TASK # 90-5.2.4

Rockingham
Planning
Commission

121 Water Street, Exeter, N.H. 03833 (603)-778-0885

Preliminary Study of Coastal Submergence and Sea Level Rise in Selected Areas of New Hampshire

September 1991

Preliminary Study of
Coastal Submergence and Sea Level Rise
in Selected Areas of New Hampshire

September 1991

Prepared by the
Rockingham Planning Commission
121 Water Street
Exeter, NH 03833
(603) 778-0885

This report was financed in part by funds provided by the New Hampshire Office of State Planning Coastal Program, through the Coastal Zone Management Act of 1972, as amended, administered by the Office of Coastal Resources Management, National Oceanic and Atmospheric Administration.

TABLE OF CONTENTS

LIST OF MAPS & FIGURES

I. INTRODUCTION

Coastal shoreline erosion and recession are well known environmental hazards in the Seacoast region of New Hampshire. The Blizzard of 1978 and more recent coastal storms serve as reminders of the hazards that natural storm events pose to low lying coastal areas. Coastal erosion and recession are caused by the combined effects of wave and wind erosion and by very gradual land submergence caused by geologic processes.[1] Within the past decade increasing concern has focused on the possibility that global climatic warming will cause a relatively rapid rise in sea level and result in greatly increased hazards from coastal erosion and flooding.

An increasing body of evidence suggests that the effects of global warming expected to appear within the next 50 to 100 years will cause a significant rise in sea level. The EPA, for example, has projected global sea level rise to be in the range of 1.8 to 11.3 feet by the year 2100.[2] Measured sea level rise during the past decade indicates that the upper range of these projects are unlikely. However, even a small rise can have a major effect in low lying coastal areas. Since 1929, relative sea level has risen nearly 0.5 feet in some areas of New England. (Giese, Aubrey, 1987)

Although the effects of climatic-induced sea level rise may not be felt in New Hampshire for several decades, it is not too early to begin examining the scope of the problem they may cause. Some of the most cost-effective solutions to property losses that could arise take several decades to implement. Future dislocations of development can be greatly lessened by directing development away from areas that lie within the range of likely sea level rise.

Over the next decade and beyond it will be important to carefully assess and quantify the threat that sea level rise will pose to New Hampshire's coastal communities. To do this accurately, detailed elevation data will eventually be needed in order to determine the precise land submergence patterns that should be anticipated. To date the evidence supporting any specific

---

[1] Passive Retreat of Massachusetts Coastal Upland Due to Relative Sea Level Rise, G.S. Giese, D.G. Aubrey, Mass. Coastal Zone Management, 1987.

[2] Projecting Future Sea Level Rise, J.S. Hoffman, D. Keyes, J.G. Titus, EPA 1983

estimate of sea level rise is not strong enough to justify the large expenditure of funds needed to develop such data. Until this evidence exists it is appropriate to attempt to use existing elevation and map sources to identify the general location and magnitude of coastal upland inundation.

Purpose and Scope

The purpose of this study is to evaluate, within a confined study area, the use of existing map sources to identify areas potentially at risk from projected sea level rise. Secondary purposes of the study are to assess, in qualitative terms, the magnitude of potential damage to facilities and property that could result from passive sea level rise and to begin to identify some of the long term planning and public policy issues that arise from this problem.

Specific objectives include:

- to apply and evaluate methods for estimating coastal upland submergence using existing USGS topographic maps;

- to test methods for interpolating one or more contour intervals between stated USGS contours based on site-specific elevation maps, and, to use this information to depict the extent of vulnerable areas under several sea level rise scenarios;

- to evaluate the applicability of the methods employed for use in other areas of New Hampshire's coastal zone;

- to assess the need to develop higher accuracy elevation data for the NH Coastal Zone and identify other related research needs.

Due to a number of problems encountered in using available site-specific elevation maps, it was not possible to achieve a usable result for the second of these objectives. Specifically, it was not possible to develop verifiable interpolations of USGS contour intervals against which different sea level rise scenarios could be applied. Nonetheless, it was possible to create a useful depiction of areas generally vulnerable to submergence using existing USGS contours (see Section IV).

Study Area

Three relatively small areas were originally planned to be included in the study: one on the Atlantic coast and two along the Squamscott River. Two of the three areas are covered by the Exeter and Hampton USGS *metric series* (1:25,000) quadrangle maps (quads). These maps feature 3 meter (about 11 feet) contour intervals. The third area was to be located within the Newmarket *standard series* (1:24,000) quad which has 20 foot contour intervals, or half the vertical resolution of the metric series quads used.

During the initial project investigation it became obvious that the Newmarket quad did not provide sufficient elevation resolution to depict areas at risk from coastal submergence. The third area was therefore dropped from the study and the others were expanded in size.

The study areas selected (see Maps 1 and 2) cover the coastal section of North Hampton (including tidal rivers/estuaries) and the portion of the Squamscott River (including tidal tributaries) located in Exeter. The North Hampton study area was selected because it contains all the features characteristic of the Atlantic coast in New Hampshire -- rocky shore, sandy beach and tidal marsh/estuary. It was also selected because detailed engineering plans were available (complete with two foot contour elevation data) which cover much of the immediate coastal area. These plans were developed by the Kimball Chase Co. in 1990 for the Rye Beach-to-Hampton Forced Main sewer project. They cover a several-hundred-foot wide corridor centered along Route 1A.

The study area in Exeter was selected because it is characteristic of the numerous tidal rivers in the New Hampshire coastal zone which may also be affected by sea level rise. The specific location was chosen because several GIS data layers useable in this study had already been developed in conjunction with a separate Coastal Program project (Inventory and Analysis of the Squamscott River Corridor, Rockingham Planning Commission, June 1991).

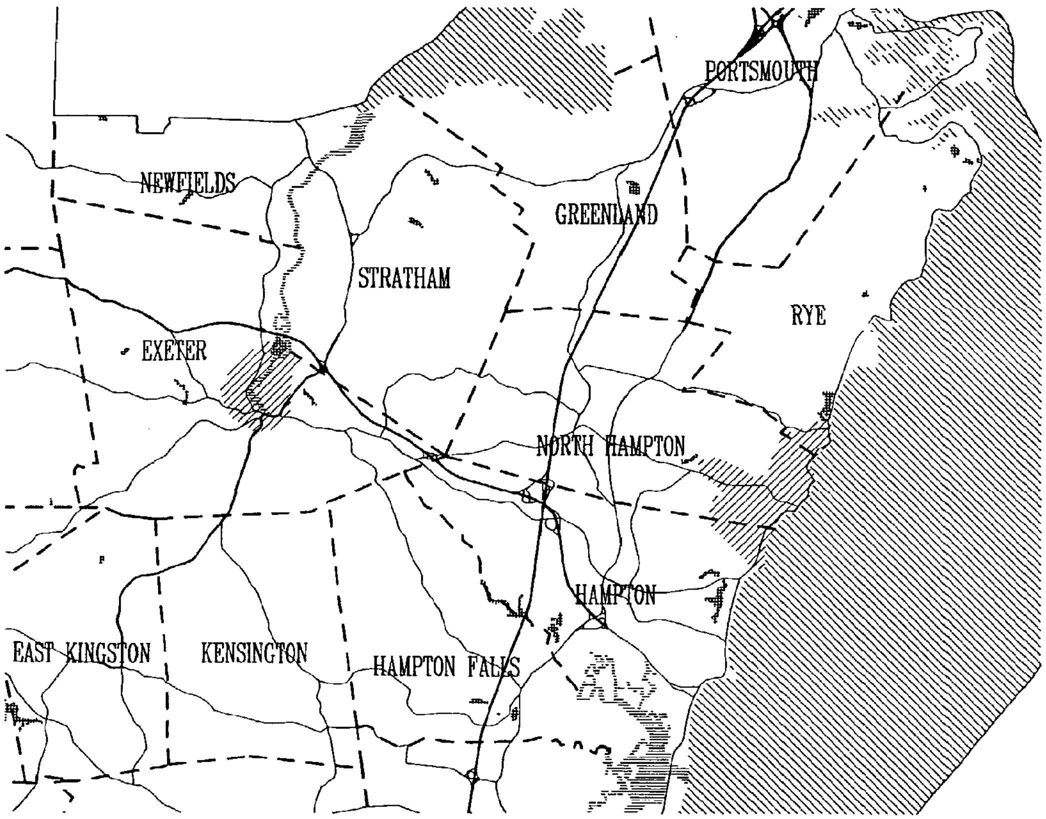
Cautionary Note

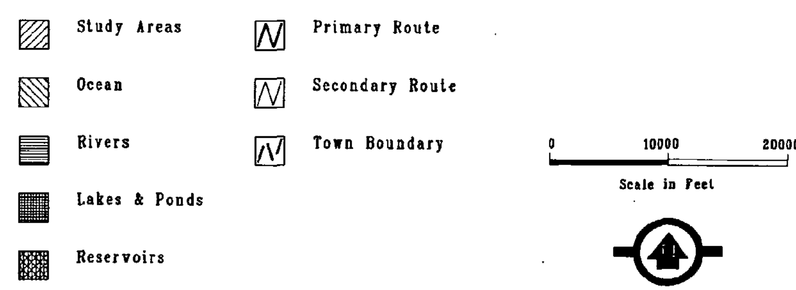
The USGS-based maps contained in this report are not designed to show site or parcel-specific information. The source map scale (1:25,000) makes them inappropriate for such use. They are not intended for use in identifying individual properties that may be at risk in the future but rather to show <u>general</u> areas that would be affected under the stated sea level rise scenario. Within the general areas identified, it is likely that smaller tracts of higher (and safer) elevation exist which do not appear separately due to the lack of elevation detail.

