Chapter Two

VULNERABILITY OF MAINE SITES TO ACCELERATED SEA-LEVEL RISE

Based on the analysis in Chapter One, it is clear that Maine faces a strong probability of a future with a higher-than-present level of the sea. The critical questions are:

1) how a higher sea level is likely to impact the coastal area if no steps are taken to respond to the threat; and
2) what efforts need to be undertaken to prevent any disasters, minimize the risk, and manage the consequences.

To assist with answering these questions, coastal managers and decision-makers need information about the potential magnitude of the problem, and the implications of the threat for both natural and socio-economic systems.

This information is typically developed in a study called a *vulnerability assessment*. It provides decision makers with an understanding of the susceptibility of the shoreline to rising sea-level, clarifies the need for advanced planning, and provides information for priority setting between specific coastal areas and/or economic sectors within the State.

A. DESIGNATION OF CASE STUDY AREAS AND SEA-LEVEL RISE SCENARIOS

The first step in the vulnerability assessment was to delineate case study areas and to specify the sea-level rise scenarios to be assumed when mapping the future position of the shoreline at representative locations. The research team identified seven representative southern Maine study sites in Casco and Saco Bays, adjoining estuaries along the western margin of the Gulf of Maine. (*See Figure 2.1)* The two bays have differing geological histories (described in more detail in "Setting of Study" in Appendix C) and typically have different land use patterns as well. Portland, Maine's largest city, is located on the southwestern edge of Casco Bay. Commerce and industry dominate its portion of the bay, with suburban residences spread out away from it. Only in the northern portions of the bay and on the islands can one find rural development (Kelley et al., 1989a). Representative Casco Bay study sites were: Gilsland Farm (Falmouth), Bungunac Bluff (Brunswick) and Wharton Bluff (Brunswick).

Saco Bay is dominated by Old Orchard Beach, Maine's largest resort beach. Motels and commercial establishments cover the former sand dunes along the central part of the main beach, while summer residences are often set back behind sand dunes elsewhere. Similar, but less intense development has occurred along other Saco Bay beaches as well. Along the landward margins of the large salt marshes, residential development has begun to occur. Representative Saco Bay study sites were Winnocks Neck (Scarborough), Pine Point (Scarborough), Old Orchard Beach, and Camp Ellis (Saco). (For additional background on the Casco Bay/Saco Bay region, see Appendix C.)

These study sites represent three different types of environmental settings: salt marsh, bluff and beach. A Gilsland Farm site and the Winnocks Neck study area are primarily on or adjacent to salt marshes. A second Gilsland Farm site, Bungunac Bluff and Wharton Bluff are located on eroding bluffs. Old Orchard Beach and Camp Ellis are located on or adjacent to sand beaches.

As discussed in Chapter One, due to scientific uncertainty about future impacts of global climate change, the study opted to use three different sea-level rise scenarios in assessing impacts. This study evaluated the future position of the shoreline at these representative locations in Casco and Saco Bays using scenarios of sea level 50, 100 and 200 cm above present sea level in the year 2100.

B. PREDICTION OF FUTURE SHORELINE POSITIONS

In the next step in the vulnerability assessment, Maine Geological Survey predicted future shoreline positions for each study site, assuming the different sea level rise scenarios. Three different methods were employed to predict future shoreline positions in differing coastal environments. The first method considered only simple submergence of the coast by the rising ocean to the predicted elevations (0.5 m, 1.0 m, and 2.0 m). To determine the distance from present mean high water to the predicted levels along a traverse, the elevation was evaluated by leveling and the distance by measuring tape. The distance from present mean high water to the predicted locations was transferred to maps (1:24,000) which depict contemporary coastal environments (Timson, 1977).

This technique was used in low-energy areas where tidal marshes border the upland (Gilsland Farm, Winnocks Neck). Three or more traverses were made at each study site, and three measurements were averaged parallel to each traverse. Erosion was not observed along the ocean-upland contact, and it was inferred that rising sea level would permit colonization of the upland by salt marsh plants. Cores from marshes like these show a landward-thinning deposit of peat reflecting the slow upward growth of the marsh with rising sea level (Kelley et al., 1988; Belknap et al., 1989).

Where an eroding bluff occurred at the high-tide line, an historical analysis of the rate of bluff retreat was made. In two locations (Bungunac and Gilsland Farm) the bluff had been resurveyed several times in the 1980's (Smith, 1990) and these measurements of bluff retreat were used to project the future shoreline position of the sea, assuming that the retreat rate remained constant. Historic photographs from 1940, 1972, and 1985 were also traced onto mylar under a zoom transfer scope, and the resulting maps digitized for comparison with the measured rates. The "long-term" rate of retreat evaluated by remote sensing was comparable to that evaluated directly by surveying in the "short term".

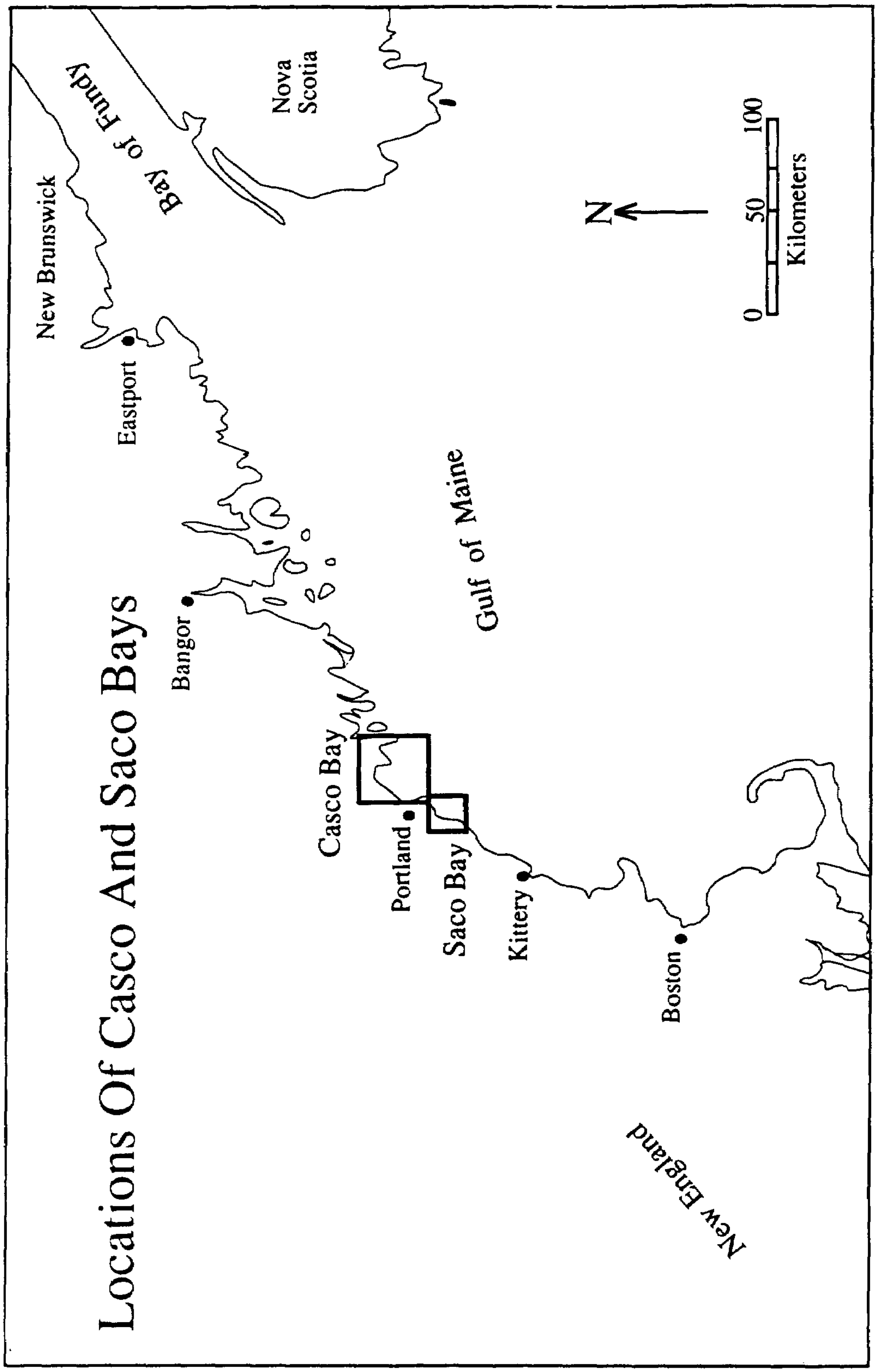


Figure 2.1. Location of Casco and Saco Bays in relation to New England and the Gulf of Maine.

The bluffs considered by this method are retreating because waves break against them at high tide. In a study of the factors controlling the rate of bluff retreat in Maine (Smith, 1990), bluffs in three bays (Casco Bay, Machias Bay, Damariscotta River Estuary) with differing rates of sea-level rise were compared. In each bay several bluffs were surveyed and evaluated, and at each bluff site, several traverses were made. An analysis of variance (ANOVA) could not discern a difference in the rate of bluff retreat between the three bays with differing rates of sea-level rise because there was so much local variability at a specific site (Smith, 1990). The reason for this is that many other factors influence the susceptibility of bluffs to erosion (orientation of the bluff, height, composition, rate of slumped debris removal etc.). It is assumed that the bluffs will continue to retreat at their present rates regardless of the rate or amount of sea-level rise, or even whether sea level rises. Although one might argue that a 2 m higher-than-present level of the sea would allow waves more time to act on already eroding bluffs, the limiting factor affecting bluff retreat appears to be the rate of removal of eroded sediment, which would not be directly related to a higher sea-level (Kelley et al., 1989a). Thus, only one 100 year shoreline position is shown for bluff-coasts, and it is based on the current rate of bluff retreat.

Prediction of future shoreline positions in Saco Bay is more complex than for the other shoreline types because the area has not behaved uniformly during the historic period. At the southern end of the bay (Camp Ellis), erosion and accretion have each occurred in the past and have been significantly impacted by engineering structures and dredging and spoils disposal activities at the adjacent river mouth (Nelson, 1979, USACOE, 1992). Based on the past record of aerial photographs and ground surveys, the United States Army Corps of Engineers has published predicted retreat rates for the area (USACOE, 1992).

Along most of the central portion of the beach (Ferry Beach and Old Orchard) the shoreline has fluctuated over the years across a very wide littoral zone, and few, if any, landmarks have ever been removed by erosion despite the rise in sea level of about 0.3 m in this century (Nelson, 1979). It is possible that this region has received sand eroded from the south in sufficient quantities to prevent erosion. Alternatively, erosion may have claimed some of the beach, but it is more than 100 m wide, and the amount of erosion is not quantitatively measurable (there are no vegetated sand dunes with which to evaluate shoreline retreat).

At the northern end of the beach (Pine Point), significant accretion has occurred because of spoils disposal and construction of a jetty (Nelson, 1979). This area is also at the depositional end of the longshore current system of the beach, and accumulates sand lost from other places in the bay.

To project future shoreline positions in such a complex bay, a geo-historical approach was utilized, and the long-term behavior of the beach system was evaluated. Approximately 10,000 years ago sea level was 15 km seaward of the present coast (Kelley et al., 1992; Shipp et al., 1991). The estimated depth of this lowstand shoreline varies from 50-65 m below present sea level, with 50 m being a conservative figure. To reach its present location, the shoreline must have retreated at an average rate of 1.5 m/yr (Kelley et al., 1992). The rate of sea-level rise was not constant during this time period, but averaged 0.5 m/century, the same value as the low estimate for the next century's rate of rise. If the system behaves as it did in the past, the beach will retreat 150 m during the next 100 years if sea level rises 0.5 m. If sea level doubles or quadruples its rate of rise to 1.0 m/yr or 2.0 m/yr, respectively, it is assumed that the retreat will double or quadruple as well. Thus, 300 meters of retreat are assumed if sea level rises 1.0 m and 600 meters of retreat if sea level rises 2.0 m by the year 2100.

These values are broadly in line with estimates that would result from employment of Weggel's (1979) calculation: $r = b/(d + s) \times h$, where r is the amount of retreat, d is the dune height, s is the offshore depth of no-sediment motion, and h is the amount of sea-level rise. This equation excessively generalizes a very complex beach and assumes the existence of a profile of equilibrium that recent literature debunks (Pilkey et al., 1993, List, et al., 1991). The extreme rates of longshore sand transport in the Old Orchard Beach system generally negate use of Bruun's (1962) two-dimensional model on the Saco Bay system. Nevertheless, values of b from 5 to 15 km, values of s from 10 to 50 and values of d from 1 to 5 yield retreat distances between 300 m and 600 m for sea-level rise scenarios up to 2 m greater than present.

These estimates of beach response to rising sea level are much less precise, much more uncertain, than predictions based on the historic retreat rates of bluffs or of land submergence. There is as yet no quantitative understanding of the volume of sand contributed by the Saco River, and no consideration is given here to where sand eroded from one part of the beach might go. Any change in the role of the Saco River as a source of sand to the bay would probably be significant to the behavior of the beaches. Similarly, a large amount of erosion from one part of the beach would likely contribute sand to other areas and lessen their erosion. To provide more quantitative information on future shoreline positions for Saco Bay, far more observational data and modelling is required. For the purpose of planning for future rises in sea level, the 150 m, 300 m and 600 m values of land retreat projected are adequate.

The detailed results of the mapping effort are discussed for each study site, beginning on page 7 of this chapter (and for Camp Ellis, on page 1 of Chapter Three). For each site, Maine Geological Survey describes the setting and summarizes its projections of future shoreline position. The mapping section is followed by a Maine State Planning Office assessment of physical changes and natural system responses, as discussed in section C, below.

The Maine Geological Survey results are summarized in Table 2.1. It is important to keep these findings in context. The rise in sea level over the past 10,000 years is responsible for the present configuration of the Maine coast. A continuation of the historic rate of sea-level rise of around 2 mm/yr (20 cm/100 years) places many properties in jeopardy. An increase in the rate of sea-level rise may occur, however. In this study, shoreline changes resulting from sea levels 0.5 m, 1.0 m, and 2.0 m greater than today, but 100 years hence, were evaluated. As described in greater detail below, the retreat of unconsolidated bluffs is not expected to change as a result of a more rapid rise in the sea, but such bluffs would continue to pose a threat to property even at their present rate of retreat (up to 0.5 m/yr). Salt marshes would passively drown upland sites, but the steepness of the bedrock-dominated coastal region will result in a much smaller area of new marsh creation (drowning) than would occur in non-rocky regions of the United States' Coastal Plain. Beaches would probably experience the most profound changes as a consequence of accelerated sea-level rise. These areas are more difficult to evaluate than other environments for many reasons, but still a retreat of hundreds of meters seems likely.

***Table 2.1*. Projected Shoreline Changes for Casco and Saco Bays, Maine**

RETREAT DISTANCE IN METERS

Location	**Environmental Setting**	**Method**	**Sea-Level Rise Scenarios**		
			0.5	**1.0**	**2.0**
Gilsland Farm (1-3)	A	1	3-18	8-36	17-75
Gisland Farm (4)	B	2	15	15	15
Bungunac Bluff	B	2	45	45	45
Wharton Bluff	B	2	26	26	26
Winnocks Neck (1-3)	A	1	4-35	23-50	33-100
Camp Ellis	C	3	60-100	60-100	60-100
Camp Ellis	C	4	150	300	600
Old Orchard Beach	C	5	18	18	18
Old Orchard Beach	C	4	150	300	600
Pine Point	C	4	+100*	50	200

Environmental Setting: A) Salt Marsh; B) Bluff; C) Beach.

Method: 1) Flooding; 2) Surveyed Rate; 3) Army Historic Photo Analysis; 4) Geo-Historical; 5) Historical Fluctuations.

* Beach Growth, Not Retreat

Location, environmental setting, methodology and retreat distance estimated for the three scenarios of future sea-level rise. Bluffs are assumed to retreat the same distance under all scenarios as well as under a continuation of the existing sea-level rise rate because they are already reached daily by ocean waves. We cannot accurately predict the behavior of marshes which respond both to sea-level rise and sediment supply. Under present rates of sea-level rise: 1) Pine Point is growing seaward because of sand introduced from erosion at Camp Ellis; 2) Old Orchard Beach is fluctuating in shoreline position due to varying inputs of sand from Camp Ellis; and 3) Camp Ellis has been eroding at rates from 0.6 to 1.0 m per year according to an Army analysis.

