FINAL REPORT

POTENTIAL IMPACTS OF
CLIMATE CHANGE
ON THE
TOWN OF MARBLEHEAD

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PREPARED FOR
THE TOWN OF MARBLEHEAD
BY

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I. EXECUTIVE SUMMARY

This study examined the potential impacts of climate change, primarily sea-level rise, on the Town of Marblehead and suggested possible management alternatives the Town might adopt to specifically address these environmental issues. The study was initiated by the Town, and funded, through the State of Massachusetts, by the Federal Emergency Management Agency (FEMA). It is one of the first such studies to assess quantitatively climate change impacts on a specific area.

The scientific analysis included the examination of tide-gauge data to determine the rate of relative sea-level rise for this area during the past several decades. Additionally, a Geographic Information System (GIS) was utilized to assess the impacts of climate change on the Town and to determine areas likely to be vulnerable to sea-level rise. Four sea-level rise scenarios were examined: 2-ft, 6-ft, 11-ft and 15-ft. While the 2-ft scenario is likely the most realistic when considering sea-level rise over the next century, the higher scenarios are useful when considering the impacts of tides and storm surge in addition to sea-level rise. For each sea-level rise scenario, the location of the inundated areas were mapped and the amount of land inundated was calculated; approximately 1.3% of Marblehead would be inundated for a 2-ft rise in sea level while almost 9% of the Town would be inundated during a 15-ft rise (such as might occur during a severe storm).

The potential impacts of global climate change and sea-level rise on the Town of Marblehead were assessed based on the GIS results. Marshes, beaches and upland will all be impacted by increases in sea level; these impacts will occur due to both long-term sea-level rise, and temporary sea level increases due to elevated tides and storm surge. Areas determined to be particularly vulnerable to flooding included the causeway and Goldthwait Reservation, Little Harbor and Wyman Cove. The marsh at Goldthwait may eventually die out, due to rise in sea level and lack of suitable substrate to which to migrate.

There will be little impact to the Town's groundwater supply, since the Town is currently served by the Massachusetts Water Resources Authority (MWRA) line. However, there is potential for salt-water intrusion into wells; therefore, if the Town considers reactivating the aquifer in Salem, an analysis should be made of possible salt-water intrusion.

Choate, Hall and Stewart examined possible procedural responses to climate change, primarily regarding existing zoning, construction and wetland regulations. Suggestions included modifications to the existing Coastal Overlay District and wetland bylaws to incorporate possible impacts of sea-level rise. The combination of scientific analysis of flooding, and policy and regulatory analysis, has identified specific responses to the threat of coastal flooding due to climate change that other towns and municipalities can utilize.

II. BACKGROUND

Concern over the issues of climate change and possible impacts of global warming have grown during the past decade. One widely discussed impact of global warming is the potential for an increase in the rate of sea-level rise. Increases in the rate of sea-level rise will have substantial impact on low-lying coastal areas, many of which are densely built and populated. Throughout the world, the results of an increase in relative sea level are already being experienced in some areas. Coastal engineering structures have been constructed to combat the rising sea. Modifications to buildings have been made to minimize adverse impacts to these structures. However, buildings and roads are still being lost during storms due to the continued encroachment of the ocean. In other areas, the problem is not as severe; the beaches are wide enough that waves do not reach the nearby infrastructure. With a continued rise in sea level, though, many of these areas also will experience the impacts of sea-level rise in the future.

When planning for the future, towns and cities commonly balance environmental ramifications against the demands for improved technology, regulatory attitudes, and growth and development pressures. In order to meet these critical needs effectively, many coastal areas must begin anticipating the potential impacts of climate change and sea-level rise. The effects of rising ocean levels on public and private properties and infrastructure must be quantified so appropriate planning and regulatory measures can be identified in advance.

The purpose of this study is to examine the impacts of climate change, largely those associated with sea-level rise, on the Town of Marblehead (Fig.1) and to suggest possible alternatives the Town might adopt that would specifically address these environmental issues. Initial investigation of the impacts of sea-level rise on Marblehead was accomplished by Giese et al. (1987) in their study "Passive retreat of Massachusetts coastal upland due to relative sea-level rise". This prior study examined impacts of sea-level rise on all coastal communities within Massachusetts; the present study concentrates on Marblehead.

The present study was initiated by the Town and funded, through the State of Massachusetts, by FEMA. The Town of Marblehead has taken the lead by initiating a study to examine the local impacts of climate change. Although the awareness of the climate change issue has increased greatly during the past decade, there are few site specific studies that examine the local impacts to an area. It is essential these potential impacts be identified and examined before appropriate planning and management strategies can be implemented.

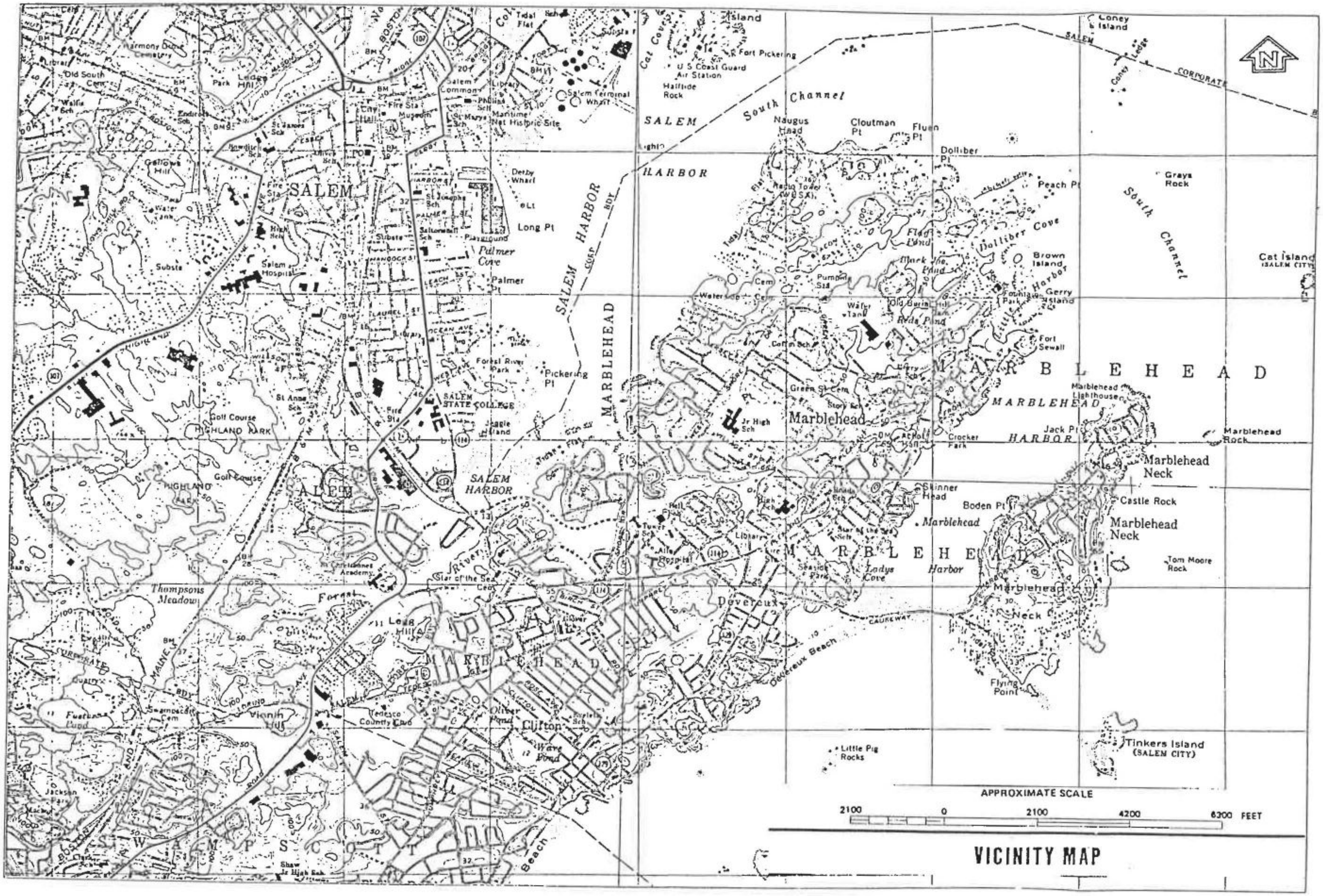


Figure 1: Location map.

III. GLOBAL CLIMATE CHANGE

A. Historical Climate Changes

Throughout the earth's history, climate change has been occurring; these changes in climate have caused fluctuations in the level of the ocean (Figs. 2a and 2b). During colder time periods, ocean water was bound as ice and thus sea level was relatively low. Warmer temperatures led to increased levels of the ocean; glaciers melted rapidly and the ocean water expanded as it heated. Both effects caused sea level to rise.

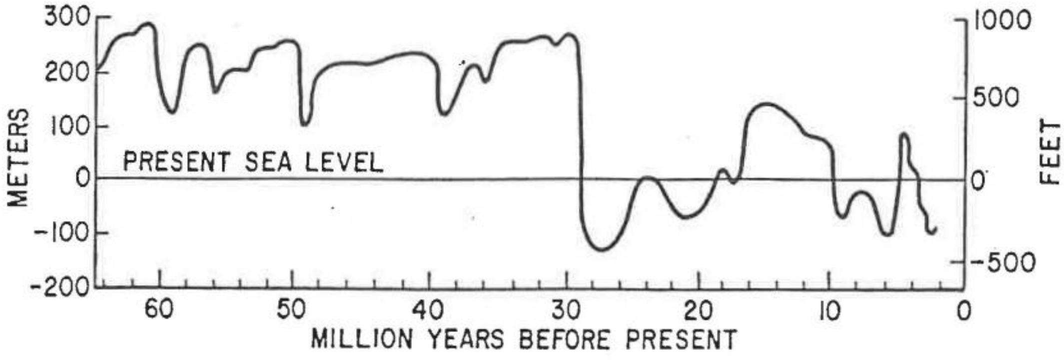
The Pleistocene Epoch, which spanned the interval approximately 1 million to 10,000 years before present, experienced several cycles of glaciation during which ice advanced and retreated. The most recent glacial stage, beginning 50,000-70,000 years ago, was the Wisconsinan Stage (Strahler, 1966). The Wisconsinan ice sheet (termed The Laurentide in North America) originated in the Labrador Sea and Hudson Bay. As the ice sheet thickened due to the accumulation of snow, the ice began to spread. In the United States, the Wisconsinan ice sheet eventually thickened to 10,000 feet and extended south to New York City, Long Island, and Nantucket, covering all of New England (Fig.3). During its advance, the glacier carved the land underneath, tearing off large pieces of rock from the terrain, sculpting mountains and grinding rocks into smaller particles.

At the time of maximum glaciation (approximately 14,000 to 18,000 years ago), the mean temperature was 5-9°F (3-5°C) cooler than today (Hansen et al., 1984) and sea level was more than 400 ft (125 m) below the present level (Fig. 2b). The shorelines throughout the world were farther seaward than today. Along parts of the east coast of the United States, the shoreline was more than 90 mi (150 km) east of its present location for the period 11,000-15,000 years before present (Fig. 4).

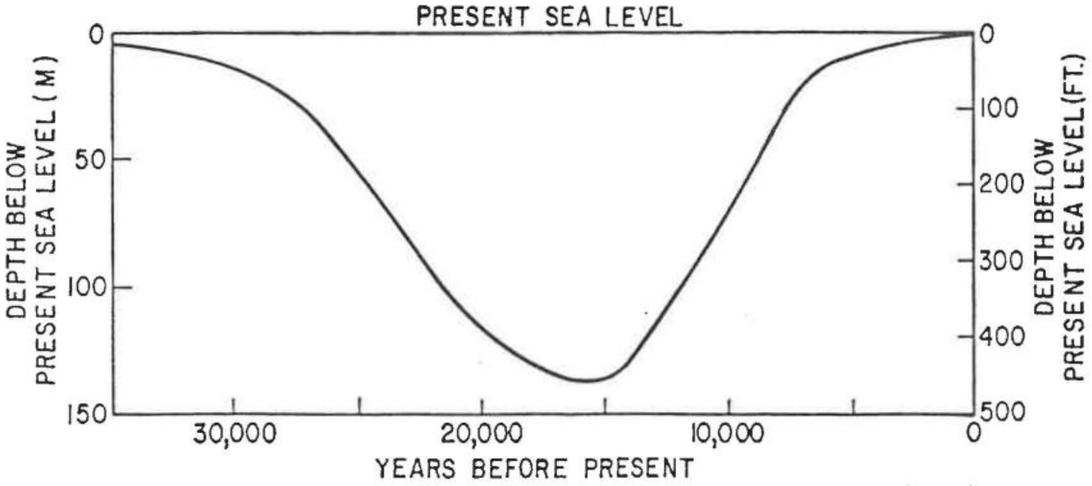
Warming of the climate began about 12,000 years ago; this warming led to renewed melting of the glaciers and a corresponding rise in sea level. From this time until approximately 5,000 years ago, sea level rose worldwide almost 5 feet (1.5 m) per century. At the peak of this interglacial period, the mean temperature was approximately 1-2°F (0.5-1°C) warmer than today (Hansen et al., 1984). The rate of worldwide sea-level rise slowed to approximately 1 ft/century (0.3 m/century) 5,000 years ago, and has continued at a lower rate to the present.

B. Global Warming

There is growing concern that global warming, accelerated by man's activities during the last century, may occur in the future. This warming will likely alter the rate of glacier melting and the temperature of the ocean, and thereby cause an increase in the rate of sea-level rise.



after Vail and Hardenbol (1979)



after Milliman and Emery (1968)

Figure 2a: Historic sea level changes.
Figure 2b. Recent sea-level changes.

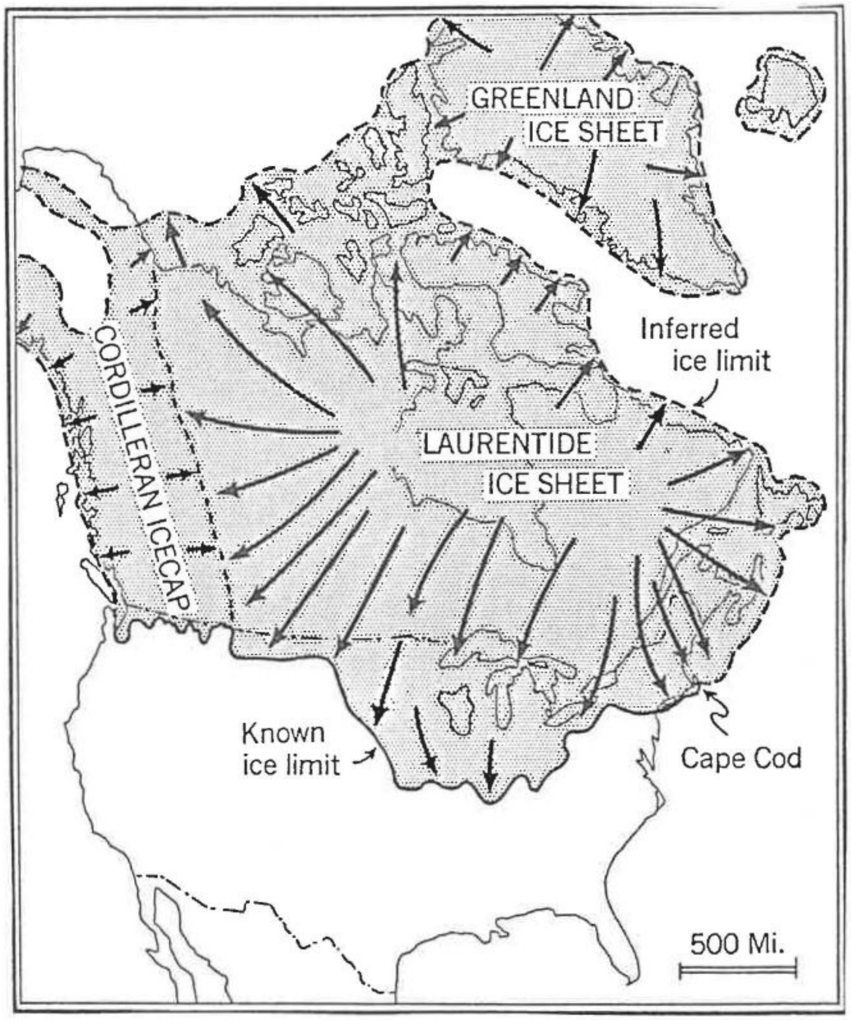


Figure 3: The southward-most extent of the ice sheet during the Pleistocene Epoch. Directions of ice flow are indicated by arrows (from Strahler, 1966).

