbeds. The deposit reaches over 50 feet (15 m) in thickness and rests on the moraine till deposited during the Lexington Substage. This clay is capped by an outwash layer that formed during further northern retreat of the ice front, which ranges from a few inches to nearly 40 feet (12 m) thick.

4.2.2 Holocene Deposition and Glacial Isostatic Adjustment

As a result of local sea level regression in the early Holocene, the marine clay deposited in the Pleistocene was exposed to wave-base erosion and subaerial erosion. In Boston Harbor, paleochannels of Holocene age sand and gravel have been observed to be down cut into the Pleistocene Boston Blue Clay. Eroded clay was moved downslope into closed depressions via turbidity currents (“Reworked Marine Clay”, Figure 7). This clay is similar to the original marine clay and may contain a basal sand and gravel layer.

Later in the Holocene, the land was relatively high due to isostatic rebound. Coastal swamp deposits blanketed topographic lows, later forming an organic deposit consisting of freshwater and saltwater peat and organic silt and clay (“Organic Sediment”, Figure 7). These deposits are generally found in formal tidal flats, estuaries, and coastal lowlands, particularly along the margins of the Back Bay and Mystic River. These deposits gradually thickened and extended landward as sea level continued to rise, eventually ranging from a centimeter to 40 feet (12 m) in thickness in channels. The typical unit includes a basal freshwater peat layer followed by a dark gray to black organic estuarine and marine low-plasticity silt and/or organic clay and fine sand, topped with a capping peat. Dark-gray silty sand to sandy silt is also spread over the marine clay onto the eastern and northern ends of Boston, reaching into East Boston. The typical thickness of the organic deposit is less than 15 feet (4.5 m), but reaches 20 feet (6 m) in the Dorchester Bay area and is thickest in the Neponset River channel. The original thickness was greater but has been reduced by autocompaction and compressed by urban fill as the city expanded.

Some beach and near-shore sand and gravel deposits have accumulated around the shores of the islands and mainland within the Boston Harbor. Within the harbor, sediment was mostly derived from the wave erosion of drumlins, although offshore material is carried in on the outer beaches.

Glacial isostatic adjustment (GIA) has led to a complex history of vertical crustal adjustment during the Pleistocene and Holocene. Currently the North American coastline in the vicinity of Massachusetts is experiencing subsidence at a rate of approximately 0.5 mm/year as documented by recent satellite gravimetry (Brandes, et al, 2025). This vertical change is due to multiple processes contributing to GIA. The hinge-line, marking the boundary between vertical uplift and vertical subsidence is currently located inland to the northwest of Massachusetts.

As the continental ices sheet associated with the last glacial maximum (Wisconsinan) retreated, GIA led to uplift of the depressed crust as the glacial load was removed. However, outboard of the glacial front the uplifted crust in the glacial forebulge began to subside due to forebulge collapse. As continental glaciation continued to retreat, the forebulge also migrated toward the receding glacier leading to forebulge uplift followed by subsidence and forebulge collapse.

Forebulge migration is evidenced by inland migration of the hinge-line, so portions of coastal New England which previously experienced uplift are now outboard of the current hinge-line and subsiding. Thus, relative sea level change as documented by surficial geology is a product of both GIA and changes in the volume of water stored in continental ice sheets.

4.2.3 Historical Fill

4.2.3.1 History of Filling

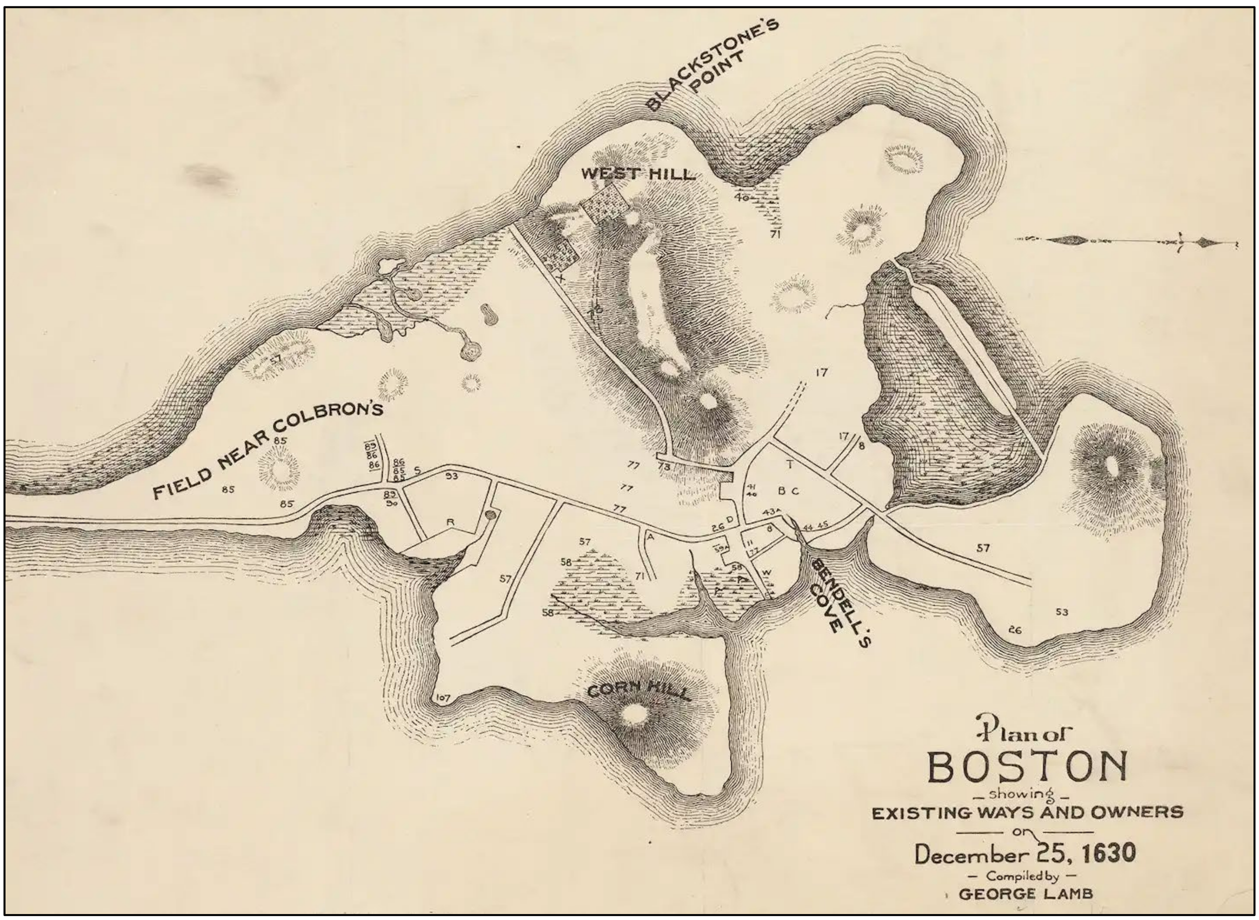


Figure 9. Map of the Boston area in 1630 (Lamb, 1903).

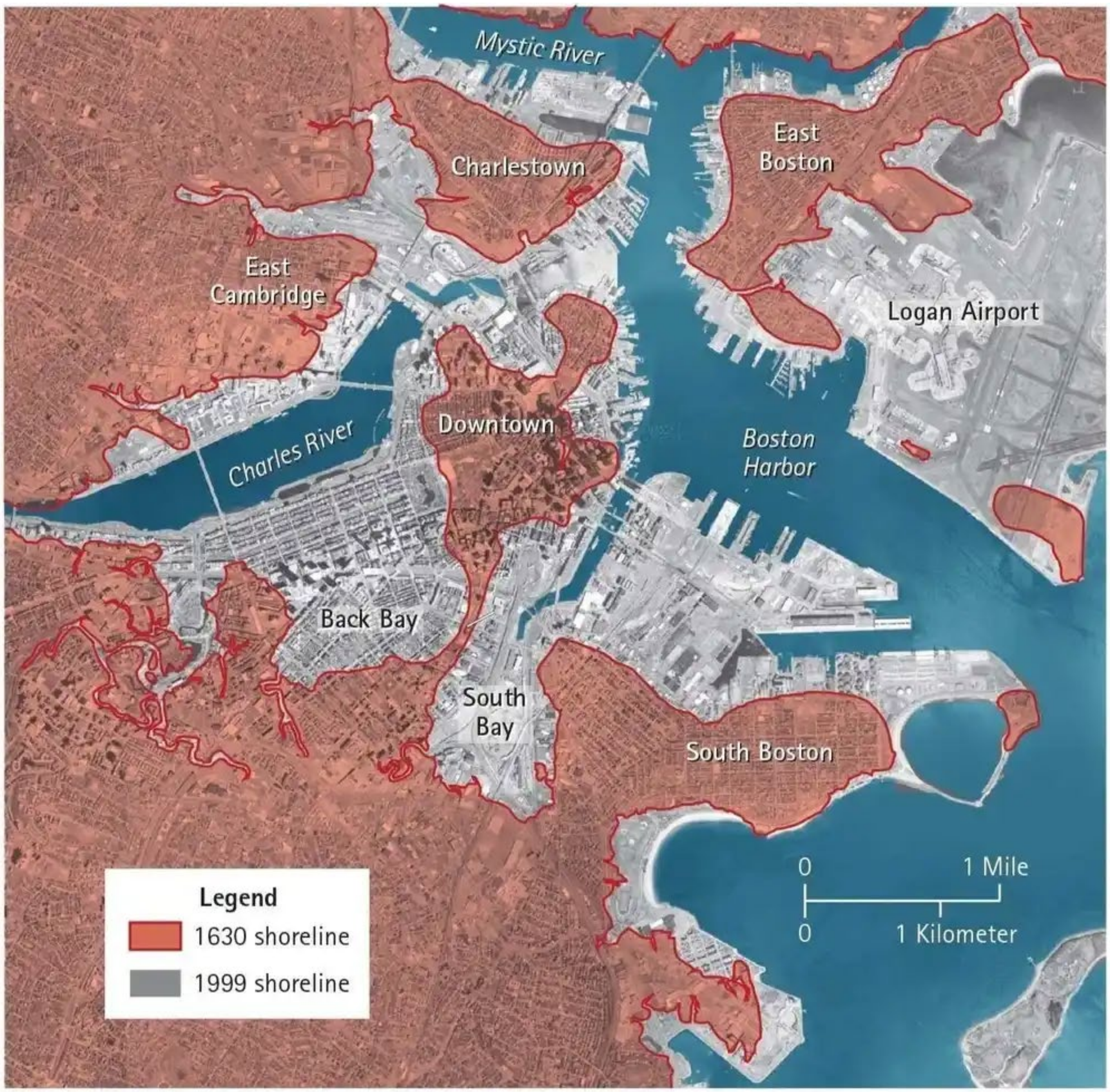
At the time of Boston's founding, the land was only a small peninsula ("Shawmut") connected to the mainland via the "Neck" (Figure 9). The peninsula measured only 487 acres, and topography was dominated by three joined hills. These hills were known as the "Trimontaine" and rose 150 feet above the surrounding basin. Much of the shore was bordered by broad salt marshes and tidal flats.

Excavation and filling by the colonial settlers significantly altered the topography of the Boston area. Generally, although wharf expansion dates to the mid-1600s (Attachment A, Figure 27), rates of filling of low-lying areas increased in the late eighteenth century (Attachment A, Figure 28 and Figure 29). The three hills served as a primary source of fill: 1) West Hill was used for Charles Street from 1758 to 1830, 2) Beacon Hill was used beginning in 1807 for the Mill Pond filling, and 3) Pemberton Hill was used in the 1830s for railroads. Other, smaller hills were used for filling tidal areas of the city.

Figure 10. Map of Boston in 1775 (Page, 1777).

The Back Bay, which was originally a mud flat within the Charles River tidal estuary, was enclosed in 1821 by the Mill Dam (Figure 10). The area was subsequently filled in between Charles Street and Fenway from 1856 to 1890. The early fill was composed of trash, cinders, and mixed material for railroad embankments and dams. Later, most of the fill consisted of clean sand and gravel derived from kame terraces. Around the city, other sources of fill included cinders and coal ash, street sweeping, hydraulic fill, dredged material, and debris from the Great Fire of 1872. On the north side of the Charles River, tidal marshes were filled in behind a granite seawall that was built around

1890. By the early 1900s, the filling of the Boston proper waterfront was nearly complete, although filling of the outlying areas, including Dorchester, East Boston, South Boston, Charlestown, and Logan Airport has continued in stages up to the present (Figure 11).



Source: Adapted from Weiskel, Peter K., Lora K. Barlow, and Tomas W. Smieszek. *Water Resources and the Urban Environment, Lower Charles River Watershed, Massachusetts, 1630–2005.* U.S. Department of the Interior, United States Geological Survey, in cooperation with the U.S. Environmental Protection Agency and the Massachusetts Department of Environmental Protection (2005), Circular 1280, Figure 9, p16.

Figure 11. Map of the Boston area showing historic land filling between 1630 and 1999 (Boston Groundwater Trust; adapted from Weiskel, Barlow, and Smieszek, 2005).

The total made land in Boston is approximately 5,245 acres. Refer to Attachment A for a series of maps demonstrating the Boston shoreline at various stages of filling between 1630 and 1995.

4.2.3.2 Types of Fill and Methods of Transportation, Excavation, and Filling

Each episode of land filling used a specific source material and distinct filling method. In general, the fill consists of loose to very dense sand, gravelly silt, or sandy gravel intermixed with varying amounts of silt, clay, cobbles, boulders, and miscellaneous materials such as brick, ash, rubble, and other trash. Source materials may include both granular and cohesive material that was generally loosely placed at sites without sorting or compaction, resulting in blow counts that may range up to refusal. Much of the fill is saturated due to a variable and shallow groundwater table.

Generally, the land was created by building a structure around the perimeter of an area to be filled, then by dumping fill until the level of fill was above the level of high tide. These structures evolved from relatively simple wooden timber cribbing in the seventeenth and eighteenth centuries to complex stone seawalls in the nineteenth century. The structures became relatively simple dikes and bulkheads in the twentieth century. Throughout the filling of Boston, the construction of these perimeter structures was often derived from the methods used for wharf construction.

In the seventeenth and eighteenth centuries, some fill-retaining structures in relatively quiet water (e.g., Mill Pond) were constructed from layers of crisscrossed timbers laid down in the bottom of the pond, then covered with fill. In the early nineteenth century, stone seawalls became the predominant type of structure. Stone seawalls were generally used to retain fill in areas of open water and were constructed of unmortared cut granite blocks. Individual blocks were often battered (wider on the base) on at least one face and ballasted on the inner face. These structures were then sometimes finished with timber caps and supported by “land ties”, which were designed to prevent slumping. When possible, these early nineteenth seawalls were often set directly on clay; if the sediment was silty, platforms of crisscrossed timbers were constructed to support the seawall.

By 1830, the construction methods changed as the seawalls were built higher and had wider bases. These larger seawalls were set on foundations of timber piles driven into underlying clay. These piles were usually placed in a trench that had been excavated down to clay; after the piles were driven, the tops were cut off below the low water mark to prevent rotting, and the spaces between the tops of piles were filled with small stones. Timbers were then attached across the tops to provide a base for the seawall. The seawalls themselves also evolved during this time. Often, single stones that extended entirely through the wall, called “binders”, were used to increase stability, and walls were topped with granite caps (“coping”).

