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THE ECONOMIC IMPACTS OF SEA LEVEL RISE ON THE CHARLESTON, SOUTH CAROLINA AREA

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FORWARD

This paper summarizes the results of a case study of the possible impacts of sea level rise on the Charleston, South Carolina area over the next century. The case study consisted of two parts: (1) an assessment of the physical effects and (2) an assessment of the economic impacts. These two components of the study, performed by Kana et al., and Gibbs, respectively, are published in:

- "Sea Level Rise Project Papers," March 30, 1983, Capital Hilton Hotel, Washington, D.C.; and
- Greenhouse Effect and Sea Level Rise: A Challenge for This Generation, Michael C. Barth and James G. Titus, eds. New York, New York: Van Nostrand Reinhold, due to be published in 1984.

Readers interested in further detail on sea level rise and its causes may refer to:

- "Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2100, and Research Needs," J. Hoffman, D. Keyes, and J. Titus, U.S. Environmental Protection Agency. U.S. GPO No. 055-000-00236-3. Washington, D.C.: U.S. Government Printing Office, October 24, 1983, second revised edition.

Comments are welcome and should be sent to Jim Titus (PM-220), U.S. EPA, Washington, D.C. 20460. Copies of "Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2100, and Research Needs" are available from the U.S. Government Printing Office.

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I. INTRODUCTION

Like many coastal communities in the eastern United States, the low-lying Charleston, South Carolina area is experiencing erosion and is subject to flooding during intense rainstorms and unusually high tides. Recent studies by the National Academy of Sciences (NAS) and the U.S. Environmental Protection Agency (EPA) imply that these coastal problems could worsen substantially over the next century as a result of sea level rise. The rates of rise predicted by NAS and EPA could have substantial impacts that may become major issues to local governments, planners, developers, coastal managers, highway officials, and homeowners.

This paper examines the consequences of a rise in sea level on the Charleston, South Carolina area. The pilot study for Charleston first examined the consequences to the area if it failed to anticipate sea level rise. Under these conditions, the economic impacts to the city could range from $1.3 billion to $1.9 billion by 2075.

Then, we estimated the costs to the area assuming that Charleston took actions in anticipation of sea level rise. Under the conditions examined, the Charleston area could reduce its economic losses by over 60 percent. Some of the actions considered include: constructing a sea wall or levee around Charleston Peninsula, building a low levee system in the area near Wappo Creek and clustering new development in its protected area, prohibiting new development near the first bend in the Ashley River, developing Mt. Pleasant in a manner that minimizes shoreline losses, and greatly reducing investment in Sullivans Island. While the actions examined for the Charleston area are reasonable options that the community might consider, they are not a blueprint for planning. We made no attempt to determine which response or set of responses would be the best one for the community to adopt. Although Charleston could save millions of dollars by planning for a rise in sea level, the city may need more accurate projections of sea level rise to do so.

This report summarizes the reasons for expecting a significant rise in sea level, the results of a pilot study on the physical and economic effects of sea level rise on Charleston, some types of anticipatory actions that the community could take, and estimates of the economic impacts to the area when such actions are undertaken.

2. BASIS FOR EXPECTING A SIGNIFICANT RISE IN SEA LEVEL

A planet's temperature is primarily determined by the amount of sunlight it receives, the amount of sunlight it reflects, and the amount of heat retained by its atmosphere. Visible light from the sun penetrates the atmosphere and warms the surface, which radiates back into space as infrared radiation. Carbon dioxide (CO_2), water vapor, oxygen, and some trace gases absorb infrared radiation, keeping the earth 30°C warmer than it would otherwise be. Because the atmosphere allows light to penetrate but retains heat much like the glass panels of a greenhouse, this phenomenon is known as the "greenhouse effect."

The greenhouse effect is not merely a hypothesis. The extent to which CO_2 absorbs heat has been known since 1896. More recently, studies of CO_2

levels and temperatures on Mars and Venus have demonstrated conclusively the importance of the greenhouse effect in determining a planet's temperature.

Our understanding of the greenhouse effect has become particularly important over the last decade as we have come to realize that we are changing the natural concentrations of the greenhouse gases in the atmosphere. The most frequently discussed greenhouse gas, carbon dioxide, is increasing in atmospheric concentration, primarily due to the burning of fossil fuels.

The National Academy of Sciences reports that the doubling of atmospheric carbon dioxide expected in the next century will raise the earth's temperature by 1.5°C to 4.5°C (3°F to 8°F).[1] The World Meterological Organization and others estimate that emissions of methane, nitrous oxides, chlorofluorocarbons, and other trace gases could add 50 to 100 percent to the warming from CO_2 alone.[2]

One important impact resulting from this projected global warming is that sea level may rise. Currently, there is a large degree of uncertainty surrounding many of the factors influencing the climate and sea level. Consequently, available scientific knowledge is inadequate to generate a precise forecast of the rate of warming-induced sea level rise. However, a global warming could lead to sea level rise via any of three mechanisms. First, the upper layers of the oceans could warm and thus expand. Second, snow and ice from mountain and polar glaciers could melt and run off into the

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[1] Charney, J., Chairman, Climate Research Board. Carbon Dioxide and Climate: A Scientific Assessment. Washington, D.C.: National Academy of Sciences Press, 1979.

[2] World Meterological Organization. "WMO Global Ozone Research and Monitoring Project, Report No. 14," 1982.

sea. Third, parts of the polar sheets in West Antarctica, East Antarctica, and Greenland could slide into the sea, raising the sea level by displacing the oceans' waters.

