Projected Impact of Relative Sea Level Rise on the National Flood Insurance Program

October 1991

FEDERAL EMERGENCY MANAGEMENT AGENCY
FEDERAL INSURANCE ADMINISTRATION

Originally published October 1991 by the Federal Emergency Management Agency, Federal Insurance Administration

PREFACE

This study of the impact of relative sea level rise on the National Flood Insurance Program was authorized by Congress and signed into law on November 3, 1989. The requirements of this study as specified by the legislation are as follows:

SEC. 5. Sea Level Rise Study

The Director of the Federal Emergency Management Agency shall conduct a study to determine the impact of relative sea level rise on the flood insurance rate maps. This study shall also project the economic losses associated with estimated sea level rise and aggregate such data for the United States as a whole and by region[1]. The Director shall report the results of this study to the Congress not later than one year after the date of enactment of this Act. Funds for such study shall be made available from amounts appropriated under section 1376(c) of the National Flood Insurance Act of 1968.

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[1] Discussions with Congress subsequent to the passage of the legislation clarified that the study by FEMA would pertain only to the impact of sea level rise on the National Flood Insurance Program.

EXECUTIVE SUMMARY

This report contains the findings and conclusions concerning how the National Flood Insurance Program (NFIP) would be impacted by a rise in relative sea level. Based on information recently released by the United Nations on the range in the magnitude of potential rise in sea level, two primary sea level rise scenarios were examined, a 1-foot and 3-foot increase by the year 2100. Under both scenarios, the elevation of the 100-year flood would be expected to increase by the amount of the change in sea level. The area inundated by the 100-year flood is estimated to increase from approximately 19,500 square miles to 23,000 square miles for the 1-foot scenario, and to 27,000 square miles for the 3-foot scenario. The region most significantly affected would be the Louisiana coast, where subsidence rates of 3 feet per century would compound the impact of global changes in sea level. Because of potential growth in population within the coastal areas of the Nation over the next century, as well as the expansion of the floodplain, the number of floodprone households is estimated to increase from approximately 2.7 million to 5.7 million and 6.8 million by the year 2100 for the 1-foot and 3-foot scenarios, respectively. Assuming current trends of development practice continue, the increase in the expected annual flood damage by the year 2100 for a representative NFIP insured property subject to sea level rise is estimated to increase by 36-58 percent for a 1-foot rise, and by 102-200 percent for a 3-foot rise in sea level.

Based on these findings, the aspects of flood insurance rate-making that already account for the possibility of increasing risk, and the tendency of new construction to be built more than one foot above the base flood elevation, the NFIP would not be significantly impacted under a 1-foot rise in sea level by the year 2100. For the high projection of a 3-foot rise, the incremental increase of the first foot would not be expected until the year 2050. The 60-year timeframe over which this gradual change occurs provides ample opportunity for the NFIP to consider alternative approaches to the loss control and insurance mechanisms of the NFIP and to implement those changes that are both effective and based on sound scientific evidence. Because of the present uncertainties in the projections of potential changes in sea level and the ability of the rating system to respond easily to a 1-foot rise in sea level, there are no immediate program changes needed. However, the possibility exists for significant impacts in the long term; therefore, the Federal Emergency Management Agency (FEMA) should:

- continue to monitor progress in the scientific community regarding projections of future changes in sea level and consider follow-on studies that provide more detailed information on potential impacts of sea level rise on the NFIP;

- in the near term, consider the formulation and implementation of measures that would reduce the impact of relative rise in sea level along the Louisiana coast; and

- strengthen efforts to monitor development trends and incentives of the Community Rating System that encourage measures which mitigate the impacts of sea level rise.

Acronyms and Abbreviations

BFE	Base Flood Elevation
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Map
FP	Floodplain
IPCC	Inter-Governmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
NFIP	National Flood Insurance Program
NGVD	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
PGR	Post Glacial Rebound
SFHA	Special Flood Hazard Area
SWFL	Stillwater Flood Level

Conversion Table -- English to Metric Units

Multiply	By	Obtain
Inches (in)	25.4	Millimeters (mm)
	2.54	Centimeters (cm)
Feet (ft)	30.48	Centimeters (cm)
	0.3048	Meters (m)
Miles (mi)	1.61	Kilometers (km)
Square Miles (mi^2)	2.59	Square Kilometers (km^2)
Temperature Change [Degrees Fahrenheit (°F)]	5/9	Temperature Change [Degrees Celsius (°C)]

To obtain absolute Fahrenheit (F) temperature readings from Celsius (C) readings, use formula:
$F = 9/5\ C + 32$

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Originally published October 1991 by the Federal Emergency Management Agency, Federal Insurance Administration

PROJECTED IMPACT OF RELATIVE SEA LEVEL RISE ON THE NATIONAL FLOOD INSURANCE PROGRAM

1.0 SUMMARY

1.1 Background

The rise of global sea level over the past century has been documented by several investigators using tide gage measurements. At specific locations, the change in sea level relative to the land is dependent upon the effects of any local land subsidence or uplift. For areas experiencing a significant rate of uplift (such as portions of the Alaskan coastline), relative sea level has been decreasing, while for areas in which subsidence is taking place (such as portions of Louisiana's coastline), relative sea level is increasing at a more rapid rate than in other areas.

Although it is known that mean sea level fluctuates over long time periods, the exact causes of these natural changes are not well understood. It has been suggested by some that the recent rise of sea level is related to global warming (the greenhouse effect) and that, as the atmosphere warms, the oceans will rise because of the melting of ice masses and thermal expansion of the oceans. The magnitude of historical global warming, its anthropogenic and/or natural origins, and its link to sea level rise are issues that are currently subject to intense scientific scrutiny. The potential magnitude of warming and the degree to which it would be delayed by the thermal inertia of the oceans are uncertain. Also, the degree to which changes in precipitation affecting the ice caps and mountain glaciers might change the volume of water removed from the sea and stored is uncertain.

The atmosphere and ocean are complex systems, making long-term climate and sea level predictions extremely difficult. Numerical models of global climate change, although ever advancing, are still limited in their ability to accurately predict changes in the atmosphere and ocean over long (decadal or centennial) time scales. Even though these limitations exist, the most sound basis for predicting changes in this global system is the combination of numerical modeling and analyses of the available long-term environmental records (the past 2-8 million years of the geologic record).

The above uncertainties have prompted investigators interested in quantifying the impacts of potential sea level rise to address a range of sea level rise scenarios. These scenarios generally assume that the rate of sea level rise will accelerate with time and that a greater rate of rise will occur in the latter half of the next century.

A significant increase in relative sea level could cause extensive shoreline erosion and inundation. Higher relative sea level would elevate flood levels and therefore require alteration of the 100-year coastal floodplain delineated by the Federal Emergency Management Agency (FEMA). Flood events would impact more property and result in greater damage as sea level increased. This problem is exacerbated by the present trend towards increased concentration of population in coastal areas.

1.2 Study Objectives and Approach

The primary objective of this study is to quantify the impacts of sea level rise on (1) the location and extent of the U.S. coastal floodplain, (2) the relationship between the elevation of insured properties and the 100-year base flood elevation (BFE), and (3) the economic structure of the National Flood Insurance Program (NFIP). The coastal floodplain area affected includes areas subject to increased erosion and submergence. In response to sea level rise, changes will occur in the extent of the coastal floodplain, in the portion of the coastal floodplain that is subject to flooding and modest wave action (A-Zone), and in the portion of the coastal floodplain subject to flooding and significant wave action (the velocity zone or V-Zone). Areas affected by flooding (both coastal and riverine) are shown on Flood Insurance Rate Maps (FIRMS) published under the NFIP.

For this study, an average insurance risk was identified based on flood-depth distributions reflected in current flood insurance policies. Different distributions were assigned to pre-FIRM and post-FIRM structure categories. For the purpose of this study, pre-FIRM structures were defined as structures built before 1980; post-FIRM structures are structures built after 1980.

Two sea level rise scenarios for the period 1990 to the year 2100 were examined in this study. Based on recent scientific investigations, the first scenario is a 1-foot rise in sea level by the year 2100. The second scenario is the high scenario of a 3-foot rise in sea level by the year 2100. Studies supporting these scenarios include the report entitled Scientific Assessment of Climate Change prepared for the Intergovernmental Panel on Climate Change (IPCC) by Working Group No. 1 (IPCC, 1990). The IPCC was jointly established by the World Meteorological Organization and the United Nations Environment Programme. For comparison purposes, a no-rise scenario is also cited in this report.

Accomplishing a study of this scope and magnitude required that several assumptions be made. It is important to understand that these assumptions can significantly influence the quantitative results of this study. The major assumptions are described below:

1. Census data were used to establish population trends in each coastal county to the year

2010. Projections beyond 2010 (to the year 2100) were based on these trends. This approach assumes a linear increase of population over time and does not account for development saturation that may occur or other factors which could significantly affect the population trends adopted for this study, such as changes in mortality rates, fertility rates, and social and recreational trends.

2. Within each coastal county, the total households (based on population estimates) were assumed to be uniformly distributed over the total land area of the county. The number of households in the county's floodplain was determined by multiplying the total number of households by the ratio of floodplain area to total county land area. This assumption was necessary because of the lack of quantifiable information about the variation of the density of households in the floodplain. This assumption could lead to either an overestimate or underestimate of the number of floodplain households in each county.
3. This study assumes that no engineering solutions or land use/coastal zone management practices are implemented over the study period other than current practices related to elevation of structures. Options that could substantially mitigate the impacts of sea level rise in open coast areas include armoring of the shoreline (e.g., constructing seawalls, breakwaters, and dikes), beach renourishment, and the adoption of setback regulations. The effect of this assumption is that the projections contained in this report will be overestimated.
4. The obsolescence of structures was not considered in this study. Based on the expected life of a coastal structure, a certain fraction of these structures will become obsolete each year and will be replaced by new structures which will be in compliance with the current NFIP regulations for construction at that time. Since obsolescence has not been accounted for, the actual insurance risk may be overestimated in this study.

1.3 Findings

The current total 100-year coastal floodplain area is approximately 19,500 square miles (50,500 square kilometers) for all coastal regions of the United States. Most of this area is contained in the coastal states from the Mid-Atlantic region to the Gulf of Mexico region. The west coast, Alaska, and Hawaii together account for no more than 5 percent of the total coastal floodplain area. The additional areas that may be affected by the 100-year flood are estimated to be approximately 2,200 square miles (5,700 square kilometers) for the 1-foot scenario and 6,500 square miles (16,830 square kilometers) for the 3-foot scenario when subsidence in Louisiana is not taken into account. When subsidence in Louisiana is accounted for, these figures become 3,400 square miles (8,800 square kilometers) and 7,700 square miles (19,900 square kilometers), respectively.

The estimated total number of households in the coastal floodplain for the 1-foot and 3-foot sea level rise scenarios for the year 2100 are shown in the following table. The numbers in brackets reflect the case when subsidence in Louisiana is taken into account. For comparison purposes, expected results for a no-rise condition (i.e., 0-foot scenario) are also shown to indicate the influence of population estimates on the number of floodprone households.

Total Estimated Households in the Coastal Floodplain (In Millions)

	Current Households	0' Scenario 2100	1' Scenario 2100	3' Scenario 2100
Households in A-Zone	2.4	4.5 [4.6]	5.0 [5.1]	5.9 [6.1]
Households in V-Zone	0.28	0.55 [0.58]	0.61 [0.64]	0.73 [0.75]
Total Households in Coastal Floodplain	2.7	5.1 [5.2]	5.6 [5.7]	6.6 [6.8]

A model representing the shifting distribution of risk characteristics of NFIP business was created to provide some insight into the relative changes in expected losses and resulting premiums caused by an increasing flood risk over time. The analysis was limited to the consideration of the standard flood insurance coverage provided to buildings insurable under the NFIP and not the additional erosion benefits afforded by the Upton-Jones Amendment, which was enacted in 1988.

The Upton-Jones program and its associated benefits were not considered in this study for several reasons. Engineering solutions, coastal zone management practices, and other options discussed in Item 3 on page 3 would influence the vulnerability of structures and their eligibility for benefits under the Upton-Jones Amendment. Although these kinds of impacts have been investigated in some studies (National Research Council (NRC), 1987; Environmental Protection Agency (EPA), 1989), the effect of sea level rise on the Upton-Jones program cannot be determined without conducting a study that specifically addresses this issue. Furthermore, even without the additional impacts of sea level rise, there are concerns about the pricing of Upton-Jones coverage and the lack of a companion erosion management program that make the long-term continuance of the present Upton-Jones program problematic. Since this study was undertaken, a bill has been introduced to repeal the Upton-Jones flood policy benefit and substitute a mitigation assistance program under which limited funding would be available for relocation of structures threatened by coastal erosion.

In assessing the potential impact of sea level rise, this study examines the sensitivity of the NFIP's rate structure to the changing conditions as an indication of the degree to which program changes would have to be made and of the criticality of the timeframe in which such changes might be needed. A rising sea level in combination with increasing population will not only increase losses, but also increase the number of policies and thus premium income available to pay losses. Therefore, the analysis focused on whether existing rate structures will be adequate to address the problem of maintaining an overall premium income level commensurate with the level of losses, and how premium charges should be distributed among the policyholders who have varying degrees of risk exposure. Because the program will be insuring a dwindling number of pre-FIRM buildings over the course of 110 years, sea level rise is mainly an issue for post-FIRM construction. The following table shows the results of the analysis for this latter category of business.

Post-FIRM Actuarial Increase in Average Premiums For Buildings Subject to Sea Level Rise Required to Maintain Actuarial Soundness

	A-ZONE			V-ZONE		
	Full Risk Premium Rate		Percent Change	Full Risk Premium Rate		Percent Change
	1990	2100		1990	2100	
1-Foot Rise	0.19	0.30	58%	0.66	0.90	36%
3-Foot Rise	0.19	0.57	200%	0.66	1.33	102%

The percent change shown in this table reflects how the average full risk premium rates per $100 of coverage, and therefore the total premium income, for post-FIRM policies subject to sea level rise would have to increase in order to cover flood insurance losses. The relative change and magnitude of the rates indicate that there is ample flexibility in the NFIP rate structure to accommodate a 1-foot rise in sea level. A 3-foot rise may require that additional measures be taken to distribute premium burdens equitably and avoid undue cross subsidies.

In addition, the potential map revision and restudy requirements were considered. It is estimated that a total of 283 counties will be affected by increases in sea level. For these counties, approximately 5,050 FIRM panels will need to be revised as sea level rises. The cost of revising the affected map panels to account for each 1-foot increase in sea level is estimated to be $30,000,000. This cost would be spread over a 4- to 5-year period.

1.4 Conclusions and Recommendations

There is a great deal of uncertainty in the current projections of the rate of sea level rise. Moreover, the aspects of flood insurance rate-making that account for the possibility of increasing risk, and the tendency of post-FIRM construction to be built more than 1 foot above the BFE combine to eliminate any immediate threat from sea level rise to the NFIP's ability to insure against flood losses through a system of pricing that is fair and that protects the NFIP's financial soundness. There is no need for the NFIP to develop and enact measures now in response to the potential risks that would accompany increasing sea levels. As more information is collected over the next several decades, our ability to analyze past trends and our confidence in predictions will increase, allowing us to better assess both the magnitude of the problem and the most appropriate responses.

The high projection of a 3-foot increase by 2100 shows that a 1-foot increase would not be realized until 2050. This 60-year horizon provides ample time to consider alternative approaches and implement those that are both effective and based on sound scientific evidence.

For these reasons, the following technical and policy procedures are recommended:

1. FEMA must continue to monitor progress made by the scientific community in improving the reliability of projections of the potential increase of relative sea level. A formal report should be prepared beginning in 1995, and every five years thereafter, by the Federal Insurance Administration (FIA) identifying the advances made in the capability to predict potential changes in global sea level. In addition, alternative fiscal and mitigation measures designed to minimize the impact of future increases of sea level on the NFIP should be examined.
2. Because of the more immediate threat and definitive trend of subsidence along regions of the Gulf of Mexico coastline, especially within and near Louisiana, FEMA must explore and consider adoption and implementation of appropriate measures to mitigate the effects of this increasing risk. The process of identifying appropriate mitigation

measures and the data needed to support these measures should include coordination with other Federal and State agencies involved with this problem. The measures implemented in these regions will serve as models for other coastal areas when the broader issue of global change of sea level requires directed action by the NFIP.

3. In the near term, FEMA will increase its efforts to encourage, through the NFIP's Community Rating System, voluntary adoption and enforcement at the State and local level of mitigation measures, such as BFE freeboard requirements and construction setbacks, that take the potential for increases in relative sea level into account. In addition to working at the State and local level, FEMA must also continue its work with national building code organizations to reflect appropriate risks associated with the possibility of rising sea levels.
4. FEMA will continue, and strengthen, its monitoring of the trend of development patterns related to zoning and density to ensure that as trends change there is no degradation that would compromise fundamental goals and objectives of the NFIP. Furthermore, a concerted effort must be made to continue to monitor redevelopment as structures reach the end of their useful life to ensure compliance with minimum NFIP standards.
5. Improvement of this study in the future will depend on the availability of more complete and accurate data and on the ease of manipulating these data. For example, the creation of digital databases of topographic and demographic information would offer the possibility of efficiently computing the physical impacts of sea level rise. These tools would allow for regional or county studies to be performed with more detail and confidence. Also, FEMA could more confidently make projections of potential flood losses.
6. FEMA may undertake in the future a broad-based study to gather and collate shoreline erosion information on a national basis. The results of this effort would permit very site-specific determinations of potential land loss due to sea level rise and would link FEMA's efforts in this area with those of other Federal agencies, e.g., U.S. Geological Survey (USGS) and the EPA. These data would be useful for the judicious implementation of construction setbacks.
7. FEMA should undertake joint studies with other Federal agencies which are involved in the global warming/sea level rise issue, e.g., EPA, USGS, National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA). The capability of FEMA to provide flood loss figures is attractive to the other

agencies that are interested in quantifying the losses or damages associated with sea level rise.

