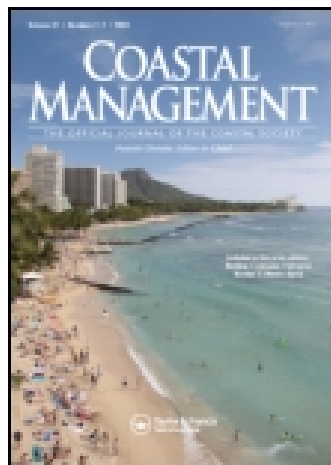


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Coastal Erosion as a Natural Resource Management Problem: An Economic Perspective

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Natural forces render the coastal environment an evolving landscape, with the majority of coastline in the U.S. exhibiting net erosion in recent decades. This article provides an interdisciplinary introduction to economic dynamic optimization models for analyzing beach replenishment and explores differences between these theoretically based welfare economic models and typical applications of benefit-cost analysis employed by public agencies and consultants. Welfare economic models conceptualize benefits of beach area as service flows accruing to nearby residential property owners, recreational beach users, and local businesses, while the costs include pecuniary engineering expenditures, opportunity costs, as well as negative impacts on the coastal environment. Combining information on net benefits with an equation representing beach dynamics, this framework is capable of identifying the conditions under which beach replenishment is welfare-enhancing, and an optimal replenishment schedule can be derived. By congressional mandate, applications of benefit-cost analysis employed by public agencies focus attention on storm damage reduction, with limitations placed on assessment of recreational benefits. We provide an overview of empirical results and compare and contrast the two approaches.

Keywords beach erosion, benefits, costs, dynamic optimization, economics

Introduction

The coastal zone is one of the most dynamic natural systems on earth, with unremitting wind and waves, occasional storms, and sea-level change playing key roles in process and evolution. Various patterns of sediment erosion and accretion can rise, with an overwhelming majority (80 to 90%) of coastline in the eastern United States exhibiting net erosion in recent decades (Galgano and Douglas 2000). Climate change threatens to increase the intensity of coastal storms (Hoyos et al. 2006) and accelerate sea-level rise (IPCC 2007). Analysis conducted by the Heinz Center (2000) suggests that one in four homes within 500 feet of the U.S. east coast could be directly or indirectly lost to erosion in the next 60 years, at a potential cost of \$530 million each year.

Options for the management of coastal erosion include armoring of the shoreline, replenishment of beach sediment, and relocation of threatened structures. Shoreline armoring can be effective at preventing land loss due to chronic erosion, but most often has

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destructive and deleterious impacts on the natural environment, including loss of beach sand, coastal vegetation, and habitat. Beach replenishment involves alteration of the sediment budget—adding sand to the beach system in order to combat erosion; this process provides storm protection to coastal property, enhances recreation potential, and may improve beach and dune habitat, but does not prevent future erosion and thus must be repeated periodically. Beach replenishment can be very expensive and may impose additional environmental costs at the sites where sand is excavated, pumped, or placed. These costs can include interference with overall sediment transport and larger scale geomorphology and environmental quality on barrier islands. Shoreline retreat entails relocating coastal buildings and infrastructure landward (or simply demolishing structures) to allow coastal landforms to evolve over time. While this strategy could seem reasonable from the perspective of many, loss of private buildings and land motivates strong opposition to this type of approach among barrier island inhabitants, especially those in close proximity to the shoreline and in highly erosive environments. Local government officials also frequently frown on this approach, due to loss of infrastructure and property tax revenue and the potential impacts on the barrier island tourist economy. Significant political pressures usually prevent serious consideration of shoreline retreat. If it were pursued, vital questions remain as to where structures will be moved to and whether lost land should be subsidized by government.

Policies for managing coastal erosion in the United States currently favor beach replenishment, with judicious use of shoreline armoring. The U.S. Army Corps of Engineers (USACE) has federal authority to conduct storm protection/beach enhancement projects that promote federal National Economic Development goals and meet other criteria. The USACE is most often the primary party responsible for planning and analysis of replenishment projects on public beaches. Some local public and private entities, however, engage in beach replenishment, such as the beach communities in Carteret County, North Carolina and the relatively affluent community at Sea Island, Georgia.

