ENVIRONMENTAL IMPACT ANALYSIS OF SEA LEVEL RISE ON GROUNDWATER RESOURCES AND COASTAL LAND USE PLANNING POLICY IN MASSACHUSETTS

by

NICHOLAS C. ZAVOLAS


Submitted to the Department of Urban Studies and Planning in Partial Fulfillment of the Requirements for the Degree of

MASTERS IN CITY PLANNING

at the

Massachusetts Institute of Technology

June 1990

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Chair, M.C.P. Committee
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By

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ABSTRACT

Natural climate change and changes in sea level have occurred in cycles throughout the earth's history. Marked by time periods spanning thousands of years, average global air temperatures and sea levels have fluctuated by as much as 10 F and 500 ft., respectively. According to leading climatologists, the continued accumulation of natural and human-made "greenhouse" gases in the atmosphere could accelerate the earth's natural warming cycle and cause sea levels to rise between 8-27 inches within the next 50-60 years.

For many coastal land areas, according to coastal geologists and hydrologists, a marked rise in sea levels could cause local groundwater tables whereby bringing local groundwater tables to rise closer to the land surface. For coastal communities relying on on-site septic systems for disposal of their wastewater, and groundwater aquifers for their sole source of drinking water, the possibility of higher groundwater tables increases the serious risk of septic system failure and harmful bacterial contamination of local drinking water supplies. The potential for such impacts raises important questions concerning the need for appropriate governmental policies and interventions designed to respond to sea level rise.

Efforts to determine the need for policy responses to sea level rise or the effectiveness of particular sea level rise response strategies and interventions can only be made once a local quantification of the potential sea level rise impacts, "vulnerability analysis", has been conducted. The use of Geographic Information Systems (GIS), and refinement of the three dimensional prototype GIS application developed and demonstrated in this thesis, could prove to be extremely helpful to coastal states and local coastal municipalities, as an
environmental scoping tool, for identifying coastal land areas which might be vulnerable to the impacts of higher sea levels and raised groundwater tables.

The federal government remains reticent to initiate policies or strategies for responding to the possibility of markedly higher sea levels. Coastal state governments along with their local municipalities could and should develop an appropriate adaptive local sea level rise response policy based upon the findings of site-specific sea level rise vulnerability assessments. An appropriate policy response will need to consider a strategic "mix" of structural and land use management interventions. This thesis discusses the importance of Massachusetts local Boards of Health and local health ordinances in implementing and enforcing appropriate local adaptive response interventions to protect the public's health and safety from the impacts to coastal groundwater resources and drinking water supplies anticipated from markedly higher sea levels.

Thesis Supervisor: Philip B. Herr

Title: Adjunct Professor of Urban Studies and Planning
This Master's Thesis is Dedicated to Fannie Zavolas, my mother, for the inspirational love and support she continues to provide and to the loving memory of my father, Constantine Zavolas (June 14, 1924 - February 19, 1979), who always strived to provide a better life for his children.
This Thesis could not have been written and completed without the help and support of many individuals both within and outside of the MIT MCP Program.

I wish to thank the members of my Thesis Committee; Professor Phil Herr for his wisdom and invaluable planning expertise; Professor Patricia Hynes for her guidance in global and local environmental issues and the humanistic sensitivity with which such guidance was provided and; Professor Lyna Wiggins for carefully reading and editing every draft I wrote and more importantly, for the many, many hours of her personal time and invaluable expertise in ensuring that my conceptual GIS ideas became the GIS prototype reality which is included in this thesis (I could not have done it without you).

I also wish to extend my thankful appreciation to John Evans for his angelic patience and the special members of the MIT's Computer Resource Laboratory, Robert Smyser and Phil Thompson, for their kind assistance. Many thanks to Steve Ervin for his support and kindness.

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My ability to complete the requirements of this degree program has also been sustained by the support of those special people in Rhode Island, where it can be said this thesis effort originated, including: Bob and Rosemary Day, Congresswoman Claudine Schneider, The Downing Corporation, and especially, Melissa Waterman and Tim Dillingham for engaging me in issues of coastal land use planning.

"Efkhare sto" to my mother and sisters; Fannie, Ramona, Mary and Joyce, for enabling me the opportunity to further my education.

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CHAPTER 1
INTRODUCTION

1.1 Background and Statement of Problem

According to climatologists and coastal geologists the phenomenon of global warming will increase the rate of relative sea level rise and retreat of shorelands experienced throughout the world. Rising sea levels are also expected to cause a concomitant rise in groundwater levels in many coastal areas.

The implications of rising sea levels raises serious concerns for the future use of our coastal land areas and groundwater resources. More specifically, marked increases in sea level could exacerbate upland migration of shorelines and the loss of upland land areas, and raise the levels of surface water bodies such as ponds and wetlands as well as local groundwater tables. For many private coastal land owners the potential loss of existing property as well as future land use opportunities resulting from migrating shorelines and raised groundwater tables could be significant.

The environmental and health ramifications associated with sea level rise and rising groundwater tables have prompted the need for environmental policy makers and coastal land use planners to re-evaluate the preparedness of existing land use policies and regulatory controls and their ability to respond to the environmental impacts posed under varying sea level rise projections. For those coastal communities relying on
groundwater aquifers as their sole source supply of drinking water, a significant rise in sea level may cause the landward migration of an aquifer's existing freshwater/saltwater boundary resulting in saltwater contamination of existing drinking water supplies. Along with the threat of saltwater contamination, heightened groundwater elevations may significantly reduce the ability of many existing on-site septic systems to filter and attenuate harmful bacteriological and chemical elements before entering and contaminating groundwater resources and inter-tidal zone habitats.

Questions pertaining to how much sea levels will rise and how such an increase will affect our coastal communities' groundwater resources, require complex scientific analysis and modeling that are not within the purview of this research. Instead, this thesis first examines the need for assessing the risks and vulnerabilities of sea level rise to coastal groundwater resources and drinking water supplies based on our current understanding of hydrogeologic processes and the dynamics associated with conventional on-site wastewater treatment systems. Upon such an examination, I will explore the subsequent need for revising coastal management policies, land use regulations, and specifically, regulations regarding on-site septic systems, to protect these resources. This thesis also asks the question: "If revision of land use regulations is determined to be a necessary component of a policy strategy for protecting the health and safety, groundwater resources and inter-tidal habitats of coastal communities from the impacts of sea level rise, who should implement and enforce such regulatory interventions and how might they be applied to both new and pre-existing coastal developments and land uses?"
The uncertainties associated with the global warming phenomenon and sea level rise creates a great deal of difficulty for decision makers who will be called upon to choose actions to respond to sea level rise and protect groundwater resources. Without detailed and accurate information concerning the environmental impacts associated with sea level rise, decision makers will be reluctant to consider the need for implementing local sea level rise response policies.

This study, therefore, establishes an initial process for addressing those land use planning and policy questions pertaining to sea level rise and groundwater resource protection. Computerized Geographic Information Systems "GIS" technology has been used to develop a "prototype" GIS program for identifying vulnerable local coastal land areas, groundwater resources and inter-tidal zones likely to be impacted by sea level rise and raised groundwater levels under three (Low Medium High) scientifically accepted sea level rise scenarios.

Due to the existence and relative availability of digitized geographic information and data, as well as its particular hydrogeologic features, the Town of Eastham, located in Cape Cod Massachusetts, was selected as the study area for conducting this prototype sea level rise vulnerability analysis. The results of this impact identification process will be used as the framework for examining the sea level rise preparedness of existing federal, state and local land use regulations and coastal management policies.
1.2 Overview

Chapter 2 provides a general discussion of current global warming literature and sea level rise projections in an effort to understand the factors which may be contributing to global climate change and sea level rise as well as the nature of the scientific uncertainties affecting global warming and sea level rise. This chapter also develops a range ("Low" "Medium" "High") of sea level rise scenarios which might be considered acceptable by the scientific, environmental and governmental communities.

According to many experts in the fields of coastal geology and hydrology, rising sea levels will directly impact the shape and position of existing unconfined coastal groundwater aquifers. In Chapter 3, I develop a simplified scenario of how sea level rise might specifically impact coastal groundwater aquifers based on a review of current hydrology and coastal geology literature as well as from expert opinion gained from personal interviews. Many environmental studies of the impacts of development on coastal ecosystems have raised concern for contamination and loss of drinking water supplies due to fluctuating water tables and failing septic systems and migrating groundwater aquifer boundaries. The information and data obtained through these environmental field studies, coupled with a review of scientific reports of on-site waste treatment experiments and expert opinion interviews, will be examined for their applicability in developing a finer understanding of the environmental impacts likely to result from sea level rise.

An environmental impact analysis of sea level rise on specific coastal communities and their aquifers and groundwater tables provides an important and necessary opportunity for community
decision makers to link global environmental causes and local site specific outcomes. In Chapter 4, using the Cape Cod coastal community of Eastham, a prototype application of GIS was developed to provide for a "scoping" environmental analysis of the potential impacts of sea level rise on Eastham's coastal aquifer and groundwater resources. Discussion of possible improvements for a more accurate and refined GIS application system is also included in Chapter 4. This application uses the ARC/INFO GIS software together with parcel based digitized land use data for the Town of Eastham.

Finally, Chapter 5 discusses the need for revising existing policies and land use regulations or creating new ones to mitigate the future impacts to groundwater resources from sea level rise. Leading experts on sea level rise, along with authorities in environmental management, environmental law and coastal land use planning were interviewed to discuss the development of fair and equitable coastal land use policies and regulations for protecting a coastal community's groundwater resources and inter-tidal habitats from the impacts of sea level rise.
CHAPTER 2
GLOBAL WARMING AND SEA LEVEL RISE

The process of reducing emissions of greenhouse gases is going to be controversial and, no doubt, very painful for many nations. But if the global warming trends continue, the major industrialized nations will have to collectively alter the ways which we organize society and conduct business in much more drastic ways.

There's a little tendency by some of the faceless bureaucrats on the environmental side to try and create a policy in this country that cuts off our use of coal and natural gas. I don't think that's what the country wants. I don't think America wants not to be able to use their automobiles.

2.1 Introduction

The sun emits radiation which is known as visible light. Some of this radiation escapes filtering by the atmosphere enroute to heating the earth. Warmed by the sun's rays, the earth reradiates infrared (IR) heat radiation of which only 30% passes through the atmosphere (Blake 1989). Nearly 70% becomes trapped by a blanket of atmospheric gases composed primarily of carbon dioxide, water vapor and trace gases such as methane, nitric oxides and chlorofluorocarbons (See Figure 2.1). A similar radiation trapping and re-radiation process typically occurs in agricultural greenhouses and residential sunrooms. The sun's incoming solar radiation passes through
HEAT TRAPPING in the atmosphere dominates the earth's energy balance. Some 30 percent of incoming solar energy is reflected (left), either from clouds and particles in the atmosphere or from the earth's surface; the remaining 70 percent is absorbed. The absorbed energy is reemitted at infrared wavelengths by the atmosphere (which is also heated by updrafts and cloud formation) and by the surface. Because most of the surface radiation is trapped by clouds and greenhouse gases and returned to the earth, the surface is currently about 33 degrees Celsius warmer than it would be without the trapping.

Figure 2.1 Heat trapping atmospheric gases and the "greenhouse" effect.

Source: (Schneider 1989)
the greenhouse's glass panels. Thermal "heat" radiation, seeking to escape, is instead blocked by the glass panels which effectively contain the heat and raise the temperatures of the enclosed greenhouse environment. This phenomenon is more commonly known as the "greenhouse effect".

The ongoing build-up of natural and man-made gases in the atmosphere is reducing the amount of radiative (heat) energy that passes out through the atmosphere. Most members of the scientific community believe this gas build-up in the atmosphere is responsible for the observed increases in average global temperatures over the last 100 years (MacDonald 1989). A few scientists however, interpret this warming trend as part of a natural climatic cycle marked by long periods of glacial formation, 3-5°C (5-9°F) cooler than today, and warmer inter-glacial melting periods whose peak temperatures have been estimated to be approximately 0.5-1°C (1-2°F) warmer than currently experienced (Hansen et al. 1984). According to these scientists, the interglacial warming we are now experiencing is part of the natural climatic response cycle which is neither accelerated or retarded by man's activities. In order to ascertain the need, if any, for governmental policies and interventions, designed to respond to the impacts associated with sea level rise, Chapter 2 reviews the current literature pertaining to global warming and sea level rise to develop a better understanding of those factors and scientific uncertainties which can affect the rate and magnitude of global climate change and sea level rise that could occur before the next century.
2.2 The Greenhouse Gases and the Global Warming Phenomenon

The earth's atmosphere is composed primarily of nitrogen, oxygen and carbon dioxide. Trace amounts of other gases including methane, ozone and nitrogen oxides are also found in the atmosphere. By far the most important contributor to the "greenhouse effect" is carbon dioxide, accounting for 50-60% of the atmosphere's composition. The other key greenhouse gases are methane (20%), chlorofluorocarbons (15%), nitrous oxide (10%) and ozone (5%) (Blake 1989). The amount of CO2 found in the atmosphere over a period of many decades has helped to support the notion of a causal relationship between the atmospheric accumulation of greenhouse gases and warming trends in the global climate. Analysis of glacial ice core samples, taken from Greenland and Antarctica, revealed the presence of increased amounts of carbon dioxide (CO2) and methane (CH4) corresponding to time periods marked by warmer global temperatures during the earth's interglacial periods (Barnola et al. 1987) (See Figure 2.2). In his description of the scientific information derived from the ice core samples, Stephen Schneider, head of the National Center for Atmospheric Research's climate-systems program in Boulder, CO states that:

During the current interglacial period (the past 10,000 years and the previous one, a 10,000 year period around 130,000 years ago, the ice recorded a local temperature about 10 degrees centigrade warmer than at the height of the ice ages. At the same time, the atmosphere contained about 25 percent more carbon dioxide and 100 percent more methane than during the glacial periods. (Schneider 1989)

More recent studies by Raynaud and Barrola, (1985) and From and Keeling, (1986) have correlated a steady 25-30% increase of atmospheric CO2 with a concomitant rise in mean global
Figure 2.2 Comparison of carbon dioxide levels and air temperature over the last 160,000 years

Source: (Canning et al. 1990)
temperature of 0.5-0.7°C (9.9-1.3°F) for the 100 year period beginning with the advent of the Industrial Revolution around 1850 (Hansen 1989) (See Figure 2.3).

The surge of carbon released to the atmosphere over the last 100 years appears to have disrupted the earth's naturally balanced carbon cycle causing more carbon to be stored in the atmosphere as carbon dioxide (CO2) gas (Woodwell 1989). Currently, the amount of carbon released and stored in the atmosphere continues to increase by 0.4% per year (Cicerone 1989). In addition, atmospheric concentrations of naturally produced trace greenhouse gases, such as methane, as well as those produced by humans, such as chloroflourocarbons (CFC's), have been increasing at an even faster rate than that of CO2. As a result, the "effective doubling" of the 1880's concentration of atmospheric CO2, a doubling of the greenhouse effect due to the combined radiative absorbency of all the greenhouse gases, is expected to occur before the middle of the next century (UNEP/WMO/ICSU, Villach Conference Statement, 1985) (See Figure 2.4).

Increasing atmospheric concentrations of methane are primarily the result of anaerobic decomposition processes naturally occurring in wet soils, marshes and rice paddies. Anthropogenic sources of methane production include the cultivation of rice paddies, cattle production, coal mining and natural gas development (Blake 1989, Schneider 1989). Within the atmosphere, methane competes with other atmospheric gases such as carbon monoxide, produced from forest clearing and fossil fuel burning, for a chemical reacting partner. As the concentrations of atmospheric methane and carbon monoxide continue to increase less opportunity is afforded for methane
Figure 2.3 Comparison of carbon dioxide and temperature since 1860

Source: (Schneider 1989)
## Greenhouse Gases

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<td><strong>Pre-Industrial</strong></td>
<td><strong>1986</strong></td>
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<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>275 ppm</td>
<td>346 ppm</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>0.75 ppm</td>
<td>1.65 ppm</td>
</tr>
<tr>
<td>Fluorocarbon-12 (CCl₂F₂)</td>
<td>Zero</td>
<td>400 ppt</td>
</tr>
<tr>
<td>Fluorocarbon-11 (CCl₃F)</td>
<td>Zero</td>
<td>230 ppt</td>
</tr>
<tr>
<td>Nitrous Oxide (N₂O)</td>
<td>280 ppb</td>
<td>305 ppb</td>
</tr>
<tr>
<td>Ozone, Tropospheric (O₃)</td>
<td>15 ppb</td>
<td>35 ppb</td>
</tr>
</tbody>
</table>

Other Fluorocarbons: Zero, see text

Key greenhouse gases: present concentrations in air, rates of increase, and pre-industrial-era concentrations. Ppm = parts per million, ppb = parts per billion, ppt = parts per trillion.

**Figure 2.4** Increasing atmospheric concentrations of key greenhouse gases

Source: (Cicerone 1989)
to chemically react and be removed from the atmosphere thus prolonging its atmospheric life and exacerbating the greenhouse warming effect (Ciborowski 1989).