2.0 INTRODUCTION

A rise in sea level could potentially have a major impact on the coastal areas of the United States. Physical effects associated with higher sea level are the inundation of coastal lowlands, increased shoreline erosion, and loss of wetlands. The loss of wetlands will affect the hydrodynamics and therefore the flooding characteristics of tidal bays and rivers. Shoreline recession and submergence of dry land are direct responses to rising sea levels.

The most vulnerable areas are coastal wetlands. A 1-meter (3.3-foot) rise in sea level by the year 2100 could result in the loss of 25-80 percent of the United States coastal wetlands (Titus et al., 1989). The greatest losses are projected to be in Louisiana, where shoreline erosion and land loss rates are presently the highest in the country. Since wetlands act as buffers to the inland penetration of coastal flooding, the loss of these areas will increase the extent and severity of flooding in many areas. An increase in the severity of coastal flooding due to sea level rise and a subsequent increase in shoreline erosion could present a potential hazard for coastal development. Research shows that a significant portion of the Nation's shorelines are currently eroding. Presently, over 70 percent of the world's coastlines are eroding (Bird, 1985). The National Shoreline Study by the United States Army Corps of Engineers (1971) reported that 43 percent of the shorelines in the United States are experiencing erosion. Leatherman (1988) estimated that 90 percent of the U.S. shoreline consisting of sandy beaches is eroding. The average erosion rate, i.e., shoreline retreat, along the Atlantic coast is 2.6 ft/yr (0.8 m/yr) (NRC, 1987). The Pacific coastline has localized areas of erosion. For example, San Diego and Los Angeles Counties have ongoing beach renourishment projects. Erosion in California is episodic and fluctuates according to climatic cycles of storm activity (see, for example, the October 1989 issue of Shore and Beach, Vol. 57, No. 4, which describes in detail the impacts of the January 1988 storm). However, the U.S. Pacific shoreline is considered to be relatively stable since the majority of the coastline is hard rock (NRC, 1987).

In the United States, shorelines are retreating because of both natural and man-induced causes. Some scientists suggest that there is a direct causal relationship between landward shoreline retreat and relative sea level rise, which results in the displacement of the shoreline and, in some cases, barrier island submergence (Leatherman, 1983, 1988; Everts, 1985). An increase in sea level will result in higher surge elevations and consequently higher waves. The overall result will be an increase in damage to coastal structures as sea level rises and the severity of storm-induced flooding increases.

Coastal structures are increasingly being threatened due to shoreline retreat. Along the Atlantic coast, residential and commercial buildings and erosion control structures are damaged or destroyed each year by moderate northeasters and tropical storms. These structures will be affected to varying degrees by a rise in relative sea level. As shorelines retreat, larger wave heights are possible due to deeper nearshore waters, resulting in increased wave power and greater destructive force (NRC, 1987). Structures currently designed to withstand a 100year storm event could be overtopped and/or destroyed. Similarly, some buildings that were built above the current BFE would be subject to flooding from such an event.

Estimates of the magnitude of sea level rise vary widely within the scientific community. To assess the possible impacts associated with a rise in sea level, the change in sea level must be established. The following sections discuss the findings of various investigators and present both current and historical rates of change. While most experts agree that sea level is rising, opinions differ about the cause and magnitude of the rise. These issues are also briefly discussed in the following sections.

2.1 Sea Level Rise in the United States

Scientists recognize and define two types of sea levels: eustatic and relative. Eustatic sea level refers to the global or worldwide height of sea levels. Changes in eustatic sea level result from a number of physical processes, primarily the melting of polar ice masses, thermal expansion of the oceans, and changes in oceanic volumes due to glacial displacement. Relative sea level refers to the height of sea level as measured from the ground at a particular point or area on the earth's surface. Change in relative sea level usually results from the interaction of two different and essentially independent processes: 1) local change (uplift or subsidence) in the absolute elevation of the land mass and 2) change in the absolute elevation of the earth's ocean (eustatic changes).

Subsidence is caused by a localized downward displacement of the land mass and can usually be attributed to a number of factors, including 1) tectonic downwarping of the earth's crust, 2) consolidation and compaction of sediments, and 3) withdrawal of subsurface fluids. It is important to note that given fixed eustatic sea levels, subsidence alone could account for dramatic rates of shoreline retreat and increased coastal erosion. For example, in the Teche basin of Louisiana, subsidence rates average 1.11 cm/yr (0.44 in/yr) which accounts for more than 80 percent of the local relative sea level rise for this region (Ramsey and Penland, 1989).

Uplift of the land surface is primarily caused by 1) tectonic uplift due to the movements of the earth's ocean and/or continental plates and 2) isostatic rebound, that is, uplift of the continental crust due to the retreat of the glaciers that covered the northern portion of the United States (and Canada) during the end of the Pleistocene epoch, approximately 15,000 years ago. The southeast coast of Alaska is an area which has been experiencing uplift of the land mass. Here, the rate of relative sea level rise ranges from -2.2 to -17.3 mm/yr (-0.09 to -0.68 in/yr) (Gornitz and Kanciruk, 1989), where a negative sign indicates that relative sea level is decreasing.

The primary method of measuring rates of sea level rise is to compare historical and recent sea level data that have been collected from tide gages. Unfortunately, accurate long-term tide gage data are unevenly distributed spatially and temporally. For example, the majority of tide gage stations are located in the northern hemisphere, and the longest records are generally for areas in the North Atlantic.

Analysis of the tide gage data shows that the rates of relative sea level rise are unevenly distributed across the globe. For example along the southeast coast of Alaska, geologic uplift associated with isostatic rebound is greater than eustatic sea level rise, thus the net result is a localized decrease in relative sea level. Conversely, in the Gulf of Mexico, the extraction of subsurface fluids has caused a decrease in the elevation of the land mass. This decrease, combined with eustatic sea level rise, results in a rapid rise in relative sea level. Tide gage measurements reflect relative changes in sea level; thus to isolate eustatic changes, the effects of uplift and subsidence of the land surface must be removed from the data[2].

Most scientists agree that eustatic sea level is rising. Prevailing theories attribute the rise to the combined effects of melting polar ice caps and thermal expansion of the oceans, processes that have been occurring since the glaciers retreated from the northern hemisphere during the end of the most recent Ice Age (Wisconsin Stage of the Pleistocene epoch), about 15,000 years ago. Prior to the decay of the Wisconsin Stage glaciation, sea level was approximately 400 feet lower than present. From 15,000 to about 6,000 years ago, eustatic sea level rose, on average, 3.5 ft/century (1.1 m/century). During the past 6,000 - 7,000 years, however, the rate of sea level rise has decelerated, and in the past century, global eustatic rise, based on historical tide gage data, has been estimated to range from 1.1 to 3.0 mm/yr (0.04 to 0.12 in/yr) (Carter, 1988).

Douglas (1991) suggests that the wide discrepancies among estimates of regional trends of sea level rise are mostly due to the location of tide gage stations on convergent plate boundaries. The resulting contribution of vertical crustal movements due to post glacial rebound (PGR) can account for as much as 50 percent of the observed relative sea level rise (Gornitz et al., 1990). Peltier and Tushingham (1989) examined tide gage records and estimated that global eustatic sea level rise is 2.4 mm/yr (0.09 in/yr) by determining a correction value for PGR at each station. Using the same correction values for PGR established by Peltier and Tushingham (1989), Douglas estimated global eustatic sea level rise to be 1.8 mm/yr (0.07 in/yr), which is comparable to Peltier and Tushingham's

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[2] Another factor that must be considered and compensated for is the unevenness of the surface of the ocean, caused by the effects of currents, winds, tides, and changes in atmospheric pressure.

estimate (Douglas, 1991). The difference was attributed by Douglas to be due to his exclusion of tide gage records located at convergent plate boundaries. This research demonstrates that a reliable estimate of sea level rise based on tide gage records can not be made without considering PGR (Douglas, 1991).

Many scientists predict that the rate of rise will increase in the future due to elevated global temperatures caused by increased levels of greenhouse gases in the atmosphere. The major contributors to greenhouse warming are carbon dioxide (55 percent), chlorofluorocarbons (24 percent), methane (15 percent), and nitrous oxide (6 percent) (IPCC, 1990). The NRC (1983) estimated that there is a 75-percent probability that carbon dioxide concentrations will double by the year 2100. With an estimated temperature increase of 1.5° to 5.5° Celsius (C) (2.7° to 9.9° Fahrenheit (F)) associated with an increase in greenhouse gases equivalent to a doubling of CO_2, global mean sea level is expected to rise over the next century. It should be noted, however, that recent studies suggest that global warming due to increased atmospheric concentrations of greenhouse gases may be overstated. For example, in a recent study, Lindzen (1990) analyzed time series for annually averaged surface temperatures dating back to 1855. He found that there was no significant variation of global temperatures in excess of 1°C (1.8° F). According to his results, temperatures have been fairly stable during the past 135 years, suggesting that current models may overestimate global warming. A chronological review of recent scientific literature pertaining to global warming scenarios and corresponding sea levels shows the variability in estimates of projected sea level rise. For example:

- Revelle (1983) estimated that sea level could rise a total of 70 centimeters (2.3 feet) by the year 2085, with a 25 percent margin of error indicated.
- Hoffman et al. (1986), in an update to Hoffman et al. (1983), predicted future sea level rise in the year 2100 to be within the range of 57 to 368 centimeters (1.9 to 12 feet).
- Robin (1987) forecast a rise in sea level of 0.8 meter (2.6 feet), with a range 0.2 to 1.6 meters (0.6 to 5.2 feet), by the year 2100.
- A report issued by the NRC (1987) entitled Responding to Change in Sea Level: Engineering Implications included a discussion on mechanisms affecting sea level. The NRC report summarized earlier studies and concluded that a realistic estimate of sea level rise associated with increased carbon dioxide concentrations is from 0.5 to 1.5 meters (1.6 to 4.9 feet).
- MacCracken et al. (1989) used the oceanic heat transport model of Frei et al. (1988) and estimated less than a 0.5- to 1-meter (1.6- to 3.3- foot) rise in sea level by the year 2100.
- Meier (1990) reports that the current "best estimate" of sea level rise is 0.3 meter (1 foot) by the year 2050, with a "high estimate" of as much as 0.7 meter (2.3 feet) by the

year 2050, and a "low estimate" near zero.

- The NRC (1990) summarized recent findings on the effect of atmospheric temperature change on the world's oceans. They concluded that "one hundred years from now, it is likely that sea level will be 0.5 to 1 meter (1.6 to 3.3 feet) higher than it is at present."
- A study prepared by the IPCC, entitled, Scientific Assessment of Climate Change (IPCC, 1990), presented 1-foot, 2.2-foot, and 3.6-foot scenarios as the low, best, and high estimates of sea level rise expected by the year 2100. The IPCC was jointly established by the World Meteorological Organization and the United Nations Environment Programme in 1988 to assess scientific information related to various components of the climate change issue. The estimates cited above correspond to a "business-as-usual" scenario; that is, it is assumed that no steps are taken to limit greenhouse gas emissions. Other scenarios were considered in which progressively increasing levels of controls reduce the growth of emissions. These latter scenarios lead to smaller projections of the sea level rise than the "business-as-usual" scenario.

Potential contributors to sea level rise include thermal expansion, the Alpine and Greenland glaciers, and the Antarctic Ice Sheet. It is controversial whether the contribution of the Antarctic Ice Sheet to sea level is negative or positive. There is no conclusive evidence to date that shows this ice sheet has contributed to sea level rise over the past 100 years (IPCC, 1990). An increase in global temperatures could increase snowfall accumulation over the sheet, resulting in a negative contribution to sea level. On the other hand, increased temperatures might eventually cause an instability of the ice sheet with outflow of ice and meltwater into the ocean and a rise of sea level. Meier (1990) suggests that much of the meltwater from the polar ice caps will percolate and refreeze in the subfreezing snow. Furthermore, it is unlikely that any contribution from the ice shelves will have an appreciable impact on sea level by the year 2050, given the slow response of the ice shelves to slight changes in global temperature. There is some speculation that this outflow could become significant beyond the 110-year time frame addressed in this report (IPCC, 1990). However, there is great uncertainty on this issue. The IPCC (1990), in formulating its sea level rise scenarios, considered that even in the worst case (high scenario) there would be no contribution from Antarctica.

Because of the number of physical parameters involved, it is not possible to assign to the various sea level rise scenarios statistical confidence intervals in a strict sense. The IPCC generated three projections -- best estimate, high, and low -- based on an estimated range of uncertainty in each of the potential contributing factors and in the resulting global warming predictions.

If global temperatures increase, changes in climate could occur that would affect hurricane activity. There has been scientific speculation about the effect of global warming on the frequency, intensity, and tracks of hurricanes. Some scientists theorize that storm frequency and intensity may increase and storm tracks may be displaced farther to the north as global temperatures increase. According to the IPCC (1990), the ocean area having the critical temperature at which tropical storms are created (26° C/79° F) will increase as global temperatures change. However, climate models to date give no indication whether the intensity and frequency of tropical storms will increase or decrease as the climate changes (IPCC, 1990). Mid-latitude storms may consequently weaken or change their tracks in response to warmer temperatures in the northern hemisphere. There is some evidence of a decrease in the irregularity of mid-latitude winter storm tracks based on model simulations (IPCC, 1990). These are research topics that are currently being investigated, and no firm conclusions are available. The effects of a change in climate on precipitation patterns and smaller scale disturbances are continuing to be researched. If these effects are proven to be significant, then there could be an appreciable impact on the characteristics of the 100-year floodplain delineated by FEMA. Because of the uncertainty in the current estimates of future storm patterns due to global warming, no attempt has been made to include these effects in this study.

Several studies have examined the local effects of relative sea level rise based on projected increases in sea level. They include the following:

- Kana et al. (1984) used a concept called "drowned-valley" to project new shorelines based on pre-existing contours for the City of Charleston, South Carolina.
- Leatherman (1984) projected current shoreline changes along southeast Galveston Bay, Texas, for the years 2025 and 2075.
- Gibbs (1984) performed an economic analysis of the effects of sea level rise on the coastline of the City of Charleston, South Carolina, and the City of Galveston, Texas. In this study, Gibbs examined anticipated losses in dollars due to shoreline retreat and increased inundation.
- Titus et al. (1991) projected the nationwide economic and environmental impact of sea level rise to the year 2100 in terms of inundation, shoreline retreat, and the costs of protecting developed areas. Because of the high cost of applying detailed models to a large number of sites, other factors, such as salt water intrusion and increased flood hazards were not examined. Estimating anticipated shoreline retreat and predicting the costs involved in holding back the sea, however, were deemed feasible goals.

Physical Effects of Relative Sea Level Rise

A rise in sea level will result in shoreline recession. The EPA estimated that a 1-meter (3.3 foot) rise in sea level would inundate 5,000 to 10,000 square miles (12,950 to 25,900 square kilometers) of dry land if attempts to stabilize the shoreline are not made (Titus et al., 1989). Shoreline erosion is a worldwide problem; over 70 percent of the coastlines are undergoing significant erosion (Bird, 1985). Shoreline changes vary from the short-term erosion associated with individual storms to the longer-term effects of sea level rise. A significant rise in sea level establishes a setting in which increased erosion can occur.

Land loss and barrier island submergence result from a combination of factors associated with relative sea level rise. Barrier islands are dynamic features which will respond to rising sea levels in various ways. Traditionally, barrier islands were thought to migrate landward due to the formation of inlets and overwash processes during storm events, allowing sand to be transported from the beach to the bay shore. However, it has been suggested that in the short term, many coastal barriers are actually eroding on both the beach and bay sides and essentially are being forced to drown in place (Leatherman, 1983).

The NRC (1987) reports that shoreline erosion is probably responsible for about 1 percent of the total annual marsh losses. Land losses in marsh areas due to sea level rise are more commonly a result of ponding, the rapid enlargement of interior ponds in marshes which occurs if there is a large increase in sea level. Shoreline stabilization, e.g., bulkheads and levees, will affect the amount of marsh area lost to sea level rise by limiting the marsh's natural ability to trap sediments and build above the rising sea level.

A change in the location and extent of coastal floodplain areas is another result of a rise in sea level. The change in floodplain area is dependent on slope, topography, use of protective coastal structures, and the magnitude of relative sea level rise. As the shoreline retreats in response to rising sea levels, additional areas of the floodplain will be submerged, and new areas will be periodically flooded. It is difficult to assess the extent of change in overall floodplain area due to a rise in sea level. However, the assumption can be made that an increase in relative sea level will result in new areas being subjected to the possibility of inundation by flood waters. Conversely, the resulting increase in shoreline erosion and submergence will cause a decrease in the area subject to flooding[3].