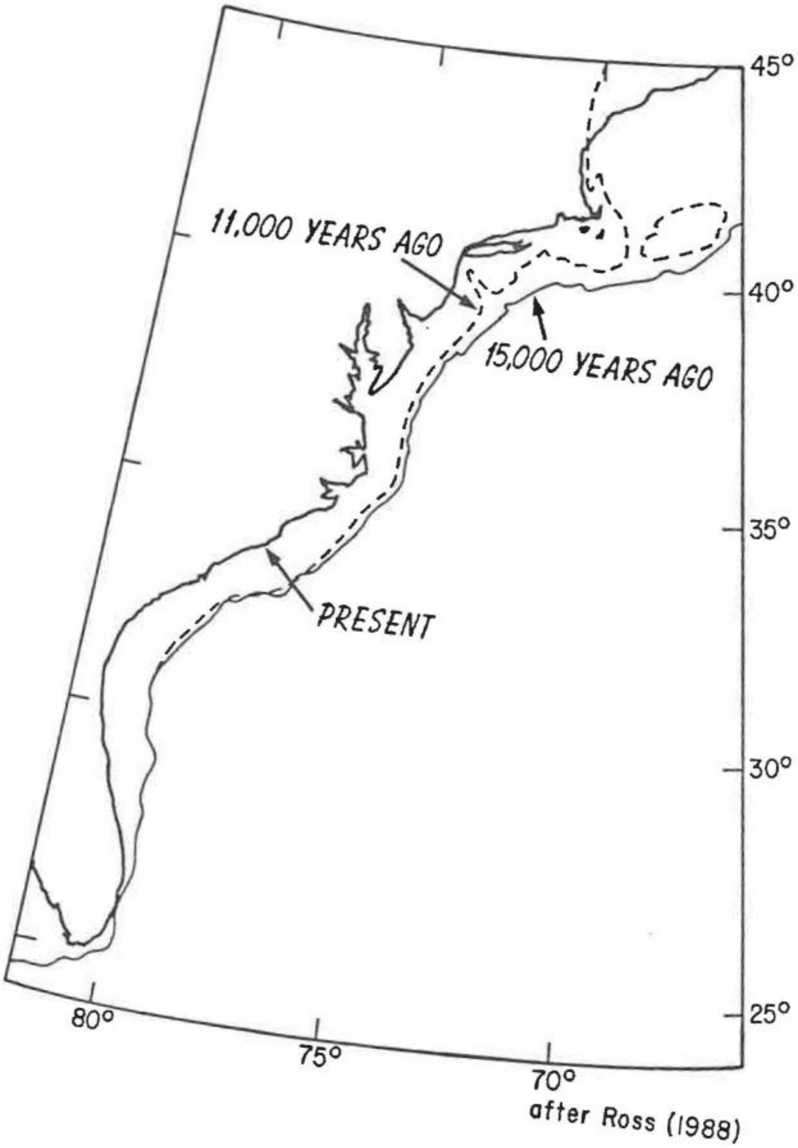


Figure 4: Approximate shoreline locations 11,000 amd 15,000 years ago.

The surface of the earth is warmed by the sun's rays. Short wave radiation, emitted by the sun, passes through the atmosphere to the earth (Fig. 5); the earth's surface radiates it back to the atmosphere as infrared radiation. Carbon dioxide, water vapor, and other trace gases in the atmosphere absorb this infrared radiation, rather than allowing it to pass unheeded into space. This trapping of radiation within the atmosphere warms the earth. The atmosphere is roughly analogous to the glass walls of a greenhouse, because they trap heat. Thus the inexact term "greenhouse effect" has arisen to describe the warming of the earth due to the addition of trace gases to the atmosphere.

During the past several decades, the concentration of carbon dioxide (CO_2) in the atmosphere has increased by almost 15 percent (Fig. 6). The primary source of this CO_2 is the combustion of coal, gas and oil (fossil fuels); 18 billion tons of CO_2 are added to the atmosphere each year due to the burning of fossil fuels. Deforestation has also increased the concentration of CO_2; plants utilize CO_2 during production of food (photosynthesis) and thus the reduction of plant biomass leads to increases in concentrations of CO_2 in the atmosphere.

Most scientists agree that a continued increase in the levels of greenhouse gases (primarily CO_2, methane, NO_x and chlorofluorocarbons) will result in an increase in the earth's temperature. The magnitude and timing of this increase are uncertain, however, because of the complexities of the climate system. Reductions in CO_2 emissions can be accomplished through energy-efficiency improvements, prescrubbing of fuels, and changes in resource uses. However, a cooperative effort between nations is necessary to reduce worldwide CO_2 levels adequately. Additionally, the effects of reductions in CO_2 emissions may not be realized for years to come due to large time lags in the climate system.

The National Academy of Sciences has estimated that the concentration of atmospheric CO_2 will likely double within the next century, and raise the atmosphere's average surface temperature by 2.7°- 8.1°F (1.5°-4.5° C) (Charney, 1979). Based partially on these estimates, scientists are attempting to model potential climate changes which result from increases in the levels of the greenhouse gases. Unfortunately these models are not sophisticated enough to account for all the parameters impacting climate change and sea-level rise.

Hansen et al. (1984) modeled temperature changes resulting from doubled CO_2 to predict spatial and seasonal temperature variations. The results indicated that the temperature increase will not be uniform around the globe; the highest latitudes will undergo the largest increase in temperature. Additionally, the models predicted the highest latitudes will exhibit the strongest seasonal variation in temperature.

Hoffman et al. (1983) described four sea-level rise scenarios: conservative, mid-range moderate, mid-range high, and high (Table 1). The conservative scenario was based on the most restrictive assumptions of scientific and economic information while the high scenario assumed the

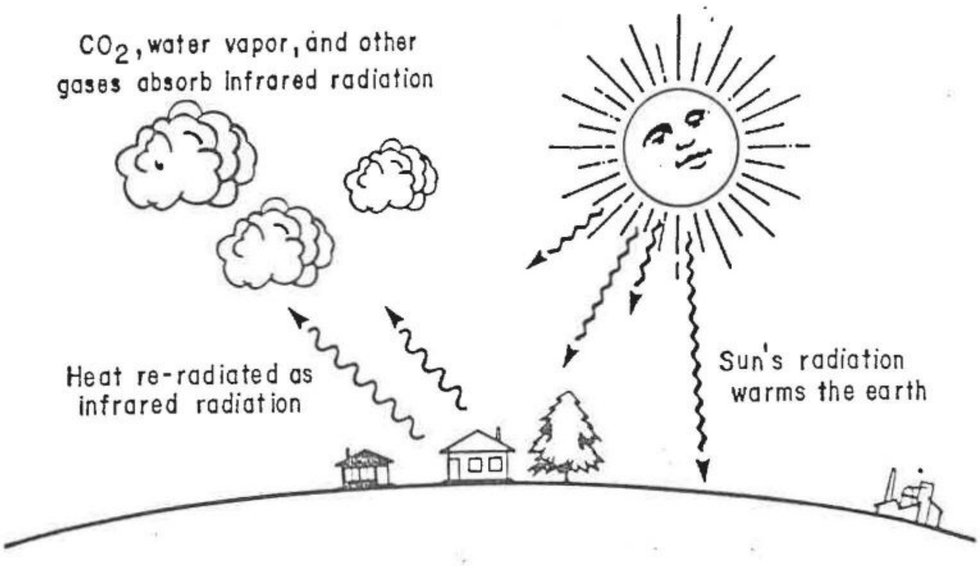
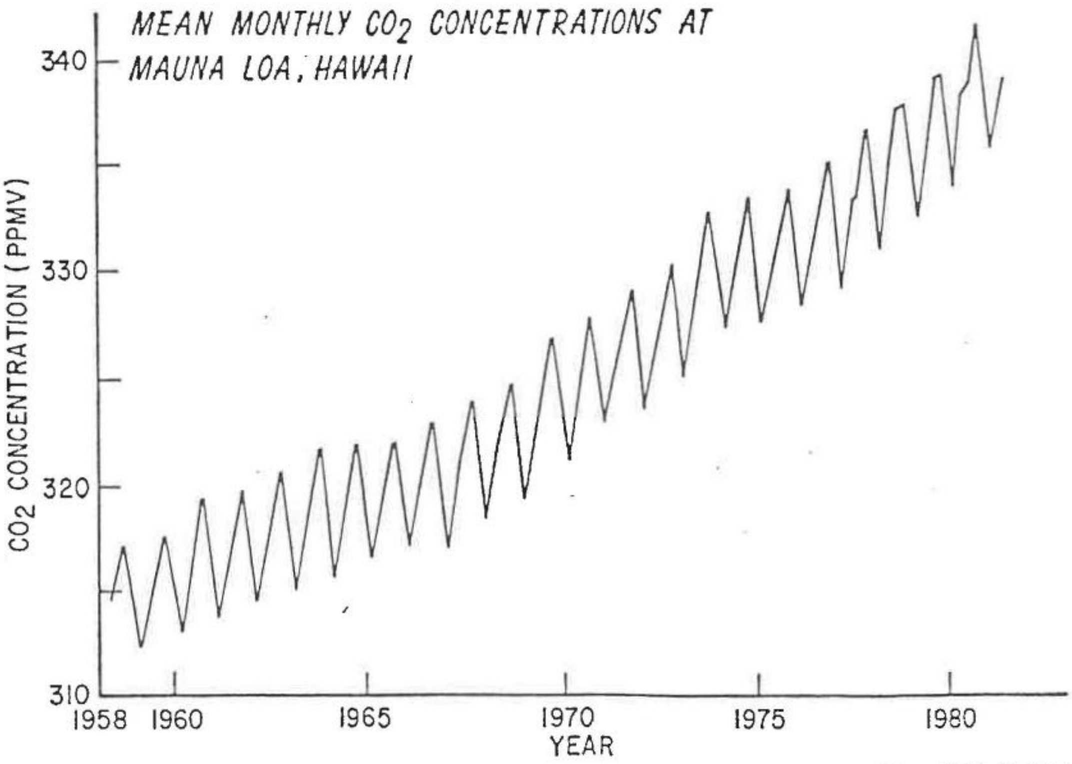


Figure 5: Warming the earth's surface.



after NRC (1983)

Figure 6: Changes in CO_2 concentrations since 1958.

least restrictive assumptions. By 2100, Hoffman et al. (1983) estimated sea level would rise between 1.8 ft (56 cm) (conservative scenario) and 11.3 ft (345 cm) (high scenario). These values are based on many assumptions regarding the future economic and environmental status of the world, and therefore are only rough approximations.

TABLE 1

WORLDWIDE SEA LEVEL RISE SCENARIOS, 1980-2100

in feet above 1980 levels
(values in parenthesis are centimeters)

Scenario	2000	2025	2050	2075	2100
Conservative	0.16 (4.8)	0.43 (13.0)	0.78 (23.8)	1.2 (38.0)	1.8 (56.2)
Mid-range low	0.29 (8.8)	0.86 (26.2)	1.7 (52.3)	3.0 (91.2)	4.7 (144.4)
Mid-range high	0.43 (13.2)	1.3 (39.3)	2.6 (78.6)	4.5 (136.8)	7.1 (216.6)
High	0.56 (17.1)	1.8 (54.9)	3.8 (116.7)	7.0 (212.7)	11.3 (345.0)

from Hoffman et al., 1983

C. Effects of Climate Change and Sea-level Rise

The major concern associated with global warming addressed here is the potential for an increase in the rate of sea-level rise. An increase in the rate of sea-level rise will have devastating effects on low-lying areas worldwide, including major cities such as Charleston and Venice as well as agricultural areas such as Bangladesh. An additional impact of climate change is the change in storm patterns resulting from increased temperatures. Given the uncertainties associated with the climate change issue, it is extremely difficult to predict the effect climate change will have on the storm climate. Some global models suggest that the sea surface temperatures in the tropical oceans may increase; this may lead to stronger tropical cyclones. However, stronger winds may cause upwelling of cooler underlying water and thus offset the possible increased intensities of hurricanes. Additionally, there may be a greater number of storms in areas that are typically on the northern edge of the present storm tracks since the ocean temperatures will likely be warmer (Golden, 1989). It is clear, however, that with continuing sea-level rise (even if the rate of sea-level rise does not increase), storm surges from hurricanes and northeasters will reach farther inland than at present.

The increase in the rate of sea-level rise due to global warming will lead to several other environmental complications, which must be considered when assessing impacts of climate change. The major impacts frequently associated with sea-level rise are flooding, loss of marshes and uplands, saltwater intrusion into groundwater, and changes in river flow and sedimentation. Each of these issues is described in general terms below. The relationship of these issues to the Town of Marblehead will be discussed further in Section VI.

1. Flooding

Rising sea level will continue to impact coastal areas. Additional land will become inundated during the daily tides as the level of the sea increases. Most major flooding will occur during storms, when water levels are elevated due to storm surge and tides. Areas previously not affected during storms will eventually become more susceptible to flooding; as sea level continues to rise, more and more of these areas will be impacted.

The increased water levels will increase the erosion of beaches, coastal banks and dunes. Damage to existing infrastructure will likely occur, especially in areas unprotected by coastal engineering structures. Buildings may have to be abandoned, rebuilt or moved landward. Some adaptations can be made to the infrastructure to minimize destruction; for example, roads can be moved away from the ocean in areas prone to flooding.

2. Loss of marshes and upland

A rise in sea level will have great impact on low-lying vegetated areas such as salt marshes. Generally, marshes require periodic inundation of sea water; they cannot exist where the land is constantly submerged. An increase in the elevation of the ocean may effectively drown these marshes (Fig. 7). If the rise is too rapid, the marsh will not be able to keep up with the rising sea and thus perish. However, new areas periodically inundated by the rising sea may develop into marsh if the conditions are suitable. If sea-level rise is slow, marsh areas simply migrate landward; the vegetation grows on the landward side of the marsh but dies on the seaward side. If no suitable low-lying upland can be inundated (because of engineering structures or local geology), sea-level rise will result in loss of marsh (Fig. 7).

Land higher than the flood plain (upland) will be impacted by sea-level rise. Unlike marshes, upland cannot respond to sea-level rise by migrating. Loss of upland is irreversible; once the upland is inundated, the land is lost (unless sea level falls). The amount of upland lost is a function of the rise in sea level and local hypsometry. The lower the land and greater the rise in sea level, the greater the upland loss.

3. Groundwater

A rise in sea level will impact the salinity of aquifers, estuaries and rivers. In some coastal aquifers, a freshwater lens overlies the more dense saltwater (Fig. 8); the saltwater/freshwater interface is a zone of brackish water. The depth to the interface generally increases with distance