C. ASSESSMENT OF PHYSICAL CHANGES AND NATURAL SYSTEM RESPONSES

The next step in the vulnerability assessment was for the Maine State Planning Office to inventory study area characteristics, identify relevant development factors and assess physical changes and natural system responses given the shoreline positions predicted by Maine Geological Survey. This portion of the analysis is not intended as a precise quantitative analysis of the vulnerability of Maine's coastline to accelerated sea-level rise. It is more accurately characterized as a planning exercise to identify the types of problems Maine is likely to experience and the potential location of these impacts. This preliminary assessment should form the basis for further discussion and evaluation of possible actions.

Scientists have compiled multiple lists of a myriad of possible impacts on the coastal zone related to global climate change (Stewart, 1990, Pernetta and Elder, 1992); they vary according to the assumptions made and the extent to which secondary impacts are included. In assessing the vulnerability of the selected sites to the impacts of global climate change, the research team tried to emphasize the *likely* over the *merely possible*. Following the lead of the first nationwide vulnerability assessments in the United States (Titus, et al., 1991), this study attempted to consider as many factors as possible, but concentrated on developing estimates of loss of dryland and wetlands for three sea-level rise scenarios. Specifically, researchers focused on four physical impacts likely to be experienced in Maine: change in shoreline position, accelerated erosion/inundation of dunes and beaches, inundation of wetlands and lowlands, and loss of natural coastal protection systems.

The research team believes this focus was appropriate for this initial study. These four impacts generally need to be studied prior to work on other physical changes, are more direct, and the resulting impacts tend to be more amenable to mitigation through governmental action. Additional studies will be required to assess the impact of other likely physical changes such as increased risk of coastal flooding and storm surges, alteration of tidal ranges, and increased potential for salt water intrusion.

The following assessments describe, in as much detail as readily available information would allow, the anticipated physical and natural systems responses to accelerated sea-level rise anticipated in each of the six study sites in Saco and Casco Bays. Whenever possible, the assessment also discusses potential impact for the Saco and Casco Bay region as a whole. (*See also* Appendix C)

An assessment of five of the six study sites is included in this chapter. The sixth site assessment, Camp Ellis, is presented separately in Chapter Three as an example of the level of analysis that could be developed for each location if additional staff time and a more detailed data base were available. The State Planning Office went beyond readily available information for Camp Ellis to develop the data necessary for a rough economic assessment of the costs and benefits of selected response strategies, presented in Chapter Four.

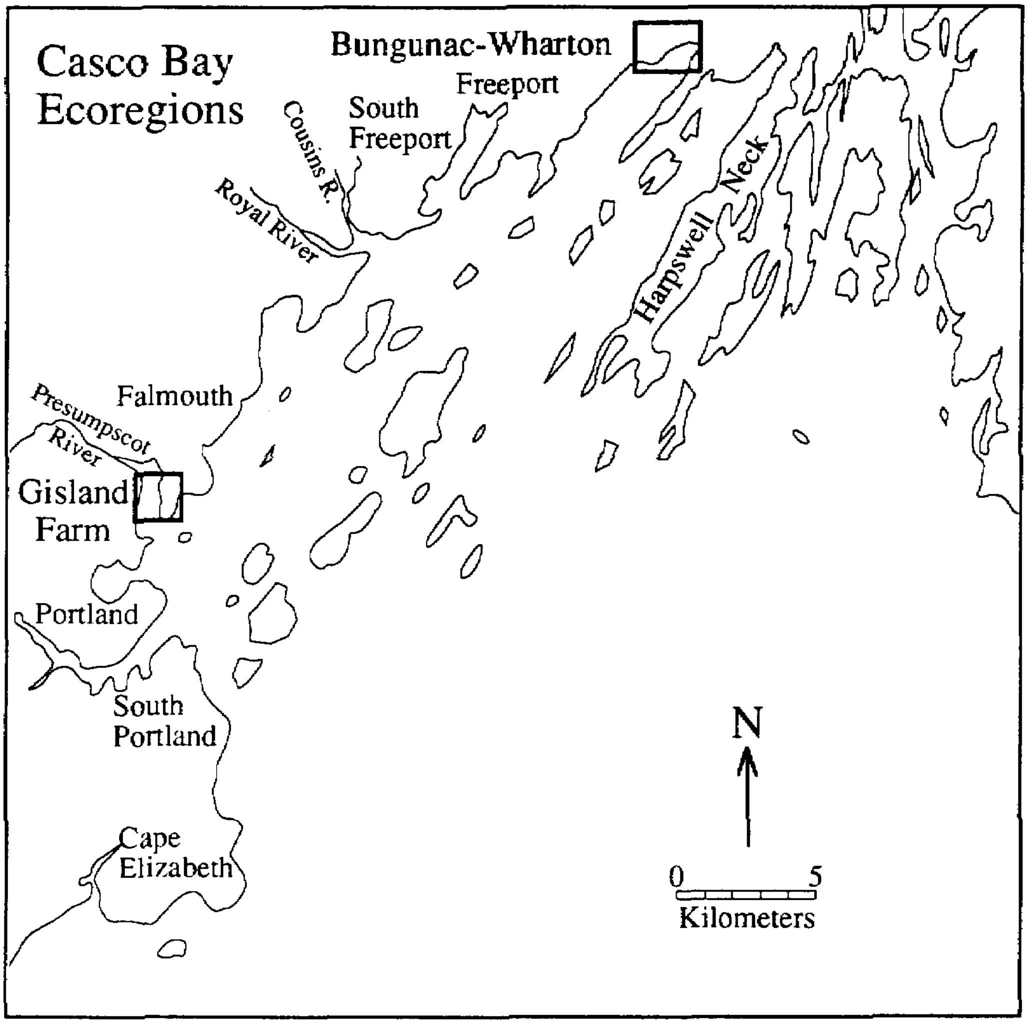


Figure 2.2. Map of Casco Bay with location of study sites enclosed by boxes.

D. RESULTS

1. Gilsland Farm

a. Shoreline Position

Gilsland Farm is located in western Casco Bay near the mouth of the Presumpscot River. (*Figure 2.2*) Bluffs of glacial-marine sediment abut the river in the western portion of the study site, while a salt marsh fills a small valley to the north. *(Figure 2.3)* The bluff rises 9 m above higher high water and large trees and blocks of sediment are actively slumping down parts of its face. (*Figures 2.4, 2.5*) The surveyed erosion rate here between 1985 and 1988 was 0.15 m/yr with a standard deviation of 0.2 (Smith, 1990). Historic air photo analyses yield retreat rates of 0.12 m/yr between 1940 and 1972, and 0.04 between 1972 and 1986, with standard deviations of 0.3 and 0.05, respectively. The large standard deviations result from the episodic erosion along the face of the bluff over time (Sunamura, 1983). The air photos were difficult to interpret because falling trees and slumping blocks partially obscurred the toe of the bluff. For this reason, the surveyed value of 0.15 m/yr was extrapolated to a retreat distance of 15 m by 2100. (*Table 2.1*) (*Figure 2.3*)

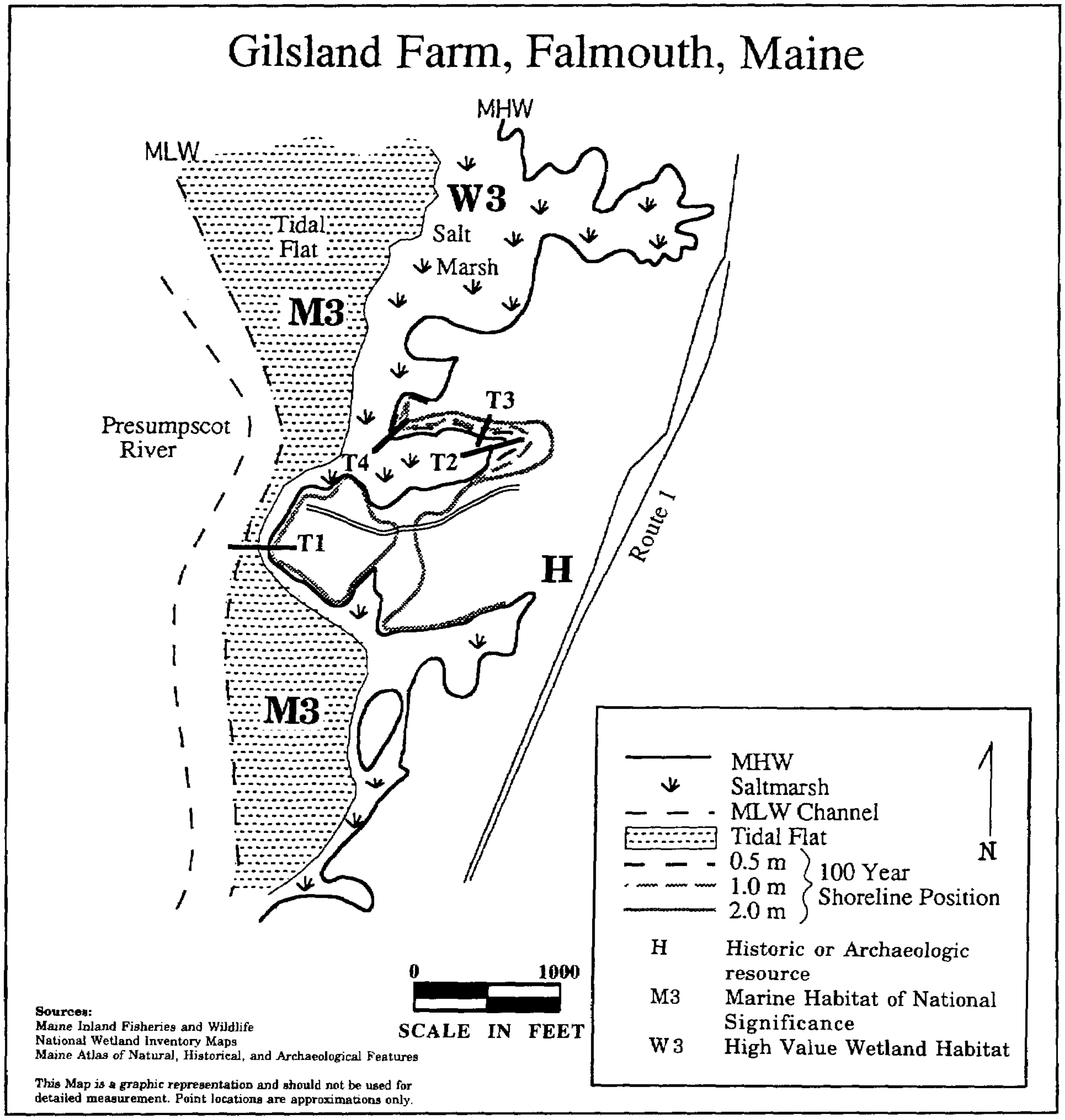


Figure 2.3. Projected shoreline change at Gilsland Farm, Falmouth, Maine. Mapping was limited to the area surrounding Gilsland Farm, although the surrounding area is also depicted. Coastal environments after Timson (1977).

Figure 2.4. Photograph of Gilsland Farm. Site of Traverse 1.

Although the salt marsh is also eroding in front of the bluff, to the north the marsh appears more stable. A *Spartina alterniflora* marsh (low marsh) grades into wetland dominated *Spartina patens* (high marsh) followed by *Typha sp., Solidago sp.* (freshwater marsh), and then upland plants. The transition from halophytes to freshwater plants was gradual, so survey traverse 2 was begun at the contact between the wetland and a mowed field. This traverse was aligned directly up the axis of the valley, the gentlest slope in the area. As a result, the distances to the 0.5 m, 1.0 m and 2.0 m elevations were more than 3 times that observed in traverses 3 and 4, along the steeper western wall of the valley. (*Figures 2.3, 2.6, 2.7, 2.8*) The greatest extent of submergence over dry upland is estimated at almost 75 m up the valley axis. (*Table 2.1*)

Because of irregularities in the slope of the land, a range of distances to the three elevations were observed and recorded. (*Table 2.1*).

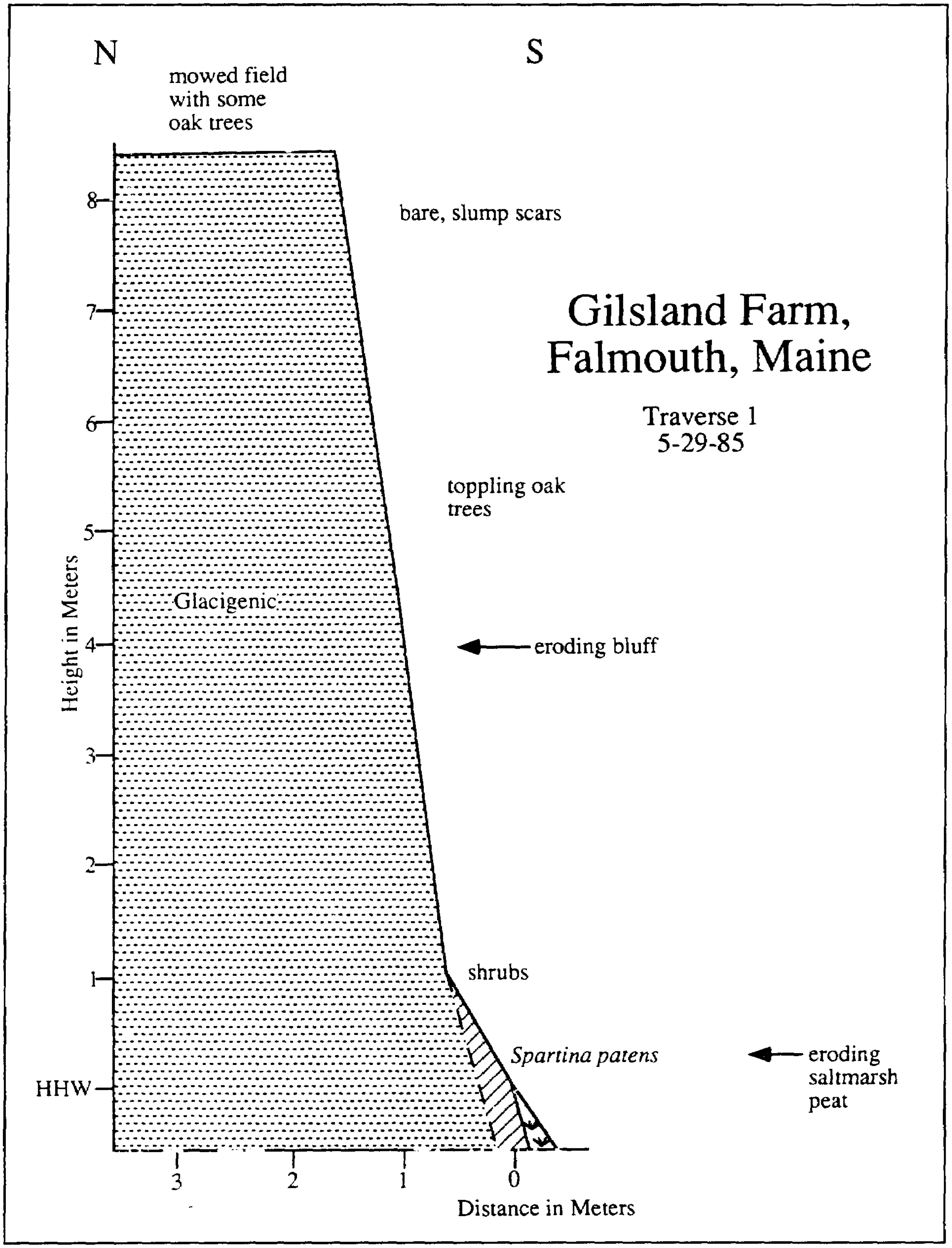


Figure 2.5. Traverse 1, Gilsland Farm. Traverse 1 is located on Figure 2.3.