The protective benefits offered by coastal structures will decline as sea level rises. Higher surge elevations and greater wave heights associated with an increase in sea level will result in an increase in destructive force and a decrease in the protection provided by the structure. Seawalls and bulkheads designed to withstand present estimates of wave action associated with a 100-year storm could be overtopped during storms of lesser magnitude, which could result in structural failure.

Seawalls and bulkheads, which are often used to stabilize eroding shorelines and other areas

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[3] FEMA defines flooding to be "a general and temporary condition of partial or complete inundation of normally dry land" (44 CFR, Part 59).

vulnerable to wave attack, are usually not built to account for a significant short-term rise in sea level. The NRC (1987) suggests two ways that sea level rise could be incorporated in the design of coastal structures. Seawalls, bulkheads, and groins could be designed to accommodate the anticipated rise in sea level within the design life of the structure. Another method would be to upgrade the structure as sea level changes. Based on current estimates of sea level rise over the next century, structures with a design life of less than 50 years need not account for anticipated sea level rise (NRC, 1987). For a period of less than 50 years, modest increases in sea level based on current rates would amount to only a few inches and would therefore have little effect on most coastal structures.

A secondary effect associated with sea level rise is an increase in coastal flooding due to the potential inundation of drainage systems beyond design capacity. Titus et al. (1987) examined the cost of constructing coastal drainage systems to accommodate a potential rise in sea level versus the retrofit cost of modifying existing structures if sea level rises. Their research indicates that retrofit costs depend on the type and design life of the existing structure, which varies from location to location, as well as on the overall change in sea level.

2.2 Purpose of Study

The purpose of this study is to assess the implications of sea level rise (both physical and economic) on the NFIP. To accomplish this goal, analyses were performed to estimate changes over time in floodplain location and extent, and population density. In addition to these analyses, this study applied relevant results obtained from previous studies (NRC, 1987; EPA, 1989; IPCC, 1990) to help evaluate the overall impact of sea level rise on the NFIP. A nationwide assessment such as this study cannot incorporate detailed information on site-specific topography and different types of floodprone structures. However, general trends can be used to assess the potential impact on the NFIP.

The task of predicting changes in relative sea level is a complex problem involving local, regional, and global factors. Undoubtedly, this complexity has led to the wide range of predictions concerning sea level change. Sea level rise during the next century will have a number of potential impacts on the NFIP. An evaluation of the effects includes consideration of flood risk assessment and flood insurance implications. The primary goals of the NFIP are the reduction of future flood losses and the transference of the costs of flood loss from the general taxpayer to those who choose to occupy floodplain areas. In support of NFIP goals, FEMA identifies flood risks and maps floodprone areas.

The primary strategy adopted by the NFIP for reducing flood losses to new construction in identified floodprone areas is requiring, at a minimum, elevating and/or flood-proofing of new structures to the elevation of the flood that has a 1percent probability of being equaled or exceeded in any given year, which is referred to as the 100-year (or base) flood. Likewise, the NFIP utilizes the difference between the 100-year flood level (BFE) and the elevation of the lowest floor of a structure as the principal risk parameter upon which to base the flood insurance premium for the structure. In simple terms, a rise in relative sea level impacts the NFIP by increasing BFEs, thus increasing flood hazards beyond those expected at the time of construction and subjecting a larger number of structures to inundation during the 100-year flood. In addition to altering the flood-depth distribution of structures, sea level rise will result in greater inland penetration of flood waters and wave action and increased erosion. Therefore, this study focuses on the impact of relative sea level rise on the NFIP, including FIRMs, the change in actuarial risk, and the fiscal soundness of the program.

The potential effects of sea level rise on the Great Lakes region were not considered in this study. The easternmost Great Lake, Lake Ontario, has an elevation of approximately 247 feet above mean sea level, and therefore is unlikely to experience any sea level rise effects propagating upstream from the ocean. Furthermore, the more interior lakes are separated from Lake Ontario by Niagara Falls and a series of manmade locks, thereby reducing the likelihood of changes in lake levels due to some of these effects. Changes in Great Lakes levels are related to precipitation patterns, variable winds, the construction of various navigation facilities, and the re-configuration of adjacent terrain (e.g., storm sewers, clearing of forests) (Ramey 1952; Harris 1981). Smith (1991) indicates that lake levels could drop as water use increases in response to higher air temperatures. If global warming occurs, precipitation patterns over the Great Lakes Basin could be altered, although it is premature to say in which direction the change would occur, i.e., the net effect of changing precipitation/evaporation patterns is uncertain. In the future, it is expected that scientists will be able to more accurately determine the contribution of each component of sea level rise.

Impact on the NFIP

In a study to determine the impact of increases in relative sea level on the NFIP, it is necessary to first establish assumptions concerning the potential increase in sea level over a specific time period. Several studies of the potential increase in sea level have reflected the uncertainty in predictive capability by reporting on various possible scenarios of increase over the next 110 years. The same approach was adopted for this NFIP impact study. The scenarios analyzed include a low level (1-foot rise by the year 2100) and an upper level (3-foot rise by the year 2100). The upper level scenario corresponds roughly to the 100-centimeter (3.3-foot) rise assumed by the EPA (Titus et al., 1989) in its report to Congress on The Potential Effects of Global Climate Change on the United States. Based on recent scientific investigations by the IPCC (1990), the upper end of a reasonable range of values is approximately a 3-foot rise in sea level by the year 2100. The IPCC report was the primary basis for the selection of the 1- and 3-foot scenarios. The first component of this study is an evaluation of the effects of sea level rise on the flood risk assessment aspects of the NFIP, including:

1. Impact on base flood elevations
2. Impact on the location and extent of the coastal floodplain
3. Numbers of existing and future structures impacted
4. Anticipated frequency and associated cost of study and mapping updates

The second component of the study deals with the costs of transferring risk through the insurance mechanism and how changing risk conditions affect the ability to equitably distribute the costs. The aspects addressed include the following:

1. Economic impacts of current FIA policies of using present (as opposed to future) risk conditions for determining flood insurance premiums. That is, how will the costs of flood losses increase under the "present conditions" policy in an environment where actual risk is increasing due to sea level rise, and how will this affect the fiscal integrity of the NFIP?
2. Estimation of the increase in the number of floodprone structures that will exist within the Special Flood Hazard Area (SFHA). This topic deals with the increase in the number of floodprone structures and changes in expected annual losses under the program.
3. The sensitivity of the NFIP's rate structure to the changing conditions as an indication of the degree to which program changes would have to be made and of the criticality of the timeframe in which such changes might be needed.

3.0 PHYSICAL CHANGES

The following key assumptions were used in the computation of the physical changes associated with sea level rise (more detailed descriptions of these assumptions are contained in the following section):

1. The change in the 100-year stillwater flood level (SWFL) is equal to the rise in sea level.
2. A single value of SWFL is used to represent each county. Even though the SWFL usually varies throughout a county, a weighted average value was estimated for each county.
3. The additional area affected by sea level rise is controlled by the ratio of the sea level rise to the SWFL (i.e., the additional area is equal to this ratio multiplied by the current floodplain area).
4. The A-Zone and V-Zone proportions of the coastal floodplain do not change as sea level rises.

These assumptions are believed to be reasonable approximations of the physical impacts that would accompany an increase in sea level, particularly on a nationwide basis.

3.1 Methodology

This section describes the sequence of steps that lead to the quantification of impacts. The major components of the computational sequence are the changes in the floodprone area and the corresponding change in the number and flood-depth distribution of properties subject to flood hazards.

Current estimates of sea level rise cover ranges of 17 centimeters (0.56 foot) to 26 centimeters (0.85 foot) by the year 2050 (Commonwealth Secretariat, 1989), and 15 centimeters (0.49 foot) to 50 centimeters (1.64 feet) by 2050 (IPCC, 1990). The IPCC estimates are based on current projections of greenhouse gas emission rates if no remedial reductions are instituted in the future (i.e., "business-as-usual"). Other scenarios that involve a reduction in these rates in the future result in lower sea level rise projections. A 1-foot rise of sea level by 2050 corresponds to the NRC 1-meter (approximately 3-foot) scenario for the year 2100. Based on the projected rate of increase of greenhouse gas emissions, the IPCC projections for the year 2100 are (1) low scenario -- 31 centimeters (1 foot), (2) "best estimate" scenario -- 66 centimeters (2.2 feet); and (3) high scenario -- 110 centimeters (3.6 feet). These estimates would decrease for scenarios under which greenhouse gas emissions are lower than for the business-as-usual scenario. A lowering of the rate of greenhouse gas emissions could be achieved by a variety of mitigation measures. If emissions over the next century are controlled, global mean temperature increases are estimated to range from 0.1° C (0.18° F) to 0.2° C (0.36° F) per decade. These values are lower than the "business-as-usual" best estimate scenario of 0.3° C (0.45°F) per decade (with an uncertainty range of 0.2°C to 0.5°C (0.36°F to 0.9°F) per decade). Sea level rise best estimate predictions associated with three reduced levels of emission controls are 34 centimeters (1.12 feet), 40 centimeters (1.31 feet), and 47 centimeters (1.54 feet) by the end of the next century (IPCC, 1990). For this study, a 3-foot rise in sea level by the year 2100 was chosen as a median value between the high estimate and best estimate cited by the IPCC under the business-as-usual scenario.

For the purpose of this study, a "1-foot increase" criterion has been selected to judge when a restudy and FIRM revision would be appropriate. In other words, when the SWFL computed for a community has increased by 1 foot, it is assumed that a restudy and revision of the flood maps will be initiated. This criterion was also used to identify the discrete points in time at which computations of revised floodplain areas and floodprone structures would be undertaken. For the sea level rise scenarios evaluated in this study (the 1- and 3-foot rises by the year 2100), the 1-foot increments of change will appear at different times. For example, the first 1-foot change will be realized earlier for the 3-foot scenario than for the 1-foot scenario. For the 1-foot scenario, the first (and only) 1-foot change will not occur until the year 2100. For the 3-foot scenario, there are three increments over which a 1-foot change will occur.

It is generally agreed that the <u>rate</u> of sea level rise will increase with time, i.e., a plot of sea level versus time would be a curve whose steepness increases with time. A formula for this curve has been proposed (NRC, 1987). In metric units, the equation is

$$T (t) = (0.0012 + M/1000)\, t + bt^2$$

where T= total relative sea level rise (meters)
t = time (years)
M = subsidence (+) or uplift (-) in millimeters/year
b = coefficient whose value is chosen to satisfy the requirement that T (with M=O) assumes the correct (pre-assigned) eustatic sea level rise value at some t

The first term on the right-hand side of the equation (.0012t) contains the estimated eustatic sea level rise rate over the past century, .0012 m/yr or 0.12 meter over 100 years. If this equation is cast in terms of English units, the equation becomes

$$T(t) = (.0039 + M)\, t + bt^2$$

where the eustatic sea level rise rate over the previous century is .0039 ft/yr, M has units of ft/yr, and b assumes the values presented in Table 3.1 for the 1- and 3-foot scenarios:

Table 3.1 Value of Coefficient b for the Scenarios Considered in this Report

Eustatic Component by Year 2100 (ft)	b (ft/yr^2)
1	0.000047
3	0.000212

A plot of this equation is shown in Figure 3.1. The computational milestones for the 3-foot eustatic sea level rise scenario are given in Table 3.2 (the years have been rounded off to the nearest decade).

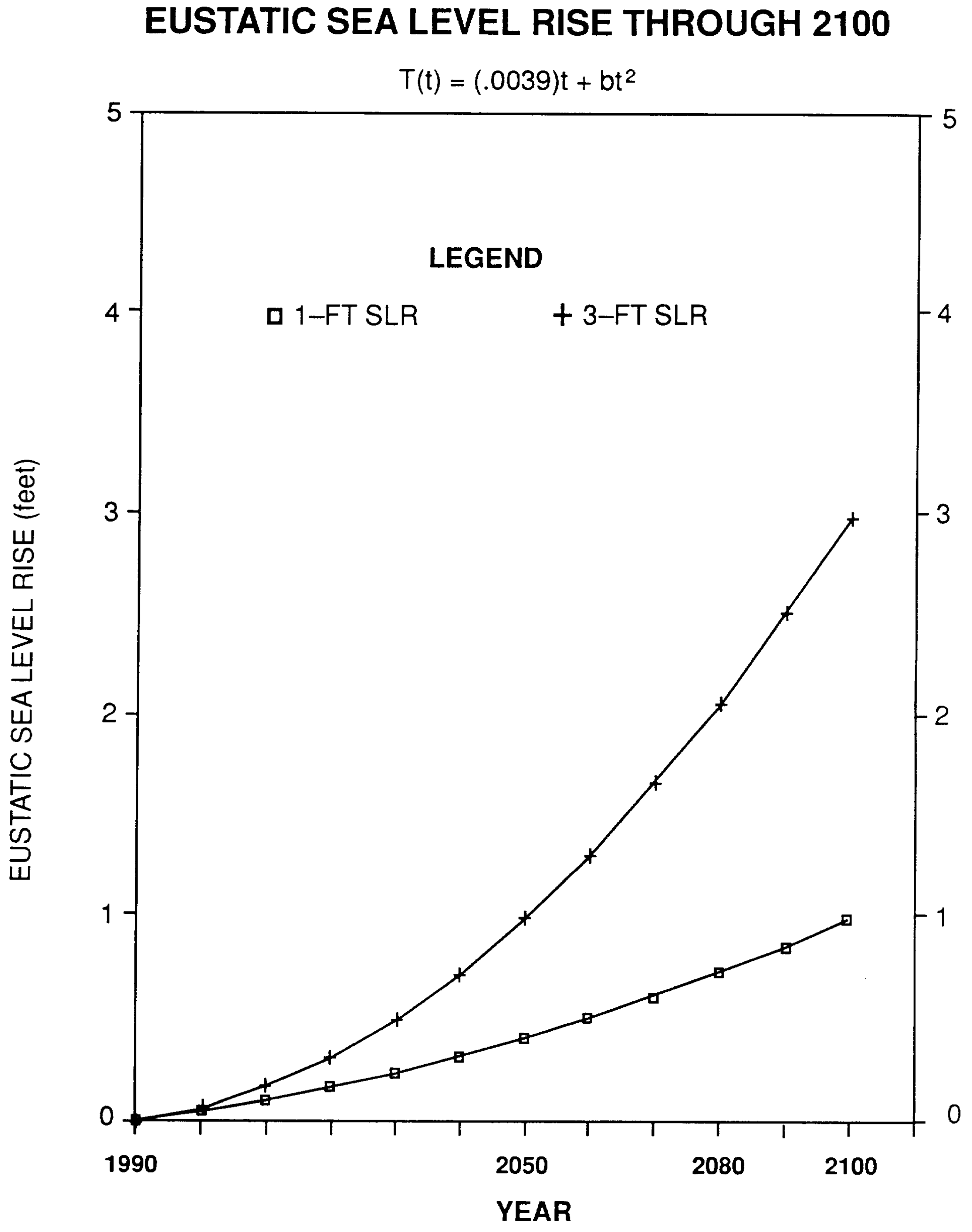

Figure 3.1–Eustatic sea level rise for the 1- and 3-foot sea level rise scenarios

Table 3.2 Milestones for 3-foot Sea Level Rise Scenario Corresponding to Successive 1-foot Increments of Rise

Sea Level Rise (ft)	3-foot Scenario, Milestone Years
1	2050 [60]*
2	2080 [90]
3	2100 [110]

* Number in brackets is number of years counted from 1990.

These milestone years have been computed with M (subsidence or uplift) set to zero, so that the eustatic component controls the result. The inclusion of subsidence or uplift will, respectively, accelerate or delay the milestones. The factors that contribute to M have been discussed in Section 2.1. Subsidence is most dramatic in the Louisiana area, although there are appreciable subsidence rates along the entire east and Gulf of Mexico coasts. Subsidence rates in Louisiana vary spatially due to differential compaction and varying thicknesses in the Holocene layers (Penland et al., 1989). Shown in Figure 3.2 are three Louisiana basins representing the range of subsidence rates in coastal Louisiana. The region with the highest subsidence rate is the Teche basin, with a rate of 1.11 cm/yr to 1.65 cm/yr (0.44 in/yr to 0.65 in/yr). These estimates are considered high because of the influence on tide gage records of flooding from the Atchafalaya River. The rate of subsidence for the Terrebone delta plain is about 1.18 cm/yr (0.46 in/yr). The lowest estimates are for the Pontchartrain basin, where subsidence rates are estimated to be 0.10 cm/yr to 0.31 cm/yr (0.04 in/yr to 0.12 in/yr). An estimate of 0.9 cm/yr (0.35 in/yr) is quoted in the NRC (1987) study, which reports a local subsidence rate of 0.89 cm/yr (0.35 in/yr) for Grand Isle, Louisiana. This subsidence rate was adopted as a representative rate in Louisiana for the purpose of this study.