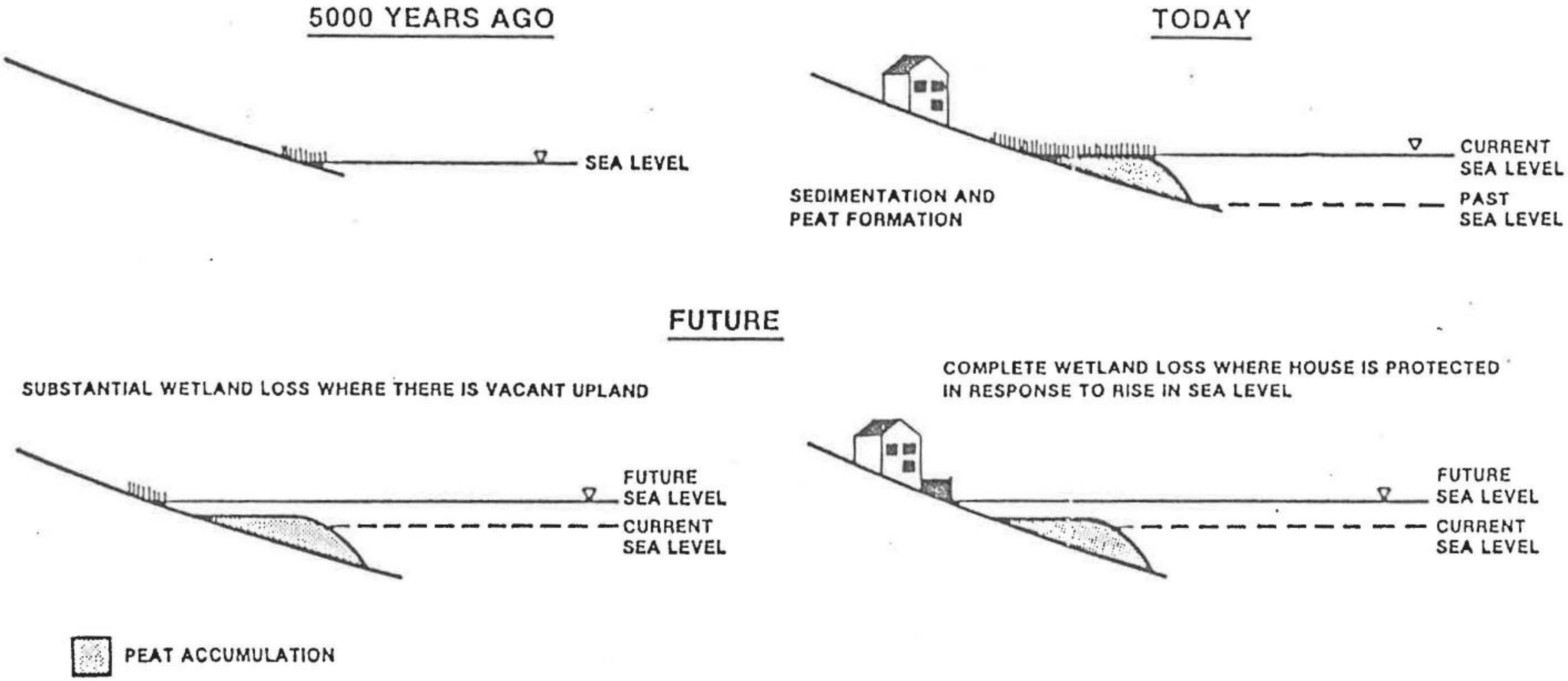
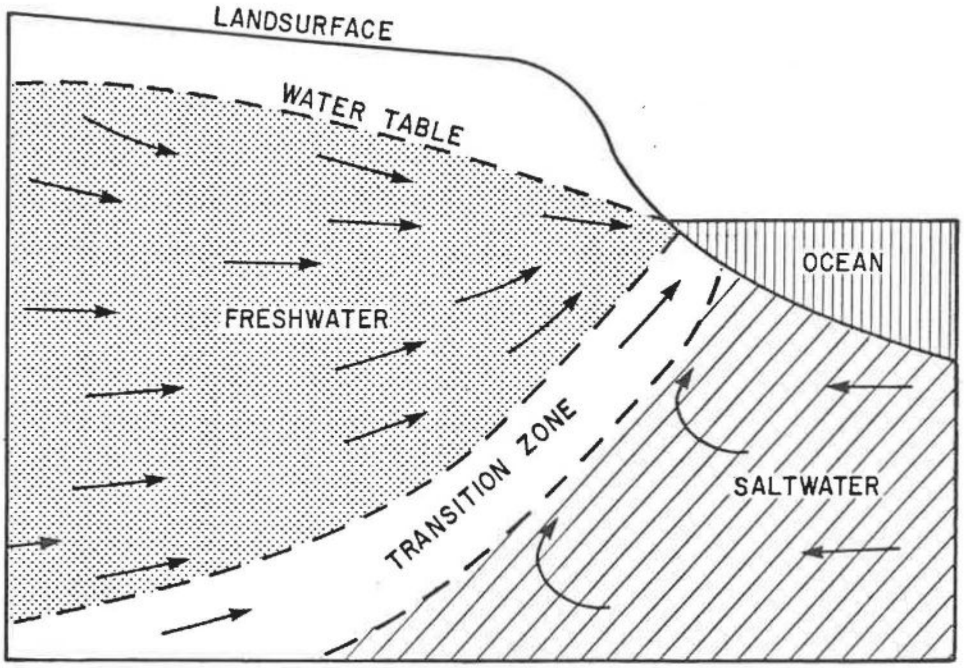
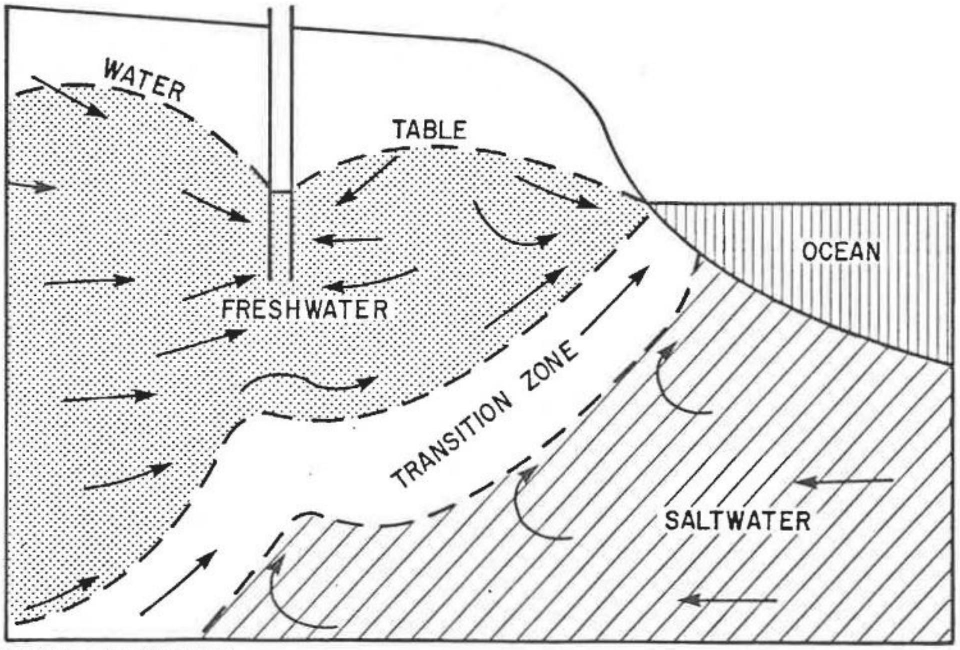


Figure 7: Potential losses of wetlands due to sea-level rise. From Titus, 1986.



NATURAL CONDITIONS



WELL PUMPING

Figure 8: Relationship between freshwater and saltwater in coastal areas, natural conditions and well pumping.

from the shoreline; the higher the water table (i.e., the thicker the layer of freshwater), the deeper the transition zone. A rise in sea level will cause a recession (landward movement) of the shoreline, and thus a recession of the transition zone and a rise in the freshwater/saltwater interface. Already many coastal communities suffer from a shortage of freshwater due primarily to overpumping of coastal aquifers. Pumping of freshwater wells (and thereby decreasing the thickness of the freshwater lens) results in a rise of the saltwater/freshwater interface (Fig. 8); in the most simplistic case (homogeneous, unconfined aquifer), if the water table is lowered 1 foot (0.3 meters) the saltwater/freshwater interface will rise approximately 40 feet (12 meters). A rise in sea level will likely exacerbate the freshwater problem by causing additional saltwater intrusion into freshwater wells.

Estuaries and rivers will also be impacted by a rise in sea level. An increase in the volume of ocean water (due to melting of glaciers) will allow salt water to migrate farther upstream into rivers and estuaries. This intrusion could reduce the freshwater supply since some coastal aquifers are recharged directly by rivers (Titus and Barth, 1984).

4. River/sedimentation changes

The warming of the earth, approximately 12,000 to 15,000 years ago, led to relatively rapid increases in the level of the ocean by melting glacial ice. The melting of the glaciers resulted in the release of large volumes of sediment, formerly bound in the ice. Many areas, including Cape Cod, Nantucket, Martha's Vineyard, and Long Island, were formed as a result of this glacial retreat and sediment deposition.

Due to the increased volume of water and sediment, rivers flowed relatively strongly and transported large amounts of sediment to the shorelines. As the melting slowed (5,000 to 8,000 years ago), the sediment supply to the existing beaches decreased. More recently, man has reduced river flow and sediment supply in some areas by the construction of dams and coastal engineering structures. In the future, river flow will change as precipitation patterns respond to climate change. Rivers may either change their total discharge, or alter their seasonal patterns. Precipitation changes may be accompanied by more droughts, and more variable stream flow. Sediment discharge may increase or decrease, depending on whether man attempts to continue to tame river flow, and on how land use practices evolve.

IV. ANALYSIS OF POTENTIAL IMPACTS

This study was designed to examine the impacts of climate change and sea-level rise on the Town of Marblehead, and to assess possible regulatory alternatives the Town may adopt to address these environmental issues. The scientific study was performed by Aubrey Consulting, Incorporated; it consisted primarily of examination of recent relative sea-level rise rates, analysis of climate change impacts by use of a GIS, and determination of areas likely to be vulnerable to sea-level rise. Choate, Hall and Stewart reviewed the major federal, state, and local regulations pertaining to coastal areas and suggested possible alternatives for policy implementation.

A. Present Trends in Relative Sea-level Rise

During the past century, changes in the level of the ocean have been monitored throughout the world. Tide gauges, installed at fixed positions, measure the level of the ocean relative to the land at a particular point. Relative sea level includes both the change in the worldwide level of the ocean and the local vertical fluctuations of the land surface. Thus, whereas the worldwide rate of sea-level rise is virtually constant everywhere on the globe (although it fluctuates through time), the rate of relative sea-level rise varies both spatially and temporally.

Aubrey and Emery (1983) examined the spatial and temporal patterns of relative sea-level rise along the United States coastline. They identified several distinct coastal compartments within which sea level behavior was consistent along the eastern coast of the United States. Sea-level rise increased north of Cape Cod, increased south from Cape Cod to Cape Hatteras, and decreased south from Cape Hatteras to Pensacola (Fig. 9).

To estimate approximate rates of relative sea-level rise for the Town of Marblehead, tide-gauge measurements at Boston, Massachusetts, and Portsmouth, New Hampshire, were examined. These tide records were chosen because they bracket Marblehead. The changes in relative sea level since the late 1920s at Boston and Portsmouth are indicated by Figures 10a and 10b, respectively.

The magnitude of the change in ocean level through time, however, can be compared between sites. The rate of relative sea-level rise for Boston, based on the tide-gauge record from 1922-1986, is 0.01 ft/yr (2.9 mm/y); this is equal to a rise of approximately 1 ft (30 cm) per century. The rate of relative sea-level rise at Portsmouth is slightly less; since 1927, the average rise in relative sea level has been approximately 0.006 ft/yr (1.9 mm/yr); this is equivalent to 0.6 ft (18 cm) rise per century.

The increases in relative sea level at Boston and Portsmouth are due primarily to the worldwide rise in sea level. Additionally, however, the land is subsiding in these areas. This subsidence reflects crustal adjustments since the last glacial period. As illustrated in Figure 11, the

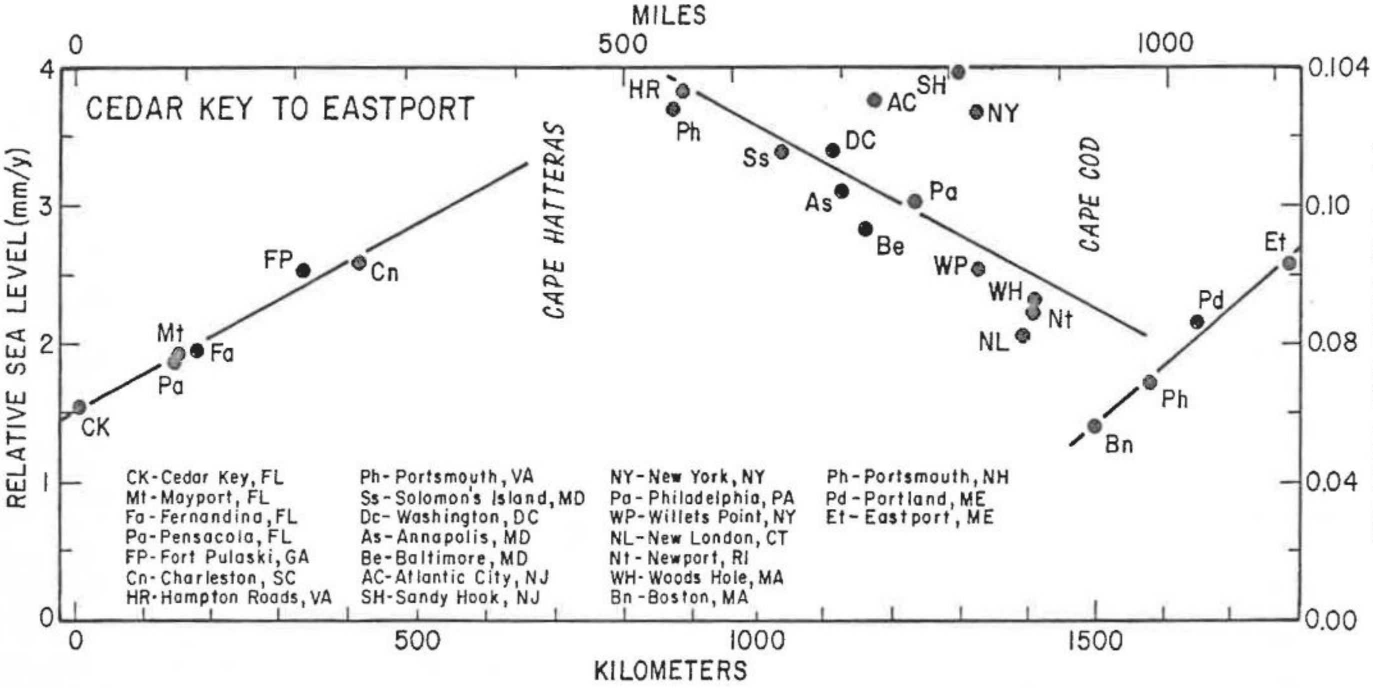
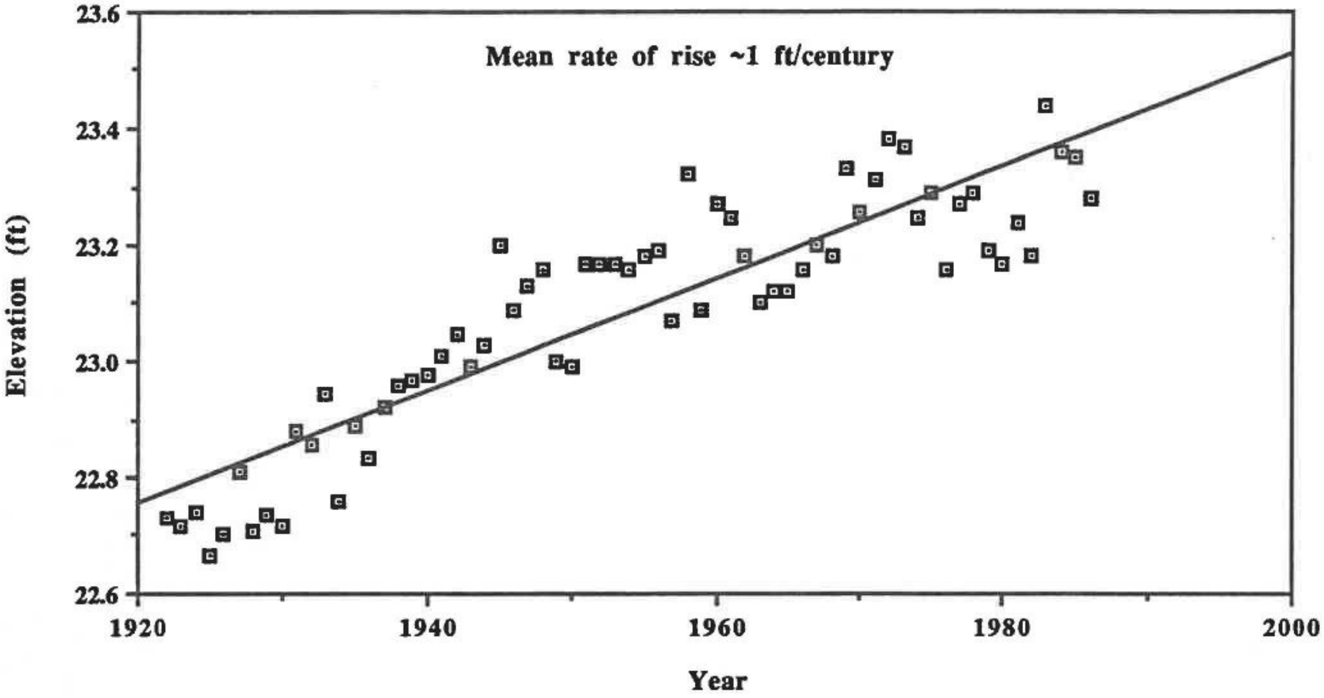


Figure 9: Variations in rates of relative sea-level rise.