Further, the reader should recognize that the submergence risk areas shown are *hypothetical* in the sense that they are based on the assumption that a significant rise in sea level will occur.

MAP 1

Coastal Submergence Project
Study Area Locus Map



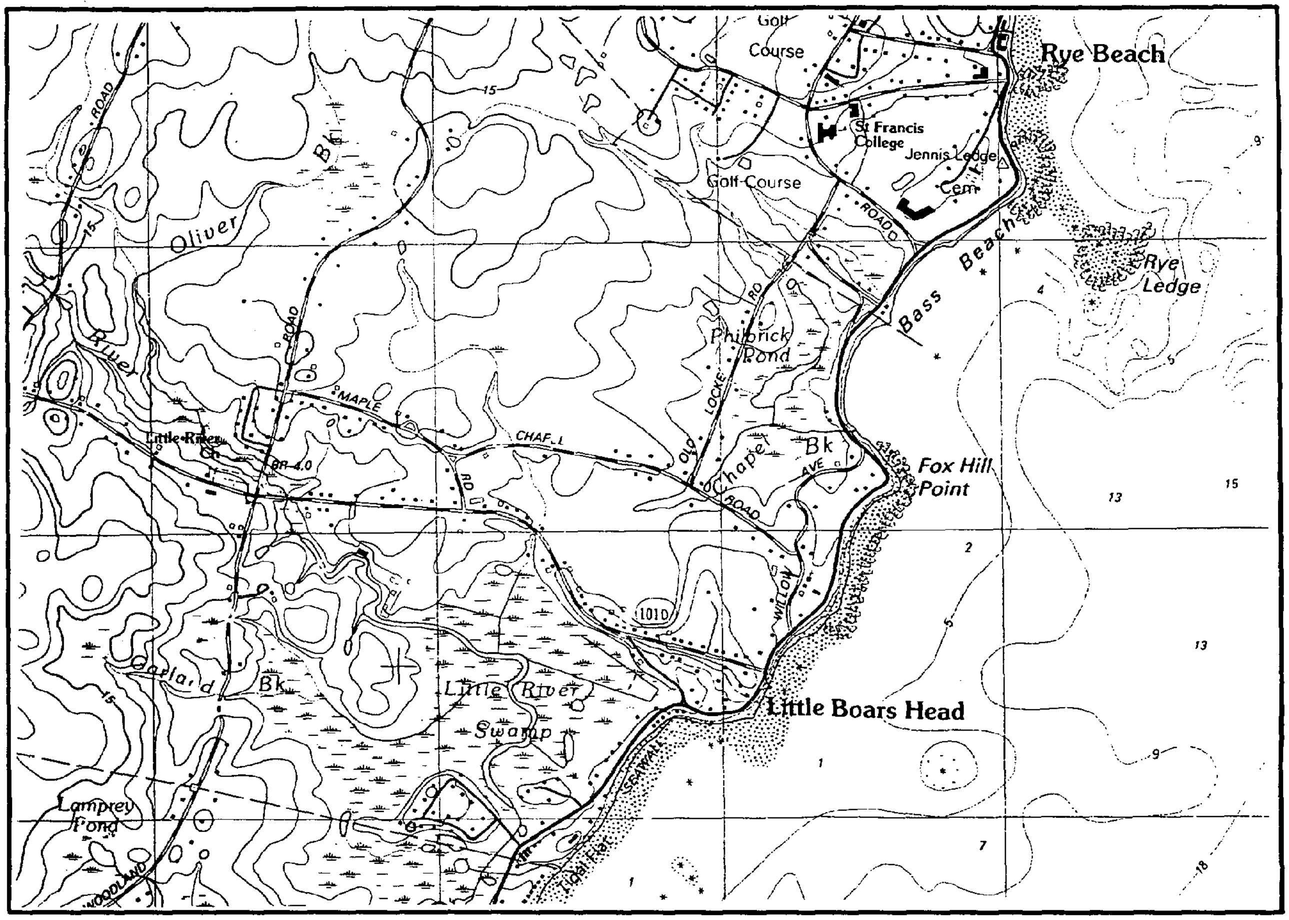


Source: USGS 1:100,000 DLG Data digitized by Complex Systems.

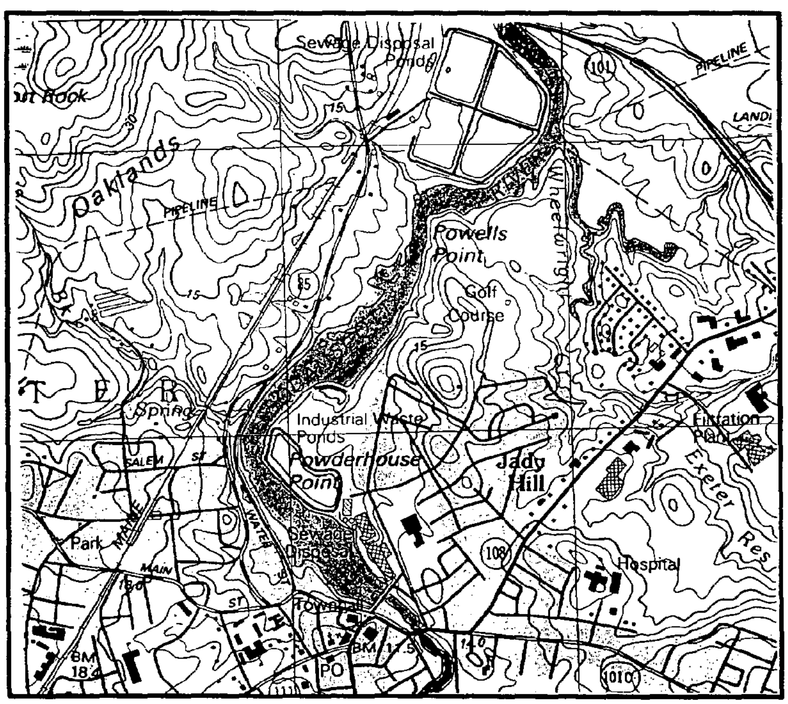
Map prepared by the Rockingham Planning Commission. October 1991. SRG

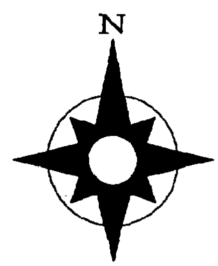
MAP 2

North Hampton Study Area - USGS Map



Exeter/Squamscott River Study Area - USGS Map





SCALE: 1" = 25,000"

SOURCE:
Exeter New Hampshire/Mass.
1:25,000-scale metric topographic map
USGS, 1985

II. METHODOLOGY

Data Sources

As proposed, the focus of this study was to use existing, readily available data sources to identify the lowest of low-lying coastal areas. Three primary mapped sources were used:

-- *Exeter, New Hampshire*, USGS metric series quadrangle map at 1:25,000 scale, 7 1/2 x 15 minute coverage, 3 meter contour interval, published in 1985.

-- *Preliminary Engineering Plans (Draft), 1990, Forced Main Sewer Project - Rye, NH - Hampton, NH*; prepared by Kimball Chase Co., Portsmouth, NH.

-- *Flood Insurance Rate Map*, North Hampton, NH (1986) and Exeter, NH (1982) FEMA, Scale: 1:4800.

The first two sources were used to identify elevation, the FIRM maps were used only to compare the low elevation areas as identified from the USGS map to the Federally defined flood hazard areas (100 and 500 year frequency floods).

Absent from the list of mapped sources is the USGS Digital Elevation Model (DEM) "map" for the study area. As of this writing, DEMs which cover the New Hampshire Coastal Zone are not yet available, except for the Hampton quad.

Important non-map data sources included a number of articles and papers from which sea level rise estimates were obtained. These sources are listed in the Bibliography included at the end of this report.