Uplift (or rebound) is prominent in Alaska and, to a much lesser degree, along portions of the west coast. The rates for subsidence and uplift are approximately 0.35 in/yr (0.9 cm/yr) (Louisiana) and 0.14 in/yr (1.7 cm/yr) (Alaska), respectively. It is difficult to define an average rate of subsidence for the United States as a whole. Some regions of the United States are experiencing uplift and will balance the effects of subsidence to some degree, and some of the causes of subsidence (e.g., subsidence due to sediment compaction, and subsidence due to withdrawal of oil, gas, and water) can be expected to become less important in the future. Excluding Louisiana and portions of east Texas, a national average subsidence rate of 1 mm/yr (0.04 in/yr) or 10 cm/century (4 in/century) is a reasonable estimate. If this small but appreciable contribution of subsidence is neglected, the results

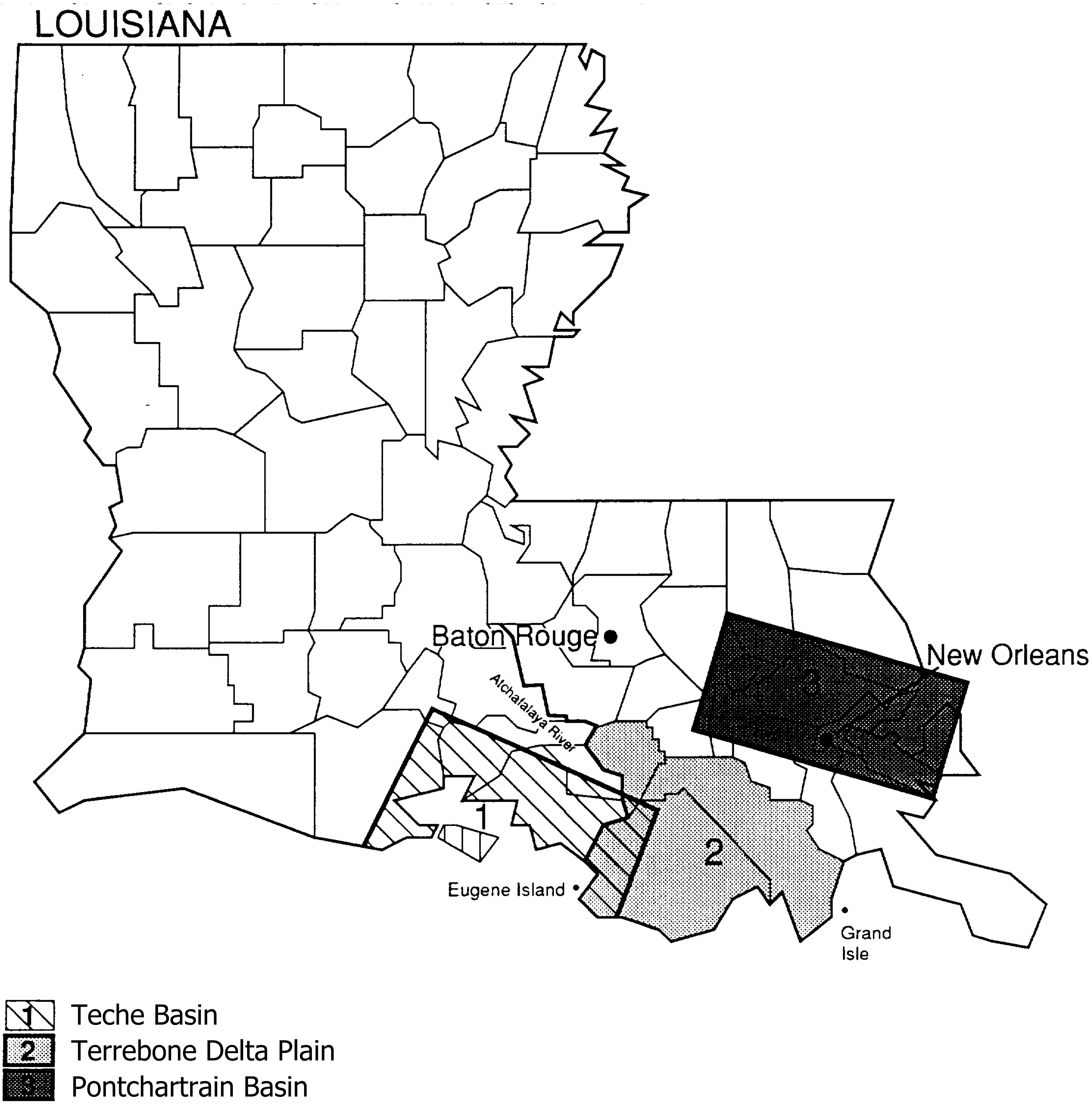

Figure 3.2 Major geomorphic regions of coastal Louisiana used to determine a representative subsidence rate for the Louisiana area (redrawn from Penland et al. 1989).

in Table 3.2 can be considered representative of relative sea level rise for the United States as a whole, with the exception of Louisiana and Alaska.

For Louisiana, the presence of subsidence means that a relative rise of sea level of 1 foot will occur earlier than indicated in Table 3.2, which accounts for only the eustatic component of sea level rise. Conversely, for Alaska, the 1-foot rise will occur later than the year 2100. The milestone years for Louisiana for the 1- and 3-foot scenarios shown in Table 3.3 are based on the assumption that the rates of subsidence given above are constant (the years have been rounded off to the nearest half-decade or decade). In addition to the combined effect of subsidence and eustatic sea level rise, Table 3.3 also shows the impact of subsidence alone (no eustatic component).

Table 3.3 Milestones for 1- and 3-Foot Relative Sea Level Rise Scenarios for Louisiana

Relative Sea Level Rise (ft)	1-foot Scenario (Subsistence + Eustatic) Milestone Years	3-foot Scenario (Subsistence + Eustatic) Milestone Years	Subsistence Only Milestone Years
1	2020	2015	2025
2	--	2040	2055
3	--	2055	2090

Table 3.3 shows that when subsidence is accounted for in Louisiana, the 1-foot increments of sea level rise occur much sooner than when subsidence is discounted, e.g., for the 3-foot scenario, the first 1-foot increase occurs in 2015 rather than 2050. Calculations of relative sea level rise were carried out to the year 2100. The combined effect of subsidence and eustatic sea level changes were considered, which resulted in 4-foot and 6-foot total rises of sea level in Louisiana by the year 2100 for the 1-foot and 3-foot eustatic scenarios, respectively.

The problem of relative sea level rise is more immediate in Louisiana than in other parts of the country because of subsidence. Therefore, special attention to the situation in Louisiana is warranted in the near term. Detailed studies that define the magnitude of changes in sea level at specific locations throughout the Louisiana area and the implementation of mitigation procedures are appropriate.

Selection of Areas for Study

In a report on population change, NOAA used political, physical, and cultural criteria to identify "coastal" counties. Inland counties whose activities might influence the environmental quality of the coast were also designated as coastal (Culliton et al., 1990). The coastal counties identified by

NOAA were used as a guide in selecting areas (counties) for this study. This information was used to include counties with nearshore areas inundated by short-term rising water levels associated with oceanic phenomena (hurricane surge, extratropical "northeaster" storm surge, tsunamis). A total of 283 counties were included in this study. Of this total, 51 counties were located on the west coast, 65 on the Gulf coast, and 167 on the east coast.

Computations of Changes in Coastal SFHAs

A reasonable working assumption is that an increase in sea level produces an equal increase in the FEMA regulatory SWFL, e.g., a 1-foot rise in sea level translates into a 1-foot increase in SWFL. The linear superposition of sea level rise and SWFL neglects some of the possible second-order dynamic interactions such as the effect of the increased water depth due to sea level rise on storm surge. This assumption does avoid complications associated with regional differences in the dynamic components that make up the SWFL, e.g., hurricane surge on the east coast versus tsunamis on the west coast. The impact of sea level rise on the BFE in the high-velocity V-Zone would be greater than the impact on the BFE in the SWFL because the V-Zone incorporates the effect of wave heights. Accompanying a 1-foot increase in SWFL would be a corresponding change in BFE (stillwater plus wave contribution) of as much as 1.55 times the change of SWFL, or 1.55 feet.

In tidally-affected rivers, the effects of sea level rise will propagate upstream. The extent of the propagation is determined primarily by the slope of the riverbed or slope of the riverine water surface. In other words, if there is a 1-foot sea level rise, a river that connects with the ocean or large embayment will not necessarily experience a 1-foot increase in elevation over its entire length. The upstream limit of the rise is a function of the "steepness" of the river or, equivalently, the absolute elevation of the river at any point along its length. The 100-year return interval event may propagate farther upstream than the sea level rise by itself. Therefore, for the case of storm surge in the presence of sea level rise, there will be potentially three distinct dynamic areas: (1) from the ocean to a point upstream where the sea level rise tails off, the combined effect of surge and sea level rise will be approximately additive, (2) from this point to some location farther upstream, the surge, previously augmented by the presence of the sea level rise, will be progressively less influenced by this rise, and (3) near the upstream terminus of the surge, there will be no effect due to the rise.

This study did not attempt to exactly define the character of the sea level rise in upstream (upriver) areas. This would have required site-specific hydraulic calculations. In upstream areas, the absolute water- surface elevation (with respect to the National Geodetic Vertical Datum (NGVD), for example) corresponding to the 100-year SWFL will tend to be higher than the flood elevation at the mouth of the river. According to the formula (cited below) adopted for this study for estimating changes in the 100-year floodplain, a larger value for SWFL results in a smaller change in the floodplain area as sea level rises. In the formula, the areal change is proportional to the ratio of sea level rise to the SWFL. With SWFL increasing in the upstream direction, computed floodplain changes due to sea level rise will become progressively smaller. Therefore, the exact determination of the sea level rise component in these upstream areas is not considered crucial to the present calculations.

A second assumption relates the above adjusted SWFL to the resultant change in the coastal floodplain area. The fractional increase in SWFL due to relative sea level rise is assumed to be matched by the same fractional increase in coastal floodplain. The fractional change in SWFL is simply the ratio of the sea level rise to the present SWFL. The formula for the change in the floodplain is:

$$\frac{\text{Sea Level Rise}}{\text{SWFL}} \quad \text{x} \quad (\text{Current Coastal FP Area})$$

where FP stands for floodplain.

For a coastal area whose land relief can be characterized by a single topographic slope, the above relationship holds exactly. The size of the coastal floodplain is a function of the topography; a steep slope would result in smaller changes in the SFHA, and a flat slope would result in larger changes. In the case of more realistic variable topography, the floodplain may be underestimated or overestimated using this formula. If a relatively flat area that is inundated by the 100-year flood connects inland with a more steeply-sloping region, a rise in sea level may cause minimal additional flooding during the 100-year event. Conversely, flooding that is initially confined to a steep nearshore region that connects to a flat inland region may, with the addition of sea level rise, overtop the steep segment and spread widely over the flatter area. In these two circumstances, the use of the proposed formula would, respectively, overestimate and underestimate the change in the floodplain. The calculations performed for this study were conducted on a countywide basis and then integrated to provide regional and national statistics. With this approach, it is expected that, overall, errors would tend to balance rather than accumulate.

For each county, the following steps preceded the floodplain calculations described above:

1. A single, countywide SWFL for coastal flooding, representative of the county as a whole, was estimated for each coastal county. The estimated SWFL was a weighted-average value chosen to reflect the flooding impact of the individual stillwaters within the county. The estimate was made to the nearest whole foot.
2. Similarly, an estimate of a single SWFL, representative of the designated V-Zones

within each county, was made.

3. An estimate was made of the total coastal SFHA within each county. Only land areas were considered in this estimation.
4. The fraction of coastal SFHA that is designated V-Zone was estimated.

Land Lost Due to Submergence and Erosion

Shoreline erosion and submergence (inundation) of coastal areas because of sea level rise are two processes that remove land area from the 100-year floodplain. However, sea level rise also adds land to the floodplain by increasing flood levels. These opposing tendencies are shown schematically in Figure 3.3. The net change in the size of the coastal floodplain should be approximately zero. It should be noted that in developed areas where land values are high (e.g. Miami Beach, Florida; Ocean City, Maryland; Atlantic City, New Jersey), shoreline protection measures are likely to be initiated. These include beach nourishment projects, and the construction of groins, levees, and seawalls (although many states prohibit the use of "hard structures," which tend to reduce the usable beach area). Such measures will diminish the amount of land lost due to sea level rise, as well as the additional land subject to flooding. These circumstances could result in a significant overestimate of the total losses (both physical and economical) reported in this study.

Shoreline erosion is a complex process that has many causes, e.g., sea level rise, storm activity, local alongshore sediment transport patterns, the influence of coastal structures. As erosion proceeds, floodplain land that was formerly habitable is lost. Floodprone households in these erosion zones will eventually become a total loss unless they are relocated, or other measures are taken to protect them (e.g., shore protection structures).

Erosion rates apply to the recent past and therefore are associated with the recent rate of sea level rise. Under the sea level rise scenarios described previously, the rate of sea level rise is assumed to gradually accelerate. It can be expected that there will be a concurrent increase in the rate of erosion. An approximation proposed by Leatherman (1985) assumes a direct correlation between the amount of shoreline retreat in the historical record and the rate of rise (feet per year) of sea level. For future years, the change in the erosion rate of the shoreline is equated to the change in the rate of rise of sea level.

Shoreline erosion is usually identified by measuring the change in the lateral position of a shoreline. For a rising sea level, part of this change in shoreline position is due to the effect of submergence, i.e., the erosion estimate will reflect the impact of submergence. Submergence occurs in all tidally affected portions of a county in contrast to erosion which occurs principally for shorelines with wave exposure. The EPA (Titus et al., 1989) has estimated that a 1-meter (3.3-foot) rise of sea level will submerge 5,000-10,000 square miles of dry land. In this study (see Section 3.2), the additional floodplain area created by a 3-foot rise of sea level is estimated to be 6,500 square miles when subsidence in Louisiana is not taken into account and 7,700 square miles when this subsidence is included. Although these numbers are derived with different parameters and methodologies, their comparable magnitudes add support to the conclusion that there will be no net change in the size of the coastal floodplain area due to sea level rise, since the addition of floodplain area will be balanced by the land lost through submergence.

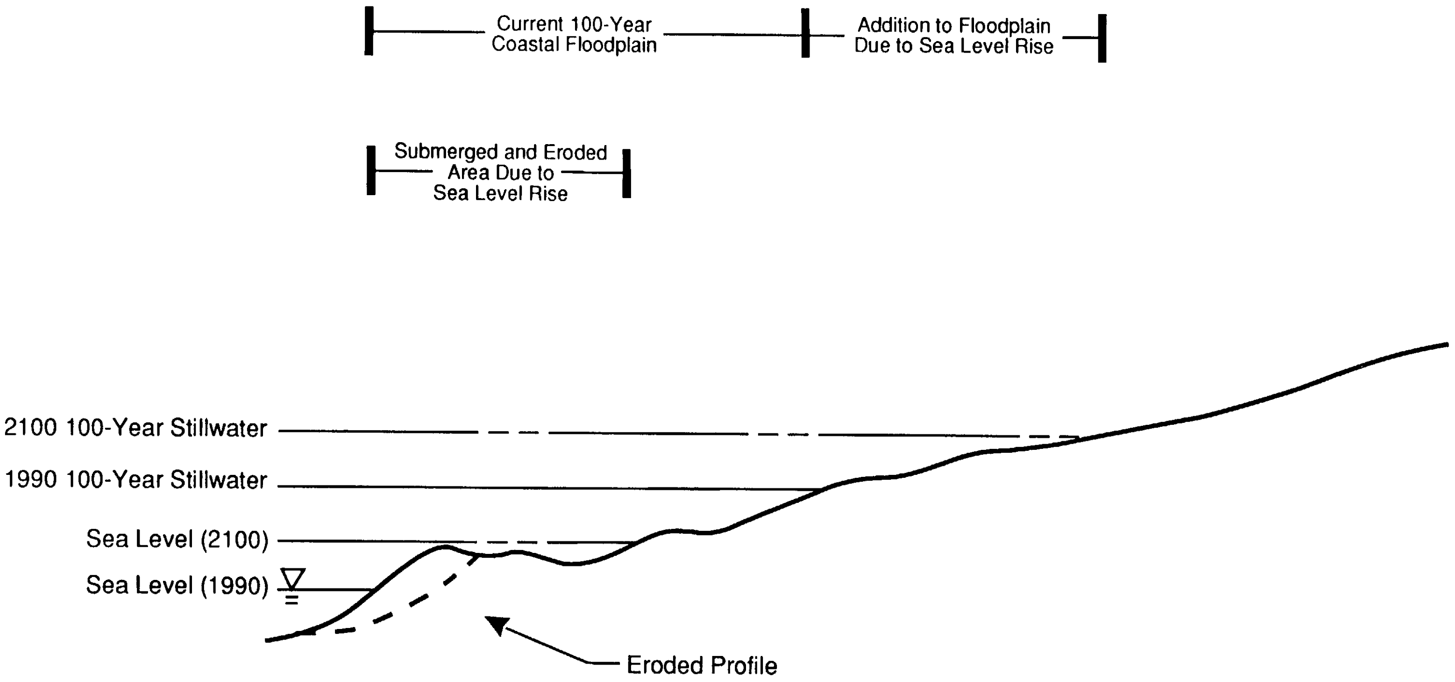

Figure 3.3-Schematic diagram of the effect of sea level rise on the 100-year coastal floodplain

Coastal Phvsiographic Regions

The coastline of the United States was divided into a series of physiographic regions to develop both a regional and national summary of the physical consequences of sea level rise. Regional divisions of the coastal United States were previously done by Lin (1980), the NRC (1987), and Armentano et al. (1988). Each analysis was based on a combination of physical and economic factors. A simplified version of the classification by the NRC (1987) was used to develop 11 coastal regions for the continental United States, including Alaska and Hawaii (Figure 3.4). The regional divisions are based on variations in coastal morphodynamics and geologic history. For simplicity, regions consist of one or more whole states (i.e., no partitioning within a state), despite some regional variation within a state. The one exception is the state of Florida, where there is a large physical variation between the barrier islands along the Atlantic coast, the coral reefs of the Florida Keys, and the barrier islands along the Panhandle. As a result, the state was divided into two regions to account for the different morphological conditions between the Atlantic and Gulf coasts. The Florida Keys form a geological break between the Atlantic and Gulf coast barriers. For the purpose of this study, the Florida Keys were included in the Atlantic coast region.