There are equity and social justice issues surrounding who should pay for beach replenishment projects (Cooper and McKenna 2008). Private property owners are often direct beneficiaries of additional beach sand, but beach visitors may also benefit if resulting beach conditions are more conducive for recreation and leisure activities. Increased visitation attributable to improved beaches will benefit local businesses (including tourism related services, restaurants, and providers of overnight accommodations), and increased local economic activity can benefit local governments through increased tax and fee revenue.¹ Currently, a community that meets the guidelines for a public beach replenishment project (including sufficient public parking and beach access) can receive a federal subsidy that amounts to 50% of the project costs (NOAA 2010). Federal funding for beach replenishment projects, however, has been reduced significantly in recent years (under the Clinton, Bush, and Obama administrations) forcing many communities to rely on local funding options without federal subsidies.

In this article, we provide an interdisciplinary introduction to dynamic optimization models for analyzing beach replenishment and explore the differences between these models—which are grounded in the theory of welfare economics—and the typical applications of benefit-cost analysis employed by public agencies and consultants. A companion piece (Landry 2010) provides a more technical treatment of the models and methods.² Dynamic welfare economic models of natural resource management focus on maximization of present value of net benefits accruing from management decisions, incorporate dynamic natural systems through some sort of transition equation (typically derived from principles in natural science), and quantify benefits and costs of management actions based on tradeoffs that economic agents are willing to make.³ Applications of benefit-cost analysis

employed by public agencies typically focus attention on estimation of storm probabilities and associated damage from historic and simulated data. By congressional dictate, recreation benefits are considered incidental and receive less attention in applied policy analysis.

Economic Models of Coastal Erosion Management

Welfare Economic Models

Broadly speaking, economics is the study of resource allocation under conditions of scarcity. The field of welfare economics involves the application of economic principles to evaluate outcomes arising from institutions designed to address this fundamental question. Welfare economics is an inherently normative field of study and builds on the basic premises of microeconomic theory—namely that benefits and costs can be measured as the economic value associated with a change in resource allocation. For example, if we are interested in evaluating an outcome that involves consumption of a service, benefits are measured as the economic value that an agent ascribes to consumption of the service, and costs are measured as the economic value of resources foregone in production of the service.

Willingness-to-pay (WTP) is a standard measure of economic value for provision of a service to which individuals do not have a prior entitlement.⁴ It reflects tradeoffs that individuals are willing to make based on their preferences for various consumption possibilities. WTP is conditioned on individuals' perceived values of the proffered service and their ability to pay (i.e., level of income or wealth). Economic costs are the opportunity cost of resources utilized in production of a service; opportunity cost is the value of the next-best foregone alternative use of these resources. In competitive input markets (e.g., labor, capital, land), opportunity costs are (approximately) the market prices of resources. If input markets are not competitive, however, such prices will not be very reliable signals of economic value of scarce resources. Also, if some inputs are not traded in markets, their value can be missed by standard accounting procedures.

Welfare economic models conceptualize benefits of beach and dune sediments as service flows accruing to nearby residential property owners (reflecting storm-protection and recreation opportunity), recreational beach users (providing space for recreation), local businesses (enhancing business opportunity and revenue), and perhaps others. Benefits can also include improvements in habitat for beach- and dune-dependent plant and animal species. The costs of maintaining beach and dune sediment in the presence of coastal erosion include expenditures on dredging, pumping, and distributing sand. Other costs can comprise negative environmental impacts on the near shore environment (submerged areas seaward from the shore). Spatial effects may also play a role in the analysis of beach management, as benefits and costs can extend along the shore to adjacent areas. This aspect of the management problem is only beginning to receive attention in the economics literature (Slott, Smith, and Murray 2008).

Building on these foundations, Landry (2008) and Smith et al. (2009) cast beach replenishment as a dynamic optimization problem. In these models, resource managers select the optimal quantity and timing of replenishment sand in order to counteract coastal erosion. We now present a sketch of how these models are structured and what key parameters and variables drive the results. We assume that additional sediment is of similar quality to native material and that the beach erodes at some exogenous rate, θ , reflecting sea-level rise, dominant wave and current patterns, and coastal storms. The erosion rate can be specified

as a constant, as random variable drawn from a known distribution (to reflect variability in storm and weather patterns), or as an evolving parameter (reflecting increasing erosion pressure due to sea-level rise). Smith et al. (2009) also introduce an exponential decay factor to reflect the beach's return to equilibrium after replenishment. Let resource quality be represented by a time-dependent variable, q_t , which represents beach width. This beach width measure reflects average beach quality (neglecting within-site variation in beach conditions).

The objective of the dynamic optimization problem is to maximize the present discounted value of the difference between total benefits and total costs of management actions subject to the way the beach responds to replenishment (described by the "transition equation"). The beach resource exhibits a decaying tendency, and the management control represents a contribution to the level of resource quality that counters this tendency to decay. The benefits of preservation are flows of service over time, while the costs are typically incurred in the period in which beach replenishment is undertaken. Under certain conditions, a sustained policy of no additional sand (i.e., a "corner solution") can be construed as a *de facto* policy of shoreline retreat in the long term.