By contrast, the production and use of chlorofluorocarbons (CFC's) in propellants and refrigerants, and their subsequent accumulation within the atmosphere, has also been increasing despite recent U.S. environmental regulations and slowdowns in international trade of manufactured products typically containing CFC's (Cunnold et al. 1986). In the lower atmosphere (troposphere), CFC's exhibit a high radiative absorbency. However, if CFC's rise to the atmosphere's outermost stratospheric layer they become chemically reactive and are responsible for the harmful depletion of stratospheric ozone which serves to filter out the most harmful ultraviolet (UV) radiation emitted from the sun (Canning et al. 1990). Atmospheric ozone, a trace greenhouse gas produced photochemically from urban smog, like chlorofluorocarbons, can be extremely effective in absorbing the earth's radiation when present in comparatively small concentrations (Ramnathan 1989).

2.3 Human Activities

Our dependency and increasing use of fossil fuels such as oil, coal, gas and wood for energy production, along with a rapid surge in the destruction of forested land areas for food production, is considered to be primarily responsible for the "anthropogenically" induced increase in concentrations of carbon dioxide found in the earth's atmosphere (MacDonald 1989) (See Figure 2.5). In fact, most of the greenhouse gases affecting climate change are produced directly or indirectly from human activities involving energy production and use and
The rate of production of carbon dioxide by man's activities (after Keeling, 1984). Units are $10^{12}$ g yr$^{-1}$. The major deviations from exponential growth between 1914 and 1945 reflect the effects of the two world wars and the worldwide economic chaos between the wars.

Figure 2.5 Carbon dioxide production by Human activity since 1860

Source: (MacDonald 1989)
industrial manufacturing activities. Keeping in mind that the infrastructures of most countries rely on the use of fossil fuels and their relative cost advantage, there is good reason to believe that increased greenhouse gas emissions over the next few decades is likely to continue. In Russia, for instance, efforts are currently underway to develop the fossil fuel resources contained within its Siberian region. Similarly, China is expected to proceed with economic development plans which rely on the use of coal as the main source of energy (Glantz ed. 1988). In the United States, the consumption of coal is expected to increase by 40% in spite of a recognition that coal produces more greenhouse gases than any other energy source (Abrahamson 1989). In their analysis examining the effects of the immediate implementation of both national and international policy interventions to reduce greenhouse gas emissions, Seidel and Keyes (1983) have shown that the short-term benefits to be derived from such policy interventions would be marginal and certainly not achievable before the year 2050.

The mounting concern for the on-going build up of atmospheric greenhouse gases and the resultant global warming phenomenon has directed a great deal of scientific interest and study towards refining our current understanding of global climatic processes in the hopes of predicting the impacts of increasing atmospheric concentrations of greenhouse gases on future global climate patterns.

2.4 Modeling Climate Change and Climatic Uncertainties

Nearly all of the scientific studies of the greenhouse effect and global climate change rely on the use of large scale, computerized general circulation climate models (GCM's), which are based upon a logically hypothesized "cause and effect" understanding of natural climatic processes.
Although a large majority of the scientific community supports the range of future global warming projections, (1.5-4.5°C) developed from these climate models, members of the climate modeling community acknowledge the very real possibility that the behavior of climate and climatic processes, unlike the logical description used in climate modeling analyses, may be a function of random and chaotic events (Fisher 1989).

The reliability of climate modeling is therefore limited by our own incomplete understanding of the complexities pertaining to natural climatic processes. Consequently, only those aspects of global climatic processes that are relatively well-understood and quantifiable under current climate theory are incorporated into the computerized GCM's and current global climate research. In addition, important climatic processes such as precipitation, turbulence and cloud formation, too small to be measured at the large, (500 kilometer geographic grid) scale for which these computer models currently operate, have been left out of current global climate modeling efforts (Schneider 1989). It is not yet clearly understood whether the absence of these climate factors has an important affect on the accuracy of global climate modeling results.

The predictive accuracy of climate models and global climate simulation studies is also limited by the uncertainties associated with temperature sensitive "positive climatic feedbacks". Warmer global air temperatures can trigger temperature sensitive feedbacks which scientists believe could produce additional greenhouse gases as well as additional increases in global air temperatures (Schneider 1989, Graedel and Crutzen 1989, Abrahamsson ed. 1989). Warmer air temperatures can increase the production of "greenhouse" gases from such natural processes as anaerobic decomposition and plant respiration and effectively increase global air
temperatures (Abrahamson ed. 1989, Schneider 1989, Canning et al. 1990). Warmer global air temperatures could also trigger the additional release of an unquantifiable amount of carbon, stored in ocean water, and methane found in ocean shelf sediments (Cicerone 1989).

The role of ocean bodies in cycling carbon and stabilizing global temperature changes and the importance of clouds in absorbing or reflecting, warming or cooling, global air temperatures, are perhaps the most important and most controversial temperature sensitive feedbacks that could be triggered by increased global temperatures.

The ocean's ability to absorb large concentrations of carbon dioxide (CO2) is regulated by a temperature-sensitive mixing process whereupon carbon enters the ocean's warm upper surface layer and circulates to higher latitudes where it cools and sinks to mix with deep, CO2 saturated, colder seawater. The concentration of carbon in the ocean's deeper water layer is 50 times greater than the atmosphere's and 20 times greater than that which is stored in the biosphere (Takahashi 1989). The warmer and less concentrated ocean surface layer serves as a cap preventing the more saturated deep ocean water from releasing carbon to the atmosphere (Takahashi 1989). An increased warming of the earth's climate could alter the existing patterns of ocean circulation and mixing subsequently releasing additional amounts of carbon into the atmosphere and further exacerbating the greenhouse effect. According to Professor Carl Wunsch of the Department of Earth, Atmospheric and Planetary Sciences at MIT, however, our current scientific understanding of the ocean circulation patterns is still too primitive to be included in global climate modeling studies (1990).
The ocean also serves as a "heat sink" which could delay, for a period of decades or longer, the global warming effect which the earth would be "committed" to from a corresponding increase of greenhouse gases in the atmosphere (MacDonald 1989, Thomas 1986, Dean 1987, Barth and Titus eds. 1984). If the thermal "heat" energy is only absorbed within the ocean's upper surface layer, the anticipated warming could be realized within a period of decades. Should the ocean's deeper waters receive such thermal lag energy the additional global warming could be delayed by a century or more (Thomas 1986). As a result of ocean thermal storage capacity, the actual response to an increase of atmospheric CO2 and its corresponding warming commitment of 1°C is .7°C plus or minus .2°C (Hoffert and Flannery 1985). The additional thermal lag warming is thought to be cumulative and unavoidable and according to Ciborowski (1989), will compound future increases to global equilibrium temperatures to which the earth continues to be committed to as a result of the ongoing production of greenhouse gases. More specifically, Ciborowski explains that:

Emissions prior to 1985 have committed us to a warming of about 0.9°C-2.5°C of which we have already experienced about half a degree. The warming that we have yet to experience is the unrealized warming. This warming 0.3 to 1.9°C is unavoidable. (Ciborowski 1989)

When the reserve of ocean "thermal lag" heating will be released is still unknown. However, it is not altogether unlikely that this additional thermal lag heating could be realized in the short term, over the next 10 years, rather than the longer time periods currently contemplated in global climate modeling scenarios (Wunsch 1990).

The role of clouds is perhaps the most important and most debated factor of uncertainty affecting the process of global warming. The possible increase in cloud formation as a
feedback response to increasing global air temperatures, and the impact of clouds on the global warming phenomenon, continues to generate a fair amount of scientific concern and debate. Most experts believe that the amount of water vapor in the lower atmosphere will increase as the earth's temperatures continue to rise. According to Hansen et al. (1981), the warmer air temperatures created by increased concentrations of CO2, will cause the atmosphere to retain more moisture. Water vapor in the atmosphere is extremely effective at trapping heat and behaves very much like a greenhouse gas. An effective doubling of atmospheric CO2 could increase the atmosphere's water vapor content by 30% and may cause global temperatures to rise by as much as 1.4°C (2.5°F) (Barth and Titus eds. 1984). Increases in atmospheric water vapor could effectively create a cyclical "positive feedback" causing more water vapor to accumulate in the atmosphere resulting in subsequently more global warming (See Figure 2.6).

In contrast, some experts believe that general circulation climate models, as with our incomplete understanding of ocean circulation behavior, do not convincingly forecast the behavior of clouds to climate change. According to Lindzen (1990), small increases in global air temperature could increase the formation of particular types of clouds and cloud cover. The increased cloud cover could act to reflect more of the sun's radiation away from the earth's atmosphere resulting in a net cooling effect. (Lindzen 1990, Wunsch 1990). Subsequently, the inability to accurately quantify the effects of these extremely important positive climate feedbacks has resulted in a rather large range (1-4.5°C) of currently accepted global warming predictions and may prompt the reconstruction of current global circulation models (Titus 1984, Lindzen 1990). Nevertheless, most of the scientific community is currently in agreement as to the existence of a
Figure 2.6 Estimated global warming due to doubling of greenhouse gases: direct effects and positive feedbacks

Source: Adapted from Hansen et al. 1984 In: Greenhouse Effect and Sea Level Rise: A Challenge for this Generation, Barth and Titus eds.
current global warming trend and concur with the current range of projected increases in average global temperature developed with general circulation computer models. Such was the sentiment recently expressed by atmospheric scientists and global warming experts during an international global warming conference. The concluding summary statement for this conference read in part:

The accelerating increase in concentrations of greenhouse gases in the atmosphere, if continued, will probably result in a rise in the mean surface temperature of the earth of 1.5 to 4.5°C before the middle of the next century.


2.5 Projections of Future Global Warming

Over the last 100 years, the concentration of CO2 in the atmosphere has increased by nearly 30% (Dickinson and Cicerone 1986). Current worldwide energy use in industrial and agricultural production continues to increase the annual atmospheric concentration of CO2 by .4% (Ramanathan 1989). At this rate, the 1880 atmospheric concentration of greenhouse gases (290 ppm) is expected to effectively double long before the end of the next century (Ciborowski 1989). According to the results of the best available climate modeling simulations, a 25-30% increase of atmospheric CO2 is thought to have already committed the earth to a global warming of 0.8-2.4°C (1.44-4.32°F) (Dickinson and Cicerone, 1986). As shown in Table 2.1, the increased global warming actually observed for the past 100 years is 0.5-0.7°C (0.9-1.26°F) (Hansen and Lebedeff 1987, 1988). As a result, an additional and allegedly unavoidable global warming of 0.3-1.7°C (.54-3.06°F) from ocean thermal lag could be realized within the next 10-50 years (Ciborowski 1989).
Table 2.1

Global Warming Projections for the Year 2050

<table>
<thead>
<tr>
<th>1880-1989</th>
<th>1990-2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ATMOSPHERIC CO2 (ppm)</strong></td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>580-600</td>
</tr>
<tr>
<td><strong>TEMPERATURE INCREASE (°C)</strong></td>
<td></td>
</tr>
<tr>
<td>Committed</td>
<td>0.8-2.4</td>
</tr>
<tr>
<td>Observed</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Thermal Lag</td>
<td>0.3-1.7</td>
</tr>
</tbody>
</table>

(*) includes: 1880-1989 Observed 0.5-0.7°C
Thermal lag 0.3-1.7°C
1990-2050 Observed 0.8-2.1°C

Sources: (Cicerone 1989, Ciborowski 1989, Ramanathan 1989)

The ongoing use of fossil fuels worldwide commits the earth to an estimated global temperature increase of 0.2-0.5°C (0.4-0.9°F) per decade (Ramanathan 1989). As illustrated in Table 2.1, a doubling of the atmospheric concentration of greenhouse gases, buffered by the ocean's thermal inertia, could result in an observed increase in average global temperatures of 1.2-3.0°C (2.16-5.4°F). Coupled with the 1880-1980 residual ocean thermal warming of 0.3-1.7°C (0.54-3.06°F), these estimates indicate that a total global warming increase of 1.5-4.5°C (2.7-8.5°F) could be observed before 2050.
2.6 Global Warming and Rising Sea Levels

Global air temperatures have increased by 1°F over the last 100 years. The potential for further increases in global air temperatures has prompted serious concern for the possible environmental impacts likely to result from warmer climates, most notably, a significant rise in global sea levels. Warmer air temperatures could contribute to rising sea levels in two ways; by warming and expanding the upper layers of ocean waters and by melting glacial ice (Dean 1987) (See Figure 2.7).

2.6.1 Snow and Ice Contributions

Natural changes in sea level occur in cycles in response to cyclical changes in the tilt of the earth's axis and natural changes in global climate (Barth et al. ed. 1984). Historically, sea levels have been relatively low during ice age periods in which sea water was frozen in land based glacial formations. The level of the ocean rose during the warmer interglacial periods due to glacial melt and the natural process of expansion that water undergoes when heated. Currently, increasing air temperatures could cause an increase in the melting of glaciers, small floating ice caps and the Greenland ice sheet. Should global warming effectively increase the temperatures of the southern ocean's waters both the East and West Antarctic ice shelves could experience significant below-surface melting.

During the peak of the most recent Wisconsin glacial period, (12,000-20,000 years ago) a sheet of snow and ice covered a large portion of the United States, including all of New England, extending as far south as Long Island (Aubrey 1989) (See Figure 2.8). The Wisconsin period was marked by global
Figure 2.7 Global temperature increase and sea level rise

temperatures averaging 3-5°C colder than today and average
sea levels nearly 400 ft below today’s (Strahler 1966). 
Approximately 12,000 years ago the interglacial period’s 
warming cycle began melting glaciers, releasing huge amounts 
of water, and raising the sea level at the rate of 5 ft per 
century (Aubrey 1989). Over the most recent 5000 year period 
sea level rise throughout the world has proceeded at the rate 
of approximately 1 ft per century.

As illustrated in Table 2.2, a global warming of 1.5-4.5°C 
(2.7-8.5°F) could increase sea level rise from glacier and 
small ice cap melting 8-25 cm by the year 2100 (Meier 1984). 
The Greenland ice-sheet, under such a global warming scenario, 
would contribute an additional 10 cm to sea level rise (Meier 
et al. 1985) (See Figure 2.9).

**Table 2.2**

<table>
<thead>
<tr>
<th>Potential Contribution of Snow and Ice to Sea Level Rise by the Year 2100 (centimeters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Alp</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>NAS (1983)</td>
</tr>
<tr>
<td>EPA (1983)</td>
</tr>
<tr>
<td>NAS (1985)</td>
</tr>
<tr>
<td>Hoffman (1986)</td>
</tr>
</tbody>
</table>

Sources: (Hoffman et al. 1983, Dean 1987)

The future impacts of global warming on the Antarctica ice- 
sheet are less certain. A sea level rise of approximately 4- 
6 inches over the last 100 years has been attributed in part 
(2 in.) to the warming and expansion of the ocean’s upper 
layers (Gornitz 1982) in addition to a 2-4 inch sea level rise
Figure 2.8  Extent of glacial ice covering during Wisconsin glacial period

Source: (Aubrey 1990)
Figure 2.9  Estimated contributions of snow and ice to sea level rise during the next century

Source: (Thomas 1986)
contribution from glacial snow and ice melting (Meier 1984). Studies by (Jacobs 1985) have shown that a global warming could alter the circulation and mixing patterns of the southern oceans. As a result, the deep seawater of the southern oceans would become warmer increasing the subsurface melting of the Antarctic ice sheet. The estimated sea level rise contribution from the subsurface melting of the Antarctic ice sheet is 20-80 cm by 2100 (Thomas 1986).

2.6.2 Thermal Expansion of Oceans

The temperature of the oceans' upper surface, 100 meters, layer will increase in direct response to increases in global air temperature. Based on an effective average global warming of 3°C by 2050, Hoffman et al. (1985) estimate the sea level rise contribution from the expansion of ocean water to be 30 centimeters. Sea level could therefore rise up to 1 meter by the year 2100 solely from the warming and expansion of the oceans' upper layers (Barth et al. ed. 1984). Warming of the deep cooler ocean waters, on the other hand, is believed to take place very slowly (Charney 1979). Should the heat from warmer air temperatures be carried, by the oceans' circulation patterns, to the deeper and more dense ocean waters, however, sea levels could rise significantly more than currently anticipated (Wunsch 1990).

2.7 Modeling Sea Level Rise

Estimates of future sea level rise are based on the previously described range of scientifically modeled global warming projections and the response of ocean bodies and glacial land formations to such temperature changes. As in the discussion of climate modeling and global warming
predictions, the ability to predict future sea level rise is complicated by the uncertainties concerning the indirect "feedbacks" affecting sea levels which could be triggered by increasing global air temperatures. The global warming feedbacks of particular importance to sea level rise experts are those which could significantly impact polar temperatures and ocean circulation patterns.