Boston, MA

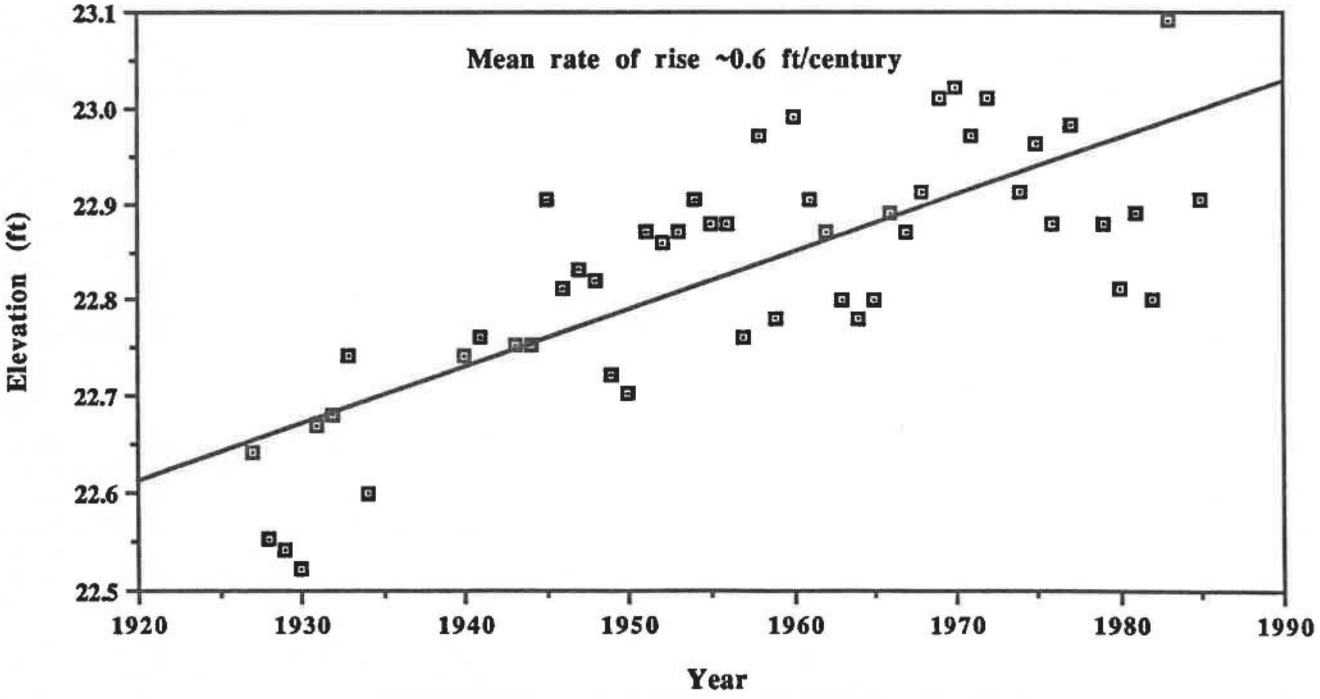

Portsmouth, NH

Figure 10a: Relative sea level, Boston, MA.
Figure 10b: Relative sea level, Portsmouth, NH.

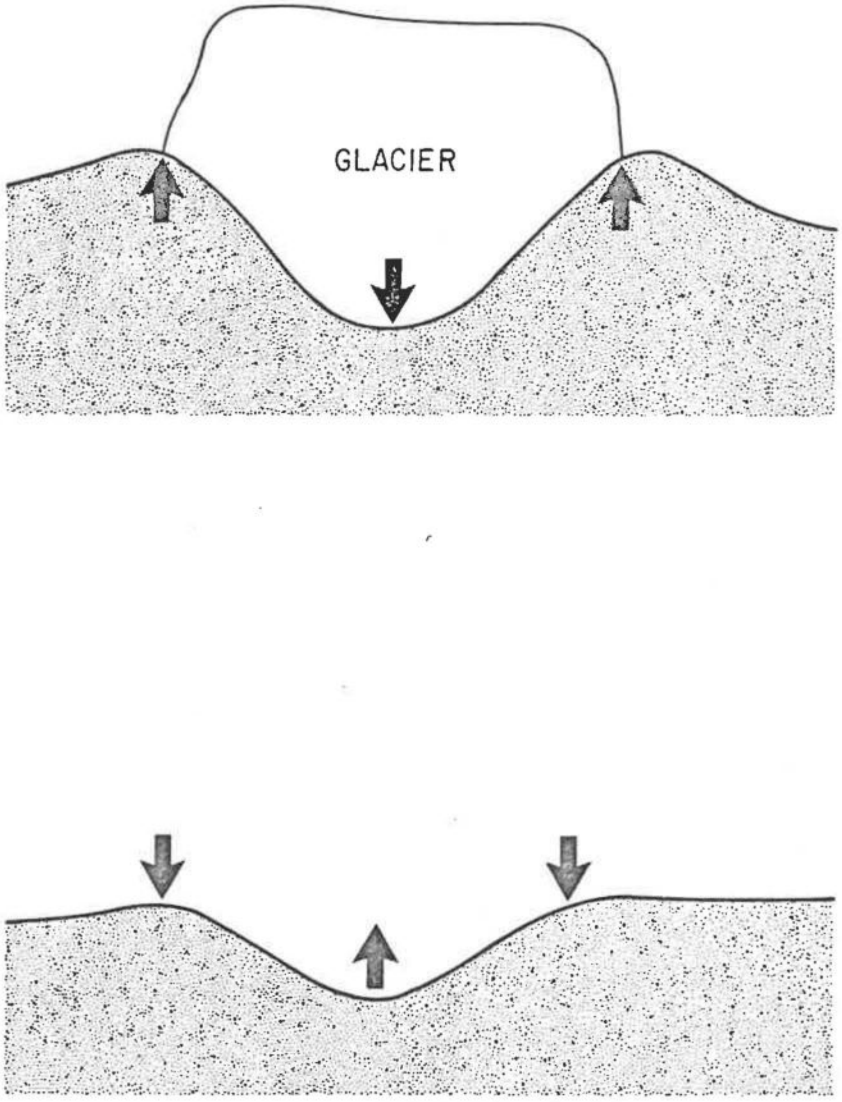


Figure 11: Subsidence and rebound due to glaciers.

weight of a glacier causes the underlying land to subside; however, land adjacent to the glacier rises to establish an equilibrium of the earth's surface. Once the glacier recedes, the land formerly underlying the glacier rebounds (uplifts) while the surrounding area, formerly uplifted, subsides. Boston and Portsmouth lay along the margins of the Laurentide ice sheet. Consequently, these areas were uplifted as nearby areas underlying the glacier subsided. Once the glacier melted, parts of New England uplifted; Boston and Portsmouth have subsided in response to this uplift.

B. Geographic Information System Analysis

In a recent study, Giese et al. (1987) quantified the passive retreat (submergence) of upland within the coastal communities of Massachusetts due to relative sea-level rise. This study was a first attempt to assess sea-level rise impacts for Massachusetts coastal towns. Digital elevation data were complied to formulate hypsometric curves for each community. These curves illustrate the cumulative distribution of upland with respect to elevation. The hypsometric curve for the Town of Marblehead is presented in Figure 12. Elevations lower than 8 ft (2.5 m) were not incorporated in the study because it was impossible to distinguish between the upland and wetland at these elevations.

The curve for Marblehead is relatively steep from approximately 10-50 ft (3-15 m) and then flattens out. Less than 7% of the upland is less than 17 ft (5 m) in elevation; however, 90% of the upland is less than 75 ft (23 m). Thus although there is little land near sea level, the overall elevation of the Town is not extremely high (for example, only 20% of upland in Sandwich, MA, is less than 75 ft).

From the hypsometric data, Giese et al. (1987) calculated the amount of upland area that each community loses annually in response to a relative sea-level rise rate of 0.01 feet (3 mm) per year (0.01 ft/yr was considered to be the historical mean annual rate of rise for Massachusetts, based on Aubrey and Emery, 1983). The Town of Marblehead loses approximately 0.16 acres of upland each year due to passive submergence alone; this value represents 0.017% of the total upland area within the Town.

The amount of retreat between 1980 and 2025 was calculated for three sea-level rise scenarios. All scenarios were based on the current rate of local subsidence; only the eustatic (global) ocean level was varied. The first scenario assumed a continuation of the present rate of relative sea-level rise (0.01 ft/yr; 0.3 cm/yr) from 1980 to 2025; if sea level continued to rise at its present rate, Marblehead would lose approximately 7 acres of upland between 1980 and 2025. If sea level were to rise 0.86 ft (0.26 m) between 1980 and 2025 (the "mid-range low" estimate by Hoffman et al., 1983), approximately 18 acres of upland in the Town of Marblehead would be lost. Finally, if eustatic sea level were to rise 1.29 ft (0.39 m) during the 45 year period

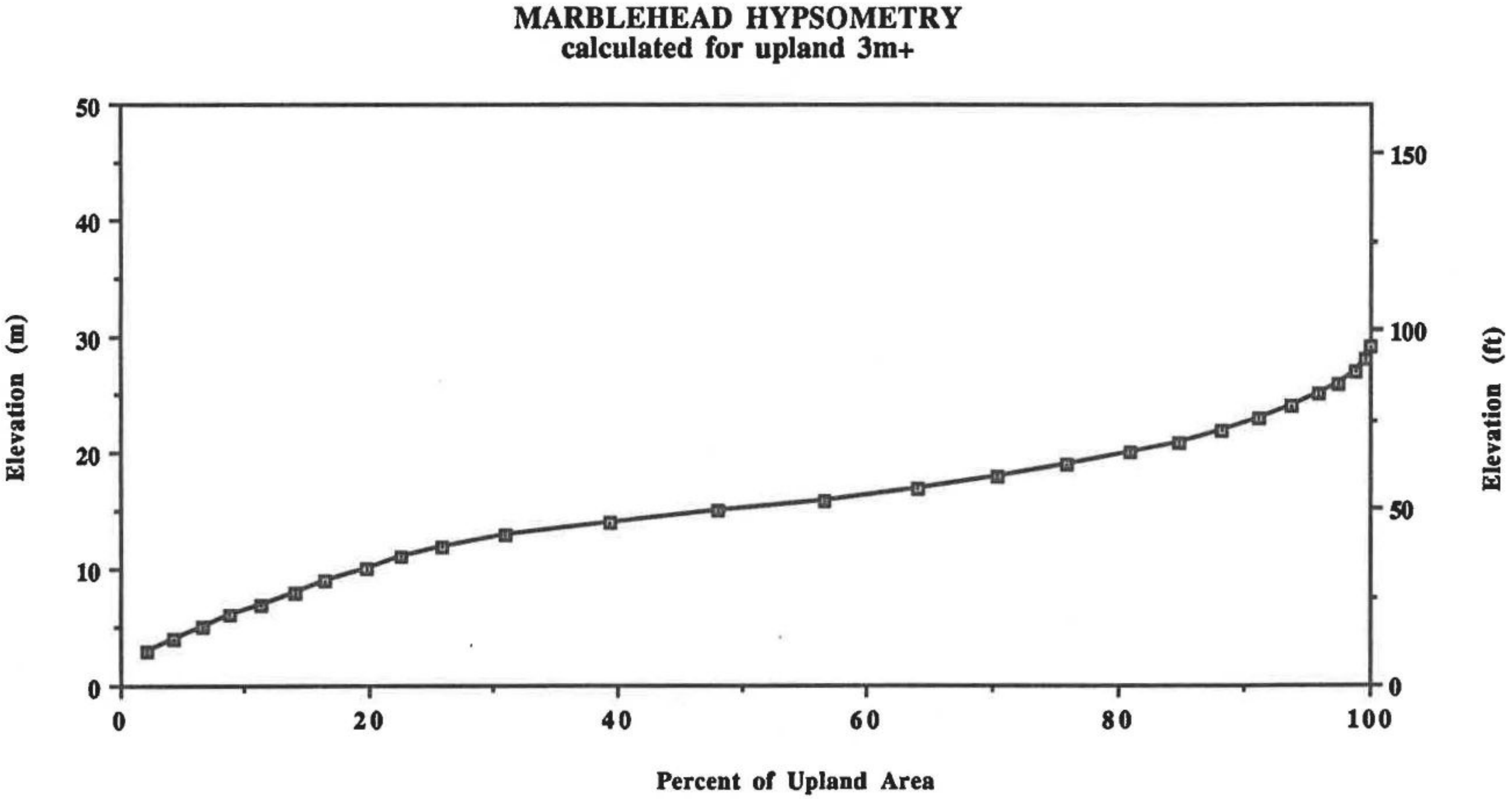


Figure 12: Hypsometric curve for the Town of Marblehead. From Giese et al., 1987.

(Hoffman's "mid-range high" estimate), then approximately 24 acres of upland would be lost in Marblehead between 1980 and 2025, or 1.1% of the upland area of Marblehead.

It was beyond the scope of the Giese et al. study to determine which areas within each community were most impacted by sea-level rise. The present study was designed to examine these concerns specifically for the Town of Marblehead using a GIS, as described below.

1. Background

A Geographic Information System (GIS) helped to assess the possible impacts of sea-level rise on the Town of Marblehead. This GIS technology offers the Town of Marblehead the opportunity to improve the efficiency and effectiveness of future planning for sea-level rise. A more complete description of the GIS is provided in Appendix A.

For this study, topographic information for the Town of Marblehead was input into the GIS. Various sea-level rise scenarios were then selected to determine potential impacts on the Town. Based on the results, several critical areas were identified and examined in more detail.

The Town of Marblehead topographic maps were used as the original data base for entry into the GIS. These maps were compiled for the Engineering Department of the Town of Marblehead from December, 1978 aerial photographs; the aerial photographs were taken by the James W. Sewall Company, Old Town, Maine. The topographic maps were compiled at 5-foot contour intervals (datum is N.G.V.D., 1929) and are at a scale of 1"=200' (1:2,400). Additionally, the Town zoning boundaries and coastal overlay district were also digitized.

The GIS analysis was performed for four sea-level rise scenarios: 2 foot, 6 foot, 11 foot and 15 foot. Due to the lack of scientific knowledge, it is impossible to provide time estimates of how long it will be until such rises occur. These scenarios should be used instead as planning tools for the Town. There is a general consensus in the scientific community that sea-level rise during the next century will be closer to the 2-ft scenario than the 6-ft, 11-ft, or 15-ft scenarios. However, these higher scenarios are realistic when tides and storm surges are considered. For example, the 10-year stillwater elevation is 8.4 feet (2.6 m) (FEMA, 1985); a 10-year storm, coupled with high tides and sea-level rise, may produce water elevations of more than 11 ft. The lower projections suggest a standard for zoning based on a realistic, dynamic ocean. The higher projections identify those areas susceptible to increased flooding potential during storms.

2. Results

The results of the GIS are presented in Figures 13-19. Figure 13 is the base map for the Town of Marblehead, including the location of Town boundaries, major roads and buildings. A composite map of 2, 6, 11 and 15 foot rises in relative sea level is presented in Figure 14. The

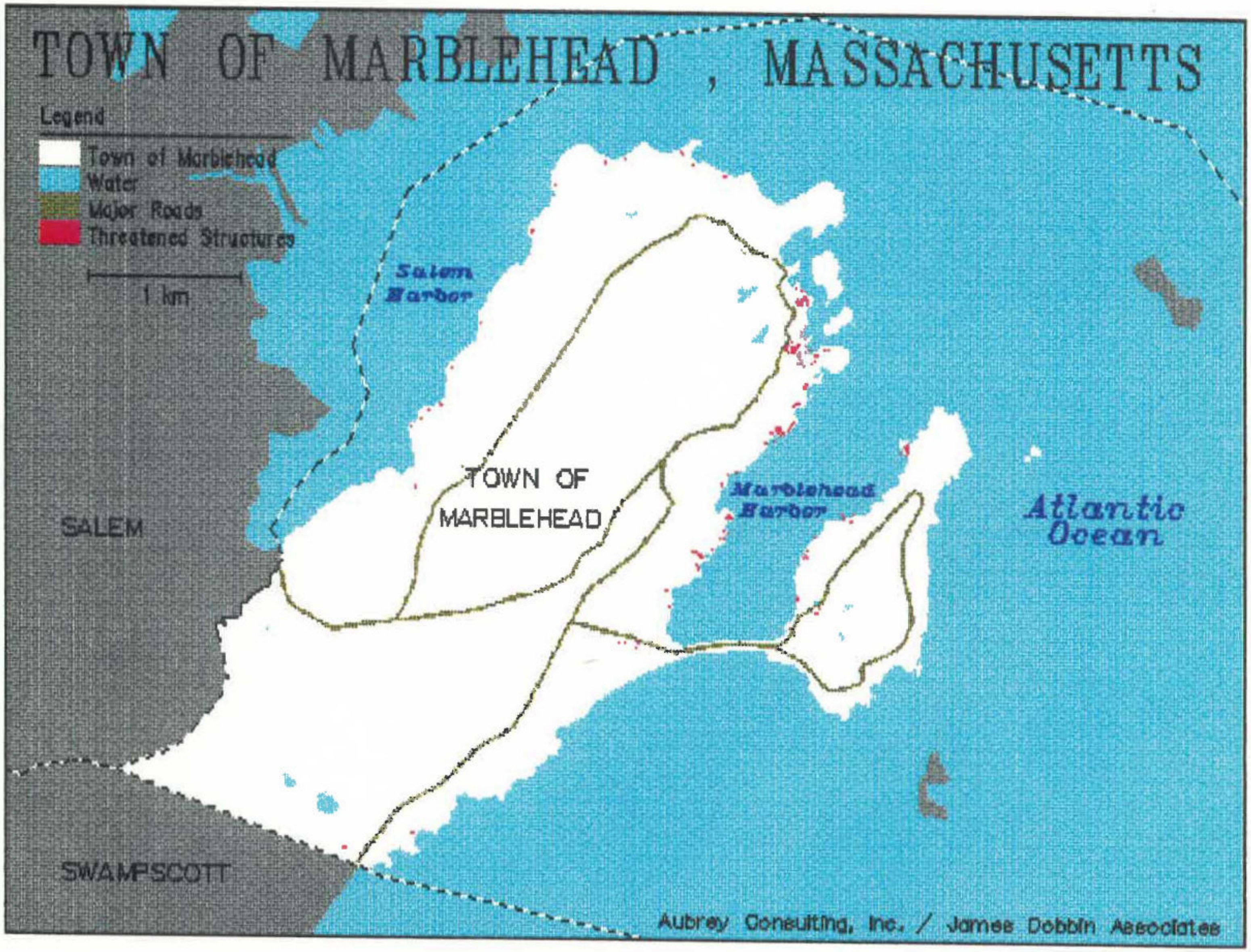


Figure 13: Base map for GIS analysis.