Interpolation

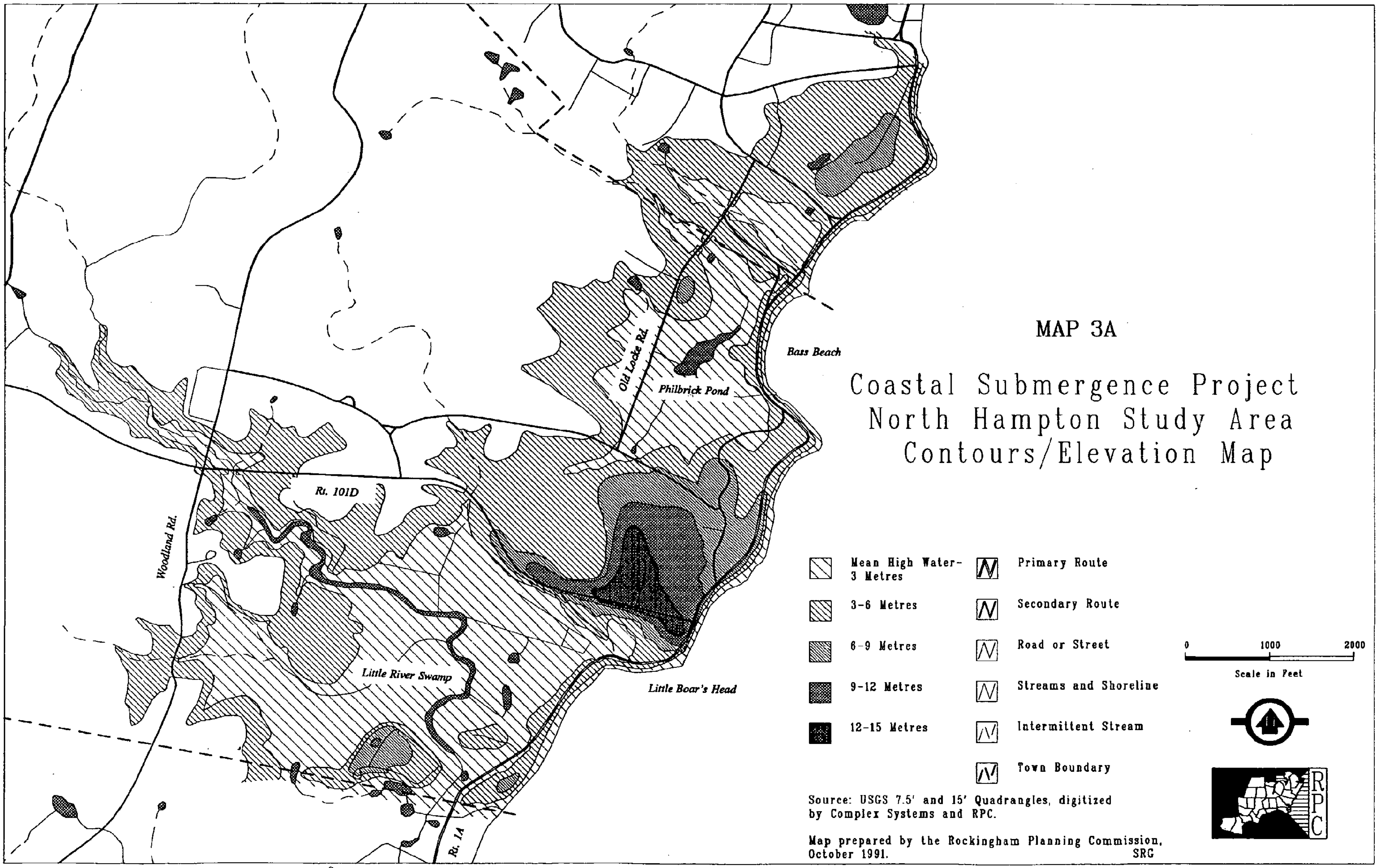
The object of interpolating between existing contour lines on the USGS map is to artificially create a higher resolution of elevation data--i.e., to improve upon the elevation detail contained on available USGS maps. A simple linear interpolation between existing contours (drawing a new contour line halfway distant between two existing contours) would, by itself, be invalid and unusable for the purpose intended. The concept tested here was to use elevations shown on a site-level engineering plan as a guide with which to produce interpolated contours on the USGS map.

To assist in both the interpolation and comparison, the USGS contour intervals (three meter resolution) were digitized from mylar quads (see Maps 3A & 3B) and plotted at a greatly expanded scale. Similarly, two-foot intervals were digitized from the sewer project engineering site plans (see Map 4). On the USGS plot a manual, linear interpolation between the indicated shoreline and the three meter contour was drawn (i.e. a "1.5 meter contour").

Unfortunately, it was not possible to rectify, within acceptable limits, the engineering plans to the USGS maps. Therefore, no GIS-based comparison between the contours could be made and no usable interpolation could be produced.

We were unsuccessful in applying the proposed method for two reasons. First and most important, the maps were not spatially compatible. After both USGS and Site Plan study areas were digitized, attempts were made to combine the coverages using the RPC's GIS system. This proved to be impossible because the site plan was not referenced to the State Plane Coordinate System, or any other spatial reference system (UTM, Lat-Long, etc.). Efforts to "force" the site plan into a common reference system were unsuccessful due to apparent distortions in the site plans relative to the USGS maps. It is evident that the site plan maps were not prepared from an orthophoto base. Failing this, the USGS and site plan coverages were plotted at a common scale (approximately 1:2400) and physically overlaid. This allowed limited manual comparisons for small segments of the study, one area at a time (by manual "rubber sheeting").

Comparing these limited areas revealed the second reason why elevation contours could not be interpolated. The large difference in scale and detail of the source maps (one order of magnitude) resulted in elevation data that was too dissimilar to be used as intended. The detailed contour shapes shown on the site plan were, in most cases, absent from the low resolution contours on the USGS map. In other words, the detailed land forms which show up on the site map are lost on the smaller scale USGS maps. This makes the transfer of information from one map scale to another impossible to do by any consistent and reproducible method. This somewhat unexpected result was explained in the written report of a more extensive submergence study prepared for


MAP 3A
Coastal Submergence Project
North Hampton Study Area
Contours/Elevation Map
Bass Beach
Philbrick Pond
Old Locke Rd.
Rt. 101D
Woodland Rd.
Little River Swamp
Little Boar's Head
Rt. 1A
Mean High Water-3 Metres
3-6 Metres
6-9 Metres
9-12 Metres
12-15 Metres
Primary Route
Secondary Route
Road or Street
Streams and Shoreline
Intermittent Stream
Town Boundary
0
1000
2000
Scale in Feet
RPC
Source: USGS 7.5' and 15' Quadrangles, digitized by Complex Systems and RPC.
Map prepared by the Rockingham Planning Commission, October 1991. SRG

MAP 3B

Coastal Submergence Project
Exeter Study Area
Contours/Elevation Map

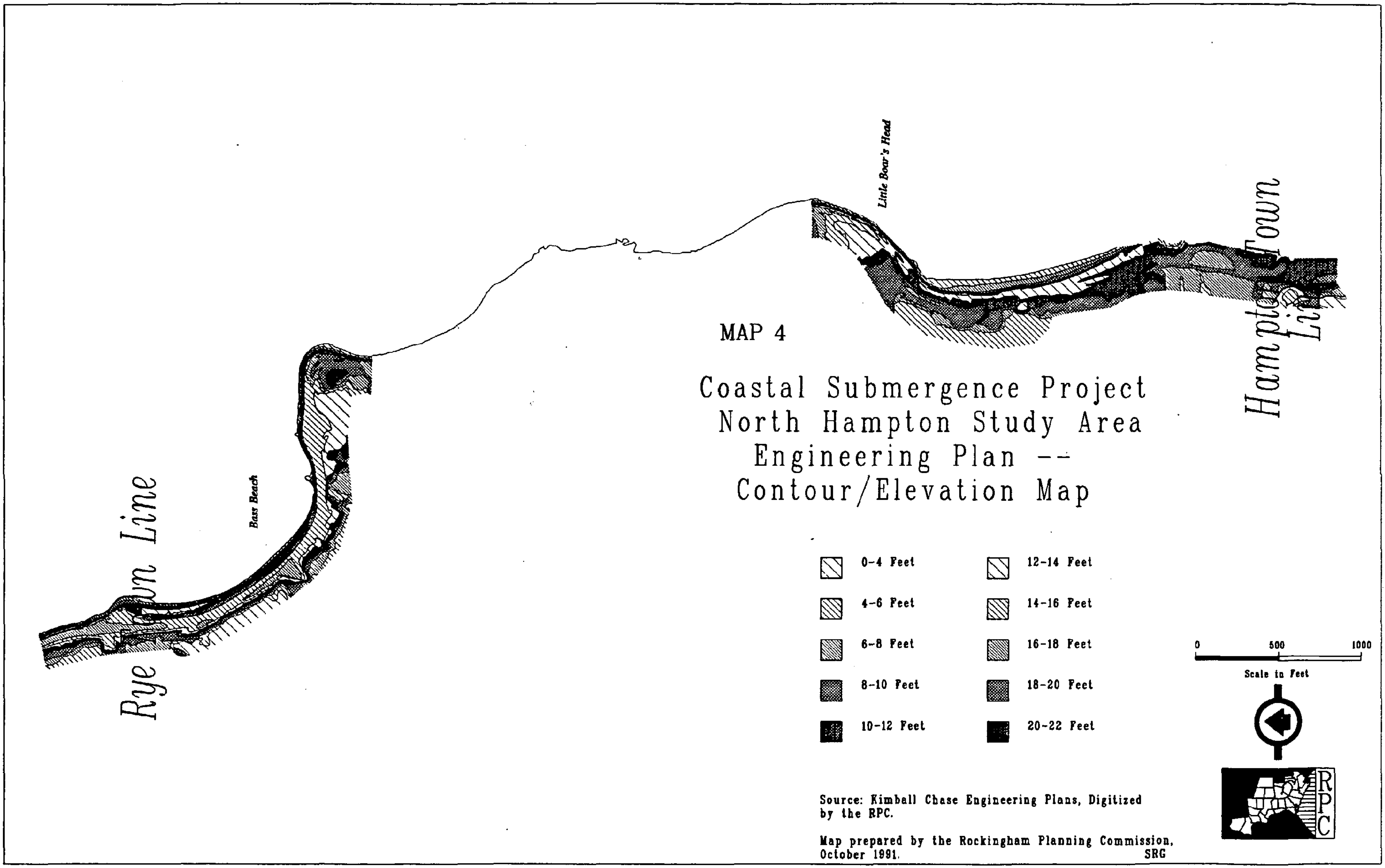
- Mean High Water-3 Metres
- 3-6 Metres
- 6-9 Metres
- 9-12 Metres
- 12-15 Metres
- Primary Route
- Secondary Route
- Road or Street
- Streams and Shoreline
- Intermittent Stream
- Town Boundary

0 1000 2000

Scale in Feet

Source: USGS 7.5' and 15' Quadrangles, digitized by Complex Systems and RPC.