2.7.1 Water Vapor, Polar Amplification, and Albedo

There is a general consensus among the scientific and climate modeling communities which holds that areas located in the highest latitudes will experience the greatest change. This "polar amplification" effect could increase polar temperatures two to three times the earth's average increase (Manabe 1983, Hansen 1989). A global warming of 1.5-4.5°C could cause the melting of existing snow covers on land and floating ice throughout the earth's polar regions. The loss of significant amounts of snow and ice cover could then reduce the earth's ability to reflect sunlight and subsequently warm the earth's temperature and the air temperatures surrounding the earth an additional 0.4°C (Hansen et al. 1984).

As average air temperatures increase throughout the world, the atmosphere's ability to retain moisture in the form of water vapor increases. Because water vapor is an extremely effective absorber of infrared radiation (McDonald 1989) a doubling of atmospheric CO2 could increase the water vapor content of the atmosphere by 30% and effectively increase global temperatures by 1.4°C (Hansen et al. 1984). The National Academy of Science's Polar Board (Meier et al. 1985) concluded that a 3°C increase in average global temperatures could either induce a significant amount of sub-surface glacial melting, resulting in a rise in sea level of up to 30
...centimeters by the year 2100, or increase the precipitation and snowfall over Antarctica, increasing the size of the ice sheet, and effectively reducing the amount of sea level rise. More recent studies however, support the notion that, contrary to melting and contributing to sea level rise, Antarctica's ice sheet would grow larger, receiving additional snowfall from warmer, moisture laden polar air, thus diminishing the glacial melt contribution to sea level rise by approximately 30 cm (12 in.) (Meier 1990) (See Figure 2.10).

Using the best available scientific information at the time, Hoffman et al., (1983) and the United States Environmental Protection Agency (EPA) undertook efforts to develop a scientifically plausible range of future global sea level rise predictions based upon the previously described range (1.5-4.5°C) of global warming modeling projections. Hoffman's original predictions contained 4 sea level rise estimates or scenarios, (High, Mid-range High, Mid-range Low and Low), ranging from a high of 3.5 meters to a low of .5 meter for the year 2100 (Hoffman et al., 1983). Within one year of its development additional information became available from new glacial process models (NRC 1985b) along with new atmospheric concentration data (Ramanathan et al., 1985) prompting the EPA to develop a more definitive High - Low revision of its original sea level rise scenarios (Hoffman et al. 1986). For the purposes of this thesis I have added a Medium estimate of sea level rise to EPA's sea level rise scenarios as illustrated in Table 2.1 below. The use of a Medium scenario, developed by linearly interpolating the arithmetic average of Hoffman's High and Low estimates, addresses the need for a more moderate, mid-range sea level rise prediction which could be considered neither too liberal or too conservative. A
Figure 2.10  Total estimated sea level rise during the next century

Source: (Thomas 1986)
Medium sea level rise scenario also provides an additional opportunity for comparing the relative sensitivity of local environmental impacts to particular sea levels elevations.

**Table 2.3**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2000</th>
<th>2025</th>
<th>2050</th>
<th>2075</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (1986)</td>
<td>5.5</td>
<td>21.0</td>
<td>55.0</td>
<td>191.0</td>
<td>358</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(8)</td>
<td>(22)</td>
<td>(76)</td>
<td>(143)</td>
</tr>
<tr>
<td>Medium (Avg)</td>
<td>4.5</td>
<td>15.5</td>
<td>37.5</td>
<td>113.5</td>
<td>207</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(6)</td>
<td>(15)</td>
<td>(46)</td>
<td>(83)</td>
</tr>
<tr>
<td>Low (1986)</td>
<td>3.5</td>
<td>10.0</td>
<td>20.0</td>
<td>36.0</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(4)</td>
<td>(8)</td>
<td>(14)</td>
<td>(22)</td>
</tr>
</tbody>
</table>

Sources: (Hoffman et al. 1983, Giese et al. 1987, Dean 1987)

In addition to the thermal expansion of surface ocean waters and melting of land based glacier ice forms, naturally occurring vertical land movements, "uplifting" and "subsidence", in particular coastal areas can diminish or further exacerbate the predicted sea level rise increases as well as their corresponding impacts (Boesch 1982, Hoffman 1984). Relative mean sea level rise is defined as the difference between the global change in sea level and the vertical changes in local land levels which result from a particular land area's response, "rebounding", to the retreat of previously existing glacial formations (Barth et al. ed. 1984). Local subsidence of land surfaces can occur naturally in response to pressures previously exerted by retreating glaciers or can occur as a result of such human activities as structural loading or extraction of groundwater, oil or gas. Individual geographic areas of the United States experience
subsidence or uplifting depending upon their particular glaciogeologic history (Dean 1987) (See Figure 2.11).

According to Giese et al. (1987), the coastal land areas of Massachusetts have been subsiding at a rate of 1.9 mm/yr (0.08 in/yr) at the same time that the average sea level has been increasing at a rate of 1mm/yr (0.04 in/yr). As shown in Table 2.5, coastal Massachusetts has experienced a relative sea level rise of nearly three inches over a period of 25 years.

Table 2.4

<table>
<thead>
<tr>
<th>Factor</th>
<th>Increase (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidence</td>
<td>1.9</td>
</tr>
<tr>
<td>Historical SLR</td>
<td>1.0</td>
</tr>
<tr>
<td>TOTAL Relative SLR</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Source: (Giese et al. 1987)

The additive contribution of local subsidence to sea level rise, as illustrated in Table 2.5, can be significant. For example, a local land subsidence of .2 cm/yr (.08 in/yr), currently experienced throughout coastal Cape Cod Massachusetts, would amount to nearly 25% of the global warming-related 8" sea level rise increase predicted for the year 2050 under the Low sea level rise scenario.
Figure 2.11 Estimated local relative sea level rise changes along the U.S. continental coastline

Source: (Dean 1987)
Table 2.5

Total Sea Level Rise Scenarios for Coastal Massachusetts by the Year 2100 (centimeters (inches))

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2000</th>
<th>2025</th>
<th>2050</th>
<th>2075</th>
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<td>56</td>
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<tr>
<td></td>
<td>(1)</td>
<td>(4)</td>
<td>(8)</td>
<td>(14)</td>
<td>(22)</td>
</tr>
</tbody>
</table>

Subsidence (MA) 2.0 7.0 12.0 17.0 22.0
(.84) (2.8) (4.8) (6.8) (8.8)

TOTAL SLR (MA) 5.5-7.5 17-28 32-67 53-208 78-380
(2-3) (7-11) (13-27) (21-83) (31-152)

Sources: (Hoffman et al. 1983, Giese et al. 1987, Dean 1987)

2.8 Conclusion

Although the cause(s) of the present global warming trend are currently being debated and the severity and rate of such climate warming remains relatively uncertain, most scientists and climate experts agree that a warming is under way. In fact, when recently pressed for a forecast of the probability of a 4°F (2.2°C) increase in global temperatures by the year 2100, leading atmospheric scientists and global warming experts, skeptics and proponents of the global warming phenomenon, found agreement in a relatively high (80-90%) probability for the occurrence of such a future warming scenario (Dumanoski 1990).

Implicit within the range of currently accepted global warming projections is the acknowledgement that global air
temperatures have been increasing and will more than likely become warmer than they are today. For the most part, the greenhouse effect/global warming debate is centered around questions pertaining to the causes of this warming and the existing temperature-sensitive uncertainties which could significantly increase the effective rate and magnitude of global warming to be faced by this and future generations. The uncertainties pertaining to the role of ocean bodies as an additional source of atmospheric CO2 and latent "thermal lag" heat coupled with the controversial role of clouds and cloud formation in decreasing or increasing global warming has led to the development of a controversally broad range, \(1.5-4.5^\circ C\) (\(2.7 - 8.46^\circ F\)), of future global warming scenarios.

The results of ongoing coastal monitoring experiments and global climate studies are expected to provide a significant amount of information and clarity to these uncertainties over the next 10-20 years (Wunsch 1990). It is also acknowledged however, that the findings of such ongoing experiments and studies may only help to refine our understanding of ocean bodies and climate processes for the period covering the time of their observation and study.

If the observed climatic processes are the results of chaotic and non-predictable behavior then we could be faced with nearly the same amount of uncertainty concerning future climate change that we are confronted with today. Natural changes in sea level, like changes in global climate, continue to occur in cycles whose time periods are characterized by many thousands of years. Over such long time periods sea levels and their inland shoreline boundaries will naturally fluctuate hundreds of feet. Over the past 100 years, while the earth's air temperature has increased by \(.5^\circ C\) (\(1^\circ F\)), sea levels
have risen approximately one foot. The rate and magnitude of sea level rise however, could be accelerated by the continued buildup of greenhouse gases in the atmosphere.

Clearly, an overwhelming consensus appears to support the notion that warmer global air temperatures and rising sea levels are not going to disappear in the near future. Similarly, the environmental changes and impacts which could occur under the current range of global warming predictions and sea level rise scenarios pose significant risks for particular coastal land areas and developed coastal communities which are also unlikely to disappear within the near future. The development of large population centers have been located in and along coastal areas which may have once been submerged beneath the ocean floor, and may now be vulnerable to sea levels which are once again rising.

For many coastal developments a sea level rise scenario of 1-2 feet within the next 50-60 years could have serious environmental consequences involving increased erosion, flood damage and elevated groundwater tables which could undermine a coastal community's safety, health and general welfare. Using a range of sea level rise scenarios, (illustrated in Table 2.5) for the year 2050, Chapter 3 examines the environmental changes and potential impacts of sea level rise to the coastal groundwater resources and drinking water supplies of particularly vulnerable coastal land areas and populated settlements.
CHAPTER 3
SEA LEVEL RISE AND COASTAL GROUNDWATER RESOURCES

...governments at all levels should reexamine the technical features of water systems and the economic and legal aspects of water supply management in order to increase the system's efficiency and flexibility.

3.1 Introduction

For many coastal municipalities and land owners the potential loss of existing property as well as future land use opportunities resulting from sea level rise could be significant. The predicted range of increases in sea level could have both direct and indirect environmental impacts for coastal areas including: erosion, flooding, saltwater intrusion and raised groundwater tables. This chapter will specifically examine how sea level rise could cause the local groundwater's table in coastal areas to rise close to the land surface and existing on-site septic systems. Under such a scenario, existing on-site septic systems could fail to prevent bacteria and virus, found in domestic wastewater, from reaching the groundwater table and thereby increase the risk of biological contamination to local subsurface drinking water supplies.

To date, numerous studies conducted on the impacts of sea level rise have focused on the concerns for wetland loss (Kana et al. 1986, Gagliano et al. 1983, Titus ed. 1986), lowland inundation (Kana et al. 1984, Leatherman 1984, Schneider and
Chen 1980), coastal erosion (Bruun 1962, Kana et al. 1984, Dean and Maurmeyer 1983), flooding and storm damage (Barth and Titus 1984, Kana et al. 1984, Leatherman 1984) and saltwater migration (Titus 1986, Hull et al. 1986, Leatherman 1984, Kana et al. 1984). Few research efforts or field studies however, have been undertaken to address questions and concerns pertaining to the impacts of rising sea levels on coastal groundwater resources and local drinking water supplies (Titus 1986). As described by Giese and Aubrey (1987), the water table level in coastal land areas where the terrain consists of unconsolidated sediments is controlled by relative sea level rise. As sea level rises, the water table level will also rise.

A large portion of the world's population lives in coastal zone areas where average land elevations are less than 10 feet above the shoreline (Dean 1987). In the United States, the physical and environmental impacts from sea level rise will vary in magnitude and severity along various portions of the country's coastline, depending on such site-specific conditions as sediment type and topography (Leatherman 1988). The Gulf of Mexico and Atlantic coastal regions, comprised of unconsolidated and extremely permeable soil sediments and characterized by low (5-10 feet above sea level) gently sloping coastal plains, stand to suffer the most severe impacts from even a small rise in sea levels (Barth and Titus, eds. 1984) (See Figure 3.1). As evidence of their vulnerability, the effects of numerous hurricanes have cost the federal government and state governments and taxpayers along the Gulf and Atlantic coasts between $50 million and $2.3 billion in damage since 1938 (NRDC 1980). The drinking water in many coastal communities is obtained from underground
Figure 3.1 Types of coastal barrier land formations along Atlantic and Gulf of Mexico coastlines

Source: (Leatherman 1988)
freshwater aquifers. For those communities relying on groundwater aquifers as their "sole source" supply of drinking water, a rise in sea level could have serious implications.

3.2 The Sole Source Aquifer

The sole source of potable water for many coastal communities located along the Atlantic coastline is a freshwater aquifer stored, in many cases, in glacial sediment deposits which formed as a result of the last glacial retreat nearly 14,000 - 15,000 years ago (Dean 1987). An aquifer is defined as a geologic formation which contains water and permits a significant amount of water to move through it (Baer 1979).

The highly permeable nature of glacial sediments also renders the groundwater resources contained within them highly susceptible to contamination. The coarse to fine grained sandy soils which make up a large portion of the coastal land areas, including barrier islands, are low in organic content and have a poor capacity for attenuating contaminants by sorption and ion exchange.

In addition, many of these areas are characterized as having shallow depths to groundwater, so contaminants do not have far to travel before they reach local freshwater aquifers and groundwater resources (Leatherman 1988, LeBlanc 1990). The flow of groundwater through the aquifer is determined by the local groundwater elevation and the capacity of sub-surface soils to transmit water, called "hydraulic conductivity". In unconfined aquifers, groundwater will move horizontally from high to low water table elevations perpendicular to the land area's predominant topographic contours and eventually
discharge to the aquifer's outer boundaries. On Cape Cod, for example, groundwater flows slowly (1 ft/day), and reflects the area's fairly flat topography (Janick 1987). Like that of many Atlantic and Gulf coast areas and barrier islands, the coarse sands and gravels comprising a large part of the Cape's land area have a high hydraulic conductivity which provides for rapid movement of water down into the aquifer (LeBlanc et al. 1986).

In an unconfined aquifer, the upper boundary is the water table which receives recharge from the land surface located directly above it. Typically, the freshwater aquifer boundaries for most coastal land areas located along the Atlantic and Gulf coast regions, are comprised of the water table (upper boundary), surrounding surface water bodies (lateral boundaries), and bedrock (lower boundary). For the Cape Cod region, the aquifer is made up of a bubble or "lens" of freshwater which floats on top of more dense saltwater. The lower boundaries for floating lens aquifers are completely underlain by salt water. This fresh water/salt water interface is characterized as a zone of brackish water created by the mixing of fresh and salt waters (Cooper et al. 1964) (See Figure 3.2a). The position of this interface is determined in large part by the elevations of both fresh and saltwater, and remains relatively stationary once a stationary elevation is reached between the saltwater and the freshwater flowing out from the aquifer (Bear 1979).

Consequently, groundwater levels naturally fluctuate, recording their lowest elevations in summer, when evaporation and transpiration rates are high, and their highest elevations in early spring following the melting of snow and ice (Frimpter and Fisher 1983). When the groundwater table becomes lower, due to excessive pumping and/or low precipitation
Figure 3.2(a) Cross-section of floating lens aquifer showing saltwater/freshwater interface
Source: (CCAMP 1988)

Figure 3.2(b) Cross-section of floating lens aquifer showing movement of saltwater/freshwater interface and saltwater intrusion into drinking water well.
Source: (CCAMP 1988)
recharge, the fresh water/salt water interface could slowly move inland. If, on the other hand, the groundwater table rises, in response to periods of high precipitation and minimal discharge, the interface boundary will move slowly seaward (Bear 1979). Typically, an unconfined coastal aquifer naturally discharges groundwater by subsurface outflows along aquifer boundaries to such surface water bodies as springs, marshes, bays and the ocean and via direct evaporation from the water table. In addition, a considerable amount of groundwater is also discharged through pumping of public and private water supply wells (See Figure 3.3).

Aquifers are recharged naturally from precipitation and artificially from wastewater which enters from the leaching beds of on-site residential septic systems. During periods of seasonally high precipitation, accompanied by increased aquifer recharge, the elevation of local groundwater tables will rise as much as 2 feet above the local groundwater table's average elevation. A raised groundwater table, caused by sea level rise, could establish a new groundwater table elevation upon which such seasonal fluctuations in groundwater table elevations would be added. Consequently, the impacts of a 2 foot sea level rise, coupled with seasonal fluctuations in groundwater table elevations, could cause the elevation of local coastal groundwater tables to rise by as much as 4 feet primarily during periods of high rainfall and cooler temperatures.
Figure 3.3  Cross-section of freshwater aquifer showing natural aquifer recharge and discharge.

Source: (CCAMP 1988)
3.3 Physical and Environmental Impacts of Sea Level Rise on Coastal Aquifers and Groundwater Resources

The physical and environmental impacts to coastal aquifers and groundwater resources which could be sustained from rising sea levels raise serious health and safety concerns pertaining to the contamination of coastal groundwater resources and drinking water supplies from saltwater intrusion and on-site septic system failure.