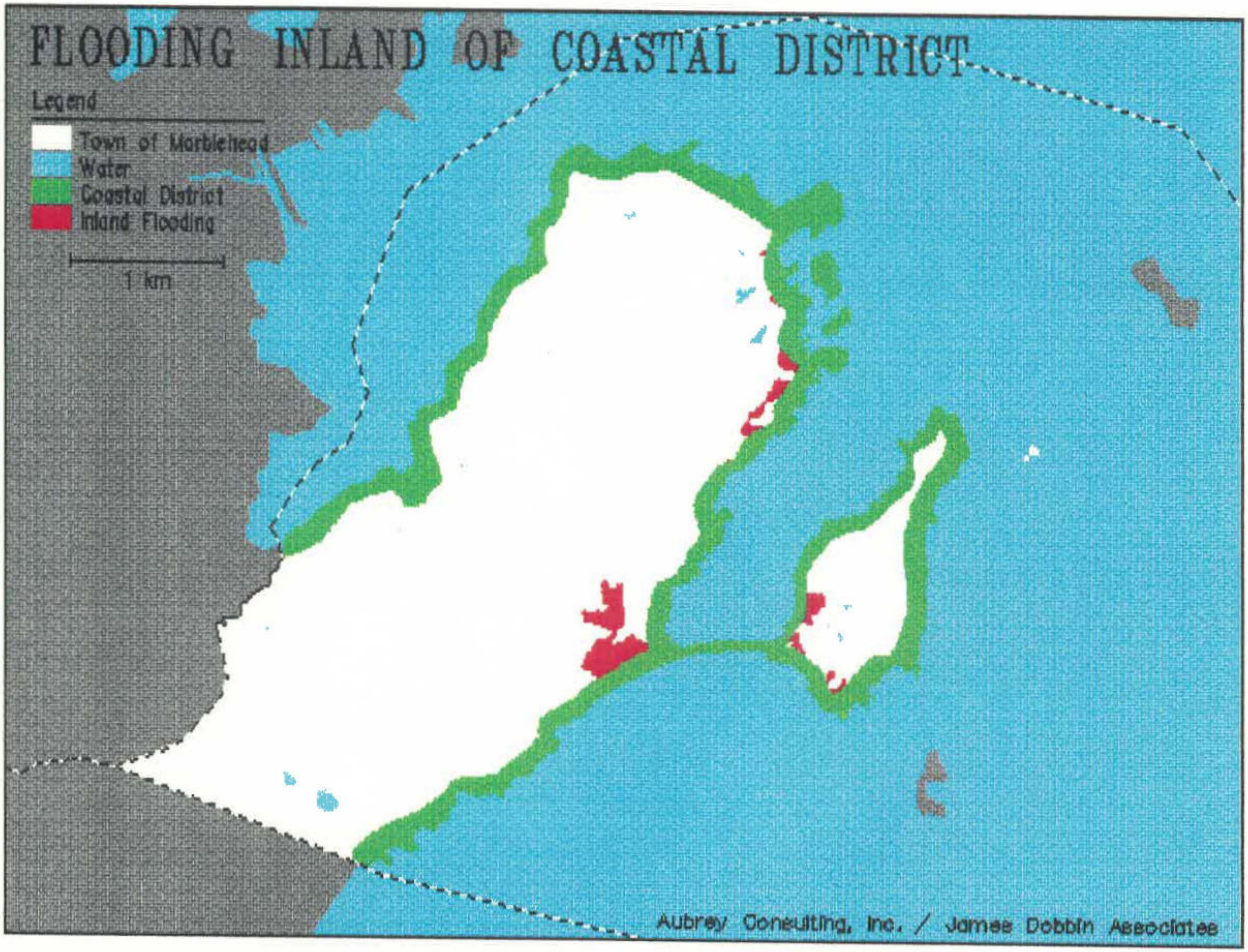


Figure 14: Composite sea-level rise.

shaded areas represent the land inundated by the corresponding rise in ocean level. As discussed previously, the increased ocean levels may be temporary, such as during a storm.

For the 2-ft and 6-ft rise scenarios (Fig. 14), most inundation occurs at the causeway and Wyman Cove. Based on these results, approximately 1.3% of the area of the Town will be inundated for a 2-ft rise while 2.6% will be inundated for a 6-ft rise (Table 2). Approximately 5% of Marblehead will be inundated by an 11-ft sea-level rise (Table 2). Little Harbor and the Goldthwait Reservation will be flooded in addition to Wyman Cove and the causeway; much of the remaining inundation will be restricted to the immediate shoreline area (Fig. 14). The 15-ft scenario (Fig. 14) indicates flooding of much of the land adjacent to the causeway as well as additional inundation at Little Harbor. Almost 9% of the Town will be flooded due to a 15-ft rise in the level of the sea (Table 2).

We emphasize that the likelihood of an 11-ft or 15-ft rise in ocean level during the next century appears extremely remote. However, flooding at these levels may occur due to combinations of relative sea-level rise, storm surges, and tides. Thus the flooding scenarios presented here should be useful to the Town for reasons other than just anticipated relative sea-level rise.

TABLE 2

AREA LOSS FOR SEA-LEVEL RISE SCENARIOS

Sea-level Rise Scenario	Area Loss (acres)	% of Area Loss	% of Area Remaining
2' sea-level rise	37.2	1.3	98.7
6' sea-level rise	74.3	2.6	97.4
11' sea-level rise	142.5	5.0	95.0
15' sea-level rise	248.9	8.7	91.3

Total area of Town = 2859 acres

Figures 15 and 16 indicate the zoning districts and coastal overlay district for the Town of Marblehead, respectively. Also indicated on Figure 16 are those areas lying outside the coastal district which are subject to flooding for a 15-ft rise in sea level, or combination of tides, surges, and sea-level rise.

As discussed previously, Giese et al. (1987) estimated upland loss for various sea-level rise scenarios. The least conservative scenario considered was a rise in eustatic sea level of 1.29 ft by 2025. This corresponds to a relative sea-level rise of approximately 1.57 ft when local land subsidence is considered. For this scenario, it was calculated that 1.05% of Marblehead's upland

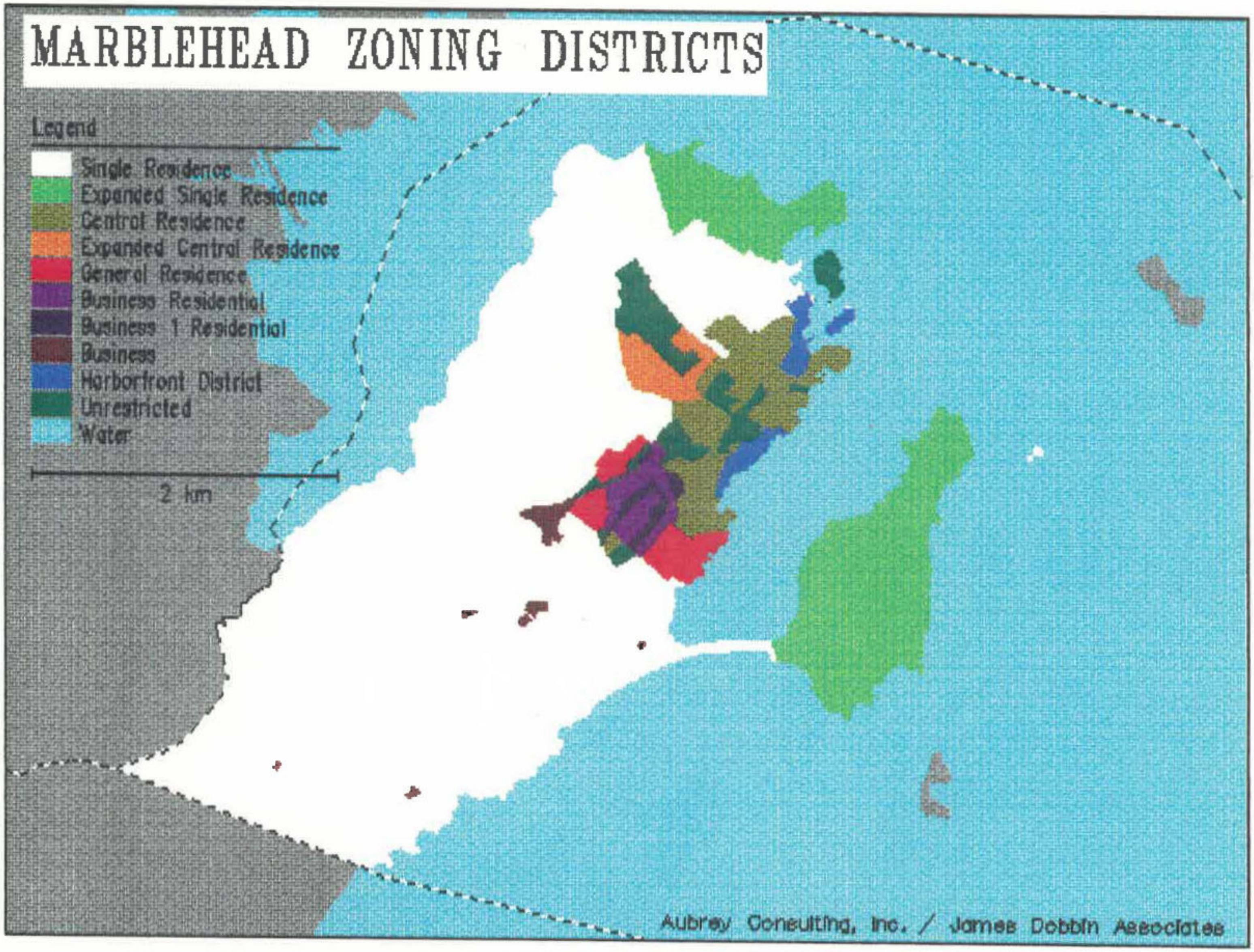


Figure 15: Marblehead zoning districts.

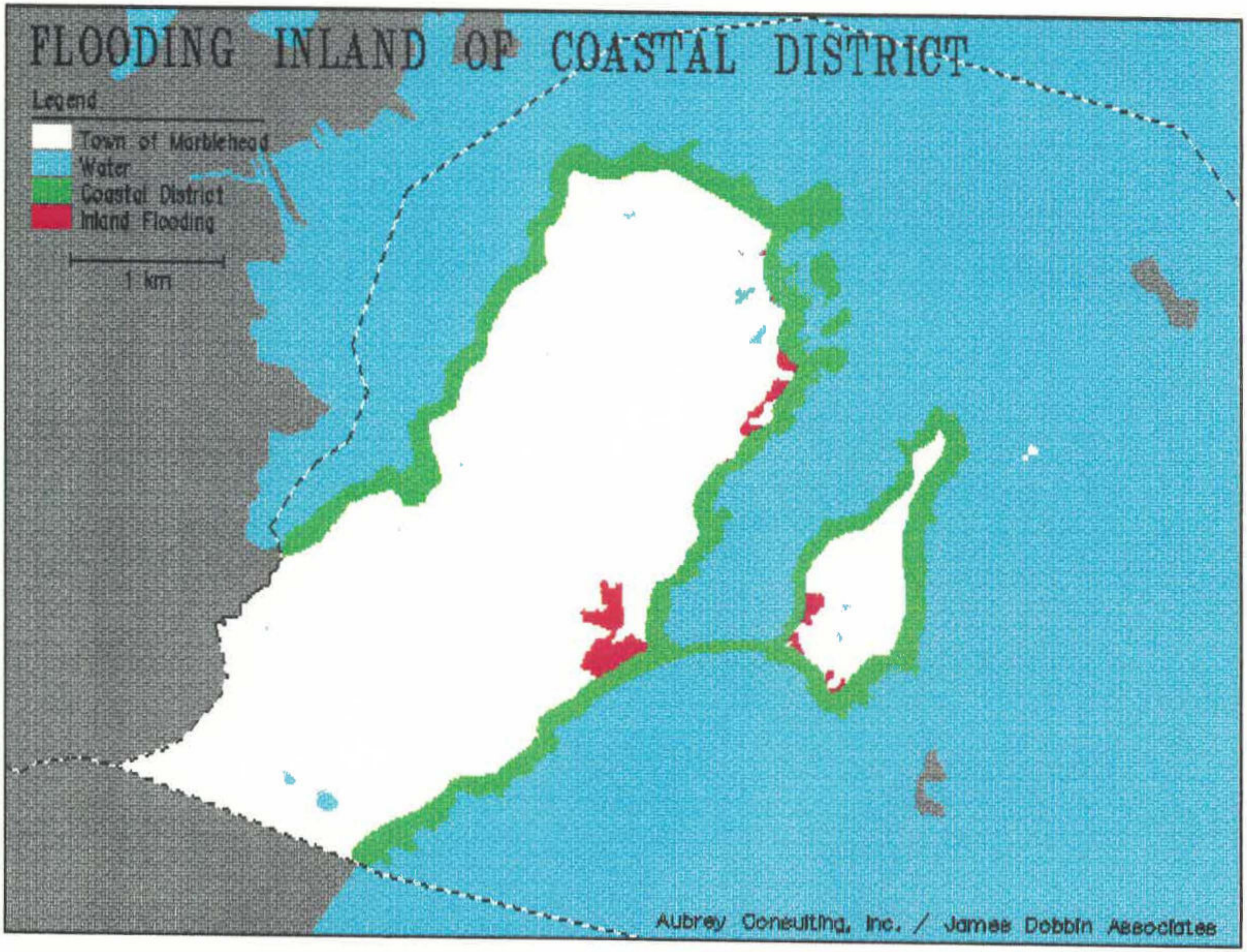


Figure 16: Flooding inland of coastal district.

would be submerged. By assuming a linear relationship between sea-level rise rate and upland submergence, estimates of upland submergence were calculated for 2-ft, 6-ft, 11-ft, and 15-ft sea-level rises. These were compared to the results of the present study (Table 3).

The GIS results for the 2 ft scenario were the same as determined by Giese et al. (1987). However, for the remaining scenarios, the GIS results of percentage of land inundated were less than those predicted by Giese et al. (1987). This was somewhat surprising since Giese et al. did not include wetlands in their analysis (only uplands were considered). Discrepancies between the data sets are likely the result of differences in technique. Since Giese et al. examined all coastal communities in the Commonwealth, they were unable to utilize detailed data sets. Giese et al. used digital elevation data at approximately 300-ft separations, rather than contour charts. Thus it is likely that the present study more accurately estimates potential inundation of the Town of Marblehead due to sea-level rise.

