Chapter 7

Economic Analysis of Sea Level Rise: Methods and Results

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INTRODUCTION

The direct physical effects of sea level rise will have a major influence on the use of the coastal zone throughout the country. An examination of these physical effects is but a first step in estimating the impacts of sea level rise on coastal communities and society. The importance of these impacts will depend on how we prepare for them.

Given our current understanding of the potential for future sea level rise and the opportunities to improve our understanding, we should identify the course of action that would best prepare us for the future. The choice of which actions to take (such as increasing research, constructing protective structures, or altering development patterns) requires balancing uncertain risks and costs.

Because many of the actions to prepare for future sea level rise must; be taken collectively, extensive analysis and political debate on the relative importance of the risks and costs should precede decisions of whether to undertake certain actions. Additionally, individuals must decide for themselves whether the potential for future sea level rise should alter their current and future private activities (such as purchasing oceanfront property).

The objective of the project summarized here is to estimate what is at stake in these public and private decisions. Methods were developed and implemented to answer two questions. First, if we take no special actions to prepare for sea level rise, what is the impact on society if it in fact occurs? And second, by how much can we reduce the impact of sea level rise if we take actions to prepare for it? If the impact is large but we can reduce it substantially through preparation, then the decision regarding how best to prepare is an important one. If the impact is small or preparation has little benefit, then the decision is not so important.

The analyses and results presented below conclude that both the impacts of sea level rise and the value of preparation are large indeed. Based on the analyses of the physical impacts of sea level rise presented in the previous chapters, the economic impact of sea level rise on Charleston and Galveston is estimated to be hundreds of millions, perhaps billions, of dollars. Preparing for future sea level rise could reduce these impacts by over 60 percent in some cases. It appears, therefore, that the stakes are high.

Like the other parts of the project described in this book, the analysis presented in this chapter is a first attempt to examine a relatively unstudied phenomenon. The analysis presented here must be refined and extended in a variety of ways. The estimated impacts of sea level rise reported below are conservative because quantitative estimates could not be made for several effects and the set of preparation actions considered is limited. More refined analyses of selected individual and public actions would improve the precision of the estimates. Nevertheless, the results serve as a first step toward a better understanding of the potential economic and societal impacts of sea level rise.

ANALYTIC METHODS

The methods developed for this analysis are based on the principles of welfare economics. The two quantities investigated, the impact of sea level rise and the value of anticipating sea level rise and preparing for it, were measured in terms of the net economic cost from the viewpoint of a community or study area. As is generally the case with economic analyses, distributional impacts are not valued; that is, if one person gains $10 and another loses $10, the net impact is estimated as zero, with no value placed on the change in the distribution of the $10. Consequently, the distributional and equity implications of sea level rise are not discussed.

This section is divided into two parts: an analysis of economic impacts and an analysis of the value of anticipating sea level rise. Before describing the details of the methods used, the following brief example provides an intuitive feel for the two quantities estimated. The example concerns a hypothetical Community X which, under alternative assumptions, undertakes three sets of economic activities: A, B, and C. The basic approach described in this example is applied below to the Charleston and Galveston study areas.

Community X is a moderate-sized coastal city. Being located on the coast, parts of the city experience erosion and run the risk of being damaged by storms and flooding. The variance of the erosion and storm hazards throughout the city is reflected by existing zoning and development patterns.[1]

If the sea level does not rise over the next 100 years, Community X will carry on a particular set of economic activities; call this Set A. These activities may include manufacturing (a refinery), transportation services (a port), housing for its inhabitants, and tourist and recreation services. Set A may include purchasing goods from other areas (such as raw materials) or supplying goods to other areas (such as finished products). This set of activities will have some economic value, which is called the net economic service value.

If the sea level does rise, Community X may carry on a slightly different set of economic activities; call this Set B. Set B may differ from Set A because areas become inundated. For example, beachfront houses and condominiums may be lost because of shoreline movement. Additionally, storm hazards increase with sea level rise, resulting in increased damages and increased expenditures for repairing damages. Consequently, Set B may include the expenditure of more funds in response to storm damages than Set A. The difference in the values of Set B and Set A is the economic impact of sea level rise. It is important to note that because the economic activities in Community X include trade with other communities, the economic impact of sea level rise may be felt outside Community X, in places that are not physically threatened by rising sea level.

Community X may be better off if it is able to anticipate sea level rise and prepare for it. Anticipation would result in a third set of economic activities, Set C. For example, by anticipating sea level rise, people may decide not to build certain beachfront condominiums because of the anticipated rate of shoreline movement. Were it not for the anticipation of sea level rise, the condominiums would have been built and subsequently lost (or protected at great expense). If the structures are not built, the money that would have been used to build them would be used for something else. The value of anticipating sea level rise is the difference in the values of Set C and Set B.

This example provides several important insights. First, the economic impact of sea level rise is measured by comparing two quantities: the values of the two sets of economic activities defined above as Sets A and B. The choice of those economic activities to be included in the analysis is important. If a particular economic activity is not affected by sea level rise, then the activity may be excluded from the analysis without biasing the results. However, excluding from consideration economic activities that are affected by rising sea level leads to a partial analysis, as discussed below.

Second, the economic impacts of sea level rise will depend on the actions people take in response to their changing environment. The actions people take will define, in part, how activity Set B differs from Set A. Consequently, the consideration of people's behavior is a critical aspect of this analysis.

Finally, this example highlights that the value of anticipating sea level rise is primarily a function of how anticipation changes people's behavior. If in the above example anticipation had no effect, then the resulting economic activities of Set C would be identical to Set B, and anticipating sea level rise would have no value. Therefore, to estimate the value of anticipating sea level rise, an assessment is required of what people might do (individually and collectively) if they knew that sea level was going to rise and had time to prepare for it.

Analysis of Economic Impacts

The objective of this economic analysis is to estimate the impact of sea level rise from the viewpoint of a community or study area. As described above, the study area carries on a set of economic activities over time that produce"net economic services." Net economic services (NES) can be thought of as the returns to a set of investments (gross services) minus the costs of the investments. Sea level rise may affect NES over time by altering the returns and costs of investments that are made in the study area and altering the mix of investments made in the study area. The second mechanism can be considered a feedback response whereby falling returns and increasing costs lead to reductions in future total investment. As explained below, property values may be used to measure NES.

This section is divided into three parts. First, the components of NES and the methods for measuring the components are presented. Then follows a discussion of the behavioral assumptions that drive the simulation of investment decisions over time. Finally, the section concludes with brief remarks on the economic impacts not captured by the analysis.

Components and Measurement of Net Economic Services. The development of the components of NES can be illustrated using an example of a house owned by an individual. The individual derives a certain level of satisfaction[2] from owning his house, which includes his valuation of the land, the capital (the structure), and all its amenities.[3] In any given year, call it year j, the individual derives some net economic services equal to NES_j. This quantity is equal to the gross services or returns derived (S_j) minus the costs of keeping the house (H_j). Therefore, NES_j for the individual is defined as follows:

$$\mathbf{NES}_j = \mathbf{S}_j - \mathbf{H}_j \qquad (7.1)$$

$\mathbf{S}_j$ equals the value the individual places on the use of his house, its location, neighborhood, and other amenities. These gross services can be likened to the amount the individual would be willing to pay in rent each year for the use of his house.

The costs of keeping the house include primarily maintenance and repair. For the purposes of this analysis, these costs have been broken down into three categories: costs of maintenance to cover routine depreciation; the costs of storm and flood damage; and the costs of actions taken to prevent, mitigate, or respond to the physical impacts of sea level rise (what are referred to in this volume as PMR activities).

Sea level rise may affect both gross services and costs. For example, a house may be located in a community near a beach. The current services derived from the house include the value of being close to the beach. With a rising sea level, the beach may be lost to erosion and rising water levels. As a result, the services derived from the house will fall by the value the user of the house placed on the beach.

The effect on costs can be seen more directly. Increasing storm surge elevations will cause increasing amounts of damage. Over time, the costs of repairing and maintaining the house will increase. If PMR actions are taken, the costs of these actions must be also considered. Finally, shoreline movement may affect both services and costs. If a house is lost to shoreline movement, both its future services and its future costs are eliminated.

To estimate the NES in a given year for a community, the NES from each of the individual properties can be added together. When summing across properties, double counting must be avoided. Using the beach as an example, its value is reflected in the services derived from the homes of individuals who use the beach.[4] It is not appropriate to estimate the service value of the beach separately and then add it to the service values of the homes. This would be double counting. The same is true for all other nonmarket amenities (such as parks). However, it is appropriate to add up the services derived from each of the individually owned properties.

When expanding the calculation of services from an individual to a community, a new term is added to the equation, namely, new investment. In the case of the individual, he only reinvests in his existing property, but in a community, new structures are required to serve the growing population. In the year in which new structures are built, the cost of construction is counted as a cost from the viewpoint of the study area. The new structures subsequently produce services during their lifetimes. Therefore, for a community, a term reflecting new investment is added (**NI**j) and equation (7.1) is expanded as follows:

$$\mathbf{NES}_j = \boldsymbol{S}_j - \mathbf{H}_j - \mathbf{NI}_j. \qquad (7.2)$$

To aggregate the net services for a community over a period of time, the present value of the time stream of NES values for each year is estimated using a chosen discount rate. The discount rate reflects the relative value of dollars in different time periods; that is, a dollar next year is worth less than a dollar this year.[5] The choice of discount rate will, of course, influence the resulting estimate of the present value of NES over time.

Because the evaluation of NES for a community covers a finite period of time, a final term must be added to the calculation. This added term reflects the value of the capital stock at the end of the period, that is, those things with remaining useful lives. For example, a building may be built in the final year of the analysis. The cost of this new investment is counted in the estimate of NES for that year. However, the future services from the building are not counted because the analysis only examines a finite set of years. A quantity must be added that approximates the net value of the remaining life of the property; call it remaining capital stock (CS).

Equation (7.2) can now be expanded to include all the necessary terms, evaluated over time. Using the symbol PV(**Ž**) to indicate the present value of a finite stream of values over time, the expression for net economic services becomes:

$$\mathbf{PV(NES) = PV(S) - PV(H) - PV(NI) + PV(CS).} \qquad (7.3)$$

The first term to the right of the identity sign is the present value of gross services. The second and third values are the present values of the costs. The final term is the present value of the capital stock term. Next, the individual components of NES, starting with the identification of those items that contribute to NES, will be measured.

Within a study area, all articles of value can be thought of as producing a stream of services (e.g., a house produces housing services). To assess the impact of sea level rise, all those articles whose services or costs would be influenced should be included in the analysis. The exclusion of items whose services or costs are adversely affected will result in an underestimation of the impacts. The exclusion of items not affected by sea level rise does not result in bias.

The general list of inputs to the production of economic services includes land, capital, and labor. Both land and capital are important to include because they are fixed in location and directly affected by sea level rise. Shoreline movement can result in the loss of productive land and the capital improvements built on the land. Increased storm surge elevations will cause increased damages to structures during flooding, resulting in increased expenditures to maintain the building. These increased risks may reduce capital investment in the future (relative to levels that would have prevailed in the absence of sea level rise), resulting in a reduction in economic services.