Through the nineteenth century, some stone seawalls began to be set upon stone foundations, including granite and concrete. Additionally, some walls began to be partially or entirely built of concrete beginning in the late nineteenth century. However, the most sweeping change during this time was the reintroduction of the wood bulkhead. These were generally constructed of thick vertical posts driven deep into sediment, which were supported by diagonal braces (“spurshores”) and later also by stringers bolted across them. These wooden bulkheads likely replaced the stone seawalls, despite the risk of decay, because they were less expensive, and they soon became the most prevalent fill-retaining structure in Boston. These were especially abundant when large areas were to be filled, such as on the South Boston and East Boston Flats.

During the twentieth century, clay dikes were commonly used, including at Moakley Park; later iterations of the dikes were faced with riprap for erosion protection, such as at Logan airport, Victory Park Road in Dorchester, and Piers 2 and 4 in South Boston. Dikes were also sometimes composed entirely of rock, such as at Bird Island Flats, at the docks between Piers 1 and 2 in South Boston, and at Subaru Pier. Sheet piling also began to be used, such as at the Navy Yard and Victory Road Park.

The type of fill used to make land evolved over time; in the seventeenth and eighteenth centuries, the fill was largely composed of household trash. By the early nineteenth century, trash was a less acceptable fill material due to prevailing theories on the origin of diseases, and thus the fill was generally composed of “clean gravel or earth” (Seasholes, 2003). Although gravel was the preferred material, other materials such as mud excavated from tidal flats and marshes was used to fill various sites, including the Central Wharf in 1815 and the east side of the Mill Pond in the 1820s. Despite general agreement that trash was not a suitable fill source as it was suspected to cause disease, there is evidence of “street sweepings and trash” used as fill on the flats west of Charles Street in the early nineteenth century (Seasholes, 2003).

From approximately 1830 to the end of the nineteenth century, clean gravel continued to be the preferred type of fill. Other acceptable types of fill used were earth excavated during construction of new buildings (“cellar dirt”), coal ashes, and dredged fill from the bottom of the harbor or rivers.

During the early twentieth century, as modern germ theory became accepted, trash once again emerged as a generally accepted source of fill, although gravel, dirt, dredgings, and coal ash continued to be used. The use of trash as fill increased and culminated in the largest trash-filled area in Boston, the trash dump at Columbia Point. Construction debris also became an accepted fill source, although some permits prohibited use of wood or other organic materials.

The techniques used to excavate, transport, and place fill evolved through Boston’s history. In the seventeenth and eighteenth centuries, the fill was likely transported in carts or large containers and dumped into the docks. At the beginning of the nineteenth century, gravel fill was dug by hand with picks and shovels and transported via horse-drawn carts. Other contemporaneous transport methods included a pulley-operated incline railroad, scows and ferries, and ox-drawn wagons. By the mid-nineteenth century, most large land-making projects used trains to transport material.

The primary methods of excavation in the nineteenth century were the steam excavator and various dredges, including the steam-powered dredge, clamshell dredge, and hydraulic dredge. Dredged fill was often dropped directly onto target areas or transported and places via pipes supported by pontoons.

4.2.3.3 Dorchester

The shoreline in Dorchester is composed entirely of filled land, and was created predominantly to build two highways, the Morrisey Boulevard and the Southeast

Expressway, and to add land to the promontories that extended into Dorchester Bay (Columbia Point, Savin Hill, Commercial Point, and Port Norfolk). Portions of the shoreline along the Neponset River have also been filled.

Most of the land filling occurred during the nineteenth and twentieth centuries. Commercial Point was the first area to be developed in 1802; however, the first major land filling project was the creation of Columbia Point in the latter part of the 1800s, after which the area was used as a sewage pumping station from 1879 until 1968.

More land was added to Commercial Point in the late nineteenth and early twentieth centuries, predominantly by private owners, at least some of which was created using dredged material from the anchorage basin between Commercial Point and Savin Hill. Concurrently, Tenean Creek was also filled between Victory Road to the west side of the railroad tracks, and Savin Hill Beach (now McConnell Park) was filled with material hydraulically dredged from Dorchester Bay. Tenean Beach was created mostly in the 1920s and 1930s, with material that included sand, ashes, and dredged material from Pine Neck Creek.

The creation of the Old Colony Parkway (now Morrissey Boulevard) began in the early twentieth century, with the primary focus on replacing the Neponset Bridge; filling on the section of the parkway near the bridge was primarily done with coal ashes and rubbish from Dorchester. In general, fill for the project was sourced from materials that could be acquired cheaply, such as coal ashes, rubbish, and dirt from construction sites. The construction of Morrissey Boulevard was succeeded by the construction of the Southeast Expressway in the 1950s, which required additional filling along the shore of Savin Hill Bay and Tenean Beach.

Most of the new land created in Dorchester after the 1930s has been on Columbia Point, with the first major land development being the use as a trash dump (Mile Road Landfill and Coleman Dump) from 1934 to 1963. Structures began to be built on Columbia Point in the 1940s and 1950s, including barracks during World War II (later converted to a housing project “Columbia Village”), Boston College High School, the Columbia Point housing project, and a shopping mall. The University of Massachusetts – Boston campus was constructed in the early 1970s by stabilizing the fill and adding a granite bulkhead around the perimeter of Columbia Point.

The filling of land for Victory Road Park and the Kennedy Library were the last major filling events, which occurred in the 1960s and 1970s. See Table 1 for a timeline of the major landfilling activities in Dorchester.

Table 1. Timeline of major land filling events in Dorchester (Seasholes, 2003).

Location	Land Filling Dates
Wharf building at Commercial Point	Mid-1830s to mid-1930s
Main Drainage – Bay State Gas Company	Late 1870s to late 1880s
McConnell Park	1906-1908
Savin Hill Bay	Mid- to late 1910s
Morrisey Boulevard	Late 1910s to late 1920s
Dump at Columbia Point	Early 1920s to early 1960s

Tenean Beach	Early to mid-1930s
Columbia Point Housing	Early to mid-1950s
Victory Road Park	Late 1960s to early 1970s
UMass/Boston	1970-1973
JFK Library	Late 1970s

4.2.3.4 South Boston

Filling of South Boston has added approximately 1,013 acres to the original 580 acres (Figure 27; Seasholes, 2003). Filling initiated in 1804 with the construction of a seawall for flood protection. As filling progressed, land was filled both by private industry (such as for foundries and machine shops) and by the City of Boston (for institutions such as jails and asylums).

The major landmaking in the mid-nineteenth century was the construction of a large wharf in the South Boston Flats. While the Flats were being filled, land was made at the east end of the South Boston peninsula (City Point) for the creation of a public park. Columbus Park, now Moakley Park, was filled between 1917 and 1919. The next major landmaking was done by the US Navy during World War II, when the Navy filled in what became known as the Navy Yard's South Boston Annex. The most recent landmaking in the area was the creation of Subaru Pier in the 1980s. See Table 2 for a timeline of the major landfilling activities in South Boston.

Table 2. Timeline of major land filling events in South Boston (Seasholes, 2003).

Location	Land Filling Dates
Seawall	1804-1806
Wharf Building (Fort Point Channel, South Bay, Reserved Channel)	Mid-1820s to 1940
Cyrus Alger	Late 1820s to late 1830s
City Institutions	Mid-1830s
Boston Wharf Company Wharf	Mid-1830s to late 1870s
South Boston (Commonwealth) Flats Project	1870 to late 1920s
Marine Park	Early 1880s to early 1890s
Day Boulevard	Mid-1890s to mid-1900s
Moakley (Columbus) Park	1917-1919
US Navy	1940-1944
Subaru Pier	Early to mid-1980s

4.2.3.5 Downtown Boston

The first landmaking event in the Boston area was the creation of wharves along the Central Waterfront (Town Cove, at the time) in the 1630s, and wharfing out was the major form of landmaking in Boston in the seventeenth and eighteenth centuries. Many of these wharves were built by private landowners. In the seventeenth century, land was created for gun batteries and forts, and these shoreline batteries were enlarged in the eighteenth century. During this time, the Town Dock was partially filled, although in general, little landmaking occurred in the mid-eighteenth century due to economic crises in Boston and the subsequent Revolutionary War. Most of the landmaking in the late eighteenth century involved filling the enclosed docks that had been created in the prior century.

Major wharves, India Wharf and Central Wharf, were constructed in the early nineteenth century; contracts from the time suggest the buildings on the wharves were set on timber piles driven into stone perimeter walls, although the fill material was not specified in the contracts. Broad, India, Commercial, and Fulton Streets were filled around the same time (1810s-1820s). Atlantic Avenue was built in the mid to late nineteenth centuries; the filling in of Atlantic Avenue extended the shoreline of the Central Waterfront out to its present position.

Changes since then have primarily involved alterations rather than the creation of new land. The Central Artery was constructed in the 1950s, which resulted in demolishing and truncating many preexisting streets and buildings. In the 1960s, much of the Central Wharf was removed for the construction of the aquarium, and in the 1970s, Atlantic Avenue was moved further west. This relocation enabled the creation of Christopher Columbus Waterfront Park. Further changes have since occurred as a result of the "Big Dig". All of these changes to the Central Waterfront occurred on land that was created by filling in the Town Cove. See Table 3 for a timeline of the major landfilling activities in the Central Waterfront area.

Table 3. Timeline of major land filling events along the Central Waterfront (Seasholes, 2003).

Location	Land Filling Dates
Wharf building	1630s to mid-1850s
Enclosed dock filling	Early to mid to late 1700s; early 1800s; 1850s
Long Wharf and South Battery	Early 1700s
India Wharf	1803-1809
Central Wharf	Mid-1810s
Commercial/Fulton Streets	Late 1820s
Custom House	Mid-1830s
Atlantic Avenue	Late 1860s to early 1870s

The Charles River in the Bulfinch Triangle area was originally dammed to create Mill Pond in the 1630s. In the seventeenth and eighteenth centuries, some land was made around the shore of the pond, likely for private wharves. The pond was later entirely filled with "clean gravel or earth" between 1807 and the 1820s (Seasholes, 2003). Much of the material used in the filling of Mill Pond came from Copp's Hill and Beacon Hill, however, there is also evidence that material from nearby mudflats were used to supplement the sand and gravel.

Land for the building of the Boston and Lowell Railroad was created in the mid-1830s using material taken from Pemberton Hill. In the early twentieth century, more land for the Boston and Maine Railroad was created using fill from Asylum Hill in Somerville, and from grading and ballasting projects on other portions of the railroad system. The fill was described as containing huge blocks of granite, pieces of steel, whole walls, debris, dirt, and other building materials. See Table 4 for a timeline of the major landfilling activities in the Bulfinch Triangle.

Table 4. Timeline of major land filling events along Bulfinch Triangle (Seasholes, 2003).

Location	Land Filling Dates
Dammed	1630s
Pond Filled	1807 to late 1820s
Boston & Lowell Railroad Land	Mid-1830s
Boston & Maine Railroad Land	Late 1920s to early 1930s
New Charles River Dam	Mid- to late 1970s

4.2.3.6 Charlestown

Wharf development began as early as the 1630s in Charlestown. In the eighteenth and nineteenth century, as Charlestown became a regionally significant port, the Town Dock was created and enlarged; however, the dock was filled in 1835-1836 to create land for private industry. The southwestern waterfront was filled in the early nineteenth century to create Prison Point, bridges, canals, and railroads. Simultaneously, land was being created on the Mystic River by wharfing out near Moulton's Point and the development of Mystic Wharf, and on the southeast waterfront, where land was made for a railroad and shipping terminal.

At the end of the nineteenth and start of the twentieth centuries, land was made for public parks, including Ryan (Charlestown) Playground and Doherty Playground (Charlestown Heights). The fill used at Ryan Playground included rubbish and coal ashes collected by the city, dirt dumped by private individuals, and dirt from grading Charlestown Heights.

The southeast waterfront of Charlestown was filled as part of a naval shipyard. This landmaking began the early nineteenth century and ended in the mid-twentieth century. The most recent landmaking in Charlestown was the construction of the new Charles River Dam in 1974-1978. Only a small area of land was filled for the dam, creating what is now Paul Revere Park. See Table 5 for a timeline of the major landfilling activities in South Boston.

Table 5. Timeline of major land filling events in Charlestown (Seasholes, 2003).

Location	Land Filling Dates
Shoreline Battery	Approximately 1640s
Mill Dam	Approximately 1650s
Wharf building (Harbor, Prison Point Bay, and Mystic River Waterfronts)	1630s to mid-1930s
Prison Point	1802-1804
Navy Yard	1802 to late 1860s; late 1890s to mid-1900s; mid- to late 1910s; and early 1940s
Town Dock filled	Early 1820s to mid-1830s

Towpath	Mid-1920s
Railroad filling	Mid-1830s to late 1840s
Prison Point Bay	Late 1860s to 1880
Mystic Wharf	Late 1870s to early 1890s
Hoosac Docks	Mid- to late 1880s
Ryan Playground	Early 1890s to 1900

4.2.3.7 East Boston

East Boston is the portion of Boston with the largest area of filled land (nearly 1,770 acres), of which the majority (1,413 acres) is the land used for the airport. East Boston was created by filling around or over what were originally five islands in the Boston Harbor: Noddles, Hog (Breed's), Bird, Governors and Apple Islands. The islands were largely undeveloped and sparsely inhabited until the 1830s, when plans were made to develop the area into residences and as a locus of industry. Much of the early landmaking was done for private interests between the 1830s and late 1850s, after which East Boston's growth slowed until the 1870s.

A significant change occurred when the Boston, Revere Beach and Lynn Railroad was built over the Basin flats. Filling of the main part of the Basin began in the 1890s and continued into the 1920s. The fill in this area was likely trash and coal ashes collected by the city. Prior to filling of the flats, some filling had occurred on Wood Island to create a public park, "Wood Island Park", plans for which also included building Neptune Road to connect the rest of the park to East Boston. Following the creation of Neptune Road, the Parkway Lands were filled with material that primarily came from two sites on the north side of Eagle Hill, although some material was composed of coal ashes and dirt brought from other areas of Boston.

Similar developments occurred in Hog/Breed's Island beginning in the 1890s. By 1900, land been created at the foot of Orient Heights and in the Bayswater section of the former Breed's Island. A playground (Noyes Playground) for the Orient Heights area was also developed in the early 1910s with dirt from Eagle Hill. The north side of the island, once a drive-in theater, is now the Belle Isle Marsh reservation.

While flats at the foot of Orient Heights were being filled, the marsh at the north end of the original Noddles Island was filled ("North of Addison Street"). The East Boston company had a contract to have large quantities of city trash and coal ashes dumped in this area for a period of ten years.

The most significant land building events in East Boston were the filling of the East Boston Flats, which included development of ports and the airport beginning in the mid-1910s and continuing into the 1970s. The method used to construct land on the East Boston Flats was similar to that used for the South Boston Flats – a timber bulkhead was built to hold dredged fill that was deposited hydraulically.

Constitution Beach was created in the 1950s as a replacement for Wood Island Park, which had been converted into land for the airport.

See Table 6 for a timeline of the major landfilling activities in East Boston.

Table 6. Timeline of major land filling events in East Boston (Seasholes, 2003).