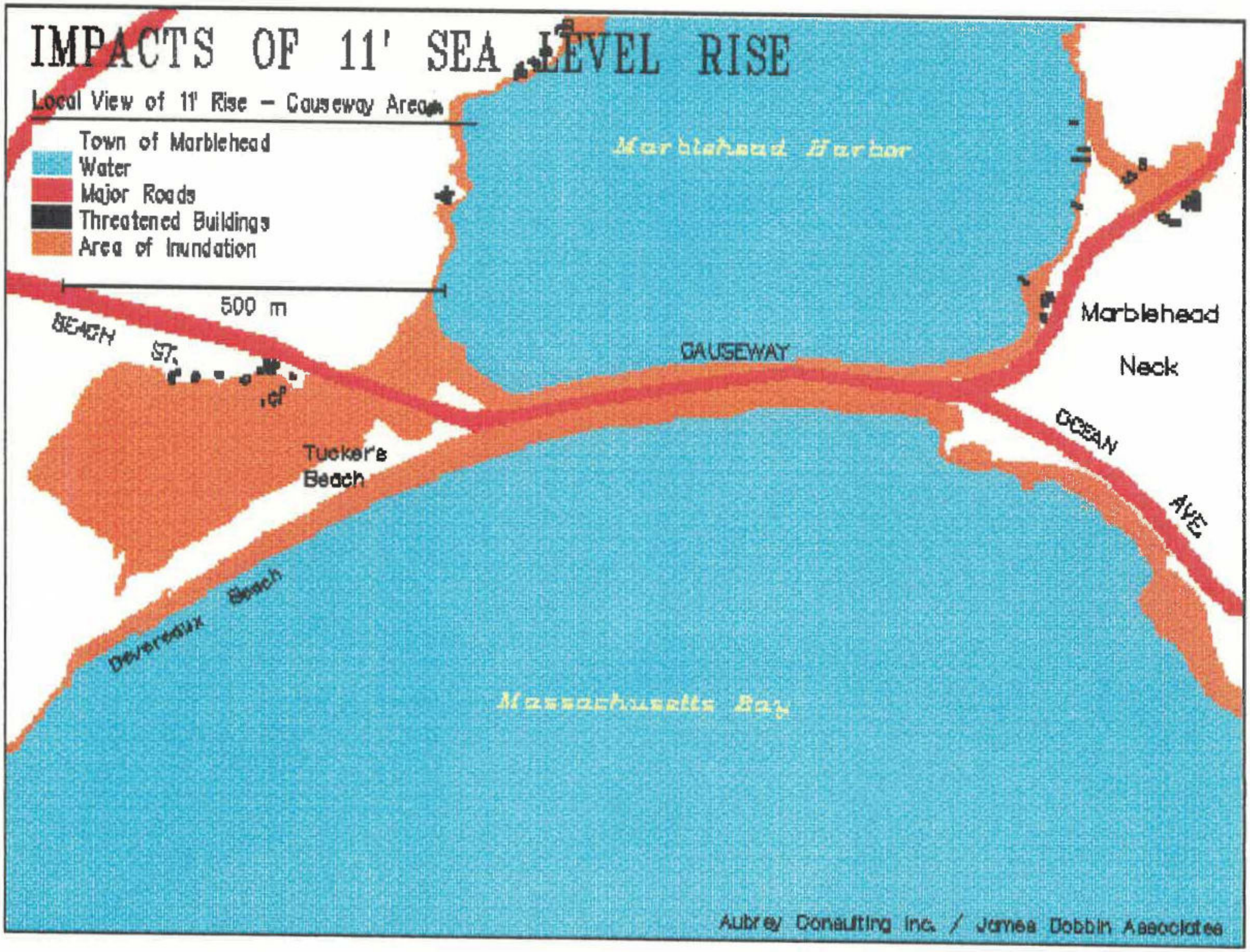
TABLE 3

COMPARISON OF RESULTS

Sea-level Rise Scenario	Present Study % of area lost	Giese et al., 1987 % of area lost
2-ft sea-level rise	1.30	1.34
6-ft sea-level rise	2.60	4.01
11-ft sea-level rise	4.98	7.36
15 ft sea-level rise	8.71	10.03

C. Vulnerable Areas

Based on the results of the GIS, three vulnerable areas were defined: the causeway, Little Harbor and Wyman Cove. Larger scale GIS maps were produced of these areas so the impacts of the 11-ft scenario could be examined in more detail (Figs. 17-19). As indicated by Figure 17, Marblehead Neck becomes an island during an 11-ft rise in sea level since the causeway floods completely. Additionally, the Goldthwait Reservation becomes inundated. The survival of the existing marsh at Goldthwait depends largely on the rate of sea-level rise and the surrounding environment. In general, marshes may be able to migrate landward with rising sea level if the rate of rise is relatively slow and suitable substrate is available. Unfortunately, the area surrounding Goldthwait contains buildings and roads, and consequently there is no area to which the marsh can migrate. It is likely the marsh will evolve into a salt water marsh as sea level continues to encroach and disappear once the ocean level becomes too high (Fig. 7).



Aubrey Consulting Inc. / James Dobbin Associates

Figure 17: 11 ft. sea-level rise, Causeway.

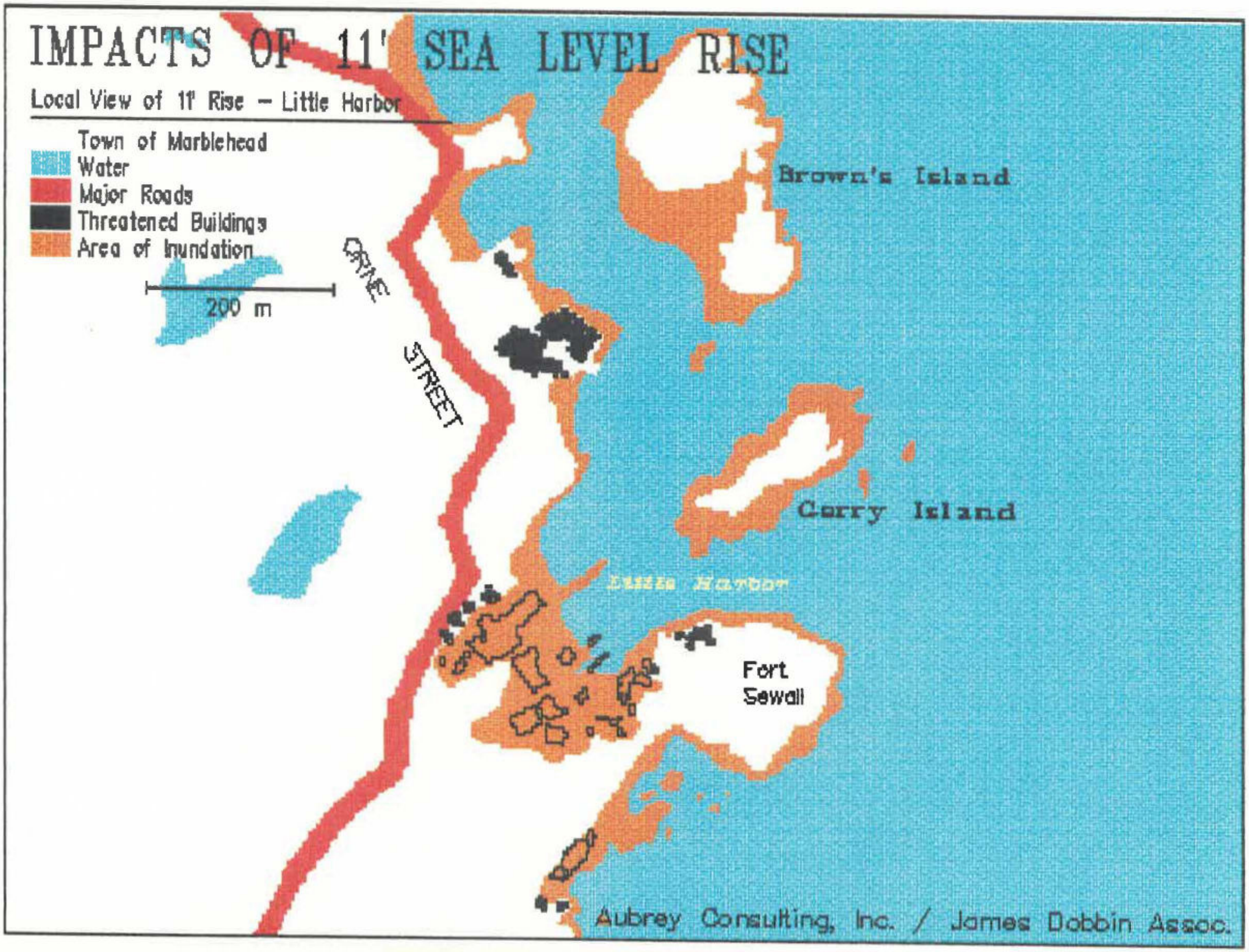


Figure 18: 11 ft. sea-level rise, Little Harbor.

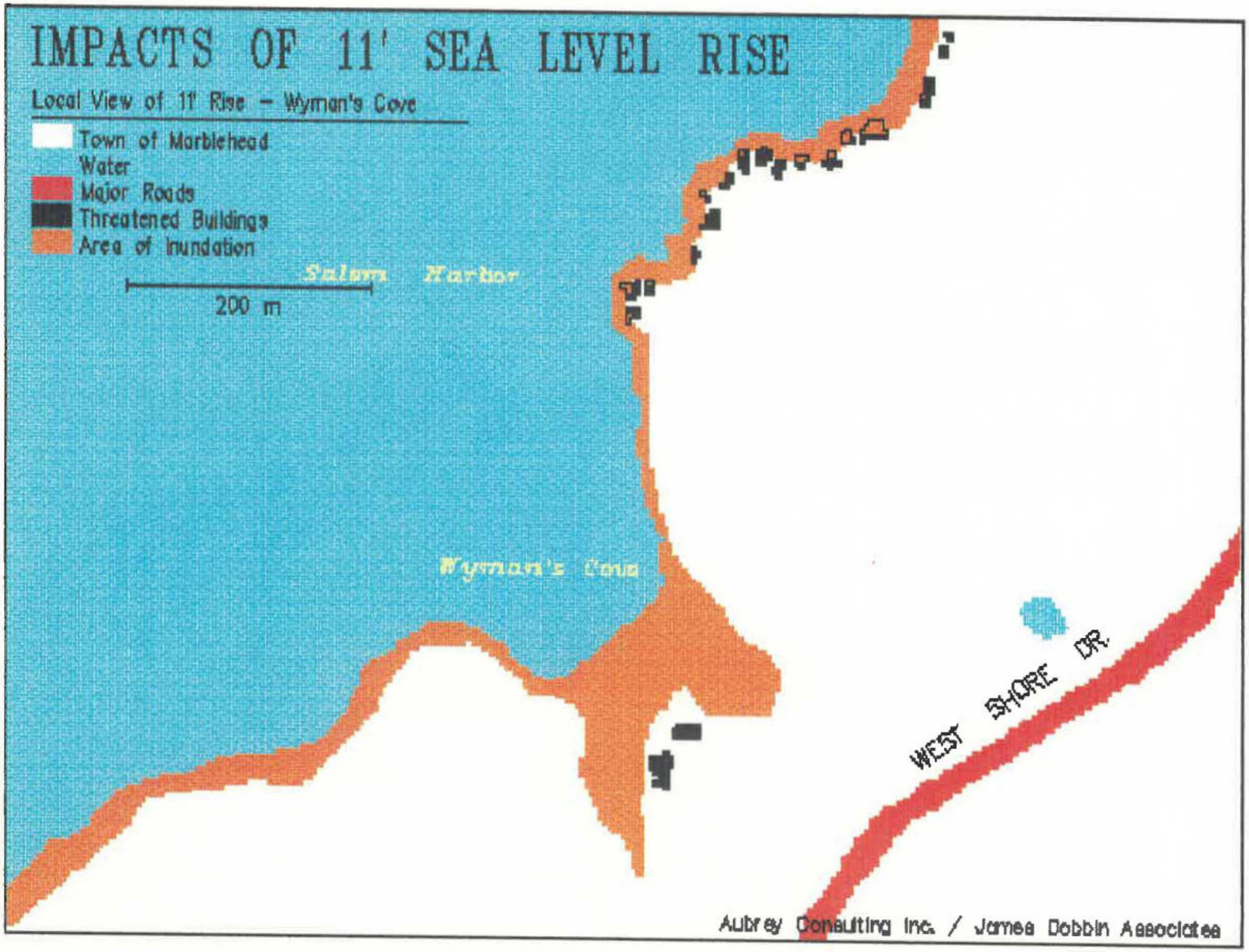


Figure 19: 11 ft. sea-level rise, Wyman Cove.

At Little Harbor (Fig. 18), the area west of Fort Sewall will be most affected by an 11-ft rise in sea level. Brown's Island will separate into two islands as the water floods through the low lying parts of the island. Based on the Town Assessors maps, 44 of the businesses and homes in the Little Harbor area will be threatened or flooded.

Wyman Cove and the adjacent shoreline will be impacted by an 11-ft sea level rise (Fig 19). However, much of the inundation at Wyman Cove also will occur for only a 6-ft sea level rise (as illustrated by Fig. 14) since this area is so low lying.

Shoreline changes for these areas were analyzed from historic maps and aerial photographs. Shoreline change maps have been compiled for the Massachusetts Coastal Zone Management (MCZM) Office by the University of Maryland Coastal Mapping Group. Historic charts from 1849, 1919, 1954 and 1978 were used for the shoreline mapping for the Town of Marblehead. The greatest shoreline change occurred at the causeway (Fig. 20). Although the causeway has undergone little erosion since 1919 (according to the shoreline change maps), there was significant erosion from 1849 to 1919. The shoreline change maps indicate the Wyman Cove area has been fairly stable (Fig. 21); no net accretion or erosion has occurred since the mid-1800's. It is more difficult to determine a trend in shoreline change for Little Harbor (Fig. 22). Much of this area has been altered due to construction of buildings, docks, and piers.

Historical shoreline changes for the Town of Marblehead were also identified using aerial photography. A series of aerial photographs ranging from 1954 to 1986 was obtained from a variety of sources. The dates, scales, and sources of photography are shown in Table 4.

TABLE 4

AERIAL PHOTOGRAPHIC SOURCES

DATE	SOURCE	SCALE
29 April 1954	Town of Marblehead	1:1200
1 April 1966	Town of Marblehead	1:1200
19 December 1978	Town of Marblehead	1:12000
23 October 1980	National Ocean Service	1:7860
1986	National Ocean Service	1:12000

Rates of shoreline change were measured from the aerial photographs in three vulnerable areas: the causeway, Little Harbor/Dolliber Cove, and Wyman Cove. These rates are compared with shoreline change rates measured from the MCZM shoreline change maps in Table 5. Relative shoreline movement was measured as the perpendicular distance from a shore-parallel baseline to mean high water and the vegetation line. Four baselines were established in the study area: two

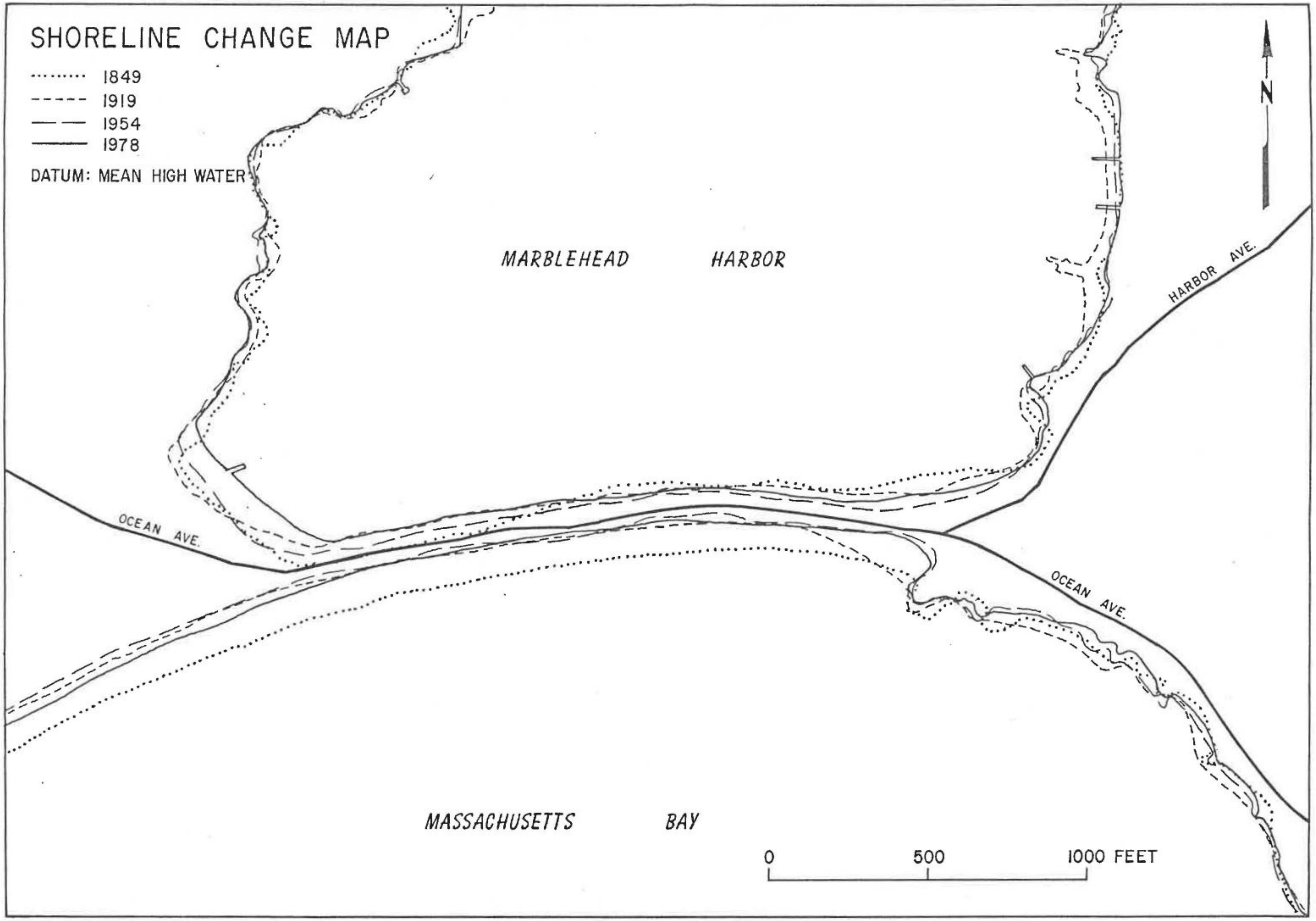


Figure 20: Historic shoreline change, Marblehead Neck.

