

**THE DYNAMICS OF SHORELINE MANAGEMENT:  
AN APPROACH USING RENEWABLE RESOURCE ECONOMICS**

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## Abstract

The combination of coastal development and naturally retreating shorelines in sensitive barrier island ecosystems has led to increased demand for shoreline management. The strategy of beach nourishment is commonly used to build an artificial beach in order to maintain recreational benefits and protect oceanfront property. A simulation model was developed to examine the costs and benefits associated with nourishment and to compare these with an alternate strategy of relocating coastal structures. This model uses principles of renewable resource economics to characterize the effect of the natural and anthropogenic rates of growth and decay on the net benefits of a beach. Hedonic property value studies of coastal areas were used to characterize some of the benefits of beaches. A regression analysis was performed to determine the structure of the cost curve for nourishment projects as a function of the volume of sand used. The results of the simulation model highlight the importance of considering the dynamics of these systems and the effects of each strategy over time. The relative efficiency of a repeated nourishment strategy is shown to depend on the frequency with which nourishments must be carried out. In addition, progress was made towards outlining the necessary components for modeling the optimal path of management decisions.

## Introduction

Beaches are important natural resources for both environmental and economic reasons. To take advantage of these resources people have been moving to and developing in coastal areas at an increasing rate. However, the continuing erosion of Atlantic and Gulf coast barrier island beaches has placed many coastal structures in harms way. The potential for property loss and damage due to flooding and erosion during coastal storms has led to the demand for shoreline management. In this study two management options, repeated nourishment and relocation of coastal structures, are discussed. The costs and benefits of these two strategies are evaluated using a dynamic renewable resource approach to management. A regression analysis is performed to characterize the costs of nourishment projects. Benefits for beaches are investigated using hedonic property value studies that establish the marginal implicit price of the beach as a function of its width. A simulation model is developed that combines the insights from the regression analysis, hedonic studies, and a systematic treatment of the intertemporal dynamics of beach systems and beach management strategies. Finally, the analysis allows for progress towards developing a dynamic optimization model of these management decisions.

## Beach Resources

The beaches that line the US Atlantic and Gulf coasts are the seaward edge of an almost unbroken chain of dynamic barrier islands that extend from the tip of Long Island to the Mexican border (Bush, Pilkey, and Neal, 1996). These beaches are important for both environmental and economic reasons. In 1982 Congress enacted the Coastal Barrier Resources Act (CoBRA) recognizing the importance of barrier island ecosystems that “provide habitats for migratory birds and other wildlife; and habitats which are essential spawning, nursery, nesting, and feeding areas for commercially and recreationally important species of finfish and shellfish, as well as other aquatic organisms such as sea turtles” (Coastal Barrier Resources Act, 97 P.L. 348; 98 Stat. 1653). A number of species that depend on healthy beach ecosystems, such as the piping plover and several species of sea turtles, are listed as endangered or threatened under the Endangered Species Act. In

fact, 45% of all species listed as endangered or threatened and 75% of listed mammals and birds rely on healthy coastal ecosystems (Heinz Center, 2000).

Although these environmental services have associated economic values, they typically provide non-use values that receive little consideration in coastal management. However, many of the most important non-market values of healthy beaches are use values and are reflected at least indirectly in property values. A sizeable tourist industry has developed around our society's desire to visit the beach. Wider beaches serve as recreational resources for walking, swimming, surf-fishing, boating, crabbing, and bird watching. In addition, healthy beaches decrease storm and flood risks to coastal development. A wider beach protects structures from high water levels and dissipates wave energy. Finally, beaches also provide aesthetic values for nearby property owners.

These valuable resources, however, are not static parts of the landscape and are subject to variation on a daily, yearly and interannual basis. Atlantic and Gulf coast barrier island beaches are dynamic features characterized by equilibrium profiles that are a function of local sediment supply, wave energy, currents, and tidal forces (National Research Council [NRC], 1990). Beach widths vary seasonally with changing weather and wave conditions (NRC, 1990). During the winter months, when coastal storms and large waves are frequent, sand is moved off shore and beach widths are generally diminished. Calmer summer conditions promote the landward transport of sand and beach recovery. Beach widths also change dramatically in response to extreme weather events such as hurricanes. Sand is again moved off shore as a result of the higher water levels and increased wave energy and then returned to the beach during calmer periods (NRC, 1990).

Long-term changes in shore profiles are of greatest concern to coastal property owners. The landward migration of shorelines can be induced by sea level rise, local land subsidence, and human induced changes in the alongshore transport of sediment (NRC, 1990). What is often called shoreline erosion is more appropriately termed shoreline retreat. As sea level rises the interactions between waves, currents, and gravity shift landward resulting in a migration of the equilibrium shore profile. In the absence of coastal development the beach migrates landward, changing location but retaining its shape. The presence of coastal structures interferes with this migration and, as the

shoreline shifts, the beach narrows and the water's edge approaches and threatens development. Congress recognized the tension between the natural processes and development of these islands in enacting CoBRA which states that "costal barriers serve as natural storm protective buffers and are generally unsuitable for development because they are vulnerable to hurricane and other storm damage and because natural shoreline recession and the movement of unstable sediments undermine manmade structures" (NRC, 1990).

### Coastal Development

Despite the continued risks, development and recreational use in coastal areas has increased dramatically over the last 50 years (Heinz Center, 2000). Over that time average incomes and car ownership increased while transportation infrastructure and access to coastal areas improved (Heinz Center, 2000). Combined with increases in leisure time, these trends led to a significant rise in people traveling to the coasts for recreation. Approximately 180 million Americans spend \$74 billion on visits to ocean and bay beaches each year (Heinz Center, 2000). Many seaside communities have changed from small fishing villages to major tourist resorts. As a result, construction in flood and erosion prone areas has increased, as have the costs of damages to those structures.

Approximately 350,000 structures are currently within 500 feet of coastline in the continental U.S. and Hawaii (Heinz Center, 2000). This accounting excludes structures in densely developed coastal cities where the majority of buildings are protected from erosion. Approximately 85,000 homes that are situated on low lying land or bluffs are projected to erode into the ocean or great lakes over the next 60 years – approximately 1,500 homes per year (Heinz Center, 2000). The loss of these homes is likely to cost, on average, \$530 million each year (Heinz Center, 2000).

### Shoreline Management

There are several strategies for protecting coastal structures from shoreline retreat. The primary ones discussed here are soft stabilization of the beach and relocation of threatened structures. Soft stabilization refers primarily to beach nourishment. Sand is

dredged from an offshore borrow site and used to build an artificial beach in front of threatened structures. If it is assumed that the first coastal storm after a nourishment project redistributes the sand so that it assumes the same shape as the equilibrium profile, then the extra width added to the beach is a function of the total volume of the project, the length of beach that is nourished and the water depth at which there is no significant movement of sediments by wave action, the so called “closure depth” (NRC, 1995).