3.3.1 Inland migration of saltwater boundaries

A marked rise in sea level will submerge and/or erode existing shorelines and establish new shorelines further upland. This "shoreline migration" is an important factor in determining the location of the aquifer's freshwater/saltwater interface in response to sea level rise and the new shoreline location (Kana et al. 1984). Exactly how far the shoreline will retreat will be determined by the magnitude of sea level rise and its impacts on local coastal inundation and erosion. Over the last 100 years approximately 25% (20,500 miles) of the ocean and lake shorelines in the United States have suffered from erosion (US Army Corps of Engineers 1971). According to May et al. (1983), the annual rates of coastal erosion for the Atlantic and Gulf coast states, .8m/yr and 1.8m/yr respectively, exceeds the national average of 0.4m/yr. Using an average of one meter of shoreline erosion for each centimeter of sea level rise, a one foot or 10-20 centimeters sea level rise would cause the shoreline to erode and migrate 10-20 meters, (33-66 feet), further inland (Goldschalk et al. 1989). A sea level rise scenario of 14 inches by the year 2050
therefore, could seriously increase the rate of shoreline erosion so that the erosion loss by the year 2050 could be much more than 120 ft.

The location of the interface can be estimated based on the thickness of the water table at a specific point (Herzberg 1961). As a rule of thumb, the depth of the interface at any point along an unconfined aquifer is 40 times the height of the water table at that same point (See Figure 3.4). A rise in sea level could cause a significant inland migration of the shoreline and the inland movement of the freshwater/saltwater interface's horizontal boundary. This horizontal movement of the interface could bring brackish and salt water precariously closer to drinking water supply wells and could increase the likelihood of saltwater contamination in many existing private drinking water supplies located closest to saltwater bodies (See Figure 3.2b).

3.3.2 Raised groundwater tables

Fresh water coastal aquifers are said to "float" on top of underlying salt water because they are comparatively less dense (fresh water= 1.000 gm/cm³, salt water= 1.025 gm/cm³) than salt water (Bear 1979). A rising sea level could therefore, force unconfined coastal aquifers and groundwater tables upward (Dean 1987). According to some experts, the groundwater table level will shift upward in proportion to the amount of sea level rise and landward in proportion to the shoreline retreat (Kana et al. 1984, Thompson 1990, Kana 1990, Geise 1990).
Figure 3.4  Thickness of groundwater lens as a function of groundwater table elevation

Source: (Janik 1987)
For unconfined aquifers characterized as a "lens of freshwater floating atop denser saltwater" a rise in sea level will raise the freshwater lens resting upon it upward through highly permeable sandy sub-soils commensurate with the amount of sea level rise (LeBlanc 1990). Concurring with this "one-to-one" correlation between sea level rise and groundwater table rise, the National Research Council's Committee on Engineering Implications of Changes in Relative Mean Sea Level has stated that the lens of freshwater:

...should simply float in the salt water at an elevation that is higher by the amount of sea level rise (Dean 1987).

Other experts, such as Professor Lynn Gelhar of MIT's Department of Civil Engineering however, argue that an increase in groundwater levels due to sea level rise could cause an increase in both local coastal inundation and erosion and an increase in the natural drainage of groundwater to existing surface water bodies such as ponds, rivers and streams (Gelhar 1990). As a result, local groundwater tables would rise in an amount somewhat less than the total rise in sea level. A marked rise in sea level could also significantly inundate and/or erode extremely low lying coastal land areas thereby decreasing their available recharge areas. A smaller recharge area would cause less precipitation to be captured and reach the groundwater aquifer, thus diminishing any effective subsequent rise in the groundwater table anticipated from sea level rise.

Along with increased inundation, erosion and drainage, the groundwater table's ability to concomitantly rise in an amount equal to that of sea level could be further complicated by the possible existence of less permeable layers of silts and clays within the subsurface sediment. These silts and clays would act to dampen, and in some cases, confine and prohibit the
freshwater lens from rising in association with sea level rise. In contrast, for some coastal land forms a significant rise in sea level accompanied by unchanged precipitation patterns could cause the groundwater table to "mound" in specific areas, resulting in increases to the local groundwater table elevations greater than that of sea level rise (Leatherman 1990, Thompson 1990).

For the purposes of this thesis research, it has been assumed that the elevation of unconfined "floating lens" freshwater aquifers will increase in a direct one to one proportion to increases in sea level. As a result, rising sea levels will cause a equal rise in groundwater tables and subsequently decrease the distance between the bottom of on-site septic system's leaching beds and the groundwater table (IEP, Inc. 1989). Keeping in mind that the unsaturated distance existing between on-site septic systems and local groundwater tables provides the necessary aerobic conditions for filtering harmful biological contaminants (LeGrand 1972), the prospect of a future rise of local groundwater tables raises serious concerns for the future quality of coastal groundwater resources and local drinking water supplies not to mention the health and safety of those coastal populations who rely on these resources. The particular land use policy implications pertaining to this impact will be discussed in Chapter 5.

3.4 Biological Contamination of Groundwater Aquifers

Many coastal communities throughout the country rely on untreated ground water from unconfined aquifers as their sole source of drinking water. In Massachusetts, where one third of the state's population relies on local groundwater resources to meet their freshwater demands, untreated
groundwater from private wells serves the drinking water needs for more than 400,000 individuals (Roy 1987). Adverse health effects from biological contamination have been closely associated with untreated groundwater supplies. Populations serviced by untreated groundwater have experienced nearly 4 times as many cases of biological contamination related illness than populations serviced by treated groundwater supplies (Mlay and Dee 1987).

Biological contaminants in groundwater such as bacteria viruses and parasites are known to cause gastrointestinal and viral outbreaks including; tuberculosis, typhoid fever, dysentery, cholera and infectious hepatitis (Mlay and Dee 1987). Cases of such illness are increasing annually and currently account for 28% of all reported water-borne diseases (Mlay and Dee 1987). As early as 1974, the Center for Disease Control in Atlanta Georgia reported a causal relationship between outbreaks of gastroenteritis and hepatitis and the consumption of biologically contaminated water. Studies by Gerba et al. (1985) have documented the enhanced survivability and movement of infectious pathogens in groundwater. Many members of the scientific community believe that a minimum effective dose of as few as 10 bacteria (Grimes 1986), or 2 infectious virus units (Hurst 1990), can cause infection and illness to humans. Interestingly, the risk of pathogenic infection and illness may be even greater for temporary visitors who consume untreated water resources than for the local resident. According to Dr. Christon Hurst of the US Environmental Protection Agency's Health Effects and Research Laboratory in Cincinnati, Ohio, local residents, by virtue of their continued exposure to the waterborne bacteria and viruses found in their groundwater resources, can develop tolerances to bacteria and viruses which might be commonly found in their groundwater (Hurst 1990). Visitors and tourists
staying in areas primarily serviced by on-site septic tank systems and individual untreated drinking water wells would not enjoy the benefits of such "tolerance" and therefore would be more susceptible to pathogenic illness caused by drinking local well water.

3.4.1 On-site Septic Systems and Groundwater Contamination

Private drinking water supplies drawn from unconfined aquifers are susceptible to various types of biological contamination, including bacteria and viruses and nitrates, from domestic on-site septic system leachate which is finally disposed of by flowing into the ground. In many instances these same coastal communities are without public sewer and thus depend on the use of conventional on-site sub-surface disposal systems to effectively treat their wastes. According to Cantor and Knox (1985), in many areas of the country, especially rural communities, the use of on-site septic systems for domestic wastewater disposal is accompanied by a reliance on private wells for untreated drinking water supplies. The potential for biological contamination of groundwater from in-ground application of untreated as well as treated septic tank system wastewater is significantly high under this setting (Vilker 1978).

Biological contaminants from on-site sub-surface disposal of waste water have been found to travel hundreds of meters beyond their point of origin despite the filtering efforts of the soils (Lofty et al. 1978). Moreover, as many as one half of all existing septic tank and soil absorption systems are believed to operate unsatisfactorily (Scalf et al. 1977). Many septic system failures are structural in nature and result from improper installation and/or material breakage (Gold
The design life of many on-site septic tank waste treatment systems, including the septic tank, pipes and leaching beds, is on the order of 10-20 years (Hill and Frank 1974). On-site septic systems installed in soils comprised of loose glacial till, soils which are typically found in coastal areas throughout the Atlantic coastal region, have been found to have a comparatively shorter (15 yr.) design life (Hill and Frank 1974). The usable life of many septic tank systems which were installed during the 1960's is therefore, currently being exceeded and thus, increasing the likelihood of groundwater contamination from increasing numbers of septic system failures (Canter and Knox 1985).

A standard on-site septic tank system is comprised of a septic tank, an effluent distribution field and the sub-surface soil lying underneath the distribution field. The septic tank serves to remove most of the suspended solids from household waste water by sedimentation. Some anaerobic decomposition also takes place in the septic tank. The typical volume of household wastewater introduced to an on-site septic tank system is between 40-45 gpd/person, 150-170 liters/day/person, (U.S. Environmental Protection Agency, 1977). As illustrated in Table 3.1, household wastes, which pass from the septic tank to the leach field and underlying soil, typically contain significant concentrations of suspended solids, BOD, COD, nitrogen and phosphorus. Septic tank waste water effluent is distributed to a leaching field where it percolates into the sub-surface soil. Final treatment of wastewater takes place in the sub-surface soil where physical, chemical and biological filtering of the wastewater contaminants occurs before reaching the groundwater (See Figures 3.5(a) and 3.5 (b)).
Figure 3.5(a) State regulated set back and depth-to-groundwater distances for on-site septic system installation

Source: (Noake 1988)

Figure 3.5(b) Disposal of household wastewater through standard on-site septic system

Source: (Cortese 1984)
Table 3.1

Typical Composition of Septic Tank Effluent

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids</td>
<td>75 mg/l</td>
</tr>
<tr>
<td>BOD5</td>
<td>140 mg/l</td>
</tr>
<tr>
<td>COD</td>
<td>300 mg/l</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>40 mg/l</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>15 mg/l</td>
</tr>
</tbody>
</table>

Source: (Canter and Knox 1985)

The use of cesspools to discharge household wastes, although no longer permitted, continues in many existing older houses and summer cottages located throughout many rural coastal communities. Cesspools located in areas having highly permeable sandy soils provide little no treatment of household wastes and can lead to serious public health problems (Noake 1988). The continued use of cesspools in areas bordering inter-tidal zones is believed to be a major non-point source of biological contamination of inter-tidal marine habitats and shellfish beds along the coasts of many of Massachusetts coastal embayments (Huefelder 1988, Thompson 1990).

The overall effectiveness of domestic on-site waste treatment systems relies on the subsoil as the final treatment of wastewater. The soil's physical, chemical and biological filtering mechanisms affect the fate and transport of those biological and inorganic contaminants, found in domestic waste water, from entering into the groundwater (Loehr 1978).

Failure of septic tank systems due to excessive drainage of septic tank effluent through highly permeable sub-soils to the water table is effectively unnoticeable and thus, potentially more serious than the more readily apparent system failure characterized by sub-surface soil clogging and surface puddling of wastewater effluent (Canter and Knox 1985) (See Figures 3.5 (a) and (b) and 3.6 (a) and (b)). The rapid
Figure 3.6(a) Contamination of groundwater from poorly sited and/or failing on-site septic systems

Source: (Cortese 1984)

Figure 3.6(b) Contamination of groundwater from poorly sited and/or failing on-site septic system.

Source: (Cantor and Knox 1985)
movement of waste water effluent through predominantly sandy sub-surface soils affords minimal travel and contact times between the wastewater's biological contaminants and the soil thus, decreasing the soil's ability to remove and prevent harmful pathogens from entering the groundwater (Bouma 1979).

A significant rise in sea level could cause groundwater tables to rise closer to the land surface and existing on-site septic systems. Cogger and Carlile (1984) found the combination of high water tables and sandy soils, typical of many coastal land areas, causes sub-surface septic systems to perform inadequately. In addition, Viraraghavan and Warnock (1976), found that the contaminant reduction efficiency of on-site waste treatment systems decreased by 20 percent in areas where the depth to ground water was more shallow, especially during seasons marked by high rainfall and higher water tables. Consequently, many experts have been calling for more stringent on-site septic system standards, typically recommending that no septic system leaching field should be allowed closer than 7 ft from the groundwater surface in highly permeable soils (Brown 1980).

The soil removes bacteria and virus, typically found in household wastewater, by the processes of physical straining and chemical adsorption respectively. These removal processes are in turn regulated by soil type and particle size (Gerba 1975). Physical straining occurs when the size of the bacteria is larger than the soil's pore openings. Coarse soils, such as sands and gravels, are much less successful than clay and silt soils in straining and preventing bacteria contaminants from entering the groundwater (Gerba 1975).
3.4.2 Viruses Removal

The chemical filtration process of adsorption to soil particles is the primary mechanism by which viruses are removed from contaminated wastewater percolating through the soil (Drewry and Eliassen 1968). The most important factors aiding the soil's ability to filter viruses by chemical adsorption are low flow rate and low soil pH (Canter and Knox 1985). The process of adsorption is enhanced in soils with larger particle sizes by providing greater opportunity for virus-soil particle surface contact (Peavy 1978). The higher permeability (flow rates > 20 in/hr), and minimal clay content, similar to the glacially-derived soils found throughout many coastal land areas in the United States (US Dept. Agriculture-Soil Conservation Service (SCS) 1987), however, are considered to be significantly less effective in adsorbing and filtering viruses contained in domestic septic system wastewater (Bouma 1979, Burge and Enkiri 1978, Drewry 1969). As described by the US SCS, these sandy soils, naturally found in coastal areas, are usually very acidic (3.6-5.5 pH) and typically exhibit "very rapid" permeability. Together these soil characteristics pose "severe" limitations for the satisfactory performance of on-site septic system leaching fields which will expose local groundwater resources to greater pollution risks (USDA-SCS 1987). Accordingly, successful adsorption of viruses in soil can also be a function of virus types. Different strains of intestinal viruses, possessing different physical and chemical properties, were found to exhibit significantly different adsorption behaviors (Gerba and Goyal 1978). In addition to rapid wastewater movement, the rapid percolation of heavy rains in highly permeable sandy soils can also cause adsorbed bacteria and viruses to wash free "desorb", and move further down towards and into the groundwater (Gerba 1975). As noted
by Gerba (1975) viruses which have been immobilized by chemical adsorption onto soil particles can later react and continue to move through the soil to the ground water.

3.4.3 Biological Contaminants in Groundwater

Once they successfully make their way into local groundwater resources and fresh water aquifers, bacteria and viruses have been shown to survive for periods ranging from 2 days to well over 4 months (Gerba 1975). Viruses enjoy longer life spans (up to 170 days) in soils and are more resistant to environmental influences than are bacteria (Canter and Knox 1985). Biological contaminants from the on-site disposal of household wastewater have been found to travel extremely long distances beyond their point of origin despite the filtration efforts of the local soil (Lofty et al. 1978). Results of both field tests and laboratory experiments conducted on the fate and transport of bacteria indicate that the average distance of travel for bacteria is 100-200 feet. In extremely coarse, gravelly soils bacteria have been shown to travel more than 2000 feet from their point of infiltration (Gerba 1975, Cantor and Knox 1985). Viruses have been reported to typically travel more than 400 meters horizontally from sewage basins in medium and fine grained soils (Keswick and Gerba 1980).

3.5 Conclusion

Although the dynamics of the impacts of sea level rise on coastal groundwater resources and drinking water supplies have been greatly simplified, they represent a real and problematic concern for a large portion of similar coastal land areas
located along the Atlantic and Gulf of Mexico coasts. As previously described, the combination of high groundwater tables and extremely permeable soils poses the greatest threat to the successful filtration of biological contaminants by standard septic tank systems (Reneau 1978, Hagedorn 1978).

The long survival periods and transport distances which characterize the behavior of bacteria and viruses in extremely permeable sandy soils raises serious concerns about the effects of sea level rise on the health and safety of those coastal populations relying on both, untreated groundwater resources for their sole source supply of drinking water and sub-surface septic disposal of their waste water effluent. For example, in the coastal Cape Cod municipality of Eastham, where the existing depth to groundwater can be as little as 7-10 feet, the cumulative effects of a 14 inch sea level rise from global warming, coupled with an 8 inch natural land subsidence, could act to decrease the already inadequate minimum 4 foot distance from the bottom of on-site septic system leach fields to the groundwater table by more than fifty percent. A situation such as this could seriously exacerbate the already limited effectiveness of existing on-site septic systems in preventing harmful biological contaminants from entering into local drinking water supplies (Gold 1990).

In Chapter 4, a prototype computerized Geographic Information Systems (GIS) application has been developed to be used with digitized geographic information for the Town of Eastham. This prototype application demonstrates how coastal states and local coastal municipalities might undertake the process of assessing their particular site-specific environmental vulnerability to the impacts of sea level rise on local
groundwater tables. A range of four possible sea level rise scenarios, taken from Chapter 2, Table 2.5, for the year 2050 are used in the prototype.
CHAPTER 4  
GIS SCOPING STUDY AND ANALYSIS OF SEA LEVEL RISE:  
IMPACTS OF COASTAL GROUNDWATER RESOURCES  
OF EASTHAM, MASSACHUSETTS


4.1 Introduction

According to Davidson and Kana (1988), it is extremely important for local coastal resource managers, land use planners and policy decision makers to anticipate the magnitude, severity, and distribution of the site-specific environmental impacts that could result from current sea level rise scenarios. Few coastal state governments and local municipalities, however, have the needed data and information concerning how sea level rise could affect their coastal zone environments. Nor do they have the information required for the development of appropriate sea level rise adaptive response policy (Hershman and Klarin 1990).