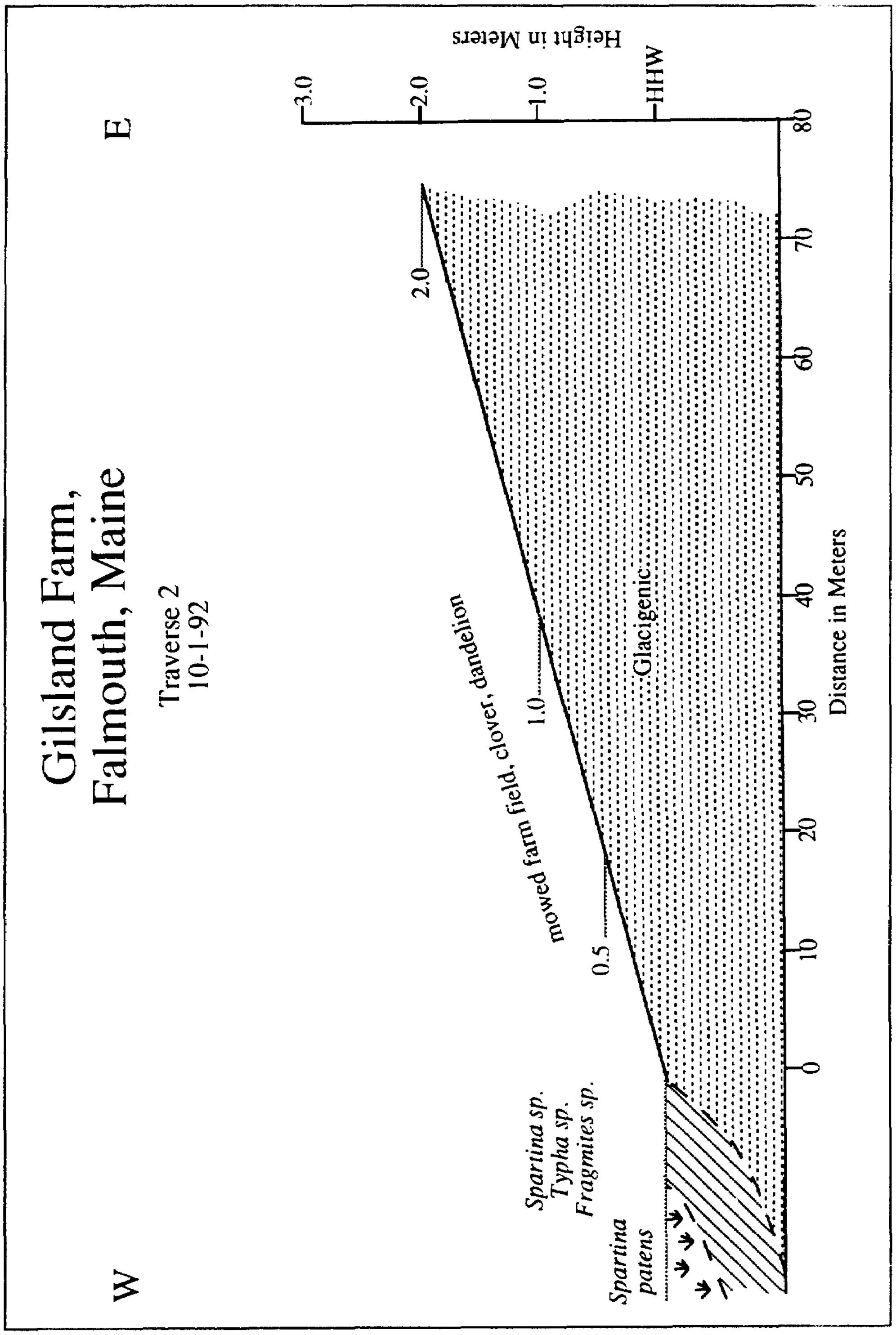


Figure 2.6. Traverse 2, Gilsland Farm. Traverse 2 is located on Figure 2.3.

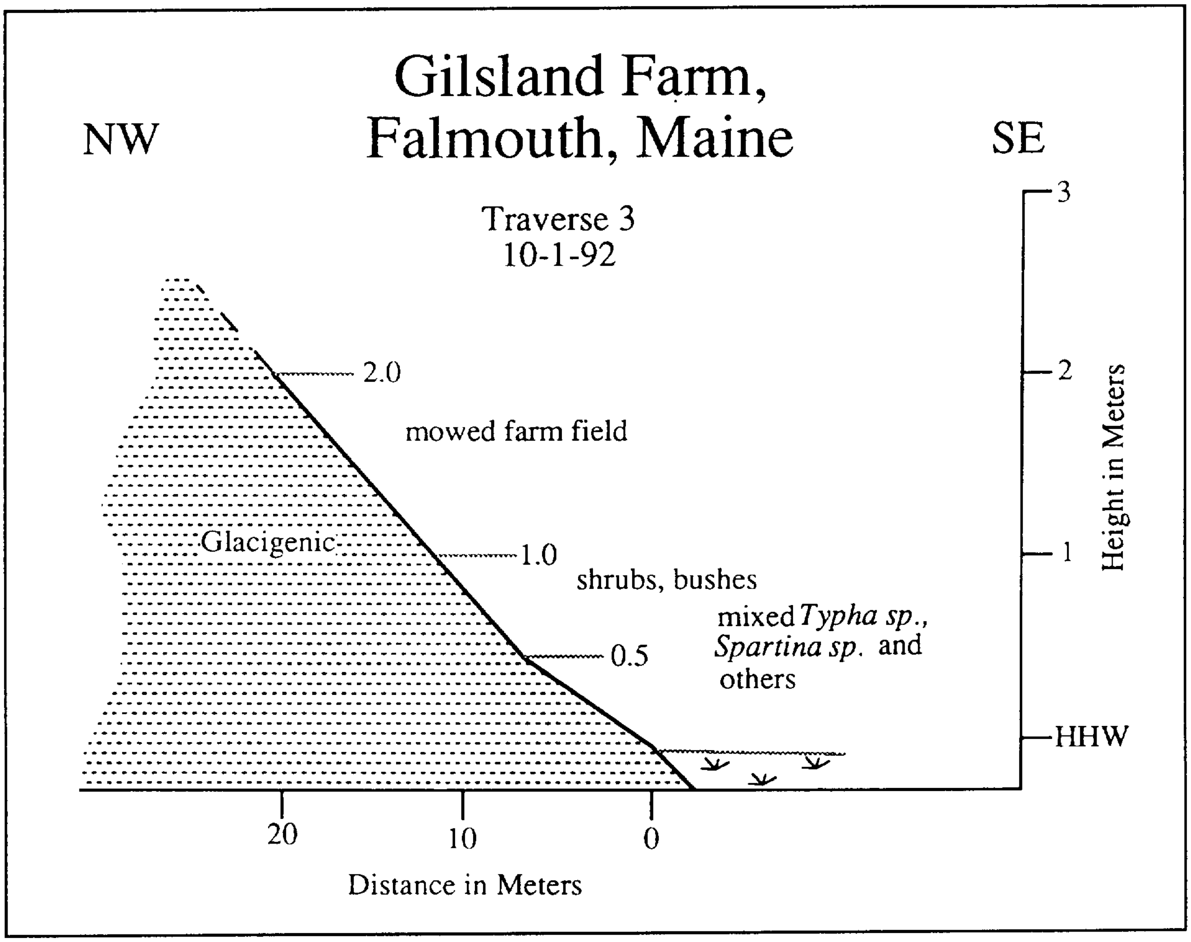


Figure 2.7. Traverse 3, Gilsland Farm. Traverse 3 is located on Figure 2.3.

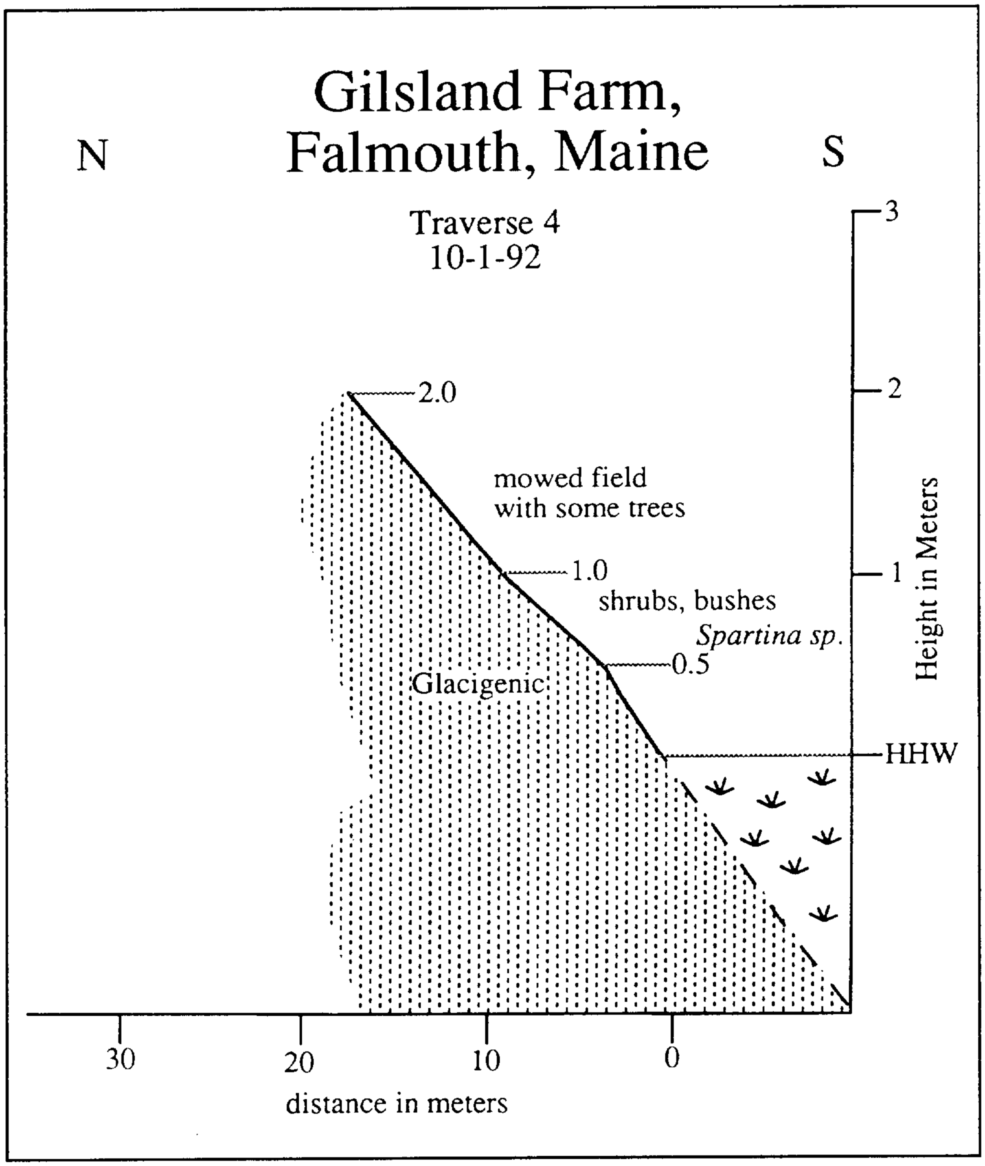


Figure 2.8. Traverse 4, Gilsland Farm. Traverse 4 is located on Figure 2.3.

b. Impact Assessment

1) Upland Impacts

The mapped study area at Gilsland Farm included approximately 50 acres of dryland, 25 acres of adjacent salt marsh and a large expanse of tidal flats. Estimates of the loss of upland according to sea-level rise scenarios are as follows:

	.5 m rise	1.0 m rise	2.0 m. rise
Dryland Lost	3 acres	5 acres	14 acres

2) Value of Land/Structures

A quantitative analysis of the monetary value of anticipated losses at this site was not possible. This site is unlike the others considered in this analysis in that it is not developed, and is owned and operated by Maine Audubon as a sanctuary and field office. Gilsland Farm has extreme local, regional, and possibly statewide significance as a recreational, educational, historic/cultural, and pristine resource. It was selected as a study site because of its accessibility for field investigations, and is illustrative of probable impacts on similar, developed sites.

3) Wetland Impacts

Wetland and marine habitats of high quality and national significance exist at this site, part of a large system of wetlands and tidal flats that comprise the Presumpscot River Estuary. The US Environmental Protection Agency (USEPA) has been a leader in studying the possible effects of sea-level rise on salt marshes (Titus, 1987, USEPA, 1989). Drawing on those studies, researchers understand that salt marshes adjust to sea-level rise by expanding inland and towards the water and increasing in elevation through accumulation of sediments and plant biomass. In general, marshes will expand when sedimentation exceeds submergence, will maintain if sedimentation balances submergence, and will drown when sediment supply and accretion is less than the rate of coastal submergence (Sea-level plus subsidence). Besides the natural availability of sediment, other factors such as slope of adjacent uplands, the presence of coastal engineering structures, the armoring of bluffs and banks limiting the amount of available sediment, and the rate of sea-level rise all affect the ability of marshes to migrate landward to keep pace with accelerated sea-level rise. In addition, marshes that have been fragmented by land development or otherwise degraded by human influences will have diminished ability to migrate (U.S. Congress, Office of Technology Assessment, October 1993.) *Figure 2.9* (Titus, 1986) illustrates these various scenarios of wetland change.

The USEPA has sponsored numerous studies which modelled anticipated wetland changes due to global warming in different regions (Barth and Titus, 1984, Park et al., 1989, Titus and Greene, 1989, USEPA, 1989). In different areas of the country, studies have documented that marshes have been able to keep pace with more gradual, historic rates of sea-level rise (e.g. 2.4 mm/yr in Charleston, South Carolina, 1 cm/yr in Louisiana). One study (Park, et al. 1989) concluded that many of New England's wetlands developed on poorly drained glacial tills and occur at elevations above those that could be inundated by sea-level rise in the

Evolution of Marsh as Sea Level Rises

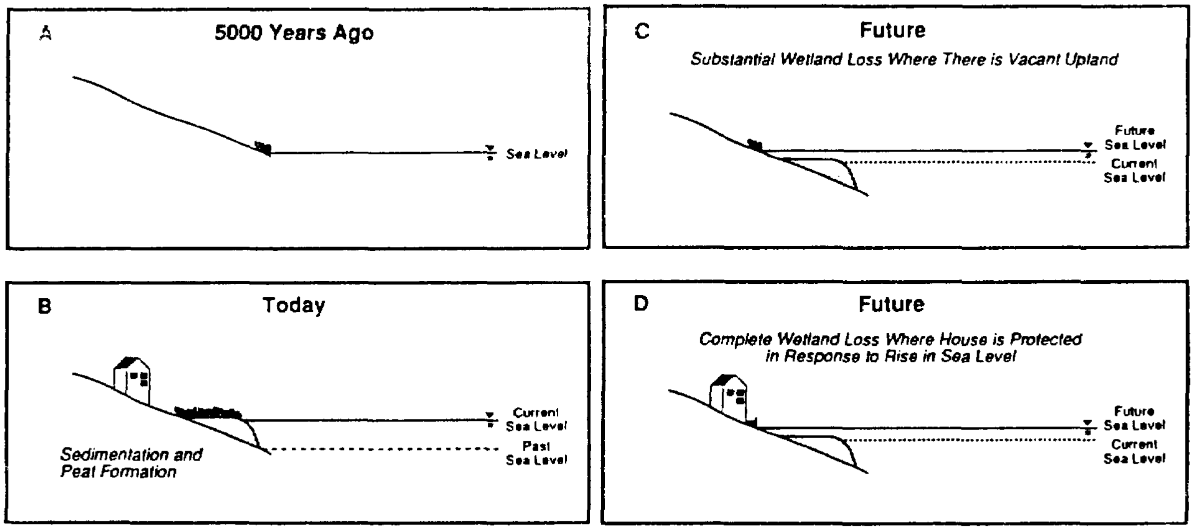


Figure 2.9. Coastal wetlands have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of wetlands increased as new lands were inundated. If in the future sea level rises faster than the ability of the wetlands to keep pace, the wetland area will decline. Construction of bulkheads or dikes to protect developed areas would prevent new wetlands from forming inland, resulting in a total loss in some areas.
Source: Titus (1986).

next century. Researchers (Armentano and Park et al., in Titus, 1987) concluded that under a scenario of accelerated sea-level rise of 1.4 m by 2100, the general response of New England wetlands would be expansion into freshwater areas, or expansion onto unprotected adjacent undeveloped lowland, dunes or beaches (especially in areas less than 3.5 m or 10 ft. in elevation). In this modelling exercise, losses of marsh due to expansion of tidal flats were small or compensated for by expansion of the salt marsh. In contrast under the high scenario of accelerated sea-level rise of 2.2 m by 2100, in sheltered places with steep slopes and cliffs (such as one of Park's study sites in Jonesport, Maine), the projected rise inundated salt marshes. In these areas, despite Maine's high tidal range, which favors the maintenance of marshes, there is little lowland to be inundated and colonized by marshes. A relatively low rate of accretion (2mm/yr), typical of New England salt marshes was assumed in these studies.