Region 1, the New England area, extends from New York to Maine. The glaciated coast is composed of a series of coastal barriers characterized by spit growth across deep embayments. The mainland is interspersed with hilly lowlands and gentle slopes with some higher areas which form cliffs near the shoreline.

Region 2, the Mid-Atlantic area, includes New Jersey, Pennsylvania, Delaware, the Delmarva peninsula (eastern shore) and the western shoreline of the Chesapeake Bay, Virginia, and North Carolina. This region is characterized by low-lying, moderately developed coastal barrier islands and marsh filled embayments. The western shoreline of the Chesapeake Bay primarily consists of low sandy shorelines, and low cliffs in some areas.

Region 3 is the mesotidal coast of South Carolina and Georgia. This area is characterized by short, stubby barrier islands with marsh-filled lagoons. Because of the topography, the larger tidal range and the coarser sediments in this area, these islands are considered relatively more stable than the barriers of the Mid-Atlantic and Gulf coasts (NRC, 1987).

The Atlantic coast of Florida, Region 4, is dominated by highly urbanized barrier islands backed by narrow lagoons. The low-lying islands of the Florida Keys, formed on coral reefs and limestone, are also included in this region. The Gulf coast of Florida, Region 5, is made up of the western shoreline of the Florida peninsula, the Florida Panhandle, Alabama, and Mississippi. This region is characterized by a continuous series of barrier islands and extensive marshes and swamps.

The deltaic coast of Louisiana, Region 6, extends from the Chandeleur Islands to Isle

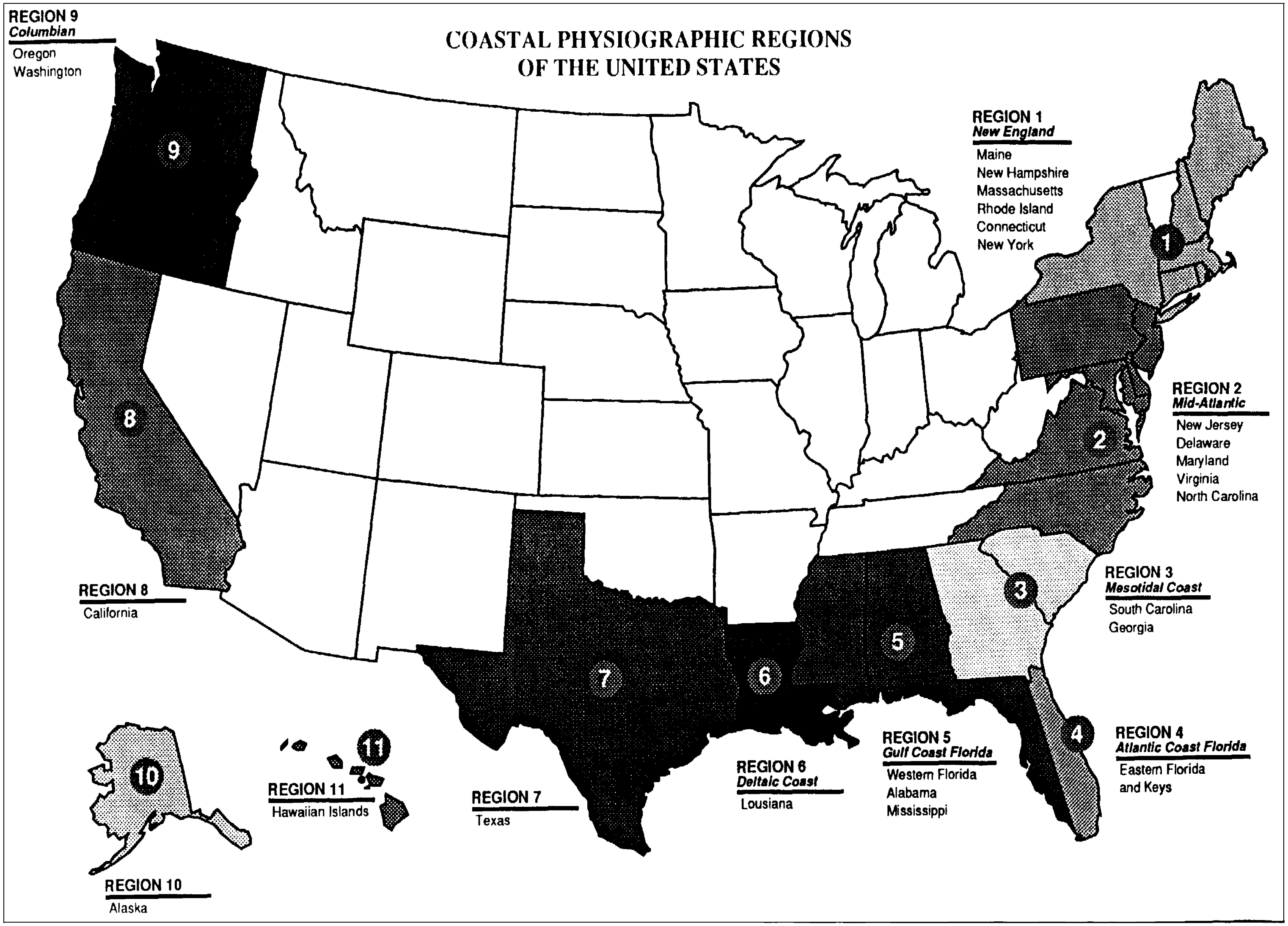

Figure 3.4 - Coastal physiographic regions of the United States based on morphological and geologic variations

Dernieres. The islands are mostly wetlands made up of fine-grained deltaic deposits.

Region 7, the Texas barrier islands, is similar to the Mid-Atlantic barrier island group. The microtidal islands are generally wide and are backed by shallow lagoons and extensive wetlands. These barriers, however, have a stable sand source; therefore, shoreline erosion is not as critical as in other areas (NRC, 1987).

The Pacific coastline varies considerably among California, Oregon, and Washington. The coastline of California alternates between a continuous narrow beach along southern California, to rocky headlands and high cliffs from north of Point Conception to the Columbia River, Oregon. Washington is mostly flat-sloped beaches, with limited wetland areas. Despite regional variation within California, the northern and southern portions of the state were grouped together as Region 8 for simplicity. Oregon and Washington make up the Columbian area, or Region 9.

The Alaskan coastline comprises fjords, rocky islands, permafrost lowlands, and low barriers and spits. The entire Alaskan coast makes up Region 10.

The Hawaiian Islands, Region 11, are mostly volcanic rock, with sandy beaches produced by wave-action on the volcanic rock and coral reefs. The extensive coral reefs, which dominate the nearshore waters, create an abrupt change in slope.

Because of the modest impact of sea level rise in Alaska and Hawaii, these regions have been combined, for reporting purposes, with the Columbian and California regions, respectively.

3.2 Results

The additional land area affected by a rise in sea level was estimated for the continental United States, Alaska, and Hawaii for the two scenarios used in this report. A schematic of the physical changes associated with a rise in sea level is shown in Figure 3.3. The additional area affected was calculated based on the methodology described in Section 3.1.

Regional and national changes in land area for the year 2100, based on land 3-foot rises in sea level, are shown in Tables 3.4 and 3.5, respectively. The estimated national coastal floodplain area is 19,500 square miles. It is estimated that approximately 2,200 square miles will be added to the floodplain by a 1-foot rise in sea level and that approximately 6,500 additional square miles will be added by a 3-foot rise in sea level when subsidence in Louisiana is not taken into account. When this subsidence is accounted for, these figures become 3,400 and 7,700 square miles, respectively. Tables 3.4 and 3.5 also partition the areas affected by sea level rise into A- and V-Zones.

Table 3.4 Area Affected Due to a 1-foot Rise in Sea Level by the Year 2100

REGION	FLOODPLAIN 1990			ADDITIONAL AREA AFFECTED DUE TO SEA LEVEL RISE		
	A-ZONE	V-ZONE	TOTAL	A-ZONE	V-ZONE	TOTAL
NEW ENGLAND	992	180	1172	97	18	115
MID-ATLANTIC	4163	344	4507	545	44	589
MESOTIDAL COAST	1899	332	2231	155	28	183
ATLANTIC COAST FLORIDA	846	42	888	111	6	117
GULF COAST FLORIDA	2524	462	2986	267	49	316
DELTAIC COAST	2684	1010	3694	301 [1203]	113 [451]	414 [1654]
TEXAS	2328	822	3150	231	82	313
CALIFORNIA/ HAWAII	428	94	522	65	16	81
COLUMBIAN I ALASKA	296	49	345	34	6	40
NATIONAL TOTAL	16160	3335	19495	1806 [2708]	362 [700]	2168 [3408]

(UNITS ARE SQUARE MILES)

VALUES IN BRACKETS ARE BASED ON A SUBSIDENCE RATE OF 3 FEET/CENTURY FOR LOUISIANA

Table 3.5 Area Affected Due to a 3-foot Rise in Sea Level by Year 2100

REGION	FLOODPLAIN 1990			ADDITIONAL AREA AFFECTED DUE TO SEA LEVEL RISE		
	A-ZONE	V-ZONE	TOTAL	A-ZONE	V-ZONE	TOTAL
NEW ENGLAND	992	180	1172	291	53	344
MID-ATLANTIC	4163	344	4507	1633	134	1767
MESOTIDAL COAST	1899	332	2231	467	82	549
ATLANTIC COAST FLORIDA	846	42	888	334	17	351
GULF COAST FLORIDA	2524	462	2986	802	146	948
DELTAIC COAST	2684	1010	3694	903	339	1242
				[1806]	[6781	[2484]
TEXAS	2328	822	3150	695	245	940
CALIFORNIA / HAWAII	428	94	522	194	48	242
COLUMBIAN / ALASKA	296	49	345	104	17	121
NATIONAL TOTAL	16160	3335	19495	5423	1081	6504
				[63261	[1420]	[77461

(UNITS ARE SQUARE MILES)

VALUES IN BRACKETS ARE BASED ON A SUBSIDENCE RATE OF 3 FEET/CENTURY FOR LOUISIANA

4.0 DEMOGRAPHICS

Demographic information was used to estimate the number of households that could be affected by sea level rise. This estimate is based on population growth projected for coastal areas.

A summary of assumptions adopted in developing the demographic information used for this study is provided below. A more detailed discussion of these assumptions is presented in the following section.

1. The standard demographic unit of households is used to characterize floodplain occupancy and development. Data on numbers and types of structures were not available for this study.
2. The population, and therefore household, projections are based on data from the Bureau of the Census, with forecasts to the year 2010 conducted by Woods and Poole Economics, Inc. (Woods & Poole, 1990). Projections to 2100 were based on the trends established for the period prior to 2010. The result is a constant linear increase of population with time.
3. The distribution within each county is uniform, i.e., the density of households at any point in time does not vary across the county. This assumption was necessary due to the lack of information that quantifies the density of households in the floodplain. The impact of this assumption depends on where the population centers are located within a county. If a center is principally within the floodplain (e.g., Miami, Florida), the assumption of uniform density may underestimate the risk; conversely, if a center is principally outside the floodplain (e.g., Jacksonville, Florida), then the risk may be overstated.
4. No consideration was given to the possibility of saturation of development. If saturation occurs, new households would be displaced farther inland and therefore farther from the various adverse effects associated with sea level rise.
5. All floodplain was considered developable, e.g., public land was not treated differently than privately owned land. Although areas defined under the Coastal Barrier Resources Act are delineated on FIRMs, quantitative data are not readily available for these areas and undevelopable land within the floodplain. Given the variable distribution of publicly versus privately owned land in each county, the effect of this assumption could lead to an overestimate or underestimate of the number of floodprone households in each county.

The overall effect of these assumptions is difficult to quantify and would require further investigation.

4.1 Methodology

As population increases, it can be expected that households will be added to the floodplain. Similar to the prediction of potential sea level rise, projections of population change are uncertain, especially as the period for the projection increases. The Bureau of the Census was initially contacted for information on demographic changes. Subsequently, data on population trends and projections were obtained from Woods & Poole Economics, Inc. (Woods & Poole, 1990) for the period 1969 through 2010. These projections relied heavily on Census data and were extended through 2100 for purposes of this study.

The population data consist of annual figures from 1969 through 2010 (41 years) for the entire United States, all states, and all counties. The data are derived from a model that considers both economics and Bureau of the Census mortality and fertility rates. County migration patterns are based on employment opportunities, with two exceptions: for population aged 65 and over and college-/military-aged population, migration patterns over the forecast period are based on historical migration and not economic conditions.

The reliability of the forecasts is limited by several circumstances. The analysis of historical data does not guarantee that some unforseen event(s) may occur in the future that does not follow the historical trend, e.g., a sudden economic change that occurs more rapidly or with more intensity than anticipated. A second limitation results from doing forecasts for small geographic areas such as counties, i.e., the smaller the area the less reliable are the statistical models. Obviously, for the period 2010 to 2100, which is not covered by these population data, the limitations cited here are even greater.

The Woods & Poole population figures through 2010 were used directly in this study. Figures beyond 2010 have been estimated by examining the trend prior to 2010 and extrapolating that trend linearly to the terminal year 2100. The trend in the sub-interval 2000 to 2010 is adopted for the period 2010 to 2100. In general, this choice would be expected to lead to a lower projected rate of population increase for 2010-2100 than for the period prior to 2010. A plateauing or saturation of the population in the second period seems intuitively reasonable and would prevent an explosive or unrealistic growth in population by 2100. However, the population trend, shown in Figure 4.1 for 1969-2010, is essentially linear and constant, which means that the adopted trend for 2010-2100 is also constant, i.e., there is no saturation predicted.

With the methodology established for calculating incremental changes in floodplain area and population (and, by further transformation, the number of households), the impacts of the two sea level rise scenarios can be evaluated for each milestone year (years corresponding to successive 1-foot increments of sea level rise). The population data were used to provide the total number of households given the number of persons per household specific to each county as reported by the Bureau of the Census. The Bureau of the Census number of households, which includes rental properties meant for occupancy, was selected to be the most representative characterization of development. Changes in population are matched by proportional changes in households.

A key assumption adopted in this study is that the population density for each county is uniform, i.e., a single population density applies to all parts of the county. Given this assumption and knowing the land area of the county, the area of the SFHA that is subject to coastal flooding, and the percentage of coastal SFHA that is V-Zone, the number of floodprone households partitioned into A- and V-Zones can be determined.