This lack of information could force state and local governments to forego consideration of the need for appropriate sea level rise response policies or could lead to the costly implementation of inadequate and/or inappropriate policy guidelines and interventions. Given the uncertainties
pertaining to specific rates and the ultimate degree of sea level rise, quantification of a range of potential sea level rise impacts to a specific coastal area might be the most appropriate policy response strategy for state and local governments to undertake at this time.

In Chapter 4, a "prototype" Geographical Information System (GIS) application is developed to provide a "first cut" scoping study and assessment of the possible local impacts of sea level rise to the Town of Eastham's groundwater resources and local private drinking water supplies. The purpose of this prototype GIS application and its map products is to provide information for the screening and identification of coastal land areas within the Eastham study area which, as a result of existing topography and groundwater elevation, may be particularly vulnerable to the impacts of sea level rise. In Chapter 5, a number of strategic policy interventions are described which could be applied to these vulnerable areas including: development restrictions, septic system prohibitions, public acquisition and transfer of private development rights.

4.2 Eastham, Massachusetts - The Study Area

The following information provides a brief overview of the study area's hydrogeologic characteristics, as they pertain to the focus of this study. Additional information is also provided which helps to describe some of the simplifications and assumptions that have been incorporated in the formation of this prototype GIS application and the evaluation of its findings. For the purposes of this analysis, the southern half of the Town of Eastham, located in Cape Cod Massachusetts, has been selected as the study area for which a prototype GIS program has been developed.
The Town of Eastham has been selected because its hydrogeologic characteristics, the focus of a number of past federal and state government groundwater/landuse studies (CCAMP 1988), could be considered representative of the geologic and hydrologic features which comprise a large portion of the coastal land areas located along the Atlantic and Gulf of Mexico coasts. Furthermore, as a result of past studies, there exists a significant amount of digitized data and information which can be incorporated in this prototype GIS analysis. This prototype application will be used to explore the potential impacts of sea level rise to coastal groundwater "floating lens" aquifers (See also Chapter 3, Figures 3.1 and 3.2).

4.2.1 Hydrogeologic Features of the Town of Eastham

Glacial sediment deposits forming the Cape Cod peninsula are composed of highly permeable unconsolidated sands and gravels which provide an excellent storage medium for large quantities of water (Janick 1987). Extremely permeable sandy soils, such as the Carver soils characterizing the Town of Eastham's soil make-up, can be rapidly overloaded with both organic and inorganic chemicals and microorganisms, thus permitting rapid movement of contaminants down and into the ground water table (SCS 1987). In Eastham, the freshwater aquifer comprises the town's sole source of drinking water supply. It is described as a floating lens, called the Nauset Groundwater Lens which encompasses all of Eastham and the lower portion of Welfleet (Janick 1987).

Illustrated in Figure 4.1 is the Groundwater Contour Map for Eastham, showing the US Geological Survey description of the aquifer lens with 5, 10, 12, 14, 15 and 17 foot water table
Figure 4.1 Digitized groundwater contour elevation - Town of Eastham
elevation contour lines. The groundwater elevation throughout the Town of Eastham typically fluctuates by as much as 1-2 feet from late summer, when precipitation is low and air temperatures are warmer, to early spring following the melting of snow and ice in March and April (Frimpter and Fisher 1983). Rising sea levels, as discussed in Chapter 3, could increase the elevation of unconfined floating lens coastal aquifers and exacerbate these seasonal groundwater fluctuations.

Higher groundwater tables could seriously affect the proper functioning of on-site septic system. All housing units within the study area are serviced by either a standard design, private on-site septic system and leaching field or a cesspool and septic pit system (Thompson, 1990). Under existing state regulations for the State of Massachusetts, the minimum distance to the groundwater table from the bottom of the leaching field for on-site septic systems is four feet. The bottom of a septic system's leaching field is typically 2 feet below the land surface. For soils that have an average depth to the water table from the land surface of 6 feet, a seasonally higher water table could mean a greater risk of biological contamination to local groundwater resources and drinking water supplies (Brown 1980). Consequently, in lieu of expert opinion recommending a safer depth-to-groundwater distance of 7 feet from the land surface, the environmental impact categorization scheme used in this analysis assigns a SEVERE impact rating where groundwater tables have been determined to be less than 6 feet from the ground surface.
4.3 Geographic Information Systems (GIS)

A GIS is a specialized data management and analysis system designed for digitizing, analyzing, managing, and displaying data commonly stored in map form. A GIS stores both cartographic "map" and attribute data. The map data are commonly stored as points, lines and polygons and are geographically referenced by their x,y coordinates. The attribute data are stored as tabular data. With GIS software, the map and attribute data sets can be combined, enabling a more complete identification of the spatial relationships existing between such data. The form of the resulting output can be controlled by selecting the possible relationships between the data sets to be analyzed. For this prototype application, data sets pertaining to the Town of Eastham's local groundwater elevation, topographic surface elevation, and parcel-level property data were selected for manipulation and analysis. ARC/INFO, developed by the Environmental Systems Research Institute (ESRI) was the GIS software package used to develop this prototype application. The analysis was performed on an IBM/PS 2 Model 80 desktop personal computer.

4.3.1 Data Acquisition

The ability to effectively use GIS technology for this case relies on the existence and availability of computerized land data pertaining to area-specific information including: geology, hydrology, topography and landuse. As listed in Table
4.1, GIS data and information were obtained for the Town of Eastham from the following sources:

Table 4.1

Data Sources for Sea Level Rise / Groundwater Impact Analysis - Town of Eastham

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessor Parcels</td>
<td>Cape Cod Regional Planning Commission</td>
<td>1:600</td>
</tr>
<tr>
<td>Groundwater</td>
<td>US Geological Survey Marlboro, MA</td>
<td>1:24000 contours</td>
</tr>
<tr>
<td>Elevation</td>
<td>MA EOEA (*) Data Cntr. (compiled from USGS sources)</td>
<td>30 m grid</td>
</tr>
</tbody>
</table>

(* ) EOEA - Executive Office of Environmental Affairs

In addition, a range of four possible sea level rise scenarios, discussed in Chapter 2 and listed in Table 4.2 below, were employed for this GIS analysis.

Table 4.2

Sea Level Rise Scenarios for the Year 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Sea Level Rise (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidence</td>
<td>5.0</td>
</tr>
<tr>
<td>Low</td>
<td>13.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>20.0</td>
</tr>
<tr>
<td>High</td>
<td>27.0</td>
</tr>
</tbody>
</table>

Sources: (Hoffman 1986, Geise 1987)
4.3.2 The Derived Analytical Maps

A series of Depth to Groundwater (DTGW) scenario maps or "coverages" (See Figure 4.2), were developed using available groundwater information contained in the USGS' groundwater elevation map. Surface elevation information contained in the USGS topographic (Digitized Elevation Model "DEM") quadrangle maps covering the Town of Eastham (See Figure 4.3) were also used. These DTGW coverages were produced through a process consisting of the following steps; 1) manipulating the existing Groundwater Elevation and Surface Elevation maps, 2) developing the analytical Depth-to-Groundwater coverages for each sea level rise scenario and, 3) devising an appropriate evaluation classification for describing the environmental impacts of sea level rise to local groundwater resources. The individual steps pertaining to this process can be broken down as follows:

1. (a) using the groundwater coverage, calculate the average groundwater elevation values between two adjacent groundwater contour lines and assign the calculated value to represent the elevation value of the entire area (polygon) between each pair of groundwater elevation contour lines;

(b) using the groundwater attribute table, create 5 separate sea level rise/groundwater elevation attributes (Existing, Subsidence, SLR-1, SLR-2, SLR-3) by increasing the values developed in 1(a) for each of the 5 sea level rise scenarios listed in Table 4.3;

(c) using the DEM elevation model, transform to a 2 meter elevation polygon coverage (See Figure 4.4). (Note: This polygon coverage delineates areas, at 2 meter intervals, with common elevation values.) These polygons represent the average surface elevation values and are derived from a 30 meter square grid of elevation data;
Figure 4.2 Sea Level Rise/Depth-to-Groundwater analytical map scenarios
Figure 4.3 USGS topographic Digital Elevation Model (DEM) 2 meter contours
Figure 4.4 USGS topographic DEM (2 meter contour) polygon transformed
(d) using the elevation polygon attribute table, convert all surface elevation contour meter values to their equivalent in feet;

2. (a) using the groundwater and polygon elevation coverages, overlay the surface elevation values on top of the groundwater elevation values and intersect;

(b) using the attribute table of the intersected coverage, subtract the elevation differences to obtain a value for the difference from the land surface to the groundwater surface, "depth-to-groundwater" (DTGW), for each scenario;

(c) using the intersected coverage DTGW and the parcel-based coverage for Eastham, overlay the coverages and perform an intersection;

3. (a) using the DTGW attribute tables, create a lookup table by devising an appropriate environmental impact classification scheme, as shown below. These values are based on information concerning the subsurface disposal of domestic wastewater in highly permeable soils, the fate and transport of biological contaminants contained in domestic wastewater, and the existing need calling for great separation distances between on-site septic systems and local groundwater tables (See Chapter 3, section 3.4). The classification selected for this analysis was:

<table>
<thead>
<tr>
<th>Depth to Groundwater</th>
<th>Impact Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>X &lt; or = 0'</td>
<td>Surface Water/SEVERE Impact</td>
</tr>
<tr>
<td>0' &lt; X &lt; 6'</td>
<td>SEVERE Impact</td>
</tr>
<tr>
<td>X &gt; 6'</td>
<td>NO Impact</td>
</tr>
</tbody>
</table>

4.4 Findings of the Prototype GIS Application

The results of this prototype GIS environmental impact analysis are analytical maps (see Figure 4.2), and their corresponding data which identify clusters or zones of coastal
land area within the Eastham study area where depth-to-groundwater distances could be seriously impacted under particular sea level rise scenarios.

Using the prototype GIS application, over 1200 acres within the study area are estimated to have extremely shallow groundwater tables and have thus been assigned a SEVERE Depth-to-Groundwater classification (See Table 4.3 - "Existing") . Under the current rate of relative sea level rise ("Subsidence") experienced for Cape Cod, Massachusetts, sea levels would rise 5" by the year 2050 but do not, at the level of aggregation used in this analysis, show a measurable impact to local groundwater tables. In the event sea levels rise 13" over the next 60 years, (predicted by experts as the LOW sea level rise scenario), nearly all of the nearly 1200 acres with shallow groundwater tables, shown in RED in Figure 4.2, could become permanently flooded by elevated groundwater tables. According to the findings, the effects of a MODERATE (20") or a HIGH (27") sea level rise scenario, as indicated in Table 4.3, would be the same, causing more than 500 additional acres, having currently acceptable depths-to-groundwater (depicted in GREEN in Figure 4.2), to become "severely" impacted (RED).

Note that the total amount of acres within the study area which are estimated to become flooded due to higher groundwater tables is the same for a LOW sea level rise scenario as it is for the MODERATE and HIGH sea level rise scenarios. This same observation holds true for the total number of SEVERE and NO Impact acres impacted under both MODERATE and HIGH sea level rise scenarios. Although this peculiarity could be due, in part, to the topographic irregularities of the study area's surface, it is more likely that this "lumpiness" in the findings is the result of the
prototype's implicit limitations which are discussed below. Because of the level of aggregation used in the prototype, we chose not to complete an analysis of parcel-level impacts. However, with a refined GIS application such a parcel-level analysis could be conducted and could prove to be extremely useful in developing appropriate local sea level rise policy response interventions.

### TABLE 4.3

Sea Level Rise (SLR) Vulnerability Analysis  
Depth-To-Groundwater Impacts for the Year 2050

Town of Eastham - south

<table>
<thead>
<tr>
<th>SLR SCENARIO</th>
<th>FLOOD 0.0'</th>
<th>&lt;6.0'</th>
<th>&gt;6.0'</th>
<th>(a+b)/Total</th>
<th>%Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>45</td>
<td>1266</td>
<td>3144</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>Subsidence (5&quot;)</td>
<td>45</td>
<td>1266</td>
<td>3144</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>LOW (13&quot;)</td>
<td>1272</td>
<td>39</td>
<td>3144</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>MODERATE (20&quot;)</td>
<td>1272</td>
<td>598</td>
<td>2585</td>
<td></td>
<td>42</td>
</tr>
<tr>
<td>HIGH (27&quot;)</td>
<td>1272</td>
<td>598</td>
<td>2585</td>
<td></td>
<td>42</td>
</tr>
</tbody>
</table>

Total study acres = 4455

4.4.1 Limitations of the Prototype GIS Application

This prototype GIS application, developed for exploring the impacts of sea level rise to groundwater resources, currently suffers from two factors; an insufficient level of
data accuracy, and the limited capabilities of the current GIS software used to implement the prototype GIS application itself.

The identification of particular parcels of land potentially affected by subsurface environmental changes, such as movements of groundwater in response to rising sea levels, calls for accurate data. For many coastal states and local municipalities such data or the resources to collect and develop such data does not exist (Hershman and Klarin 1990). A prudent response in such situations, as some experts have suggested, is to do the best with the information that is available rather than doing nothing at all (CCPEDC 1989).

However, the resolution provided by the scale of more readily available data, such as that used in this analysis (groundwater elevation contours, 2 meter topographic elevation contours representing 30 meter square grid surface areas), is too coarse for conducting accurate parcel-specific analysis. The USGS' 30 meter square DEM topographic elevation data (Level 1) for example, uses one point to aggregate and represent the average surface elevation for a 30 meter square portion of land area. The DEM data can have a horizontal accuracy tolerance of 7 meters and up to 7 meters in vertical accuracy tolerance (Evans 1990, US DOI 1987). The vertical and horizontal accuracy tolerance for Eastham's the groundwater elevation coverage is within 1 foot (Barlow 1990).

It should be noted, however, that this is the most accurate data available for this region in either paper or digital form. At the current level of aggregation it is not possible to be sufficiently accurate so as to delineate specific zones of SEVERE impact. The use of this prototype GIS application, as a result, is currently limited to serving as an important
map-based "first cut" screening tool which could be employed for generating a starting point for focussing local adaptive sea level rise response concerns (Harris 1989).

The limitations of the particular PC-based commercial GIS software, used to develop this prototype GIS program, were another important factor affecting the prototype's level of application. Specifically, a more accurate analysis would be fully grid-based, and would allow for finer interpolations between contour lines on both the groundwater coverage and the topographic elevation coverage. The intersection and subtraction of these 2 elevation coverages would also be carried out using a full grid of data points allowing finer interpolation and resulting in more accurate Depth-to-Groundwater findings. Because of limitations of the current PC-based ARC/INFO package, this prototype GIS application required the aggregation of the 30 meter grid values into polygons of approximately equal values (eg. 2 meter elevation polygons).

The use of a relatively crude "stepped pancake" scheme (See Figure 4.5) to describe the elevations of the groundwater table, surface topography and depth-to-groundwater, as shown in Table 4.3 above, creates a "lumpiness" in the range of environmental impact classifications (SEVERE Impact and NO Impact). This lack of impact specificity, (ie. finer gradations of impact categories), fails to provide the requisite level of accuracy for determining the specific impacts of rising groundwater tables to individual parcels and their specific on-site septic systems and private drinking water wells. Implementation and enforcement of particular regulatory adaptive response strategies and interventions
Figure 4.5 Comparison of Prototype and Refined GIS Application
would almost always have to be made through a process involving the site-specific surveying of land elevation and groundwater table monitoring.

4.4.2 Benefits of a Refined GIS Application

In discussing the refinement of this prototype GIS application a distinction needs to be made between refinement of the GIS software application and the use of more refined data and information in the GIS application. Refinement of the prototype GIS application would eliminate the need to aggregate the elevation data, creating the "lumpiness" in the prototype analysis findings, and instead, would allow for interpolations at the same level of accuracy as the USGS data. Once refined, this GIS prototype application could prove to be an invaluable scoping tool for both state environmental policy makers, including coastal zone management agencies, and local Town planners and Planning Boards, Boards of Health and community residents. In particular, the refined GIS program could provide a more complete geographic description of the range of sea level rise impacts likely to affect the on-site septic systems and drinking water wells of private property parcels located within SEVERE impact areas and local coastal groundwater resources (See Figures 4.6-4.8). For local municipalities and regional land use authorities charged with the implementation and enforcement of environmental regulations and health and safety ordinances, the GIS application could provide the capability for any number of important initiatives including:

1. tracking the fate of existing vacant developable parcels located in SEVERE impact areas;
Figure 4.6 Parcel coverage - Town of Eastham (south)  Source: (CCPEDC 1989)
Figure 4.7 Enlarged section of Parcel coverage - Town of Eastham (south) Source: (CPEDC 1989)
Figure 4.8: Enlarged section parcel coverage DTGW analysis Town of Eastham.