Recent scientific studies have estimated the possible rise in sea level for the next century. One study, conducted by Roger Revelle of the National Academy of Sciences, projects a worldwide rise of 70 cm (2.3 ft) by 2075.[3] The actual rise may be greater, however, because Revelle assumed that there would be no additional contribution to sea level rise from Antarctica.

Hoffman et al. used assumptions, models, and data provided by the NAS, Goddard Institute for Space Studies, U.S. Department of Energy, Oak Ridge Associated Universities, and others to develop a variety of scenarios for worldwide sea level rise.[4] The scenarios take into account each of the major sea level rise determinants and their uncertainties.[5] These scenarios predict that the global sea level could rise between 26 cm (0.9 ft) and 39 cm (1.3 ft) by 2025 and 91.2 cm (3.0 ft) and 136.8 cm (4.5 ft) by 2075. However, their study states that a rise as low as 56.2 cm (1.8 ft) or as high as 345.0 cm (11.3 ft) cannot be ruled out.

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[3] Revelle, R. "Probable Future Changes in Sea Level Resulting from Increased Atmospheric Carbon Dioxide," in Changing Climate, Carbon Dioxide Assessment Committee. Washington, D.C.: National Academy Press, 1983.

[4] Hoffman, J., et al., U.S. Environmental Protection Agency. "Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2100, and Research Needs." U.S. GPO No. 055-000-00236-3. Washington, D.C.: U.S. Government Printing Office, October 1983, second revised edition.

[5] The factors about which assumptions were varied include: CO_2 emissions, the fraction of carbon emissions that remains in the air, trace gas concentrations, climate sensitivity, thermal expansion of the oceans, and the impact of a global warming on the deglaciation of land-based snow and ice.

The case study of Charleston used four scenarios of sea level rise, shown in Table 1. The trend scenario assumes a continuation of Charleston's historical rate of change in relative sea level. The low, medium, and high scenarios are consistent with the estimates of Revelle and Hoffman et al. The high and trend scenarios are both extremely unlikely, but are included for completeness because they cannot be ruled out.

TABLE 1

SEA LEVEL RISE SCENARIOS FOR CHARLESTON:
1980 to 2075
in centimeters (feet)

Scenario	1980	2025	2075
Trend	0	11.2 (0.4)	23.8 (0.8)
Low	0	28.2 (0.9)	87.6 (2.9)
Medium	0	46.0 (1.5)	159.2 (5.2)
High	0	63.8 (2.1)	231.6 (7.6)

3. DESCRIPTION OF THE CHARLESTON, SOUTH CAROLINA STUDY AREA

Physical Setting

The Charleston study area consists of the land around Charleston Harbor, which is formed by the confluence of the Cooper, Ashley, and Wando Rivers (see Figure 1). It includes all of Charleston and parts of North Charleston, Mount Pleasant, Sullivans Island, and James Island.