Location	Land Filling Dates
Wharf Building (Harbor and Chelsea Creek Waterfronts)	Early 1830s to mid-1930s
Maverick Square, Meridian Street, and Chelsea Street	Early to mid-1830s
Grand Junction Railroad	Late 1840s to early 1950s
Basin seawall	Late 1840s to early 1950s
Neptune Road	Mid-1880s
Parkway Lands	Late 1880s to mid-1890s
Wood Island Park	Early to mid-1890s
Basin flats	Mid-1890s to mid-1910s
Noyes Playground	Early 1910s
North of Addison Street	Early to late 1910s
East Boston Flats/Airport	Mid-1910s to mid-1920s; early 1930s; mid-1940s; and mid-1960s to mid-1970s

5 Hydrogeology and Groundwater

Much of the precipitation that falls over Boston is discharged via overland runoff and through storm drains. Direct recharge to groundwater occurs primarily at parks and other unpaved areas, although recharge is also derived from the Charles River and Muddy River. Sewer and water main leaks also provide a significant amount of water to the groundwater system.

Most groundwater discharge, especially in areas comprised of fill, is to sewer and storm drainage systems. Additional groundwater discharge occurs to the Charles River downstream of the dam, Boston Harbor, Fort Point Channel, and South Bay. Groundwater is discharged to tidewater in the northeastern portion of the peninsula. Groundwater withdrawal at shallow depths is typically for dewatering construction sites or for mitigating leaks into basements. Groundwater flow is generally in the direction of the ocean; groundwater elevations are likely tidally influenced.

The complex stratigraphy of subsurface deposits in Boston, both vertically and horizontally, drives groundwater elevations and movement. Generally, the more permeable units (outwash and fractured bedrock) are aquifers, whereas the less permeable units (Boston Blue Clay, lower and upper till, lacustrine clay) act as aquitards or aquicludes. Historical fill can be either an aquifer or aquitard depending on the composition of the fill.

Shallow groundwater flow in much of the original land area of Boston and in the areas filled prior to 1850 is hindered by low permeability, fine grained, poorly sorted deposits. The water table is highest in the original parts of Boston, including the peninsula and the "Neck" due to these low-permeability units (Figure 12; Figure 13). The water table is also high near the Boston Common, reflecting higher than average recharge due to greater infiltration. Generally high water table elevations are seen along Washington Street, reflecting the slow groundwater movement through fine-grained sediment in the area.

Figure 12. Composite high water table map, 1936-1940 (Cotton and Delaney, 1975). Groundwater elevations are given in sea level datum of 1929.

Figure 13. Composite low water table map, 1936-1940 (Cotton and Delaney, 1975). Groundwater elevations are given in sea level datum of 1929.

Areas with a low water table likely reflect dewatering, high leakage into sewers or drainage systems, or high permeability units (some fill, particularly post-1850s fill, or outwash deposits).

In the filled portions of the city, the elevation of the groundwater table is critically important for the structural integrity of buildings built upon wooden pilings. The pilings are typically located 15 to 25 feet below the ground surface, and the majority of buildings constructed on filled land prior to the twentieth century are on wooden piles.

Piling cut-off elevations, or the top elevation of the wooden piling, can vary substantially between neighboring buildings or even within one building. Dewatering during large construction projects increases the risk of exposing the pilings to oxygen, causing deterioration and potential settlement or warping. An adequate cutoff system is required to be installed to control drawdown beyond the site area during any construction excavation below the groundwater table. Dewatering may perch the groundwater table in some areas where fill is underlain by silt and clay over sand and gravel.

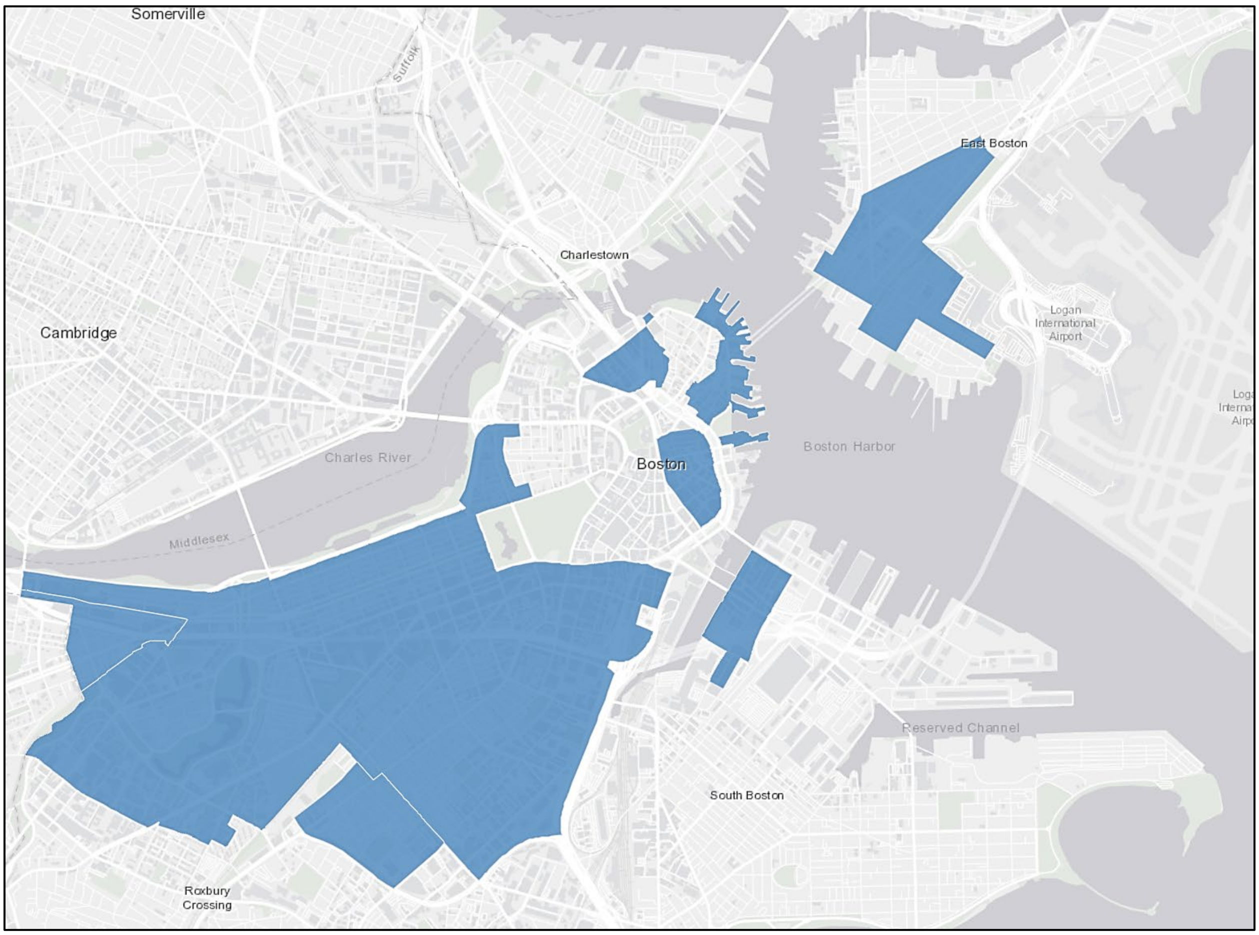


Figure 14. Map of the Boston Zoning Groundwater Conservation Overlay District (GCOD), Article 32 of the Zoning Code (City of Boston, 2025).

The Boston Groundwater Trust was established by the Boston City Council in 1986 to monitor groundwater elevations in portions of the city where foundations are threatened by low water levels. Additionally, the City of Boston has introduced a Groundwater Conservation Overlay District (GCOD; Figure 14), mandating that “individuals constructing or renovating properties in the affected area prevent any reduction in groundwater levels and implement rainwater recharge systems to channel water back into the ground” (Boston Groundwater Trust, n.d.). The following website, maintained by the City of Boston Planning Department, may be used to determine if a given parcel is

located within the Groundwater Overlay District:
https://maps.bostonplans.org/zoningviewer/ (Figure 14).

Only certain projects are subject to the regulations under the GCOD. The GCOD states that any applicant seeking a building permit for a proposed project within the GCOD shall be subject to the requirements of Article 32 where such Applicant seeks:

- The erection or extension of any structure, where such new structure or extension will occupy more than fifty (50) square feet of lot area
- The erection or extension of any structure designed or used for human occupancy or access, mechanical equipment, or laundry or storage facilities, including garage space, if such construction involves the excavation below grade to a depth equal to or below eight (8) feet above Boston City Base (other than where such excavation is necessary for, and to the extent limited to, compliance with the requirements of Article 32)
- To substantially rehabilitate any structure
- Any paving or other surfacing of lot area

Applicable projects need to certify there will be no negative impact on groundwater levels and incorporate a groundwater recharge system that captures water onsite. Applicable projects require approval from Boston Water & Sewer Commission, Boston Groundwater Trust, and Zoning Board of Appeals.

6 Seismic Hazard

6.1 Background

Boston, Massachusetts is located the Central and Eastern United States. The 2023 update of the National Seismic Hazard Model (NSHM) by the U.S. Geological Survey (USGS) (Petersen et al. 2023) provides consensus-based regional analyses of seismic hazard, using Central and Eastern United States (CEUS) seismic sources, Western United States (WUS) seismic sources, combined geologic/geodetic information, and revised ground-motion models. This report represents the most current assessment of seismic hazard for large regions of North America. The 2018 NSHM declustered seismicity catalog is shown in Figure 15, as no corresponding figure for the 2023 NSHM seismicity catalog is currently available.

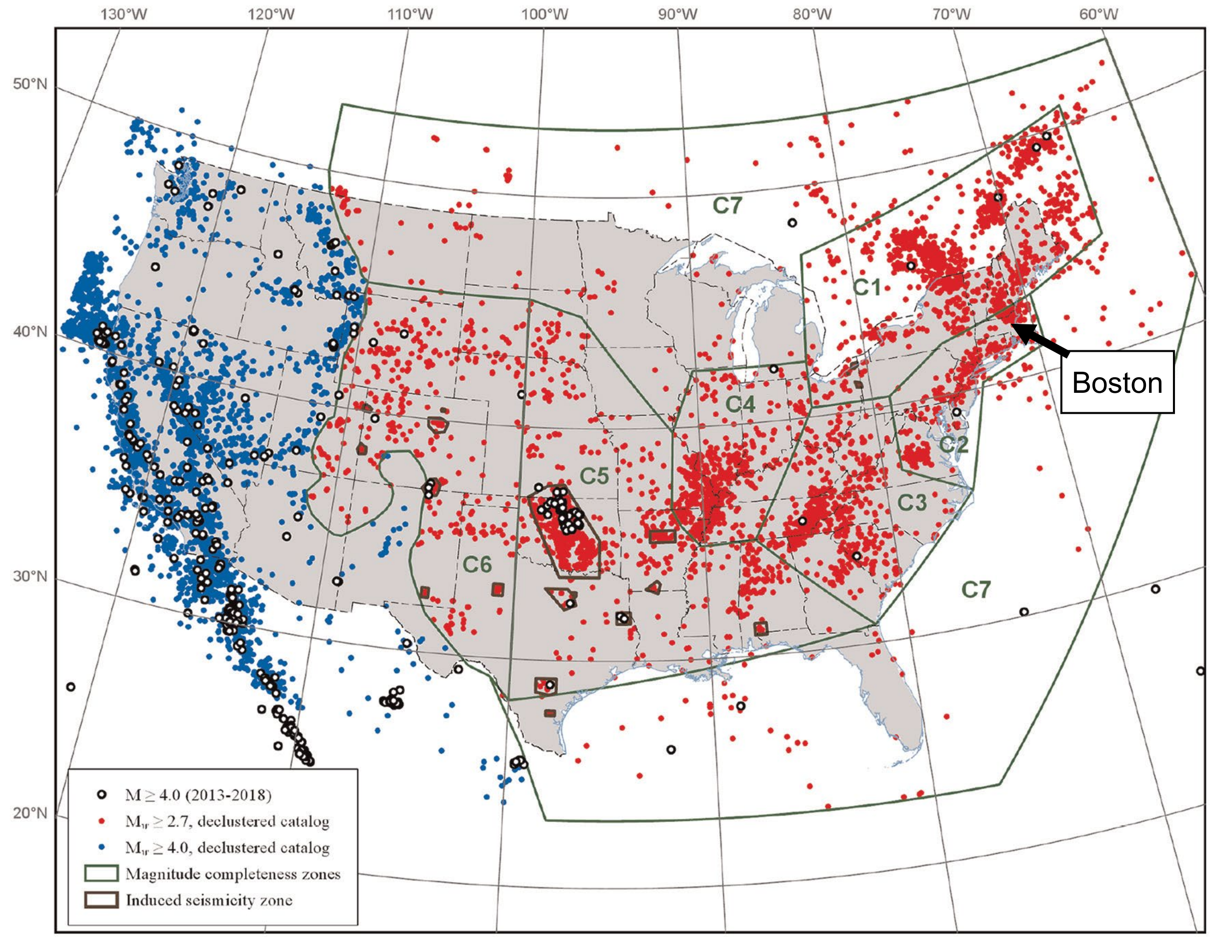


Figure 15. 2018 NSHM declustered seismicity catalogs for $M_w \geq 2.7$ (Petersen et al. 2020). No corresponding figure for the 2023 NSHM seismicity catalog is currently available.

The NSHM for the CEUS considers both seismicity-based background earthquake source zones and fault-based sources and utilized data and models from the CEUS Seismic Source Characterization for Nuclear Facilities (CEUS–SSCn) project, which accounts for broader uncertainties and replaces older seismic source models. The seismicity-based source model for the CEUS assumes that future large earthquakes are more likely to nucleate near previous earthquakes with moment magnitude (M_w) greater than or equal to 2.7. The model also distinguished seismotectonic zones in the CEUS with distinct seismicity and maximum earthquake magnitudes, in order to accommodate some possibility that the historical seismicity does not fully represent likely sources of background earthquakes.

Boston lies in the Extended Continental Crust - Atlantic Margin (ECC-AM) seismotectonic zone (Figure 16). Seismicity within the ECC-AM is spatially variable with moderate concentrations of earthquake activity separated by areas of very low seismicity (US NRC, 2012). Adjacent seismotectonic zones include the Paleozoic Extended Zone (PEZ) located to the west and south, the Northern Appalachian zone (NAP) to the north, and the Atlantic Highly Extended Crust zone (AHEX) to the east.