Given the information discussed above, and lacking the ability to conduct expensive, site specific studies of coastal marshes in Maine, this study assumes that (provided there are no physical constraints to landward movement and excepting areas of steep slope), the marsh surrounding Gilsland Farm (and other salt marshes covered in this study) will migrate inland in equilibrium with the .5 meter and 1.0 meter levels of accelerated sea-level rise. Under the extreme case of a projected 2.0 meter rise by 2100, losses of coastal wetlands might be anticipated. However, as noted above, Maine's coastline is more typically relatively steep and bedrock-dominated, thus, due to physical constraints and steep slopes, it is expected that a change in shoreline position will frequently result in a much smaller area of new marsh creation. No assumptions were made about the quality of the habitat provided by the newly created wetlands.

4) Extent of Similarly Situated Land in the Region

Salt marshes with associated mudflats make up more than 20% of the coastline of the larger Saco Bay/Casco Bay region. NOAA estimates that there are 2,900 acres of salt marsh in the Saco Bay estuary and 2,400 acres within the Casco Bay estuary (U.S. Department of Commerce, 1991).

A more accurate assessment of wetland impacts for the region would require more site specific analysis of different slope conditions, sediment availability, and the extent of shoreline armoring, because protection of private lands by construction of shoreline protective measures will preclude migration and result in wetland losses. However, national studies, broken down by region, have been prepared which may provide additional information. Titus and Greene (in USEPA, 1989) expanding upon Park's assessment of New England wetland losses (Park et al., 1989), estimated that between 15% and 17% of coastal wetlands could be lost if all of the shoreline was protected with bulkheads or similar structures; similarly they estimated between 6% and 10% of New England's coastal wetlands could be lost if only already developed shoreline areas were protected. If shorelines are able to retreat naturally, losses would be smaller, and in certain conditions, there might be a possible net gain of wetlands.

Using these estimates, wetland losses for the Casco and Saco Bay region, would be projected as follows:

***Table 2.2.* Range* of Potential Wetland Losses for Region**

	Natural Migration (1-5% loss)	**Developed Areas Protected** (6-10% loss)	**All Shores Protected** (15-17% loss)
Saco Bay	29-145 ac.	174-290 ac.	435-493 ac.
Casco Bay	24-120 ac.	144-240 ac.	360-408 ac.

* Range represents estimates for .5 meter, 1.0 meter, 2.0 meter sea-level rise scenarios.

5) Analysis

This site highlights the importance of protecting the ability of marshes to migrate to keep pace with rising sea level. In developed areas, there will be pressure to harden the shoreline to protect public and private investment. Much more research is needed on the relationship of marshes to sea-level rise in Maine. According to a recent newsletter of the Wells Estuarine Research Reserve (Dionne, 1993), marshes in the northeast are beginning to show signs of changes in zonation from high marsh to low marsh, indicating impacts by changing water levels and variations in available mud supplies.

Gilsland Farm is also one of the two mapped sites in the study area to contain eroding bluffs. If this were a developed site, a projected bluff retreat of .15 meters per year (about .5 ft/yr) or 15 meters by 2100 (49.2 ft) would be cause for concern.

2. Bungunac Bluff-Wharton Point

a. Shoreline Position

The coastline from Bungunac Bluff to Wharton Point forms the northwestern corner of Casco Bay. (*Figure 2.2*) Bluffs of glacial-marine sediment greater than 10 m high are common at Bungunac Bluff and decrease to a gentle slope covered by salt marsh north of Wharton Point. Where they are exposed to waves from the southwest, the bluffs are fronted by a mudflat and are very unstable. (*Figures 2.10, 2.11*) As at Gilsland Farm, large trees and blocks of slumping debris are common along the bluff face. (*Figure 2.12*) The surveyed retreat rate between 1985 and 1988 averaged 0.45 m/yr with a standard deviation of 0.16 (Smith, 1990). This compares favorably with rates evaluated from historic photographs of 0.52 m/yr between 1940 and 1972, and 0.89 m/yr between 1972 and 1986, with standard deviations of 0.28 and 0.58, respectively (Smith, 1990). The predicted shoreline reflects the surveyed retreat rate of 45 m for the year 2100. (*Table 2.1*)

To the northeast of Bungunac Bluff, wave exposure is reduced, and a salt marsh protects bluffs from direct wave attack. (*Figures 2.10, 2.14*) Here, the surveyed retreat rate was 0.26 m/yr with a standard deviation of 0.26. In historic photographs the bluff was obscurred by shadows from overhanging trees and no longer-term evaluation was possible (Smith, 1990). The projected retreat distance here is 26 m. (*Table 2.1*)

At Wharton Point no bluff erosion is occurring, and the salt marsh is locally expanding out across the tidal flat (Smith, 1990). (*Figure 2.13*) This is likely to continue into the next century because mud eroded from eleswhere in the bay is apparently collecting at the upper end of Maquoit Bay (Hay, 1988).

b. Impact Assessment

1) Upland Impacts

The mapped study area in Maquoit Bay included about 100 acres of dryland and 25 acres of wetland. Extensive tidal flats also occur all along this shoreline. The mapped 100 year shoreline position results in a loss of about 18 acres of upland.

2) Value of Land/Structures

While the area affected by slumping bluffs is usually small and localized, individual property owners can be greatly impacted by shifting shorelines. In the Bunganuc Point study area, two properties are currently experiencing land loss. Five homes may be impacted over the study period. Town of Brunswick 1988 assessment records value the Bunganuc Landing Road properties (five acre lots with substantial homes) at between $140,200 to $310,100. Two properties at Wharton Point mapped transect are valued at $199,600 and $248,500.

3) Wetland Impacts

Mudflats and wetlands in Maquoit Bay are among the most productive in the region, and are rated of national significance with high habitat values. In Bunganuc Point, there will be slight wetland losses, as slump material from bluffs is periodically dumped on the marshes. At Wharton Point, marshes are growing seaward into mud flats due to transport of Maquoit Bay mud supplies to this area.

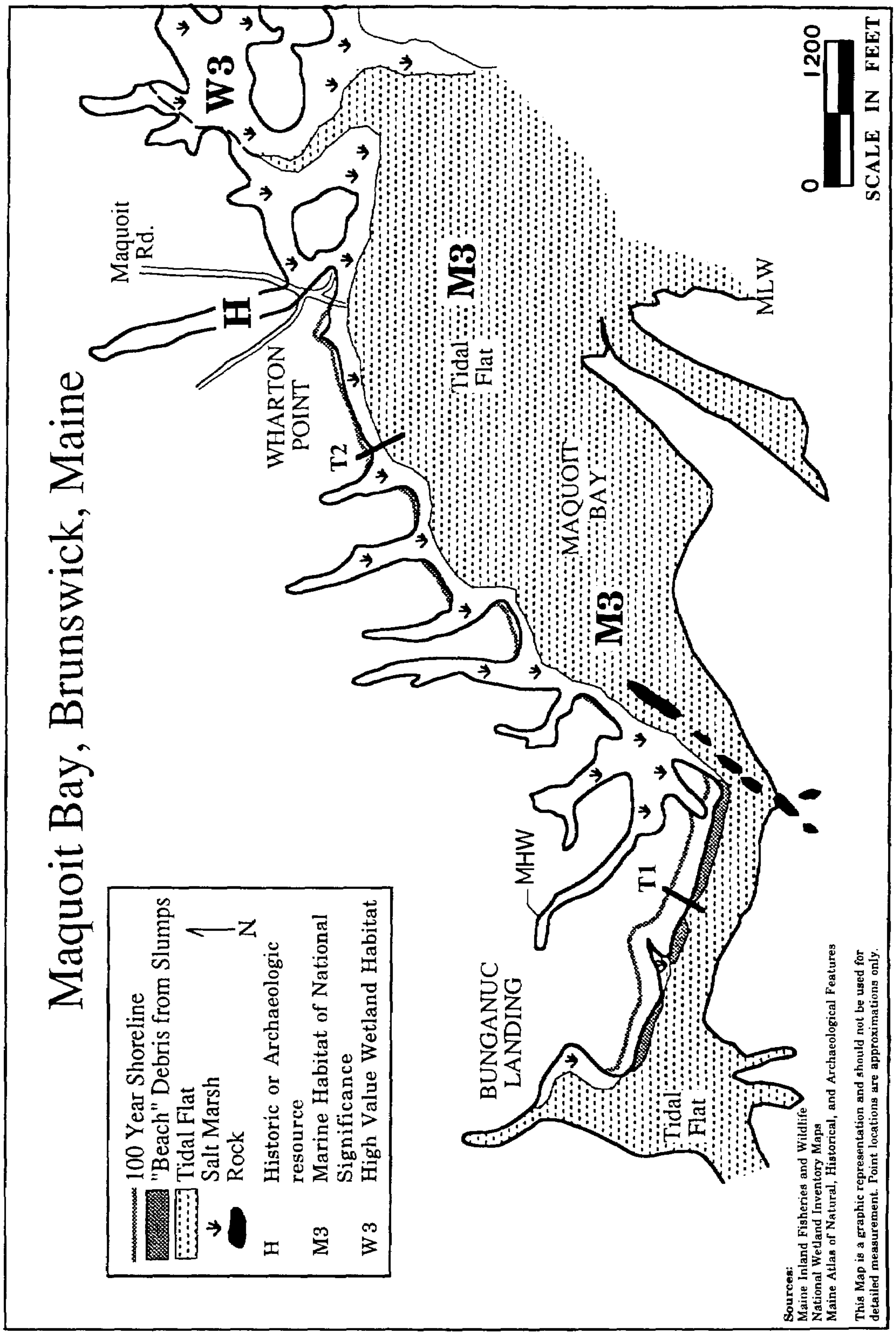


Figure 2.10. Projected shoreline change map at upper Maquoit Bay, Maine. Coastal Environments after Timson (1977).

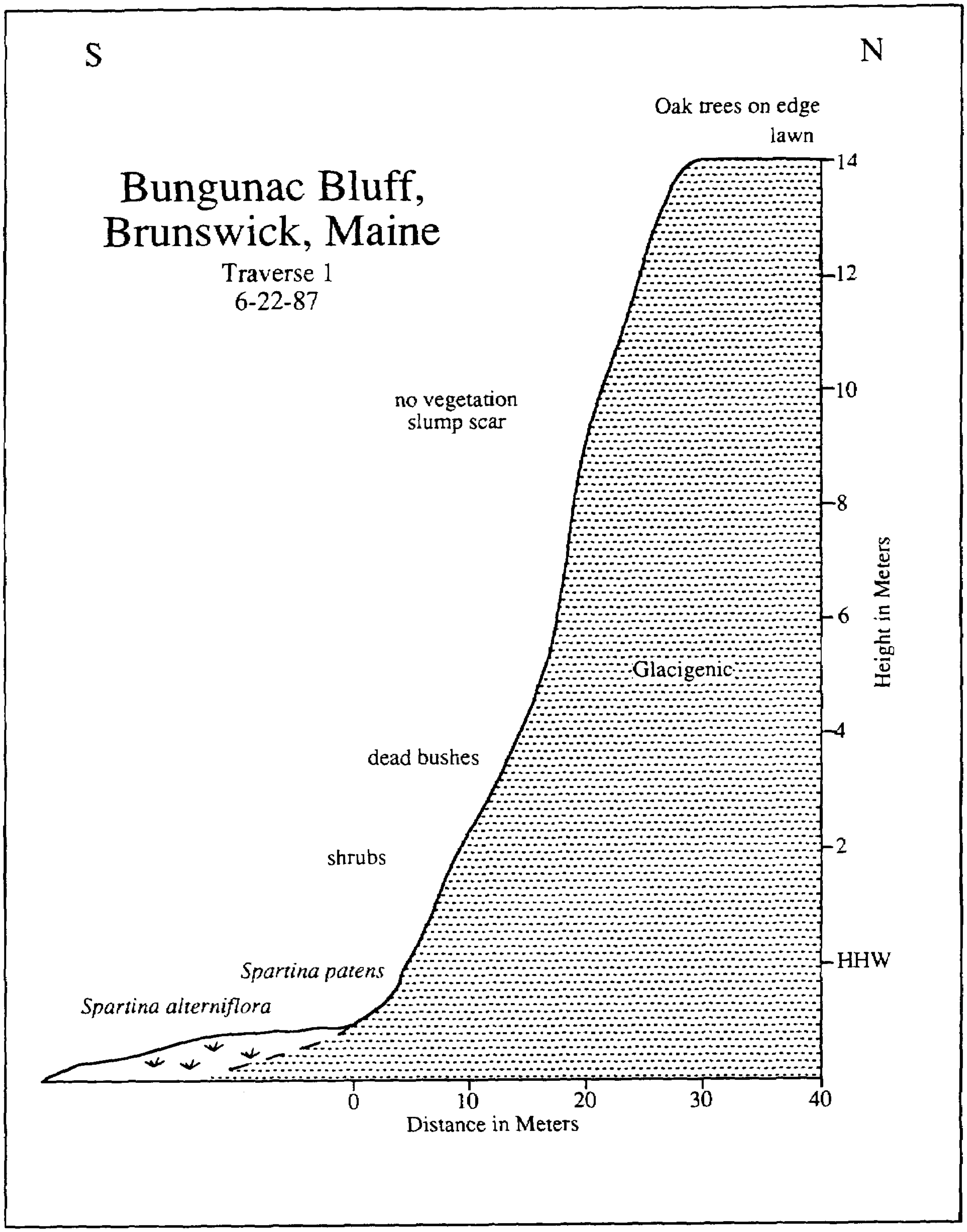


Figure 2.11. Traverse 1, Bungunac Bluff, Brunswick, Maine. Traverse 1 is located on Figure 2.10.

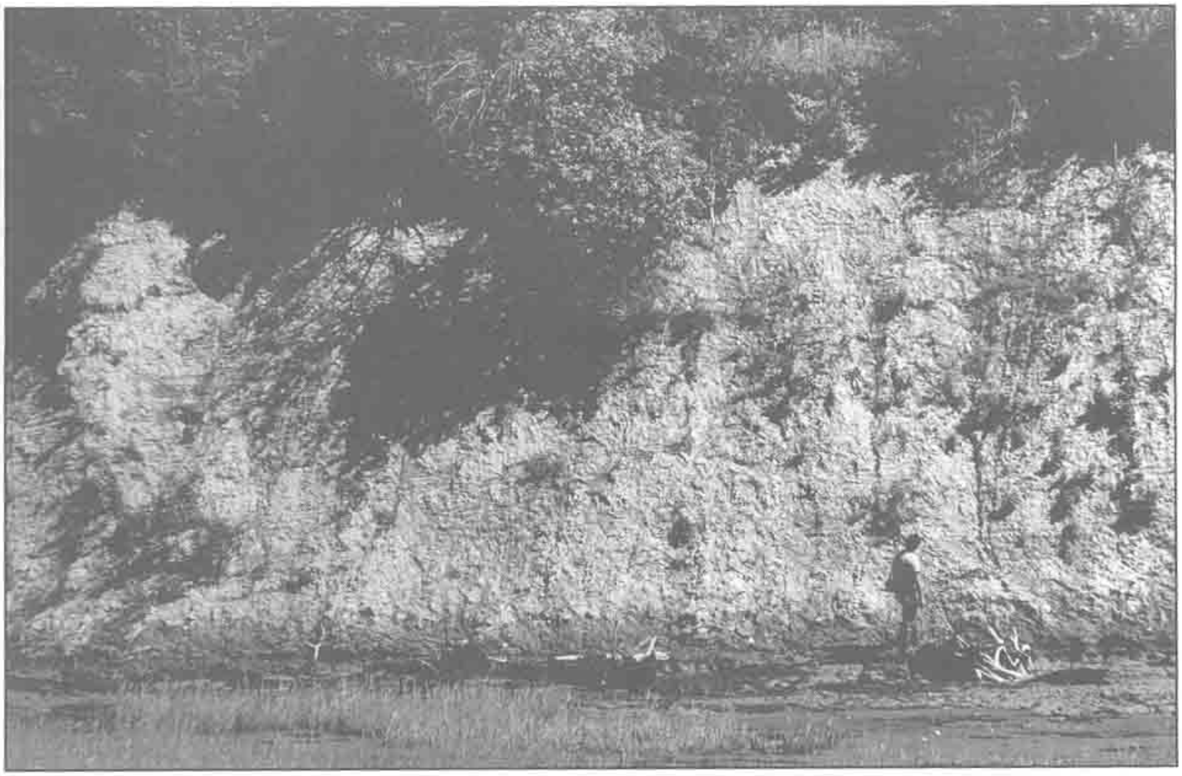


Figure 2.12. Photograph of Maquoit Bay shoreline. Site of Traverse 1.