Map prepared by the Rockingham Planning Commission, October 1991. SRG



MAP 4
Coastal Submergence Project
North Hampton Study Area
Engineering Plan --
Contour/Elevation Map
Rye Town Line
Bass Beach
Little Boar's Head
Hampton Town Line
0-4 Feet
4-6 Feet
6-8 Feet
8-10 Feet
10-12 Feet
12-14 Feet
14-16 Feet
16-18 Feet
18-20 Feet
20-22 Feet
0
500
1000
Scale in Feet
RPC
Source: Kimball Chase Engineering Plans, Digitized by the RPC.
Map prepared by the Rockingham Planning Commission, October 1991.
SRG

the Massachusetts Coastal Zone Program (Giese and Aubrey/Woods Hole 1987). As explained in that report, the complexity of land forms does not simplify as smaller and smaller segments are analyzed. Although the size of the area covered changes with the scale of he map, the complexity of the land forms shown remains more or less constant. This means that the contour shapes representing land forms at a small scale are not necessarily consistent with those at a large scale -- therefore, large scale contours cannot be used to "fill-in" contours at a small scale.

Despite the problems associated with creating a corrected interpolated contour, a qualitative assessment of the linearly interpolated "1.5 meter" contour was made. A manual comparison of the USGS-interpolated and site plan-derived contours suggests some general conclusions about the interpolated contour. In relatively straight shoreline sections and in areas where vertical relief is pronounced (such as Little Boars Head and other rocky shore sections) the interpolated contours appear reasonably accurate. In areas with low and irregular relief such as the tidal marshes and surrounding uplands, the interpolations appeared much less accurate. It is in these flatter areas, unfortunately, that the greatest accuracy is needed.

USGS Depiction of Low Lying Areas

Despite the failure in generating interpolated contours on the USGS map, a reasonable depiction of sections vulnerable to sea level rise is possible using USGS maps alone.

During the course of this study, research was conducted into the relationship between USGS-depicted contours, the shoreline elevation, and tide elevations. Based on the results of this research, *it appears that the three meter contour interval can serve as a reasonable demarcation of the upland extent of risk from coastal submergence*. This finding is significant in that it suggests that a readily available data source already exists which can be used to map, for general planning purposes, the areas that are potentially at risk.

As is more fully explained in Section IV of this report, the three meter contour is equivalent to an elevation of approximately 5.3 feet above mean high tide. This elevation is within the upper range of sea level rise projected to occur within the next 50 to 100 years.

III. SEA LEVEL RISE

Causes

As briefly described in the Introduction Section, the apparent rise in sea level has two components: the very gradual sinking or subsidence of the land surface ("isostatic" change) occurring along the New England coast and the actual rise in average sea level ("eustatic change"). The land surface and sea level elevations change independently of one another -- hence the terms "relative" and "absolute" sea level rise.

Land subsidence is the result of vertical movement in the earth's crust caused by geologic processes. Isostatic changes vary greatly throughout coastal areas of the U.S. Some areas are undergoing subsidence while others experience uplifting. In the New England coastal area the land is sinking (as documented in local tide-gauge data in Massachusetts) at a rate estimated to be 1.9 mm/year.[3]

Absolute sea level rise is caused by a long term, natural climatic warming which began at the end of the Pleistocene era (Ice-Age), approximately 15,000 years ago. Most geologists agree that the ocean level reached a low of about 130 meters below its present position at about that time, and rose rapidly toward its current level by about 5,000 years ago.

Since then it has risen very slowly (see Figure 1). In recent studies of sea level rise in Massachusetts, the absolute sea level rise was estimated to be 1 mm/year (Aubrey and Emery, 1983).

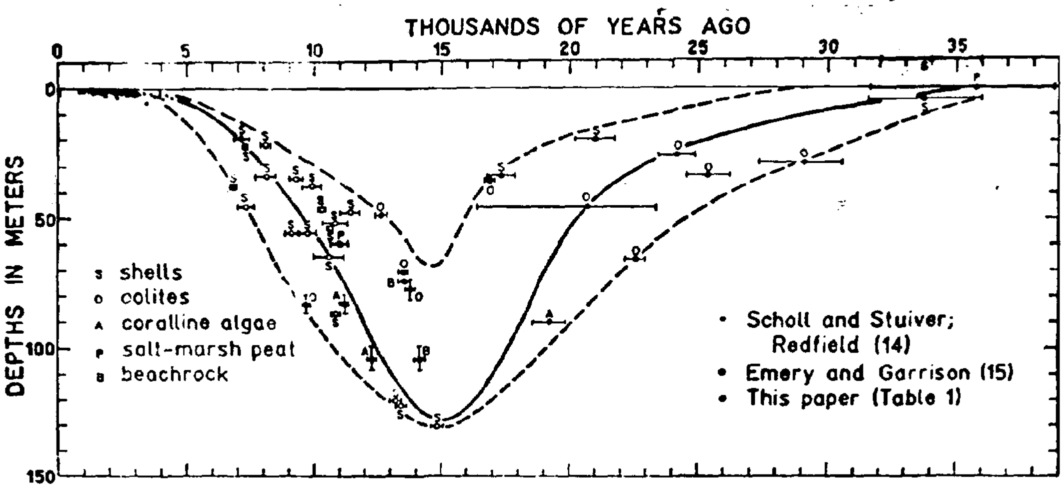
Changes in absolute sea level cause a change in ocean elevations with respect to a reference point on land. Since the land may be sinking or emerging as well, change in the relative sea level is what must be considered in evaluating potential risks to the environment. Isostatic and eustatic changes are combined to yield the current rate of relative sea level rise -- approximately 2.9 mm per year. Two-thirds of the change is due to subsidence and one-third to ocean level change. Since 1929, the reference year of the National Geodetic Vertical Datum (NGVD), mean sea level in our area has risen by 0.17 meters or 0.5 feet. Projecting this rate into the future, relative sea level rise in New England can

---

[3]Eigenanalysis of Recent United States Sea Levels, D. Aubrey and K. Emery Continental Shelf Research, Vol. 2, No. 1, 1983.

be expected to rise 0.75 feet above the existing levels over the next 100 years, *excluding* any rise caused by the affects of global warming.

Figure 1
Sea Level Change Over the Past 35,000 Years



Sea level curve for the past 35,000 years, showing a low stand about 15,000 years B.P., with a rapid rise until about 5000 years B.P. and a more gradual rise since then. (*From* Milliman and Emery 1968)

SOURCE: Barrier Island Ecology, Godfrey and Godfrey, National Park Service Monograph No. 9, 1976.

A growing body of scientific evidence suggests that an accumulation of "greenhouse gases" (mostly CO_2) in the atmosphere will result in relatively rapid global warming. Meteorological records indicate that global mean temperatures were warmer in the 1980's than at any previous decade for which data exists. One of the many effects of this change will be a relatively rapid rise in absolute sea level. Therefore, in addition to the natural relative sea level rise occurring in New England, a far more significant rise could occur causing an accelerated landward migration of the existing shoreline.

It should be noted that the scientific community is not unanimous in the opinion that an era of accelerated global warming has begun. Over the past several years a number of studies have been published which refute the hypothesis. Not in dispute, however, is the fact that the proportion of greenhouse gases in the atmosphere has grown significantly since the mid 1800's. It is inevitable that greenhouse gases will continue to accumulate so long as fossil fuels provide the greatest share of energy supply for the developed world. Although trends showing increases in average temperatures have been observed, some scientists maintain that it is too early to say with certainty that these increases are part of a warming trend induced by the greenhouse effect. Most believe that by the end of the century enough time will have elapsed to reveal with relative certainty whether significant and permanent global warming is occurring. Even then, uncertainty will remain as to the magnitude of the warming and how it will translate into sea level rise.

The consensus of the scientific community is that, based on observed trends in CO_2 accumulation, global warming will result in an increase in average atmosphere temperatures of 3° to 5°C in the next century -- as much warming as has occurred since the last Ice Age. Regardless of how successful mankind is in curbing future emissions of greenhouse gases, most climatologists have concluded that it is too late to prevent a 1° to 2°C warming.[4]

Atmospheric warming will translate into rising sea levels through several mechanisms including ocean water expansion, the melting of mountain glaciers and the eventual disintegration of polar ice sheets. In addition to causing sea levels to rise, global warming is also expected to modify climate patterns. Of particular importance to coastal area is the prediction that large ocean storms will tend to increase in frequency and intensity, thereby increasing the vulnerability of low-lying areas to storm-driven erosion and flooding.

Current Projections

Projecting future sea level rise is very uncertain business. In developing the analytical tools with which to forecast sea level, many assumptions and variables must be considered including: world population, economic growth, CO_2 emissions, CO_2 absorption in the oceans, heat dispersion in the ocean and atmosphere, effect of cloud cover, melting of polar ice, etc.

---

[4] Strategies for Adapting to the Greenhouse Effect, James G. Titus, APA Journal, Summer 1990.

One of the earliest comprehensive attempts to project sea level rise was made by the EPA in 1983[5] That effort took into account many of the factors listed above and resulted in the following low and high ranges of sea level rise:

TABLE 1

ABSOLUTE SEA LEVEL RISE PROJECTIONS
(Hoffman, et al. (EPA) 1983)

Year	Low Estimate (in feet)	High Estimate (in feet)
2000	0.16	0.56
2025	0.42	1.80
2050	0.79	3.84
2075	1.25	6.96
2100	1.84	11.32

Now, eight years later, it can be said that the high estimate projections for the year 2000 appear to be over-stated. Based on observed rates of sea level rise (1 to 2 mm/yr), it would appear that less than 25% of the high estimate will be reached by the year 2000[6].