SEA LEVEL RISE - GROUNDWATER IMPACT COMPARISON
TOWN OF EASTHAM - SOUTH
EXISTING SUBSIDENCE 5" SEA LEVEL RISE 27"

- Surface Water
- Less than 6'
- More than 6'
2. identifying high risk developed and developable coastal land areas for more detailed groundwater monitoring studies;

3. developing local septic system maintenance and management programs including site-specific replacement and upgrade strategies and;

4. designing alternative clustered wastewater treatment interventions.

4.5 Conclusion

The prototype GIS application demonstrates how readily available USGS surface elevation data, coupled with local groundwater elevation information, can be manipulated to develop analytical maps which identify clusters or zones of problematic coastal land areas. In these areas, groundwater resources and drinking water supplies could be vulnerable to rising sea levels and thus require further detailed analysis. The ability to overlay and manipulate site-specific geographic-based information provides an important scoping-level opportunity for identifying potential impacts to natural coastal resources and properties which could be incurred under a range of sea level rise scenarios. More importantly, refinement of this particular GIS prototype could enable local sea level rise impact assessments to include important information pertaining to impacts of sea level rise to coastal groundwater resources and drinking water supplies heretofore only marginally considered in local studies of sea level rise impacts.

Used in conjunction with other data and existing information, including: FEMA's Federal Insurance Rate Maps (FIRM) and state coastal zone management Areas of Critical Environmental Concern (ACEC's), this GIS program could become an important tool for state governments and local coastal municipalities
in conducting comprehensive site-specific vulnerability assessments of the environmental changes and impacts of sea level rise. In Chapter 5, exactly how and why such local vulnerability assessments could form the basis for developing appropriate state and local adaptive sea level rise response policies and interventions will be discussed.
CHAPTER 5
SEA LEVEL RISE AND GROUNDWATER RESOURCES PROTECTION: IMPLICATIONS FOR POLICY

The important point is that we now foresee a global warming, though the time scale is not firm, and we are convinced that such a drastic climate change will bring with it major readjustments at all levels of society. Some educated speculation is in order so that we can do some intelligent long-range planning. Societal Responses to Regional Climate Change: Forecasting by Analogy, 1988, Michael H. Glantz ed., Westview Press, Boulder, CO.

5.1 Introduction

As illustrated in Chapter 4, increases in sea level elevation, coupled with natural land subsidence, could raise local water tables and lead to the biological contamination of local groundwater resources and drinking water supplies for those populations located along vulnerable sections of the country's coastline. Yet, in the face of increasing global air temperatures and marked increases in sea levels, decision makers and environmental policy makers remain reluctant to consider the need for developing and implementing appropriate strategies to address the risks posed by rising sea levels. In Chapter 5, some of the more prevalent factors which tend to impede policy responses to climatic change will be examined. In addition, the need for coastal states and local coastal municipalities to consider efforts to pursue an "adaptive" sea level rise response strategy, consisting of
specific interventions designed to address the impacts of sea level rise on groundwater resources and local drinking water supplies, will also be explored.

5.2 Policy Responses to Environmental Changes

Responses to environmental change typically focus on addressing either the cause(s) of the environmental change or its resulting consequences (Glantz and Ausubel 1988). Three categories of response to global climate change; prevention, compensation and adaption, developed by Meyer and Abich (1980) for discussions of CO2-induced environmental impacts, provide a useful framework for discussing local response strategies for sea level rise. The range of response strategies to sea level rise and rising groundwater elevations could include interventions designed to: prevent or eliminate the causes of the problem (i.e., stop the groundwater table from rising); compensate for the problem with measures to suspend the undesirable effects of a raised groundwater table, possibly by decreasing the amount of groundwater recharge or increasing the amount of groundwater discharge; and finally, adapt to the consequences of a rising groundwater table by selecting one of many intervention alternatives ranging from boiling all drinking water to developing public waste treatment facilities.

5.3 Impediments for Sea Level Rise Policy

Due to the uncertainties surrounding the rate and extent of global warming, environmental experts and policy analysts continue to debate the merits of adopting a national "take action now" or "wait and see" policy strategy to address
global warming and its potential impacts, including sea level rise. Proponents of a "wait and see" policy remain steadfast in the belief that additional information is needed to properly identify the existence of an ongoing global warming trend. In their view, the need for an active take-action-now global warming policy response has not yet been convincingly demonstrated (Solow and Broadus 1989). Moreover, some experts argue that undertaking immediate global warming policy interventions involving changes in national energy production and industrial manufacturing along with costly structural interventions could result in impacts more costly and more detrimental to the nation's well being than the environmental impacts originally anticipated from global warming (Solow and Broadus 1989).

Underlying this "wait and see" policy choice is the assumption that the impacts associated with global warming and sea level rise will occur very slowly over a period of many decades. Such slow rates of environmental change, unlike the devastating changes brought on by single catastrophic events such as earthquakes, storms and floods, would provide ample time to respond, and therefore eliminate the need for inappropriate and costly response interventions which could compromise the nation's industrial productivity and economic welfare. In addition, wait-and-see advocates presume that the magnitude of global warming and sea level rise will not be large enough to undermine the public's safety or the public and private investments made during the intervening years (Mintzer 1988). By contrast, some members of the scientific community warn that the impacts and environmental changes associated with global warming could occur over comparatively shorter time scenarios (10 years) than those currently contemplated in global warming policy discussions (Ramnathan 1989). Under such a scenario, neither the general public nor
those governmental agencies responsible for the public's health and safety would be adequately prepared to respond (Broecker 1988).

As argued by its advocates, the principal merit of the "wait and see" strategy is one of cost effectiveness. Using traditional economic cost/benefit analyses, the total benefits (cost savings) which the U.S. could realize by not adopting a global warming policy involving costly changes in national energy use and industrial manufacturing, would be greater than the benefits associated with the implementation of such a policy (Schelling 1983). Some wait and see policy analysts have even argued that the costs savings could be greater than the costs of mitigating the environmental losses sustained throughout the country from relatively minor increases in global warming and sea level rise (Schelling 1983).

Brown (1988), on the other hand, points out that traditional cost/benefit analyses typically employ future discount rates which, when applied to the long term environmental changes associated with global warming and sea level rise, significantly diminish the "cost effective" value of any necessary global warming response interventions. Furthermore, the aggregation of national costs and benefits overlooks, if not disregards, the important distributional differences, geographically and financially, of the environmental changes and impacts to be realized from rising sea levels.

The environmental impacts likely to be incurred by particular coastal states and local municipalities under current sea level rise scenarios could be staggering. Under the current range of sea level rise scenarios put forth by the scientific community, and discussed in Chapter 2, low lying coastal communities could face more immediate and perhaps more
devastating impacts to private property and public health and safety than in other parts of the country. Along with the likelihood of increased coastal erosion, catastrophic storms and flooding, rising sea levels could lead to increased failures of on-site septic systems and biological contamination of local drinking water supplies. Following the argument offered by wait and see policy proponents, the greater risks and economic burdens faced by coastal states and local municipalities in responding and adapting to the local impacts of sea level rise could pale in comparison to the total benefits to be realized by the country as a whole should we continue with our "wait-and-see" approach to the global warming phenomenon.

According to recent case study analogies of state and local responses to regional climatic change, inadequate political institutions and insufficient financial resources have been identified as the most important factors impeding state and local policy responses to the environmental impacts associated with long term climate changes (Glantz 1988). State and local decision makers typically demand detailed information as to how the anticipated sea level rise scenarios will affect their specific geographic areas. According to Davidson et al. (1988) local decision makers insist on being provided with information documenting their community's particular vulnerability to sea level rise and when the anticipated rate of sea level rise will take place. The need to know when sea levels will rise reflects the decision maker's concern that the life of existing local structures and infrastructure and the coastal community's health and general welfare will not be seriously impacted during his or her political tenure.
Underlying this rather narrow focus of the governmental decision maker is an important misconception concerning the nature of global warming and sea level rise. The misconception may be responsible for some of the reluctance exhibited by state and local governmental leaders in addressing the issue of sea level rise. Decision makers, along with others who believe the greenhouse effect will result in a natural catastrophic event, such as a rapid rise in sea level or major changes in regional climate patterns, have continued to remain complacent concerning the need for sea level rise policy until such time when an event, clearly related to sea level rise, actually occurs. In contrast, those calling for immediate policy interventions perceive the effects of global warming to be a subtle cumulative process in which short term impacts are indistinguishable but could become more noticeable and more serious within a period of a few years or decades.

Highlighting the nature of climate change as a process rather than an event also helps to highlight the mismatched time horizons characterizing the relationship between the short term focus of our political institutions and the long-term processes of global climate change and sea level rise. This allows governmental decision makers to remain reluctant to pursue appropriate policy responses to the potential impacts associated with global climate change and sea level rise (Glantz et al. 1988). Local government and regulatory decision makers hold office for an average of 4-6 years and, in most cases, no longer than 10 years. In contrast, under current sea level rise scenarios, it could take 50-100 years for sea levels to rise by 2-3 feet; far beyond the tenure and scope of interest of most of our policy makers and existing political institutions. The issues that typically garner most of their political concern are those that have the potential to yield relatively short-term "successes" which often result
in longer political careers. Without the needed support and
guidance from federal, state and local decision makers,
concerns for the potential impacts of sea level rise on the
country's coastal zone areas are left to grass-roots arenas
where the required public consensus and support for such long-
term issues of concern often quickly dissipates as a result
of the general public's and the media's relatively short
attention spans.

As described above, the accepted practice of discounting
future value serves to reduce the cost effectiveness of
otherwise appropriate and perhaps necessary, local sea level
rise response options. Some of the more substantial costs
associated with the local environmental changes caused by sea
level rise include; property loss and damage costs due to
increased inundation, erosion and flooding and in some
instances, the need for costly renovation of on-site waste
treatment alternatives in response to elevated groundwater
tables (Canning et al. 1990). Appropriate response
interventions could involve significant "up front" financial
commitments while their benefits remain uncertain and unlikely
to be realized until far in the future. As reflected in
traditional economic cost/benefit analyses, each generation
tends to value its own immediate consumptive needs more highly
than that of succeeding generations and will opt for short
term gains rather than long term benefits (Brown 1988).
Consequently, the use of traditional cost/benefit analysis and
future value discounting to evaluate appropriate response
interventions for adapting to uncertain local sea level rise
impacts, will more than likely force policy makers to put off,
or eliminate from consideration, extremely important and
extremely expensive adaptive response interventions (Glantz
5.4 Adaptive Response Strategies for Sea Level Rise and Groundwater Resources Protection

Missing from the debate over the merits of an "immediate" versus "wait-and-see" global warming response strategy is a more sensitive and substantive recognition of the regional and local environmental changes anticipated from rising sea levels and the more serious and perhaps more immediate concern these changes hold for many developed coastal areas throughout the country. In the U.S., intensified urban populations have been established in coastal areas which may have once been completely submerged by ocean waters, with the implied but unrealistic expectation that the movement of the sea and shoreline will remain relatively fixed. Nearly 103 million people already live within 50 miles of the coast (Edwards 1989) and more of the population is expected within the very near future (EPA 1986). Clearly, rising sea levels of the rate and magnitude described under the current range of sea level rise scenarios could have significant impact for a large number of coastal inhabitants throughout the country.

Coastal land areas formed from glacier melting processes and glacial sediment, including barrier islands, dunes and spits, are particularly vulnerable to the impacts associated with natural climatic events such as coastal storms and floods. Primarily located along the Atlantic and Gulf of Mexico coasts, these areas have also been inundated with increasing amounts of development. Prior to World War II merely 28 of the nearly 300 US barrier islands were built upon, whereas today more than 70 have been extensively developed (Gilbert 1986). Many local coastal municipalities cannot realistically prevent sea levels from rising and subsequently elevating local groundwater tables closer to the land surface. Nor can they typically afford to compensate for significantly higher
groundwater tables by undertaking costly engineering responses to regulate the height of the aquifer lens (Sorensen et al. 1984).

Similarly, state governments would not be capable of undertaking such engineered interventions for each coastal municipality. In fact, few coastal state governments have moved beyond the point of acknowledging sea level rise as an issue of concern and towards developing an appropriate comprehensive sea level rise response policy. In addition, the federal government, while actively supporting the need for further studies concerning the scientific aspects of global climate change, has remained reticent in providing sea level rise response guidelines or technical assistance to coastal states or local municipalities for initiating adaptive response strategies.

In view of their particular geographic vulnerability and the federal government's disconcerting "wait and see" policy response to global warming and sea level rise, coastal states and their local municipalities might do well to work together to initiate their own efforts to develop a basic understanding and quantification of the site-specific vulnerabilities and impacts to sea level rise they face within their coastal zones. Similarly, efforts undertaken to evaluate the effectiveness of particular sea level rise response strategies and interventions can only be made once a local quantification of the potential sea level rise impacts has been completed (Mintzer 1988).

An appropriate state-local sea level rise response strategy could be developed which might look at the next 50-60 years and determine what interventions would be necessary to protect vulnerable coastal communities and environmental resources
from the environmental impacts which might be anticipated under the current range of sea level rise scenarios. Within a time frame of 50-60 years the range of increases to sea level, predicted under the current sea level rise scenarios, could be large enough to cause significant environmental changes to many vulnerable coastal land areas. These changes could be compared with the structural integrity and the typical 50-60 year design life of existing coastal development. Furthermore, within a period of 50-60 years, many of the existing homes and other development that might be vulnerable to sea level rise and higher groundwater tables, will come before state, regional or local regulatory bodies for special permit approvals pertaining to the structural alteration or change in the development's use. These permit approval processes could serve as an appropriate opportunity for implementing and enforcing any number of the local sea level rise adaptive response interventions, discussed below, which may be necessary to protect the health and safety of existing and future generations of coastal community inhabitants.

5.5 What is Needed - An Active Adaptive Planning Response

Coastal states and local coastal municipalities share a fundamental need to identify and better understand their particular sea level rise risks and vulnerabilities. Once identified, decision makers, policy makers and town meeting attenders can begin the process of evaluating the effectiveness of implementing specific adaptive response interventions to address those risks. Efforts therefore are needed to identify the site-specific vulnerabilities of coastal areas to the full range of currently accepted sea level rise scenarios. Response strategies that might be
appropriate for the entire range of uncertainty should receive preference over those that would be designed to only address a particular sea level rise scenario to the exclusion of the others (Dean 1987). An appropriate adaptive response strategy for sea level rise should include a sea level rise response plan containing a local monitoring program to track local environmental changes and a prioritized schedule of necessary adaptive sea level rise interventions.

5.5.1 Mapping Sea Level Rise Impact Areas

Efforts to develop and evaluate appropriate adaptive sea level rise response interventions could begin with a Sea Level Rise Impact mapping effort which could be based upon a site-specific "vulnerability assessment" of the magnitude and geographic reach of impacts, likely to affect the coastal groundwater resources and drinking water supplies under the full range of currently accepted sea level rise scenarios. While a number of site-specific sea level rise impact studies have been conducted for selected coastal areas in the United States, few have been found to include a detailed assessment of the sea level rise impacts to coastal aquifers and groundwater resources (Aubrey 1989, Leatherman 1984, Kana et al. 1984). As described in Chapter 3 and illustrated in Chapter 4's prototype analysis of sea level rise impacts to the Town of Eastham's groundwater resources, rising sea levels could bring coastal groundwater tables and local drinking water supplies dangerously close to existing on-site septic leaching beds, sources of unsafe biological contaminants. Therefore, in addition to determining the impacts of sea level rise for such factors as coastal erosion, storm surge and property loss, such vulnerability analyses should also include an assessment of the impacts of higher sea levels on coastal
groundwater aquifers, especially if such aquifers are characterized as "floating lens" and constitute a coastal municipality's sole source of drinking water.

5.5.2 Sea Level Rise Adaptive Response Plan

Beyond its geographic component, the local sea level rise vulnerability assessment can serve as the basis for the development of a comprehensive local sea level rise response plan. Borrowing from the federal government's Hurricane Preparedness Planning Program, authorized by the Disaster Relief Act of 1974 (Godschalk et al. 1989), an adaptive sea level rise response plan could include a land use protection component specifically designed to regulate all on-site wastewater disposal activities within the zones of impact identified in the mapping program described above. In addition, such a plan could describe a prioritized range of individual or centralized structural interventions which could be necessary for protecting the health and safety of coastal developments from contamination of their drinking water supplies resulting from elevated groundwater tables. Such structural interventions would be prioritized to provide for the incremental accommodation and adaptation to particular rates (High, Moderate, Low) of measured sea level rise.