Figure 2.13. Photograph of Maquoit Bay shoreline. Site of Traverse 2 is located in forested area in distance.

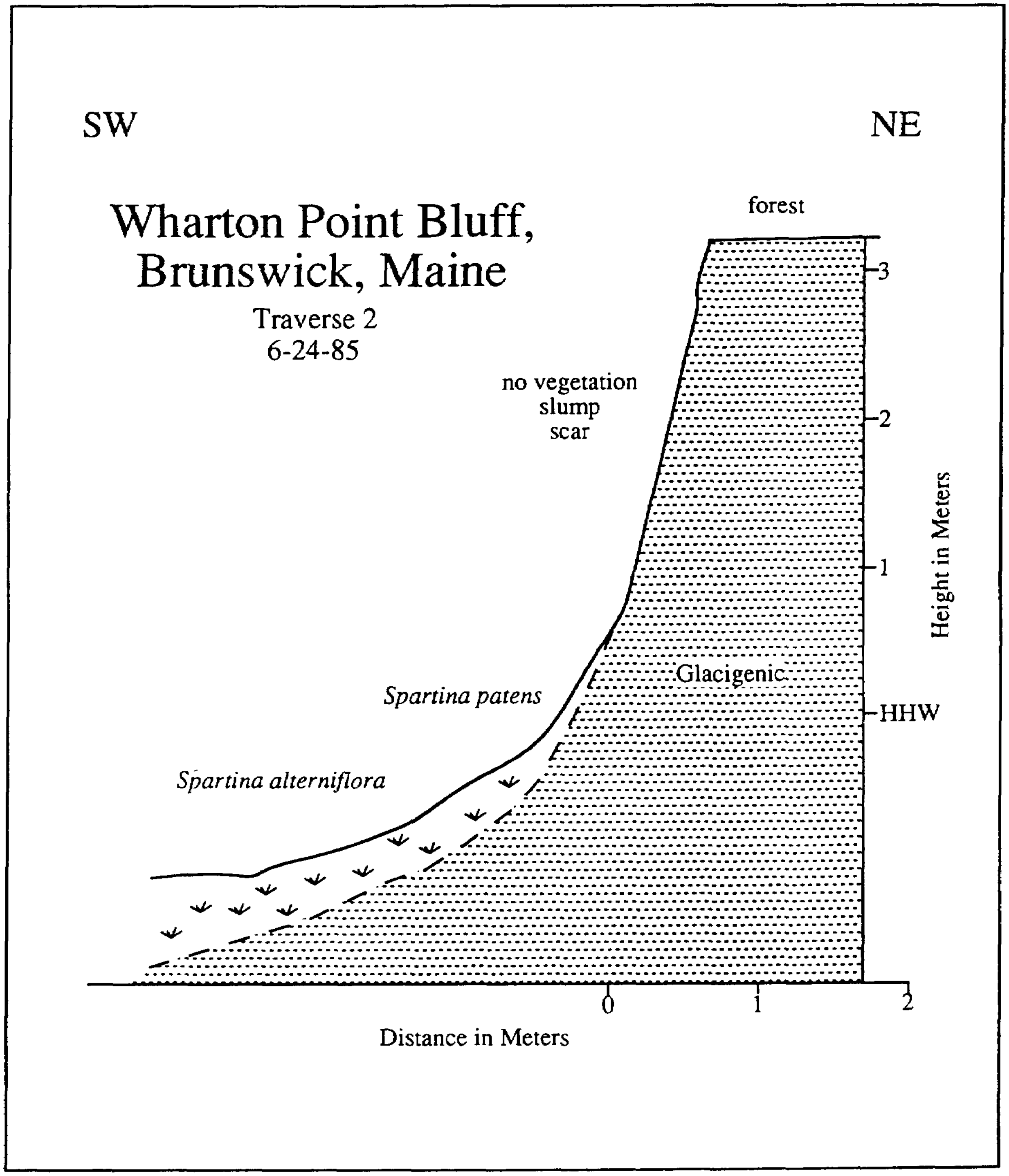


Figure 2.14. Traverse 2, Wharton Bluff, Brunswick, Maine. Traverse 2 is located on Figure 2.10.

4) Extent of Similarly Situated Land in the Region

Although bluffs make up only about 3% of the total shoreline of the region, much of the area's suburban shoreline from the Presumpscot River in Falmouth to the Harraseeket River in Freeport is supported by bluffs of sand or mud. Mackworth Island, Brunswick, and the Casco Bay islands also have isolated bluff areas.

Impacts associated with eroding bluffs are confined to a smaller area than the widespread inundation associated with the impact of rising seas on other coastal environments. Typically, impacts will be experienced only by adjacent landowners who have built close to the bluff line. There are no known major built features other than residences threatened by bluff erosion in the region.

However, as many as 200 homes in the region may be affected by the range of shoreline positions projected during the study period. Property assessment data was not gathered for the region, but the average value of individual properties in the Bunganuc Landing area may provide a useful comparison for the region.

5) Analysis

The Bunganuc area highlights the fact that bluff environments, while not directly affected by rising sea level, are unstable and dynamic areas. Clearing vegetation to improve views or attempting to stabilize the slopes with gravel or other materials increases the threat of erosion.

Relatively recent development has occurred in these areas despite the existence of local and state land use and environmental regulations. This points to possible inadequacies in those laws, lack of knowledge about bluff shoreline processes, the need for more data on bluff behavior, and the need for public education about shoreline processes and slope maintenance.

It is generally not feasible to stabilize eroding bluffs; a retreat from the affected area is usually the only solution. Homes that are currently threatened have experienced loss of usable yard space and have moved septic systems away from the eroding bluff edge. Soft technologies such as the planting of vegetation at the base of the bluff only slow rates of erosion. Due to the steepness of some of these areas, hard structures, such as riprap, to protect individual properties would be prohibitively expensive. Use of hard structures to stabilize bluffs would also have significant environmental costs due to the interference with transfer of sediment from bluffs to coastal wetlands.

3. Winnocks Neck

a. Shoreline Position

Winnocks Neck, Scarborough is a peninsula extending into the Scarborough River salt marsh. (*Figure 2.15*) The Neck is bounded by the Nonesuch River and Mill Brook to the east and west, and by the Scarborough River to the south. (*Figure 2.16*) The peninsula is supported by bedrock more than 30 m high (90 feet) which is mantled by till and glacial-marine sediment. Within the marsh many small "islands" of glacigenic material (like Plummer Island) project above the marsh surface and are being slowly drowned by the marsh as it grows upward with rising sea level. (*Figure 2.18*)

Three traverses were selected to evaluate changes in the shoreline as a consequence of future submergence. Traverse 1 extends west from the Nonesuch Marsh and parallel to the Plummer Island Rd. There is a distinct topographic and vegetative break from a *Spartina patens*-dominated high marsh to a freshwater marsh with *Typha sp* which was used as higher high water. (*Figure 2.17*) The 0.5 m elevation averaged 26 m from higher high water, but most of this distance was across the freshwater marsh. (*Table 2.1*) The 1.0 and 2.0 elevations were relatively closer to higher high water because the traverse steepened up a partly mowed hillside. (*Figure 2.18*)

Traverse 2 passes over a narrower part of the peninsula where the topographic relief was less. (*Figure 2.20*) Although the distance to the 0.5 m elevation was less than at traverse 1, the land flattened out and the distance to the 2.0 elevation was twice as far as at traverse 1. If the traverse were extended along a road into a small subdivision, the distance to the 2.0 m elevation was greater than if the traverse (*Figure 2.19*) went through the more uneven ground of the adjacent forest. (*Table 2.1*).

Traverse 3 extends up the western side of the peninsula from the Mill Brook marsh. (*Figures 2.16*, *2.21*) There is a distinct topographic break at the landward edge of the *Spartina patens* salt marsh which is considered higher high water. The upland beyond this is forested, but relatively steep as in traverse 1. The 2.0 m elevation occurs near Sandy Point Road, and a hill with houses on it rises on the opposite side of the road. (*Table 2.1*)

Because of irregularities in the slope of the land, a range of distances to the three elevations were observed and recorded. (*Table 2.1*)

b. Impact Assessment

1) Upland Impacts

The mapped study area at Winnock's Neck included about 275 acres of developed upland and adjacent salt marsh. Upland losses are projected as follows:

	.5 m rise	1.0 m rise	2.0 m. rise
Dryland Lost	23 acres	43 acres	66 acres

Most of the area is developed with large-lot, "upscale", single family structures, whose backyards gradually fade into the adjacent marsh. The low and medium sea-level rise scenarios would inundate the shores at greater or lesser levels depending on the steepness of the slope. Because sea-level is predicted to rise over a prolonged period of time, impact on these properties will also be gradual, as the wetland-upland edge migrates inland, resulting in a net loss of usable backyard area for these homeowners, and over time, complete conversion of the affected area to salt marsh. Under each of the sea-level rise scenarios, the most apparent changes in shoreline position occur at the terminus of the peninsula. The 2.0 meter rise boundary breeches the road that provides access to the end of the peninsula. Over the very long term, Winnock's Neck will become an island surrounded by marsh, similar to the existing pattern of small islands scattered throughout the marsh.

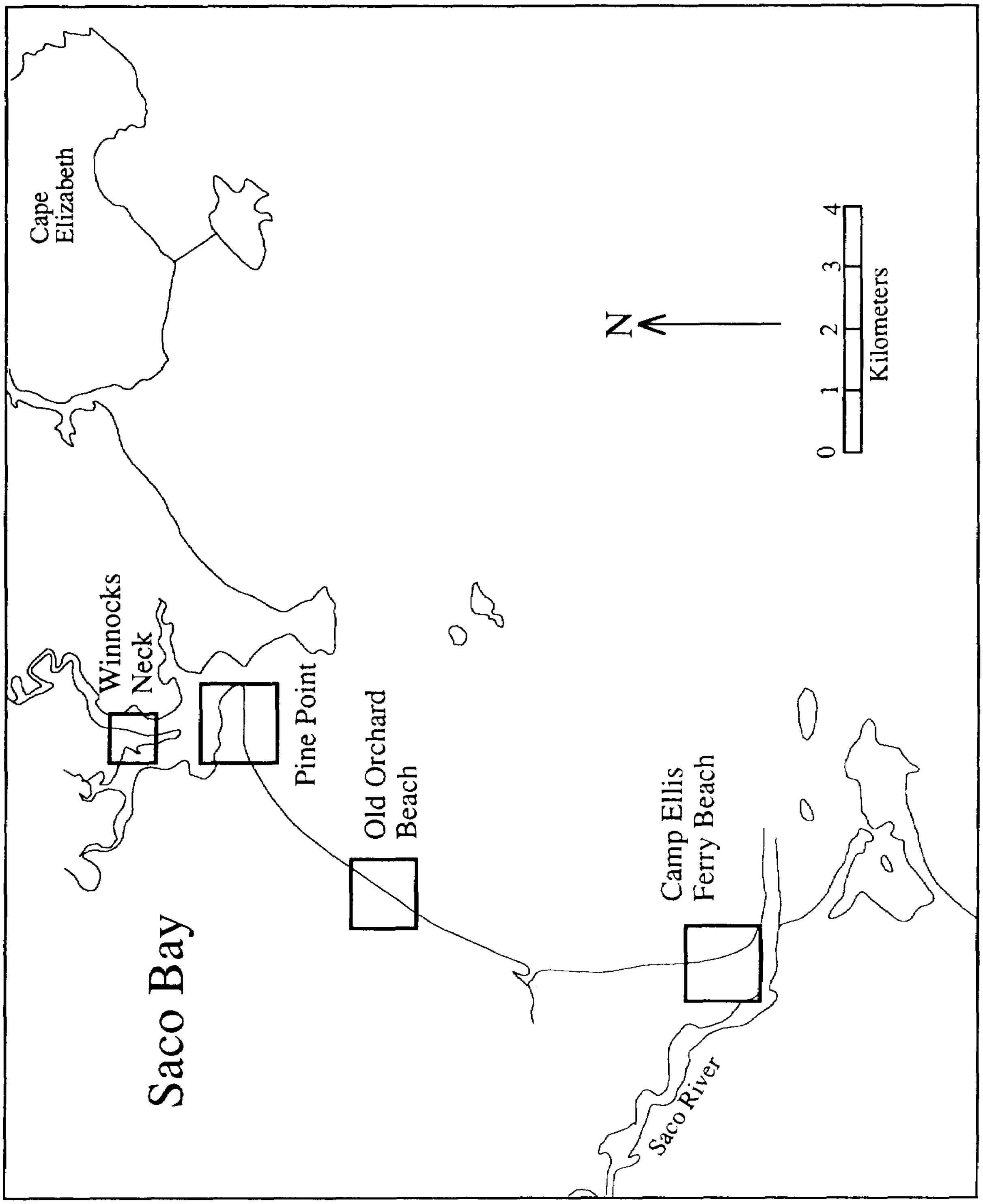


Figure 2.15. Map of Saco Bay with location of study sites enclosed by boxes.

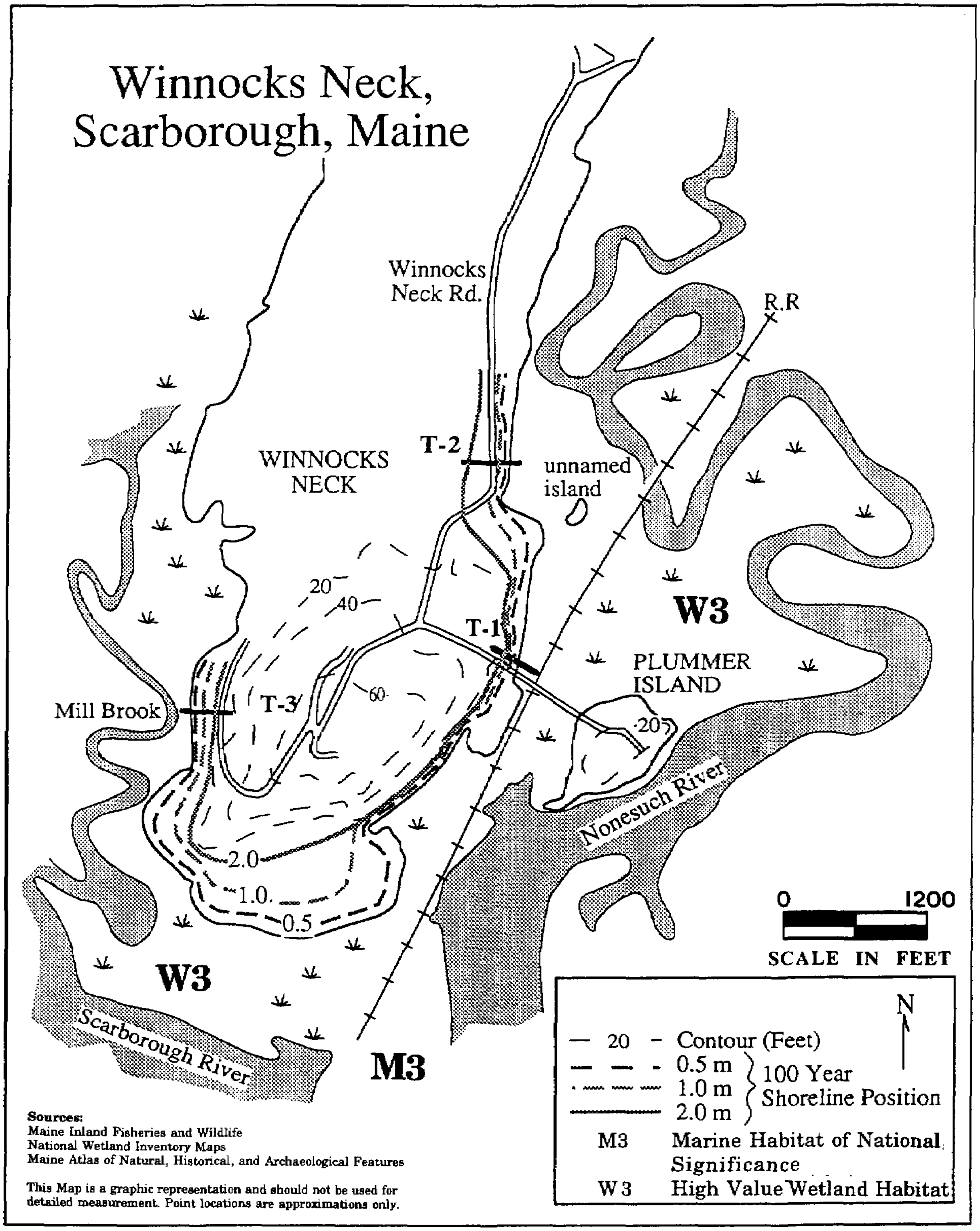


Figure 2.16. Projected shoreline change map for Winnocks Neck. Mapping was limited to the area surrounding Winnocks Neck, although the surrounding area is also depicted. Coastal environments after Timson (1977).