As nourishment preserves the physical presence of the beach, it has become an increasingly popular option for coastal communities. However, erosion continues, making nourishments temporary solutions. In fact, some studies suggest that the profile of the artificial beach is out of equilibrium with the near-shore forces, and that as a result erosion of nourished beaches may occur more rapidly than for natural beaches. The duration of time before the artificial beach is lost has been highly variable along the East Coast; 26% of nourished beaches were effectively gone in less than 1 year and 62% lasted between 2 and 5 years (Pilkey and Dixon, 1996).

Given the need for maintenance and renourishment, beach nourishment can be quite costly as a long-term strategy. Between 1950 and 1993, the Army Corps of Engineers spent approximately \$700 million (expressed in 1993 dollars) to nourish 200 miles of U.S. coast (Heinz Center, 2000). The continued maintenance and renourishment costs for these projects are estimated to be \$300,000 per year per mile of beach (Heinz Center, 2000). A recent study by the H. John Heinz III Center for Science, Economics, and the Environment (Heinz Center) found that projected erosion damages exceeded nourishment costs in only 10% of the Atlantic and Gulf coastal counties that were studied (2000).

Many people oppose nourishment because it has the potential to create significant environmental impacts in the surrounding ecosystems. These include threats to whales, dolphins, and porpoises that feed in offshore dredging areas (Associated Press, 2001) and adverse effects for seagrass beds that serve as protective environments for the larval development of a variety of marine species (National Oceanic and Atmospheric Administration [NOAA], 2002). As sand is placed on the beach, worms, clams, and crabs are buried. This, in turn, affects migratory birds and young fish that feed on these organisms. Harmful impacts to benthic organisms can also result from the increased

sediment and turbidity produced in the surf zone from the dredge and fill activities (NOAA, 2002). Significant threats exist for already threatened and endangered sea turtles. One potential impact is the incorporation of long-lived pollutants into turtle eggs after they are brought on shore by a nourishment project (Associated Press, 2001). Also, failed turtle nesting seasons may occur as a result of the changes in sand quality and grain size (Pilkey, 2002). In addition, artificial beach profiles that are in disequilibria with the surf zone forces that shape them often lead to large erosion scarps. These erosion scarps are like small cliffs that form in the sand and can prevent turtles from accessing appropriate nesting sites further inland (Pilkey, 2002).

An alternate strategy for protecting coastal structures from shoreline retreat is the removal or relocation of the structures themselves. This is particularly applicable in areas where the narrowing of the beach is due to sea level rise induced landward migration. In these cases, relocation recognizes the potential to maintain a beach simply by relocating structures away from it. This is the most environmentally friendly solution in that the physical presence and biological integrity of the beach and surrounding ecosystems are preserved. Already, some coastal areas are encouraging relocation through zoning laws that require property lots of a certain depth to allow for the landward relocation of structures (Heinz Center, 2000).

### Beaches as Renewable Resources

In considering the different approaches to shoreline management it is useful to frame the problem as a question of dynamic renewable resource management. Renewable resources, such as fish stocks and harvested forest stands, exhibit significant rates of growth and depletion within economic timeframes (Conrad, 1999). Optimal management of these resources must take into account these processes of change as well as the costs and benefits associated with different management strategies.

Framed in these terms, beaches exhibit growth through management decisions over nourishment and relocation. The depletion of the beach is simply erosion. As with other renewable resources the state of the resource in any given year is dependent on the choices and changes made to it in the previous years. Beaches are unlike renewable resources like fish and forests in that they are physical systems governed by physical

processes as opposed to biological ones. In addition, for most renewable resources, the anthropogenic influence enters in on the side of depletion of the resource through harvest. For beaches, the anthropogenic influence is on growth. However, decisions about nourishment can also affect erosion rates. A final distinction between beach systems and other renewable resources is that, for beaches, benefits stem from the stock of the resource. For more traditionally considered renewable resources, benefits come primarily from the “flow” of the resource and only sometimes from the stock.

The usefulness of considering beach systems in terms of a dynamic renewable resource management problem comes from the emphasis that this places on determining the optimal path for resource management. In addition to trying to optimize the benefits drawn from the system, this approach recognizes the connection between actions taken in one time period and the state of the resource and rates of change in the next time period.

What follows is an attempt to model the beach as a renewable resource. This involves considering the strategies of repeated nourishment and relocation over a certain time horizon with attention to the intertemporal forces that affect the state of the beach. For each strategy, benefits of the beach are calculated over time, as are the costs of each management approach. From this, the present value of the net benefits for each management strategy can be compared.

### Evaluating the Benefits of Beaches

The benefits associated with management through nourishment or relocation are due to increasing or preserving the presence and width of a beach. These benefits have been measured a number of ways including using travel costs methods, contingent valuation surveys, and hedonic property value studies (NRC, 1995).

The last of these, hedonic property value studies, is based on the idea that some benefits are capitalized into the price of coastal properties and these studies can tease out the marginal implicit price associated with beach amenities. However, the studies discussed here are limited to considering only private use values that are capitalized into the value of coastal properties. Public goods, such as habitat and biodiversity protection, are not accounted for. Nor are the private benefits experienced by day visitors or other tourist related businesses outside of residential areas.

## Hedonic Property Value Models

All hedonic property value studies are based on the premise that differences in housing prices correspond to differences in the quantities of various housing characteristics (Freeman, 1993). The basic theory of rents specifies that the price of a piece of land is equal to the present value of the stream of rents produced by that land. As productivity of land varies, so does the price (Freeman, 1993). Therefore, the price of a given piece of land can be seen as a function of the different productivity enhancing characteristics that it possesses. These could be structural characteristics, neighborhood characteristics, or even environmental characteristics. Regression models that predict housing prices based on the different bundles of these characteristics can be used to tease out the marginal implicit price of environmental goods. In a market equilibrium the marginal implicit price associated with an environmental good is equal to the marginal willingness to pay for the good (Freeman, 1993). A number of these studies have looked at coastal housing markets to determine willingness to pay for beach amenities. Table 1 summarizes eight of these studies. Varying in the geographical location as well as the type of shoreline (ocean coast, gulf coast, lake shore), all eight provide evidence that shoreline amenities are positively related to housing prices.

The majority of studies have looked at proximity measures such as distance to the beach, water frontage and water views. The analyses by Brown and Pollakowski (1977); Edwards and Gable (1991); Milon, Gressel, and Mulkey (1984); Parsons and Powell (2001); Parsons and Wu (1991); and Wilman (1981) all found a negative and significant relationship between distance and housing prices. This indicates that people are willing to pay more to be closer to the shore. Several of these studies also found significant relationships indicating that home buyers will pay more for houses that have water views (Edwards and Gable, 1991; Milon, Gressel, and Mulkey, 1984; and Parsons and Wu, 1991) or that are located on waterfront lots (Edwards and Gable, 1991; Parsons and Powell, 2001; Parsons and Wu, 1991).