More recent predictions have tended to exclude or diminish the disintegration of polar ice sheets as a major factor in sea level rise. This has had the effect of reducing sea level rise estimates significantly. Recent studies suggest that a one foot rise by 2050 is more likely than EPA's original "high" estimate of 3.8 feet. This estimate would be more consistent with a 3 to 6 foot rise by 2100 -- as opposed to the EPA "high" estimate of 11.3 feet. The area mapped as "submergence risk" for this study is defined by a 5.3 foot rise in sea level -- an elevation within the range of current estimates for 100 years hence.

These estimates represent absolute sea level change only. The local rate of subsidence must be added in order to obtain the relative sea level rise estimate. As discussed in Section III,

---

[5] Projecting Future Sea Level Rise, Methodology, Estimates to the Year 2100, Hoffman, Keyes, and Titus, U.S. EPA 1983.

[6] Contemporary Climate Change and its Related Effects on Global Shorelines, F. Gable, Woods Hole Oceanographic Institute, 1989.

over the past 60 years, the Massachusetts coast has been sinking at 1.9 mm/year. If the subsidence rate for New Hampshire is the same as that of Massachusetts, then an additional 0.21m or 0.69 feet in local sea level rise can be expected by 2100 and should be added to the absolute sea level rise estimates for that year.

Potential Land Use and Natural Resource Impacts

It is estimated that, nationwide, a one meter (3.28 foot) rise in sea level will cause the submergence of about 7,000 square miles of dry land in the U.S. (an area roughly the size of Massachusetts), (Titus, 1990). Shorelines in many locations would be severely impacted, retreating hundreds of feet landward. A recent study of the impacts of sea level rise on wetlands showed that a rise of 2 to 7 feet could result in the loss of 50% to 90% the tidal marshes in the U.S. (assuming no inland migration of the marshes).

An earlier N.H. Coastal Program study on sea level rise described extensively the kinds of impacts that can be expected along a coastal area like New Hampshire's[7]. Several types of impacts were identified in that report which are briefly summarized here: *Inundation, Adjustment of Baselevel, Erosion, and Current Velocities*.

-- **Inundation of Land**

Rising sea level will cause land that is currently above the high tide line to be submerged at high tide. As the sea level rises, coastal wetlands will migrate landward if there are no obstructions (i.e. road berms, bulkheads, etc.) to this movement. Low marsh areas will be destroyed and replaced with open water or mud flats. Some freshwater marshes may become brackish or salt water marsh (assuming no tidal flushing restrictions). Very low lying roads and developed land may be submerged at highest tides. Actual impacts from inundation will be determined by the extent of sea level rise, the topography of the upland and the extent to which the current shorefront is displaced.

---

[7]Rise in Sea Level and Coastal Zone Planning, Shevenell Gallen and Assoc./N.H. Office of State Planning, 1987.

-- **Adjustment of Baselevel**

A rise in sea level will change surface and groundwater flows. For example, the slope of tidal stream beds will change and tend to increase in the deposition of sediment in stream channels. Storm drainage in very low lying areas will fail as high tide levels exceed drain elevations. The freshwater/saltwater interface in the groundwater will migrate landward, possibly contaminating near shore wells with salt or brackish water.

-- **Erosion**

The impact of sea level rise on the shorefront will be determined from topography. In low lying coastal beaches, the whole beach profile will tend to migrate landward if not obstructed by attempts to save the existing shoreline and avoid property losses. This migration will be caused by severe wave erosion of the existing beach, especially during storm events. In areas of rocky and steeply sloping shorelines, minimal changes will occur. Average water depths in intertidal zones will increase, allowing longer wind driven waves to form and cause more erosion of bottom sediments.

-- **Current Velocities**

Tidal currents in constricted tidal rivers, streams and culverts will increase in velocity as a result of higher tides and the larger volume of water which flow in and out with each tide cycle. Culverts that are not now constricted may become so, and the flushing of wetlands will be altered.

In summary, a wide variety of impacts to the coastal environment can be expected from rising sea levels as the various natural systems attempt to maintain a dynamic equilibrium with the changing conditions.

Impacts from passive (meaning not caused by wave erosion) land submergence are the simplest to predict and evaluate and they are the only ones considered in the remaining sections of this report.

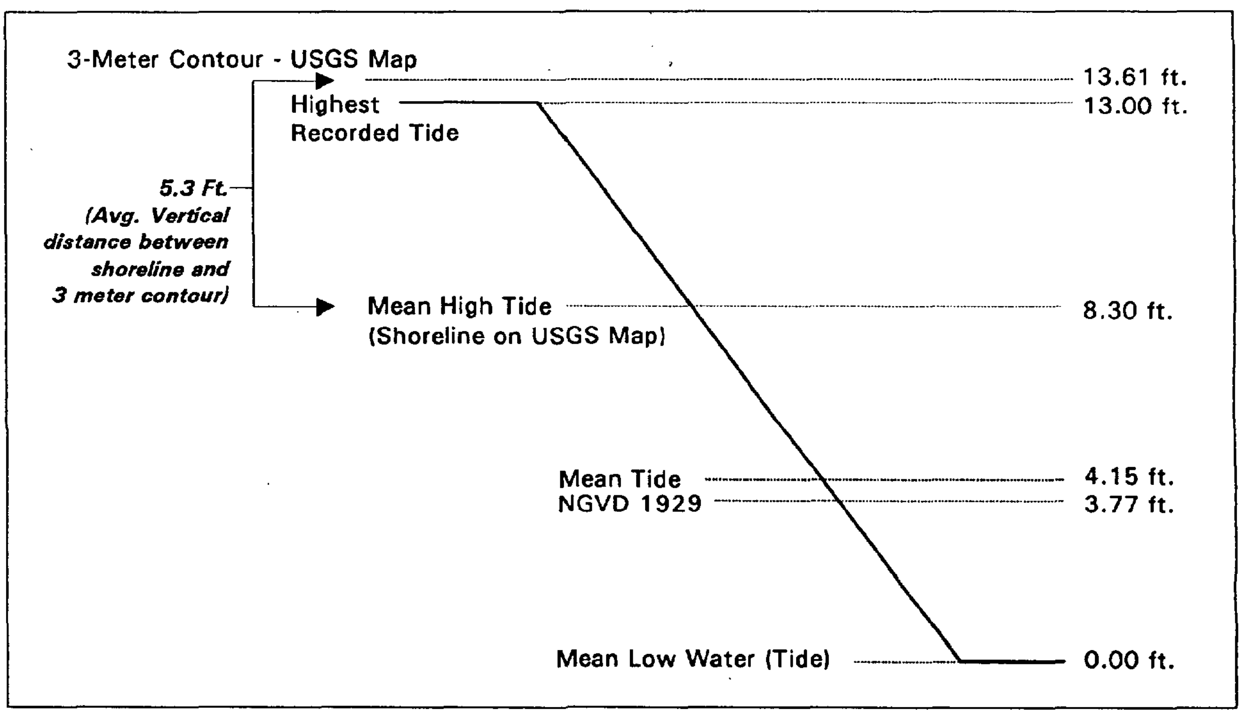
IV. IDENTIFICATION OF POTENTIALLY THREATENED AREAS

Data Sources

As explained in Section II - Methodology, the three meter contour line which appears on the USGS metric series quad maps (1:25,000) is approximately 5.3 feet above the mean high tide line. The mean high tide line is represented by the shoreline on these maps. The shoreline contour is not, as is commonly assumed, the "zero" elevation. Rather it is equivalent to "mean high tide". The relationship between the various vertical datum references shown in Figure 2.

Although the average vertical distance between the shoreline and the three meter contour is 5.3 feet, the USGS cautions that this relationship may vary from place to place. The USGS contours use 1929 NGVD (mean tide in 1929) as their zero vertical datum, however, the shoreline shown on the map is from a different source -- the NOAA Nautical charts. The shoreline is noted on the USGS maps as indicating the "approximate line of mean high water."

Figure 2
Differences in Vertical Datum and Sea Level
(based on New Hampshire tide ranges)



Because the shoreline is from a different source and uses mean low water as its datum rather than the NGVD of 1929, USGS cannot certify that the elevation accuracy is consistent with national mapping standards. For our purposes however, we have assumed that vertical distance is constant at 5.3 feet.