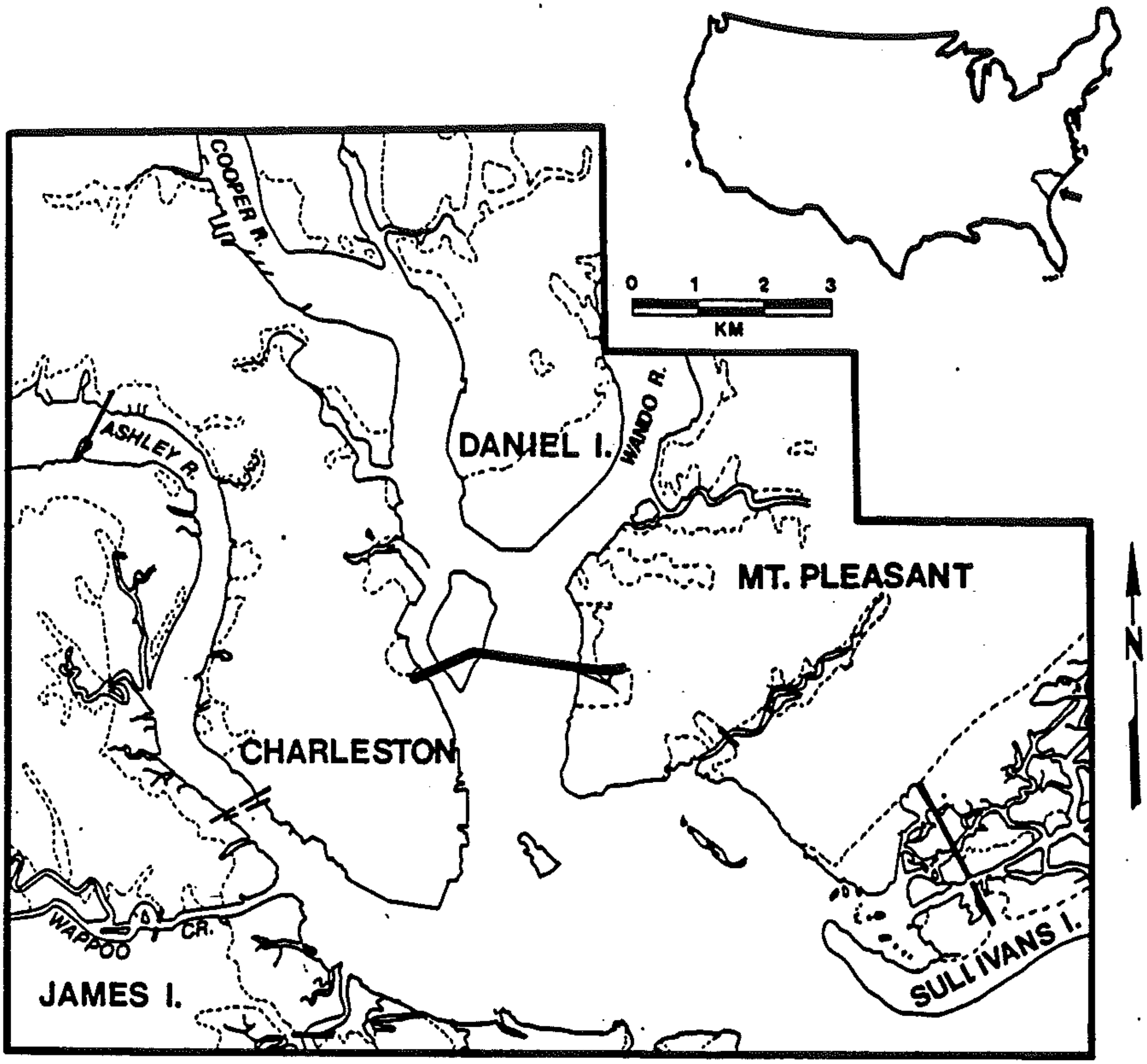

FIGURE 1. CHARLESTON STUDY AREA

Lower Charleston Peninsula, in the center of the study area, has a maximum elevation of only 6 meters (20 feet) and includes several low-lying areas that have been reclaimed from the harbor. North Charleston, on the upper part of the peninsula, has elevations up to 10 meters (33 feet). West Ashley, to the west of the peninsula, has elevations of 3 meters or less, and Mount Pleasant has elevations between 3 and 10 meters. Sullivans Island is a narrow barrier island with an average elevation of less than 3 meters above sea level. Due to the jetty that protects Charleston Harbor and collects sediment, much of the island's ocean beach is currently accreting.

Although the Charleston area does not have a history of extensive hurricane damage, its 2 meter tidal range exposes parts of the area to periodic flooding. Thus, the only major flood protection structure in Charleston is the Battery. This sea wall, located at the tip of the Lower Charleston Peninsula, has a maximum elevation of 6 feet above sea level. It protects Charleston from a 10-year storm, but not a 100-year storm.

Economic Development

The southern end of Charleston Peninsula has a densely populated historic district and other residential, commercial, and port areas. The central peninsula consists of industrial parks and marshland; and the upper peninsula (North Charleston) has a combination of residential areas and industry, including a large naval reservation.

Because most of the peninsula is already highly developed, its potential for growth is limited. Some shifts in land use are expected, primarily to more high-density development. Its population and employment are expected to grow about 16 percent in the next twenty years.

West Ashley and James Island consist mostly of low-density single-family housing. Future development in these communities will be mostly single-family housing on currently-vacant land.

Mount Pleasant, a commuter town with light commercial development, has the greatest potential for growth of any community in the study area. Most of this growth will be in the form of additional housing. However, industrial development is expected in the northern parts of this community.

Sullivans Island, a residential and resort community, has been extensively developed with single-family homes. Its zoning regulations currently prohibit high-rise and condominium construction. Changes in those regulations would be a prerequisite to any substantial growth on Sullivans Island.

4. THE IMPACTS OF SEA LEVEL RISE IF CHARLESTON FAILS TO PREPARE

The first analysis of the physical and economic impacts of sea level rise on the Charleston area was performed assuming that the community does not take action in anticipation of sea level rise, but only in response to it. The next section describes how anticipating sea level rise may reduce these impacts. While the effects of all four scenarios are displayed in the tables presented below, the discussion centers on the low and medium scenarios, which are the most likely.

The results presented in this section should be viewed with extreme caution. They are approximations for illuminating our understanding of sea level rise, not precise forecasts of the fates of particular city blocks.

Physical Impacts

The physical consequences of sea level rise can be broadly classified into four categories: shoreline retreat caused by erosion and inundation, increased flooding from storms, higher water tables, and salt intrusion into surface and fresh water. This paper discusses only shoreline retreat and storm flooding.[6]

Kana et al. estimated the impacts of sea level rise on shoreline retreat and storm flooding under the assumption that no additional protective measures would be implemented (e.g., sea walls, bulkheads). They also assumed that existing protective structures would withstand the increased stresses expected with sea level rise.[7]

A rise in sea level would cause shorelines to retreat (i.e., move inland) in two ways. First, they would retreat because the land lying below the future (higher) sea level would be permanently flooded (inundated). Additionally, some coastal areas with sufficient elevation to avoid being inundated could be lost to erosion. Coastal geologists have shown that a rise in sea level of one foot can cause beaches to erode one to several hundred feet.

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[6] Kana et al. found that Charleston's fresh/salt water interface could shift landward by up to 60 meters (200 feet). Because the continued pumping of the area's coastal aquifers will result in much more severe salt water intrusion than that predicted from a rise in sea level, the 60-meter shift was considered of negligible importance.

[7] For a full discussion of the assumptions and methods used to predict the physical and economic consequences of sea level rise, the reader should refer to: <u>Greenhouse Effect and Sea Level Rise: A Challenge for This Generation</u>, <u>op</u>. <u>cit</u>.

A rise in sea level could cause increased storm damage. Kana et al. assumed that water levels during floods would increase in elevation by the amount of sea level rise, resulting in new areas becoming vulnerable to storm damages and greater damage to areas that are already vulnerable. For protected areas, they assumed that there would be no flooding unless storm surges were high enough to overtop barriers. Once a barrier was overtopped, they assumed that the water level on the protected side would rise to the level to which it would have risen without the barrier.