Four of the studies listed in Table 1 go beyond proximity related amenities to consider the quality or quantity of the beach or shorefront recreational area. Wilman's (1981) study of Cape Cod housing prices looked at the marginal implicit price of the presence of debris on the beach as a way of measuring the quality of beach areas. The

**Table 1: Results of Hedonic Studies in Coastal Areas**

Authors	Study Area	Dist.	Frontage	View	Other Amenity Variable
<b>Brown and Pollakowski (1977)</b>	Seattle, WA Lakeshore	(-)	NA	NA	Width of lake shore open space (+)
<b>Edwards and Gable (1991)</b>	South Kingstown, RI Ocean coast	(-)	(+)	(+)	NA
<b>Milon, Gressel, and Mulkey (1984)</b>	Apalachicola Bay, FL Gulf coast	(-)	(+)*	(+)	NA
<b>Parsons and Powell (2001)</b>	Sussex County, DE Ocean coast	(-)	(+)	NA	NA
<b>Parsons and Wu (1991)</b>	Anne Arundel County, MD Chesapeake Bay	(-)	(+)	(+)	NA
<b>Pompe and Rinehart (1994)</b>	Surfside Beach and Garden City, SC Ocean coast	(-)**	(+)	(+)	Beach width at high tide (+)
<b>Pompe and Rinehart (1999)</b>	Seabrook Island, SC Ocean coast	(-)**	NA	(+)	Beach width at high tide (+)
<b>Wilman (1981)</b>	Cape Cod, MA Ocean coast	(-)	NA	NA	Presence of debris on beach (-)

\* insignificant at researchers' threshold level

\*\* interaction term of beach width \* distance to nearest beach

author's results showed a negative relationship, indicating higher property values for houses near better quality beaches.

Of particular interest are attempts to measure the value associated with additional beach width. Unlike measures of distance, view, and frontage, beach width not only captures the recreational benefits associated with a larger area, it also reflects the protection that an additional foot of beach provides for coastal structures. For decisions about setback regulations, whether or not to carry out beach nourishments, and how large any given nourishment project should be, it is the willingness to pay for beach width that is perhaps most relevant.

Brown and Pollakowski (1977) looked at a similar issue by considering the width of open space along lakeshore areas. Their results show a positive relationship between lakeshore open space and housing prices, reflecting recreational values similar to what we might expect in beach communities. However, their study does not capture benefits provided by beaches in the reduction of erosion and storm risks. Only two studies by

Pompe and Rinehart (1994 and 1999) look specifically at the variation in property values as a function of beach widths.

The study published by Pompe and Rinehart in 1994 analyzed actual transaction data for 385 houses sold between 1983 and 1991 in the residential communities of Surfside Beach and Garden City, South Carolina. A quadratic Box-Cox transformation showed optimal functional form corresponding to the double-log. Using this functional form, a model was built considering various structural characteristics as well as beach width, ocean frontage, and water views. Several measures of beach width were investigated including width at high tide, low tide, and sand volume. Width at high tide was found to be the best estimator in terms of  $R^2$  and t values. Measures of beach width were taken in the spring of 1989. An interaction term of beach width and distance to the nearest beach was also included to capture the recreational benefit from wider beaches. Neighborhood and locational variables were ignored as the two communities were presumed to be sufficiently similar in these characteristics. All coefficients had the expected signs.

The 1994 study produced a coefficient for beach width of 0.2632. The double log model corresponds to constant elasticity so that a marginal increase in beach width of one percent corresponds to a 0.26% increase in value. For beach nourishment, non-marginal changes are more likely to interest policy makers. For a non-marginal change, although the percent changes are not tied to the starting values, we do not simply multiply 0.26 by the percentage increase. For example, a doubling of beach width is associated with a multiplicative change in property value of  $2^{0.2632}$ . This is equivalent to a 20% increase in property value.

A similar study published by Pompe and Rinehart in 1999 considered the private community of Seabrook Island, South Carolina. Transaction data for 238 developed and 297 vacant lots were analyzed with respect to beach width, water frontage and view, as well as an interaction term of beach width and distance to the beach. Width at high and low tide were considered as well as a five-year average beach width. Again, high tide width was selected as it provided the highest  $R^2$  value. Pompe and Rinehart used the same procedure for determining functional form and again settled on a double log model.

In this study the coefficient for beach width was estimated to be 0.134 for developed lots and 0.304 for vacant lots. As such, a doubling in beach width corresponds to an increase in property value by a factor of  $2^{0.134}$  or 10% for developed lots and  $2^{0.304}$  or 23% for vacant lots. The fact that the value of vacant lots rises at a greater rate with increasing beach width may simply reflect the fact that there are fewer components involved in the value of a vacant lot.

In using these studies it is important to note that beach width is a temporal characteristic that varies naturally and through management over time. Property values, on the other hand, are expressed in terms of the present value sum of the infinite stream of benefits that a given piece of property is expected to generate. In order to use property values to evaluate the marginal implicit price of a beach these two timescales need to be reconciled. In developing the model that follows, the time scale of a single year is used. Property values are expressed in terms of the yearly rental value and beach widths are expressed in terms of yearly average width at high tide.

Using these hedonic studies the changes in benefits associated with a management strategy designed to produce a given change in beach width can now be estimated. In order to evaluate the relative economic efficiency of nourishment and relocation one must also be able to estimate the costs associated with these two management strategies.

### Costs of Nourishment

The cost of an individual nourishment project consists of paying for the labor and capital to carry out the project. Project costs are thought to vary as a function of the size of the project, both in terms of the volume of sand placed on the beach as well as the length of the beach to be nourished. Other factors, such as the method of sand emplacement, the location of the sand borrow site, or other location specific costs, may also influence the total cost of a project.

Using data from the Program for the Study of Developed Shoreline at Duke University, a regression analysis was performed to characterize the costs of a nourishment project as a function of the volume of sand used and the length of the nourished beach. The data set included information on project costs, total sand volume, and length of nourished beach for 132 different nourishments performed at different sites

along the US Atlantic and Gulf coasts over the last 50 years. As shown in Table 2 the mean project used 19,909,239 ft<sup>3</sup> of sand to nourish 10,429 ft of beach. Depending on the individual beach profile and closure depth, this would correspond to adding somewhere between 80 and 160 ft of width to the beach (NRC, 1995). All costs are reported in 2002 dollar values and the average project cost was \$4.6 million.