Labor may also be affected, in terms of both supply and productivity. With increasing flood and erosion hazards in a coastal area, fewer individuals may choose to live and work there.[6] From the standpoint of the community, what is lost from a reduction in the use of labor is the value of the productive capacity of the labor minus the cost of the labor. Even if the amount of labor remains unchanged, its productivity may decrease. For example, more frequent interruptions due to flooding may reduce the average number of working days in a year, potentially affecting productivity.

Finally, important nonmarket amenities are likely to be affected, most notably beaches. If a beach is lost, the reduction in recreational opportunity is clearly a cost attributable to sea level rise.

To measure the net services produced by these various items, the analysis begins with observed market values of privately owned properties in the study area. Property values reflect the market's assessment of the present value of all future NES derived from a property. Included are people's valuations of nonmarket amenities such as beaches and parks. Additionally, for commercial properties, land values reflect the present value of future profit streams, including the appropriate estimate of the value of labor in excess of its costs.[7] Therefore, property values form a comprehensive measure of the market's expectations of future NES.

To estimate impacts, the current (and estimated future) property values were transformed into streams of gross services and costs. The impact of sea level rise on these streams was assessed directly.

The stream of gross services is affected by shoreline movement (which eliminates productive land and buildings) and by reductions in future economic activity. The cost stream is influenced primarily by changes in storm damage but also by the cost of community PMR actions and by reductions in future rates of new investment. The costs of routine maintenance were defined as the rate of depreciation of the structure times the value of the structure and are assumed to be constant.[8]

Sea level rise causes storm damage to increase because storm surge elevations will increase. The data required to calculate storm damages include: storm surge elevations and frequencies, the locations of high- wave-energy storm surge, topographical data, number of structures by location, the value of structures, and depth-damage functions (which relate the damage to a building to the depth of the flood above the first floor of the building). The storm surge and topographical data were obtained from the analyses of the direct physical effects of sea level rise reported earlier in this book.[9] Land use data were collected from a variety of sources for each study area.[10] Empirically derived depth-damage functions were used to calculate the value of storm damage to structures (including high-energy storm surge damage).[11]

The costs of storm and flood damages were calculated on an expected value basis. The total expected damage was computed by multiplying the damage from each storm type (e.g., a 100-year storm) times the probability of the storm occurring in any given year. The expected value of damages is analogous to an actuarially fair premium for insurance that would cover 100 percent of flood losses. This quantity reflects the true cost of the risk of storm damages on an annual basis. Of course, in any given year, a damaging storm may or may not occur. Consequently, the actual storm damages in any given year will rarely equal the expected value of storm damages. However, over a long period of time, the total damage experienced would approach the total expected value of damages, making the expected value an appropriate valuation of flood risk for the purposes of an economic analysis such as this.

It should be noted that an alternative approach to estimating storm damages is to simulate individual storm events over time. On average, the results of the simulation approach would be very similar to the expected value approach taken here. Nevertheless, the approaches would differ in an important way. Because severe storms (e.g., a 100-year storm) cause significant damage, the post-storm time period presents an opportunity to anticipate future sea level rise by significantly altering land use patterns. The expected value approach does not address this possibility and consequently results in an underestimation of the value of anticipating sea level rise. (The expected value approach was adopted here because of its relative simplicity from a computational point of view. The simulation of storm events was beyond the scope of the computing resources available for this effort.)

The costs of community PMR actions (e.g., seawalls and levees) were estimated from the unit costs provided by Sorensen et al. in Chapter 6. Insufficient data were available to simulate PMR costs on a per structure basis; consequently, individual PMR responses are omitted from this analysis.

The final component of NES is the amount of new investment occurring over time. New investment, by land use, is simulated to be driven by population changes within the study area. Detailed community development plans were used to project development to the year 2000. After that time, local, regional, and national population growth estimates were utilized. All land use was projected to increase at the rate of population growth after 2000, except for large special structures (such as the refining complex in Texas City, Texas), which were assumed to remain constant in size.

As described in the next section, the manner in which these components of NES change over time is driven by people's behavioral responses to sea level rise. In general, the shifts in land use and development are not devastating for the study area as a whole. For individual locations in the study area, however, simulated changes in land use in response to rising sea level can be quite significant.

Before turning to the discussion of the behavioral assumptions that drive the allocation of investment dollars and the choice of PMR actions over time, a technical consideration regarding the social value of capital investment must be mentioned. When individuals invest in a house or a commercial property, they evaluate the services derived from that property at their own private discount rate. It is often argued that the evaluation of economic activity from society's perspective should use a different (generally believed to be a lower) discount rate. Because of the divergence between social and private discount rates, the marginal value of an investment dollar is greater than one. Consequently, knowledge of the marginal value, or shadow price, of investment is required to estimate accurately the true NES over time from the social perspective of the study area. The calculation of this shadow price is particularly important because changes in investment are important responses to rising sea level.

Behavioral Assumptions. A key component of this analysis is an assessment of how individuals, firms, and public bodies would respond over time to rising sea level. Models of rational economic behavior, as well as other models, have been applied to the question of how people respond to natural hazards such as floods and earthquakes." The results of these investigations invariably demonstrate that people do not respond to risks from natural hazards in a manner consistent with models of rational behavior. Consequently, the assumption of rational behavior was rejected for the purposes of this analysis.

Once rationality is rejected as an adequate representation of human behavior, little is left in the way of quantitative bases for describing likely responses to the phenomenon of sea level rise. Nevertheless, simple approach was developed by dividing behavioral responses into two types, which are simulated separately: the changes in investment decisions made by individuals and coordinated community PMR responses. The characterization of each type of behavioral response is discussed separately.

Individual investment decisions dictate the amounts of funds each year that will go toward reinvestment in existing properties to cover operation and maintenance costs, expenditures to fix storm damages, and investment in new development. For two reasons, the response of individuals is modeled as a slow, incremental process. First, the sea level rise phenomenon will unfold slowly. People will slowly adjust their behavior as their perceptions of the risks posed by the phenomenon develop. Barring major efforts on the part of government bodies (perhaps in concert with the scientific community) to influence people's actions (e.g., through land use regulation), it is likely that people will change their habits very slowly. Large, identifiable catastrophic events are not part of the unfolding sea level rise phenomenon; consequently, natural events will not jolt people's actions in a discontinuous fashion.

The second reason why an incremental approach is appropriate is that the impact of sea level rise, although important, is only one factor affecting the use of coastal areas. Coastal areas are used despite their hazards for a variety of economic and cultural reasons. Although the risk of storm damage may double or even quadruple with sea level rise, these costs remain only one factor affecting the use of the coastal environment. For example, in the Galveston case study, the annual cost of depreciation was estimated to be over 30 times the cost of expected annual storm damage (storm damage is low in part because of the extensive protective structures that have been built). Consequently, one would expect only small shifts in investment behavior as a consequence of the slowly increasing risk from storm damage. Of course, large increases in the rates of erosion and in annual risk of storm damage may have major consequences for portions of the study areas. As a whole, however, the general economic viability of the two coastal cities examined in this project is not threatened.

The small shifts in investment behavior were estimated by comparing the simulated condition of the study area over time to a reference case of economic development. The reference case was constructed under assumptions that there is no sea level rise and economic growth takes place as indicated by local community development plans and projected population growth. The reference case is characterized over time by the total market value of developed properties within the study area and the total amounts of funds expended on new investment, reinvestment (maintenance), and storm damage repair. As the actual case (e.g., the medium sea level rise scenario) begins to deviate from the reference case, people's investment behavior is simulated to shift away from the pattern characterized in the reference case.

Table 7-1. Summary of Simulated Private Investment Behavior

Quantity Estimated	*Basis of Estimate*
Step 1	
Initial estimate of total investment funds	Rate of investment in reference case
Adjustment for population growth	Census Bureau projections
Allocation of funds among	Allocation in reference case
Reinvestment	
Damage repair	
New investment	
Step 2	
Adjust total investment and allocation among investment types to reflect perceived increases in risks due to sea level rise	People's simulated perceived risks relative to reference case risks
Step 3	
Adjust damage repair investment to reflect actual damages	Damages simulated to be experienced

Table 7-1. Summary of Simulated Private Investment Behavior

Investment behavior was simulated in three steps, as summarized in Table 7-1. As the first step, the total amount of investment was calculated using the reference case as a guide. Total investment funds were initially set equal to the rate of investment per value of existing structures (determined from the reference case) times the value of existing structures in the actual case. This initial quantity of funds was then adjusted to reflect that new investment in structures is influenced heavily by population growth in the long run, which will deviate from the reference case only marginally (if at all) through changes in migration patterns in response to sea level rise. Consequently, a feedback was provided, whereby the rate of new investment is adjusted upward in proportion to the degree to which the existing structural values fall short of the values attained in the reference case. This feedback is important because it is a mechanism via which perturbations in the growth path of the community are dampened, allowing growth to approach the reference case values over time if the cause of the perturbation is eliminated. This adjusted level of investment funds was initially allocated among reinvestment, damage repair, and new investment in similar proportions to the reference case.

The second step was to compare people's perceived damages with the reference case damages. If the perceived rate of damages is equal to the rate in the reference case, then the initial allocation among investment types is used. However, with rising sea level, the perceived damages will generally exceed the reference case damages (as a percent of total property value) as people slowly perceive changes in risk." Consequently, a greater proportion of the available investment funds is required to cover damages. These funds must either be taken out of new investment and reinvestment, or the total amount of investment must increase.

The propensity of individuals to increase total investment in response to increasing damages is unclear. A variety of assumptions were investigated, including a decrease in total investment funds equal to one-half the increase in storm damage risk, no changes in total investment funds, an increase in investment funds equal to one-half the increase in storm damage risk, and an increase in investment funds equal to the increase in storm damage risk. The first two approaches resulted in significant reductions in total property values relative to the reference case by 2025. These reductions appeared to be too large to be realistic, particularly in light of the fact that during this period, most of the sea level rise costs are small relative to other factors affecting investment. The last approach results in no change in total property values relative to the reference case; that is, people continue to build everything they would have built in the absence of sea level rise. The third approach results in plausible changes in investment behavior as a function of changes in perceptions of risk and was adopted for use in this analysis.

Clearly, a more sophisticated and empirically validated model of investment behavior would be preferable. If people's behavior in response to their changing perceptions would in fact look more like the last approach, then the estimates of the impacts of sea level rise reported here are biased downward. If investment behavior would look more like the first approach, then the estimates are biased upward. Biases in the estimates of the value of anticipating sea level rise as a consequence of this behavioral assumption move in the opposite direction.