In Landry (2008), the coastal planner chooses the amount of beach replenishment to be conducted in each time period. Using optimal control theory, the short-run management problem (over T years) can be represented as:

$$\max_{n_t} \sum_{t=0}^{T-1} \kappa^t \{B(q_t) - C(n_t)\} \quad (1)$$

$$\text{subject to: } q_{t+1} - q_t = -\theta + \tau n_t \quad (2)$$

$$q_{t=0} = q_0, q_T = \text{free} \quad q_0 \geq 0 \quad (3)$$

where $B(q_t)$ reflects aggregate benefit for beach quality level q_t accruing to all agents concerned in period t ; $C(n_t)$ represents the economic costs of beach replenishment, with n_t representing the total volume of sand (or "beach fill") per unit of beach length; and $\kappa^t = (1 + \delta)^{-t}$ is a discount factor that converts values in period t to present value (at a discount rate of δ). Equation (2) is the "transition equation" (or "equation of motion") for beach quality and describes the dynamic motion for beach width, which decays by rate θ and increases with nourishment (with τ as a parameter that converts sand volume to incremental beach width). Conditions in Equation (3) specify the initial given (q_0) and terminal free (q_T) levels of beach quality condition. Equations (1) through (3) describe an optimal control problem with one control variable (n_t) and one state variable (q_t).

Anecdotal evidence indicates that fixed costs⁵ of beach replenishment can be of significant magnitude (especially mobilization/demobilization costs), such that beach replenishments are undertaken periodically in order to reduce the occurrence of fixed costs. This periodicity may also reflect scarcity of capital equipment—dredges, in particular. The existence of fixed costs leads to a rotation-type solution, with intermittent periods of nourishment following periods of no activity. This implies that the costs will only be realized in periods in which replenishment activities are engaged, at which time the beach quality also witnesses a discrete change [according to Equation (2)]. Benefits flow through time according to the function $B(q_t)$,⁶ and all future benefits and costs are discounted back to the present via the κ^t function.

Equations (1)–(3) can be solved through application of numerical dynamic programming, which involves converting the state and control space to discrete measures and applying Bellman's backward recursion algorithm (Landry 2008).⁷ Output includes an

optimal replenishment schedule and specified amounts of sand to be added to the beach during each replenishment operation. In an application to Tybee Island, GA, Landry (2008) determines that the optimal beach width is 30 meters, and the optimal rotation length is about 12 years. Landry (2008) does not account for beach profile adjustment in returning to equilibrium, which would reduce the value of the τ parameter and affect the optimal rotation length. A graph of the state variable (beach width) across time displays a zig-zag pattern as beach width erodes and is replenished at regular intervals.

Explicitly recognizing the rotation-style solution that arises when benefits and costs are independent of time, Smith et al. (2009) formulate an optimal rotation model. They define the choice variable as the rotation length, $\tilde{T}$, or period of time between beach replenishment operations, and their optimization problem is thus:

$$\max V(\tilde{T}) = [B(\tilde{T}) - C(\tilde{T})]/[1 - e^{-\delta\tilde{T}}], \quad (4)$$

where $B(\tilde{T})$ represents the present discounted value of economic benefits accruing over the time horizon $\tilde{T}$, and $C(\tilde{T})$ represents the costs associated with returning the beach to its initial width. The cost function is nonlinear in beach width, which reflects exponential erosion associated with return to equilibrium profile; this implies that the marginal cost of beach width is not constant, but rather depends on $\tilde{T}$. The denominator of Equation (4) is a discounting factor that puts the entire stream of net benefits in present value terms. Equation (4) represents the present discounted value of an infinite number of beach replenishment rotations, and the problem can be solved numerically producing an estimate of the optimal rotation length. For Landry (2008) and Smith et al. (2009), the suitability of beach replenishment as a short-term management strategy can be evaluated by assuring that the present value of net benefits is positive. Smith et al. (2009) use their theoretical framework to derive the conditions under which the optimal rotation length will vary with changes in fixed costs, variable costs, benefits of beach maintenance, the erosion rate, and the discount rate.