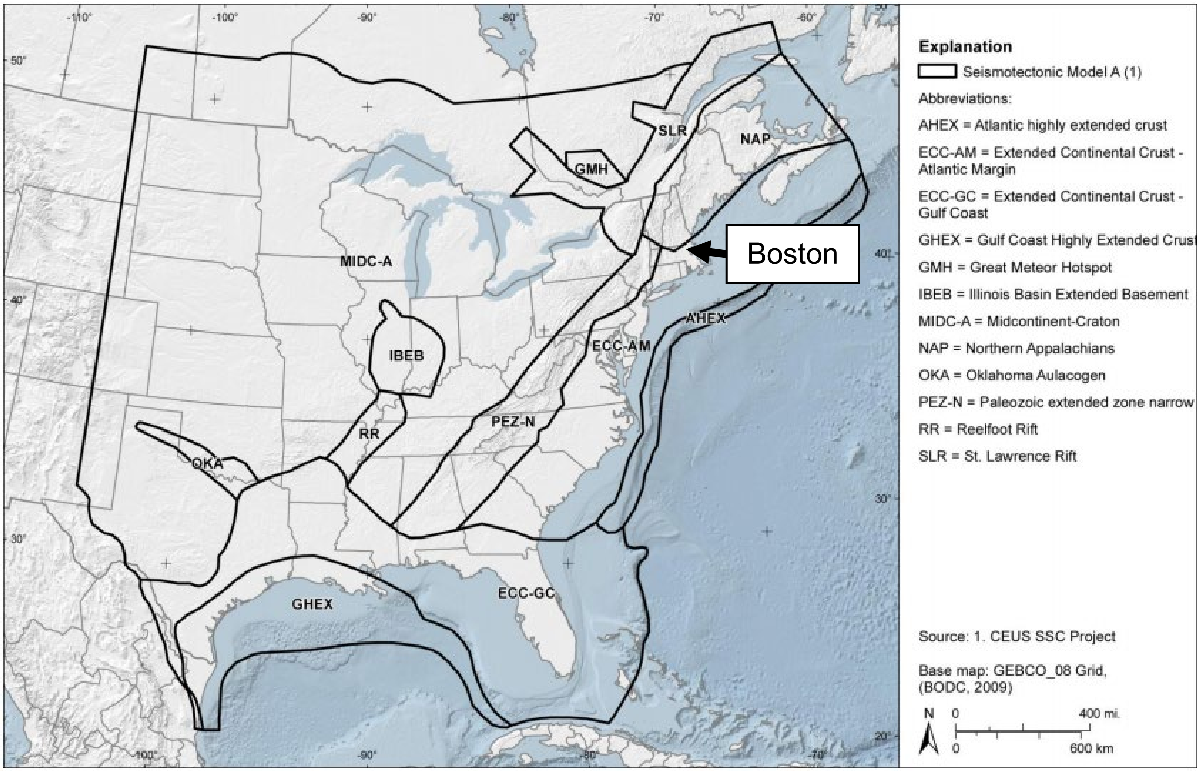


Figure 16. 2018 Generalized seismotectonic zonation of the CEUS (US NRC, 2012).

Defining the ECC-AM (Mesozoic extended crust) as a seismic source also separates it from adjacent regions of the crust that appear capable of producing earthquakes which have differing maximum magnitude or rupture characteristics (Figure 17; USNRC zones map). For example, the ECC-AM is detached from the ECC-GC (Gulf Coast) because the structural grain of the two seismotectonic zones is different and will likely generate different future rupture characteristics (e.g., particularly rupture orientation). Crust of the ECC-AM seismotectonic zone is separated from Mesozoic extended crust of the Northern Appalachian (NAP) seismotectonic zone because of both the lack of rift basins expressed in the NAP and the multiple phases of reactivation and differences in future earthquake rupture characteristics (US NRC, 2012).

During the past 400 years in the ECC-AM and NAP, Northeastern Massachusetts, southeastern New Hampshire, and southern Maine have experienced many small, and several moderate earthquakes. The two most notable earthquakes, the 1727 felt-area M 5.5 Newburyport and the 1755 M 6.1 Cape Ann earthquakes in Massachusetts, induced liquefaction and caused damage to buildings (Ebel, 2000, 2001).

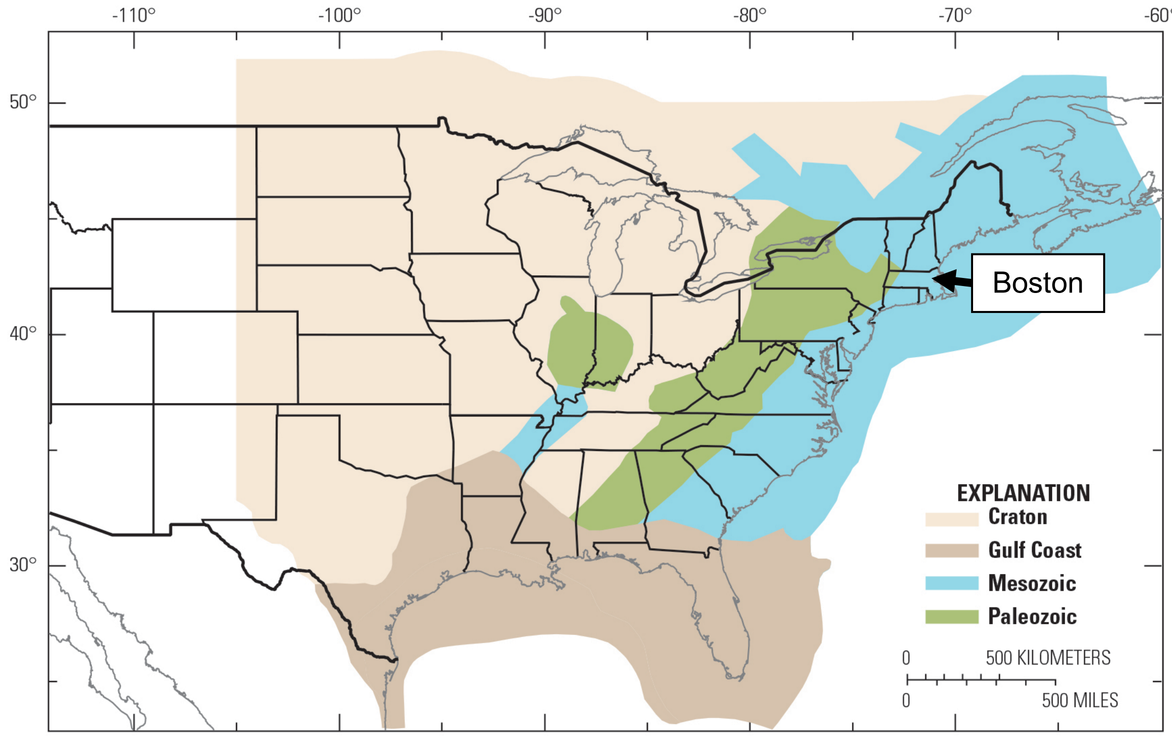


Figure 17. 2018 Generalized seismotectonic zonation of the CEUS (US NRC, 2012)

During a paleoseismology study in the Newburyport area in the late 1980s, Tuttle and Seeber (1991) found both historical and prehistoric liquefaction features. The historical features were attributed to the 1727 earthquake, and the prehistoric features were estimated to have formed during the past 4,000 years. More recent searches for earthquake-induced liquefaction features in the region yielded only one small sand dike (Tuttle, 2007, 2009). The limited paleoliquefaction features in New England do not provide sufficient information to characterize the recurrence, geometry, or Mmax parameters of the ECC-AM seismotectonic source.

The USGS Quaternary Fault and Fold Database of the United States and interactive fault map (https://doi.org/10.5066/F7S75FJM) were reviewed for faults and associated folds in the vicinity of the site that demonstrate geological evidence of coseismic surface deformation in large earthquakes during the past 2.58 million years (Myr). The results are portrayed in Figure 18. No quaternary features are documented close to Boston.

New England is located in an area of moderate seismicity. The region tends to display localized seismicity, wherein some regions have been consistently active over the four-hundred-year record and others have remained consistently inactive. Northeastern Massachusetts is one of the relatively more active areas. Earthquakes in the region tend to be very shallow, mostly less than 10 kilometers in depth.

Figure 18. Quaternary features (USGS Quaternary Fault and Fold Database, Accessed May 4, 2026).

Several historic earthquakes in the region have caused significant ground motion. In 1638, an earthquake with an estimated magnitude of about 6.5 struck in central New Hampshire. In 1663, an earthquake in southern Quebec had a magnitude (M_{bLg}) of approximately 7.0 and produced shaking in Boston, damaging several chimneys in the city. An earthquake struck Newbury in 1727, producing a moment magnitude (M_w) of 5.6 and generating sand boils, an indicator of liquefaction. The largest historic earthquake was the 1755 Cape Ann earthquake, which had a M_w of about 5.9, estimated ground motions in Boston from 0.08 to 0.12g, and caused damage throughout eastern Massachusetts. Between 1,500 to 5,000 chimneys were destroyed in Boston, and the earthquake reportedly affected water levels in wells in central and western Connecticut.

The Boston area includes extensive regions of filled land, which are capable of amplifying earthquake ground motion. Brankman and Baise (2008) prepared liquefaction hazard maps for the Boston metropolitan area. The maps are based on surficial geology and geotechnical data and the study used a design earthquake of 6.0 Mwe and PGA of 0.12g for design ground motion (Figure 19; Figure 20). Regions mapped as artificial fill have the highest liquefaction potential due to the material often being saturated, cohesionless, and loosely placed. Within the study, 29 percent of borings in artificial fill contained at least one liquefiable sample. Complete liquefaction of the entire fill region is not likely, but large contiguous zones of liquefiable material can be expected. Because many newer structures in Boston have either removed historic fill prior to construction or utilized deep foundations seated in material below the fill, the hazard to large, modern structures is likely minimal, but small, older structures, and surface/near-surface roadway and utilities are likely at risk.

Marsh deposits and Holocene beach deposits also exhibited high liquefaction susceptibility. Glaciofluvial deposits may have some liquefiable material and thus were classes as a moderate hazard; however, the liquefiable samples within this unit were isolated and thus are unlikely to produce continuous zones of liquefiable materials. Drumlin deposits and ground moraines, which are dense to very dense, were mapped as low liquefaction hazard.

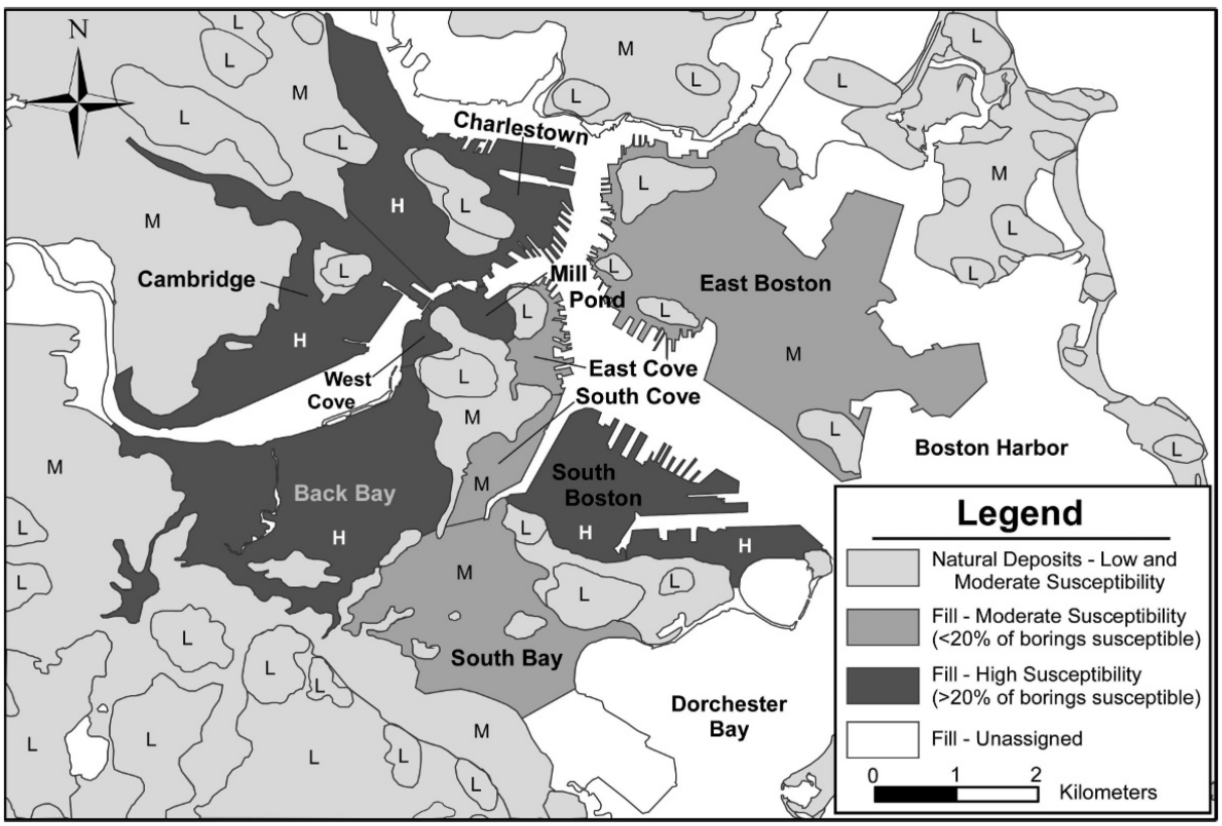


Figure 19. Detail map showing liquefaction susceptibility of geological and artificial fill units in Boston (Brankman and Baise, 2008).

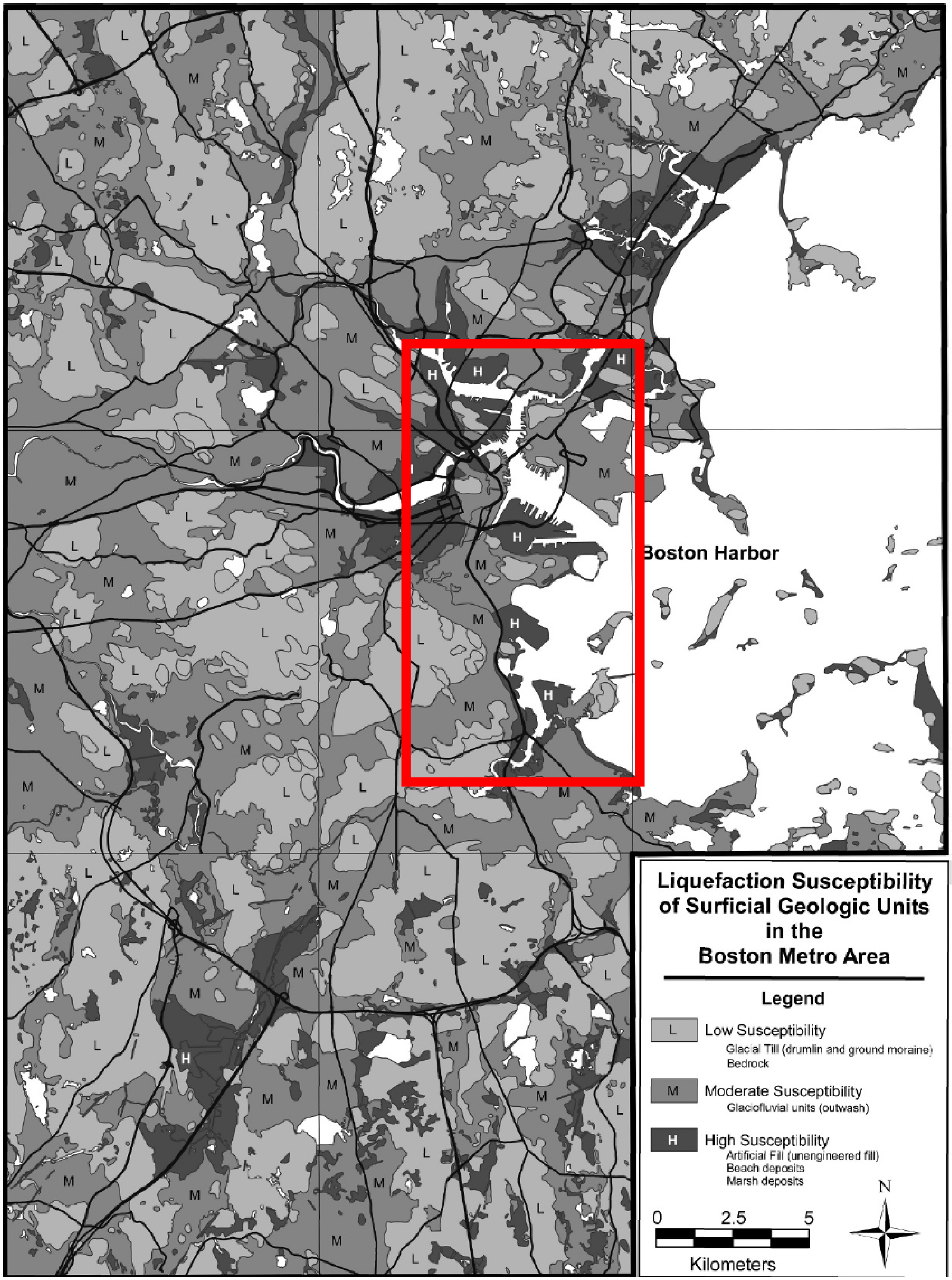


Figure 20. Liquefaction susceptibility of Quaternary geologic units and artificial fill in the greater Boston area (Brankman and Baise 2008). Approximate extents of Boston CSRM study area are outlined in red.