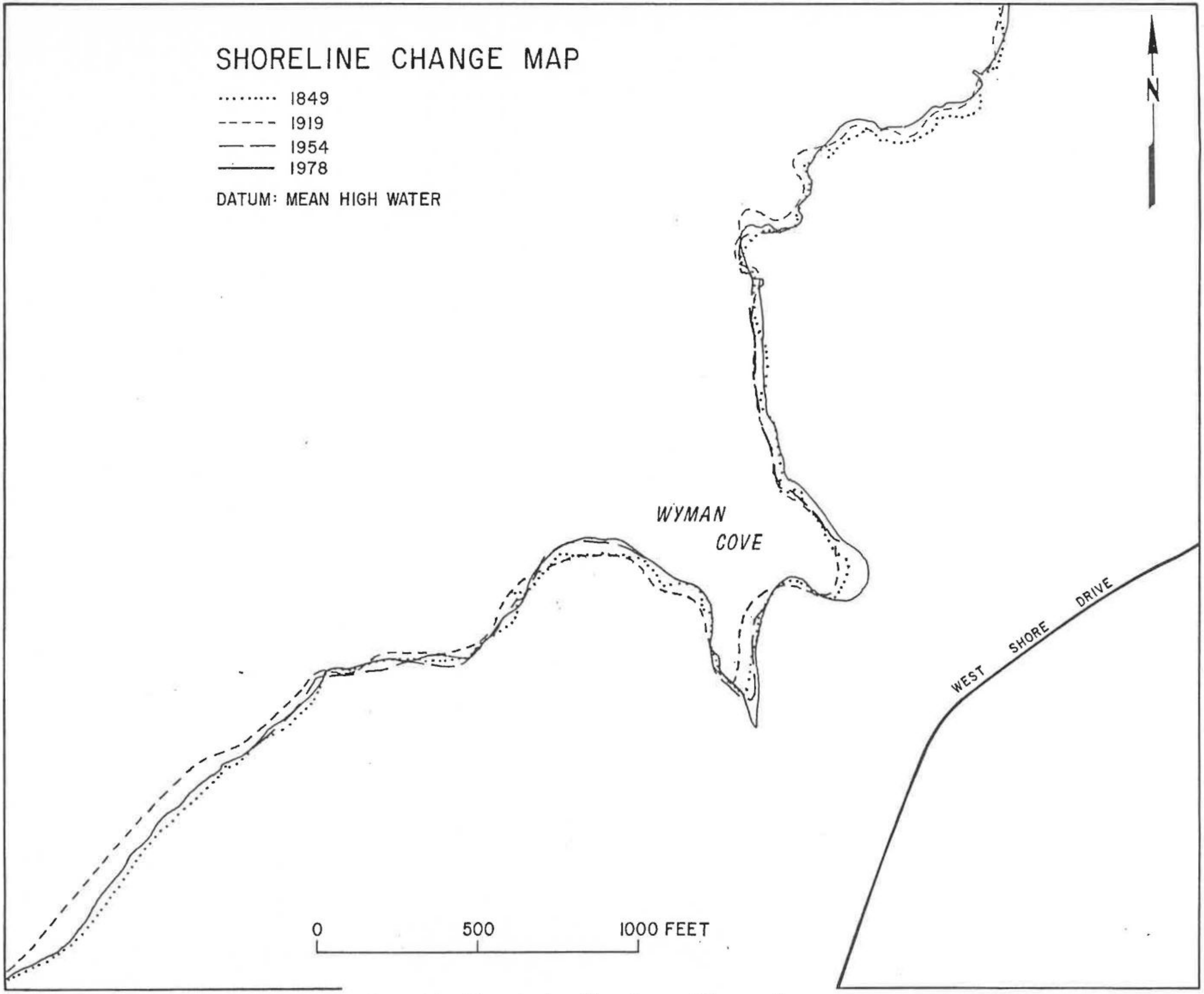


Figure 21: Historic shoreline change, Wyman Cove.

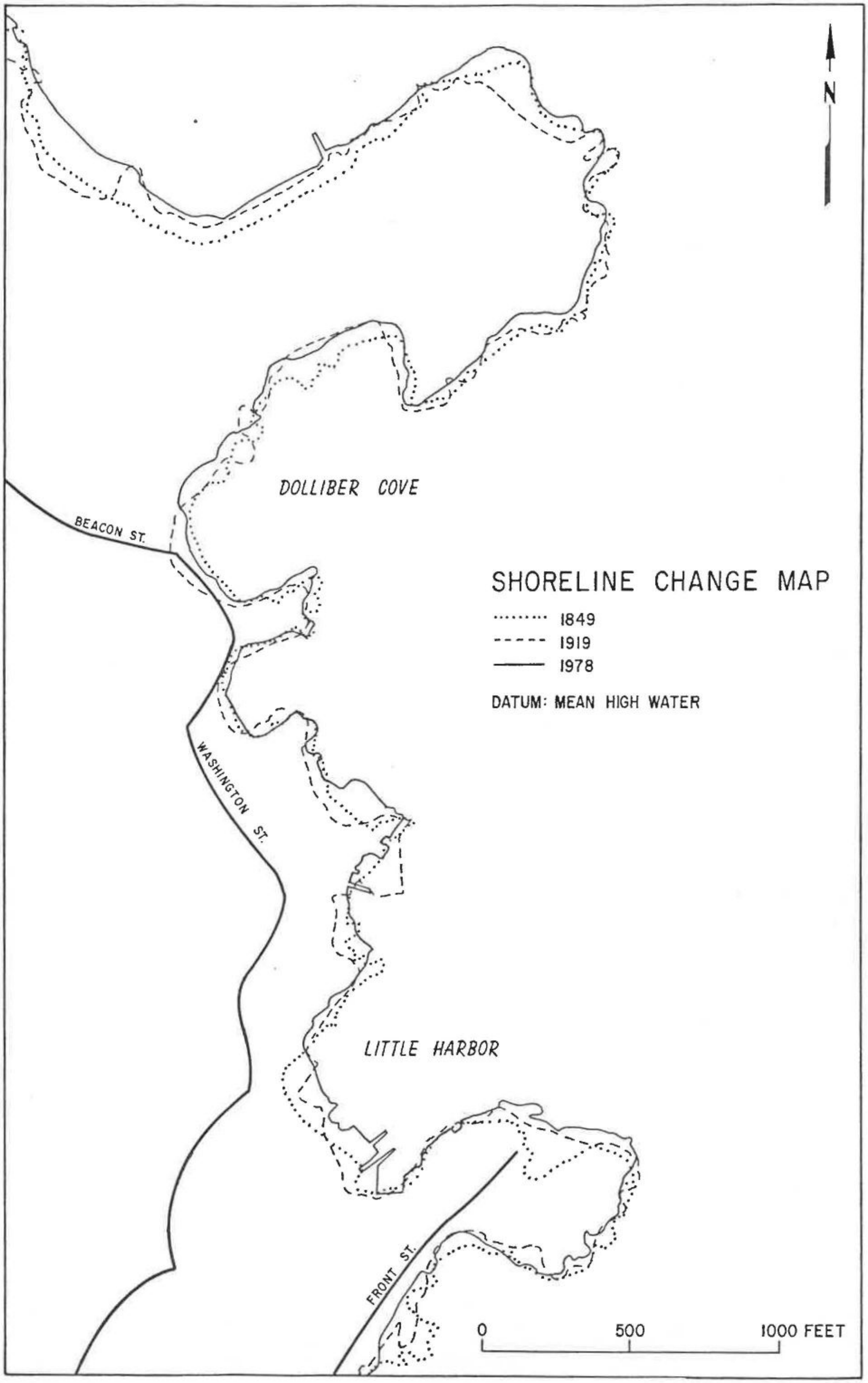


Figure 22: Historic shoreline change, Little Harbor.

along the causeway and one each in the Little Harbor and Wyman Cove areas. The mean high water line and the vegetation line were used as indicators of shoreline position through time. These shoreline indicators were chosen because they are independent of the level of the tide during the time the photograph was made, and because they were easily identified on the aerial photographs.

TABLE 5

RATES OF SHORELINE CHANGE AERIAL PHOTO ANALYSIS VS. SHORELINE CHANGE MAPS

AREA	PHOTOS (ft/year)	COVERAGE (years)	MCZM MAPS (ft/year)	COVERAGE (years)
Causeway	-0.7 to -2.6	1954-1980	-0.6 to -0.8	1849-1978
Little Harbor	+1.2 to +1.3	1954-1986	+0.8 to +0.9	1849-1978
Wyman Cove	0.0 to +1.9	1954-1986	+0.4 to +0.6	1849-1978

Note: (-) indicates erosion; (+) indicates accretion

Net shoreline change rates along the Marblehead causeway between 1954 and 1980 ranged from 0.7 to 2.6 ft/yr (0.2 to 0.8 m/yr) of erosion (Table 5). These rates represent changes on the south side of the causeway which is exposed to wave energy from the Atlantic Ocean. Shoreline change rates could not be determined for the north side of the causeway due to poor image quality and shadowing in this area. Although the aerial photographic data do not cover the same time interval as the shoreline change maps produced by the MCZM Office, there is qualitative agreement for net erosion in the causeway area.

Results from the aerial photographic analysis of the Little Harbor/Dolliber Cove areas show a net accretion of 1.2 to 1.3 ft/yr (0.4 m/yr) between 1954 and 1986 (Table 5). Shoreline movement in Little Harbor and Dolliber Cove was measured at Gashouse Beach and Norman Street Beach. These results are somewhat higher than the shoreline trends presented in the MCZM shoreline change maps, however both shoreline change studies show net accretion in these areas. It is difficult to assess whether or not these are natural trends in shoreline evolution, since these areas have been heavily impacted by the construction of buildings, docks, and piers. In contrast to beaches which frequently change, one section of rocky shoreline in the Little Harbor and Dolliber Cove areas was measured for relative shoreline movement. As would be expected, this rocky area showed no net movement during the period of photographic coverage.

Net shoreline change rates in Wyman Cove between 1954 and 1986 ranged from 0.0 to 1.9 ft/yr (0.0 to 0.6 m/yr) accretion (Table 5). The MCZM shoreline change maps show lower accretion rates of 0.4 to 0.6 ft/yr (Table 5).

D. Possible Procedural Responses

Federal, state, and many local governments have regulatory programs and agencies designed to address a variety of coastal environmental issues, including coastal flooding, zoning, standards for construction, and the protection of wetlands. However, none of these programs directly address issues related to climate changes and sea-level rise. In the following section, several methods for considering these issues are derived and discussed.

The legislative and regulatory response can take a two-tiered form. Most regulations assume a static sea-level, except those concerned with storm flooding. A first-tier response might be to recognize that sea levels are not static, and that historical rates of change, at least, must be incorporated into appropriate legislation and regulations. This is a minimum level of modification, but one that is scientifically and legally defensible while paving the way for consideration of legislating and regulating for increases in these rates. The second-tier response would be to make policy decisions based on the most defensible projections of relative sea-level rise as impacted by human modifications to our climate system.

The development of any new legislation or regulations to respond to sea-level rise must be carefully tied to the protection of public safety. This threat to public safety must be real; the greater the potential for harm from sea-level rise, the greater the need for regulation. However, from a legal standpoint, government regulation of private property risks conflict with the U.S. Constitution's prohibition against the taking of property without compensation. No taking occurs, however, if the regulation is necessary to protect public safety.

1. Zoning

The Massachusetts zoning enabling statute specifically cites that one of the purposes of zoning is to secure the safety of the public from flooding. If current scientific knowledge can show certain detrimental effects from sea-level rise within appropriate time frames, coastal communities can use the zoning power to exercise the retreat option of responding to sea-level rise.

a. Setback regulations for new structures

A coastal community may amend its zoning laws to require that any new building be set back from the current mean high water (MHW) line by a distance defined by the anticipated rise in sea level. For maximum flexibility, the setback for any new building could be determined by analyzing the vulnerability of the building lot to sea-level rise. However, this procedure could lead to a battle of experts, leaving a building inspector or Zoning Board of Appeals with a subjective choice between varying projected scenarios.

As an alternative, a community could map the coastal areas subject to sea-level rise for a given period of time or for a specific scenario, based on a study tailored for that community. In effect, the community would establish a coastal overlay district which becomes the setback within which no new buildings or structures would be allowed. Other than this restriction the zoning regulations of the underlying district would apply. The coastal overlay setback provisions might authorize a variance procedure to those property owners whose property lies within the boundaries of the district who can prove that the predicted sea-level rise will not affect their particular property. The standards normally required for a variance include the following:

i. literal enforcement of the setback requirement would cause the property owner substantial hardship;
ii. owing to circumstance related to the soil, topography, etc. of the particular lot, the setback requirement is unreasonable;
iii. the causes of the substantial hardship do not affect the coastal overlay district in general;
iv. granting the variance will not be substantially detrimental to the public good or derogate from the intent of the community's zoning laws.

These standards should suffice for variances to the zoning regulations of the coastal overlay setback.

Additional permutations to a coastal overlay scheme could address sea-level rise as a time dependent variable. For example, the district could be sub-divided into areas affected by sea-level rise during the next 50 years, 100 years, 150 years, etc. Coastal property owners would be forced to choose between building permanent or movable structures within the overlay district or building the structure farther inland. A structure with an expected lifetime of sixty years could be built in the 100-year zone but not in the 50-year zone. A movable structure need only comply with the setback provisions of the underlying district, and must be relocated when the sea actually encroaches upon it. The property owner must record their agreement to move the building or structure inland as the sea-level rises. In addition, the property owner must maintain a reserve area which meets current zoning provisions for future relocation of the building or structure.

Finally, the overlay district provisions could exempt from further restrictions those structures which meet criteria in the State Building Code for structures within high hazard coastal areas and/or flood plains. These structures may be located within the coastal overlay district indefinitely. This type of zoning provision may be in conflict with Massachusetts General Laws Chapter 40A Section 3. That statute prohibits a municipality from regulating the use of materials or methods of construction on structures currently regulated by the State Building Code. The different formulas can be combined in various ways to create a flexible and carefully tailored setback retreat program responding to anticipated sea-level rise.

b. Setback regulations for existing structures

Whereas the above measures provide a framework for undeveloped coastal areas, they do not address sea-level rise setbacks in more developed coastal areas. Massachusetts law prohibits a community from applying current zoning laws to existing buildings which were erected in compliance with older zoning laws. Unless a building is abandoned or left unused for two years or more, the building is insulated from changes in a community's zoning laws. In fact, even a building which was not legally constructed is protected under Massachusetts law after a certain period of time. Under Section 7 of Chapter 40A, a six-year statute of limitations applies to structures legally constructed, but which at some point lose their non-conforming structure protection. Furthermore, a ten-year statute of limitations exists for buildings which were constructed without any legal authorization.

A community does have one potentially powerful weapon to use against non-conforming structures in coastal areas. Any addition to, or extension of, a non-conforming use or structure requires a new building permit, and thus brings the entire structure within the current zoning law. Chapter 40A gives authority for the community to grant a permit to allow the alteration, if the community determines that the change in use, structural change, extension, or alteration shall not be substantially more detrimental than the existing non-conforming use or structure. However, this procedure is discretionary. A community may prohibit any changes in use, structural change, extensions or alterations, or any reconstruction of a non-conforming structure. The one caveat to this rule is that a community must allow the reconstruction of single or two-family residential structure where such reconstruction will not increase the non-conforming nature of the structure.

The case law on loss of non-conforming use and/or structure status is rich and beyond the scope of this report. It is sufficient to say that almost any change in the use or structural alteration of a non-conforming structure will bring that structure within the zoning power of the community within which it is located.

2. Construction standards

The State Building Code governs the construction of every building and structure within the Commonwealth. Enacted in 1975, the Building Code provides for uniform standards of construction which may not be altered by the imposition of either lesser or more onerous requirements in any given community. Two exceptions exist to this uniformity rule:

i. Section 101.3 of the Code allows a local building inspector to impose a construction requirement essential for the safety of the building or its occupants when the Code is silent on the matter.

ii. A coastal community may recommend to the State Board of Building Regulations and Standards the adoption of regulations imposing more restrictive standards within the State Building Code for that particular community based on the anticipated sea-level rise within that town.

The Code does contain specific requirements for buildings located in flood plains and high hazard coastal zone areas, but does not take into account rising sea levels. Therefore, it is arguable that local building inspectors should have the authority to impose requirements for buildings to be erected within a predicted sea-level rise/storm surge area.