These models can provide a foundation for examining long-run coastal erosion management problems. Under some simplifying assumptions, the terminal time for beach replenishment can be identified within the framework of Equations (1)–(3). Let T go to infinity, and specify a time path for the erosion rate that is monotonically increasing with sea-level rise. Under these conditions, the replenishment costs for producing a given beach width should be increasing monotonically as well. With significant sea-level rise, major public works, including raising the average ground elevation and elevating buildings and infrastructure, would be required to maintain island location and beach width. The costs associated with such an endeavor could be difficult to estimate, but would likely dwarf the standard costs associated with beach replenishment. If the maximum possible benefits can be specified, the terminal time for beach replenishment can be implicitly defined by the balance of total benefits and costs in the penultimate period (Chiang 1992). In the absence of beach replenishment, a policy of shoreline retreat is implicit.

While long-run economic costs of maintaining beach width and island location depend on sea-level rise, storms, erosion, and available sand resources, the benefits reflect the value of economic activities located in the coastal zone that are dependent on beach width and the island location. These include baseline values of existing property inventory, net aggregate economic value of beach and coastal recreation, and the net value of coastal businesses. These benefits can be very difficult to measure. For example, baseline property values can fluctuate, depending upon conditions in the coastal housing market, fundamental understandings of coastal processes on the part of buyers and sellers, and expectations of public

and private interventions in shoreline evolution (beach replenishment, shoreline armoring, elevation of threatened properties, etc.) (Landry and Hindsley 2011). With sufficient notice on a shift to shoreline retreat, the baseline value of threatened properties could be driven to zero. Likewise, lost recreation value and business opportunities depend upon the extent to which substitute locations for such activities are available, which likely reflect particular details of the sea-level rise scenario under consideration.

In an application to Tybee Island, GA, Landry (2004) estimates terminal time of beach replenishment focusing on different baseline value trajectories for existing properties. If baseline property values were to remain at their 1998 levels, terminal times for beach replenishment are 98 years, 168 years, and indeterminate (greater than 500 years), for sea-level rise trajectories of 80, 55, and 30 cm (over the next century), respectively. On the other hand, if baseline property values were zero, terminal times for beach replenishment on Tybee Island are 23 years, 38 years, and 128 years under sea-level rise trajectories of 80 cm, 55 cm, and 30 cm, respectively. Clearly, the adjustment of economic activity in response to environmental change can have a large impact on optimal coastal policy responses. More research is necessary to better understand the influence of sea-level rise on economic activity and the inherent tradeoffs involved in coastal defense.

Neither the approach of Landry (2008) nor Smith et al. (2009) considers the long-shore dimension of coastal erosion management, effectively ignoring variability in beach quality and erosion. While most previous research focuses on replenishment of a representative beach profile in isolation, Slott and colleagues (2008) consider the influence of beach replenishment operations on adjacent beaches. They find external spatial benefits of replenishment on downdrift beaches, which can reduce the overall monetary cost of beach maintenance in a given area by as much as 25%.

Applied Policy Models

Planning of federal water resources projects is based on the Water Resource Council Principles and Guidelines (P&G) (USACE 2000). The P&G provide a framework for planning and evaluation, promoting National Economic Development (NED) goals, balancing net economic benefits with environmental protection, and encouraging comprehensive analysis to explore a full range of alternatives. The P&G clearly states that “contributions to NED are the direct net benefits that accrue in the planning area and the rest of the Nation. Contributions to NED include increases in the net value of those goods and services that are marketed, and also *of those that may not be marketed*” (USACE 2000) [emphasis added]. The P&G require that non-structural alternatives be considered (e.g., shoreline retreat or property acquisition), in addition to no action. The NED plan is to be the alternative that provides for the greatest net economic benefit, while protecting the nation’s environment.⁸

Following the Water Resources Development Act of 1986, the primary objective of coastal protection projects is hurricane and storm damage reduction. Control of coastal erosion not associated with storms has no separate status as a potential objective. Benefits of hurricane and storm damage reduction stem from protection of existing coastal structures and infrastructure, with undeveloped land having a low priority and recreation benefits treated as an incidental output. The P&G dictate that recreation benefits may not be more than 50% of the total benefits required for economic justification.

For hurricane and storm damage reduction projects, benefits are measured as “reductions in actual or potential damages to affected land uses” due directly to a storm or storm-induced shoreline erosion, including wave damage reduction, inundation damage reduction, reduction of loss of land, structural damage prevention, reduced emergency

costs, reduced maintenance costs, and other benefits (USACE 2000). The P&G lay out detailed procedures for estimation of hurricane and storm protection benefits, which include: (1) delineation of study area and adjacent areas that could be affected; (2) definition of problem; (3) selection of planning shoreline “reaches”; (4) establishment of risk frequency relationships, including two types of probability distributions, one describing wave height and water level and the other describing the magnitude of shoreline erosion or accretion; (5) inventory of existing conditions, including affected structures and land; (6) development of damage relationships, which involves estimation of dollar damages to structures and contents due to physical factors such as water depth, wave height, and so on; (7) combination of (4) and (6) into damage-risk frequency relationships that are used to estimate probability distributions for damage mechanisms (inundation, wave attack, erosion, etc.) and each land use category; and (8) calculation of expected annual damages (EAD) and benefits for each alternative. EAD are calculated by computing the area under the damage-risk frequency curve, and EAD are computed for with- and without-project conditions, with the difference representing the benefit associated with each alternative (USACE 2000).