6.2 Historical Seismicity

The USGS Earthquake Catalog was searched for events with magnitude (M) greater than or equal to M4.5. Table 7 summarizes these events with respect to magnitude and epicentral distance. Table 8 provides details of some selected earthquakes of interest.

Table 7. Historical seismicity since 1 Jan 1600 (USGS).

Magnitude Interval	Search Radius from Site	Number of Events
4.5 ≤ M < 5	10 mi (16 km)	0
5 ≤ M < 6	50 mi (80 km)	3
6 ≤ M < 7	75 mi (121 km)	0
7 ≤ M < 8	125 mi (201 km)	0
M ≥ 8	200 mi (322 km)	0

NOTE: https://earthquake.usgs.gov/earthquakes/search/ accessed on 4 May 2026 and 1 July 2026.

Table 8. Selected historical earthquakes with M4.5+ since 1 Jan 1600 (USGS).

Date	Name	M	Latitude (deg)	Longitude (deg)	Depth (km)	Distance (km)
11 Jun 1638	Central New Hampshire	6.5	43.4	-71.6	N/A	124
05 Feb 1663	Near La Malbaie, Quebec, Canada	7.0	47.6	-70.1	N/A	588
10 Nov 1727	Near Newburyport, Massachusetts	5.6	42.842	-70.979	N/A	54
16 Sep 1732	Near Montreal, Quebec, Canada	6.3	45.5	-73.6	N/A	405
14 Jun 1744	Near Salem, Massachusetts	4.7	42.6	-70.9	N/A	30
18 Nov 1755	1755 Cape Ann, Massachusetts Earthquake	5.9	42.7	-70.3	N/A	72
12 Mar 1761	East of Rockport, Massachusetts	4.6	42.7	-70.3	N/A	73
23 Dec 1857	Near Lewiston, Maine	4.5	44.1	-70.2	N/A	205
10 Aug 1884	New York City area, New York	5.25	40.51	-73.83	N/A	310
15 Jul 1905	Near Sabattus, Maine	4.5	44.2	-70	N/A	221

Date	Name	M	Latitude (deg)	Longitude (deg)	Depth (km)	Distance (km)
20 Apr 1931	2 km SSW of Warrensburg, New York	4.7	43.471	-73.785	5	254
20 Dec 1940	8 km W of Tamworth, New Hampshire	5.2 6	43.872	-71.37	10	170
19 Jan 1982	1 km NW of Sanbornton, New Hampshire	4.5	43.5	-71.6	8	134
07 Oct 1983	8 km WSW of Newcomb, New York	5.1	43.938	-74.258	12.5	314
20 Apr 2002	8 km NNW of Au Sable Forks, New York	5.3	44.51233	-73.69733	4.83	320
16 Oct 2012	5 km W of Hollis Center, Maine	4.6 7	43.59733	-70.656	16.09	141
05 Apr 2024	2024 Tewksbury, New Jersey Earthquake	4.8	40.6963	-74.7596	2.624	360

NOTE: https://earthquake.usgs.gov/earthquakes/search/ accessed on 4 May 2026 and 1 July 2026.

6.3 Site Classification and Seismic Hazard Curve

6.3.1 Site Classification

Based on the anticipated stratigraphic sequence and the nature of both surficial and subsurface materials along the proposed alignments, most of the coastal Boston area within the CSRM study area is projected to be classified as American Society of Civil Engineers (ASCE/SEI 7) Site Class E. However, localized geological variations present the potential for some competent strata to be classified as ASCE Site Class D.

Surficial deposits in the vicinity of the Boston CSRM study area are predominantly composed of artificial fill (Figure 6). This historic fill often consists of heterogeneous, poorly sorted, and uncompacted materials (ash, rubble, dredge spoils, and sand) placed directly over tidal mudflats and salt marshes. Due to its loose nature and generally low shear-wave velocities, this material exhibits poor geotechnical competence under seismic loading, which generally warrants a baseline classification of Site Class E. While unengineered fill deposits may be classified as Site Class F, this classification necessitates site-specific testing that falls outside the scope of this appendix. Consequently, Site Class E is utilized as a representative baseline to conduct seismic hazard evaluations, including seismic hazard curves and disaggregations, across the study area.

Given the potential for encountering Site Class F soils in the study area, we recommend that a site-specific geotechnical investigation be conducted during the design phase to definitively establish the seismic site classification at each alignment where unengineered fill is likely to be encountered. In accordance with ASCE/SEI 7-22, this investigation should include the field determination of shear wave velocity (Vs30) utilizing appropriate geophysical methods (e.g., Multichannel Analysis of Surface Waves [MASW], crosshole/downhole geophysics, or Vp-Vs suspension logging). Data from these investigations will allow for the appropriate assignment of Risk Categories (ASCE 7-22, Table 1.5-1) and Seismic Design Categories (ASCE 7-22, Table 11.6-1) to proposed structures. All subsequent seismic hazard modeling, site classification procedures, and structural designs should be executed in accordance with ASCE/SEI 7-22 (ASCE, 2022) and USACE Engineering Regulation 1110-2-1806 (USACE, 2024).

Beneath the surficial material, the local geology is influenced by the presence of Boston Blue Clay. The thickness of this clay stratum is highly variable across the study area, ranging from a few feet to nearly 250 feet (76 m) in deeper bedrock valleys. Under the ASCE/SEI 7 standards, any soil profile containing a discrete layer of soft clay thicker than 10 feet (3.05 meters) must be automatically designated as Site Class E. This classification applies regardless of the stiffness, density, or shear-wave velocity of the overlying artificial fill or granular materials. Because the Boston Blue Clay frequently exhibits the requisite parameters for "soft clay" under ASCE 7, much of the Boston area could likely be classified as Site Class E.

While less common along the immediate coastline, competent surficial deposits of coarse sand, sand and gravel, and mixed gravels may be encountered during the construction of specific proposed alignments. Notably, these granular, ice-contact, or glacial outwash deposits are present in Dorchester (in the vicinity of Pope John Paul II Park and Commercial Point) and in East Boston (near the Orient Heights Railroad) (orange deposits in Figure 6).

Where these deposits are naturally consolidated, medium-dense to dense, and absent of underlying soft clay deposits or liquefaction hazards, they may potentially be classified as Site Class D. This classification indicates a stiffer soil profile that generally results in less ground motion amplification than the softer Class E profiles.

Given the high variability of the surficial and subsurface deposits along coastal Boston, we assume that either Site Class D or Site Class E parameters apply to most sites of the proposed alignments. Consequently, the following seismic hazard analyses have been performed for both soil classifications.

6.3.2 Seismic Hazard Curve

A local (site-specific) probabilistic seismic hazard analysis (PSHA) has not been performed for this project. The mean seismic hazard curve for the peak horizontal ground acceleration (PGA) and Site Classes D and E were generated using the 2023 NSHM, as shown in Figure 21 and Figure 22. The PGA corresponding to selected common values of return periods were interpolated from this mean hazard curve and are shown in Table 9 and Table 10. The location chosen for Site Class E (42.362794° N, -71.048931° W) is situated in Downtown Boston, where artificial fill has been mapped, along the proposed alignment on Lewis Wharf. The location chosen for Site Class D (42.2836620° N, -71.0420585° W) is situated along the proposed alignment in Pope John Paul II Park in Dorchester.

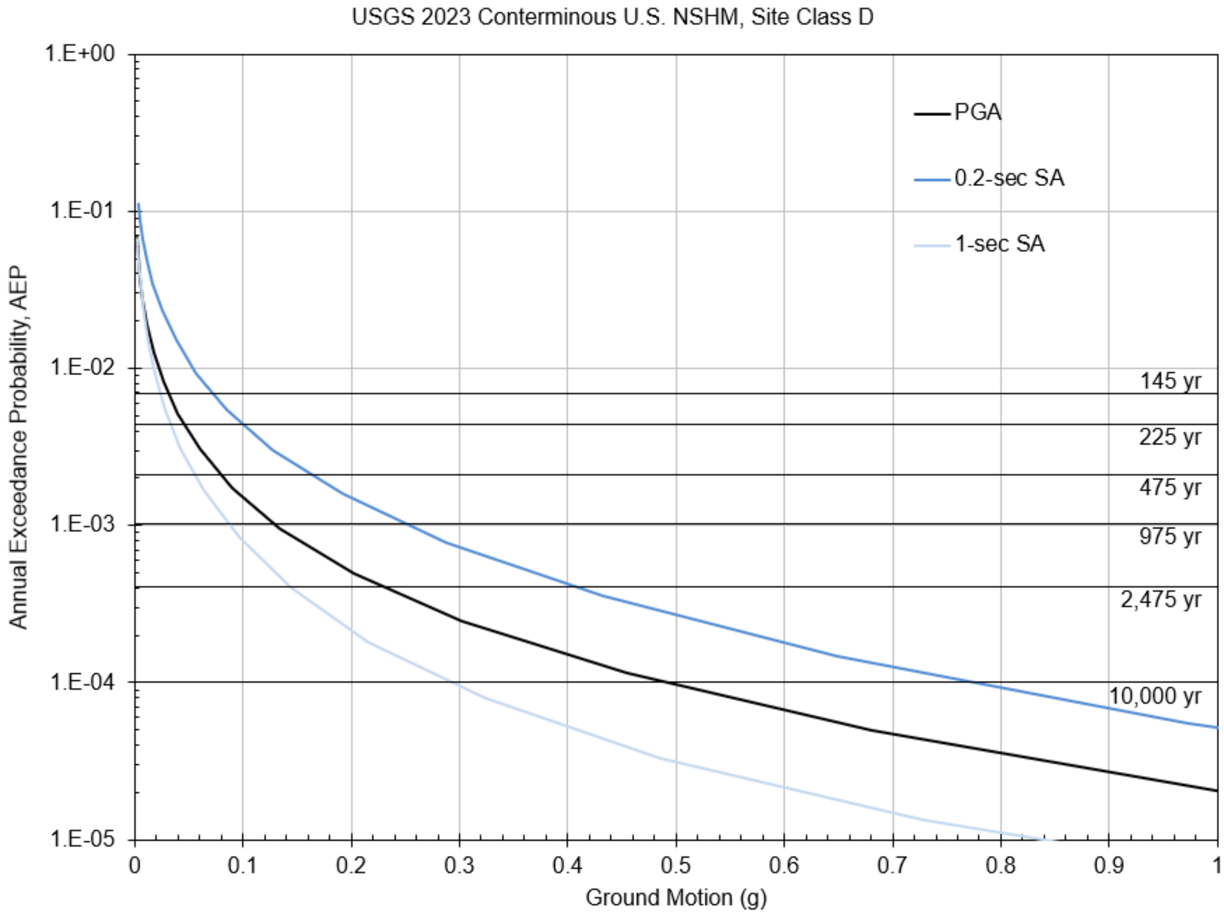


Figure 21. Seismic hazard curve for PGA and Site Class D in Dorchester (USGS 2023).

Table 9. Peak horizontal ground acceleration summary for Site Class D (USGS 2023).

Return Period (years)	PGA (g)
145	0.0311
225	0.0447
475	0.0784
975	0.128
2,475	0.228
10,000	0.488

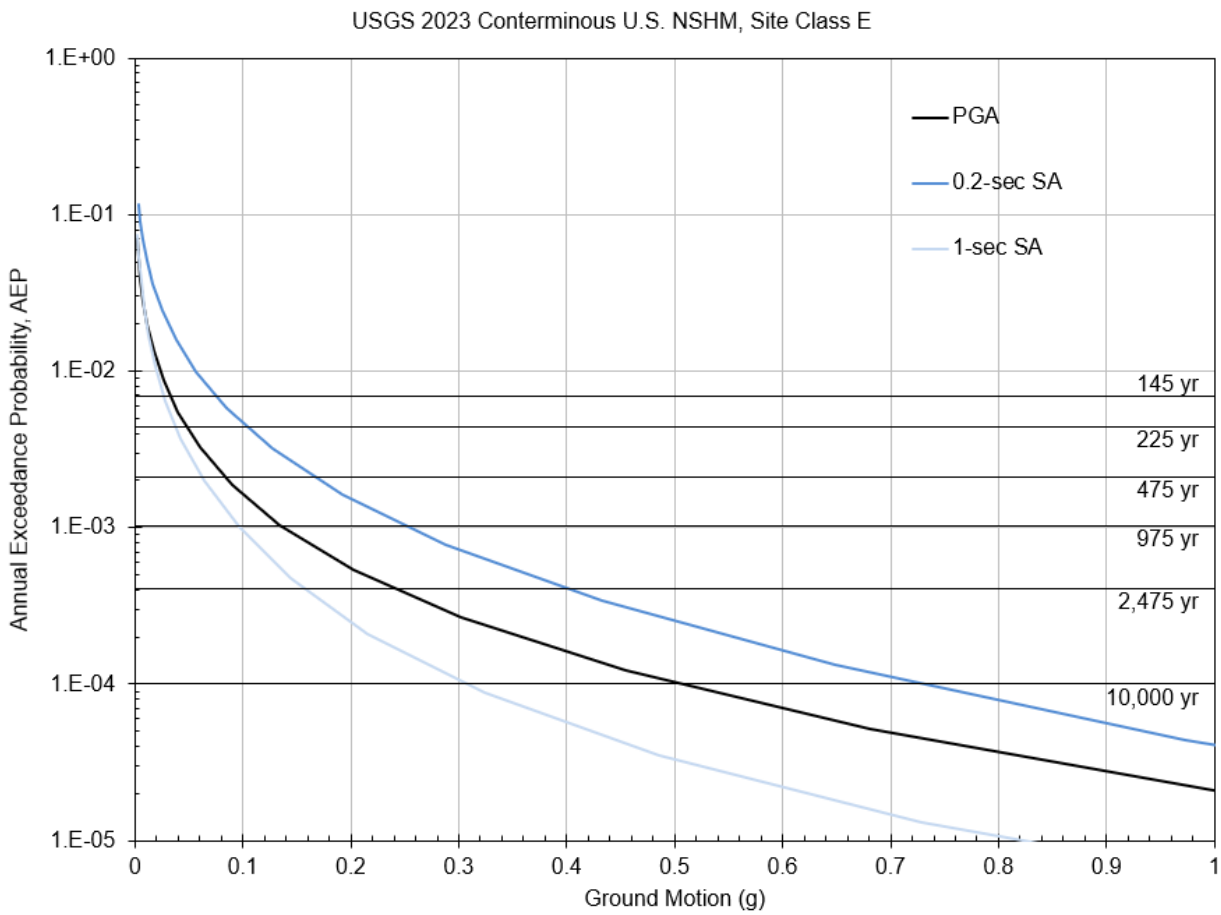


Figure 22. Seismic hazard curve for PGA and Site Class E in Downtown Boston (USGS 2023).