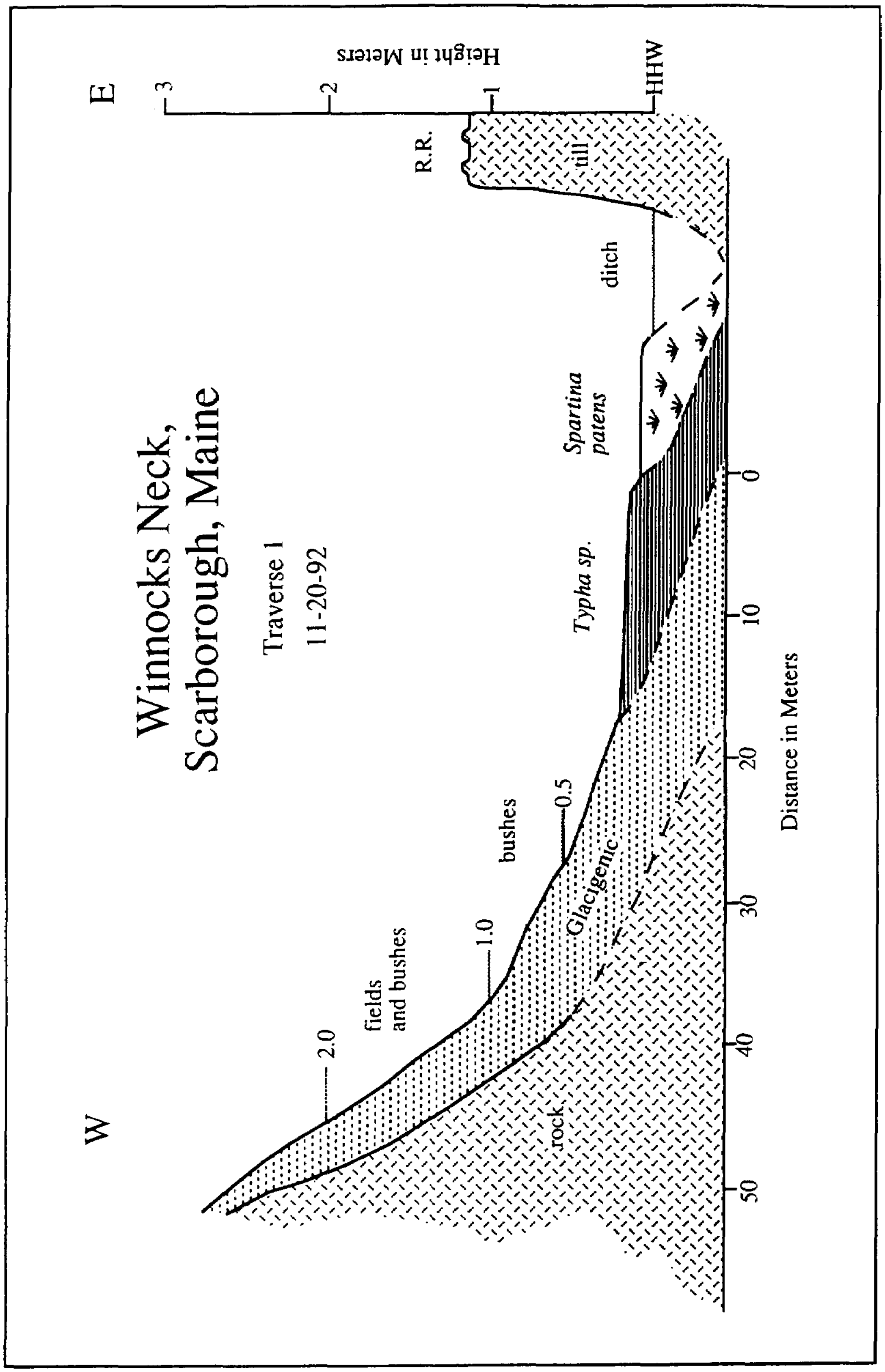


Figure 2.17. Traverse 1, Winnocks Neck. Traverse 1 is located on Figure 2.16.

Figure 2.18. Photograph of Winnocks Neck. View toward north at Traverse 1.

Figure 2.19. Photograph of Winnocks Neck. View down road into subdivision at Traverse 2.

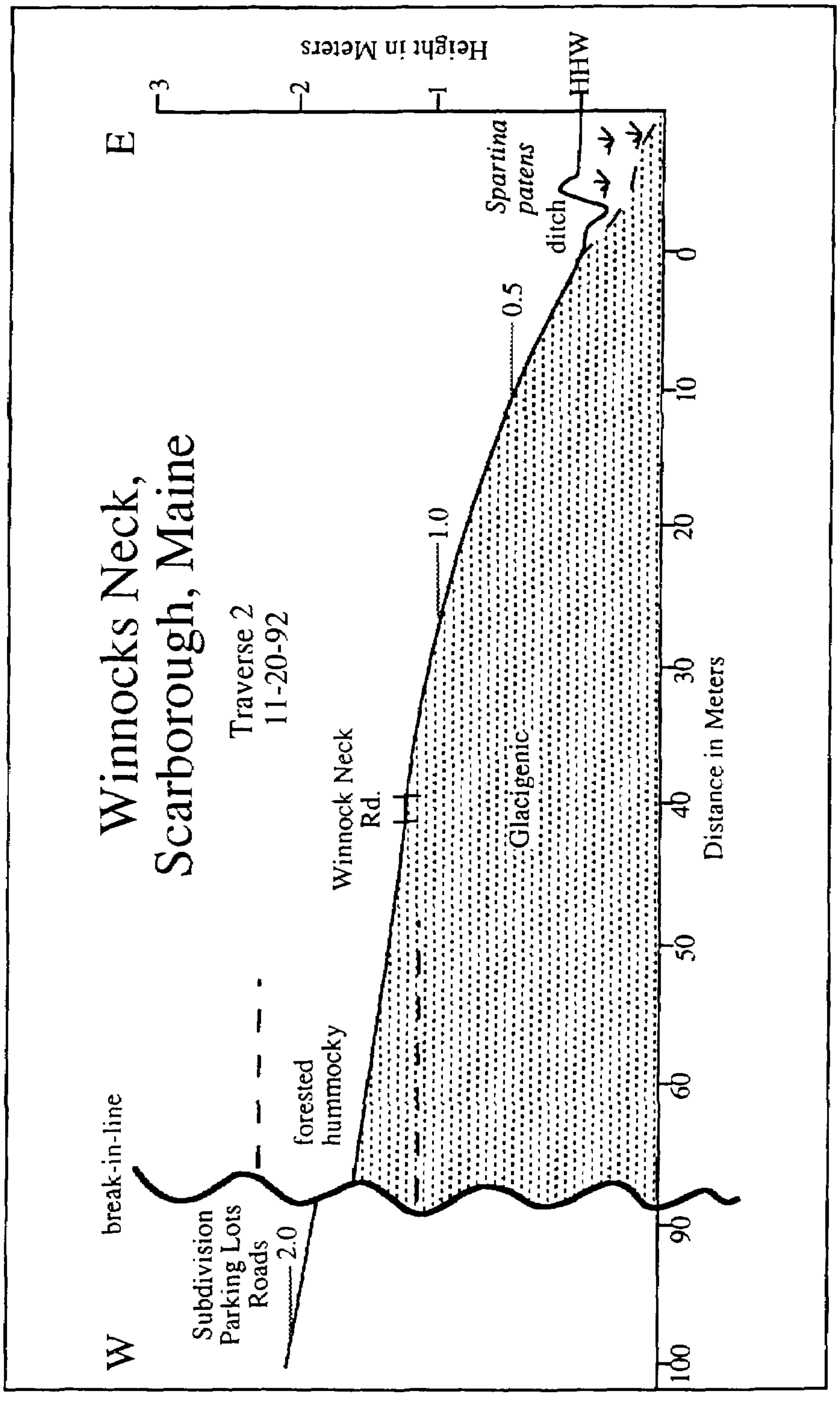


Figure 2.20. Traverse 2, Winnocks Neck. Traverse 2 is located on Figure 2.16. The dark wavy line indicates a break in the section. If the traverse were extended down a paved road and into a subdivision it would be farther to the 2.0 m elevation than if the traverse went through woods. Even within the woods there is considerable relief indicated by the dashed, parallel lines.

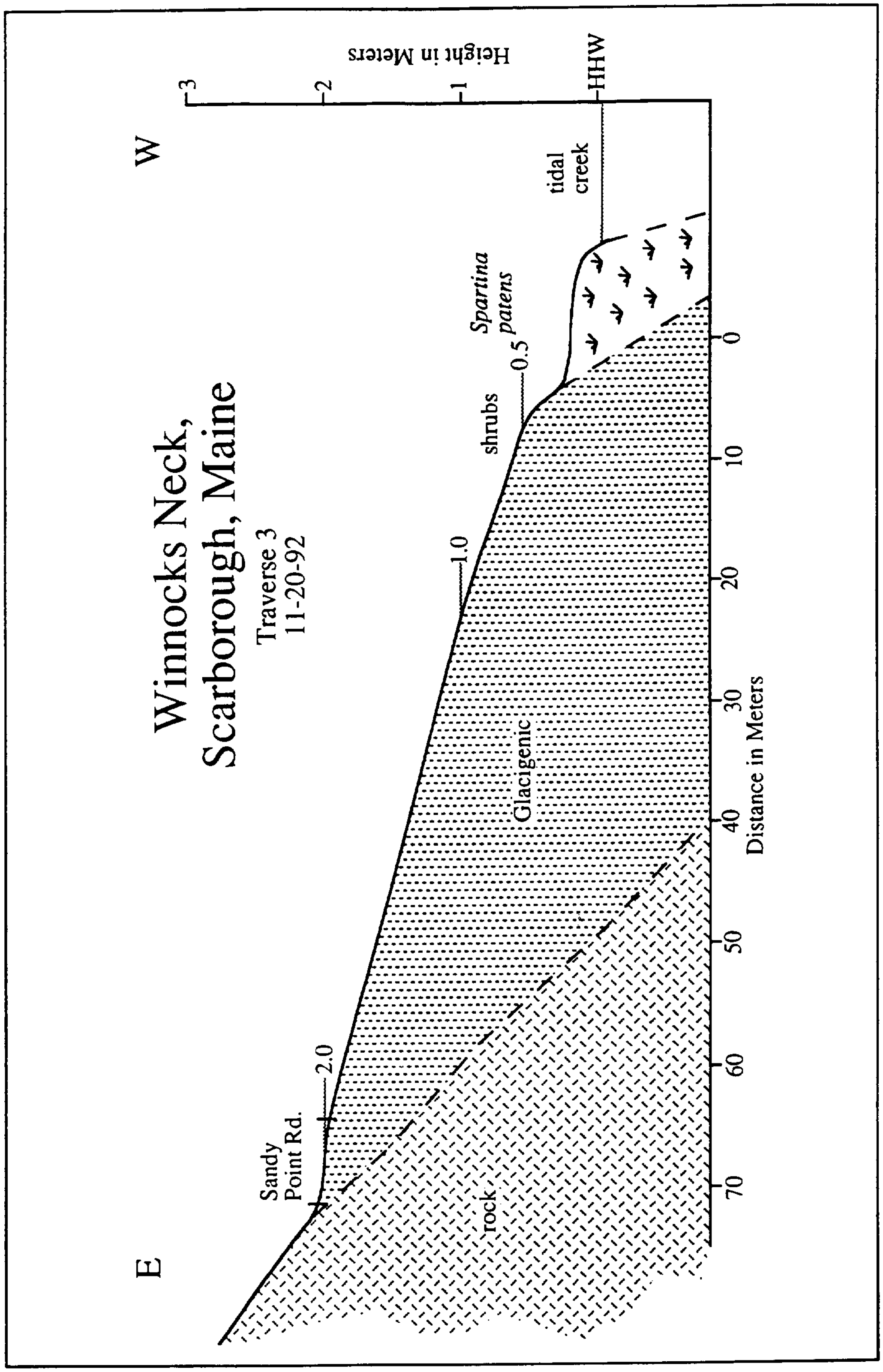


Figure 2.21. Traverse 3, Winnocks Neck. Traverse 3 is located on Figure 2.16.

2) Value of Properties

The majority of properties at risk are located at the terminus of the Winnock's Neck peninsula, where shoreline slopes are more gradual, and a network of cul-de-sacs (not shown) wind through developed lots. According to Scarborough assessor's records, the value of land and buildings in this area is about $7.2 million. The assessed value of structures (excluding land) in the area ranges from $100,000 to $180,000, while lots range in value from $78,000 to $110,000.

3) Wetland Impacts

The predominant natural feature in Winnock's Neck is the valuable marsh land surrounding the peninsula at the confluence of the Scarborough River and the Nonesuch Rivers. Marine habitat in this area is rated of national significance, while wetland habitats are also of high value. For a summary of potential wetland impacts, see the discussion under the Gilsland Farm study area.

4) Extent of Similarly Situated Land in the Region

(*See* discussion under Gilsland Farm study area.)

5) Analysis

Winnock's Neck illustrates the dilemma of migrating marshlands. In order to allow wetlands to survive an accelerated rise in sea-level, they must be allowed to migrate inland. This causes a conflict in wetland edge areas that have been developed. Adjacent property owners will be tempted to keep wetlands at bay by hardening of their shoreline.

Recent debates concerning state-mandated shoreland zoning have included disagreement over what is considered an adequate width of protective buffer between wetlands and adjacent development. Wetland setbacks have typically been static boundaries based on that "critical edge" required to preserve the wetland's value for wildlife habitat. In order to preserve valuable wetlands (for a variety of functions, habitat, flood retention, etc.) and to minimize future property losses accruing from migrating wetlands, zoning and subdivision standards should begin to consider wetlands as dynamic systems, with setbacks sufficient to accommodate anticipated changes in shoreline position.

4. Old Orchard Beach

a. Shoreline Position

Old Orchard Beach is located between Saco and Scarborough on the longest unbroken stretch of beach in Maine. (*Figures 2.15, 2.22*) The beach possesses a wide berm and low-tide terrace, but most of the original sand dunes were leveled in the 19th century to construct hotels. (*Figures 2.23, 2.24*) Landward of the former dunes are a mixture of lowlands and higher rocky areas, and occasionally rock outcrops are observed on the beach.

The 0.5 m, 1.0 m, and 2.0 m shoreline positions at 150 m, 300 m, and 600 m, respectively, reflect the uneven back-barrier terrain by projecting into the swampy areas and outward at the rocky hill. (*Table 2.1*) This depiction assumes that no new sand from the Saco River or elsewhere within the system is supplied to the beach in the next century, and neglects the impact of the two 1.3 m diameter sewage pipes under the dunes.

In addition to the shorelines predicted on the basis of the modified historical method, a 100 year shoreline supplied by the Town of Old Orchard Beach is depicted. It was produced as part of a permit application to locate a stormwater pipeline beneath the beach. Since there has been no more than 18 m of shoreline fluctuation mapped with certainty over the past century, this line is drawn 18 m landward of the high water line.

b. Impact Assessment

1) Upland Impacts

Development along Old Orchard's coast today is quite varied; high density, high rise condominium structures are intermixed with cottage style homes, commercial establishments, and seasonal dwellings. The mapped study area includes the heart of OOB's development district, including The Pier, the East Grand Avenue (Route 9) business strip (motels, restaurants, amusements), numerous Town facilities and part of the downtown area.