Table 2 summarizes the impacts of sea level rise on shoreline retreat and on the 10- and 100-year flood zones for the years 2025 and 2075 under the four

TABLE 2

CHARLESTON STUDY AREA:
SUMMARY OF DIRECT PHYSICAL IMPACTS BY SCENARIO
square kilometers (percent of total area)*

Scenario	Year	Area Lost Due to Shoreline Movement	Area in 10-Year Flood Zone**	Area in 100-Year Flood Zone**
No Sea Level Rise:	1980	--***	30.8 (32.9)	59.2 (63.2)
Trend	2025	1.8 (1.9)	32.9 (35.1)	61.1 (65.2)
	2075	3.9 (4.2)	34.9 (37.2)	62.9 (67.1)
Low	2025	4.9 (5.2)	35.7 (38.1)	63.7 (68.0)
	2075	14.2 (15.1)	45.0 (48.0)	71.2 (76.0)
Medium	2025	7.8 (8.3)	38.6 (41.2)	66.0 (70.4)
	2075	28.7 (30.6)	58.5 (62.4)	78.7 (84.0)
High	2025	13.0 (13.9)	41.4 (44.2)	68.4 (73.0)
	2075	43.0 (45.9)	69.4 (74.1)	83.9 (89.5)

* One square kilometer equals 0.38 square miles.
** Includes area lost due to shoreline movement.
*** Total area in 1980 is 275 square kilometers.

scenarios. If only current shoreline retreat trends continue, the study area would lose 4.2 percent of its land by 2075, mostly on Sullivans Island and in the marshes along Charleston Harbor. Under the low scenario, the study area would lose 5.2 percent of its land by 2025 and 15.1 percent by 2075. Under the medium scenario, it would lose 8.3 percent by 2025 and 30.6 percent by 2075. The impacts of the high scenario in 2025 are slightly less than the impacts of the low scenario in 2075.

Figure 2 illustrates the projected locations of mean high spring water under the low and medium scenarios in 2075. The present shoreline shown in the figure is the current location of mean high spring water. This location represents the current limit on development because the area between mean high spring water and mean sea level (shown as the solid line in Figure 2) is periodically inundated, and consequently cannot be developed. As shown in Figure 2, developed portions of the Charleston Peninsula would not be threatened by shoreline movement under the low scenario, partly because of the existing sea wall and bulkheads. However, these protective structures would not prevent the inundation of a significant portion of the peninsula by 2075 under the medium scenario. The West Ashley/James Island area is also vulnerable, while Mount Pleasant would be the least affected. Under the medium scenario, Sullivans Island could lose the first one or two rows of houses along the ocean by 2025, and would migrate landward by its own width by 2075, destroying virtually all existing development.

Table 2 shows that about one-third of the study area is currently in the 10-year floodplain, and about two-thirds is within the 100-year floodplain. While the projected effects on flood-zone boundaries are small for both the low and medium scenarios in 2025, by 2075 under the low scenario, almost