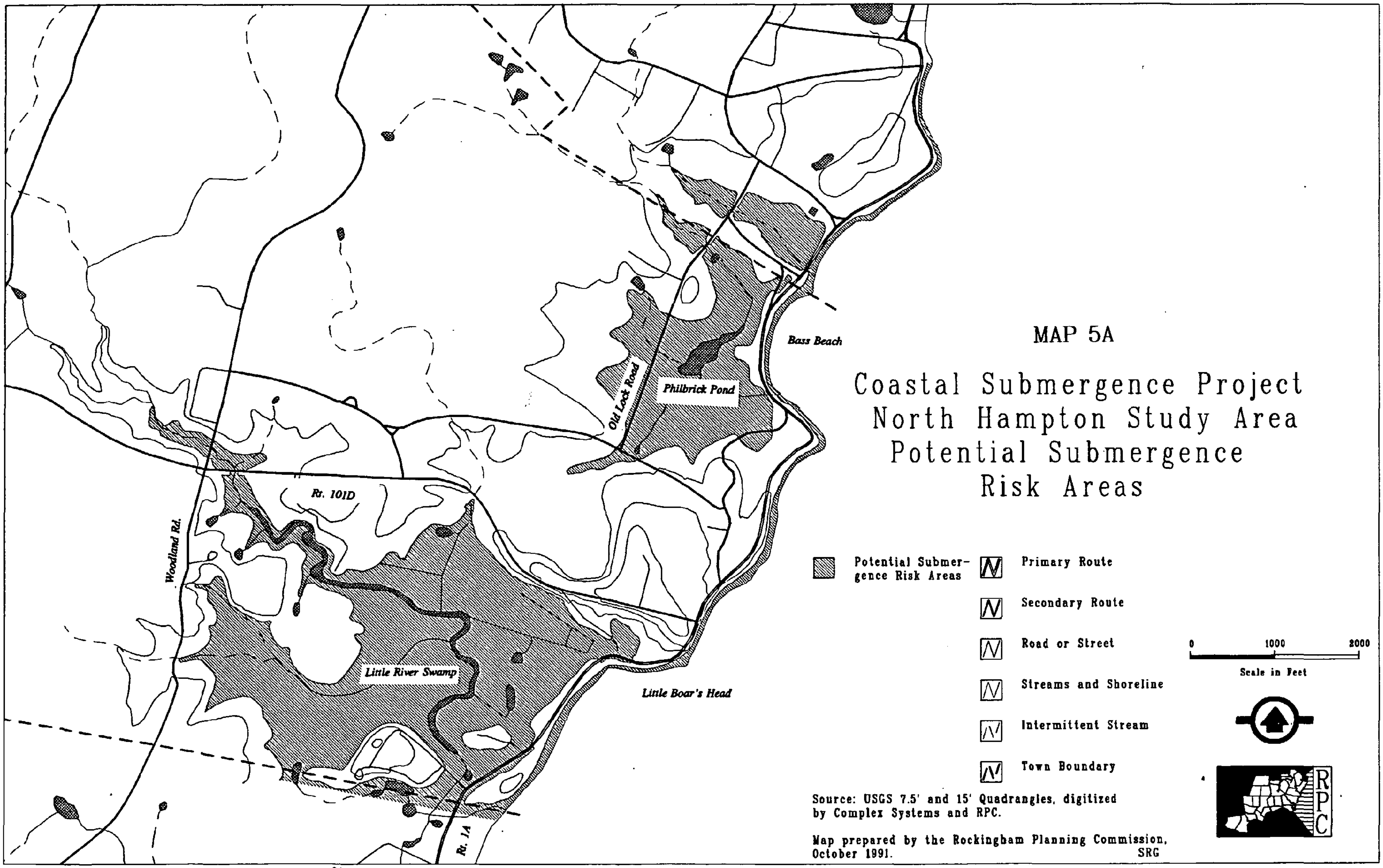
Based on our understanding of the datum references, and of current sea level rise estimates, it appears that the three meter contour elevation adequately serves as a reasonable boundary of the upland extent of sea level submergence projected for the next century. This assumes that a sea level rise of slightly more than five feet will occur in this timeframe -- probably close to a "worst case scenario".

Preliminary Results

Maps 5A and 5B depict the land area in each study area which has an elevation of three meters (NGVD) or less. This area is labeled *"Potential Submergence Risk Areas"* and indicates those places which would be inundated when the mean high tide rises to a level approximately 5.3 feet higher than present levels. *It indicates only areas influenced by passive submergence, not areas which may be affected by erosion and storm damage.*

Approximately 340 acres in the North Hampton study area would be affected. This represents approximately 20% of the defined study area and 3.9% of the total land area of North Hampton. The area described is nearly identical in shape and size to the tidal marsh soils shown on the SCS/NCSS Soil Survey Map for that area of North Hampton. Virtually all of the Little River Swamp, as well as the marshes in the vicinity of Philbrick Pond, would become open water for more than half the tide cycle. Inland of the Woodland Road/ Route 111 intersection, the Little River would become ponded at high tide. Also, it appears from the maps that Old Locke Road would be submerged at high tide in several locations adjacent to Philbrook Swamp. However, field observations show that the road itself is elevated above the surrounding area and would probably not be flooded at mean high tide.

In Exeter the area below three meters is much less extensive due to relatively confined floodplain of the river. Approximately 81 acres would be affected. This represents less than one percent of the Town's total land area. As with the North Hampton study area, there is a strong correlation between tidal marsh soil types and the submergence area. The submergence area generally remains



Bass Beach
Philbrick Pond
Old Lock Road
Rt. 101D
Woodland Rd.
Little River Swamp
Little Boar's Head
Rt. 1A
MAP 5A
Coastal Submergence Project
North Hampton Study Area
Potential Submergence
Risk Areas
Potential Submergence Risk Areas
Primary Route
Secondary Route
Road or Street
Streams and Shoreline
Intermittent Stream
Town Boundary
0
1000
2000
Scale in Feet
RPC
Source: USGS 7.5' and 15' Quadrangles, digitized by Complex Systems and RPC.
Map prepared by the Rockingham Planning Commission, October 1991.
SRG

MAP 5B

Coastal Submergence Project
Exeter Study Area
Potential Submergence Risk Areas

- Potential Submergence Risk Areas
- Primary Route
- Secondary Route
- Road or Street
- Streams and Shoreline
- Intermittent Stream
- Town Boundary

0 1000 2000
Scale in Feet

RPC

Source: USGS 7.5' and 15' Quadrangles, digitized by Complex Systems and RPC.

Map prepared by the Rockingham Planning Commission, October 1991. SRG

within 100-200 feet of the river except at the lower end of Swasey Park and along sections of Wheelright Creek, particularly at the Stratham/Exeter town line. The map indicates that Swasey Parkway is sufficiently above the three meter level to avoid flooding at mean high tide, however, field observations show the road to be nearly level with the ground on either side. Currently, extreme high tides have been observed to flood portions of the Parkway.

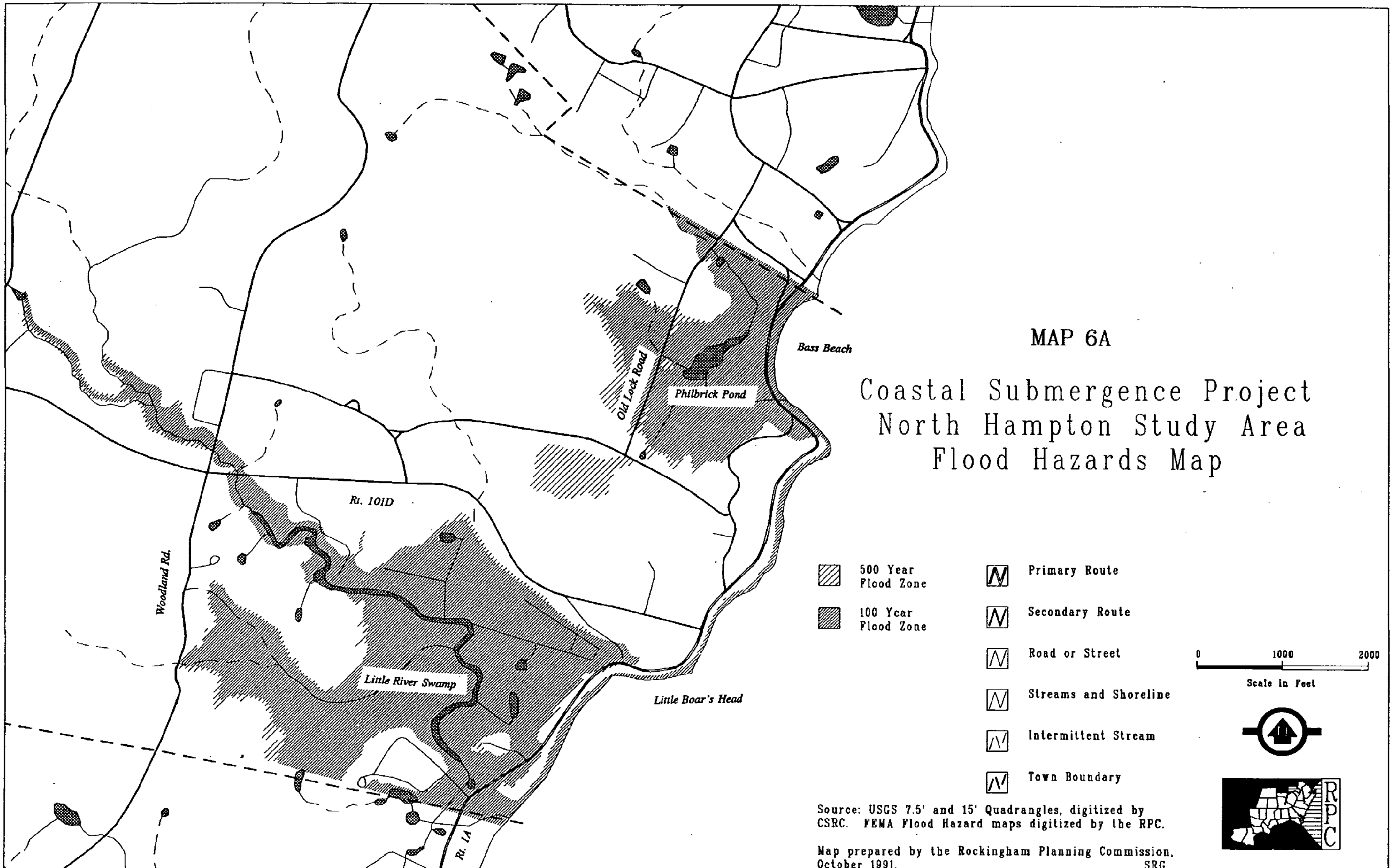
Maps 6A and 6B plot flood hazard areas defined in FEMA Flood Insurance Rate Maps (FIRMs). In North Hampton (1986 FIRM) a very close correlation can be observed between the potential submerged area and the 100-year frequency flood hazard area. In the Exeter study area the correlation is not as close; the 100 year flood correlates more closely with the area below the six meter elevation area than to the three meter area. The flood stage of the Squamscott is affected not only by tide but by the inflow from the Exeter River. The higher apparent flood stage may be explained by the contributing influence of the Exeter River -- which ends just upstream of the study area.