The third and final step in simulating investment behavior was an adjustment reflecting the fact that people's perceptions of risk may be incorrect. As the result of the second step, investment goals have been set and funds have been committed to each of the three investment types. However, people underestimate damages because they underestimate the rate at which the sea level is rising and hence underestimate their risk. In order to meet the investment goal of covering a certain proportion of damages, the damage investment must be increased. Because damages occur probabilistically, people may not attribute these increased costs to sea level rise. Instead, increased damage expenditures (over expectations) may be attributed to unusually bad weather or other factors. Funds are not taken away from new investment or reinvestment be-cause these funds are assumed to be committed. Instead, new funds are assumed to be added. By initially underestimating damages, the total investment increases, and the relative distribution of investment funds among the competing uses is altered.

A general model of urban development would be a useful extension of this method of simulating investment behavior. The current approach is clearly only a partial analysis because the wide range of alternative investment opportunities is not considered. However, this method results in shifts in investment behavior that move in the right direction at plausible rates. By rejecting the notion of optimal investment decisions in favor of incremental changes over time, the analysis provides an aspect of realism.

Community PMR actions were simulated separately from private investment decisions. Again, economic models of rational behavior were rejected as descriptors of likely responses. The actual experience of Galveston Island provides a good example of the misleading results that would be obtained by assuming rational economic behavior.

In the mid-1970s, the U.S. Army Corps of Engineers proposed the construction of a seawall to protect most of Galveston Island from bayside flooding." Looking only at the costs of building the project and the benefits in terms of reduced storm damage to existing properties, the seawall was estimated to be beneficial and, based strictly on rational criteria incorporating quantifiable consequences, should have been built. However, the community rejected the proposal. The reasons for the rejection were not researched for this project but may include factors such as the inability to cover the community's share of the costs, environmental concerns, or possibly a belief that owners will not have to bear the full cost of damages because of the availability of disaster relief funds. In any case, the relationship between the cost of the protection project and the quantifiable benefits of the project in terms of reduced storm damage and erosion loss is insufficient for purposes of modeling the implementation of community PMR actions.

A more detailed model of community decision making could prove useful for this analysis. Such a model would describe communities' concerns and the decision process they go through when undertaking large protection projects. Numerous projects have been built by communities with the assistance and support of the Army Corps of Engineers. The data on the numerous projects built and the various projects rejected could be used to validate such a model.

Unfortunately, the resources and time available for this project did not allow a detailed examination of community response behavior. Instead, three basic types of PMR actions were defined, and the choice and timing of the actions were varied. The types of action are: stop or reduce the rate of shoreline movement through the use of revetments, levees, or other means; eliminate the threat of storm surge (up to a given elevation) through the use of seawalls and levees; and reduce or prohibit investment in given areas by "promulgating land use regulations." Other options not considered may include changes in building codes, beach nourishment, off-shore breakwaters, reclamation, and others.

The community PMR actions were assumed to be taken in various locations within the study areas at various times. Seawalls and high levees were used in threatened areas with high development density and high property values such as the Charleston Peninsula and Galveston Island. Revetments and low levees were used in places with medium development density that are threatened by rapid shoreline retreat. Land use regulations were applied in areas of significantly increasing hazard that were of low density.

The potential timing of the initiation of the PMR actions was divided into near term (1980-2010), medium term (2020-2050), and long term (2060-2080). In general, PMR actions were assumed to occur in the medium and high sea level rise scenarios, in the long and medium terms respectively. These time frames are reasonable because at these times the physical changes caused by sea level rise would be clearly distinguishable from routine background variations.

By anticipating future sea level rise, the choice and timing of these PMR actions would be altered. This effect of anticipation is discussed in the next section. Under the assumption that no major intervention on the part of the federal government is undertaken to influence communities to make rapid responses to sea level rise, the community PMR actions simulated in this analysis are plausible representations of what may, in general, occur. The PMR actions are not chosen to be optimal (in the sense of maximizing net benefits) but instead are chosen to represent the major courses of action available to communities and the general time periods in which they are likely to be taken.

An example of a PMR action is shown in Table 7-2. To define the action the action type must be identified as one of the three possible actions discussed above. The location in the study area that would be influenced by the action is also defined. Capital and operation and maintenance (O&M) costs are provided in terms of 1980 dollars. Finally, the applicable scenarios and times at which the action is taken are provided. The example in Table 7-2 is the modification of the Texas City levee system to protect areas of Texas City and La Marque from the increasing storm surge elevations found in the high sea level rise scenario. As shown in the he table, the action is assumed to be taken in 2070 in both the medium and high sea level rise scenarios. As discussed below, to evaluate the value of anticipating sea level rise, the timing or the choice of the actions taken is altered.

Table 7-2. Sample Data for Specifying a Community PMR Action

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Community PMR Action Data	
PMR Action Type	Eliminate storm surge below a given elevation: 22 ft (6.7 m)
Location	Portion of Texas City/La Marque that becomes vulnerable to storm surge in high sea level rise scenario
Capital Cost	$100 million
O&M Cost	$0.1 million per year
Applicable Scenarios and Years Taken	Medium scenario; taken in 2070 High scenario; taken in 2070

Impacts Not Captured by This Method. As described above, to the extent which this method excludes economic activities that are affected by rising sea level, the results will be of a partial nature. In three major areas, potentially important activities were omitted, resulting in an underestimate of the economic impacts of sea level rise. First, the costs of saltwater intrusion were not estimated. The annual value of the reduced availability of potable water should be added to the results derived here. Because the groundwater used in the two study areas analyzed here is not significantly affected by saltwater intrusion, this bias is not serious for the cases presented below.

The second impact omitted was the potential loss of economic value supplied by the near-shore zone. The loss of beach areas was not explicitly incorporated into the analysis. If a beach is lost, the value of the recreational opportunity it would have produced is lost. This cost could be very large, particularly if many beaches were affected simultaneously, reducing the availability of substitute recreation. Additionally, changes in the populations of aquatic species were not addressed. If the sea level rises rapidly, such as in the high scenario, various commercially important species may be unable to adapt to this changing environment, resulting in additional economic impacts.

Finally, the analysis does not address impacts outside the study area. Changes in investment behavior may have positive or negative secondary impacts elsewhere. From the viewpoint of this study, the changes in the two cities as a result of sea level rise are unlikely to have significant consequences for the rest of the nation as a whole. However, if sea level rise has a significant impact on investment behavior in all coastal communities simultaneously, then the secondary effects could be considerable. This question warrants further consideration.[16]

Analysis of the Value of Anticipating Sea Level Rise

The most general way to think about the value of anticipating sea level rise is to ask what would happen if sea level rise were not anticipated and what would happen if it were. The answers to these questions are, by the nature of the analysis, uncertain. It is not known what will happen because it is not known how fast the sea level is going to rise. It is clear, however, that the value of anticipating sea level rise will depend, in part, on how rapidly the sea level actually rises. For example, if the high scenario is true, it is more valuable to plan for it ahead of time than if the low scenario is true.

Because the uncertainty about sea level rise is large, the uncertainty over the value of anticipating it is also large. To address this uncertainty, the approach used here was designed to produce separate estimates for each scenario of rising sea level. The results of the analysis should be interpreted as contingent estimates, such as: if the low scenario is true, then the value of, anticipating sea level rise is $X million.

Individual readers may decide for themselves the likelihoods of the various scenarios.

To estimate the value of anticipating sea level rise, the economic impact analysis method was augmented to incorporate alternative investment behaviors and community PMR actions. The economic impact analysis implicitly assumes that people act as though they currently believe that the sea level is rising at a rate less than or equal to historical trends. These beliefs are simulated to slowly approach the accurate perception of the sea level rise scenario being analyzed. If sea level rise is anticipated, these simulated investment and PMR behaviors win change. To estimate the values of these behavioral changes, the results of the economic impact analysis were used as a baseline of comparison. The reduction in the impact of sea level rise due to the simulated changes in behavior is the value of anticipating sea level rise.

Exactly how individuals and communities would behave in anticipation of sea level rise is uncertain. How people will behave will depend, in part, on how accurately future rates of sea level rise can be predicted and the level of confidence associated with the predictions. The role of federal, state, and local governments will be important, particularly in regard to their regulatory activities and economic incentives.

One method of modeling this behavior would be to develop optimal strategies to undertake in anticipation of sea level rise and to determine how people and communities should behave to minimize the adverse impacts of sea level rise. Such analyses are needed to inform the sea level rise debate. Of course, the definition of the optimal strategy (or strategies) is always constrained by the ability to quantify and value all the important impacts.[17] Consequently, the results of such analyses of optimal solutions should be viewed as guides to decisions, not as definite answers.

Rather than ask how people should act, this analysis examined how people probably would act. The differences in approach and results are considerable. Optimal behavior was not estimated; instead (for the same reasons discussed in the previous section), individual behavior was assumed to change slowly in an incremental manner. Additionally, individuals were assumed to be rather near-sighted in their investment decisions. Whereas an optimal preparation strategy would utilize all available information about future sea level rise, individual investment decisions are assumed to have horizons of only 10 years. This limited decision horizon for individuals was adopted as representative of a variety of factors, most principally, the potentially high discounting of the future by individuals, the uncertainty associated with long-range predictions, the inability or unwillingness of individuals to incorporate uncertain information into their decisions, and the costs associated with obtaining or developing information. Consequently, individuals were simulated to improve their investment behavior by preparing only for the true increases in risks during the coming decade.

Investment behavior is improved by reducing investment funds (relative to the base case) in areas of increasing risks. The investment fund allocation procedure described in the previous section was utilized. However, whereas in the base case individuals systematically underestimate risks, by anticipating sea level rise they accurately assess risks in the coming decade.

Community PMR actions also change because of the anticipation of sea level rise. Primarily, PMR actions were assumed to be taken in anticipation of increasing hazards instead of in response to increasing hazards. Consequently, the timing of the building of protective structures and the promulgation of zoning restrictions was assumed to be 20-40 years earlier than assumed in the economic impact analysis.

The primary weakness of the approach taken here is its subjective nature. A variety of assumptions are made about how individuals and communities might prepare for future sea level rise. Although these assumptions are both internally consistent and plausible, they have not been empirically validated; consequently, they should not be ascribed predictive ability. Instead, the results presented here provide an estimate of the order of magnitude of savings that could be realized by anticipating sea level rise.

In many respects, our methods biased the estimates of the value of anticipating sea level rise downward. No advancement in the state-of-the-art of protective structures was assumed. Opportunities to advantage of rises in sea level were not examined (e.g., in siting port facilities). Finally, the actions simulated to be taken in anticipation of se, level rise are only small shifts away from the behavior simulated in the economic impact analysis. In fact, preparatory actions could be much more comprehensive, particularly if the federal government were to take a strong leadership role by restructuring incentives for development in the coastal zone to be more appropriate for a rising sea level.

RESULTS

Results for the Charleston and Galveston case studies are reported separately below. A variety of values was used for the private and social discount rates and other parameters. The results presented below represent one set of assumptions and parameters, including a private real discount rate of 10 percent per year; a real appreciation rate of property Of 2 percent per year; total storm damages equal to twice the damages to privately owned structures to account for damage to contents, publicly owned structures, and economic disruption;[18] is and real social discount rates of 3 percent, 6 percent, and 10 percent per year.