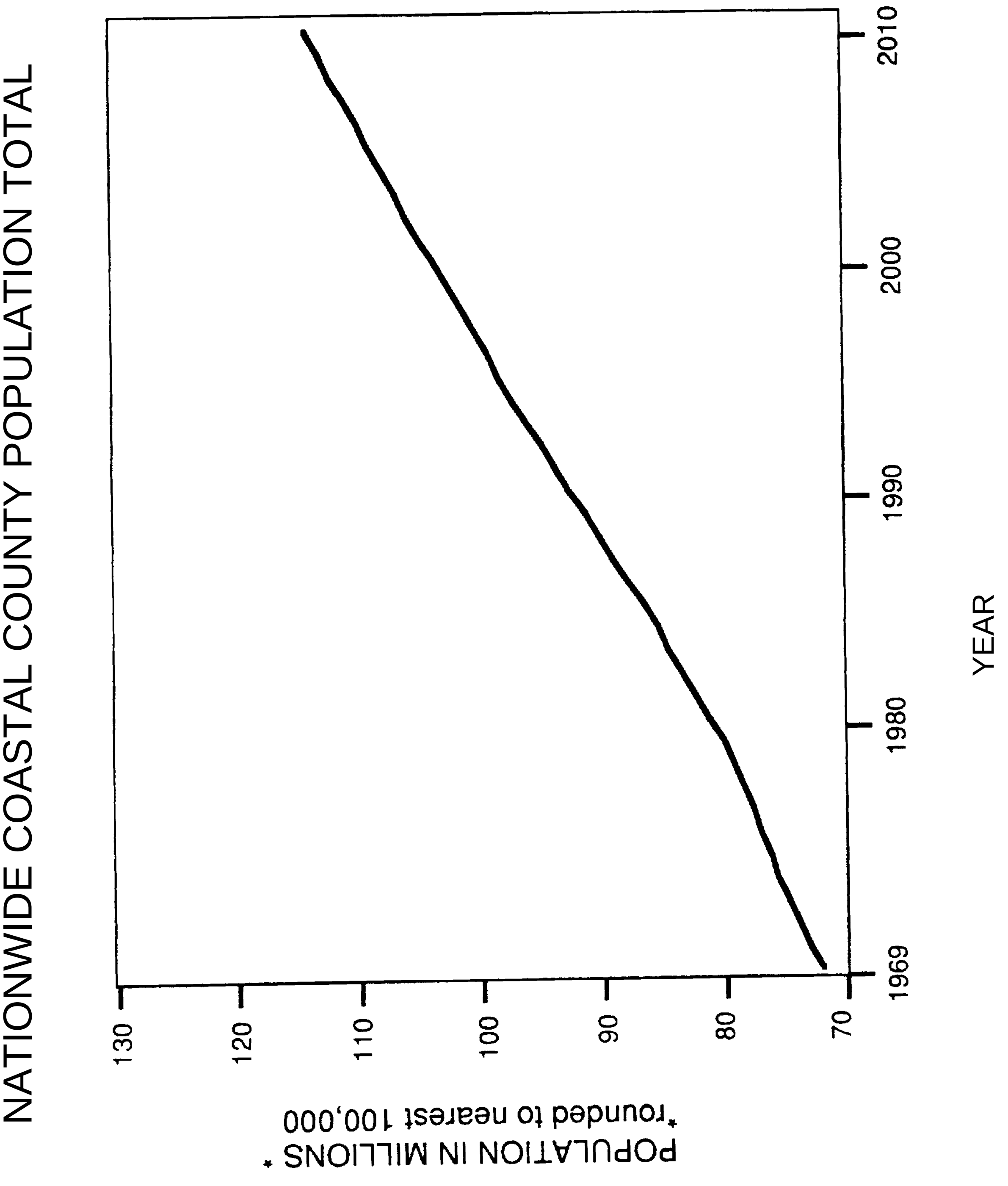

Figure 4.1 - Population as a function of time based on information supplied by Woods & Poole, 1990

4.2 Results

The number of households affected by sea level rise is directly related to the physical changes described in Section 3.0. The number of households added due to growth in population is calculated just prior to imposing each successive 1-foot rise in sea level. The growth calculation is based on the coastal floodplain at the previous milestone year and the change in population from that milestone year to the current milestone year. Households added due to the expansion of the floodplain are calculated just after imposing a 1-foot rise in sea level. The expansion calculation is based on the increased area due to a 1-foot rise in sea level and the total population at the milestone year. The number of households lost due to erosion and submergence was not determined, because of the uncertainties involved in this calculation. These uncertainties include the density of households in the nearshore areas affected by erosion and submergence and the effects of mitigation actions such as coastal management (setbacks) and engineering solutions (protective structures, beach renourishment). These actions could appreciably alter the makeup of the nearshore households from that assumed in this report. These types of responses could not be considered in this type of study.

The current number of pre-FIRM households in the coastal floodplain is estimated to be 2.4 million. The total number of households (pre- and post-FIRM) in the current (1990) coastal floodplain is estimated to be 2.7 million. The total number of households projected to be in the coastal floodplain by the year 2100 for the 1- and 3-foot scenarios is shown in Table 4.1. A 0-foot scenario is also shown for comparison and considers only the addition of households due to growth in population. The total number of households of 5.6 and 6.6 million by the year 2100 for the 1- and 3-foot rise scenarios, respectively, reflects both expansion of the floodplain and growth due to population increases. These estimates assume no subsidence in Louisiana. If subsidence is accounted for, the number of households become 5.7 and 6.8 million, respectively. The increase of floodplain households is strongly influenced by the growth in population, which accounts for 90 percent and 76 percent of the households added to the floodplain for the 1- and 3-foot rise scenarios, respectively. Table 4.2 shows a regional breakdown of the total number of households projected to be in the coastal floodplain by the year 2100 for the 0-, 1-, and 3- foot scenarios.

Table 4.1 Estimated Total Households in the Coastal Floodplain for the 0-, 1-, and 3-foot Sea Level Rise Scenarios by the Year 2100 (In Millions)

	1990 FLOODPLAIN HOUSEHOLDS	0' SCENARIO[1] 2100	1' SCENARIO 2100	3' SCENARIO 2100
HOUSEHOLDS IN A-ZONE	2.4	4.5 [4.6]	5.0 [5.1]	5.9 [6.1]
HOUSEHOLDS IN V-ZONE	0.3	0.55 [0.58]	0.61 [0.64]	0.73 [0.75]
TOTAL HOUSEHOLDS IN COASTAL FLOODPLAIN[2]	2.7	5.1 [5.2]	5.6 [5.7]	6.6 [6.8]

[1] This scenario is provided to 1llustrate the increase in households due to population growth only

[2] Includes 2.4 million pre-FIRM households

Values in brackets are based on a subsidence rate of 3'/century for Louisiana

Table 4.2 Estimated Number of Households by Region in the Coastal Floodplain for the 0-, 1-,And 3-foot Sea Level Rise Scenarios by the Year 2100 (In Thousands)

REGION	1990 Floodplain Households		0' Scenario Floodplain Households 2100		1' Scenario Floodplain Households 2100		3' Scenario Floodplain Households 2100	
	A-Zone	V-Zone	A-Zone	V-Zone	A-Zone	V-Zone	A-Zone	V-Zone
New England	868	54	1,306	98	1,432	108	1,677	126
Mid-Atlantic	591	33	937	69	1,042	76	1,256	92
Mesotidal Coast	107	18	193	33	209	36	239	41
Atlantic Coast Florida	135	4	368	11	419	13	509	16
Gulf Coast Florida	221	25	765	57	845	62	983	72
Deltaic Coast	267	59	421 [552]	78 [102]	467 [605]	86 [111]	552 [696]	102 [128]
Texas	109	55	210	122	229	132	268	153
California/Hawaii	100	26	274	83	317	96	392	119
Columbian/Alaska	19	2	41	3	46	4	55	5
National Total	2,417	276	4,516 [4,647]	554 [578]	5,006 [5,144]	613 [638]	5932 [6,076]	726 [752]

Values in brackets are based on a subsidence rate of 3'/century for Louisiana

5.0 ECONOMIC IMPLICATIONS FOR THE NFIP

A summary of the assumptions and considerations that relate to the insurance implications is provided below:

1. The current elevation distribution of post-FIRM construction (policies) relative to the BFE, is assumed to hold for future construction.
2. The obsolescence of buildings is not accounted for; realistically, the number of pre-FIRM and post-FIRM buildings built to outmoded BFE standards would decline with time. Replacement structures would be in compliance with NFIP regulations in effect at the time of their construction. Thus, loss expectations may be overestimated.
3. All monetary figures reflect 1990 dollars.
4. This study examines the standard flood insurance coverage and not the expanded benefits afforded by the Upton-Jones Amendment.

5.1 Background

The NFIP is a risk management program for the Nation's floodplains that emphasizes loss control, effected at the local level, and risk transfer, through an insurance mechanism that pools risks on a nationwide basis. The costs of implementing the Program's loss control measures are balanced with the concerns of pricing the insurance. Sea level rise could have implications for the insurance rating structure that protects the financial soundness of the NFIP and for the Program's loss control requirements that are promulgated as the baseline for local community participation.

In assessing the potential impact of sea level rise, this study examines the sensitivity of the NFIP's rate structure to the changing conditions as an indication of the degree to which Program changes would have to be made and of the criticality of the timeframe in which such changes might be needed. If rates can remain reasonable, then other risk management measures, while still beneficial, are not as necessary as in the case of the rating structure becoming unreasonable.

The analysis of the impact of sea level rise on the NFIP premium requirements has been done at a national level viewpoint since rates are set on a national risk classification basis. Although, even without sea level rise considerations, there are regional differences in flood risk, a national rating structure provides administrative simplification and better meets the concerns of spreading the risk. Some regionalized loss control measures might be needed to respond to sea level rise, but the criticality of these measures to the NFIP can be examined within the context of the national insurance capability.

The impact of sea level rise in this study was limited to the standard flood insurance coverage provided to buildings insurable under the NFIP and not the additional erosion benefits afforded by the Upton-Jones Amendment (Section 1306[c] of the National Flood Insurance Act of 1968). The FIA has long expressed two major objections to the Upton-Jones Amendment. One is that the actuarial premiums, required by the NFIP legislation, could very well be unaffordable, thus making the risk uninsurable, and the other is that the Amendment does not include any loss control requirements. The effects of a rising sea level merely exacerbate these problems. While this sea level rise study has been underway, a bill has been introduced in Congress to repeal Upton-Jones and to create an erosion management program under the NFIP. The effect of sea level rise on erosion management requirements and any insurance coverage that might be provided would be better examined during the development of regulations implementing that program.

5.2 Methodology

For purposes of assessing the potential impact of sea level rise on the NFIP and the resulting revisions of premium charges that might be necessary to maintain adequate policyholder funding of the loss payments, a model representing the shifting distribution of risk characteristics of NFIP business was created to examine the relative changes in expected annual losses for policies in SFHAs. While a rising sea level exacerbates the flood risk, the expansion of the areas exposed to that risk also has the effect of increasing the number of flood insurance policies and thus increasing the premium income available to pay losses. By focusing on rates per $100 of insurance in force, the relative magnitude of the problem could be analyzed without a detailed projection of the NFIP's future book of business. No matter how much insurance will actually be in force in the areas affected by sea level rise, the changes in the average rates projected by the model are an indication of how sensitive the NFIP will be to the phenomenon and whether existing rate structures will be adequate to address the problem of maintaining an overall premium income level commensurate with the level of losses.

The NFIP uses the elevation of the lowest floor relative to the BFE as one indicator of risk for an insured property. Depth-damage relationships and flood elevation-frequency relationships are used to calculate actuarial rates, which reflect expected annual damages and vary according to location relative to the BFE. For the purposes of this study, representative rates were computed for A-Zones using a 1-4 Family/One Floor-No Basement building as a model, and for V-Zones using a No Obstruction building as a model. These particular rates (expressed in dollars per $100 of coverage) are not paid by all policyholders. However, since it is the relative change over time of the average rate based on damage expectations, and consequently the premium income level, that is of interest, these rates are adequate to examine increases in losses and to judge how the overall premium level would need to change as risk conditions are modified by a rising sea level.

To estimate expected losses, it was necessary to develop the distribution of household elevations relative to the BFE. In this study it was assumed that future floodprone households added due to population change and A-Zone floodplain expansion will reflect the elevation distribution of existing post-FIRM flood insurance policies. Post-FIRM households added to the V-Zone due to its movement inland were assumed to follow a distribution 2 feet lower than existing post-FIRM policies in order to reflect the additional hazard of wave action. It was also assumed that all pre-FIRM households, for which the NFIP has no elevation data, followed an elevation distribution that was developed in such a way that it could be expected to produce results similar to actual loss experience. The number of pre-FIRM households was estimated by assuming that the county population/household figures for the year 1980 reflect pre-FIRM conditions. Households added to the floodplain after 1980 due to changes in population were considered post-FIRM. In addition, a distinction was made between pre-FIRM A-Zone and pre-FIRM V-Zone household elevation distributions. Because of the limited differences noted in data obtained from actual policies, only one post-FIRM household elevation distribution was adopted in this study for both A- and V-Zones. The exception to this was the aforementioned 2-foot adjustment for post-FIRM buildings added to the V-Zone as it shifts inland. Graphical representations of these distributions are shown in Figures 5.1A, 5.1B, and 5.2.

The next step in the study required the calculation of the elevation distribution at the milestone time points previously discussed. For the pre-FIRM group, the elevation distribution was recalculated at each milestone year assuming a 1.0-foot increase in BFE and that households below -5.0 feet would drop out of the population. For the post-FIRM category, it was also necessary to account for the introduction of new households where the construction during each time period would be built to increasing BFE requirements.

A weighted average elevation and average insurance rate that reflect the distributions as a whole were computed for each milestone for each risk category including, for each of the A- and V-Zones, pre-FIRM subsidized and post-FIRM actuarially rated. In the case of the latter category, the average elevation and rate reflect that, as the BFE changes and is shown on the FIRMS, construction after that point takes place in compliance with the new BFE. An increase of sea level would cause some households in the current A-Zone to be in a V-Zone. This is due to increased wave heights associated with sea level rise. In order to account for these households, a 2-foot shift was incorporated in the distribution of household elevations with respect to the BFE. At the milestones, the average full risk premium rate was used to represent what would have to be charged in order to meet the expected annual losses at that point in time for those buildings in areas subject to the effects of sea level rise.

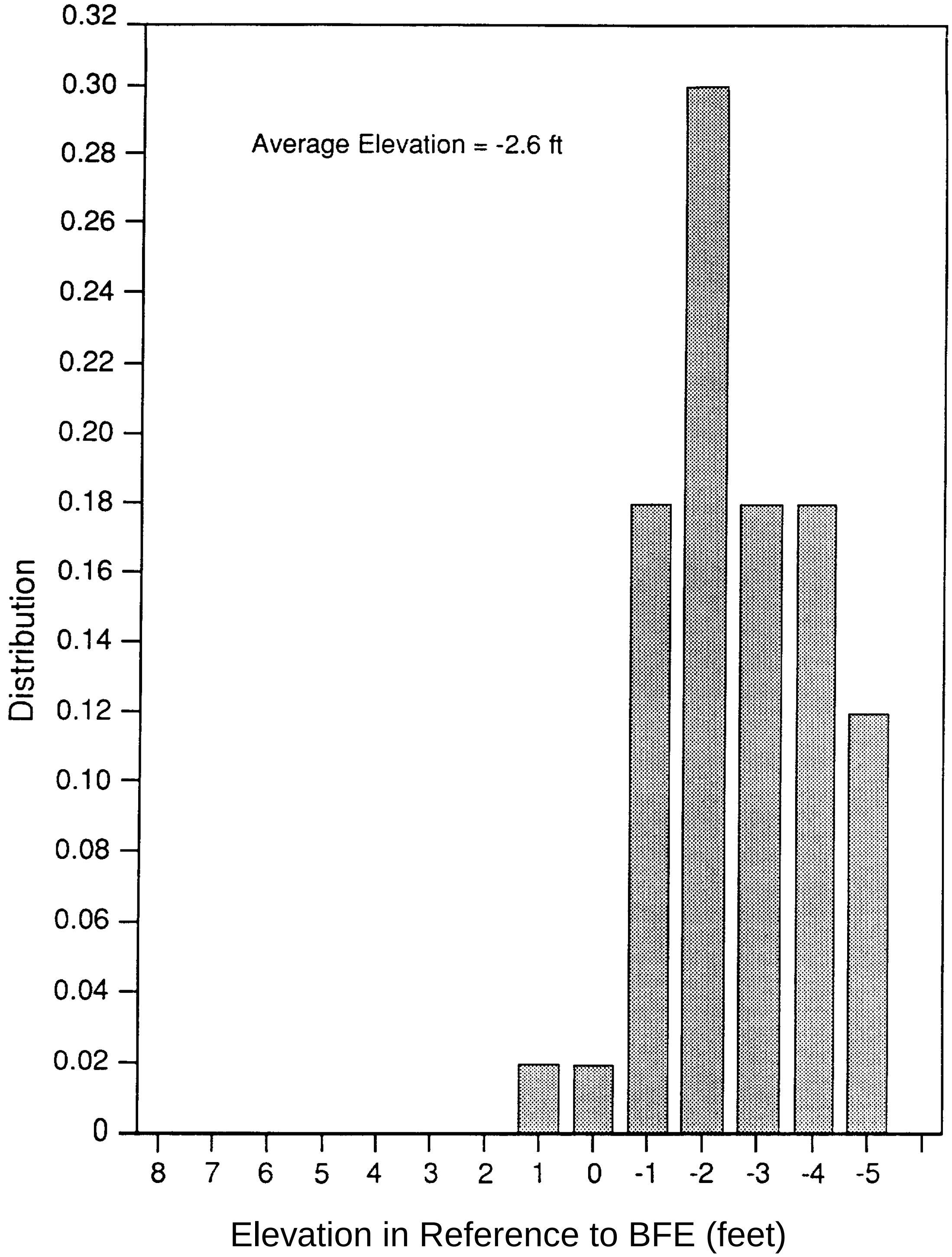

Figure 5.1 A : 1990 Representative Pre-FIRM Distribution (V-Zone)