Table 10. Peak horizontal ground acceleration summary for Site Class E (USGS 2023).

Return Period (years)	PGA (g)
145	0.0326
225	0.0469
475	0.0825
975	0.135
2,475	0.239
10,000	0.502

6.4 Disaggregation

The disaggregated seismic hazard for the PGA for Site Class D is shown in Figure 23 and Figure 24 using the USGS Earthquake Hazard Toolbox. Since shear wave velocity data was not available for the site, Site Class D corresponding to an average vs30 of 260 m/s (853 ft/s) was used to perform the disaggregation and generate these figures.

The disaggregation suggests that the primary contributors for AEP 1/2,475 and AEP 1/10,000 seismic hazards at the site include local and regional background seismicity (Mw = 6) at distances less than approximately 150 kilometers. It is expected that the 1/10,000-year event corresponds to a mean Mw 5.84 at a distance of 23.21 kilometers.

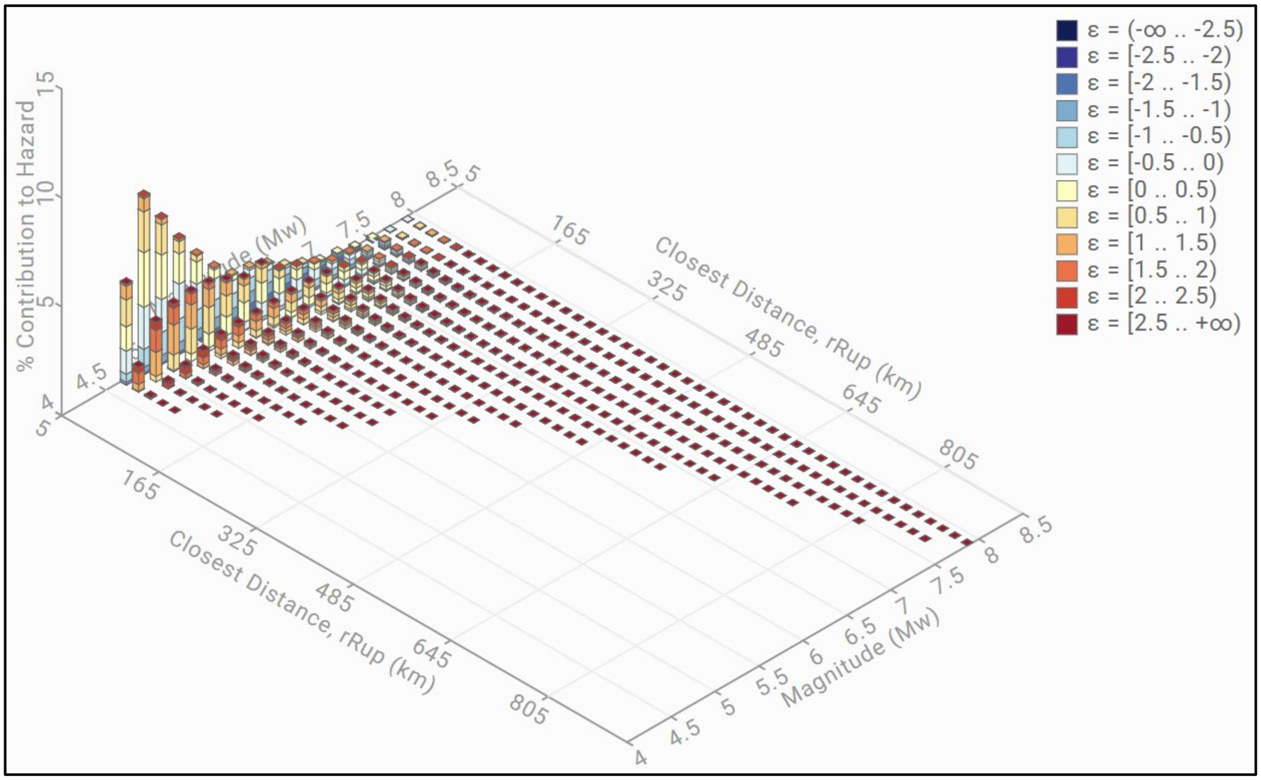


Figure 23. Probabilistic seismic hazard disaggregation for PGA and Site Class D with 1/2475 AEP (USGS 2023).

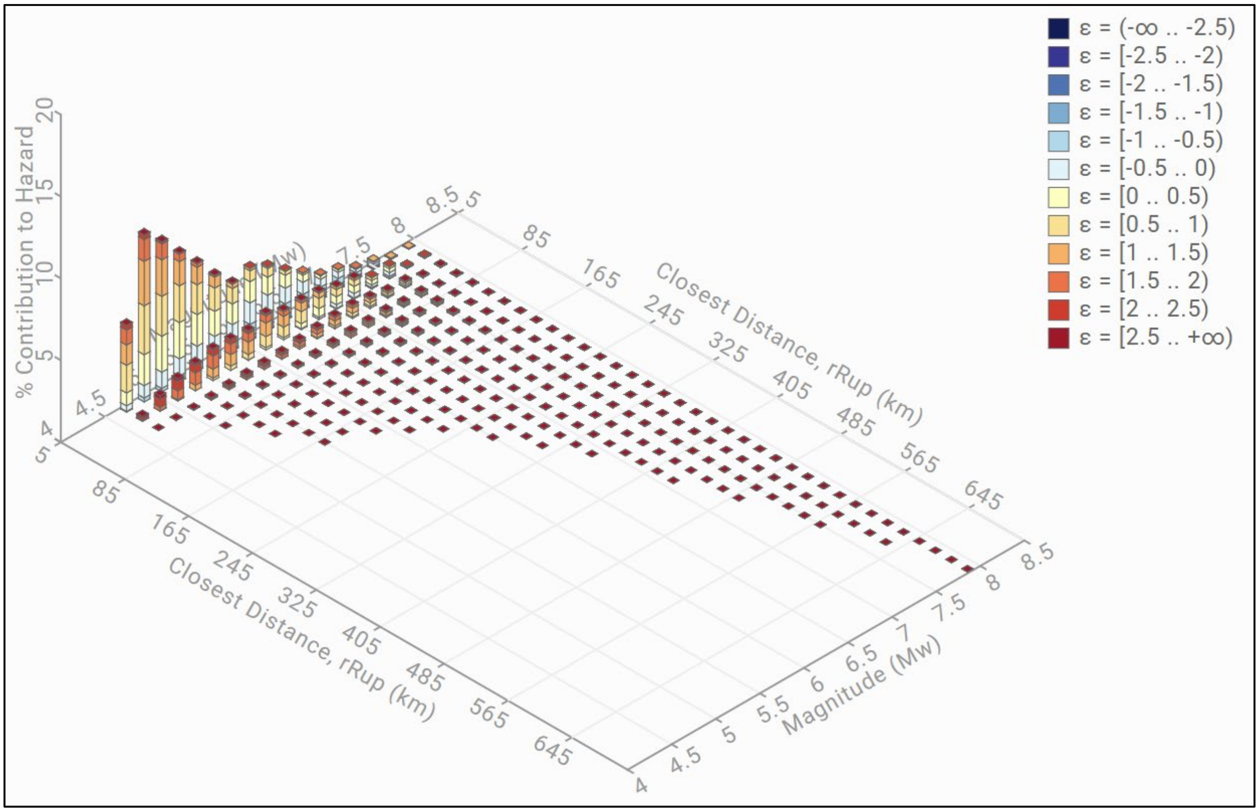


Figure 24. Probabilistic seismic hazard disaggregation for PGA and Site Class D with 1/10000 AEP (USGS 2023).

The disaggregated seismic hazard for the PGA for Site Class E is shown in Figure 25 and Figure 26 using the USGS Earthquake Hazard Toolbox. Since shear wave velocity data was not available for the site, Site Class E corresponding to an average vs30 of 150 m/s (492 ft/s) was used to perform the disaggregation and generate these figures.

The disaggregation suggests that the primary contributors for AEP 1/2,475 and AEP 1/10,000 seismic hazards at the site include local and regional background seismicity (Mw = 6) at distances less than approximately 150 kilometers. It is expected that the 1/10,000-year event corresponds to a mean Mw 5.7 at a distance of 27.82 kilometers.

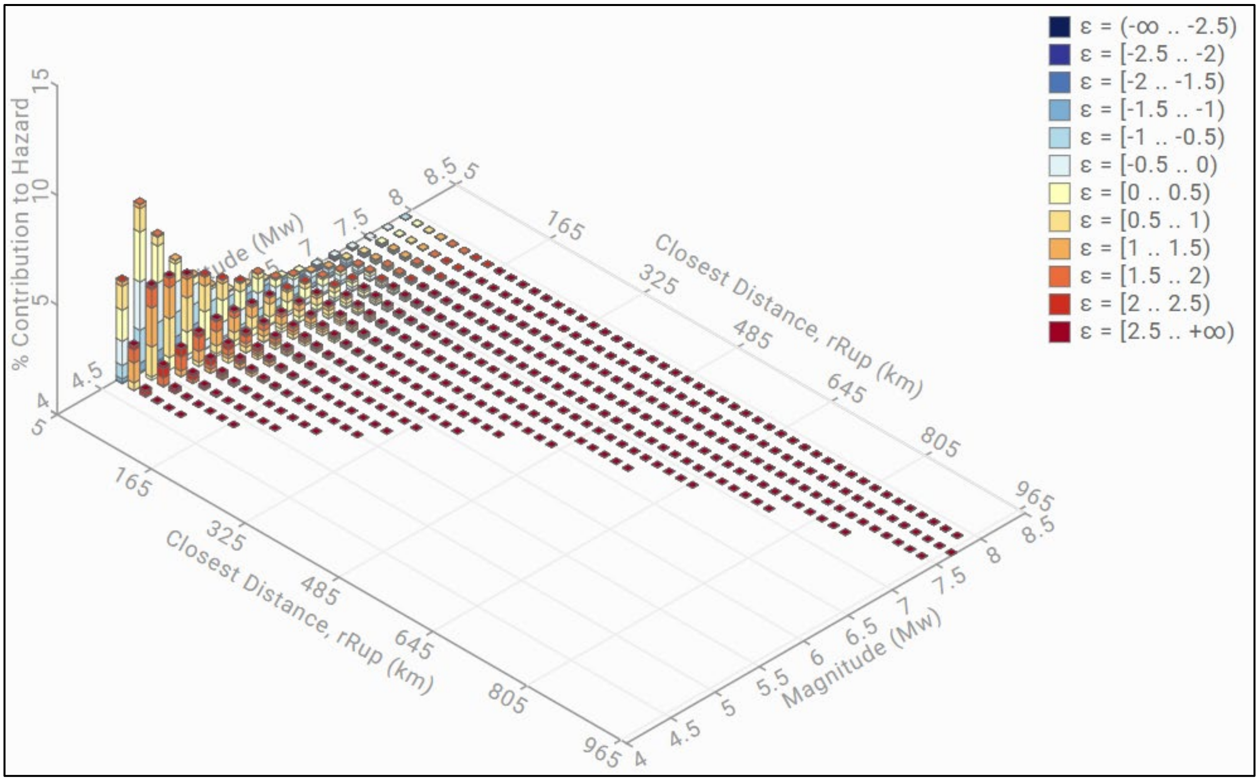


Figure 25. Probabilistic seismic hazard disaggregation for PGA and Site Class E with 1/2475 AEP (USGS 2023).

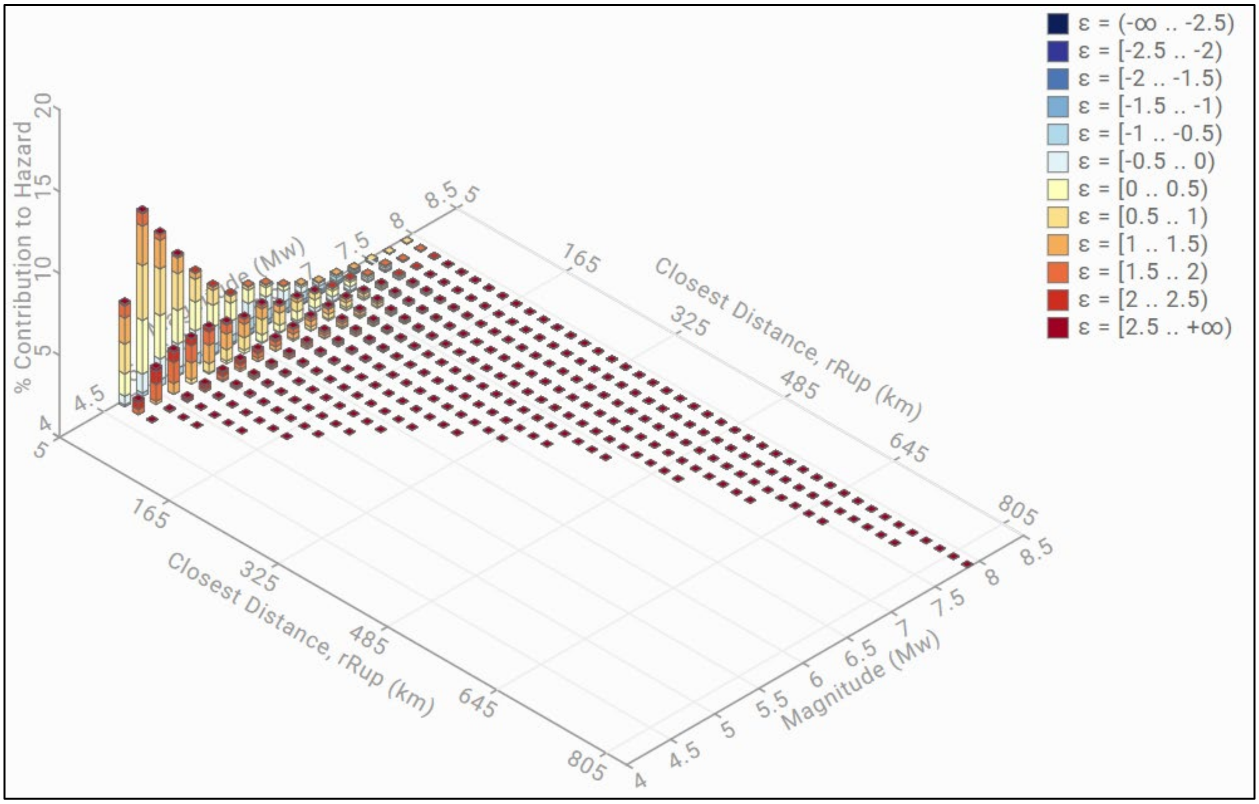


Figure 26. Probabilistic seismic hazard disaggregation for PGA and Site Class E with 1/10000 AEP (USGS 2023).