This planning process would enable coastal municipalities to devise the local response strategy best suited for its particular circumstances. Local decision makers in particular, could address questions concerning the relationship between the need for specific structural interventions and/or land management regulations and their timeliness as well as their costs. The timing of particular public interventions, in relationship to the magnitude and rate of sea level rise can
influence, broaden or narrow, the range of available options and alternatives for adapting to the environmental impacts accompanying rising sea levels (Glantz 1988, Gibbs 1984). An adaptive response plan might, therefore, help to avoid the possibility of ill-informed decision making leading to the pursuit of inappropriate response interventions which call for immediate commitments of financial resources. Instead, under a local sea level rise adaptive response plan, such decisions and commitments could be made and modified at fixed periods (5 years) or over time as the existing uncertainties surrounding sea level rise diminish. The degree of local self-determination which this type of adaptive response strategy affords is also in keeping with the "home rule" preferences typical of many coastal municipalities concerned with natural hazard mitigation (Godshalk et al., 1989).

5.6 Initiating Adaptive Response Strategies and Interventions for Sea Level Rise

As described by Meo, (1988) the planning horizons of federal, state and local government agencies can sharply contrast, thereby leading to disparate and conflicting analyses and evaluations of appropriate local responses to sea level rise.

5.6.1 The Federal Government's role

Arguably, the federal government's reluctance to become more active in responding to increasing global air temperatures and rising sea levels eliminates the need to discuss its role in developing an adaptive response strategy for the impacts associated with sea level rise. Ironically,
however, the federal government's continued, albeit diminishing, national role in flood hazard mitigation serves as an interesting source of applicable intervention options from which to suggest opportunities for appropriate federal interventions to respond to the risks and uncertainties of rising sea levels.

Federal policy makers continue to refuse to acknowledge the existence of a global warming phenomenon, perhaps out of a desire to refrain from having to adopt costly "greenhouse gases" reducing policies which might reduce the industrial and economic standing of the U.S. within the international community. Separate and distinct from national policies aimed at the reduction of greenhouse gas emissions, the federal government could however, encourage and support relatively low cost sea level rise response strategies, including the adaptive response planing as discussed above, without having to change it's current position concerning the existence of a global warming phenomenon. To accomplish this goal, the Federal Emergency Management Agency (FEMA) could be assigned the responsibility to provide assistance to coastal states and their local municipalities in the re-evaluation of coastal flood-prone potential based on current sea level rise scenarios and existing flood hazard designations. Flood insurance rate maps (FIRM), indicating likely areas or zones of flooding impact, could then be revised and expanded to include additional land areas (SEVERE sea level rise/groundwater impact zones) likely to be impacted by increased flooding and/or raised groundwater levels which could result from raised sea levels.

Many coastal states and local municipalities lack the requisite technical and baseline data and/or the necessary resources to collect such data in order to conduct vitally
important site-specific sea level rise vulnerability assessments (Hershan and Klarin 1990). In conjunction with the US Geological Survey's technical assistance, federal funding could be made available for those coastal communities, solely dependant on local groundwater aquifers for their drinking water needs, to develop site-specific groundwater elevation models, such as those used in the Town of Eastham prototype GIS analysis (see Chapter 4), for assessing their particular groundwater resource vulnerabilities to rising sea levels. Much like the requirements of section 406 of the Federal Disaster Assistance act (Godschalk 1989), such federal funding would be made to coastal municipalities contingent upon the efforts of state agencies and local coastal municipalities to conduct site-specific sea level rise vulnerability assessments and evaluations of appropriate adaptive response intervention. Federal funding assistance could also be provided directly to state coastal zone management programs (CZMP) for the regional assessment of environmental impacts of sea level rise. In turn, state CZMP's could provide oversight and technical assistance to coastal municipalities conducting local sea level rise vulnerability assessments or for developing statewide comprehensive guidelines for local sea level rise adaptive response planning. For example, according to Magnusson (1990), section 310 of the current version of House bill HR4050 which seeks reauthorization and funding of the Coastal Zone Management Act, includes a provision to provide 100% grant funding to improve individual state coastal zone management programs. Hazard Mitigation planning, including mitigation planning for sea level rise, is one of 5 "Areas of Program Improvement", listed under sec. 310 of the House bill, eligible for federal grant funding assistance.
5.6.2 The Role of State Government

It remains unlikely however, that the federal government will initiate an appropriate sea level rise response strategy or guidelines to provide the needed assistance to coastal states and coastal regions for particular sea level rise-related interventions. In light of the federal government's movement towards a new federalism, characterized by diminishing federal government intervention and fiscal responsibility, it also appears inevitable that state and local governments will have to act more proactively rather than reactively in addressing the need to reduce costly coastal zone losses associated with climate-related storms and flooding as well as sea level rise. According to leading flood hazard and mitigation experts, the net result of the federal government's diminishing role will be a marked growth of decision making and financing responsibilities at the state and local government levels (Rosen and Reuss eds. 1988). State governments can, however, regulate the use of private property as an exercise of the police power to protect the safety of the general public. If, as in the case of sea level rise, the safety of the public is in greater danger from the impacts of natural environmental changes as a result of human's continued activity on private property, state governments have the legitimate right to regulate the activity or prohibit the use of the property altogether (Conners 1990). State governmental agencies can therefore, shape the environmentally based policies and programs implemented by their localities.

For most coastal states, the geographic and natural resource makeup of land areas comprising their coastal zones are, by function or by statute, considered "common property" and therefore are extremely important to the interests of all residents throughout the state. As a result, coastal state
governments have been slowly assuming a greater role in addressing the concerns and the activities of local coastal municipalities as they pertain to the protection of the coastal zone's natural resources (Ditton 1977). The role of individual state environmental agencies in addressing the specific concerns pertaining to the impacts of catastrophic climatic events, and now sea level rise, has been found to typically depend on the personal priority given to such concerns by individual agency heads and policy makers (Godschalk et al. 1989, Hershman & Kirin 1990). In fact, in a recent survey of coastal state government officials and coastal management programs (Hershman & Kirin 1990) no correlation was found between a coastal state's policy response to sea level rise, or lack thereof, and the state's particular sea level rise vulnerability.

Under the existing institutional framework of most Atlantic and Gulf of Mexico coastal states, state and local governments possess the necessary authority and tools for developing an appropriate adaptive sea level rise response policy (Marine Law Institute 1989, Magnusson 1990). By virtue of existing federal government regulations and initiatives including the Coastal Zone Management Act "CZMA" (16 USC 1451), coastal state government agencies do in fact have the ability to establish performance standards and criteria by which local decisions affecting the environmental resources located within the coastal zone must abide.

Therefore, under the purview of the state's existing environmental mandates and coastal zone management responsibilities, issues and concerns pertaining to the impacts of sea level rise on local coastal municipalities could be addressed directly through a state's existing environmental regulations or by the individual state CZMP's
project review process. The Coastal Zone Management Act encourages state CZMP's to control land and water uses by; 1) state established standards which are implemented at the local level and subject to the state's administrative review and compliance enforcement, 2) direct state land and water use planning and regulation and, 3) state administrative review for consistency of all development plans, projects and land and water use regulations (Ditton et al. 1977). In an advisory capacity, the state coastal zone management agencies could also assist local coastal municipalities with the necessary regulatory guidance and technical assistance in conducting site-specific sea level rise vulnerability assessments and adaptive response planning oversight. Coastal zone management agencies can also play an extremely important role in directing the attention and concern of state environmental policy makers towards the need for new or revised state environmental regulations which could address specific sea level rise related concerns.

Charged with the responsibility of environmental resource management and protection, state policy makers can draft new environmental regulations or revise existing ones to address the specific concerns pertaining to the impacts of sea level rise on local on-site wastewater septic systems and drinking water quality. In Massachusetts, regulations which provide protection for the state's groundwater resources and drinking water supplies could be expanded to account for the impacts that rising sea levels might have on these resources. In particular, under the state's environmental code (310 CMR 15) the Department of Environmental Quality Engineering (DEQE) is responsible for establishing minimum statewide requirements for the sub-surface disposal of sanitary sewage (Title V). Interestingly, up to now the state's minimum standard for the depth to groundwater from the bottom of the on-site septic
system leaching field has been 4 feet, (6' from the land surface), regardless of the septic system's geographic location and in contradistinction to expert studies which have long called for greater depth to groundwater separations in areas having sandy, extremely permeable soils (see Chapter 3). Although Massachusetts is in the process of re-evaluating its Title V regulations it is unclear whether such a re-evaluation will incorporate variable structural and design standards for varying site-specific conditions.

Where established, regional land use regulatory authorities, such as the Martha's Vinyard Commission and the newly formed Cape Cod Regional Commission in Massachusetts, can undertake the development of region-specific regulations, such as on-site septic system design and implementation, and thus, can be an extremely important player in developing and implementing adaptive sea level rise response strategies. Representing a geographically defined collection of local municipalities with similar environmental characteristics and concerns, coastal orientated regional commissions can provide guidance to local municipalities in their efforts to conduct site-specific sea level rise vulnerability assessments and evaluations and ensure uniform compliance and enforcement of appropriate response interventions among all the communities represented by the commission. While federal and state agencies could very well be instrumental in developing preparatory sea level rise response guidelines or intervention strategies, they typically do not have the requisite staff or funding to implement and enforce them on a local level. State agencies would quickly become bogged down if they have to consider individual cases of sea level rise impact damage or individual requests for variances from local sea level rise-based land use regulations (Matthiessen 1989).
5.6.3 Local Government Responsibility

Using a Louisiana sea level rise case study as an analogue, Meo (1988) points out that local government agencies are, by necessity, the first line of response to the impacts of sea level rise and are vested with the responsibility to remain actively involved in local efforts to mitigate any adverse environmental impacts. Similarly, Godskalk et al., (1989) found the pre-disaster and post-disaster interventions undertaken by some local governments to be the most important factor in successfully mitigating the local environmental impacts associated with catastrophic coastal storms. Unfortunately, as Godschalk et al. (1989) points out, local governments have remained largely indifferent to devising innovative programs and interventions for mitigating natural coastal hazards.

The fiscal constraints of a local municipality typically dictate the substance and timing of the local response (Davidson and Kana 1988). Local governments and their decision makers will most likely need to obtain the requisite financial and technical assistance with which to properly conduct sea level rise vulnerability analyses and develop adaptive response interventions. As I have pointed out, decisions involving the prioritization and funding of both structural and non-structural interventions designed to preserve and protect existing coastal land uses, lifestyle, and activities, will more than likely favor relatively short-term and less costly options over more expensive and perhaps more effective longer-term interventions.

On the other hand, local adaptive response interventions calling for a near-term commitment of financial resources could receive greater public support if such interventions were also shown to be capable of satisfactorily addressing a
community's existing environmental problems and concerns (Lave 1988, Glantz ed. 1988). In instances where the potential impacts of sea level rise could exacerbate existing drinking water quality problems, adaptive response strategies and interventions designed to protect local drinking water supplies from the impacts of sea level rise could provide valuable "tie-in" benefits for the community, even in the event a significant rise of sea level does not occur.

In many cases, existing state and local land use regulations, designed to protect local groundwater resources and aquifer recharge areas, could be amended or revised to include both land use management and structural interventions specifically designed to protect groundwater resources and drinking water supplies from the impacts associated with rising sea levels and elevated coastal groundwater tables. Local municipalities have the primary responsibility for their implementation and enforcement within the context of existing local land use regulations and thus, could implement appropriate adaptive sea level rise interventions by electing to revise existing Zoning Bylaws, Board of Health Ordinances and Title V Regulations. As such, responsibility for the administration and enforcement of a local adaptive sea level rise response strategy would fall primarily within the purview of a local municipality's Board of Health and Planning Board or Board of Zoning Appeals.

One particularly important purpose of Zoning Bylaws is the conservation and management of natural resources. Local municipalities may enact zoning restrictions to protect groundwater for the following reasons: to conserve health, facilitate adequate provision of water supplies and sewerage and prevent pollution of the environment. In Massachusetts, groundwater-related zoning is typically used to prevent
contamination of existing water supplies by regulating activities in land areas that feed or recharge the underground water resource (Cortese 1982).

A SEVERE sea level rise/groundwater Impact Overlay District, could be created, using the information developed from the local sea level rise vulnerability analysis and mapping process described above, and adopted as an amendment to the municipality's existing zoning bylaws. More specifically, a SEVERE groundwater impact overlay zoning designation would identify those local coastal land areas whose average depth-to-groundwater, under the current range of sea level rise scenarios, could become seriously less than the Board of Health's minimum safe standard for on-site septic systems and wastewater disposal. The SEVERE zoning classification would also inform those new and existing developments located in such zoning districts of the corresponding range of regulatory interventions, related to the protection of public's health, safety and welfare, (see Table 5.1 below), which affected properties could be subject to should sea levels continue to rise.

Because the introduction of new or revised regulations that anticipate the impacts of sea level rise may promote divisive and costly legal opposition from affected property owners, legal experts suggest that such regulatory requirements be carefully tied to the protection of public's health and safety, and be based upon the best available information in the belief that the greater the threat to public safety, the greater the need for regulation (Conners 1990, Aubrey, 1989). Consequently, local Boards of Health and health ordinances may therefore be particularly well suited for implementing effective response interventions designed to address the concerns for elevated groundwater tables and the potential
degradation of local drinking water supplies (Conners 1990, Aubrey 1989). Local Boards of Health typically have a great deal of exercisable authority to protect their community's groundwater quality and prevent the biological contamination of local groundwater drinking water supplies from failing or failed on-site septic systems. Unlike zoning bylaws, Board of Health ordinances do not require public hearings for their adoption and more importantly, they can effectively regulate pre-existing uses within a community (Cortese 1982).

5.7 Implementing Adaptive Sea Level Rise Response Interventions - The Eastham Example

According to the scoping-level results of the sea level rise vulnerability analysis described in Chapter 4, a significant amount of the Town of Eastham's land area is currently characterized as having shallow groundwater tables. Under the currently predicted range of sea level rise scenarios used in this thesis, the local groundwater table could rise extremely close to the surface of particular coastal land areas (SEVERE Impact Overlay Districts), and thereby expose serious health implications and environmental impacts to many members of the Eastham community.

Based on the Town of Eastham's existing "zoning blueprint", the potential for new growth and development is limited to an estimated 1000-1500 additional housing units, approximately 20% of the town's existing housing stock (APCCC 1985, Coco 1990) (See Figure 5.1, WHITE area = Developed Residential, RED area = Vacant and Developable Residential). Local sea level rise response interventions designed only for new development, would not adequately address the risks of biological contamination to Eastham's groundwater resources and drinking
Figure 5.1 Land Use coverage Town of Eastham (south)
water supplies posed by the impacts of higher groundwater tables on existing older development and their older on-site septic systems. Many of these existing older housing units are apt to be relying on inadequately operating or failing on-site septic treatment systems, installed under less rigorous standards, and as a result, could represent a greater risk of biological contamination to local drinking water supplies than new development.

As illustrated in Table 5.1 below, a "mix" of structural and land use management-based strategies and interventions, applicable to new and existing development, for protecting local drinking water supplies, should be considered by state and local decision makers in their efforts to protect the health and safety residents located in vulnerable coastal areas.
Table 5.1

Local Adaptive Response Interventions for Sea Level Rise

<table>
<thead>
<tr>
<th>NEW AND EXISTING Housing Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea Level Rise/Groundwater Impact Zoning</strong></td>
</tr>
<tr>
<td>a) &quot;SEVERE&quot; designated zones of impact</td>
</tr>
<tr>
<td><strong>On-Site Septic System Design &amp; Management</strong></td>
</tr>
<tr>
<td>a) revised Title V requirements - increasing the minimum Depth to Groundwater requirement to 5 feet (7' from the land surface)</td>
</tr>
<tr>
<td><strong>Individual and Centralized Structural Interventions</strong></td>
</tr>
<tr>
<td>a) individual septic system replacement</td>
</tr>
<tr>
<td>(i) conditional requirement for RE Transfer</td>
</tr>
<tr>
<td>(ii) conditional requirement for construction or alteration permit</td>
</tr>
<tr>
<td>b) centralized wastewater treatment</td>
</tr>
<tr>
<td>c) centralized water supply</td>
</tr>
<tr>
<td><strong>Temporary Use</strong></td>
</tr>
<tr>
<td>a) relocation</td>
</tr>
<tr>
<td>b) public acquisition</td>
</tr>
</tbody>
</table>

These sea level rise response strategies represent a comprehensive mix of structural and land use management interventions, applicable for new and existing development, which might be considered in addressing the potential impacts of sea level rise on local coastal groundwater resources and drinking water supplies. These interventions might also be ranked in the order of their stringency or restrictiveness and the corresponding amount of resources and political will required for their individual enforcement and implementation. To some extent, each of the interventions, discussed below, might also provide additional "tie-in" benefits capable of addressing existing local environmental and water quality concerns in the event future sea levels do not increase substantially.
5.7.1 SEVERE Sea Level Rise/Groundwater Impact Zones

In Massachusetts, towns may enact zoning restrictions to protect local groundwater resources for the following reasons: protect health and safety, prevent overcrowding and facilitate adequate provision of water, drainage and sewerage. Groundwater or aquifer protection zones/districts are typically added to municipal zoning by-laws in cities and towns throughout Massachusetts (DEQE 1984). These zoning bylaws are commonly prepared as "overlay districts" whose areas are superimposed on existing zoning maps with provisions allowing the requirements of the underlying land use district to continue except where the over-lying district is more stringent.