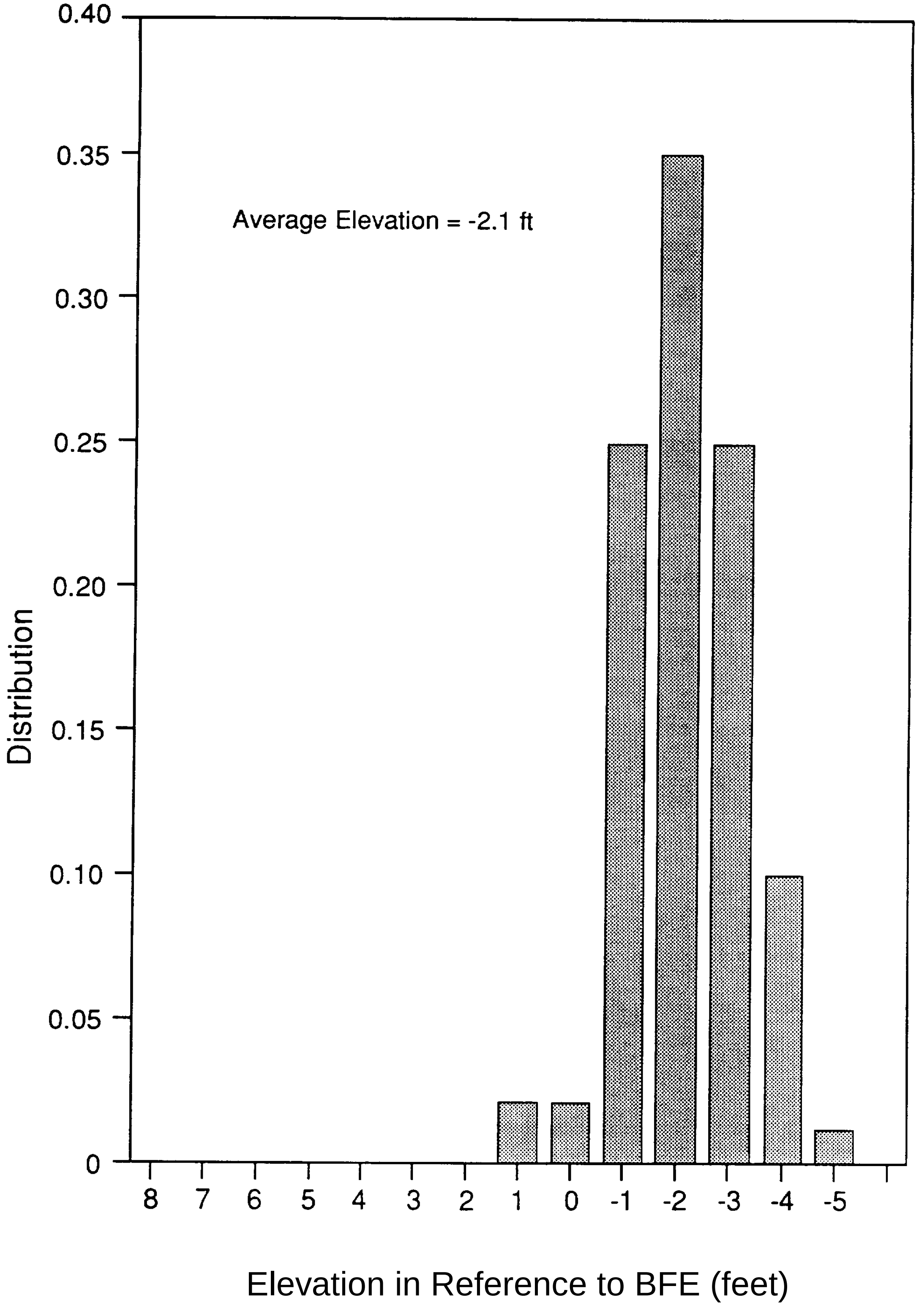

Figure 5.1 B : 1990 Representative Pre-FIRM Distribution (A-Zone)

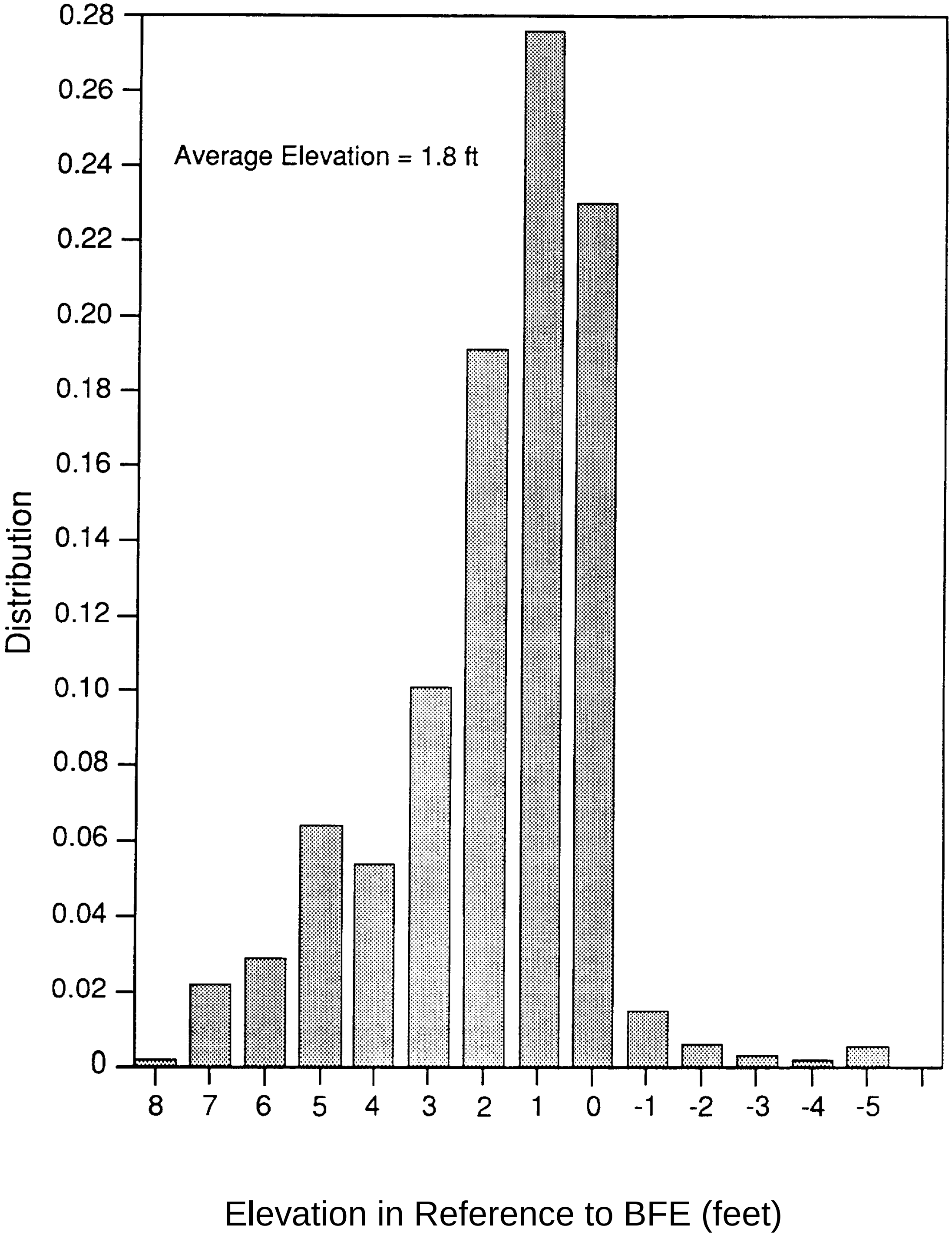

Figure 5.2 : 1990 Representative Post-FIRM Distribution

5.3 Impact on Insurance Premium Requirements

Figures 5.3 through 5.6 show how the average full risk premium rates change as the actual risk changes through time. Again, it is the relative change that is important and not the specific rates in this modeling exercise. For example, in the 3-foot rise scenario, the average rate for A-Zone actuarial policies in 1990 is $.19 based on an average building elevation of 1.8 feet above BFE. In 2100, the average full risk premium rate is $.57 based on an average building elevation of 0.1 foot below BFE (see Table 5.1A). Thus, in order to maintain actuarial soundness for policies issued in this risk category subject to sea level rise, the average premium would have to increase by 200 percent, because expected annual losses increase by that amount. Likewise, in order to maintain the current approximately 67 percent level of subsidy of pre-FIRM A-Zone policies subject to sea level rise, the average premium would have to increase by 144 percent over what it is today (see Table 5.1B).

It should be apparent that many assumptions underlie these results. The model is only an approximation, and the inclusion of other considerations could very well raise or lower the projections. One aspect of the effect of time on the NFIP's policy base that has not been included, and merits particular mention, is the gradual depletion of the older building stock. Certainly in the case of pre-FIRM buildings, over the course of 100 years the Program will be insuring a dwindling number, some buildings being lost to flooding, some suffering other damage, but most merely coming to the end of their useful lives and being replaced by new buildings compliant with the BFE in effect at that time. Even in

Table 5.1A Post-FIRM Actuarial Increase in Average Premiums For Buildings Subject to Sea Level Rise Required to Maintain Actuarial Soundness

	Zone A			Zone V		
	Full Premium Risk Rate		Percent Change	Full Premium Risk Rate		Percent Change
	1990	2100		1990	2100	
1-Foot Rise	0.19	0.30	58%	0.66	0.90	36%
3-Foot Rise	0.19	0.57	200%	0.66	1.33	102%