Charleston, South Carolina

The Charleston study area, shown in Figure 7-1, includes the city of Charleston and portions of North Charleston, Mount Pleasant, Sullivans Island, James Island, and Daniel Island. The developed portion of the study area (the entire area excluding Daniel Island) was divided into 37 subareas of approximately 2.2 sq km (0.85 sq mi) each. The subareas, identified from Charleston County property tax assessment maps,[19] represent fairly homogeneous areas of land use.

The following information was obtained for each subarea: the physical impacts of each sea level rise scenario in terms of storm surge (elevation and frequency) and area loss due to shoreline movement,[20] topography,[21] the number and average value of existing structures by land use type,[22] and anticipated land use changes by the year 2000.[23]

The results for the study area are reported in terms of four quantities: the market value of structures over time, the expected value of storm damages over time, losses due to shoreline movement by decade, and the present value of net economic services in 1980 dollars. The changes in market values represent, in part, changes in investment in response to sea level rise. Also, changes in the expectations of storm damage are important. Potential losses due to shoreline movement play a more important role in the Charleston study area than in the Galveston area, which is mostly protected by existing seawalls and levees. Finally, the aggregate economic impacts are summed up in the NES estimates.

Figure 7-2 displays how market values are affected by rising sea level. Curve *A* displays the trend case and shows steadily increasing market values over the next century from the current $1.27 billion. The high scenario without anticipation (Curve *B*) diverges from the trend case beginning in the year 2000. Beginning in 2020, the community is simulated to take actions to reduce the losses to shoreline movement by protecting the Charleston Peninsula and areas west of the Ashly River. However, without anticipation of sea level rise, these measures are assumed to be less than totally effective because the rate of sea level rise is underestimated. Consequently, additional actions that could eliminate the shoreline movement problems in most areas are simulated to be taken by 2060. Between 1980 and 2060, some areas will have been developed that cannot be protected, resulting in additional losses after 2060.

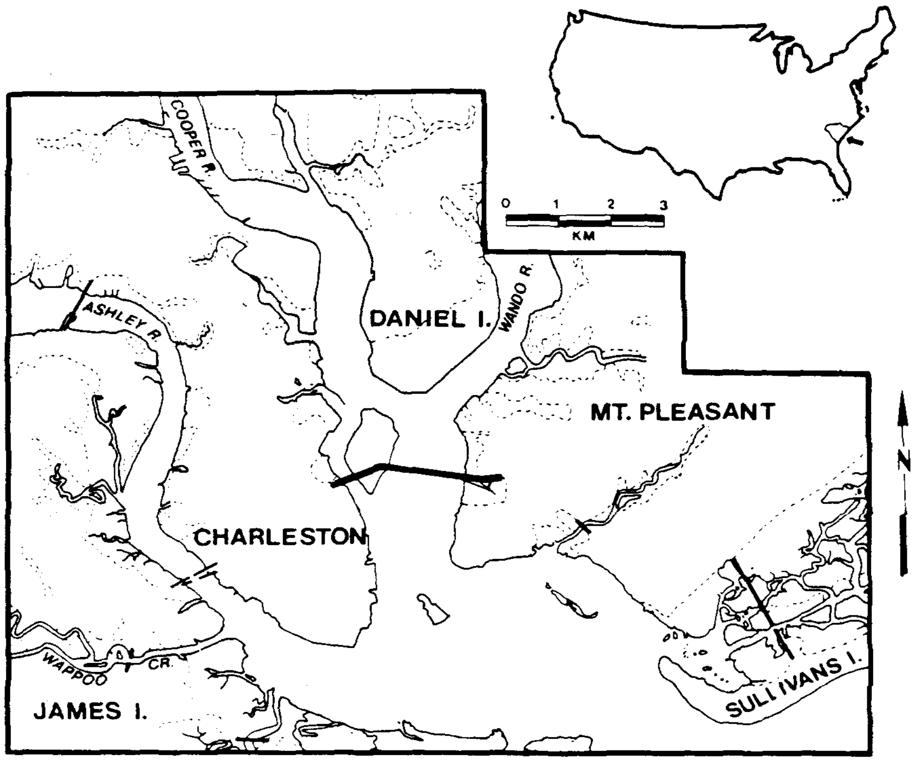

Figure 7-1. Map of the Charleston case study area. *(Map supplied by Research Planning Institute. Columbia, S.C.)*

Figure 7-1. Map of the Charleston case study area. *(Map supplied by Research Planning Institute. Columbia, S.C.)*

Curve *C* shows the results of the high scenario with anticipation of sea level rise. In anticipating sea level rise, several coordinated responses are simulated to be taken. First, the Charleston Peninsula is protected from shoreline movement by a levee or seawall constructed in 2010. This structure is assumed to be effective in stopping shoreline movement throughout the highly developed peninsula and in providing some protection from storm surge. Second, the area west of the Ashley River is divided into two parts. The area near the Wappo Creek is protected from shoreline movement with a low levee system, and new development is intensified. The area north of there, near the first bend in the Ashley River, is presumed to go unprotected, and new development is assumed to be prohibited. Third, Mount Pleasant is presumed to be developed in a manner that minimizes subsequent loss to shoreline movement, Possibly with the use of revetments. Last, investment in Sullivans Island, an area of rapidly increasing storm hazard and shoreline movement, is presumed to be reduced significantly.

Even with these various actions, however, market values continue to decline. This continuing decline is due in part to the simulated choice to reduce investment in certain areas but is also due to the increasing risk of storm damage and continued shoreline movement.

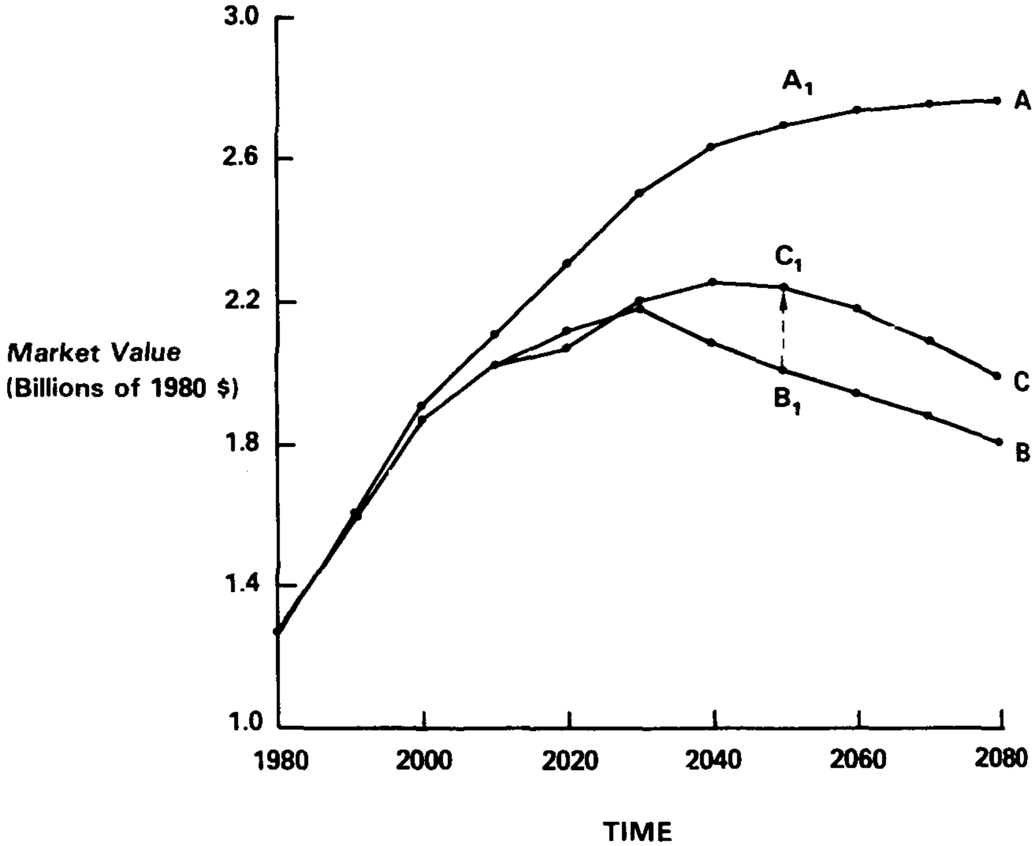

Figure 7-2. Market values in the Charleston case study area over time for three scenarios. (*A*) trend rate of sea level rise; (*B*) high sea level rise scenario without anticipation; and (*C*) high sea level rise scenario with anticipation.

Figure 7-2. Market values in the Charleston case study area over time for three scenarios. (*A*) trend rate of sea level rise; (*B*) high sea level rise scenario without anticipation; and (*C*) high sea level rise scenario with anticipation.

The community PMR responses in Charleston would require significant cooperation among a variety of jurisdictions. Protecting the peninsula would involve both the cities of Charleston and North Charleston. Additionally, there is a 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 Clark Expressway, is anticipated to be constructed west of the Ashley River. Therefore, an effective community response in the Charleston study area would 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.

Figure 7-3 shows the pattern of storm damage for three scenarios. The trend scenario (curve *A*) displays a slowly increasing amount of storm damage over the next century, driven primarily by increasing market values. Curves *B* and *C*, showing the high scenario, diverge significantly from the trend scenario by the year 2000. Without anticipating sea level rise (curve *B*), the storm damage continues to rise through 2030. By that time, shoreline movement is causing such large losses that the total storm damage actually begins to decline because fewer structures remain to be damaged. Although the risk of storm damages is increasing, the total value of structures at risk is decreasing, resulting in lower aggregate damages. Damages continue to decline through 2060 as the area continues to experience large losses due to shoreline movement. By 2060, the shoreline movement problems are assumed to be arrested and total storm damages begin increasing.

The high scenario with anticipation (curve *C*) diverges from curve *B* in 2010 when coordinated protective actions are simulated to be taken. Storm damages decline through 2020 but increase substantially thereafter. By 2080, the storm damage in the with-anticipation case exceeds the without-anticipation case by a considerable amount. This counterintuitive result is caused by the protection of areas from shoreline movement. Areas west of the Ashley River are simulated to be protected by a low levee that does not significantly reduce storm surge. As a consequence, storm damages increase significantly with sea level rise. From the standpoint of storm damages, this response is probably not the best possible response. However, given the medium density development projected for the area, it is a likely response.

Figure 7-4 shows the considerable reductions in shoreline movement losses simulated to be realized with anticipation in the high scenario. Without anticipating sea level rise, shoreline movement losses grow rapidly through 2040. By 2060 actions are simulated to be taken to reduce losses. Even so, shoreline movement losses average $57 million per decade from 1980 to 2080. Anticipating sea level rise reduces shoreline movement losses by an average of approximately $5 million per decade over the same period.