Using a refined GIS application, the geographic identification of critical areas of sea level rise impact can be incorporated as overlay districts ("Sea Level Rise Overlay District") in local planning and zoning regulations pertaining to new construction as well as existing land use activities. This sea level rise overlay district designation would contain regulations and requirements defining the minimum allowable septic system depth-to-groundwater distance in lieu of the range of the currently anticipated sea level rise scenarios. As previously discussed, this overlay zoning designation would serve to inform residents and private landowners of the potential risks and vulnerabilities posed by rising sea levels in their particular areas, and the local municipality's range of adaptive response interventions to such environmental changes and impacts.
On-Site Septic System Design and Management Programs

a) Board of Health Ordinances - Title V design revisions

Municipal Boards of Health have far reaching powers to protect the groundwater quality in their communities. Under provisions of M. G. L. Ch. 111 sec. 31 and Ch 21A, sec.13, Boards of Health can regulate the disposal of sanitary wastes (DEQE, 1984). Under the provisions of Title V, local Boards of Health can adopt more stringent standards pertaining to setback distances from water supplies and greater heights for leaching beds above seasonally high groundwater tables.

In many areas throughout coastal Massachusetts, local conditions and soil types warrant higher on-site septic system standards. State environmental regulators and local governmental bodies including Boards of Health, however, continue to refrain from adopting more stringent regulations to ensure proper functioning of septic systems. Although Title V of the Massachusetts State Sanitary Code currently requires the bottom of new septic system leaching beds to be at least four feet from the seasonally high groundwater table elevations, a careful enforcement of this standard will not guarantee a community safe, uncontaminated drinking water supplies (Noake 1988). In their analysis of existing on-site septic system regulations for the State of Massachusetts, Beardsley and Lurie, (1987) found the state's existing four foot minimum depth to groundwater requirement to be seriously inadequate for preventing biological contamination in areas comprised of coarse sands and gravels and characterized by rapid percolation rates such as those typically found throughout the Cape Cod peninsula.
To address the issue of contamination the Board of Health for the Town of Eastham, as well as other local Boards of Health, should consider the need to supplement existing Title V regulations by adopting a more stringent (5 ft) on-site septic system depth to groundwater requirement to compensate for their excessively permeable soils (Heufelder 1988, Brown 1980). However, for those coastal municipalities deemed to be vulnerable to sea level rise and rising groundwater elevations even a 5 foot separation between the bottom of a septic system's leaching field and the groundwater table may prove to be wholly inadequate in preventing the contamination of local groundwater resources and drinking water supplies. As currently recommended by the MA Coastal Zone Management Agency, local Boards of Health should require an increase of at least 2 feet to Title V's minimum depth to groundwater commensurate with the currently anticipated range of sea level rise scenarios (Benoit 1989).

b) Septic System Management Programs

Municipal Boards of Health have the authority to require periodic inspection and pumping of every septic system in the community. If necessary, the Board can order a system to be cleaned or repaired and require all expenses to be paid by the owner (Noake 1988). Recently, the towns of Orleans, Brewster and Eastham established a tri-town Groundwater Protection District (GPD). This effort also included the construction of a Tri-Town Septage Treatment Facility and the development of an Inspection and Maintenance Program (Tri-Town Bd. of Managers Resident Letter, 2-2-90). Acting under the authority of MGL Chp 111, sec 31, each of the towns' Boards of Health will oversee a comprehensive town-wide program designed to regulate the maintenance, disposal and treatment of on-site septic system waste contents as an alternative to the
construction of a public waste treatment facility, including a common sewer system. According to Patricia Ballo, Assistant Health Agent for the Town of Orleans, individual Boards of Health for the three towns comprising the GPD have the responsibility to implement an inspection and maintenance program including the authority to inspect on-site septic systems and require their maintenance, and if necessary their repair or replacement in order to protect the town's surface and groundwater resources from pollution (Ballo 1990).

Unfortunately, under the existing mandate of the Tri-town Groundwater Protection District and its Inspection and Management Program, the less visible and more problematic type of on-site septic system failure, characterized by excessively permeable soils and/or shallow depths to groundwater, will not be addressed. According to Wayne McDonald, the GPD's Assistant Director, the Groundwater Protection District's Board of Managers are not aware of any problems associated with excessively permeable soils and inadequately functioning on-site septic systems on Cape Cod and thus, have not considered the need for inspection of such septic system failure (McDonald 1990).

5.7.3 Individual and Centralized Structural Interventions

A second type of adaptive response strategy involves the employment of individual and centralized structural solutions for adapting to higher local groundwater tables. Structural interventions are by their very nature extremely costly to undertake. As previously described, limited fiscal resources has been cited as an extremely important factor in discouraging the implementation of appropriate adaptive response interventions at the local level. In the Eastham sea
level rise GIS vulnerability analysis illustrated in Chapter 4, SEVERE depth-to-groundwater impact zones were identified consisting of relatively small clusters of coastal land area containing both developed and developable privately owned parcels. Biological contaminants could enter any one or more of the private drinking water supply wells located within these zones from a number of different septic systems located within or adjacent and upgradient to these SEVERE impact zone clusters (See Figure 3.6(a)). As such, it would be virtually impossible to determine the specific origin of such biological contamination. Under such a scenario, local government decision makers would not only be required to decide upon the appropriate adaptive response intervention, but also whether the costs the particular intervention should be borne at the expense of the public sector or the impacted private property owner. In fulfilling their responsibility to prevent the degradation and contamination of local groundwater resources and drinking water supplies, local coastal municipalities as well as state environmental protection agencies could insist that individual septic systems located in SEVERE impact zones be replaced, at the owner's expense, in response to current sea level rise scenarios and future increases in local groundwater elevations.

Arguably, the responsibility for protecting the public's health and safety belongs to government and therefore, any structural interventions and associated costs deemed necessary to protect members of the general public from biologically contaminated drinking water should be undertaken by the public sector. This thesis will not endeavor to develop a prescriptive solution for what is a local government decision making function. Instead, it will refer to particular structural adaptive response interventions as either
"individual" or "centralized" and will leave the issue of their respective cost responsibilities with the appropriate governmental decision making process.

5.7.3.1 Individual Structural Intervention

(i) On-site Septic System Replacement - Conditional permit requirement for construction and alteration

Chapter 40A of the Massachusetts General Laws gives local municipalities special permit granting authority for allowing the alteration of an existing structure if it is determined that the alteration will not be more detrimental than the existing non-conforming use. Permit applicants whose existing structures are located in SEVERE Impact Overlay Districts and whose septic tank systems do not conform with new more stringently revised on-site septic tank system regulations could be required to upgrade their septic system as a condition of the permit approval.

(ii) Conditional Requirement for local Real Estate Transfer

All sales and property transfers of developed property located in SEVERE Impact Overlay Districts could be conditioned upon a favorable site inspection of existing septic system conducted by the Board of Health. If deemed necessary, a requirement to upgrade an existing septic system could be made a necessary condition of the transfer of property. In some instances, the existing shallow depth-to-groundwater characterizing particular coastal land areas in Eastham will not permit private property owners to meet these more stringent Title V requirements with conventional on-site
septic tank treatment systems. Mounded on-site septic systems will therefore be the only type of remedial individual structural intervention capable of providing the needed depth-to-groundwater distance for the safe on-site treatment of wastewater within the SEVERE zones of groundwater impact. Unfortunately, as shown in Table 5.2, individual mound systems have the highest cost of any individual or centralized structural intervention. Requiring such a structural intervention for affected individual homeowners could pose a significant economic burden to the property owner which he or she is incapable of addressing.

Another alternative to a individual structural intervention strategy includes the development of a more localized wastewater treatment facility which might be devised so as to service only those private land uses located in a coastal community's SEVERE impact zoning district. Under such an intervention, wastewater from the individual on-site septic systems located in the SEVERE zones could be collected and removed off-site to a suitable location for either in-ground sand filter application, wetland discharge or spray irrigation.

In Anne Arundel County Maryland, the Mayo Peninsula Water Reclamation Facilities integrates a centralized or "cluster" adaptive intervention to local wastewater management (Lambert 1990). This particular innovative solution, used on the eight square mile Mayo peninsula, was designed to address problems concerning on-site wastewater management and local drinking water quality, problems similar to those which could be incurred by the Town of Eastham under the current range of sea level rise scenarios. More specifically, the Mayo system clusters 79 homes, otherwise located in coastal areas with significant environmental constraints including high water
tables and extremely permeable soils, and uses a communal leaching field, located off-site, to treat the residential wastewater from the cluster.

Table 5.2
Cost Comparison of Structural Interventions for Sea Level Rise

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Average cost/hu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INDIVIDUAL SYSTEMS</strong></td>
<td></td>
</tr>
<tr>
<td>Repair &amp; Replace-</td>
<td></td>
</tr>
<tr>
<td>Std. Septic Tank</td>
<td>$1200-3000</td>
</tr>
<tr>
<td>Mound Systems</td>
<td>6500-7700</td>
</tr>
<tr>
<td>Sand Filters</td>
<td>3000-4200</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>3000-7500</td>
</tr>
<tr>
<td><strong>CENTRALIZED SYSTEMS</strong></td>
<td></td>
</tr>
<tr>
<td>(500,000 gpd)</td>
<td></td>
</tr>
<tr>
<td>Secondary Treatment</td>
<td>1432-2231</td>
</tr>
<tr>
<td>Tertiary Treatment</td>
<td>736-1085</td>
</tr>
<tr>
<td>Lagoons</td>
<td>431-917</td>
</tr>
<tr>
<td>Marshpond/Wetland</td>
<td>340-910</td>
</tr>
<tr>
<td>Sand Filter</td>
<td>1100-2400</td>
</tr>
<tr>
<td>Spray Irrigation</td>
<td>110-330</td>
</tr>
<tr>
<td>Public Well Water Supply Systems</td>
<td></td>
</tr>
<tr>
<td>Wellfield &amp; Pump Station</td>
<td>1600-2200</td>
</tr>
</tbody>
</table>

* estimates include Capitol Costs + Operation and Maintenance based on 5000 total Housing Units

Sources: (Wastewater Management: Alternative Small Scale Treatment Systems 1985, SEA Consultants Inc. 1985)

5.7.3.2 Centralized Structural Intervention

(i) Wastewater treatment

As shown in Table 5.2, the development of a centralized wastewater treatment facility could prove to be less costly per household than an option requiring the upgrading and
replacement of an existing individual on-site septic system. Furthermore, a centralized wastewater treatment facility could provide additional environmental "tie-in" benefits including; the amelioration of local concerns for safe quality drinking water and the degradation to inter-tidal marine habitats. In rural coastal areas, pathogens, which successfully reach the groundwater from domestic on-site septic tank systems, can be transported by groundwater flowing through highly permeable sand aquifers to the semi-enclosed inter-tidal waters of adjacent bays and estuaries where they can become effectively trapped. Human pathogens have been shown to survive in marine and estuarine environments for periods of many months (Jones 1971). High levels of fecal coliform bacteria in estuarine and bay waters have resulted in restrictions to shellfish harvesting. Throughout the United States the incidence of shellfish borne viral disease is believed to be increasing (Goyal 1984, Morse et al. 1986). In Massachusetts, the total number of acres of shellfish beds that have closed due to bacterial contamination of shellfish has increased by more than 43% since 1980 (McLaughlin 1989). Sub-surface domestic sewage disposal systems, located in rural coastal communities along Cape Cod and the Islands, are believed to be responsible for over 90% of the shellfish bed closures in those areas (Hickey 1986).

Of particular importance in determining the benefits of a centralized structural intervention is the determination that its development will not cause unaccounted for adverse secondary impacts which could diminish the facility's intended benefits. More specifically, the development of a centralized wastewater treatment facility raises serious concerns for the prospect of increased growth and development which could
result from removing existing environmentally based local land use restrictions including those pertaining to nitrate loading and on-site septic system requirements.

It is not clear whether such a facility could be designed with a limited capacity cap commensurate with the community's existing "zoning blue print" buildout capacity. Furthermore, it is possible that the final disposal of centrally treated wastewater could adversely impact the existing quality of local groundwater resources and drinking water supplies. For example, in the Town of Barnstable, Massachusetts the public waste treatment facility applied its secondary treated wastewater to on-site leaching fields causing elevated concentrations of nitrate in the groundwater located down gradient from the treatment facility's leaching field (SEA Consultants, Inc. 1985). The disposal of secondary treated wastewater to open water bodies, including coastal embayments, raises serious environmental impact concerns and regulatory questions whose mitigation could become too costly to be economically feasible.

ii) Centralized water supply

As illustrated by the scoping study in Chapter 4, a sea level rise of 27 inches over the next 60 years may affect a significant amount of privately owned property in the Town of Eastham. These impacts could result in serious degradation of many of Eastham's existing private drinking water wells further exacerbating the town's drinking water quality concerns. For example, in 1968, the Town of Eastham, responded to concerns of poor local water quality and sought federal assistance in developing a public water supply and distribution system (Whitman and Howard Inc. 1968). The town
contemplated the authorization of a $1.9 million dollar (1968 dollars) general obligation bond to construct the necessary wells, pumping stations and water mains with which to deliver potable water to more than half of its then existing population (Whitman and Howard Inc. 1968). For the Town of Eastham, the development of a public water supply system, once thought to be too expensive for mitigating the town's concerns for drinking water quality, could be viewed as affordable and attractive if considered in combination with its "tie-in" benefits as an adaptive response to the environmental impacts to local drinking water supplies associated with sea level rise and raised groundwater tables.

5.7.4 Temporary Use, Relocation and Acquisition

The third type of local adaptive response strategy could be considered the most stringent and perhaps the most costly of all the interventions listed in Table 5.1. Under such an intervention, owners of private property located in areas designated as SEVERE Impact Overlay Districts would contractually agree to continue to enjoy the use of their property until their properties actually became severely impacted by sea level rise and raised groundwater tables. Properties thus impacted and prevented from repairing or replacing their on-site septic systems, as defined by local municipal ordinances, would be purchased through public funds, and the property owner(s) would agree to relocate to property located away from any SEVERE Impact zoning district. The public's purchase cost under such a contractually-based scheme would be the difference between the property's market rate and the property owner's insurance proceeds. For currently vacant
but developable properties located in SEVERE zones, use of incentives such as Transfer Development Rights (TDR) could prove to be a less costly form of this type of intervention.

The public acquisition of impacted property could take place at the local, state or federal level. Under the federal government's Flooded Property Purchasing Program, (Section 1362 National Flood Insurance Act of 1968), the Federal Insurance Agency can purchase structures "seriously damaged" by a storm event or located in areas where existing regulations or ordinances preclude their repair (Godschalk 1989, Milleman 1989). Conceivably, a high groundwater table "flooding" of existing on-site septic systems could constitute serious damage under the federal program.

Public purchase of SEVERE impact land areas could also be coordinated as part of on-going state or municipal Open Space Acquisition programs. In some cases, the decision to acquire a severely impacted property could be coordinated with the decisions of local or regional private conservation organizations and land trusts. However, the use of public purchase and acquisition as a local sea level rise adaptive response intervention could be particularly costly in coastal areas and local communities experiencing significant demands for developable land. Local governments might also be concerned with the fiscal impacts of a public acquisition intervention as it pertains to their tax base.

5.8 Conclusion

Many coastal states and local coastal municipalities have been experiencing natural and man-made problems which have led to the degradation of local natural resources including
erosion, overdevelopment and groundwater contamination. Our society, however, tends to react only when confronted with an observable crisis. As a result, many of these existing environmental degradation problems persist despite public interest and concern. When available, coastal area inhabitants will seek temporary alternative solutions to existing natural resource problems rather than addressing its causes.

For example, when faced with problems of poor local drinking water quality some coastal residents will choose to boil their water or opt for the purchase of bottled water as a solution to the problem (Glantz 1990). Similarly, consumers have learned to refrain from consuming shellfish harvested from polluted local marine environments or harvested during periods when local inter-tidal marine waters are known to have seasonally high bacteriological concentrations.

As representatives for these residents and consumers, as well as future generations of residents and consumers, governmental decision makers and environmental policy makers cannot opt for such temporary solutions to such persisting environmental problems. State government, including environmental management agencies and coastal zone management programs, along with local coastal municipalities share in both the environmental risks and the responsibilities associated with the environmental changes and impacts that could occur from rising sea levels. Together they are capable of addressing these impacts in a comprehensive and systematic manner. An appropriate local adaptive response strategy for protecting coastal groundwater resources from the potential impacts of an ongoing sea level rise does not necessarily need to be complex to be effective. It will, however, require response interventions that are politically feasible, and conditionally flexible.
Linking sea level rise risk management to existing and more tangible issues such as coastal erosion, natural subsidence, groundwater contamination, septic system failure and flood protection provides an opportunity for developing adaptive response interventions which have important associative "tie-in" benefits. Coastal states and local coastal municipalities could and should undertake efforts to address the impacts of sea level rise to their local groundwater resources and drinking water supplies by incorporating site-specific adaptive sea level rise response interventions within the milieu of existing state and local regulations designed to protect the public's health and safety.
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