**Table 2: Nourishment Dataset**

	<b>Length (ft)</b>	<b>Volume (ft<sup>3</sup>)</b>	<b>Cost (2002\$)</b>
<b>Minimum</b>	100	2,430	942
<b>1<sup>st</sup> Quartile</b>	2,588	3,780,000	990,524
<b>Mean</b>	10,429	19,909,239	4,623,636
<b>Median</b>	7,140	7,101,000	1,976,220
<b>3rd Quartile</b>	15,250	25,565,152	6,124,956
<b>Maximum</b>	47,520	162,000,000	57,832,988
<b>Total N</b>	132	132	132
<b>Standard Deviation</b>	10,491	26,947,778	6,867,003

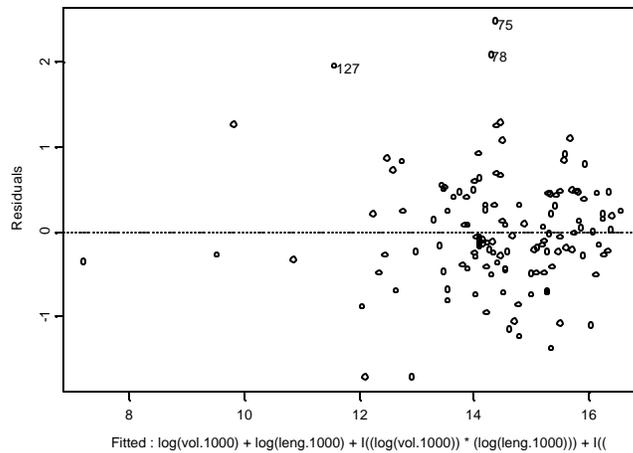
An all subsets model selection process was run and models were evaluated on the basis of Mallows Cp and Bayesian Inference Criteria (BIC). Several of the top performing models were then further compared in terms of coefficient p-values and residual plots. The final model selected is shown below with standard errors in parenthesis beneath each regression coefficient. In this model volume is in units of 1000 ft<sup>3</sup> and length is in units of 1000 ft.

$\text{Est. mean } \ln(\text{Cost}) = 3.0656 + 2.0319 * \ln(\text{Volume}) - 1.1589 * \ln(\text{Length})$ <div style="display: flex; justify-content: space-around; margin-top: 5px;"> <span>(1.4411)</span> <span>(0.4079)</span> <span>(0.4670)</span> </div> $+ 0.1274 * \ln(\text{Volume}) * \ln(\text{Length}) - 0.0831 * (\ln(\text{Volume}))^2$ <div style="display: flex; justify-content: space-around; margin-top: 5px;"> <span>(0.0528)</span> <span>(0.0280)</span> </div> $\hat{S} = 0.68 \text{ on } 126 \text{ degrees of freedom}$
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Exploratory analysis of the data showed increasing variance as the volume and length of the nourishment project increased. A log transformation was performed on all

variables. This improved the distribution of the data as shown in the plot of residuals vs. fitted values for the above model shown in Figure 1.

The model suggests that both volume and length are important in explaining the variation in nourishment project costs. The squared term reflects the fact that volume enters into the model in a non-linear way. As volume changes the relationship between cost and volume changes. The interaction term for volume and length suggests that the changes in cost associated with one factor cannot be interpreted independently of the other. In addition, volume and length are correlated and for a project of a given volume there is a limited range of lengths over which these results make sense.



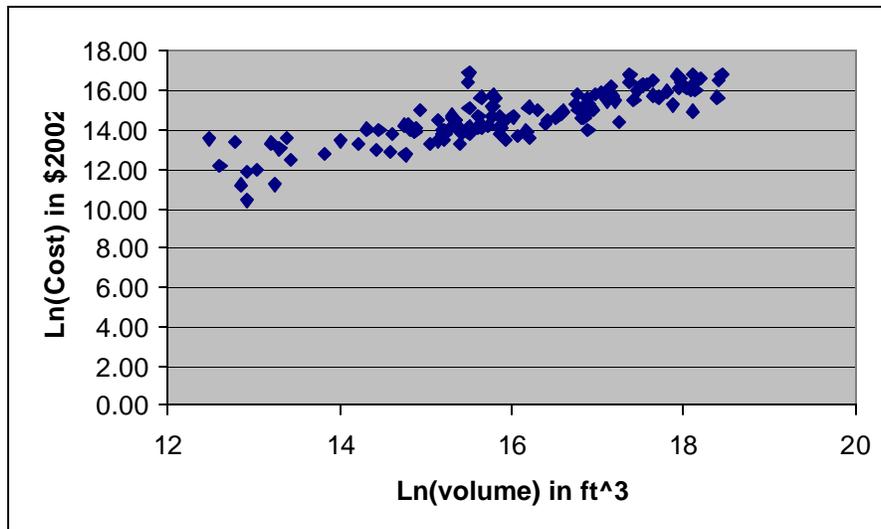
**Figure 1: Residuals vs. Fit from Nourishment Cost Regression**

The residual plot for the model above also shows a scarcity of points at low values of the fitted model (see Figure 1). Four points stand out that correspond to projects with volumes of less than 160,000 ft<sup>3</sup>. The scarcity of points in this range suggests that there is very little data to characterize nourishment costs for smaller projects. If the goal of this analysis is limited to trying to predict the range of nourishment costs for a particular project, it may be appropriate to limit the analysis and only consider larger, more typical projects. To do this the four low volume projects were removed from the data set and the remaining data were analyzed again using an all subsets model selection process.

For this restricted data set the model that performs the best according to Mallows Cp and BIC is simply a function of volume. Volume is again in units of 1000 ft<sup>3</sup>.

$\text{Est. mean } \ln(\text{Cost}) = 7.8702 + 0.7452 * \ln(\text{Volume})$ $(0.3807) \quad (0.0416)$ $\hat{S} = 0.68 \text{ on } 125 \text{ degrees of freedom}$
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This model suggests that the complexity of the original model is a result of trying to characterize the costs of nourishment projects at particularly low volumes. When only projects with volumes of sand greater than 160,000 ft<sup>3</sup> are considered the relationship is fairly straightforward (see Figure 2). The slope of the regression line indicates that a doubling in the project volume is associated with a 68% increase in the median project cost.



*Figure 2: Transformed Raw Data on Beach Nourishment for Projects With Volume > 160,000 ft<sup>3</sup>*

To determine the appropriate form of the nourishment cost curve in general, it may be important to consider the shape of the curve at low sand volumes more carefully. One consideration is the expectation that nourishment projects are likely to be associated with fairly large fixed costs. Performing a nourishment project of any size requires some amount of equipment and labor. The cost of hiring and transporting a dredge and a hiring a crew is likely to be considerable.

Beyond the relationship found in the regression analysis above, several additional issues bear mentioning. First, project costs reflect the cost of the capital and labor necessary to carry out a project and do not include any price paid for the actual sand used.

Historically, sand taken from state waters has been free to nourishment projects (NRC, 1995). In the future, as demand for sand resources increases and non-state sources of sand are sought out, this may change, adding another dimension to the cost of a project. Moreover, in some cases sand may be thought of as a non-renewable resource. Under these circumstances, as more sand is extracted over time, the marginal cost of using the resource will increase.

In addition, nourishments are rarely single events and need to be considered as long-term strategies. The costs of a nourishment approach to beach management will depend significantly on the frequency with which nourishments must be performed. The longevity of a nourishment project is taken to be the time between the initial emplacement of sand on the beach and the time when a loss of “at least” 50% of the volumetric fill is first documented (Leonard, Clayton and Pilkey, 1990). A study by Leonard, Clayton, and Pilkey (1990) considers this a conservative estimate of beach lifetimes because, for the majority of the cases in their study, the loss at the time of first documentation was greater than 50% and, for many projects, the loss within the recorded lifetime interval was closer to 100%.