The diverse impacts of changing market values, land use, shoreline movement, and damages are summarized in the NES calculation. Table 7-3 reports the NES values for the trend scenario and the high scenario, with and without anticipation of sea level rise for the period 1980-2025. The economic impact of the high scenario is estimated by subtracting the NES for the high scenario (without anticipation) from the trend scenario NES. From Table 7-3 it is seen that the economic impact of the high scenario evaluated at a real 3 percent discount rate is $1,065 million. Anticipating future sea level rise could reduce this impact by over 60 percent, and the value of anticipation is estimated at $645 million. The values are somewhat smaller when a 6 percent or 10 percent discount rate is used.

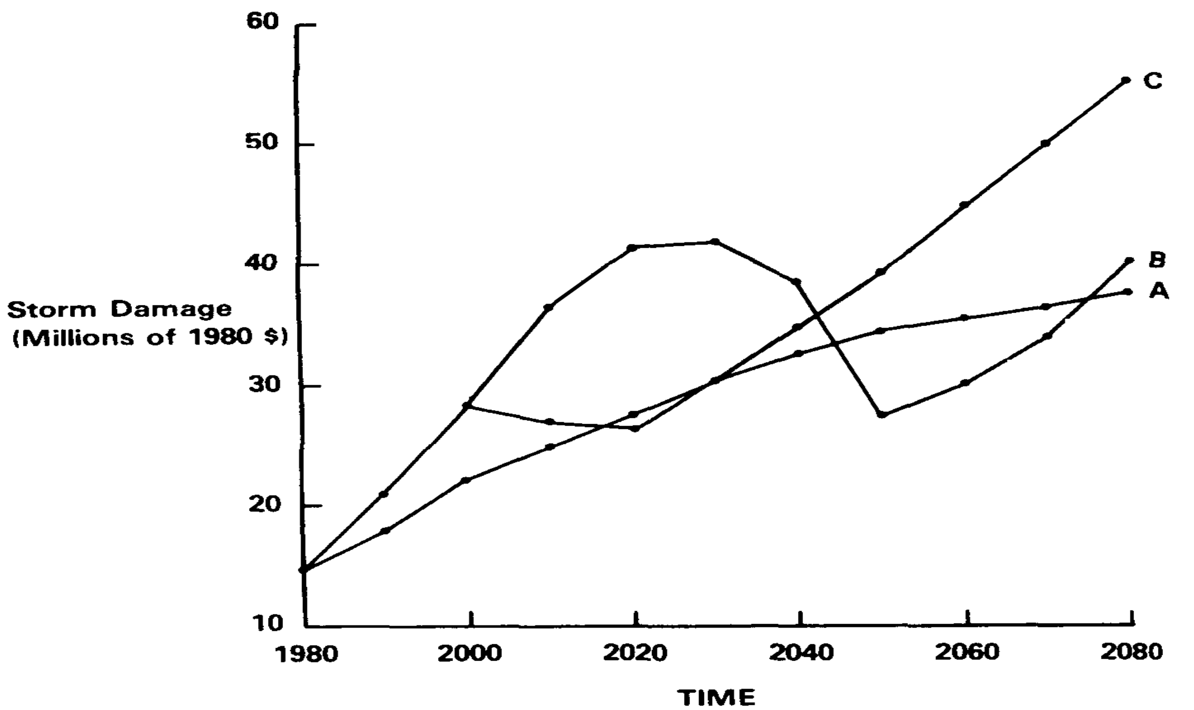

Figure 7-3. Storm damage in the Charleston case study area over time for three scenarios. (*A*) trend rate of sea level rise; (*B*) high sea level rise scenario without anticipation; and (*C*) high sea level rise scenario with anticipation.

Figure 7-3. Storm damage in the Charleston case study area over time for three scenarios. (*A*) trend rate of sea level rise; (*B*) high sea level rise scenario without anticipation; and (*C*) high sea level rise scenario with anticipation.

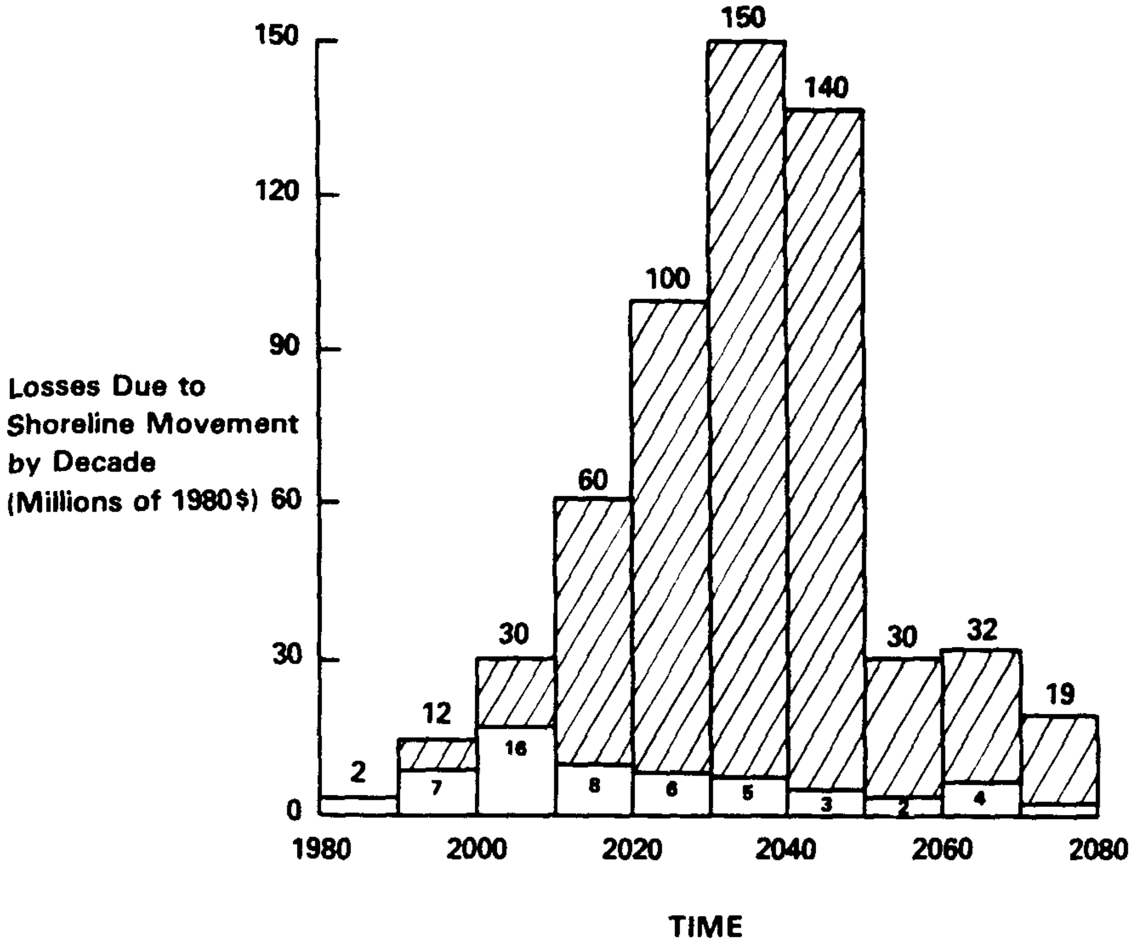

Figure 7-4. Charleston case study results—losses due to shoreline movement by decade. High scenario without anticipation = upper number. High scenario with anticipation = lower number. Savings attributable to the anticipation of sea level rise = shaded area.

Figure 7-4. Charleston case study results-losses due to shoreline movement by decade. High scenario without anticipation = upper number High scenario with anticipation = lower number. Savings attributable to the anticipation of sea level rise = shaded area.

The significance of Figure 7-2 is that by anticipating sea level rise, development and protective measures can be undertaken to reduce the losses from sea level rise. For example, by 2050 in the high scenario, anticipating sea level rise results in over $200 million in additional market value relative to the case when sea level rise is not anticipated (point B_1 to point C_1 in Figure 7-2). However, even with anticipation of sea level rise, point A_1 (projected market value in the trend case) is not attained.

Table 7-3. Estimates of Net Economic Services for the Charleston Case Study Area, 1980-2025 (in millions of 1980 dollars)

Table 7-4. Economic Impacts of Three Sea Level Rise Scenarios in the Charleston Case Study Area at Three Discount Rates and for Two Periods of Time (in millions of 1980 dollars)

	Real Discount Rate (in Percent)[a]					
	1980–2025			*1980–2075*		
Scenario	*3*	*6*	*10*	*3*	*6*	*10*
Low	280	70	15	1,250	110	20
	(4.9)	(2.4)	(0.8)	(17.3)	(3.6)	(1.1)
Medium	685	165	40	1,910	305	50
	(12.0)	(5.6)	(2.2)	(26.5)	(10.1)	(2.8)
High	1,065	270	65	2,510	440	80
	(18.7)	(9.1)	(3.7)	(34.8)	(14.6)	(4.5)

[a]Values in parentheses report percentage of total net economic services estimated in the trend case.

Table 7-4. Economic Impacts of Three Sea Level Rise Scenarios in the Charleston Case Study Area at Three Discount Rates and for Two Periods of Time (in millions of 1980 dollars)

Table 7-5. The Value of Anticipating Future Sea Level Rise for the Charleston Case Study Area, Contingent on Each of the Three Sea Level Rise Scenarios (in millions of 1980 dollars)

	Percentage Real Discount Rate (in Percent)[a]					
	1980–2025			*1980–2075*		
Scenario	*3*	*6*	*10*	*3*	*6*	*10*
Low	120	25	5	810	55	5
	(43)	(36)	(33)	(65)	(50)	(25)
Medium	340	50	10	1,180	160	10
	(50)	(30)	(25)	(62)	(53)	(20)
High	645	115	10	1,400	230	25
	(60)	(43)	(5)	(56)	(52)	(31)

[a]Values in parentheses report percentage of total ecomonic impact.

Table 7-5. The Value of Anticipating Future Sea Level Rise for the Charleston Case Study Area, Contingent on Each of the Three Sea Level Rise Scenarios (in millions of 1980 dollars)

Table 7-6. Economic Impact and Value of Anticipating Sea Level Rise for the High Scenario, 1980–2075: Charleston Case Study Area

Portion of Charleston Study Area	Economic Impact of High Scenario (Percent of Study Area)	Value of Anticipating High Scenario (Percent of Study Area)
Peninsula: Charleston 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%)

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

Table 7-6. Economic Impact and Value of Anticipating Sea Level Rise for the High Scenario, 1980-2075: Charleston Case Study Area

Tables 7-4 and 7-5 summarize the estimates of economic impacts and value of anticipating sea level rise for each of the scenarios. The economic impacts are much larger for the 1980-2075 period than for just 1980-2025, as would be expected. Because these values are present values of streams over long periods, the discount rate has a significant influence on the outcome.

Table 7-4 indicates that even the low scenario will have impacts in excess of $1 billion by 2075 (evaluated at a 3 percent discount rate). Relative to the trend scenario, this is over a 17 percent reduction in the value of the economic activity in the study area over the 100-year period analyzed. (Percentage reductions are reported in parentheses in Table 7-4.) Table 7-5 reports that by anticipating sea level rise, the impacts can be reduced significantly. For example, by anticipating the low scenario, the study area could be $810 million better off, offsetting 65 percent of the economic impact of the low scenario.