The 100 year flood stage for the tidal marshes in North Hampton is indicated on the FIRM Map as "EL 9" meaning nine feet above 1929 NGVD. This is equivalent to a height above mean low tide of 12.8 feet, or 0.8 feet lower than the elevation encompassed by the three meter contour. Given this small difference, it is not surprising that the land areas they describe are so similar in size and shape.

The FIRM maps which cover the Exeter study area (dated May 1982) indicate a 100 year flood stage elevation of "EL 8". The lower flood elevation is consistent with the fact the tidal range of the Squamscott is smaller than that of tidal marshes directly adjacent to the ocean.

Land Use Impacts

The final maps in the report show generalized land uses in the two study areas (Maps 7A and 7B), and a combination of submergence risk areas with land uses (Maps 8A and 8B). The North Hampton study area shows 10 to 12 areas where existing development is located within the submergence areas. A further evaluation was made based on the Town's land use map and on the USGS map. Based


MAP 6A
Coastal Submergence Project
North Hampton Study Area
Flood Hazards Map
Bass Beach
Philbrick Pond
Old Lock Road
Rt. 101D
Woodland Rd.
Little River Swamp
Little Boar's Head
Rt. 1A
500 Year Flood Zone
100 Year Flood Zone
Primary Route
Secondary Route
Road or Street
Streams and Shoreline
Intermittent Stream
Town Boundary
0
1000
2000
Scale in Feet
RPC
Source: USGS 7.5' and 15' Quadrangles, digitized by CSRC. FEMA Flood Hazard maps digitized by the RPC.
Map prepared by the Rockingham Planning Commission, October 1991. SRG

MAP 6B

Coastal Submergence Project
Exeter Study Area
Flood Hazards Map

500 Year Flood Zone

100 Year Flood Zone

Primary Route

Secondary Route

Road or Street

Streams and Shoreline

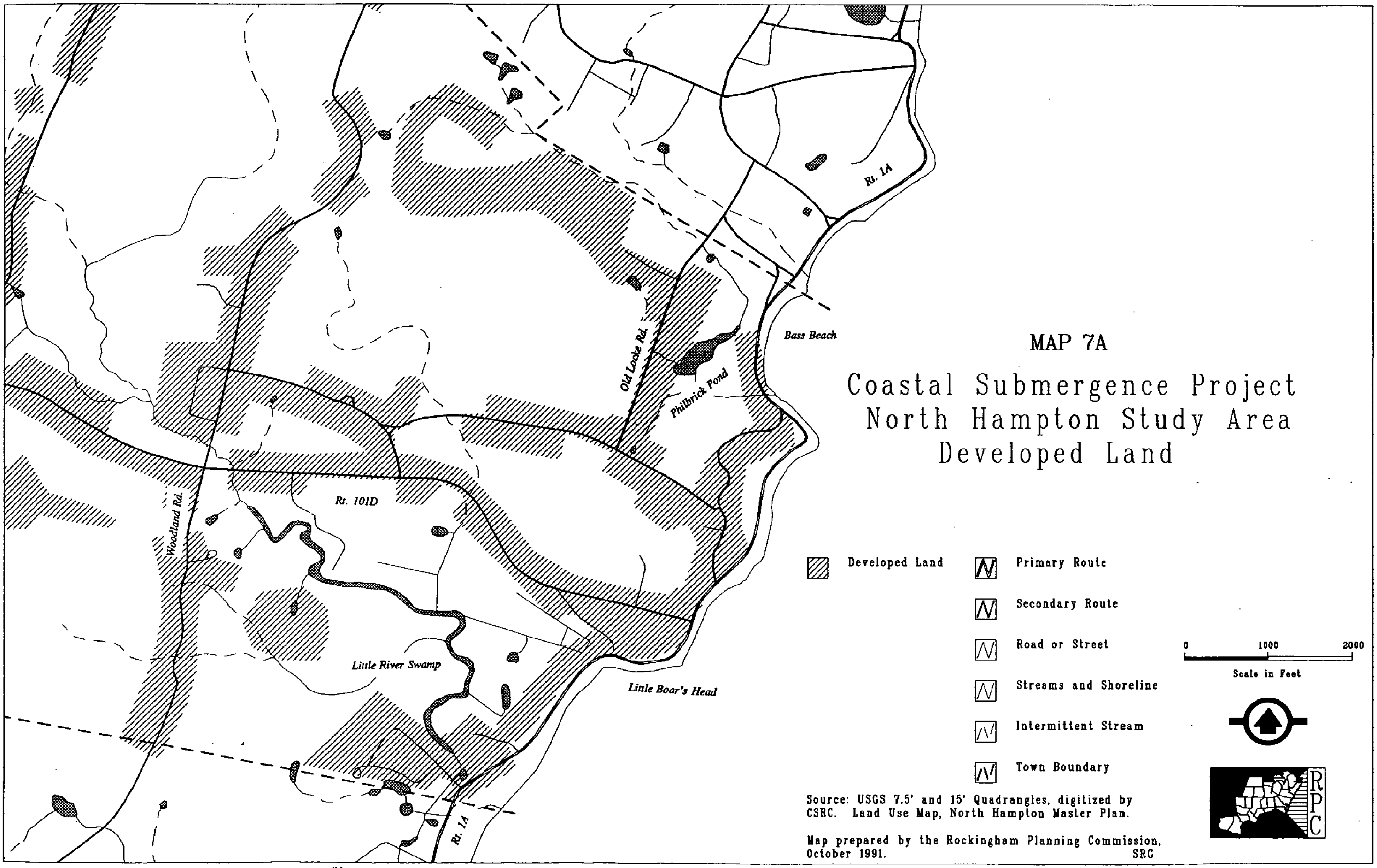
Intermittent Stream

Town Boundary

0 1000 2000
Scale in Feet

Source: USGS 7.5' and 15' Quadrangles, digitized by CSRC. FEMA Flood Hazard maps digitized by the RPC.

Map prepared by the Rockingham Planning Commission, October 1991. SRG


MAP 7A
Coastal Submergence Project
North Hampton Study Area
Developed Land
Developed Land
Primary Route
Secondary Route
Road or Street
Streams and Shoreline
Intermittent Stream
Town Boundary
0
1000
2000
Scale in Feet
RPC
Source: USGS 7.5' and 15' Quadrangles, digitized by CSRC. Land Use Map, North Hampton Master Plan.
Map prepared by the Rockingham Planning Commission, October 1991.
SRC
Rt. 1A
Bass Beach
Old Locke Rd.
Philbrick Pond
Rt. 101D
Woodland Rd.
Little River Swamp
Little Boar's Head
Rt. 1A