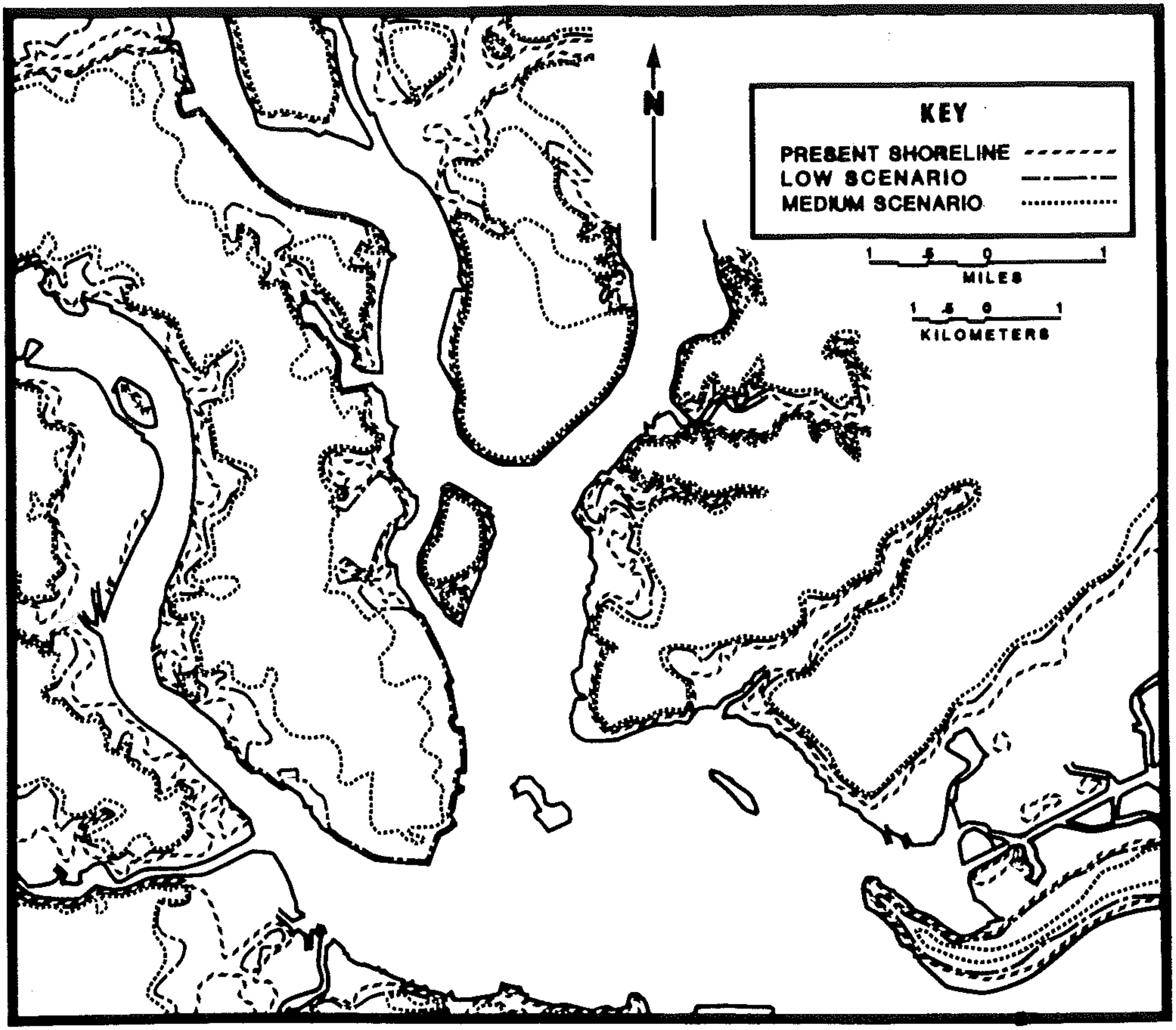

FIGURE 2. SHORELINE RETREAT UNDER THE LOW AND MEDIUM SCENARIOS FOR 2075

one-half the study area would be in the 10-year floodplain, and three-quarters within the 100-year floodplain.

Under the medium scenario, over 60 percent of the study area would be within the 10-year floodplain by 2075, and 84 percent would be in the 100-year floodplain. Some new areas of residential property would be located in the 100-year flood zone under this scenario, particularly between the Ashley River and Wappo Creek. Nearly all of Sullivans Island would be in the 10-year flood zone. Also, by 2075 under the medium scenario, a 10-year storm would flood an area which is approximately equal to the area that a 100-year storm would flood today.

Economic Impacts

To estimate economic impacts, Gibbs projected the area's development and land use over the next one hundred years. Charleston's economic activities would be influenced by the physical impacts of sea level rise (i.e., shoreline movement and storm damage) as well as the actions individuals and the community take in response to sea level rise (i.e., building protective structures).

Estimating the economic impacts requires that several possible responses to sea level rise be considered. Responses might include sea walls, levees, beach nourishment, and other engineering responses, as well as planning responses such as altering the mix of development, curtailing development, or abandonment. It is not possible to predict precisely how individuals and communities would respond to a rise in sea level. Nevertheless, it was necessary to specify a scenario to conduct the economic analysis.

Table 3 displays the actions Gibbs examined in the low and medium scenarios. In the low scenario, he assumed that actions would only be taken to reduce the rate of shoreline movement. Gibbs assumed the rate of shoreline movement in the peninsula and West Ashley/James Island areas would be reduced by 75 percent beginning in 2050. This reduction could be achieved using levees, bulkheads, rip-rap, or other shore protection methods.

In the medium scenario, Gibbs assumed that more actions would be taken because this scenario's physical impacts will be larger and more visible sooner. He assumed that actions would be taken first in 2020 to reduce shoreline movement in the peninsula and West Ashley/James Island areas. He assumed that more substantial measures are taken by building a sea wall in 2060 on the peninsula to stop all shoreline retreat and to protect it from the 100-year storm, and building a low levee system in the West Ashley/James Island area to reduce the rate of shoreline movement by an additional 75 percent. Gibbs assumed that bulkheads would be built in 2050 in the Mount Pleasant and Sullivans Island areas to protect new and existing development threatened by shoreline movement. He assumed that no investment would be made on Sullivans Island after 2070 because of increased storm damage and the difficulty in traveling to the mainland.

Table 4 shows Gibbs' projections of economic impacts on the Charleston area.[8] The table shows that in the low scenario, the impact of sea level

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[8] Because the values in Table 4 are present values of streams over long periods, the discount rate used to summarize the values has a significant influence on the estimate. A higher discount rate would result in a smaller economic impact.

TABLE 3

ACTIONS TAKEN IN RESPONSE TO SEA LEVEL RISE*

	Low Scenario	Medium Scenario
Peninsula		
Shoreline Retreat	Reduce rate by 75% after 2050	Reduce rate by 50% after 2020 Stop retreat in 2060
Storm Surge	No action	Stop retreat in 2060 for all surges below the 100-year storm surge elevation (22 ft.)
Investment	No action	No action
West Ashley/James Island		
Shoreline Retreat	Reduce rate by 75% after 2050	Reduce rate by 50% after 2020 Reduce rate by 75% after 2060
Storm Surge	No action	No action
Investment	No action	No action
Mt. Pleasant		
Shoreline Retreat	No action	Stop damages in 2050
Storm Surge	No action	No action
Investment	No action	No action
Sullivans Island		
Shoreline Retreat	No action	No action
Storm Surge	No action	No action
Investment	No action	Stop in 2070

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* Actions for the High Scenario are shown in Appendix A.

TABLE 4

ECONOMIC IMPACTS OF THREE SEA LEVEL RISE SCENARIOS ON THE CHARLESTON STUDY AREA AT A THREE PERCENT DISCOUNT RATE FOR TWO PERIODS OF TIME*
(millions $1980)

	1980-2025	1980-2075
Scenario:		
Low	280	1,250
	(4.9)**	(17.3)
Medium	685	1,910
	(12.0)	(26.5)
High	1,065	2,510
	(18.7)	(34.8)

* Values are estimated as:

Impact = Economic value for trend scenario - economic value for ___ scenario, where the blank is either low, medium, or high.