Table 7-6 presents a breakdown of the results by four subareas. The peninsula area has the highest impact in the high scenario, $900 million. By anticipating sea level rise, the actions simulated to be taken more than offset this adverse impact. The peninsula is simulated to be protected by seawalls and low levees in the high scenario. This raises the question whether the peninsula would be better off with these protective measures, 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. 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 has the second-highest impacts, $685 million. Without anticipation of sea level rise, significant new development would take place over the next 20-40 years that would subsequently be either lost to shoreline movement or subject to a greatly increased risk of storm damage. By anticipating sea level rise, development can be limited 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 case study area. Although Mount Pleasant and Sullivans Island both suffer significant impacts, responses resulting in significant savings were not identified. However, 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 transportation system and commerce in the area.

Galveston, Texas

The Galveston study area, shown in Figure 7-5, includes a portion of Galveston Island, Texas City, La Marque, San Leon, and some unincorporated areas. The study area was divided into 97 subareas of approximately 2.8 sq km (1.08 sq mi) each. These subareas are the same units used by Leatherman[24] to characterize the physical impacts of sea level rise. The following information was obtained for each subarea: the physical impacts of each sea level rise scenario in terms of storm surge (elevation and frequency) and area loss due to shoreline movement,[25] topography,[26] population in 1980 and projected population in 2000,[27] the number and average value of existing structures by land use type, and anticipated land use changes by the year 2000.[28]

The results for the study area are reported in terms of three quantities: the market value of structures over time, the expected value of storm damages over time, and the present value of net economic services. The changes in market values of land and structures indicate the extent to which investment in the area is reduced in response to sea level rise. Expected storm damages are reported because they are the major physical impact on the study area. The cost of storm damages is approximately one magnitude larger than the value of the land lost to shoreline movement. Finally, the estimates of net economic services (NES) sum up the total impact on the study area. NES estimates are provided for two time periods, 1980-2025 and 1980-2075. As indicated below, the NES values are sensitive to the choice of discount rate.

Figure 7-6 displays estimates of the market value of land and structures for three scenarios. The top curve (Curve A) represents the simulated results if the sea level rises at a rate equal to recent historical trends. Driven by population growth, the value of structures (currently $3.3 billion) is anticipated to grow steadily over the next century. Curve B represents the high scenario, analyzed without anticipation of sea level rise. The impact of sea level rise on market values is moderate from 1980 to approximately 2030, after which time impacts are significant. The time period between 2020 and 2030 is a turning point for this scenario because at this time, the protected areas within the Texas City levee system and behind the Galveston seawall are simulated to become vulnerable to storm surge. However, without better information, it is assumed that the communities would not recognize this threat arid consequently would not respond until later. Market values begin to fall because of the rising expense from storm damage. As events unfold between 2030 and 2050, people recognize their increased risk and by 2070, the levee system and seawall are simulated to be upgraded to provide the necessary protection. By that time, however, the increased risk of storm damage has had a significant impact. The rate of decline in values slows after 2070.

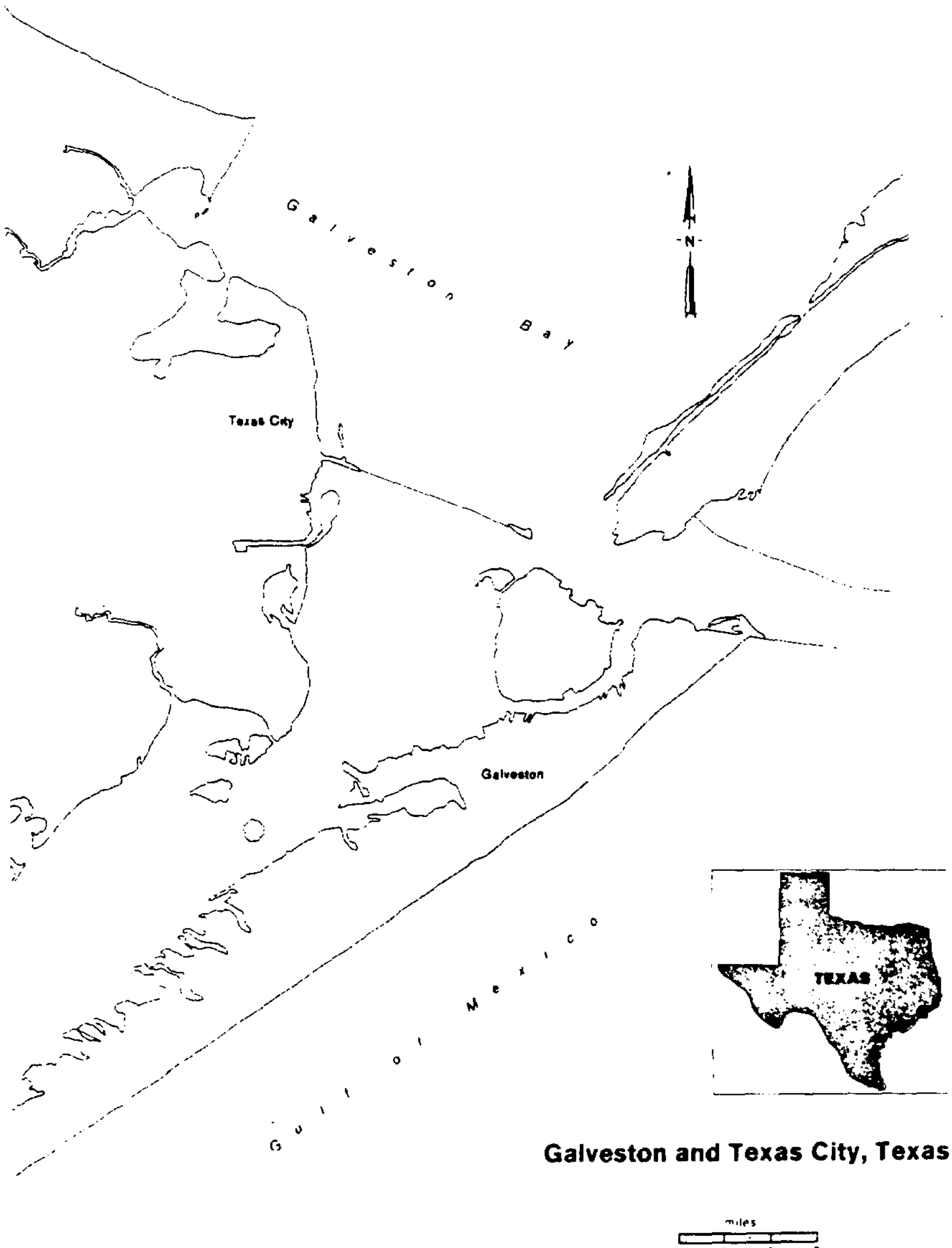

Figure 7-5. Map of the Galveston case study area. *(Map supplied by Stephen P Leatherman, University of Maryland.)*

Figure 7-5. Map of the Galveston case study area. *(Map supplied by Stephen P Leatherman, University oi Maryland.)*

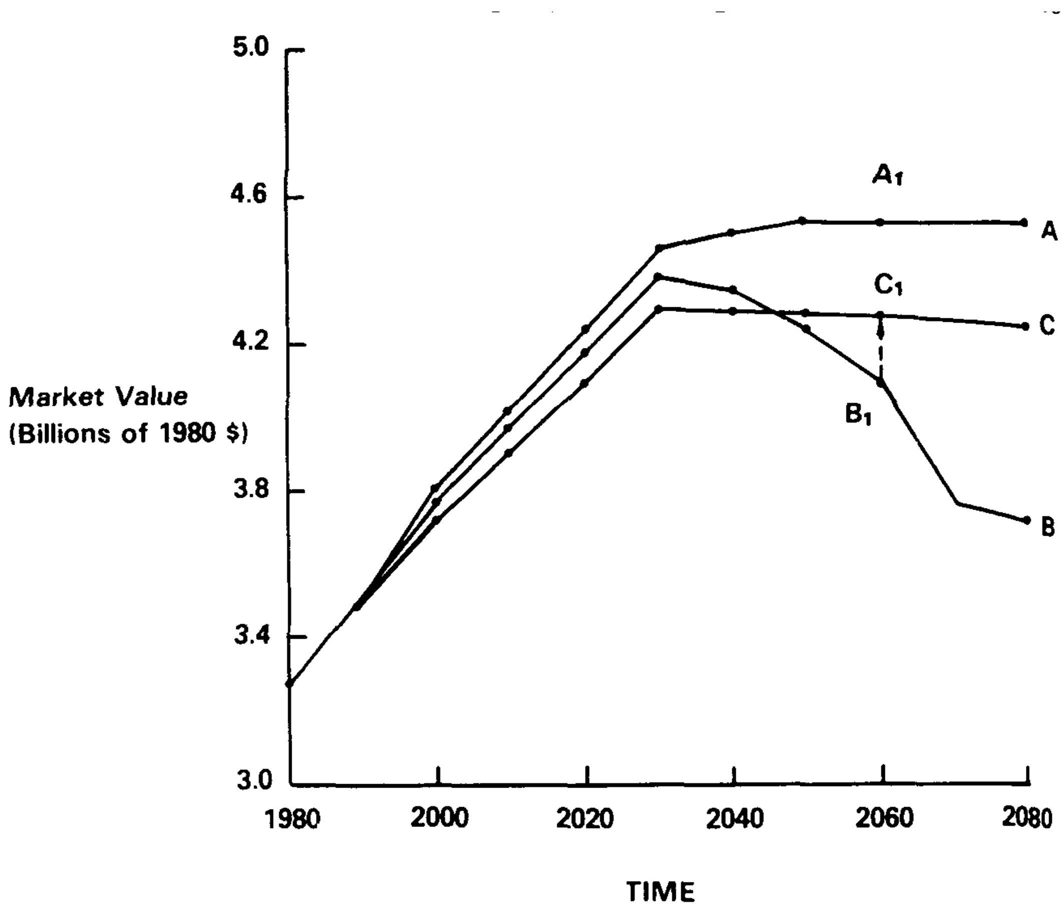

Figure 7-6. Market values in the Galveston case study area over time for three scenarios. (*A*) trend rate of sea level rise; (*B*) high sea level rise scenario without anticipation; and (*C*) high sea level rise scenario with anticipation.

Figure 7-6. Market values in the Galveston case study area over time for three scenarios. (A) trend rate of sea level rise; (B) high sea level rise scenario without anticipation; and (C) high sea level rise scenario with anticipation.

Figure 7-7 presents the storm damages over time for the same three scenarios. The trend case shows slowly increasing damages, in part because of the increasing market value. The high scenario without anticipation (curve B) displays how the risk of storm damage jumps up after 2020 and again after 2050. These jumps occur in part because of the discontinuous nature of the protective structures and in part because of the discrete function used to estimate storm damages.[29] In the 2020 -2030 period, damages jump to nearly $40 million per year because the protected area becomes vulnerable to the 100-year storm.[30] By 2060 many of the protected areas would also become vulnerable to the 50-year storm, as is indicated by the jump in damages during that decade. By 2070 it is assumed that the community upgrades its protection systems and that risks decrease substantially.