The mapped study area included about 270 acres of upland. Projected losses of dryland are as follows:

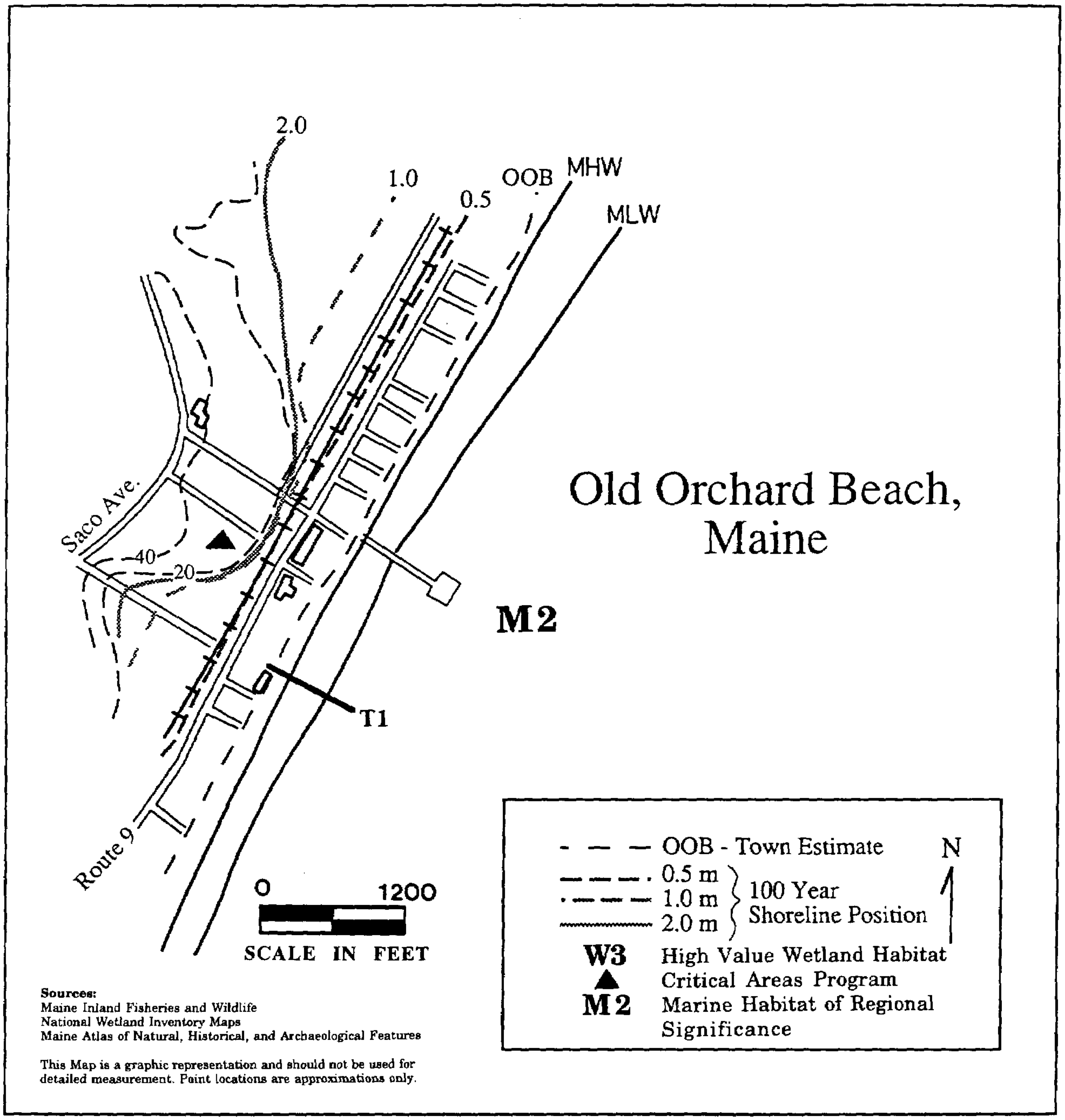
	.5 m rise	1.0 m rise	2.0 m. rise
Dryland Losses	80 acres	135 acres	169 acres

The .5 meter scenario potentially inundates all beachfront development and Grand Avenue to the railroad tracks. This area includes an amusement park, arcades, retail shops, motels, restaurants, and high density residential structures. Other built features at risk under this scenario include the network of sewer lines and the new stormwater outfall.

In addition to the development inundated by the .5 meter rise described above, the 2.0 meter rise scenarios would threaten town facilities such as a small park, tennis court, library, public restrooms, and parking lots. This area has been targeted for public and private improvements as part of an ongoing community revitalization, and discussed in further detail in the following section. Additionally, the 2.0 meter rise would also impact a small, lowlying area of moderate density residential development to the north. Due to the small difference in the land area covered by the 1.0 and 2.0 meter scenarios, impacts associated with the 1.0 meter rise were not analyzed separately, but most impacts identified with a 2.0 meter rise would also occur with a 1.0 meter rise.

2) Value of Land/Structures

According to information provided by the Old Orchard Planning Office, the value of land and buildings within the mapped .5 meter inundation area is about $32.4 million. It should be kept in mind however, that the mapped study site includes only a portion of Old Orchard's developed shoreline. If a .5 meter sea-level rise scenario was anticipated all along Old Orchard's shoreline, the value of potential property losses would greatly increase. For example, to the north of the mapped study area towards Pine Point, there are 6 high-rise condominium structures containing a total of 251 units (7-8 stories high, 28-55 units each) located directly on the beachfront. A current value assessment for these properties is $35,347,600.



Sources:
Maine Inland Fisheries and Wildlife
National Wetland Inventory Maps
Maine Atlas of Natural, Historical, and Archaeological Features

This Map is a graphic representation and should not be used for detailed measurement. Point locations are approximations only.

Figure 2.22. Projected shoreline change map for Old Orchard Beach. The projections from this study are compared with that of the Town (Timson et al., 1992).

Figure 2.23. Photograph of the Old Orchard Beach area. Aerial photography of the study area.

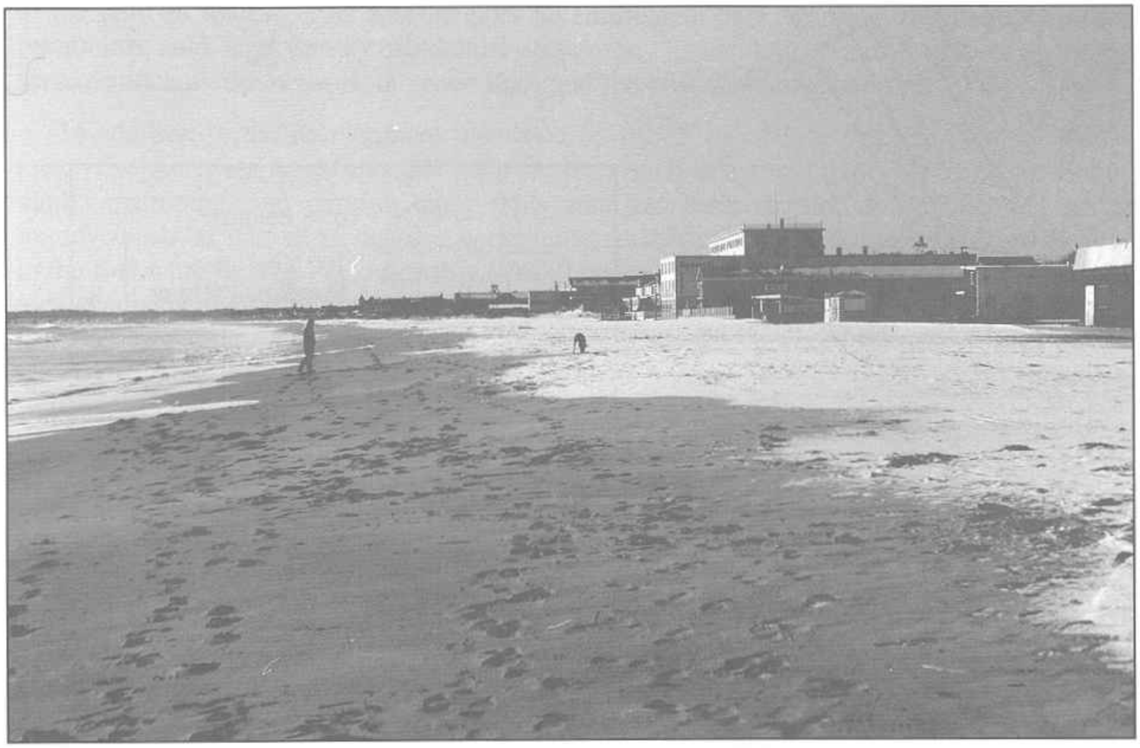


Figure 2.24. Photograph of the Old Orchard Beach area. Ground plot from near the study area.

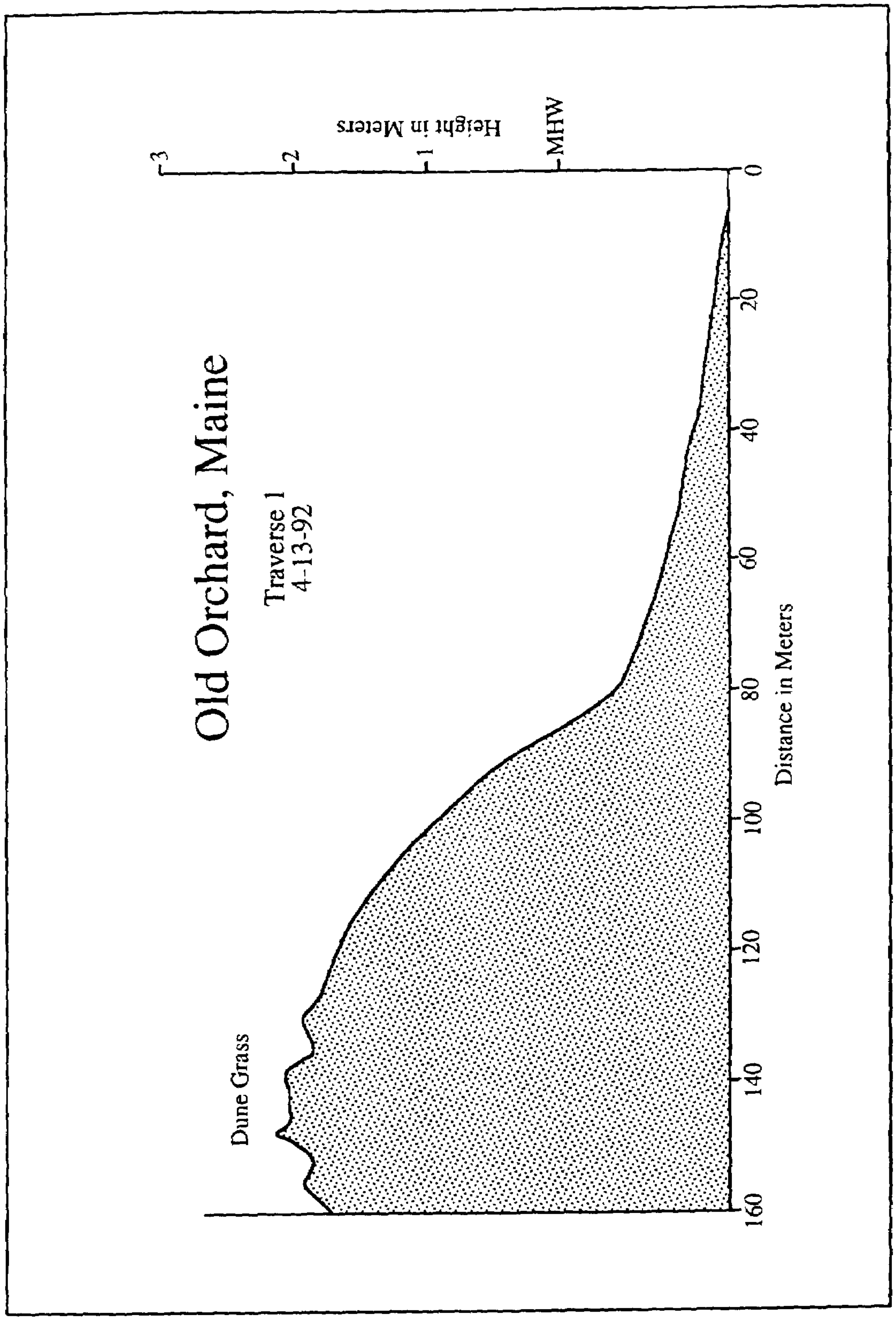


Figure 2.25. Traverse 1, Old Orchard Beach, Saco Bay. Modified from Timson et al., 1992).

The 2.0 meter scenario potentially impacts an additional area of mostly residential development, assessed at $6.9 million. Because the 1.0 meter boundary was substantially similar to the 2.0 meter boundary in high-density areas, data on assessed value of these properties was not separated from figures gathered for the 2.0 meter analysis.

According to the Old Orchard Beach Planning Office, recent public improvements in the waterfront and downtown area represent about $3.9 million in investment (*see Table 2.3 below*).

Table 2.3. **Recent Public Improvements—Old Orchard Beach**

Project	**Year Completed**	**Source of Funds**	**Cost**
1. Pumping Station	1991/2	Local	$1,100,000
2. Stormwater Outfall	1993	Local	$800,000
3. Tax Increment Finance District Improvements	1993	Local, MDOT, Job Bond	$2,000,000
TOTAL PUBLIC INVESTMENT			$3,900,000

Of the public improvements listed in Table 2.3, the first two projects listed would be potentially affected by the .5 meter sea-level rise scenario. Also at risk under this scenario, is the network of sewer lines constructed under the dune system in the 1980's. No costs were available for the sewer project. The tax increment finance district investments listed above were completed throughout the downtown development district. Only a portion of these improvements will be threatened by the .5 meter rise scenario.

Table 2.4. **Tentative Public and Private Improvements—Old Orchard Beach**

Project	**Anticipated Completion**	**Possible Sources of Funds**	**Cost**
1. Ocean Outfall/Sewer Treatment	NA	Local, federal	$4,500,000
2. Train Station	1994/5	Federal	$200,000
3. Proposed New Pier	NA	Private	NA
4. Boardwalk	1995/6	Fed., MDOT, Local	NA
5. Retail Complex	NA	NA	NA
6. Memorial Park Improvements	NA	NA	NA
7. Construction of New Chamber Building	NA	Private	NA

NA = Information not available.

Table 2.4 provides a list of tentative projects that are currently under *preliminary discussion* in the Old Orchard downtown and shorefront area. Note that funding sources for these projects are not secure, in some cases voter approval of bond issues will be necessary.

Of the public and private projects under discussion, listed in Table 2.4, the ocean outfall/sewer treatment improvements, the pier, and the boardwalk would be potentially affected under the .5 meter sea-level rise scenario. Improvements associated with the downtown revitalization effort (Depot Square Area redevelopment), including the passenger train station, infill retail development, park improvements and new construction to house the Chamber of Commerce fall within the 1.0 and 2.0 meter sea-level rise boundaries.

3) Wetland Impacts

A series of small wetlands are just outside of the 2.0 meter rise boundary.

4) Extent of Similarly Situated Land in the Region

(See discussion under Camp Ellis/Ferry Beach, Chapter Three.)

5) Analysis

Of all the sites covered in this analysis, the potential impacts of sea-level rise in this study area are perhaps the greatest. Given the nature of the existing development, and the reliance on beach-related tourism, sea-level rise potentially threatens the basis of the local/regional economy and the roots of the cultural identity of Old Orchard. The level of public and private investment here may test the State's determination to adhere to its retreat policy and current ban on construction of seawalls.

This site illustrates the extreme danger associated with eliminating natural protective features and building within the sand dune system without appropriate setbacks from high hazard areas. It also highlights the dilemma associated with allowing public investment in infrastructure in unprotected beach environments. A sewer line was located in the sand dune system in 1980's to serve existing and planned development—development that now appears to be threatened within the 100 year study horizon.

This site also illustrates the need for provision of reliable data concerning coastal hazards to local and state decisionmakers, and agreement regarding what methodologies are acceptable for projecting future shoreline positions. Old Orchard Beach's estimate of the 100-year shoreline position (based on the maximum amount of shoreline fluctuation that had been mapped with certainty over the previous century) is quite different than the shoreline position mapped for this analysis using a geo-historical approach.