As reported by Leonard, Clayton, and Pilkey, design parameters such as beach length, grain size, shoreface slope, shelf width, and method of fill emplacement are generally considered in determining the lifespan of a project. However, the authors found that project lifespan showed little correlation with these parameters and was better explained by the number and frequency of storm events after the initial sand emplacement (Leonard et al., 1990). The uncertainty associated with future storm events poses an additional problem in predicting nourishment lifespans and their associated costs. In the models that follow post nourishment dynamics are approximated as constant conditions. However, the relationship between storm activity and project lifespan indicates that future work might be done to look at these systems in a stochastic model.

Finally, many people who opposed nourishment as a shoreline management strategy do so on the grounds that these dredge and fill projects involve significant environmental impacts. One way to incorporate these factors into a decision making process would be to characterize these impacts in terms of environmental costs and then include them in a cost benefit model.

The cost of the environmental impacts can be seen as the loss of the environmental benefits that beaches provide in terms of habitat and preservation of biodiversity. However, as opposed to the protective and recreational benefits of beaches, the environmental benefits are primarily non-use values. Moreover, these benefits are nonexcludable and nondepletable; everyone can enjoy the benefits of better habitat and greater biodiversity, and one individual's enjoyment does not diminish the amount of benefit available to others. As such, the environmental benefits can be characterized as public goods with all the associated implications for free rider incentives. Therefore, trying to estimate the costs associated with damaging or destroying these environmental resources due to nourishment is a difficult task. The hedonic valuation technique described above is used to estimate the value of beaches, however this technique is based on observations of actual choices made by coastal property owners as a way to identify their willingness to pay for these benefits. The nonuse, public good nature of the environmental benefits means that coastal property owners cannot fully appropriate the gains from protecting them. To estimate the value of these nonuse, public goods hypothetical valuation techniques such as contingent valuation would be needed (Freeman, 1993). While these environmental benefits are important characteristics of beaches, their value or the cost associated with damaging or destroying them is difficult to estimate and has been essentially omitted from the model that follows.

### Costs of Relocation

One benefit of the relocation strategy is the potential to avoid negative environmental impacts and the costs associated with them. The costs incurred under a relocation strategy are primarily the direct costs of moving coastal structures. This includes moving the structure, building a new foundation, and restoring the original site. The Federal Emergency Management Agency (FEMA) estimates the cost of moving a 1000 sq foot house to a new site less than 5 miles away and restoring the original site at approximately \$47,000 (1998). The average size of coastal housing in many areas is likely to be greater than 1000 sq ft and therefore relocation costs are likely to be higher. However, FEMA also notes that relocation costs do not increase proportionally with house size. Moreover a study by the Heinz Center cites an example of a 1200 sq ft house

that was relocated for only \$25,000, about half of the FEMA estimate. For the individual homeowner the costs of purchasing new land for relocation may be significant. However, for the purposes of this study, the cost of buying new land is a distributional issue and not an overall cost to the system.

Another cost incurred by the individual homeowner relocating an oceanfront structure to an inland lot is the loss of the amenity values associated with the original lot. These include the ocean frontage, and ocean views. Again, these losses are important in considering the distributional effects of a relocation policy, but are not net costs within the overall system. When an oceanfront house is relocated to an inland lot the amenity values are simply transferred to the owner of the lot directly behind the original one (Parsons and Powell, 2001).

Finally, on a barrier island that is experiencing a net amount of erosion, the cost of land lost to the system may be significant. In this case it should be noted that inland property is lost, not coastal property (Parsons and Powell, 2001). The geometry of the shoreline stays the same as erosion continues. As such, the total beachfront acreage stays constant and it is the amount of inland property that decreases. For the purposes of this study, however, it is assumed that there is no net land loss. This may not be such a problematic assumption in the case of barrier islands that are truly migrating. Sediments from the beach are transported to the bay side during coastal storms so that the land lost on the ocean side of the island is equivalent to the land gained on the bay side.

#### Seabrook Island Simulation Model

The private development community of Seabrook Island is located just north of Charleston on the South Carolina coast. Pompe and Rinehart's 1999 hedonic regression analysis looked at property values in this community. As reported in their paper the development includes 2,350 properties, 1,498 of which are developed while 852 are vacant lots. The average width of the beach in Seabrook Island is 322 feet, with erosion rates as high as 5 feet per year in some areas. The average selling prices between the years of 1989 and 1994 were \$137,000 for developed properties and \$53,221 for vacant lots (1989 \$). As describe above, the authors' regression analysis produced a double log model of selling price as a function of the housing characteristics they modeled. For

beach width, the regression coefficient for developed lots was 0.134 and for vacant lots 0.304. These data were used to calculate the benefits of the beach as a function of its width. The average rental value of developed and vacant lots was determined by multiplying the average selling price by a discount rate of 0.03. This was converted to an average rental value in the absence of a beach by assuming a beach width of 322 ft, using the regression parameters discussed above, calculating, and then subtracting out the property value due to the beach alone. Then, in any given year, the full rental value was calculated by plugging in the width of the beach in that year.

Two management strategies were compared over a 60 year time horizon. The first strategy, repeated nourishments, modeled scenarios in which 150 feet of width were added to the beach at regular intervals. In all cases the initial beach width was 300 feet. A 1990 nourishment project added 685,000 cubic yards of sand to a Seabrook Island beach 5,805 feet in length (NOAA, 1999). Given a closure depth of about 20 feet this is likely to produce similar beach width as the model describe here. The cost of this project in 1990 was \$1.66 million (NOAA, 1999). A reasonable estimate for a similar project in 2003 might be \$2 million dollars. The regression analysis described above, however, predicts a cost of approximately \$3.96 million for a nourishment of this volume. Clearly there is some variation in project cost depending on a number of factors. However, \$2 to \$4 million can be taken as a reasonable range for the purposes of this model. It is important to remember that environmental costs of nourishment are not included in this cost estimate. The results of the model, however, might provide information about the range of values within which environmental costs might be significant in determining which strategy is more efficient.

In order to look explicitly at the effect of project lifespan, four different scenarios were modeled with different nourishment frequencies. Repeated nourishment scenarios were modeled in which nourishment took place every 5 years, every 10 years, every 15 years, and every 20 years. For each scenario erosion in the intervening years was set at a constant rate sufficient to create a loss of sand equal to the nourishment amount.

The results of this repeated nourishment strategy were then compared to a relocation scenario. The relocation approach to shoreline management recognizes the presence of coastal structures that prevent the landward migration of the beach as the

cause of beach narrowing. If the structures are moved when the beach reaches them, the width of the beach will remain constant. This is equivalent to setting growth equal to depletion. In this simulation the beach is assigned a constant width of 300 ft.