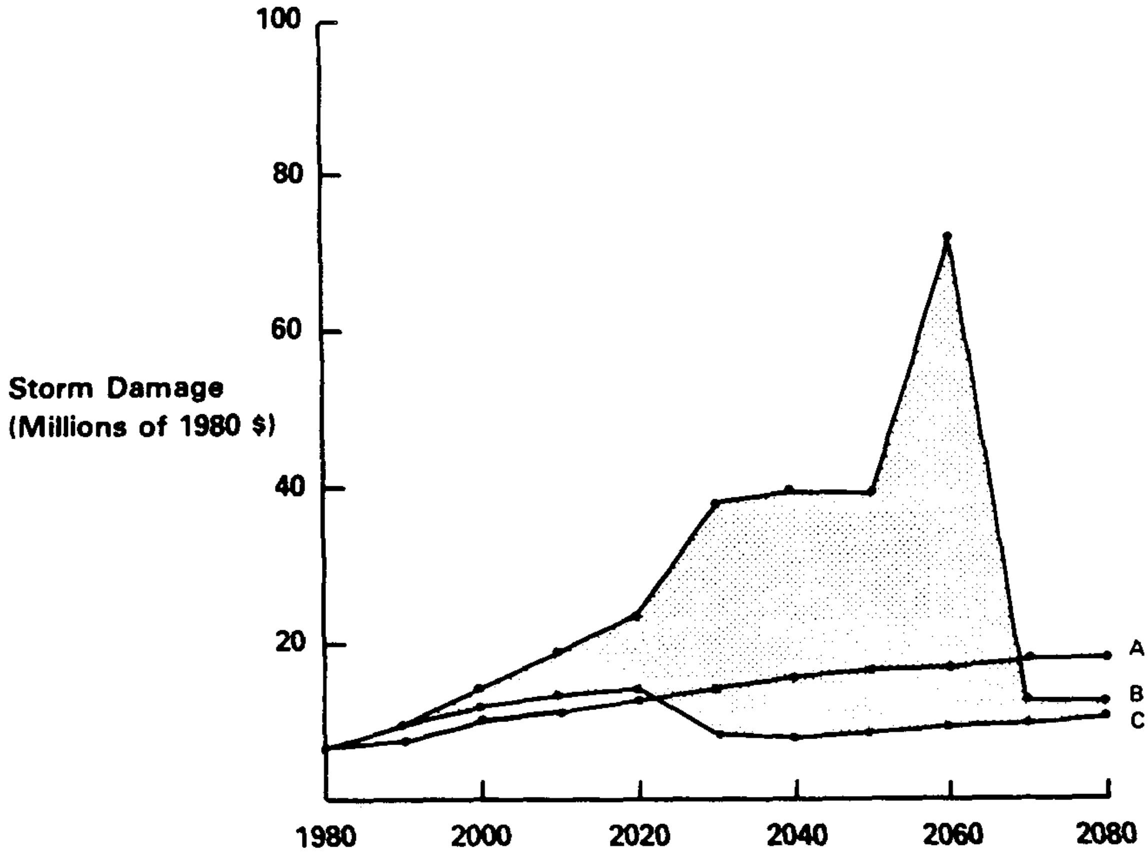

Figure 7-7. Storm damage in the Galveston case study area over time for three scenarios. (*A*) trend rate of sea level rise; (*B*) high sea level rise scenario without anticipation; and (*C*) high sea level rise scenario with anticipation.

Figure 7-7. Storm damage in the Galveston case study area over time for three scenarios. (A) trend rate of sea level rise; (B) high sea level rise scenario without anticipation; and (C) high sea level rise scenario with anticipation.

With anticipation of sea level rise (curve C), the damages are initially below curve B because investment is reduced in areas of increasing hazard. Curves B and C diverge dramatically after 2020 when the upgrading of the protective systems is assumed to take place. The shaded area in Figure 7-7 is the total reduction in damages attributable to the anticipation of sea level rise.

The diverse impacts of changing market values, land use, and damages are summarized in the NES calculation. Table 7-7 reports the NES values for the trend scenario, and for the high scenario with and without anticipation, for the period 1980-2025. The economic impact of the high scenario is estimated by subtracting the NES for the high scenario without anticipation ($9.65 billion) from the trend scenario NES ($10.1 billion). From Table 7-7 it can be seen that the economic impact of the high scenario evaluated at a real 3 percent discount rate is $360 million. Anticipating sea level rise could reduce this impact by over 60 percent; the value of anticipation is estimated at $220 million. The estimates are much larger for the 2025-2075 period than for 1980-2025.

Table 7-7. Estimates of Net Economic Services for the Galveston Case Study Area, 1980-2025

Table 7-7. Estimates of Net Economic Services for the Galveston Case Study Area, 1980–2025

	Real Discount Rate (in Percent) 3	6	10
Scenario			
A. Trend Scenario	10,010	6,015	3,985
B. High Scenario without Anticipation	9,650	5,915	3,960
C. High Scenario with Anticipation	8,870	5,970	3,975
Results			
Economic Impact (A–B)	360	100	25
Value of Anticipating Sea Level Rise (C–B)	220	55	15

Tables 7-8 and 7-9 summarize the estimates of economic impact and value of anticipation for each of the scenarios. Because these estimates are present values of streams over long periods, the discount rate has a significant influence on the outcome. The values are substantially smaller when a 6 percent or 10 percent discount-rate is used.

Table 7-8 shows that the economic impact of sea level rise in the Galveston study area may range from $555 million for the low scenario to nearly $1.9 billion for the high scenario through 2075. These impacts represent a reduction of 4.9 to 16.0 percent of the total present value of economic activity in the study area during that period. The impacts would have been much larger were it not for the existing seawall and levee systems in the area. Leatherman assumed that the seawall and levee systems would be upgraded as necessary so that they would remain effective with a sea level rise. Consequently, in this analysis, they provide protection from the increasing frequency of storm surge at elevations below the minimum height of the structures. Only storm surges in excess of the minimum height of the structures were assumed to cause damage. If the structures were assumed to fail, then the impacts would be larger because storm damages would be larger. (The existing protective structures were also assumed to halt shoreline movement at their current locations.)

Table 7-8. Economic Impact of Three Sea Level Rise Scenarios in the Galveston Case Study Area (in millions of 1980 dollars)

Table 7-8. Economic Impact of Three Sea Level Rise Scenarios in the Galveston Case Study Area (in millions of 1980 dollars)

	Real Discount Rate (in Percent)[a]					
	1980–2025			1980–2075		
Scenario	3	6	10	3	6	10
Low	115	30	10	555	70	10
	(1.1)	(0.5)	(0.2)	(4.9)	(1.2)	(0.2)
Medium	260	65	15	965	150	20
	(2.6)	(1.1)	(0.3)	(8.4)	(2.5)	(0.5)
High	360	100	25	1,840	220	35
	(3.6)	(1.7)	(0.6)	(16.0)	(3.6)	(0.9)

[a]Values in parentheses report percentage of total net economic services estimated in the trend case.

[a]Values in parentheses report percentage of total net economic services estimated in the trend case.

Table 7-9. The Value of Anticipating Future Sea Level Rise for the Galveston Case Study Area, Contingent on Each of the Three Sea Level Rise Scenarios (in millions of 1980 dollars)

Table 7-9. The Value of Anticipating Future Sea Level Rise for the Galveston Case Study Area, Contingent on Each of the Three Sea Level Rise Scenarios (in millions of 1980 dollars)

	Real Discount Rate (in Percent)[a]					
	1980–2025			1980–2075		
Scenario	3	6	10	3	6	10
Low	25	6	1	245	27	2
	(22)	(20)	(10)	(44)	(39)	(20)
Medium	150	30	5	550	60	5
	(58)	(46)	(33)	(57)	(40)	(25)
High	220	55	15	1,110	130	15
	(61)	(55)	(60)	(60)	(59)	(43)

[a]Values in parentheses report percentage of total economic impact.

[a]Values in parentheses report percentage of total economic impact.

Table 7-9 shows that by anticipating sea level rise, its adverse impacts can be greatly reduced: impacts from the high scenario can be reduced by approximately 60 percent. Table 7-10 displays how the economic impact and value of anticipating sea level rise are distributed throughout the study area for the high scenario. Both the Galveston Island and TexasCity/La Marque areas are significantly affected by the high sea level rise scenario. By anticipating sea level rise, the impacts in these areas can be reduced substantially. In the Galveston Island area, the anticipation of sea level rise is simulated to result in earlier implementation of measures to protect the island from bayside flooding. By taking these actions before the risk increases substantially, damages are prevented.

Table 7-10. Economic Impact and Value of Anticipating Sea Level Rise for the High Scenario, 1980-2075: Galveston Case Study Area

Table 7-10. Economic Impact and Value of Anticipating Sea Level Rise for the High Scenario, 1980–2075: Galveston Case Study Area

Portion of Galveston Study Area	*Economic Impact of High Scenario (Percent of Study Area)*	*Value of Anticipating High Scenario (Percent of Study Area)*
Galveston Island/Bolivar Peninsula	620 (34%)	565 (51%)
Texas City/La Marque	950 (51%)	535 (48%)
San Leon	270 (15%)	10 (1%)
Total Study Area	1,840 (100%)	1,110 (100%)

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

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

The impact of the high scenario in the Texas City/La Marque areas is caused primarily by currently protected areas becoming vulnerable to storm surge. To protect the areas, the levee system is simulated to be extended, thus reducing the risk of storm damage. The anticipation of sea level rise is assumed to result in an earlier extension of the levee system than would otherwise occur. Additionally, there are unincorporated areas south of La Marque that are very low-lying and are not protected by the levee system. Under the high scenario, these locations would be inundated. These areas are expected to be developed over the next 40 years. By anticipating the high scenario, it is assumed that additional development after 1990 would not be undertaken in these very vulnerable areas.

The San Leon area is also very vulnerable to inundation under the high scenario, as is indicated in Table 7-10 by impacts of $270 million. Although this is only 15 percent of the impact for the entire study area, it represents 70 percent of the value of the economic activity simulated to be undertaken in the San Leon area. Anticipating sea level rise is estimated to have only a small benefit for San Leon because it was assumed that the medium to low density of development there was insufficient to justify large protective structures. Consequently, development patterns are simulated to shift away from the areas of increasing hazard, resulting in a slight reduction in impacts. If San Leon could be protected (possibly as a part of a larger protection effort for all of the Galveston Bay area), then the benefit of anticipating sea level rise would probably be higher.

SUMMARY

This chapter has presented the implementation of a method for assessing the economic impacts of sea level rise and has examined the value of anticipating sea level rise. Although significant work remains to be done, this work provides a step toward developing improved assessments of the economic and societal impacts of sea level rise.