Figure 5.3 : 1-Foot Sea Level Rise Scenario : V-Zone

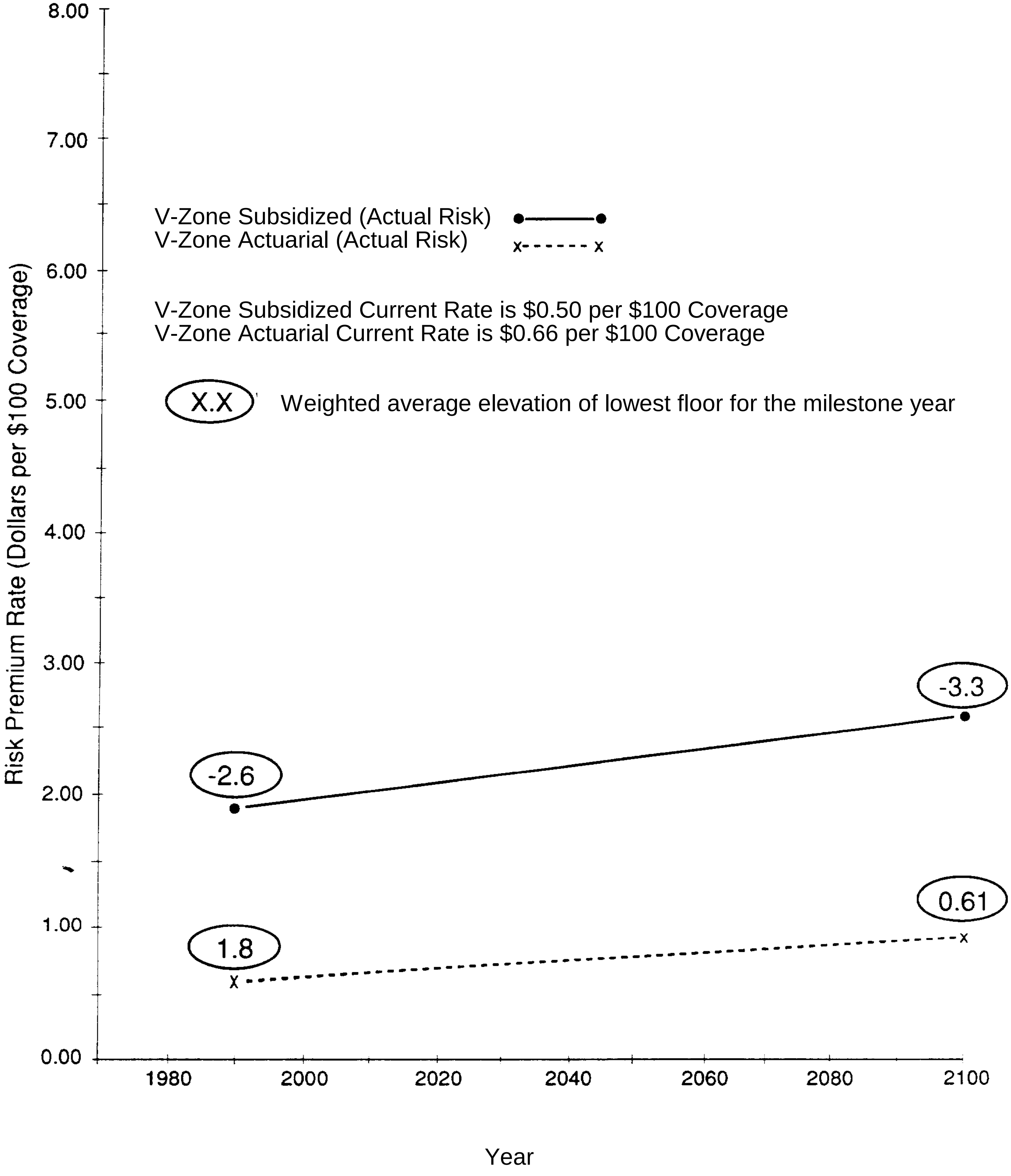

Figure 5.4 : 1-Foot Sea Level Rise Scenario : A-Zone

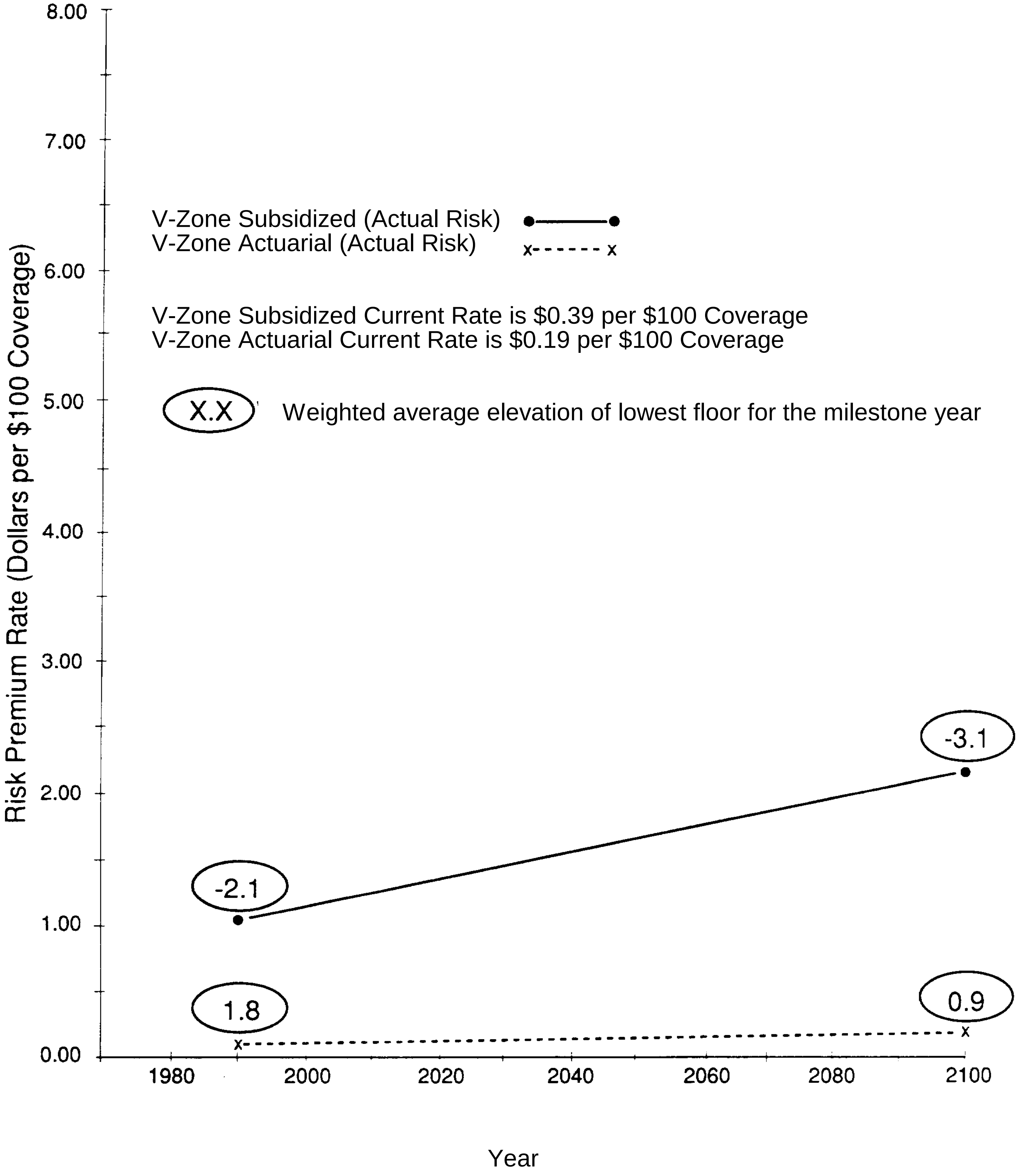

Figure 5.5 : 3-Foot Sea Level Rise Scenario : V-Zone

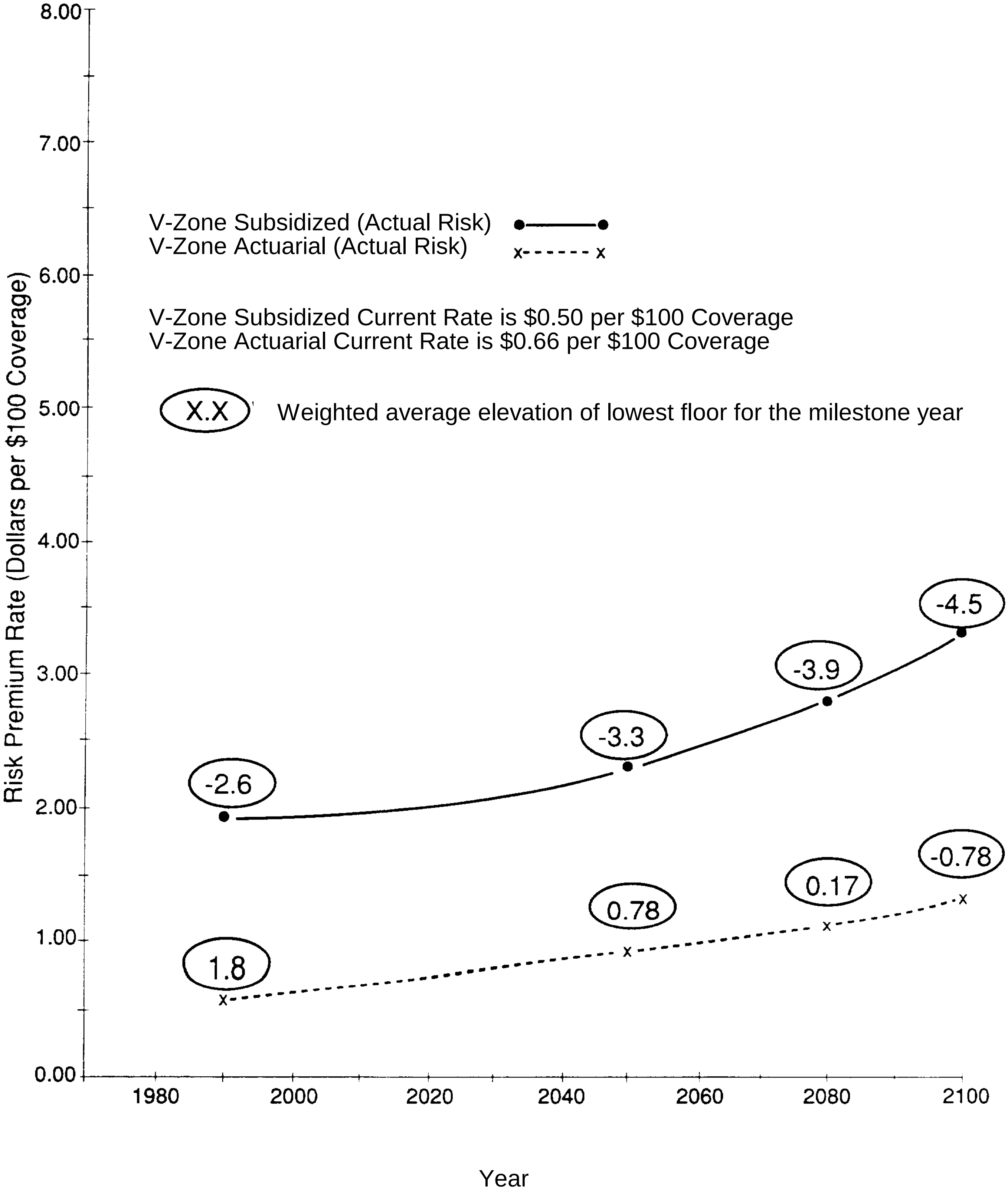

Figure 5.6 : 3-Foot Sea Level Rise Scenario : A-Zone

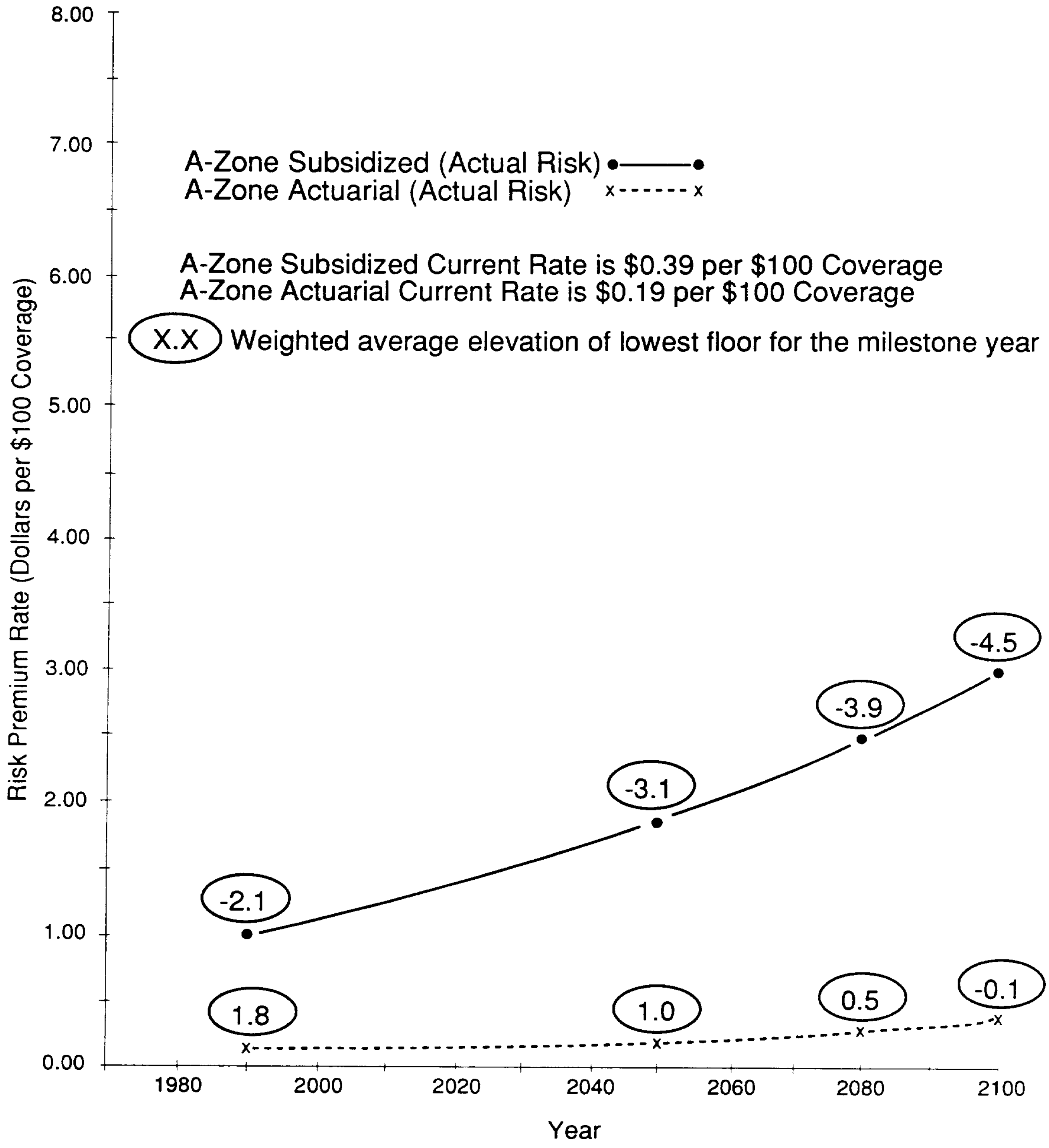

Table 5.1B Pre-FIRM Subsidized Increase in Average Premiums For Buildings Subject to Sea Level Rise Required to Maintain Current Subsidy Level*

	Zone A			Zone V		
	Subsidized Rate		Percent Change	Subsidized Rate		Percent Change
	1990	2100**		1990	2100**	
1-Foot Rise	0.39	0.60	54%	0.50	0.63	26%
3-Foot Rise	0.39	0.95	144%	0.50	0.79	58%

*Current subsidy level is estimated to be 67% (A-Zone) and 76% (V-Zone) based on average $.39 (A-Zone) and $.50 (V-Zone) rates charged compared with average full risk premium rates in 1990 of $1.18 (A-Zone) and $2.09 (V-Zone).

**2100 subsidized rates equal 0.33 (A-Zone) and 0.24 (V-Zone) times the <u>average</u> full risk premium rate. While this calculation produces a V-Zone rate that falls below the A-Zone rate, it is assumed that this would not actually be allowed to happen.

the case of post-FIRM construction, in the long timeframes associated with estimates of sea level rise, there will be older buildings which will be constructed to outmoded BFE standards and will be removed from the book of those being insured. Because this depletion has not been included, the argument can be made that the estimates of future annual damage expectations are high. Of course, there are also arguments that can be made for these estimates being low. Suffice it to say that there is a fair amount of uncertainty in these figures that should be borne in mind when using them.

So far, the relative change in rates, as an indicator of increased loss expectations and resulting premium increases, has been emphasized. However, it is also important to examine the magnitude of the rates in assessing the potential impact on the NFIP. One reason for establishing the 100-year flood elevation as the BFE for post-FIRM construction was that owners of buildings constructed to this standard would be able to transfer the remaining risk through the purchase of reasonably priced insurance. The consideration of the affordability of full risk premiums for pre-FIRM construction, generally built to much lower standards, prompted Congress to "grandfather" in that existing construction at subsidized rates.

Under the 1-foot rise scenario, the average insurance rates for post-FIRM construction in V-Zones and A-Zones, over the course of 110 years, never rise above that currently charged for buildings built to the BFE, a level that has already been deemed to provide insurance at a reasonable price. Even under the 3-foot rise scenario, these average rates do not become absolutely unreasonable. In the A-Zones, the rate is substantially less than that charged for buildings at 1 foot below the BFE. In the V-Zones, the rate is only 8 percent greater than that charged at 1 foot below BFE. These results indicate that ample flexibility exists within the NFIP rate structure to accommodate the generation of enough premium, at reasonable rates, from the policyholder base to cover flood losses to the actuarially rated policies. The question arises as to how these premium charges should be distributed among the policyholders who have varying degrees of risk exposure.

The NFIP has long known and anticipated that risk conditions can change, precipitating a rise in an area's BFE. This possibility is not unique to coastal regions, but is an aspect of risk assessment in inland areas as well, where increased urbanization can easily cause a 1- to 3-foot rise in the BFE over time. All policies are subject to this additional risk. The rating structure currently considers unquantifiable effects of influences such as watershed urbanization and coastal erosion through the application of contingency loadings on the rates (5 percent in A-Zones and 10 percent in V-Zones) and the establishment of minimum rates for insurance.

A 1-foot rise in sea level over 110 years would not seem to tax the NFIP's ability to apply current approaches in spreading the costs over all post-FIRM policyholders. A 3-foot rise, or more, in sea level may require that additional measures be taken to distribute premium burdens equitably and avoid undue cross subsidies. In spreading the costs of the additional risk that flood hazard conditions may worsen, current program rules allow post-FIRM buildings, built in compliance with NFIP requirements at the time of construction, to retain their original risk classification. This grandfathering may have to be modified so that more of the additional costs are borne by the owners of the buildings subject to worsening conditions rather than by the group of insureds as a whole. One mechanism might be to always rate structures according to current risk conditions, but capping the rates for the buildings previously built in compliance. Furthermore, if the relative homogeneity of the nationally used risk zones is disrupted by inordinate numbers of buildings becoming more flood prone due to sea level rise than due to other factors common also to inland areas, then it may become necessary to create coastal A-Zones that are distinct from inland A-Zones. Rate loadings could also be increased to build reserves in anticipation of later losses.

As mentioned already, there will be a continuously decreasing number of pre-FIRM buildings that the NFIP will be insuring and therefore a dwindling number that will remain long enough to be affected by sea level rise in the contemplated timeframes. The model's results indicate that the rates necessary to maintain current levels of subsidy reach amounts that are probably higher than those, at least currently, considered to be affordable. Thus, it is likely that, for however many pre-FIRM buildings are still insured, the subsidies would increase. If there really were to be substantial numbers of these structures remaining long enough to be affected by sea level rise (which is highly unlikely), then it seems that other program changes, besides insurance methods, would have to be employed in order to reduce taxpayer subsidies going to this older construction.

5.4 Impact on Losses

Because of the relatively long timeframe in which sea level rise would affect flood risk conditions, it is essentially an issue concerning post-FIRM construction. Owners of these buildings are charged full risk premiums under the NFIP so that losses over the long term are fully funded by the policyholders. However, the ability to appropriately price the transfer of risk through insurance does not mean this mechanism is the only risk management tool that should be employed. The efficiency of loss control measures should also be explored and their costs balanced against those of insurance.

To provide some order of magnitude estimates of the additional flood losses that can be expected due to sea level rise, NFIP underwriting experience data from 1978 - 1989 were used in conjunction with the household data and indicated premium increases developed for this report. Because the NFIP experience period of 12 years is relatively short for its being employed in the analysis of a low probability event such as flooding, the most credible use of the data is at the national level. Therefore, these flood loss estimates were made for all areas affected by sea level rise on a national basis.

Assuming a 45-percent market penetration of households located in the coastal areas affected by sea level rise and expressing the amounts in constant current dollars (i.e., no trending for future inflation), a 1-foot rise in sea level will gradually increase the expected annual NFIP flood losses by about $150 million by the year 2100. Similarly, a 3-foot rise will gradually increase expected annual losses by about $600 million by the year 2100. To help put these amounts in perspective for insurance purposes where the risk is spread over all policies subject to sea level rise, expected annual losses per policy in the year 2100 would be about $60 more than today under the 1-foot rise scenario and about $200 more under the 3-foot rise scenario. If expected losses were examined either on a regional basis or an individual building basis, the amounts could differ significantly from these figures. This would have great importance for local loss control decisions.

5.5 Program Impact

The impact of potential sea level rise and the development of an appropriate Program response must be considered and prioritized within the context of many NFIP concerns. From the standpoint for insuring against flood losses through a system of pricing that is fair and that protects the NFIP's financial soundness, sea level rise does not pose any immediate problem. Currently, 74 percent of the post-FIRM structures insured in A-Zones and V-Zones have been built to elevations at least 1-foot higher than the BFE. Thus, new construction is well protected. The rating system for flood insurance appears to be able to reasonably respond to the pricing changes that would be necessitated by a 1-foot rise in sea level by the year 2100. Even under the 3-foot scenario, a rise of 1 foot is not expected until the year 2050. Although this scenario might eventually call for more extensive adjustments to the insurance system, there are no changes needed so soon that at least another 20 years cannot be used to first gather more definitive information concerning sea level rise.

The ability of the insurance system to absorb the costs of the additional risk posed by a rising sea level does not mean that other risk management efforts may not be appropriate. The concerns of a particular region or locality may produce a different perspective on the priority of sea level rise than at the national level for the NFIP. The costs and benefits of implementing other risk management measures must be balanced with the option of risk transfer through an insurance mechanism. However, this is no different than other issues the NFIP already faces in fashioning a national level response to flood hazards that can vary widely around the country. The recently implemented NFIP Community Rating System, by providing community-wide credits on flood insurance premiums, is designed to recognize and encourage State and local floodplain management efforts that go beyond minimum national requirements. A number of the activities recognized in this system are also potentially very effective in mitigating the impact of sea level rise (e.g., freeboard above BFE and open space policies).

This study has considered only the impact of sea level rise on the provision of the standard flood insurance coverage. The provision under the Upton-Jones Amendment of relocation and demolition coverage for buildings subject to imminent collapse due to the effects of erosion has not been considered. The costs of continuing to provide these automatic insurance policy benefits could eventually be increased by the effects of sea level rise. However, a bill recently introduced in Congress would repeal this benefit, substituting a mitigation assistance program that would prioritize and fund relocation projects within a specified budget. Additionally, the bill would create a coastal erosion management component of the NFIP. Erosion management activities in combination with the repeal of the Upton-Jones insurance policy benefits would tend to further reduce the potential effects of sea level rise on the NFIP.

5.6 Study/Mapping Requirements

With a continuous rise in sea level, there will be a need to restudy and remap coastal flood hazard areas. Using the criterion that a restudy will be conducted when sea level has risen 1 foot, the first restudy would occur in the years 2050 and 2100 for the 3- and 1-foot scenarios, respectively.

An estimate was made of the cost of updating and revising the technical studies and accompanying mapping for the counties directly affected by a rise in sea level. This estimate is based on the cost of past studies involving storm surge and wave analyses and the preparation of revised FIRMs. The cost associated with these efforts was expressed in terms of the cost per county for the technical study and the cost per map panel for the mapping and distribution process. The average cost of conducting the technical study was estimated to be $150,000 per county. The total cost of preparing revised mapping was estimated to be $1500 per map panel. For each county, the number of FIRM panels affected was determined by computing the ratio of the current coastal floodplain area to the total floodplain area and multiplying this ratio by the total number of panels in the county. The costs for the individual counties were then summed. For counties with less than 10 FIRM panels affected by sea level rise the costs for conducting the technical study and mapping ($150,000) were excluded.

The total number of counties estimated to be affected by sea level rise is 283. Approximately 5,050 map panels in these counties will need to be revised for each 1-foot rise in sea level. The total cost associated with the restudy and remapping of these counties is estimated to be $30,000,000, which would be spread over a 4- to 5-year period. These figures do not reflect the possibility that coastal studies and maps are likely to be revised for reasons other than sea level rise. Such a consideration would show a substantial reduction in the actual cost of study and map revisions directly associated with sea level rise.

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