Certain procedures must be followed when a local building inspector imposes any additional requirements under Section 101.3. Most importantly, the local building inspector must report such action to the State Board of Building Regulations and Standards within seven (7) days. In addition, the developer may appeal the local building inspector's action to the State Building Code Appeals Board. Similarly, the Commissioner of the Department of Public Safety can review, on his own initiative or upon the application of the state inspector, any action of a local building inspector which results in the non-uniform implementation of the State Building Code. The Commissioner may reverse, modify, or annul such action.

Despite these possible procedural hazards, building inspectors may decide that it is worth the increased level of effort to impose additional requirements based on sea-level rise. As stated above, the Code already contains design requirements for construction in both flood plains and high hazard coastal zones (See 780 C.M.R. Section 744). These requirements include the following: construction of the lowest floor of any building, including the basement and cellar, above the base flood elevation; use of a permanent foundation or pilings; and a prohibition against the use of fill for structural support. Expanding these and other similar design requirements already cited in the Code to construction within a greater geographic area as determined by anticipated sea-level rise may pave the way for amendment to the State Building Code.

Exception (ii) is less subject to challenge than *ad hoc* local imposition of construction standards; however, it is also more time consuming. An additional drawback is the standard used by the State to determine whether such action is appropriate. The community-based standard must conform with accepted national engineering and fire practices, public safety, and the purposes of a State Building Code. It is doubtful whether there is, as yet, any accepted national engineering practice in response to sea-level rise. Assuming that these criteria can be met, the State Board of Building Regulations and Standards may implement this community-based standard after a public hearing on the matter.

A final alternative for implementing new building code requirements responsive to sea-level rise is for coastal communities to join together to propose amendments to the State Building Code. The State Board of Building Regulations and Standards holds a public hearing in May and

November of each year to consider petitions to amend. The petitions must be submitted to the State Board of Building Regulations and Standards at least sixty days prior to the public hearing.

As with zoning regulations, existing buildings and structures need not meet the changing requirements of the Code. However, any addition or substantial improvement (defined as anytime the cost of the improvement is greater than 50% of the market value of the structure pre-improvement) must comply with the Code as then current. Ordinary repairs, however, do not require a building permit. Legislation can alter this grandfathering scheme for a given Code requirement. Obviously, this legislative route is time-consuming and by no means does it ensure that the regulation requirements will be changed.

3. Wetlands Protection

The protection of wetlands presents a unique set of policy issues. Present federal and Massachusetts wetland laws strive to prevent any further net loss of wetland area. To this end, Massachusetts law generally prohibits development within a wetland or 100-ft buffer zone around a wetland without an authorizing Order of Conditions. Local Conservation Commissions share jurisdiction with the Department of Environmental Protection over development activity covered by the state law. Communities may also pass their own restrictive wetland protection by-laws under either their Home Rule or zoning powers. More than half of the communities in Massachusetts have done this. Thus, wetland regulation is a familiar ready-made tool with which a community can respond to some of the problems presented by sea-level rise.

a. Wetland replacement

As sea level rises, coastal wetlands become submerged. Wetlands can replace themselves by migrating landward, given the space to do so. However, when space is limited due to existing infrastructure, the wetlands have no place to retreat. Should property owners have to move inland to give wetlands the space required to prevent inundation by the rising sea? Present law offers no guidance to this problem. The policy issues are so complex that only comprehensive planning legislation, preferably at the state level, can thoroughly address this issue.

b. Septic system setbacks

A relatively easier problem to battle concerns the pollution of wetlands by sanitary sewage disposal systems. Title V, the Massachusetts State Sanitary Code, requires every new septic system be placed at least 50 ft from a wetland area (310 CMR 15.03 (7)). Leaching fields, trenches, chambers, galleries and pits may not be constructed in areas where the maximum groundwater elevation is less than 4 ft below the bottom of the excavation (310 CMR 15.11-15.15). In addition, a project proponent must set aside a reserve area of land with a capacity at least equal to that of the present leaching facilities. If the system fails, it must be relocated to the reserve area (310 CMR 15.02 (22)).

The preface to Title V states that a local Board of Health may enact sanitary sewage regulations with more stringent requirements than those of Title V (310 CMR 15.00). Thus, the Board of Health may require greater setback distances or depth to groundwater requirements based on anticipated sea-level rise, or even require extension of and connection to the public sewer system for any development in an area threatened by sea-level rise. Again, such regulations may be tied to the expected life of the structure to be built.

The Title V setbacks apply to the renovation or replacement of existing systems, except those constructed before the enactment of wetland protection regulations in 1972 and for which no reserve area is available. The Title V setbacks apply to the substantial enlargement of any existing septic system. In addition, Title V requires that all systems perform up to current operating standards. This general lack of grandfathering allows a local Board of Health to require adjustments as sea level rises, even in developed areas.

VI. IMPACTS AND RESPONSES FOR MARBLEHEAD

The major impacts most frequently associated with sea-level rise are flooding, the loss of uplands and wetlands, saltwater intrusion into groundwater, and changes in river and estuarine flow and sedimentation. The magnitude of each of these impacts on the Town is examined below. Additionally, specific procedural responses are provided for the Town to adopt in anticipation of the impacts of climate change and sea-level rise.

A. Impacts

1. Flooding

The GIS results document the intense flooding of the Town for varying sea-level rise scenarios. These GIS results can be interpreted as indicating those areas within the Town that are susceptible to flooding, either for a net rise in ocean levels or a combination of ocean level, tide and storm surge. This latter interpretation is examined here. Previous work by FEMA shows that the flooding level for the Town of Marblehead at present for a 10-year storm is 8.4 feet above mean sea level (NGVD), whereas it is 9.6 feet above mean sea level for a 100-year storm. These estimates include storm surge and high tides. However, the estimates ignore changes in relative sea-level and storm wave runup. The USACE has estimated the 10-year flood to be 9.0 feet above NGVD, and the 100-year flood (such as the storm of February 6, 1978) as 10.2 feet above NGVD. By adding from one to four feet of relative sea-level rise to these estimates, one can obtain flooding levels that include our 11-foot scenario and approach the 15-foot scenario.

The GIS shows that for an 11-foot rise in ocean level, certain areas of Marblehead will be flooded (5% of the Town). These areas include the causeway, which may remain closed during the period of flooding. The increased water levels will increase the erosion of the beach fronting the causeway, and eventually cause structural damage to the causeway protection itself. The flooding levels shown by the 11-foot scenario appear to suggest a minimum flood district that may bear increased regulation and attention.

2. Loss of marshes and uplands

The GIS analysis indicates that approximately 1.3% of the Town will be inundated for a 2-ft rise in sea level, whereas almost 9% of the Town will be inundated for a 15-ft rise. The inundated land includes both marsh and upland. The three critical areas, as defined based on the GIS results, are the causeway, Little Harbor, and Wyman Cove. Of these, the impacts to the causeway will likely be the most significant to the Town; the causeway is essentially flooded for the 11-ft sea-level rise scenario, thus isolating Marblehead Neck as an island. Additionally, the marsh at Goldthwait Reservation will eventually disappear due to the encroaching sea and the lack of available substrate for redevelopment.

Town parks within these critical areas will also be impacted by the 11-ft sea-level rise scenario. Near the causeway, Riverhead Beach, Devereux Beach, and Tuckers Beach, in addition to Goldthwait Reservation, will be flooded during an 11-ft sea-level rise. Fort Sewall and Grace Oliver Beach, in the vicinity of Little Harbor, may also be impacted during flood conditions.

Although the 15-foot scenario is unlikely in the near future (other than for intermittent flooding), it does provide a useful landward margin for possible encroachment of the sea. The intrusion limits for this scenario may form the basis for a flooding overlay district, that can be enforced in a concentric fashion through time.

3. Groundwater

Presently, most of the water for the Town of Marblehead is supplied by the MWRA line. The few remnant wells may be impacted by sea-level rise; the increase in the level of the ocean may result in salt water intrusion of these wells.

However, in a related sense, changes in climate may cause increased periods of drought in Massachusetts and elsewhere along the eastern seaboard. This increase in drought duration may impact MWRA's ability to continue to provide high quality water to Marblehead. The Town has investigated the possibility of reactivating the Town aquifer, located in the Marblehead Water Department in Salem. Although this would not likely be the sole water supply to the Town, it could be used to augment the MWRA line. The Town should continue to monitor this possibility as we learn more about likely consequences and timing of climate change. The Town may eventually require alternate sources of water to supplement decreased MWRA capacity or increased local demand.

As discussed previously (Section III.C.3.), pumping of coastal freshwater wells results in a rise in the saltwater/freshwater interface. The amount of rise depends on the amount of pumpage, are well as other factors such as local geology. Therefore, before reactivating the Town aquifer, an in-depth study should be made to evaluate the potential for salt water intrusion due to changes in the interface likely to result from increased pumping.

Additional impacts to the water supply include flooding of pumping and ejector stations. Based on conversations with Dana Snow, Superintendent of the Water and Sewer Commission, many of these stations were flooded during the Blizzard of 1978. These included the stations at Phillips Street, Sargent Road, Fort Sewall Terrace, Crowninshield Road, Harbor Avenue, Corn Point Road, Mooring Road, and Seaview Avenue. As sea level continues to rise, these stations and others will likely be flooded more frequently. Additionally, changes in storm patterns, such as more frequent or severe storms, will cause increased damage at these stations.

4. River/estuary flow and sedimentation

The considerations for changes in river/estuary flow and sedimentation are not as important for Marblehead as for other communities for several reasons. First, local wells do not supply a significant portion of the freshwater needs of Marblehead, so intrusion along river courses is not a major issue. Second, Marblehead is served by only a small river, that has wide exposed tidal flats, and that drains a relatively small basin. We identified no river issues that were of particular importance for the Town related to rising sea-levels.

B. Suggested Procedural Responses

1. Zoning

a. Coastal Overlay District

Marblehead already has asserted its zoning powers to control building along its waterfront by enacting a Coastal Overlay District (COD). Although the Land Court struck down the COD, Marblehead can use this experience to fashion a new COD that will respond to the threat of rising sea level as well as survive scrutiny by the courts.

The 2-ft, 6-ft, 11-ft, and 15-ft sea-level rise scenarios provide a useful tool for mapping out a new COD. Because of the uncertainties associated with climate change and sea-level rise, a COD based on the 2-ft rise scenario likely stands the best chance against judicial attack. However, the 11-foot scenario may be useful for flood zoning. A concentric COD based on different time scales (25, 50, 75, 100 years) could be modeled.

To protect against flooding, long-term inundation should not be the sole measure of the COD's geographic scope. Instead, the COD could encompass those areas subject to storm surges and extreme high tides under the 2-ft scenario. The 11-foot scenario is the appropriate level for flood consideration. The basis for the COD's area should be made explicit in the bylaws so that the connection between sea-level rise and setback is clear. Furthermore, this detailed background information demonstrates that the re-zoning is the result of a thoughtful, reasonable planning effort.

While the old COD concentrated on the nature of the proposed use, especially whether it was water dependent or not, the new COD can be use-neutral. Whatever uses are allowed in the underlying district should be allowed in the COD. Instead, the COD will concentrate on expected structural lifetime and setbacks from the high water line.

One possible scheme would prohibit any new structures within the COD. A special permit process could be used to allow structures with limited lifetimes (for example, lifetimes less than the time projected for rising sea levels to threaten the site). A special permit could also be issued if the owner agrees to relocate the structure upland as the sea level rises. This process could employ height and floor area ratio standards to ensure a structure can be moved when necessary. In addition, the owner of the building site must keep a relocation area available meeting all present zoning requirements for dimensions and use of the proposed building. Relocation to this reserve area would grandfather application of zoning bylaws. If the reserve area is sold into separate ownership, the structure must nevertheless be removed when the sea level rises. No special permit can be granted until these conditions are recorded in the Registry of Deeds.

b. Existing structures

Most of Marblehead's coastline presently is developed. Regulation of new development may reduce flooding in some areas, but the real problem is the developed coastline. Marblehead's current zoning bylaws allow alteration, change in use, and extension of a non-conforming structure by special permit without compliance with current zoning bylaws. The Board of Appeals will issue such a special permit if it determines the revamped structure or use will not be significantly more detrimental than the existing non-conformity to the neighborhood (Article VI.1B). Furthermore, the bylaws do not require zoning compliance for a structure repaired or reconstructed because of accidental damage (Article VI.1C).

If the Town wishes to remove existing structures in areas particularly vulnerable to sea-level rise, the above non-conformance provisions for structures within the COD may be revised. This may be politically unpopular, but C. 40A merely allows, rather than requires, a municipality to grandfather such changes to non-conforming structures. As long as the structure is not a single or two-family residence, Marblehead can apply current zoning regulations, such as setbacks from the high-water line under the COD, to revamped non-conforming structures.

c. Development fees for armoring coastline

Marblehead may decide that a certain portion of its coastline should be more intensively developed than the above COD scheme would allow. For that area, a building permit could be conditioned on the developer's contributions to "armoring" the coastline for the length of the project. In order to streamline the M.G.L. Ch. 91 regulation of such structures, Marblehead could establish a coastal protection agency which would actually construct the improvements. The developer would pay a fee to the agency in accordance with the cost of protecting his lot.

This complex scheme requires a lot of planning. The following is a non-comprehensive list of concerns to be addressed before implementing such a scheme:

i. only those areas which could be armored without adversely affecting surrounding unarmored coastal areas should be targeted for this type of development.

ii. any activity under the armoring program on public trust lands, will require approval from DEP under Ch. 91. Rather than take a case by case approach, the municipality should try to have the entire program authorized as part of its Ch. 91 municipal harbor plan.
iii. in order to defeat a takings challenge, the fee exacted must be used to advance substantially the same public purpose the development would adversely affect (e.g., must help protect the developed property from sea-level rise).
iv. amount of fee must be proportionate to proposed development.
v. in order to avoid characterization as an illegal tax, every development fee exacted must be segregated into a separate account to armor that area of coastline at issue.
vi. coordination of armoring entire area to be developed with exactions.
vii. fees collected may not exceed costs of armoring and if not spent must be refunded.

2. Wetlands Protection

Marblehead's present wetlands bylaw prohibits any development "within 100 feet of any land subject to flooding or inundation by groundwater, surface water, tidal action, or coastal storm flowage" without the approval of the Marblehead Conservation Commission (Wetlands Protection Bylaw, Section 2). This language is ready-made for regulation based on sea-level rise. By simply defining "subject to" to include the effects of a 2-ft sea-level rise, the Conservation Commission can create a future wetland buffer zone.

Within this buffer zone, the Conservation Commission may impose special drainage, sewage, site modification, and sedimentation controls to ensure the ability for inland wetland migration. Where the geology of the buffer zone would prevent such migration, the requirement might be less stringent.

Marblehead currently has no sanitary sewage regulations. Unless the Town requires a sewer system connection for every building, the Board of Health should consider enacting sanitary sewage regulations to supplement Title V. These regulations could impose a septic system setback from wetlands coordinated with the above mentioned future wetland buffer zone. In addition septic system location should take into account the rising sea level's effect on groundwater elevation levels. Title V prohibits locating systems where the groundwater is closer than four feet from the surface. Board of Health regulations could increase this minimum requirement to take into account sea-level rise.

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APPENDIX A
GIS DESCRIPTION

A GIS is a specialized data management and analysis system designed for digitizing, analyzing, managing, and displaying data commonly stored in map form. A GIS stores both cartographic and attribute data. The map data are commonly stored in the computer in vector form so that points, lines, and polygons are geographically referenced to x,y coordinates. The attribute data are stored as tabular data. A GIS processes the combined cartographic and attribute data sets. The user selects which of all the possible relationships between these data sets will be analyzed, and controls the form of the resulting output.

James Dobbin Associates were subcontracted by Aubrey Consulting, Incorporated to digitize the Town of Marblehead topographic maps and enter the data into the GIS. James Dobbin Associates operate a SPANS (Spatial Analysis System) GIS developed by TYDAC Technologies. This GIS system permits a full range of data entry, management, and analysis tools for application to spatial data of various types. SPANS has developed a versatile data format that has translation capabilities to a variety of other GIS systems, such as AMS and GIS by GeoVision of Ottowa, ARC/INFO, AutoCAD, GeoBased Systems, Intergraph, Synercom, Meridian by MacDonald Detwiler, ERDAS, EASI-PACE, and ARIES.

The SPANS GIS has many attractive features in addition to its translation capabilities and efficient data format. The system can overlay up to 14 map layers at one time; most GIS systems are limited to only two map layers. SPANS can transform data to and from most commonly used map projections, including Lambert Conformal Conic, Universal Transverse Mercator, Polyconic and others. The Massachusetts State Plane Coordinate system, for instance, is based on the Lambert projection. In contrast, the USGS uses a polyconic projection for the same area. Information exchange between the Town of Marblehead and various state and local agencies using different map projections is simplified and automated by SPANS.