As one would expect, coastal cities currently without protection are more vulnerable to sea level rise and have the most to gain by anticipating it. As shown in Table 7-11, the Charleston study area appears to be somewhat harder hit by sea level rise, primarily because of its current unprotected state relative to Galveston. Evaluated at a 3 percent real discount rate, the impact of the high scenario is 16 percent of the total NES in the Galveston study area for the 1980-2075 period. In Charleston, the impact is over 34 percent.

The estimates of the value of anticipating sea level rise must be considered to be somewhat speculative but nevertheless highly suggestive. The small, marginal shifts in behavior modeled here are found to have considerable value. As described in the text, the values reported here may be biased downward by the conservative assumptions employed.

Based on the results presented here, it appears to be justified to ask what should be done in anticipation of sea level rise. The analysis illustrates that the stakes are large and that appropriate preparation can significantly reduce adverse impacts. Consequently, investigating what we ought to do to prepare ourselves is clearly warranted. Choosing a preparation strategy requires an analysis very similar to that described here. In addition, the uncertainty surrounding how much sea level will actually rise must be incorporated into the analysis.

Table 7-11. Summary of Economic Impacts and Value of Anticipating Sea Level Rise in the Charleston and Galveston Case Study Areas

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	Charleston Study Area		*Galveston Study Area*	
Scenario	*Economic Impact*	*Value of Anticipation*	*Economic Impact*	*Value of Anticipation*
Low	1,250	810	555	245
Medium	1,910	1,180	965	550
High	2,510	1,400	1,840	1,110

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

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Even with our current uncertainty regarding future sea level rise, the large potential impacts combined with the possible savings from preparing for sea level rise suggests that taking actions today should be considered. If actions are taken today (e.g., accelerating research or incorporating the possible future need for protective structures into current designs), they may turn out to be unnecessary if the sea level does not rise. Alternatively, if the sea level is rising as fast as indicated by the scenarios used here, we will be much better prepared 20 years from now and as a result will be much better off. Analysis and political debate are required to balance the risk of taking unnecessary actions against regretting 20 years from now that opportunities were missed. The estimates reported here provide a basis upon which the analysis and debate can be built and suggest that a resolution of this issue is very important to Charleston and Galveston.

NOTES

1. To the extent that investors and developers have knowledge of erosion and storm hazards and incorporate this knowledge in their investment decisions, development patterns will reflect people's perception and valuation of hazards. For examples, see J. R. Barnard, 1977, "Economic Costs Associated with Increased Flood Hazards from Urban Growth," in *Proceedings of International Symposium on Urban Hydrology, Hydraulics, and Sediment Control.* Bulletin 114. Lexington,
K.: Kentucky University Office of Research and Engineering Services.
2. The specification of utility functions as measures of satisfaction were omitted from this analysis. Instead, dollars are used.
3. Amenities may include nice weather, scenic views, air quality, and others. For more detail on amenities see Douglas B. Diamond, Jr., and George S. Tolley, eds., 1982, *The Economics* of Urban *Amenities,* New York: Academic Press.
4. If people who use the beach live outside the study area, then the value of the beach will be underestimated because their property values reflecting their valuation of the beach will be excluded. This bias can be eliminated by incorporating the value that people living outside the study area place on the beach (estimated by other means).
5. The reader interested in discounting and discount rates may refer to E. J. Mishan. 1976, *Cost-Benefit Analysis,* New York: Praeger, pp. 199-218.
6. From the standpoint of the individual, sea level rise may reduce the attractiveness of a coastal community because of increased storm hazards. Consequently, the individual may decide to leave an area (or, whereas he or she would otherwise have lived there. In this case, the individual is worse off. This impact is not captured by this analysis.
7. Surplus value of labor refers to the"producers' surplus"or portion of the worker's value captured by the employer. For more on producers' surplus see Mishan, *Cost-Benefit Analysis,* pp. 55-64 (note 5).
8. The following rates of depreciation were used:
Single-family houses: 2 percent per year, based on the assumption of a 50 year lifetime for homes generally used in property value assessments. See George F. Bloom, and Henry S. Harrison, 1978, *Appraising the Single Family Resi*dence, Chicago: American Institute of Real Estate Appraisers of the National Association of Realtors.
Manufactured housing: 5 percent per year, based on an expected life of 20 years. Commercial/industrial properties: 9 percent per year. See William Williams, 1961. *The Measurement of the* Impact *of State* and Local Taxation on Indus*trial Locations,* Boulder: University of Colorado, Department of Economics.
Multi-family housing: 5 percent per year, assumed to be approximately divided between single family housing and commercial/industrial properties.
9. See Chapters 4 and 5.
10. Land use data were collected for each of four land uses: single-family houses, multi-family houses, manufactured housing (e.g., mobile homes), and commercial/industrial properties.
11. See Don Friedman. 1975, Computer Simulation *in Natural Hazard Assessment,* Institute of Behavioral Science, NTIS PB-261-755, Boulder: University of Colorado.
12. Based on the principles discussed in Lind, the marginal value of investment is estimated by putting all the returns from an investment in consumption units. Assuming that sea level rise has little or no impact on the savings rate nationally, the marginal value of investment can be expressed in terms of the private discount rate **(r),** the social rate of time preference (i), the appreciation rate (a), the total rate of depreciation [including expected value of storm damages (m)], and the expected rate of reinvestment (h). Assuming that initial investment, depreciation, and reinvestment begin in year 0, and returns begin in year 1, then the marginal values of new investment and reinvestment can be expressed as:

Marginal value of new investment $\dfrac{\dfrac{r-a}{1+a} + m + h \bullet \dfrac{(r-a)}{(1+a)}}{\dfrac{i-a}{1+a} + m + h \bullet \dfrac{(i-a)}{(1+a)}}$ and

Marginal value of reinvestment $\dfrac{\dfrac{(r-a)}{(1+a)} \bullet \dfrac{(i-a)}{(1+a)} + m \bullet \dfrac{(r-a)}{(1+a)} + \dfrac{r-a}{1+a} + m}{\dfrac{(i-a)}{(1+a)} \bullet \dfrac{(i-a)}{(1+a)} + m \bullet \dfrac{(i-a)}{(1+a)} + \dfrac{i-a}{1+a} + m}$

As expected, when **r** equals *i*, the marginal values equal 1.0. When **r** exceeds i, the marginal values exceed 1.0. See Robert C. Lind, 1982, "A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options," in R. C. Lind, ed., *Discounting for Time* and *Risk in Energy Policy,* Washington, D.C. Resources for the Future, pp. 21-94.

13. Howard Kunreuther. 1978, *Disaster Insurance Protection: Public Policy Lessons,* New York: John Wiley & Sons.

14. People's perceptions are simulated to increase slowly over time at the rate at which the sea level rise signal could be statistically distinguished from the noise. At the beginning of the analysis, people are assumed to believe with equal probability that the sea level is either not rising or is rising at the rate of the recent historical trend for their location. As time goes on, their expectations gradually approach the true scenario (low, medium, or high) at the rate at which the lowest believed scenario can be statistically differentiated from the scenario being investigated. Statistical differentiation is assumed to be two standard deviations of annual average sea level position. This approach implicitly assume, that sea level rise will not change the variance of unrelated fluctuations in sea level position and that direct observation is the information most strongly affecting people's perceptions and hence behavior.

15. U.S. Army Corps of Engineers, Galveston District, 1979, Galveston Study Segment: Texas Coast Hurricane Study, Feasibility Report, Galveston: U.S. Army Corps of Engineers.

16. This question could be approached using regional economic models. The supply and demand links between the coastal and inland regions would be quantified, followed by an analysis of how changes in economic conditions in the coastal regions would affect the inland regions, detailed transportation analysis may also be warranted.

17. In optimization programming, this is generally referred to as the specification of the objective function. In a complex problem such as identifying the optimal actions to take in anticipation of sea level rise, the objectives will be multi-dimensional and in a variety of units. Consequently, relative weights must be given to the various objectives reflecting value judgments. Additionally, the nonlinear and dynamic aspects of the analysis would require either unrealistic simplifying assumptions or considerable computing power.

18. Total damages will far exceed damages to privately owned buildings. Two estimates of damages from earthquakes put total damages at two to four times the damage to privately owned structures. A conservative estimate of twice the damage was used here. See Harold C. Cochrane, 1974, "Predicting the Economic Impact of Earthquake," in *Social Science Perspectives on the Coming San Francisco Earthquake:* Economic Impact, *Prediction, and Reconstruction,* Boulder:University of Colorado, and Worcester, Mass.: Clark University, p. 32.

19. Tax assessment maps and data were provided by Robert W. Ragin, assessor, Charleston County. The tax data provided by Mr. Ragin form the foundation upon which the economic analysis was built, and this project is indebted to him for his cooperation and assistance.

20. The storm surge information was obtained from FEMA Flood Insurance Rate Maps for the 100-year flood. Estimates of the 10-year and 50-year storm surge elevations were provided by RPI. The area loss for each sea level rise scenario for each subunit was developed by RPI.

21. The topographical data describing each subunit were developed by John Jenson, University of South Carolina.

22. The number of existing structures was obtained from property tax data supplied by Robert W. Ragin (see note 19). The average value of structures by land use within each subarea was computed by multiplying the assessed value of the structure by an empirically derived ratio of market value to assessed value, also provided by Mr. Ragin.

23. Land use changes and rates of growth were identified from planning documents from the city of Charleston, city of North Charleston, and Mount Pleasant.
24. Stephen Leatherman, Michael S. Kearney, and Beach Clow, 1983. *Assessment of Coastal Response to Projected Sea-Level Rise: Galueston Island and* Bay *Texas.* URF Report TR 8301; report to ICF under contract to EPA, College Park: University of Maryland.
25. Ibid.
26. The distribution of topographical elevations above mean sea level within each subarea was developed at the University of Maryland by Stephen Leatherman and Beach Clow.
27. Carlton Ruch of the Research Center, College of Architecture, Texas A&M University, provided economic and population data developed in his ongoing research of the effects of hurricanes. The data provided by Dr. Ruch not only, contributed significantly to the Galveston case study but also provided a model after which the development of the data for the Charleston case study was patterned.
28. Expected changes in land use were indicated in the data provided by Dr. Ruch (see note 27). These data were augmented with information in local planning documents from Texas City, Texas.
29. Storm damages were simulated by interpolating between three storm types (a 10 year storm, 50-year storm, and 100-year storm) to calculate a frequency-damage function that is integrated to estimate the expected value of damages in a given year. Protective structures (such as seawalls and levees) produce a discontinuous frequency-damage function. Although the continuous nature of sea level rise produces a continuous shifting of the discontinuity, the use of only three storm types to develop the frequency-damage function results in a large discontinuous jump in damages as soon as one of the three storm types overtops the protective structure. A more sophisticated model of the impact of protective structures on storm surges whose elevations exceed the height of the protective structures would eliminate this problem of discontinuity.
30. The mechanisms via which protected areas become vulnerable to storm surge in the high scenario are described in Leatherman et al. (see note 24).