Pompe and Rinehart (1999) report the presence of 150 oceanfront properties on Seabrook Island. My model assumes that of these properties, only a certain number contain houses that must be relocated in any given year. This number of houses is constant throughout all time periods within the model. Average relocation costs were considered in the range of \$20,000 - \$80,000 per house.

Once values are assigned for the costs of nourishment, the number of houses relocated, the cost of relocation per house, and the discount rate, the net value of the beach is calculated for each time period. The value of the beach is simply the total value of the property in the community given the width of the beach in that period, minus the total value of property in the community in the absence of a beach. The net value calculated for each period is simply the above minus the costs of any management actions in that period. These net values are then discounted back to the first time period using a discount rate of 0.03. The sum of these present value net benefits for the nourishment scenario is then compared to that for the relocation scenario. The scenario that produces greater net benefits represents the more efficient management strategy.

### Results

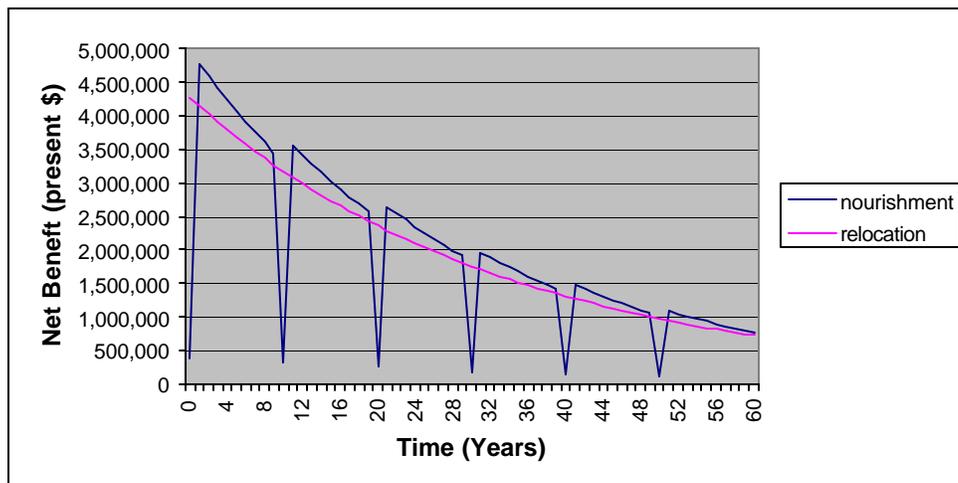
The outcome of this simulation is, as one might expect, dependent on the values assigned for the nourishment and relocation costs. For example, relocation is preferred in scenario A (shown in Table 3), in which nourishment costs are high and relocation costs are low. Whereas nourishment is the more efficient approach in scenario B in which nourishment costs are low and relocation costs are high.

*Table 3: Simulation Scenarios*

	<b>Cost per Nourishment Project</b>	<b>Relocation Cost per house</b>	<b>Preferred Strategy</b>
<b>Scenario A</b>	\$8,000,000	\$20,000	Relocation
<b>Scenario B</b>	\$2,000,000	\$80,000	Nourishment

The number of houses that must be moved in each time period determines the overall costs of relocation. As such, it too can affect the relative efficiency of these management strategies. The number of houses that must be moved could depend on the natural erosion rate in the area, or the rate at which the beach and island are migrating landward. The density of development, as well as local development ordinances, could also affect this in determining the distribution of houses along the shore.

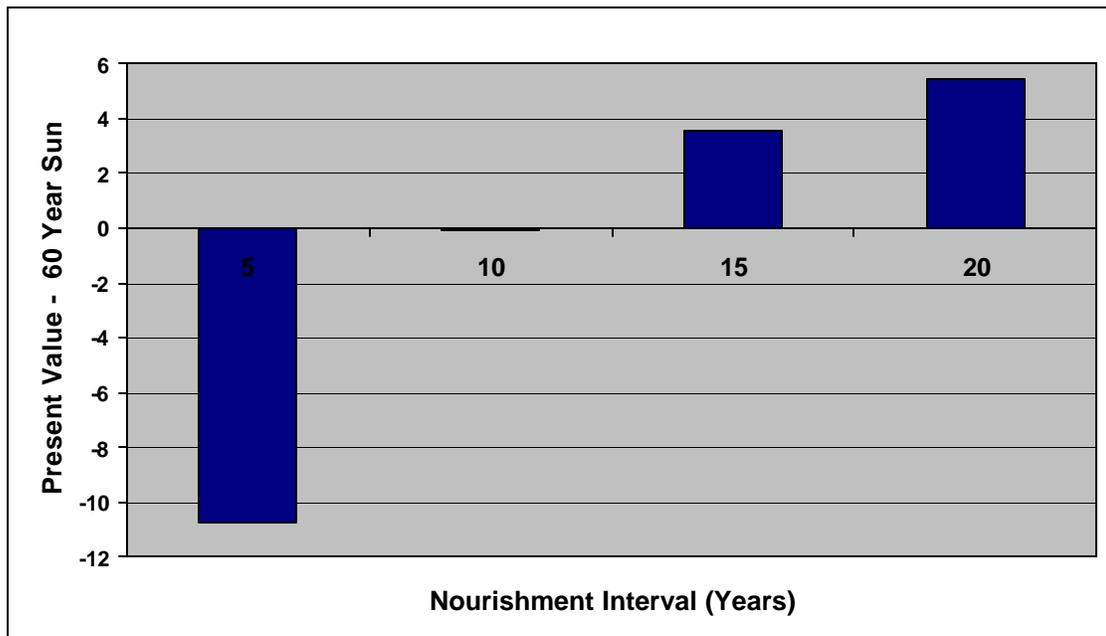
The results of the model are also sensitive to the initial width of the beach, as well as the percentage change in beach width due to nourishment. The exponential form of the benefits function means that the percentage change in the benefits is proportional to the percentage change in beach width. Adding 150 ft to a beach that is initially 50 ft wide, for a developed lot, will produce a 20% increase in the benefits, whereas adding 150 ft to a 300 ft wide beach will only increase the benefits by 6%. The solution to this problem involves a comparison of the areas underneath the two curves shown in Figure 3. In this figure the top line represents the net benefits of the beach under a nourishment management strategy. In this scenario, nourishments occur every 10 years. The large costs of nourishments are reflected in the significant dip in the net benefits curve each time a project is carried out. The lower line represents the net benefits of the beach under a relocation strategy. Costs of relocation are incurred in each time period, producing a smooth curve. The percentage change in beach width due to nourishment controls the steepness of the nourishment curve between events.



*Figure 3: Net Benefit of Beaches for Relocation and Nourishment*

The model is also sensitive to the relative vertical position of these two curves. This is determined by the beach width under relocation as compared to the maximum and minimum nourishment beach widths. If the relocation width is equal to the maximum beach width achieved through nourishment, then the two curves will intersect closer the peaks in the nourishment curve. However, the net benefits under nourishments dip dramatically in every year in which a nourishment project is performed, thus reducing the area under the nourishment curve. As such the area under the relocation curve will be greater. On the other hand, setting the width under relocation equal to something the less than the maximum width achieved through nourishment displaces the relocation benefits curve downward, decreasing its integral in comparison to that of the nourishment curve.