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Attachment A: Historical Fill Maps

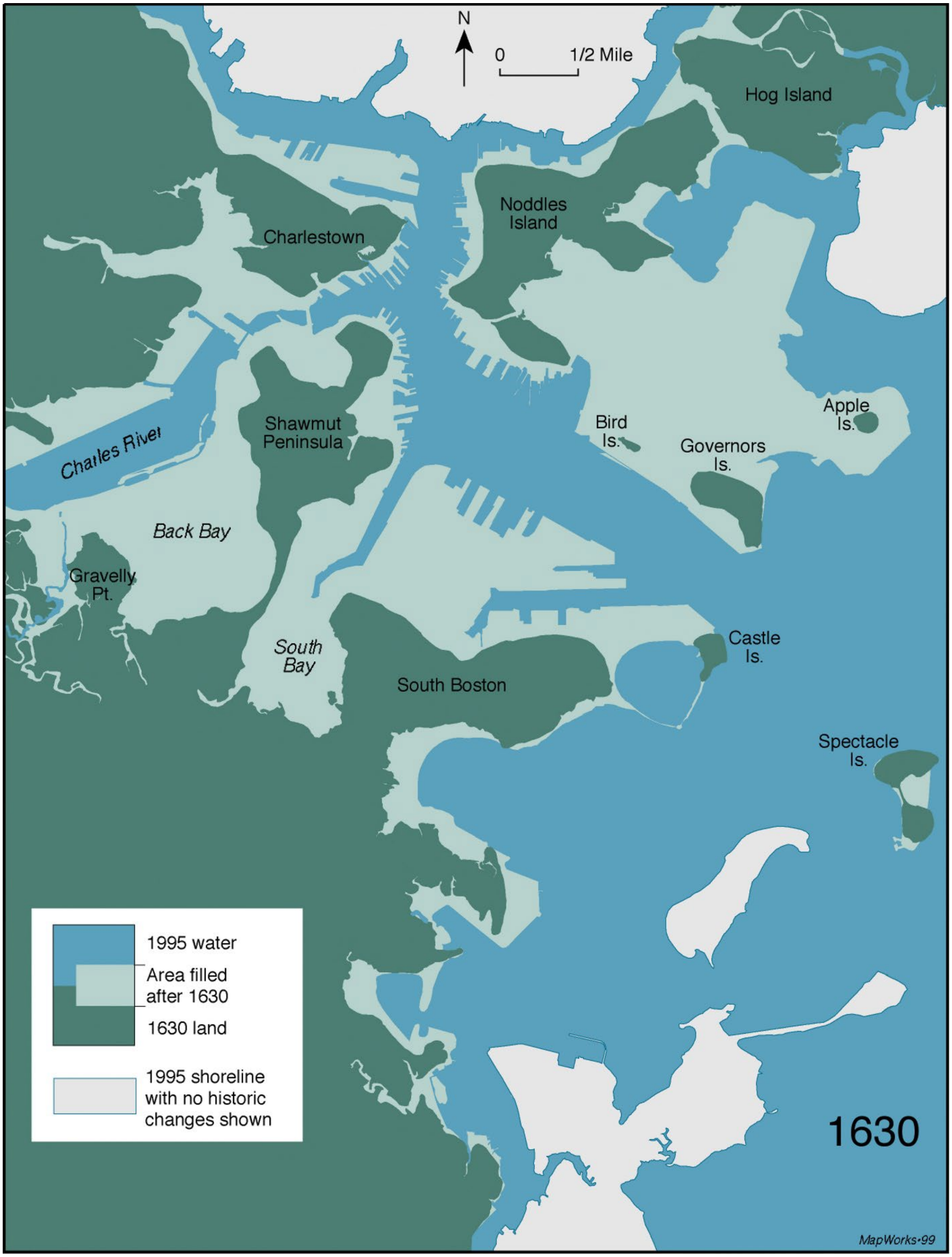

Figure 27. Map showing the changes in the Boston shoreline between 1630 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999a).

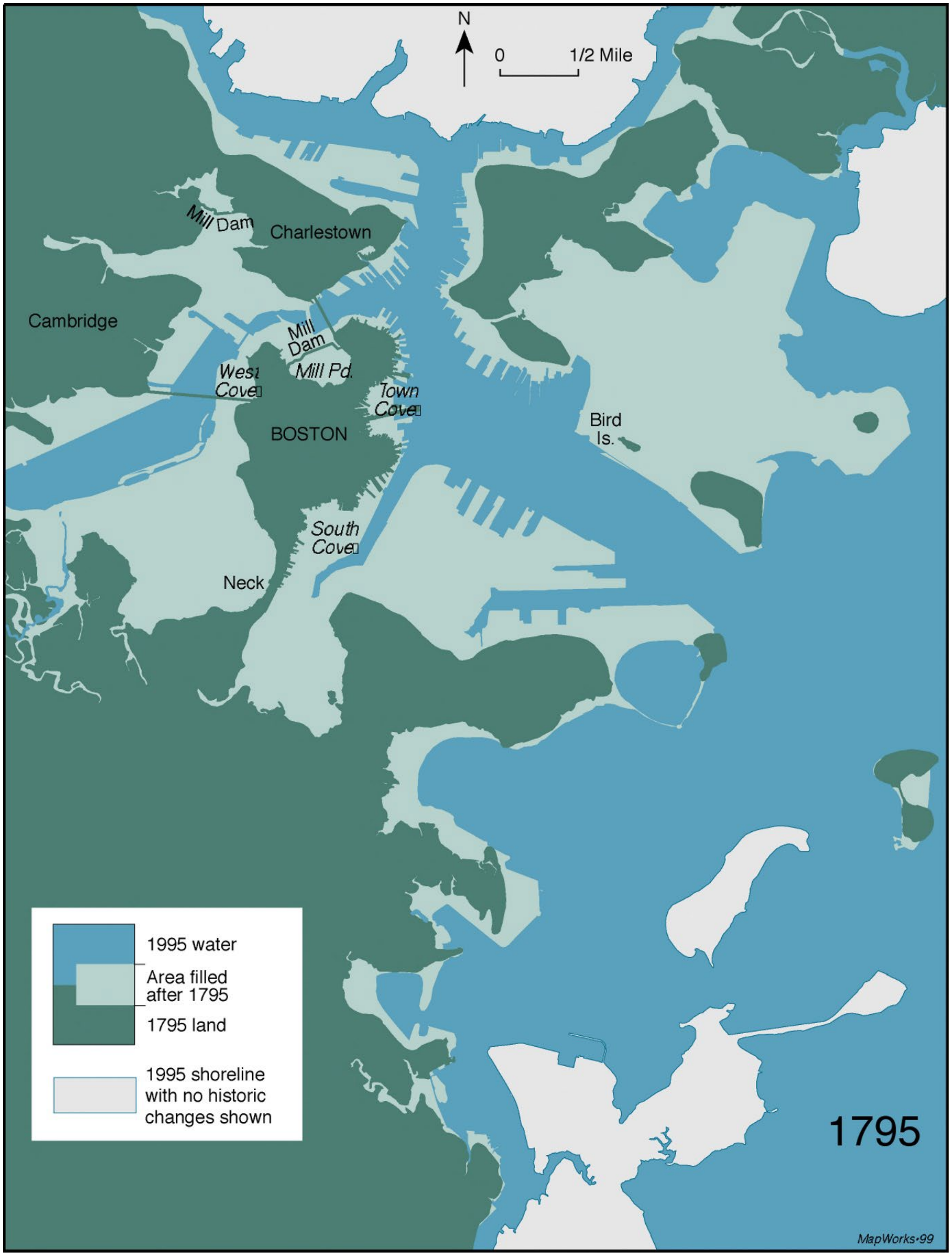

Figure 28. Map showing the changes in the Boston shoreline between 1795 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999b).

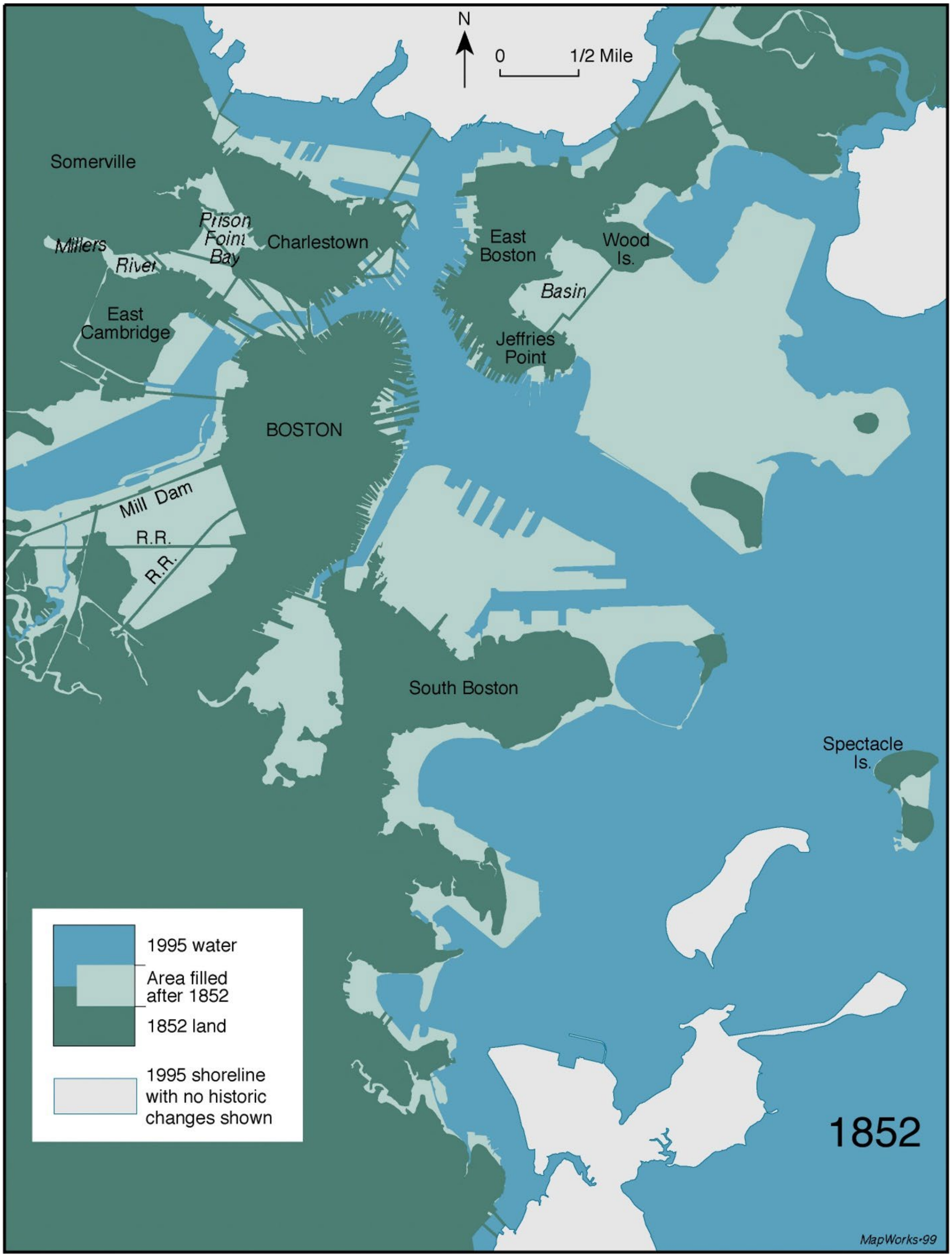

Figure 29. Map showing the changes in the Boston shoreline between 1852 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999c).

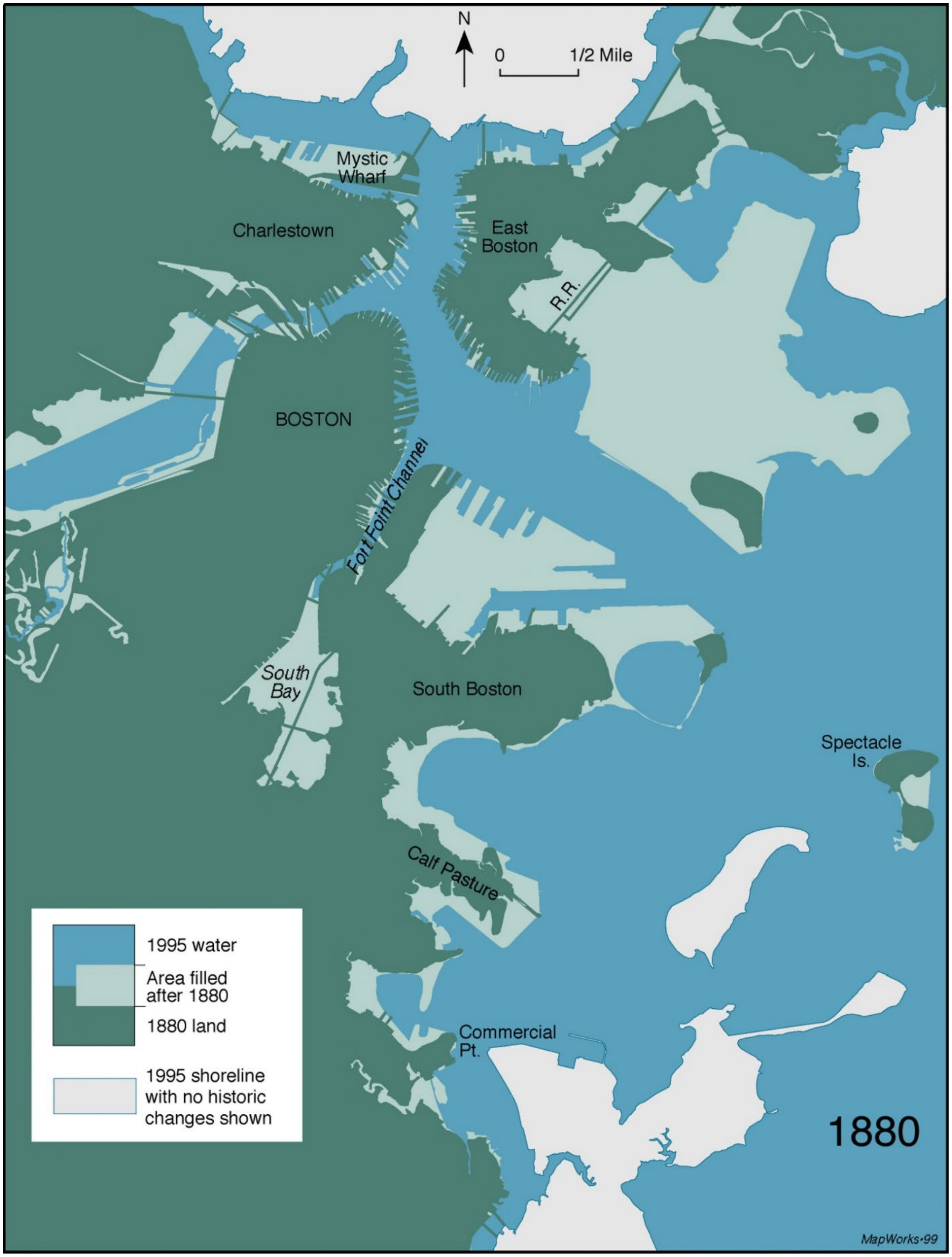

Figure 30. Map showing the changes in the Boston shoreline between 1880 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999d).