** Values in parentheses report percentage of total value of economic activity estimated in the trend case.

rise will be more than $1 billion by 2075 (evaluated at a 3 percent discount rate). Relative to the trend scenario, this is more than a 17 percent reduction in the value of the economic activity in the study area over the 100-year period analyzed. Under the medium scenario, this figure would exceed $1.9 billion, reducing the area's economic activity by almost 27 percent.

5. THE POTENTIAL FOR AVOIDING DAMAGES BY PREPARING FOR SEA LEVEL RISE

The adverse impacts of sea level rise can be reduced substantially if communities and individuals prepare for it. This section briefly describes a variety of preparatory actions that may be appropriate given the rates of sea level rise discussed in this paper. Then, we present the results of the economic analysis, which demonstrate how one set of preparatory actions could substantially reduce the impacts of sea level rise. The actions examined in the analysis would not necessarily be optimal.

Potential Preparatory Actions

The variety of actions that may be taken in anticipation of sea level rise can be divided into engineering options and planning options. Engineering options generally attempt to reduce the physical impacts of sea level rise by building physical barriers. These options may include: bulkheads, sea walls, levees, revetments, and off-shore breakwaters. Although they do not necessarily require building artificial structures, artificial beach nourishment, dune building, and marsh building can also be considered engineering solutions to shoreline problems caused by sea level rise.

Planning options differ from engineering options in that they do not attempt to influence the physical impacts of sea level rise. Instead, people take actions to adapt to the expected physical changes. Examples of planning options include:

- establish land use policies that permit only certain types of development in low-lying areas;
- require new construction to be elevated to a height that includes the potential for sea level rise during the expected lifetime of the building;

- allow new development to take place only in designated areas which either will not be affected by sea level rise or can be protected (e.g., with an engineering option);
- establish post-disaster plans that prohibit rebuilding or repairing properties which would subsequently be lost due to sea level rise;
- reduce investment in areas of rapidly-increasing hazard; and
- postpone investment in areas of potential hazard until the risks from sea level rise are better understood.

Each of these options may be valuable in the Charleston study area. For example, sea walls and bulkheads may be appropriate for the peninsula area. Alternatively, post-disaster plans could be a reasonable approach for Sullivans Island.

In Section 4, we included several engineering solutions that could be expected to be taken in response to sea level rise. By anticipating sea level rise, the same actions may be taken sooner, they may be taken in conjunction with various planning options, or completely different actions may be warranted. The best set of actions for a particular area will depend on the costs and benefits of each. These costs and benefits will in turn depend on the area's existing and future economic development, topography, and vulnerability to sea level rise. Consequently, a detailed site-specific analysis would be required to develop a complete plan for anticipating sea level rise. As we have mentioned, such a plan is outside the scope of this paper.

The Value of Anticipating Sea Level Rise

As shown in Table 5, anticipating sea level rise is defined as leading to more actions being taken in the low scenario than when sea level rise is not anticipated (Table 4). In 2030, the community builds a sea wall around the peninsula which would halt shoreline movement and protect the area from the 100-year storm, while West Ashley/James Island undertakes an enclave strategy: beginning in 2050, all new development takes place in a protected area around Wappo Creek and investment near the first bend in the Ashley River is reduced.

From 1990 on in the Mount Pleasant area, development proceeds in a manner that minimizes losses due to shoreline retreat. This would possibly entail building larger and higher revetments, bulkheads, and piers than would otherwise be called for. Additionally, the choice of development location could be influenced. Finally, Gibbs assumed that investment is halted in Sullivans Island starting in 2070.

The actions examined for the medium scenario are similar to the set used for the low scenario, but the community takes them sooner (see Table 5).[9]

These actions would require significant cooperation among a variety of jurisdictions in the Charleston area. Protecting the peninsula would involve the cities of Charleston and North Charleston, and the federally-owned naval facility on the northeastern portion of the peninsula. The area west of the Ashley River includes James Island, the City of Charleston, and some unincorporated land controlled by the county. Also, a new highway, the Mark

[9] Appendix A presents the results for four Charleston-area communities under the high scenario to illustrate the value of actions taken in anticipation of sea level rise.

TABLE 5

ACTIONS TAKEN IN RESPONSE TO SEA LEVEL RISE AND IN ANTICIPATION OF SEA LEVEL RISE

	Low Scenario	Medium Scenario
Peninsula		
Shoreline Retreat	Reduce rate of retreat after 2030	Reduce rate of retreat after 2010
Storm Surge	Stop in 2030 for all surges below the 100-year storm surge elevation (18 ft.)	Stop in 2010 for all surges below the 100-year storm surge elevation (22 ft.)
Investment	No action	No action
West Ashley/James Island		
Shoreline Retreat	Enclave strategy (2050)	Enclave strategy (2030)
Storm Surge	No action	No action
Investment	No action	No action
Mt. Pleasant		
Shoreline Retreat	Stop damages in 1990	Stop damages in 1990
Storm Surge	No action	No action
Investment	No action	No action
Sullivans Island		
Shoreline Retreat	No action	No action
Storm Surge	No action	No action
Investment	Stop in 2070	Stop in 2030

Clark Expressway, is anticipated to be constructed west of the Ashley River. Thus, implementing the enclave strategy (used here for analysis purposes) may be very difficult. Implementing an effective set of community actions will likely require a mechanism for performing regional planning. The time lags involved in establishing and developing such a regional planning authority could be an important factor affecting the magnitude of the impact of sea level rise.