Finally, my model suggests that the timing of nourishments can have dramatic effects on the overall efficiency of each management approach. Figure 4 shows the results for a scenario in which nourishment projects cost \$4 million and 3 houses are relocated each year at an average cost of \$40,000 per house. Plotted along the y-axis is the difference in the net present value sum for a 60 year management scheme of nourishment compared to relocation (nourishment minus relocation). The x-axis indicates the nourishment interval. The four bars show this difference in net value under



*Figure 4: Beach Value: Nourishment Minus Relocation in Millions*

nourishment and relocation when nourishments are repeated every 5 years, every 10 years, every 15 years, and every 20 years. As the graph shows, the outcome depends heavily on this nourishment interval. When nourishment projects must happen every 15 or 20 years, a nourishment strategy yields greater net benefits than does a relocation strategy. However, the difference between nourishment and relocation is negative when nourishments have to be repeated every 5 or 10 years, making relocation the preferred management approach.

### Discussion

The simulation above highlights the importance of considering shoreline management decisions in the context of a dynamic renewable resource problem. Within this system there are important interactions between growth and depletion processes from year to year. As such, the relative efficiency of a strategy may be different if options are compared in terms of the time-path of the resource as opposed to a series of static decisions made independently of each other. In this case the lifespan of each nourishment project influences the path of the resource in that it reflects the degree to which erosion increases after a nourishment. While it is obvious that the interval between nourishment projects determines how frequently the costs of nourishment are incurred, it should be noted that this interval also determines the path of the benefits of nourishment over time.

Cost-benefit analyses that have been done to demonstrate the economic basis for nourishment often compare the costs of nourishment with the costs of doing nothing. If no management action is taken, enormous costs are incurred in terms of structural damage and property loss. A study by Parsons and Powell (2001) determined that the cost of letting Delaware beaches retreat and tearing down houses as the beach migrates landward could be anywhere from \$200 million to \$500 million depending on the erosion rates and discount rates used. In this comparison it is difficult to believe that environmental costs could be high enough to sway the decision to nourish the beaches. However, a relocation strategy will provide the same benefits as nourishment in terms of avoided property damage and may, as noted by Parsons and Powell, offer a more efficient approach to management. When relocation is the policy alternative against which

nourishment is evaluated, even in the absence of environmental costs, my model suggests a range of circumstances in which relocation is preferred. This can only mean that including environmental costs would expand that range of circumstances. In addition it is possible to use the results of this study to bound the question of how large the environmental impacts would have to be in order to change the outcome of the model.

These results also suggest that it may be valuable to consider the dynamics of environmental costs. The simulation points out the importance of understanding and modeling the way in which the state of the resource and the processes of change in one period affect those same variables in the next. The environmental impacts of nourishment, and therefore the environmental costs, are likely to vary over time. Beyond just estimating the magnitude of environmental costs it may be important to consider the timeframe over which they occur. Studies such as those by Peterson, Hickerson, and Johnson (2000) and Rakocinski et al (1996) that characterize short-term and long-term biological responses may lend some insight into the path of the environmental costs of nourishment. In addition, it would be interesting to look at environmental costs associated with a repetitive nourishment strategy and whether or not there is a cumulative nature to these impacts.

### Policy Considerations

The model described here evaluates two policy alternatives based on their relative economic efficiency. However, the distributional effects of each policy also need to be considered. For nourishment and relocation, the distribution of costs and benefits are significantly different. Currently the costs of nourishments are primarily borne by the federal government, which contributes 65% of the funding for these projects (NRC, 1995). Set up in this way, the costs of nourishment are paid by all US taxpayers and the benefits are primarily experienced by coastal homeowners. On the other hand, individual homeowners bear the costs of a relocation strategy. Moreover, when one considers the transfer of amenity values when an oceanfront house is moved, it is clear that there are distributional issues even within a given coastal community.

To some, a policy option where the primary beneficiaries of the management strategy also bear the costs of those actions is preferable to a policy in which the costs are

paid by all and the benefits are received by a few. However, the increased costs for coastal homeowners may lead to intense resistance from these communities and impair the political feasibility of a relocation strategy.

If a relocation strategy were to be implemented, the fact that the costs are paid by individual homeowners may also have an effect on the behavior and investment patterns of those homeowners. With the knowledge that, at some point in time, any coastal structure will have to be moved, homeowners may make different choices about when, where, and how much to build in coastal communities. This, in turn, could affect the overall cost of relocation, making it more efficient. In the presence of a relocation strategy homeowners may build smaller houses or may build houses in such a way to make them less costly to move. Individuals may also build structures further back from the beach to push off the eventual costs of relocation farther into the future. Finally, it may be desirable to purchase and build on property lots that extend further inland and therefore might allow for relocation away from the water while still within the original waterfront lot. This could decrease the overall density of development in coastal areas, thus lowering the rate at which houses might need to be moved.

#### Toward a Dynamic Optimization Model

The ultimate goal of framing shoreline management choices in terms of a dynamic renewable resource problem would be to develop a dynamic optimization model. The model described above evaluates the efficiency of two specific resource management paths. An optimization model would mathematically solve for the optimal resource path. While this is a fairly complex challenge, a fair amount can already be said about what such a model might look like.

An optimization model for a single piece of oceanfront property would begin with a state equation describing the path of the beach in front of the property. This might look like:

$$W_{t+1} = W_t - E_t + R_t + N_t \quad (1)$$

This simply says that the width of the beach ( $W$ ) in any time period is a function of the width in the previous time period, the erosion ( $E$ ) that occurred in the last time period and

the additions to beach width made through relocation (R) and nourishment (N). Solutions would be constrained to non-negative numbers for all variables.

The costs of relocation ( $C_R$ ) are likely to involve a significant fixed cost ( $\mu$ ) with the total increasing slightly as a function of the distance ( $x$ ) that the structure is moved.