4. Pine Point

a. Shoreline Position

Pine Point is a northward-projecting spit bordering the Scarborough River inlet. (*Figures 2.15, 2.26*) This spit was formerly a barrier island before the railroad line closed the tidal inlet in the 19th century (Farrell, 1972). Possibly because of sand by-passing that inlet, the Scarborough River inlet began to narrow and fill with sand, and the COE constructed a jetty at the inlet entrance in the

1960's. That jetty now traps sand derived from the south, and sandy spoils from the dredging of the tidal channel have also been placed on Pine Point. For these reasons the beach has grown seaward at a rate averaging 2.5 m/yr between 1976 and 1991. (*Figure 2.26*) Beach growth has been greater near the influence of the jetty than to the south, where little growth has occurred. Because of the growth of this beach residential development also grew since the 1960's, and the entire area is covered with residences and commercial buildings. (*Figure 2.27*)

If the assumption of continued beach progradation due to an influx of sand from the south holds, a 0.5 m rise in sea level will not result in any retreat of the shoreline, rather in a 100 m advance at Traverse 1. Growth will be less to the south. Even a 1.0 m rise in sea level will only result in 50 m of retreat at Traverse 1 if sand sources to the south persist. A 1.0 m rise of the sea, however, will lead to a breach in the barrier at the southern end of Pine Point where growth is not presently occurring. An extreme rise of the sea by 2.0 m will lead to 350 m of retreat at Traverse 1, and complete destruction of Pine Point. A hypothetical realignment of the beach is depicted as the 2.0 m shoreline. (*Figure 2.25*)

b. Impact Assessment

1) Upland Impacts

The Pine Point study area included about 630 acres of land, with dryland accounting for approximately one-half of that total, and the Scarborough Marsh accounting for the balance of the site. Loss of dryland associated with various rates of sea-level rise at Pine Point are projected as follows:

	.5 m rise	1.0 m rise	2.0 m. rise
Dryland Lost (gained)	(25 acres)	83 acres	315 acres

2) Value of Land/Structures

According to the Town of Scarborough's assessor's records, the value of properties inundated in the 1.0 meter rise scenario is estimated at roughly $32 million. In addition to properties lost, costs associated with 1.0 meter sea-level rise would also include bridge/road improvements to maintain access to Pine Point. At the 2.0 meter rise, the value of land and buildings at risk in the Pine Point study area would be $50.2 million.

3) Wetland Impacts

Natural features that could potentially be affected by rising sea-level and changes in Pine Point's shoreline position include nationally significant marine habitats, and the high value wetland habitat associated with Scarborough Marsh. Given the study assumptions described earlier in this chapter, Scarborough Marsh would probably not suffer any net loss immediately (assuming that the marsh could migrate landward unimpeded). Scarborough Marsh, because of its large contiguous mass and healthy state would probably migrate more easily than smaller, fragmented wetlands. Higher rates of sea-level rise (i.e. 2.0 meters) could lead to wetland drowning.

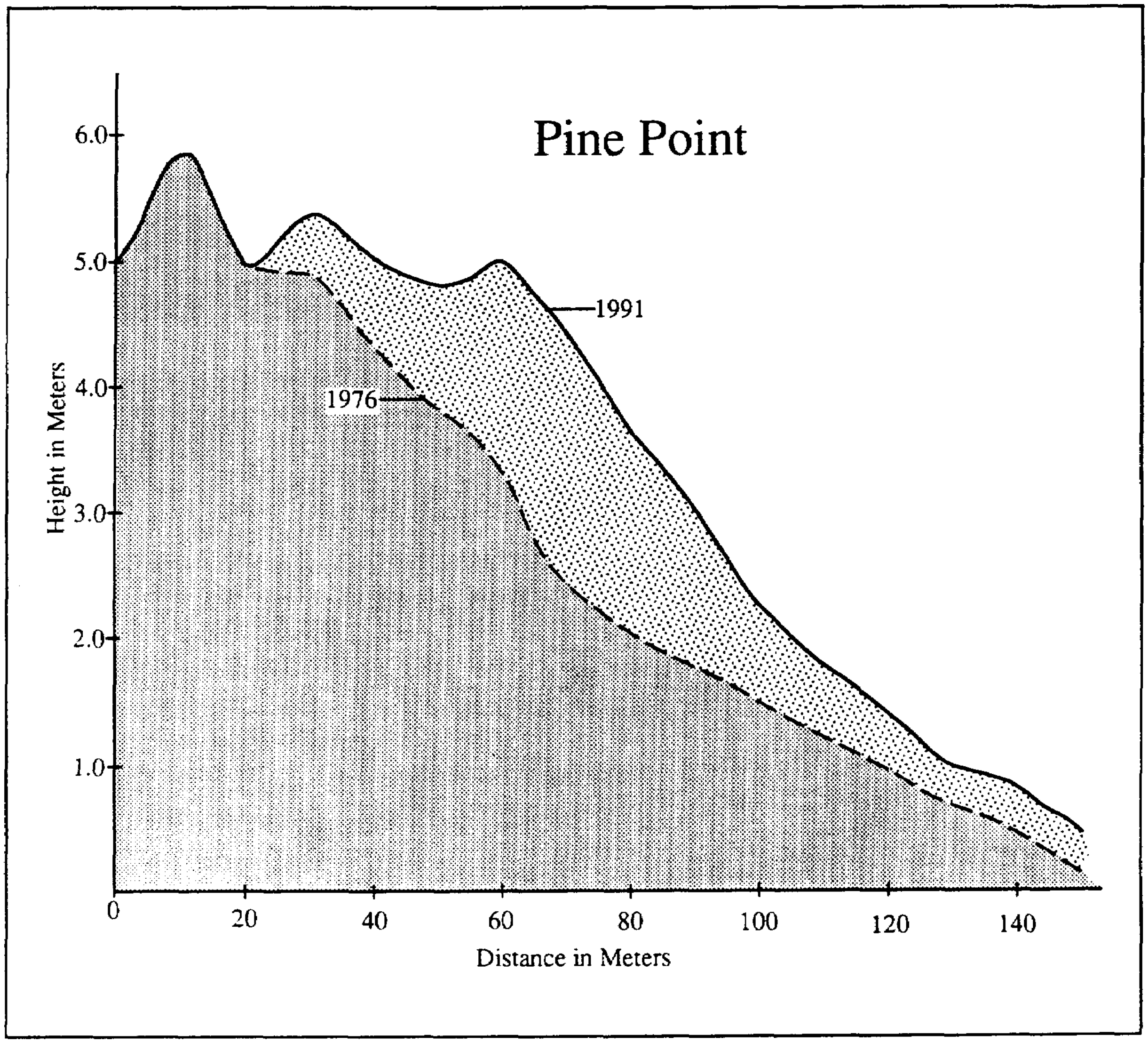


Figure 2.27. Traverse 1, Pine Point, Saco Bay. Survey line from Fink (personal communication 1992).

Figure 2.28. Photograph of the Pine Point area. Aerial photography of the Pine Point area.

Figure 2.29. Photograph of the Pine Point area. Ground photograph of the study area at Pine Point.

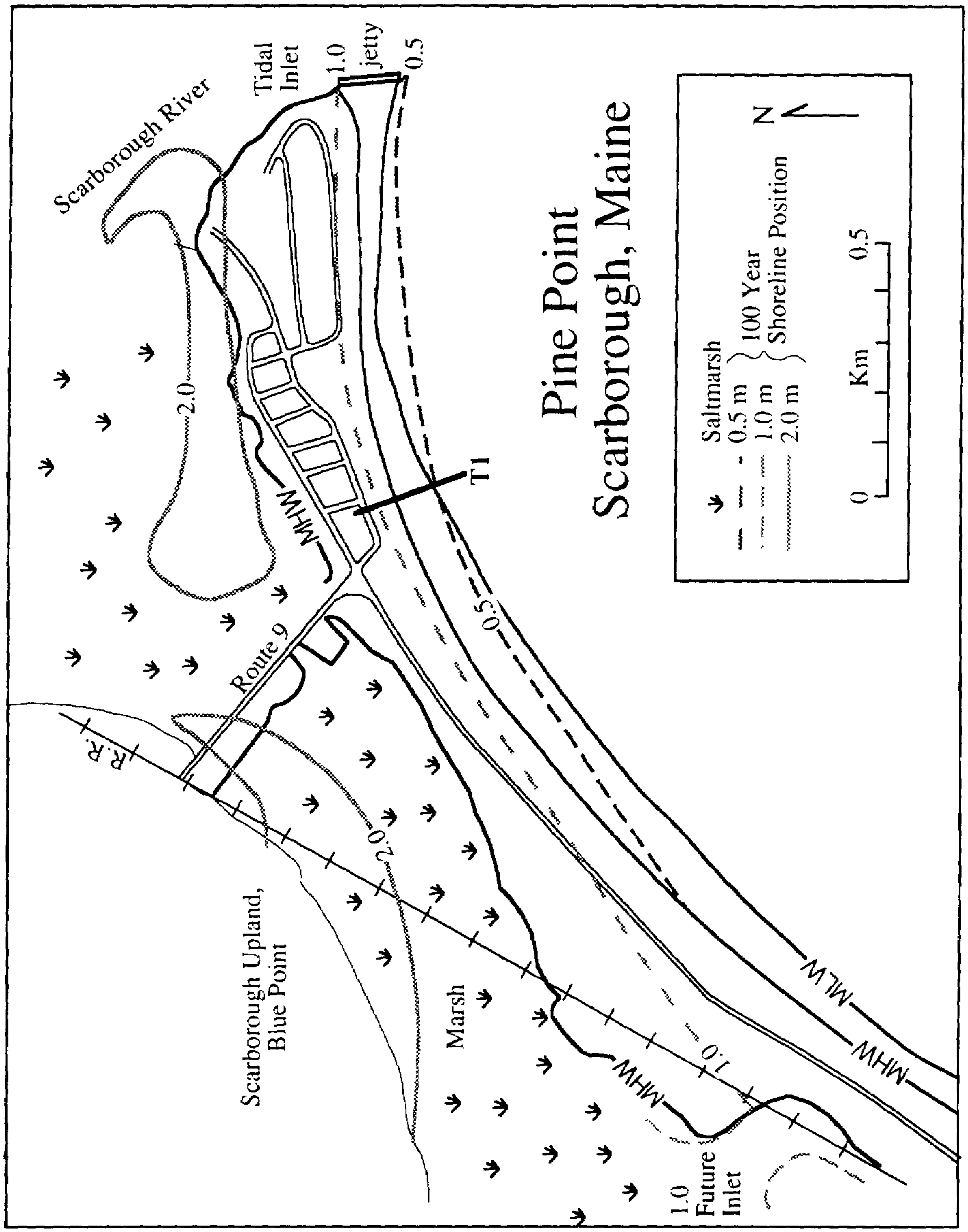


Figure 2.26. Projected shoreline change map for Pine Point, Saco Bay. Note that the barrier beach may be breached by a tidal inlet at the 1.0 m projected shoreline. At the projected 2.0 m shoreline, the entire barrier is profoundly altered, and the shape of the shoreline projection is highly speculative. Coastal environments after Timson (1977).

4) Extent of Similarly Situated Land

(*See* discussion under Camp Ellis/Ferry Beach section of this chapter.)

5) Analysis

Since lots sizes in Pine Point have been increasing substantially due to accretion, theoretically, there could be a corresponding change in the allowable density for those accreting lots, allowing for redevelopment to multi-family units. Thus, the Pine Point site analysis raises the question of how to treat areas along Maine's shoreline that are accreting in the short term, when geologists suspect that these areas are subject to change over the long term. Maine's Sand Dune Rules attempt to deal with this issue by requiring analysis of possible shoreline changes over a 100 year planning horizon.

5. Other Predominant Coastal Types

Two other coastal types are characteristic of portions of the shoreline of Maine, but were not mapped for this study by Maine Geological Survey: urban engineered shorelines and rocky shores. Expected impacts are discussed briefly, below.

a. Urban Engineered Shorelines

1) Upland Impacts

The Fore River section of the Portland waterfront was also evaluated for possible impacts of accelerated sea-level rise, although site features were not mapped. Since the engineered shoreline in this area is built up to 2 meters above mean high water in most locations, sea-level rise alone probably will not affect the shoreline position along the Portland waterfront. As has been the case in the past, property owners will probably continue to raise the height of their shoreline structures gradually over time, or in response to crisis flooding.

2) Extent of Similarly Situated Land

Only 5% of the region's shoreline consists of urban, engineered waterfront. In the region, only the Portland/South Portland waterfront, and a small area in South Freeport have urban, "unmovable" shorelines.

Water dependent businesses (those that must be located on, or adjacent to oceans, bays, and estuaries) are prevalent in this area and include fisheries, fish processors, ship builders, water transportation support facilities and others that rely on a waterfront (or in-water) location. These businesses and industries stand to be affected by sea-level rise in at least two ways: by changes in the productivity of marine habitats and wetlands, and by impacts on waterfront infrastructure. Bigford (1991) notes that typical ports with low-lying structures can expect impacts such as: increased stress on pilings, piers, docks and elevated structures; loss of access to waterfront landings; flooded utility lines; and loss of coastal lands for water dependent structures and uses. In Casco Bay, Colgan (1990) estimated that more than 2000 employees worked in "coast dependent" industries/businesses, with the value of that sector's output estimated at more than $104 million.

Urban services such as sewer treatment and stormwater drainage also may be affected by rising sea-level. In the case of sewer plants and outfalls, sea-level rise may result in inundation of plants, transmission of untreated sewage into area waters, and may result in delays getting plants back into operation. Every municipality in the region has outfalls that may be affected by rising sea-level.

No attempt was made to project costs of worst case property losses or costs associated with protection strategies for urban waterfronts.

3) Analysis

Although major impacts from a change in shoreline position due to sea-level rise are not anticipated along Portland's Fore River shoreline, the potential effects of storm surges and the potential for increased and more widespread flooding along engineered shorelines should be investigated. A study of potential effects of sea-level rise in Saint John, New Brunswick (Martec Limited, 1987) found that under a 1 meter rise, what is now the 100 year floodplain would become the 20 year floodplain. Kana, in studies of the physical impacts of sea-level rise in Charleston, South Carolina (in Barth and Titus, 1984) concluded that a five-foot rise in sea-level would double the size of the ten-year floodplain to the approximate size of the hundred-year floodplain unless additional levees and seawalls were built. Similarly, Leatherman (in Barth and Titus, 1984) studied changes in storm surge levels and inland inundation as a result of projected rates of sea-level rise in Galveston Bay, Texas. Leatherman concluded that a .4 meter rise in sea-level by 2025 would convert a 75-year storm into a 100-year storm. Under the high scenario of sea-level rise, flooding associated with a 100 year storm would occur at a 10 year frequency by the year 2075, resulting in catastrophic damage to the study area. Implications of this research for Maine's urbanized low-lying areas should be further researched. Further studies may reveal the need to make improvements to existing bulkheads, docks, etc. and may indicate the need for low-lying industries to floodproof machinery.

b. Rocky Shoreline

Although not considered as a specific coastal environment type investigated in this study, rocky shores (dotted with occasional, pocket, gravel beaches) comprise more than half of the Casco/Saco Bay region shoreline. It is not anticipated that accelerated sea-level rise will have a significant impact on shoreline position along rocky shores. Further study would be needed to determine the shoreline retreat rates associated with gravel pocket beaches.

6. Summary/Conclusions

Prior studies of shoreline change and coastal erosion in Maine have determined that the components of Maine's *soft coast*—coastal sand dune systems, coastal wetlands, and coastal eroding bluffs—may experience significant coastal erosion and inundation with a continuation of the historical rate of change. Along sand beaches and coastal wetlands, that erosion and inundation would be exacerbated by an accelerated rate of sea-level rise associated with global climate change. The findings of projected change in shoreline position by 2100 under the different scenarios for the study sites, grouped by environmental setting, are summarized in Table 2.5.

***Table 2.5.* Composite Result for Study Sites by Environmental Setting**

Environmental Setting	**Sea-Level Rise Scenarios Projected Shoreline Change, Retreat in Meters**		
	0.5 m	1.0 m	2.0 m
Salt Marsh	3-35	8-50	17-100
Bluff	15-45	15-45	15-45
Beach	50-150	100-300	200-600

The preceding assessment of the vulnerability of selected mapped areas in Casco and Saco Bays to accelerated sea-level rise leads to the following general observations:

- Estimates of shoreline change portrayed in this report by the three mapped scenarios are more substantial than previous estimates, which simply projected historic rates of sea-level rise over a 100 year period. Coastal managers need to understand and appreciate the differences in the assumptions used in each type of projection.
- The areas most threatened by accelerated sea-level rise are sand beaches and salt marshes; eroding coastal bluffs are also faced with significant impacts from a continuation of current erosion.
- There is already significant development in threatened areas. Population projections and economic forecasts suggest that pressure for coastal development will continue.
- Existing and projected levels of public and private investment, and the value of recreational beaches may lead to attempts at extensive "solutions" to "control" sea-level rise.
- The extent of development in unstable areas, and the probable impacts associated with accelerated sea-level rise in the study area, suggest that current land use and environmental laws may be inadequate to deal with issues such as wetland migration and eroding bluffs.
- There is a need for additional study on: the potential impacts on fisheries and habitat associated with accelerated sea-level rise, wetland migration, and storm surges/flooding.
- There is a need for increased public education for local officials and existing and future residents on the topic of shoreline dynamics and methods for developing and living safely in coastal environments.

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