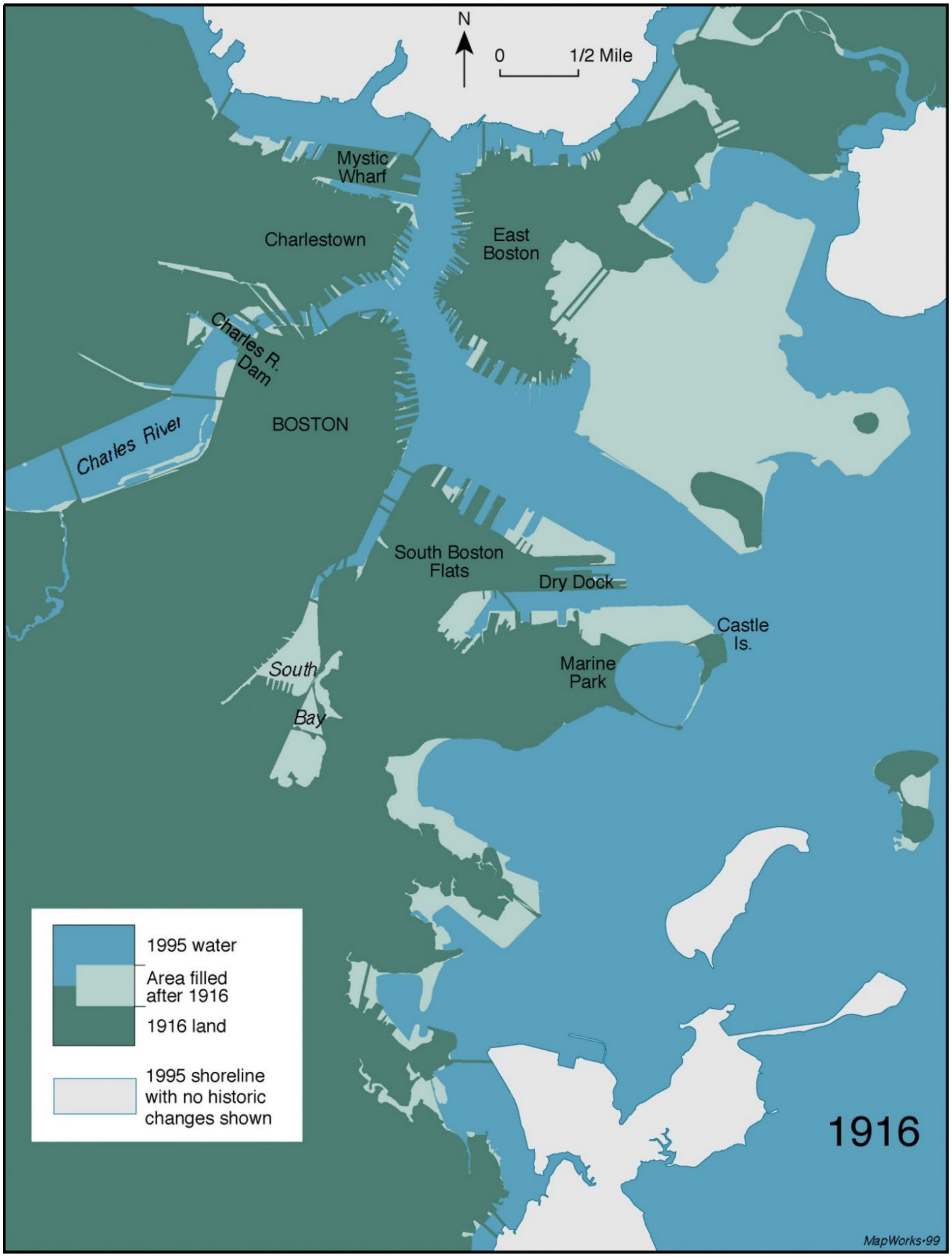

Figure 31. Map showing the changes in the Boston shoreline between 1916 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999e).

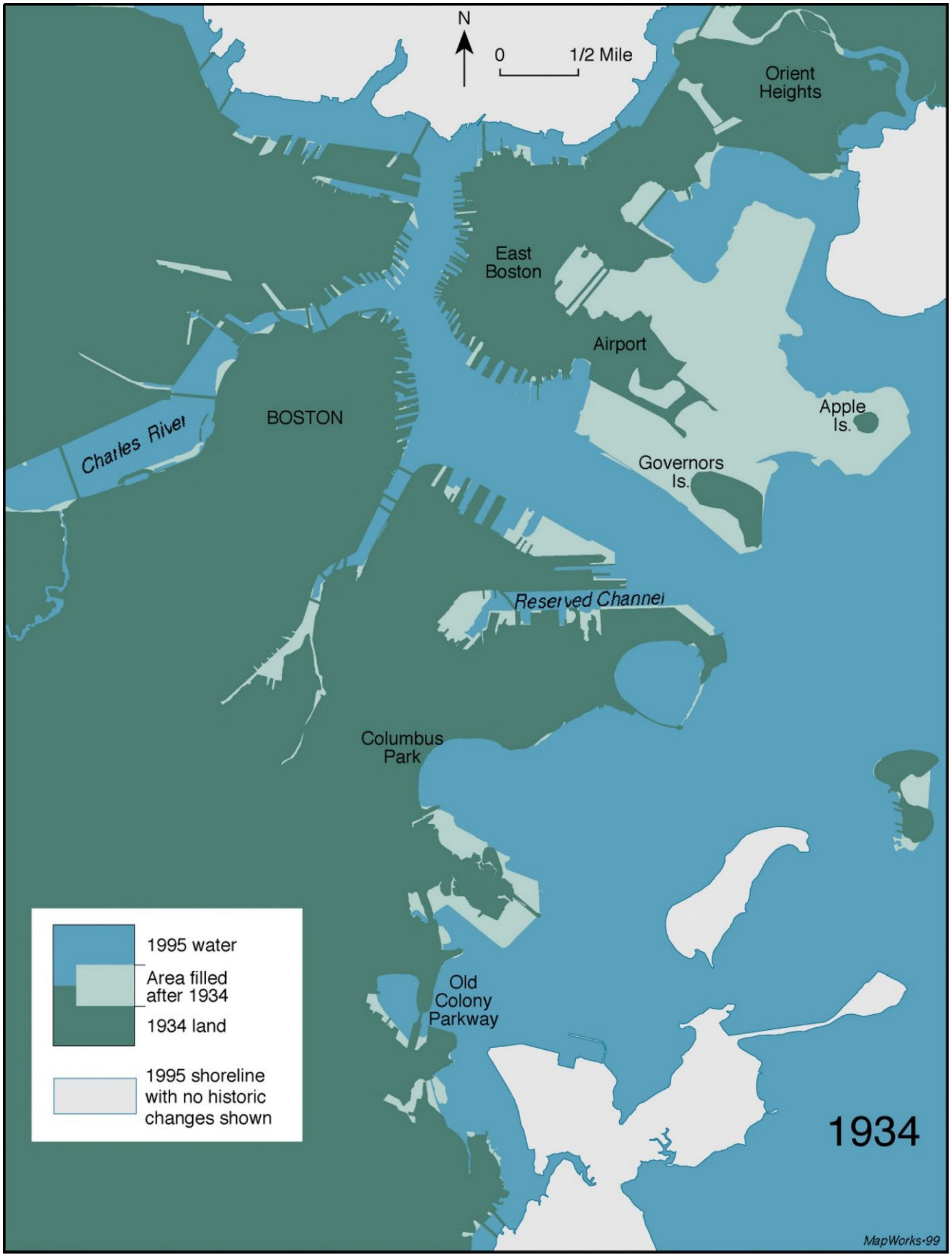

Figure 32. Map showing the changes in the Boston shoreline between 1934 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999f).

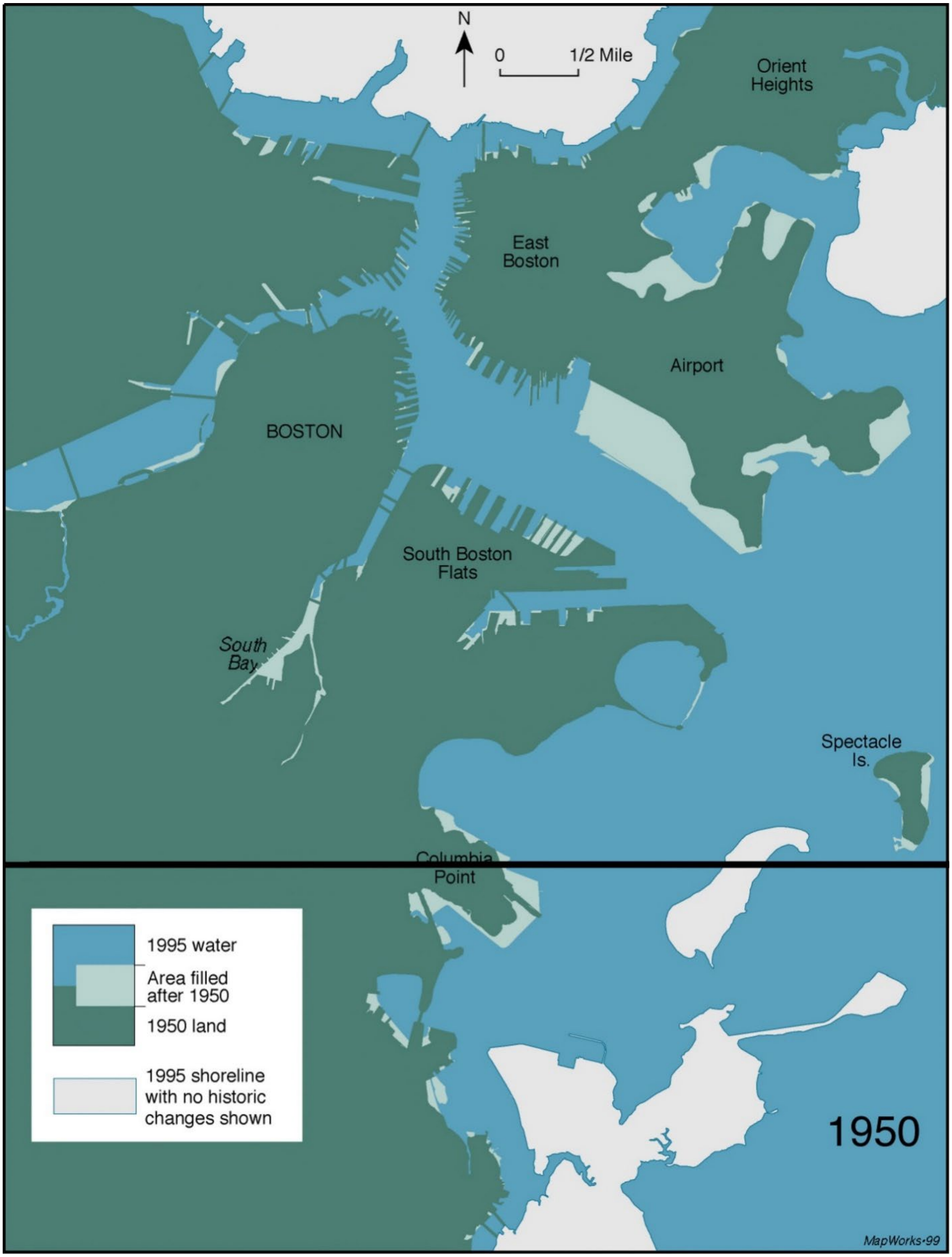

Figure 33. Map showing the changes in the Boston shoreline between 1950 (dark green) and 1995 (light green) due to historical filling (Map Works, Inc., 1999g).

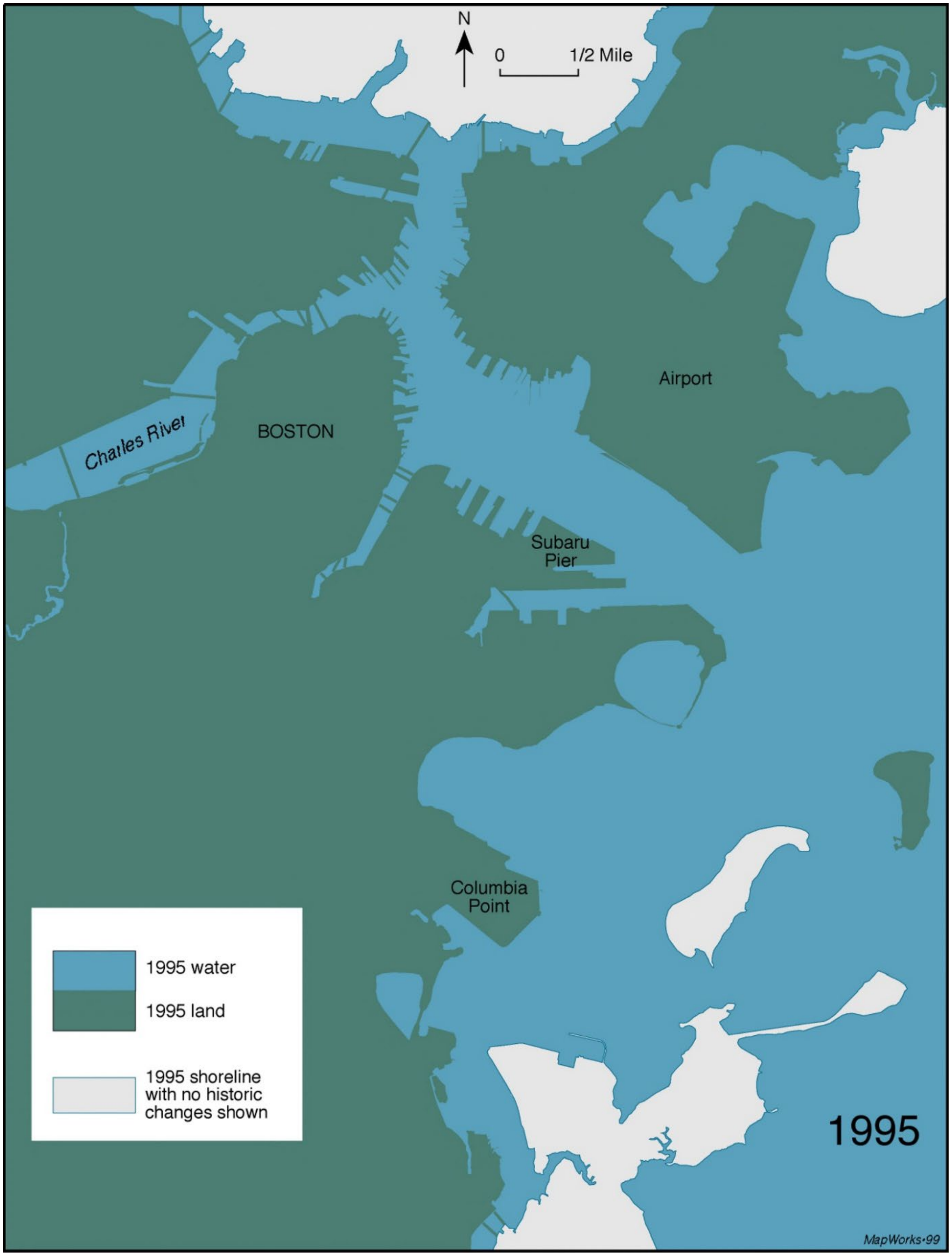

Figure 34. Map showing the Boston shoreline as of 1995 due to historical filling (Map Works, Inc., 1999h).