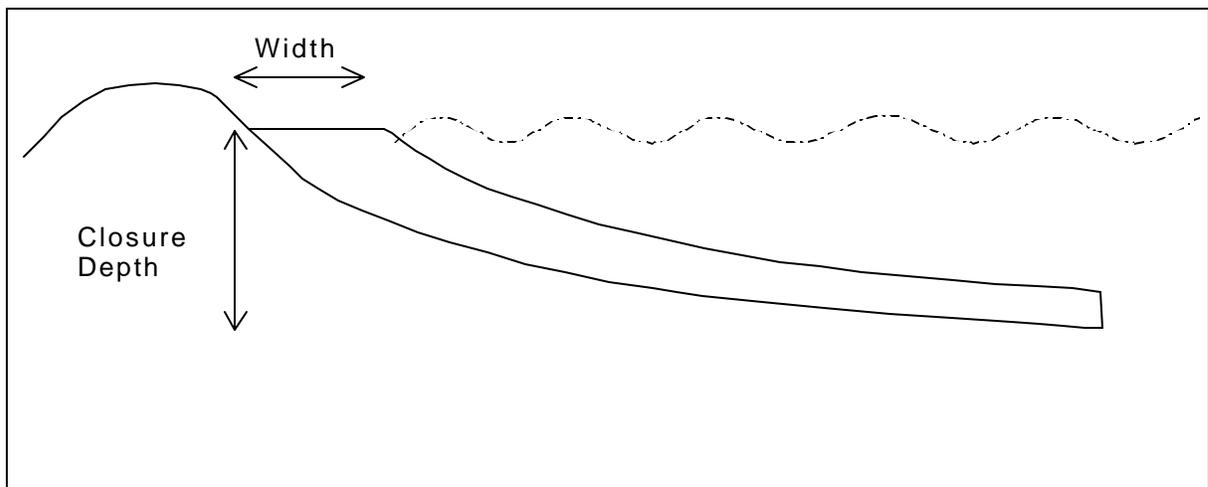
$$C_{r_i} = m + w * x \quad (2)$$

The cost curve for nourishment can be described by the regression results presented earlier. In order to convert the project volume and length into the width of beach that is added, the closure depth must be determined. The closure depth represents the water depth at which there is no significant movement of sediments by wave action (NRC, 1995). If it is assumed that the first coastal storm after a nourishment project redistributes the sand so that it assumes the same shape as the equilibrium profile, then:

$$Volume = w * l * d \quad (3)$$

Volume is simply a function of the width added to the beach ( $w$ ), the length of beach nourished ( $l$ ), and the closure depth of the local shore face profile ( $d$ ).

**Figure 5: Beach Profile Schematic**



This relationship can then be combined with the results of the earlier regression analysis of nourishment costs to express the costs of a nourishment project ( $C_N$ ) as a function of the width it adds to the beach.

$$C_N = q * (w * l * d)^f \quad (4)$$

The results of the previous regression analysis provide values of  $r$  the constant ( $q$ ) and the exponent ( $\phi$ ). For these purposes the restricted model is used and so it should be noted that this equation only holds for projects with volumes of greater than 160,000 ft<sup>3</sup>.

Benefits are again modeled using the results of the hedonic property value studies so that in any time period  $t$  the value of the beach ( $V$ ) is:

$$V_t = r^t ((H * W_t^b) - H) \quad (5)$$

In this equation  $\rho$  is simply the discount factor ( $1/(1+\delta)$ ) and  $H$  is equal to the annual rental value of the property in the absence of a beach.

Equations 1, 2, 4, and 5 can then be combined to give the net present value of a piece of property over time. In discrete time:

$$NPV = \sum r^t * (H_t * W_t^b - H_t - C_{R_t} - C_{N_t}) \quad (6)$$

The goal of the optimization model would be to choose values for nourishment and relocation in each period in order to maximize this sum of net present values.

Additional issues might include how to incorporate the effect of diminishing sand resources. One way to do this could be to add a constraints such that:

$$S_0 \geq \sum_{t=0}^T S(N_t) \quad (7)$$

This indicates that the total volume ( $S$ ) used in all nourishments cannot exceed the original amount available ( $S_0$ ).

An alternative way to incorporate the fact that sand resources are limited might be to add something similar to a stock effect to the nourishment cost curve.

$$C_N = m * (w * l * d)^f + g * \sum N_t \quad (8)$$

In this case the cost of a given nourishment depends on the amount of nourishments that have been done previously.

The approach outlined above presents some difficulties in actually solving this problem. First, ideally the cost curves would be smooth twice differentiable curves, positive in the first and second derivatives. However, the cost curves outlined above that most accurately represent the realities of these costs contain kinks and discontinuities.

One might address this by working with smooth curves that approximate the descriptive equations.

Another difficulty with the approach outlined above is that it considers shoreline management decisions for a single property. Due to the potential returns to scale involved in the costs of a nourishment project, it may make more sense to consider management choices on a community wide level. However, in that case the relocation option may need to be structured differently. One might need to assume that all houses are at an equal distance from the beach and that only one row of houses exists. Additional information would be needed, such as the number and spacing of houses along the beach.

Finally, the above model describes a situation in which nourishment and relocation occur quasi-continuously. In reality, however, both nourishment and relocation are more cyclical in nature. As such it may be possible to apply concepts from rotational harvesting in commercial forestry. In this field the Faustmann equation is used to determine the optimal forest harvest rotation, the optimal period of time to wait between planting and harvesting a stand of trees. The solution to this dynamic optimization is to balance the marginal benefits and marginal costs of postponing all harvests by one year. In rotational forestry the marginal value of waiting comes from the fact that an additional year will usually result in a larger volume of wood to be harvested. The marginal cost of waiting reflects the foregone interest payment on what could be harvested a year earlier (Conrad, 1999).

The decision over nourishment could be cast in terms of trying to find the optimal nourishment interval. In doing so, one would have to consider the rate of erosion between nourishments and perhaps the stochastic nature of this process due to the large influence by storm activity. Again the solution would be a balance between the marginal value and marginal costs of waiting a year. However, in this case the marginal cost would reflect the fact that delaying nourishment for a year means incurring another year of erosion. The marginal benefit of waiting might be the earned interest payment on the money that would otherwise be spent on the nourishment project. An added dimension in the beach problem is that the management decision to be made is not only when to

nourish, but also how much to nourish. The latter would balance the marginal costs and benefits of adding width to the beach.

A similar Faustmann approach could be taken with the relocation option. A given piece of property could be sequentially moved back from the beach. Here, the cost of waiting is incurring the loss of distance between the house and the water. The value of waiting would again be the interest payment on the funds to be used for the relocation. As with the nourishment option, the optimal solution would need to describe both the relocation interval as well as the distance to move the house each time. The latter would balance the marginal benefits and costs of proximity.

### Conclusions

The primary finding of this study is that it makes sense and may be useful to characterize beaches as renewable resources. In doing so, the concepts and tools of dynamic renewable resource management can be applied to the analysis of shoreline management strategies. Hedonic property value studies help accomplish this by providing evidence in support of the relationship between the value of a beach and the width of that beach. Moreover, these studies provide a way of describing and quantifying that relationship.

Applying a dynamic renewable resource approach to beach management requires the consideration of a long time horizon. This approach highlights the importance of the interactions of growth and depletion processes over time. As demonstrated in the simulation model, a measure of one of these interactions, the lifespan of a nourishment project, can be the critical factor in determining the relative efficiency of a management strategy. It may also be important to consider the dynamics of the factors involved in these management systems that have yet to be quantified, namely the environmental costs of nourishment projects.

Future directions for this work include the development of a dynamic optimization model. Some progress has been made in characterizing the different components of such a model. However, this complex problem requires further study. Early work in this area suggests that concepts from rotational harvesting may have potential in creating and solving an optimization model of beach management.

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