In addition to these community actions, it is likely that private individuals will change their investment behavior in anticipation of sea level rise. To assess the impact of this changing behavior, we examined the implications of slight reductions in private investment in areas of increasing hazard. These reductions reflect the likelihood that individuals will naturally reduce their fixed capital investment in areas that repeatedly experience increasing levels of storm damage.

The overall effects of the various anticipatory actions on the study area are:

- Peninsula: less area is lost to shoreline movement and less storm damage occurs because a sea wall is built sooner.
- West Ashley/James Island: the enclave strategy results in a small, protected, and intensively developed area.
- Mount Pleasant: losses due to shoreline movement are reduced by incorporating future sea level rise into current and future designs.
- Sullivans Island: investment is reduced so that when losses do occur (from shoreline movement or storms), there is less development to be lost or damaged.

These diverse influences on the area's development are summarized in the calculation of the value of the area's economic activity. Table 6 reports

TABLE 6

CHARLESTON AREA'S VALUE OF ECONOMIC ACTIVITY (1980-2075) AND VALUE OF ANTICIPATING FUTURE SEA LEVEL RISE

(Millions of 1980 Dollars;
Evaluated at a 3 Percent Real Discount Rate)

Scenario	Total Value of Economic Activity	Economic Impact Relative to Trend Scenario*	Savings Due to Planning**
Low, without Anticipation	5,965	1,250	-
Low, with Anticipation	6,775	440	810 (65)
Medium, without Anticipation	5,305	1,910	-
Medium, with Anticipation	6,485	730	1,180 (62)
High, without Anticipation	4,705	2,510	-
High, with Anticipation	6,105	1,110	1,400 (56)

* Value of economic activity in trend scenario was estimated at $7.215 billion.

** Values in parentheses report percentage of area's total economic impact.

these values for the low, medium, and high scenarios, with and without anticipation of sea level rise for the period 1980-2075. Gibbs estimated the economic impact of each scenario by subtracting the value of the economic activity for that scenario (without anticipation) from the value of the economic activity for the trend scenario. The economic impact of the medium scenario, for example, is $1.91 billion. Anticipating future sea level rise could reduce this impact by 62 percent; the estimated value of anticipation is $1.18 billion.

6. NEXT STEPS

The results presented here suggest that it could be very important for Charleston to plan for sea level rise. The stakes are large, but appropriate preparation could significantly reduce the adverse impacts.

Although the cost estimates presented in this paper lack the precision necessary for developing a plan to address sea level rise, the magnitude of the impacts and the potential for avoiding them strongly suggest that such a plan should be developed. The complete implementation of such a plan may have to wait for improved estimates of future rates of sea level rise. However, the time required to develop or revise a master zoning plan is so long that it could be very risky to delay the entire planning process. Communities that wait for improved estimates run the risk of being unable to address sea level rise once it is verified, or of having to adopt makeshift policies out of the need to "do something."

Even today's knowledge of future rates of sea level rise may be sufficient to influence some planning decisions. For example, some projects that are now being contemplated may be vulnerable to a small increase in the rate of sea level rise, which is almost certain to occur. It may be acceptable to modify such projects based on our current understanding of sea level rise. Other projects may be so vulnerable to large increases that even a very small chance of a large rise would justify changes. Although current knowledge may not be sufficient for developing design specifications, the prudent planner or investor may want to identify the implications of sea level rise for projects. If the analysis points to catastrophic consequences from a rate of rise which cannot be ruled out when the analysis is made, then alternative approaches to the project may be worth considering.

Finally, planning will require a better understanding of the magnitude of future sea level rise. Many public officials, design engineers, and project managers do not feel comfortable planning for sea level rise with today's uncertainty. Alleviating that uncertainty will require both additional research and the dissemination of the results by professional societies and other respected institutions in forms that are useful to decision makers.

Because current uncertainty about future sea level is a major impediment to planning, the value to Charleston of reducing it could be a substantial fraction of the hundreds of millions of dollars that planning might save. Given that Charleston is but one of many U.S. coastal cities, a more accurate understanding of future sea level rise may be worth billions of dollars to this nation alone.

APPENDIX A

THE VALUE OF ANTICIPATING SEA LEVEL RISE FOR THE PENINSULA, WEST ASHLEY/JAMES ISLAND, MOUNT PLEASANT, AND SULLIVANS ISLAND

Tables A-1, A-2, and A-3 show the areas of Charleston that would be lost to sea level rise under the four scenarios as well as areas in the 10- and 100-year floodplains for 1980, 2025, and 2075. These tables show the losses to the area that would occur if no actions were taken in response to or in anticipation of sea level rise.

Table A-4 shows the types of actions that might be taken under the high scenario to lessen or prevent the effects of sea level rise. (See Section 5 for a description of these actions.) Table A-5 shows the economic impact of sea level rise under the high scenario for the four areas of Charleston. This high scenario was based on EPA's least-restrictive set of assumptions, and is consequently viewed as an upper bound. The values presented here are illustrative of the expected impacts under a scenario, which is not believed to be the most likely rate of future sea level rise.

As Table A-5 shows, the Peninsula area would bear the greatest impact in the high scenario, $900 million. By anticipating sea level rise, the anticipatory actions more than offset this adverse impact. This raises the question of whether the peninsula would be better off with protective measures (sea walls and levees), even without sea level rise. The results of our analysis indicate that the benefits of such protection would currently outweigh its costs by an order of tens of millions of dollars. However, the analysis presented here does not consider reduced access to the waterfront, a reduction in the scenic beauty of the area, or environmental impacts.