MAP 7B

Coastal Submergence Project
Exeter Study Area
Developed Land

Developed Land

Primary Route

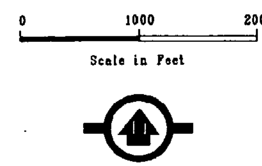
Secondary Route

Road or Street

Streams and Shoreline

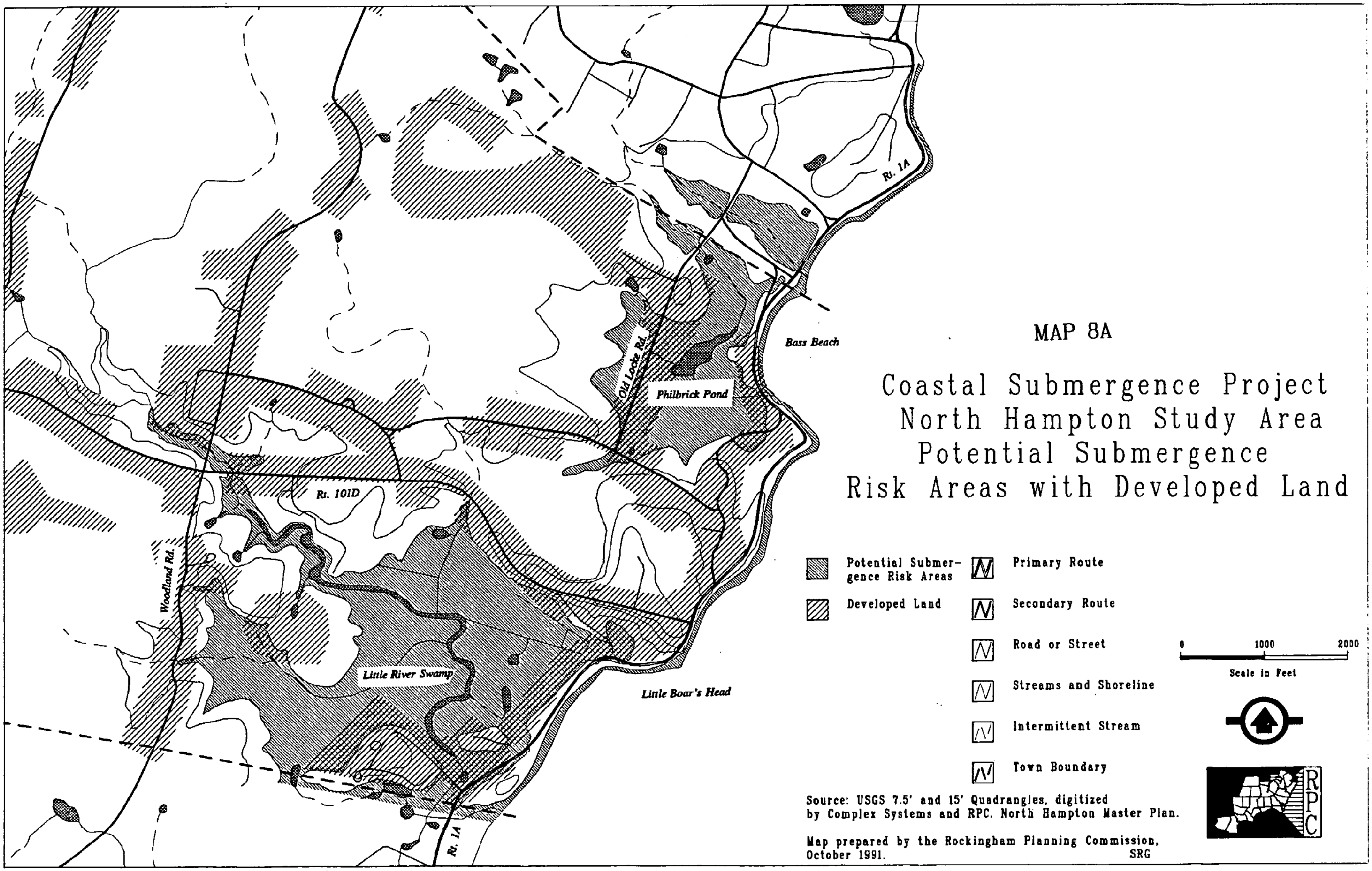
Intermittent Stream

Town Boundary



Source: USGS 7.5' and 15' Quadrangles, digitized by CSRC. Land Use Map, Squamscott River Study, 1991.

Map prepared by the Rockingham Planning Commission, October 1991. SRG


MAP 8A
Coastal Submergence Project
North Hampton Study Area
Potential Submergence
Risk Areas with Developed Land
Potential Submergence Risk Areas
Developed Land
Primary Route
Secondary Route
Road or Street
Streams and Shoreline
Intermittent Stream
Town Boundary
0
1000
2000
Scale in Feet
RPC
Source: USGS 7.5' and 15' Quadrangles, digitized by Complex Systems and RPC. North Hampton Master Plan.
Map prepared by the Rockingham Planning Commission, October 1991. SRG
Rt. 1A
Bass Beach
Philbrick Pond
Old Locke Rd.
Rt. 101D
Woodland Rd.
Little River Swamp
Little Boar's Head

MAP 8B

Coastal Submergence Project
Exeter Study Area
Potential Submergence
Risk Areas with Developed Land

- Potential Submergence Risk Areas
- Developed Land
- Primary Route
- Secondary Route
- Road or Street
- Streams and Shoreline
- Intermittent Stream
- Town Boundary

0 1000 2000

Scale in Feet

RPC

Source: USGS 7.5' and 15' Quadrangles, digitized by Complex Systems and RPC. Squamscott River Study.

Map prepared by the Rockingham Planning Commission, October 1991. SRG

on this evaluation it appears that approximately 24 of 196 structures (12%) within the study area are located at or below the submergence risk elevation. In addition, it appears that Old Locke Rd., as well as segments of Route 1A near the Hampton line and segments of Rt. 111 and Woodland Road near their intersection will be partially submerged during normal tidal cycles. (See Map 8A)

The Exeter study area shows less impact. Only four small areas of existing development appear located within a submergence risk area: Water Street - only the waterfront itself (from the Waterfront Park to the dam, the parking area and access road appears vulnerable); building on the Swasey Park side of the Water St./Swasey Parkway intersection; a portion of the residential area below Jady Hill Rd., and development immediately adjacent to Wheelright Creek on Portsmouth Ave. With the possible exception of Swasey Parkway, no public streets appear to be affected.

Overall, the direct land use impacts of passive submergence from a sea level rise of 5 feet appear relatively minor in both study areas. This conclusion is not unexpected given the fact that the submergence risk areas are nearly the same as the areas defined as tidal marshes and flood hazard areas. For the most part, structures within the submergence areas are already at risk from storm driven flooding.

It should be noted that some of the structures identified as located below the 3 meter contour may, if fact, be slightly above it. The USGS maps do not have sufficient vertical resolution to pick-up minor elevation variations that often exist around homes and along roads in low lying areas. Field investigations revealed, for example, that the structures along Old Locke Rd. and the Road itself are elevated several feet above the nearby tidal marsh.

While the direct impacts from passive submergence may be low, a sea level rise of this magnitude will expose many developed areas to increased risks from flooding, erosion and salt water intrusion. For example, higher sea levels will expand existing flood hazard areas; some structures that are now safely outside flood hazard areas may well be within them after a significant rise in sea level occurs. An assessment of these additional risks will require further study.

Natural Resource Impact -- Wetlands

One of most serious environmental impacts that is expected to arise from sea level rise is the destruction of coastal wetlands. Recent EPA research on the subject concluded that wetlands losses in the range of 26% to 82% would accompany a sea level rise of 1 meter[8] The role of coastal wetlands in providing fishery nursing grounds, habitat for migratory and nesting birds and other crucial ecological functions is well understood. A significant loss of coastal wetlands is cause for great concern.

The natural impact of a rising sea is to cause the entire wetland system to migrate landward (Titus, 1991). Under natural conditions, rising sea levels will cause the conversion of low marsh into open water or tidal flats, the conversion of high marsh to low marsh and the conversion of adjacent low lying uplands to high marsh. This is the process that enables the wetland system to migrate landward. If sea level changes occur slowly enough, and if adjacent uplands are of gradual slope, then it is possible for the migration to occur with little net change in wetland acreage or productivity. After all, coastal wetlands have been migrating "inland" for thousands of years as the sea level has slowly risen.

Unfortunately, there is good reason to believe that this kind of gradual migration will be disrupted in the future. One reason is that the projected rapid rate of sea level rise may overwhelm the ability of the wetland ecosystem to keep pace. A second problem is that much of the upland immediately adjacent to tidal marshes is developed. Landowners will surely resist the wetlands migration by erecting berms or bulkheads to stave off the advance. This will effectively halt wetland migration in such areas and contribute to the permanent loss of coastal wetlands. According to EPA estimates, eliminating migration obstructions (i.e preventing property protecting structures) can cut in half the total potential wetland loss due to sea level rise.

If coastal wetland losses are to be minimized it will be crucial for federal, state and local policy makers to devise fair and equitable ways to abandon development that is in the path of wetland migration.

---

[8]"Greenhouse Effect and Coastal Wetland Policy...", J.G. Titus, US EPA, Environmental Management Vol. 15 No. 1, 1991, Table 1

Such approaches might include: acting now to limit future development in areas where wetlands are likely to migrate to; allowing development in sensitive areas only on the condition that no attempt will be made to protect the property (via bulkheads, seawalls, etc.) from advancing wetlands, and modifying the federal flood insurance program to greatly discourage or disallow reconstruction of structures damaged as a consequence of sea level rise.

BIBLIOGRAPHY

Cooke, R.U. and Doornkamp, J.C., Geomorphology in Environmental Management, An Introduction, Oxford University Press, Great Britain, 1977

Federal Emergency Management Agency, Flood Insurance Study, Town of North Hampton, New Hampshire, Rockingham County, Federal Emergency Management Agency, 1984

Gable, Frank, Contemporary Climate Change and its Related Effects on Global Shorelines, Coastal Research Center, Woods Hole Oceanographic Institution, Woods Hole, MA

Giese, G.S. and Aubrey, D.G. and Zeeb, P., Passive Retreat of Massachusetts Coastal Upland Due to Relative Sea-Level Rise, Woods Hole Oceanographic Institution, Woods Hole, MA, 1987

Godfrey, Paul J. and Godfrey, Melinda M., Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina, National Park Service Scientific Monograph Series Number Nine, U.S. Government Printing Office, Washington, D.C., 1976

Gornitz, Vivien and Kanciruk, Paul, Assessment of Global Coastal Hazards from Sea Level Rise, NASA GSFC Institute for Space Studies and Columbia University, New York, NY and Oak Ridge National Laboratory, Oak Ridge, TN, 1987

ICF, Incorporated, Developing Policies to Improve the Effectiveness of Coastal Flood Plain Management, ICF Incorporated, Fairfax, Virginia, July 1989

Shevenell Gallen and Associates, Inc., Technical Report: Rise in Sea Level and Coastal Zone Planning, Shevenell Gallen and Associates, Inc., 314 South Main Street, Concord, NH, October 1987

Titus, James G., Greenhouse Effect and Coastal Wetland Policy: How Americans Could Abandon an Area the Size of Massachusetts at Minimum Cost, Environmental Management, Vol. 15, No. 1, Springer-Veriag New York Inc., 1991

Titus, James G., Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey, Coastal Management, Vol. 18, United Kingdom

Titus, James G., Strategies for Adapting to the Greenhouse Effect, APA Journal, Summer 1990