TABLE A-I

CHARLESTON STUDY AREA: AREA LOST TO SEA LEVEL RISE BY SCENARIO (Square Kilometers)

	1980	2025				2075			
	Area	Trend	Low	Medium	High	Trend	Low	Medium	High
Charleston Peninsula	27.4	0.5	1.0	1.8	2.8	1.0	2.8	7.5	13.2
Mount Pleasant	29.8	.5	1.3	2.1	3.6	0.8	3.6	6.2	10.4
Sullivans Island	2.8	*	0.3	0.5	0.8	*	1.0	2.1	2.3
West Ashley/ James Island	14.0	.5	1.0	1.8	3.1	1.0	4.9	6.0	9.3
Total	74.0	1.5	3.6	6.2	10.3	2.8	12.3	21.8	35.2

* Less than 0.1 square kilometer.

TABLE A-2

CHARLESTON STUDY AREA: AREA IN 10-YEAR FLOODPLAIN BY SCENARIO (Square Kilometers)

	Total Area (1980)	1980	2025 Trend	2025 Low	2025 Med.	2025 High	2075 Trend	2075 Low	2075 Med.	2075 High
Charleston Peninsula	27.4	5.4	6.0	7.0	7.8	8.5	6.7	9.8	14.8	18.9
Mount Pleasant	29.8	8.3	8.8	9.3	9.8	10.4	9.3	11.1	14.2	16.8
Sullivans Island	2.8	2.3	2.3	2.6	2.6	2.6	2.6	2.8	2.8	2.8
West Ashley/ James Island	14.0	6.5	6.7	7.2	7.5	7.8	7.0	8.5	10.9	12.7
Total	74.0	22.5	24.8	26.1	27.7	29.3	25.6	32.2	42.7	51.2

TABLE A-3

CHARLESTON STUDY AREA: AREA IN 100-YEAR FLOODPLAIN BY SCENARIO (Square Kilometers)

	Total Area (1980)	1980	2025				2075			
			Trend	Low	Med.	High	Trend	Low	Med.	High
Charleston Peninsula	27.4	14.7	15.3	16.3	17.3	18.1	16.0	19.4	22.3	24.0
Mount Pleasant	29.8	14.2	14.8	15.5	16.1	16.8	15.3	17.6	20.7	23.8
Sullivans Island	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
West Ashley/ James Island	14.0	11.4	11.7	12.2	12.4	12.7	11.9	12.9	13.7	14.0
Total	74.0	43.1	44.6	46.8	48.6	50.4	46.0	52.7	59.5	64.6

TABLE A-4

ACTIONS TAKEN IN RESPONSE TO SEA LEVEL RISE AND IN ANTICIPATION OF SEA LEVEL RISE: HIGH SCENARIO

	Actions Taken in Response	Actions Taken in Anticipation
Peninsula		
Shoreline Retreat	Reduce rate of retreat by 25% after 2020 Stop retreat in 2050	Stop retreat in 2010
Storm Surge	Stop in 2050 for all surges below 100-year storm surge elevation (24 ft.)	Stop in 2010 for all surges below the 100-year storm surge elevation (24 ft.)
Investment	No action	No action
West Ashley/James Island		
Shoreline Retreat	Reduce rate by 25% after 2020	Enclave strategy (2010)
Storm Surge	No action	No action
Investment	No action	No action
Mt. Pleasant		
Shoreline Retreat	Reduce rate by 75% after 2050	Stop damages in 1990
Storm Surge	No action	No action
Investment	No action	No action
Sullivans Island		
Shoreline Retreat	No action	No action
Storm Surge	No action	No action
Investment	Stop in 2050	Stop in 2010

TABLE A-5

ECONOMIC IMPACT AND VALUE OF ANTICIPATING SEA LEVEL RISE FOR THE HIGH SCENARIO, 1980 TO 2075: CHARLESTON STUDY AREA*

Portion of Charleston Study Area	Economic Impact of High Scenario (% of Study Area)	Value of Anticipating High Scenario (% of Study Area)
Peninsula: Charleston and and North Charleston	900 (36)	950 (68)
West Ashley/James Island	685 (27)	310 (22)
Mount Pleasant	600 (24)	80 (5.7)
Sullivans Island	325 (13)	60 (4.3)
Total Study Area	2,510 (100)	1,400 (100)

* Values are present values in millions of 1980 dollars evaluated at a real discount rate of 3 percent per year.

Nevertheless, if faced with the high sea level rise scenario, major protective structures would be required to prevent the loss of large areas of the highly-developed center of Charleston.

The West Ashley/James Island area would experience the second-highest impacts, $685 million. Without anticipating sea level rise, significant new development would take place over the next 20 to 40 years which would subsequently be either lost to shoreline movement or be subject to increased risks of storm damage. By anticipating sea level rise, the community could limit its development to those areas that can be easily protected with low levees. This strategy offsets nearly 50 percent of the impacts.

The Peninsula and West Ashley/James Island areas account for 63 percent of the impacts and 90 percent of the value of anticipating the high sea level rise scenario in the Charleston study area. Although Mount Pleasant and Sullivans Island both suffer significant impacts, we did not identify responses resulting in significant savings. However, in order for any regional preparation for sea level rise to be implemented, these areas would have to be involved because of the integrated nature of the area's transportation system and commerce.