This approach to risk analysis is intuitively appealing, but computationally demanding. Numerous analytical computer modules have been designed to perform the risk analysis outlined in the above steps. See Gravens, Males, and Moser (2007) for a description of the most recent incarnation, “Beach-*fx*.” With appropriate input (i.e., meteorologic, coastal morphologic, economic, and management data), the Beach-*fx* model is capable of estimating storm damage caused by erosion, flooding, and wave impact.

Hurricane and storm damage reduction projects can entail both recreation gains and losses, depending on the nature of the project. The Federal Water Project Recreation Act of 1965 requires full consideration of the effects of federal water projects on outdoor recreation. USACE P&G recognize travel cost models, stated preference methods (in particular, the contingent valuation method), and other “quantifiable methods” based on sound economic rationale as valid approaches to estimating recreation values (USACE 1983). In practice, analysis often relies on “unit day values,” which use expert opinion and judgment to estimate the average user’s willingness to pay for a day of beach recreation. Nonetheless, recreation benefits can account for at most 50% of project benefit in benefit-cost analysis.

Economic Benefits of Coastal Erosion Management

In welfare economics, empirical measures of economic value associated with natural resources are derived by revealed (RP) or stated preference (SP) methods. RP data reflect observations of or inquiries into past or current behavior and reflect individual choices under time and income constraints. SP data are derived from inquiries into planned behavior under hypothetical or expected conditions (such as changes in beach width or access). RP and SP data are often combined, which allows for greater flexibility and improved statistical efficiency. Landry, Keeler, and Kriesel (2003) identify primary beneficiaries of beach erosion control as coastal property owners and beach visitors. We review the literature on empirical benefit estimation for each of the groups in turn, and then consider other prospective benefits.

Property Owners

Local beaches provide erosion, storm surge, and flood protection to coastal housing, in addition to recreation and leisure potential for those that live at the beach. Beaches and dunes also may supply scenic amenities. If buyers and sellers of coastal property value these

services, the economic value of beaches can be capitalized in home sales prices. As such, the influence of beach quality on coastal property values can be analyzed with hedonic property price analysis. This RP approach utilizes the variation in housing prices in order to estimate the capitalization of spatial amenities and dis-amenities, such as environmental quality and risk factors, in sales prices.⁹ We note that this method is not necessarily concerned with the magnitude of property values themselves, but rather uses data on property values to estimate the implicit value of natural resource quality.

The hedonic price function is typically represented as:

$$P = P(x, q), \quad (5)$$

where P is the sales price, which is a function of structural and neighborhood characteristics, x , and, in our case, beach quality, q . Assuming that $P(\cdot)$ is continuously differentiable and that there is sufficient variation in the housing attributes of interest, the first derivative of Equation (5) (e.g., $\partial P/\partial q$ is the first-derivative with respect to beach quality) produces an estimate of implicit attribute price, which in equilibrium is the representative households' marginal willingness to pay (WTP) for an additional unit of that attribute (Rosen 1974). In this context, marginal WTP is an economic concept that recognizes that the economic value of a housing attribute depends on the level of the attribute. For example, WTP for square footage is likely to be decreasing in the total amount of square footage (implying a greater marginal value for initial units relative to subsequent units). Theoretical foundations and empirical results lead us to expect diminishing marginal WTP for most economic goods and services.

A number of studies have attempted to estimate marginal WTP for beach width with hedonic price multiple regression models, utilizing data on property sales and spatially explicit measures of beach quality that vary along a given shoreline. The WTP estimates derived in these studies can be expressed in dollars or percentage ("elasticity") terms. Some results from the literature are displayed in Table 1; all economic values are converted to constant 2010 dollars using the Consumer Price Index. Table 1 also includes the level of initial beach quality with which marginal WTP is associated.

Pompe and Rinehart (1995) estimate the implicit marginal value of high-tide beach width in South Carolina, and Landry, Keeler, and Kriesel (2003) focus on low-tide beach width in Georgia. The estimates are difficult to compare given differences in the way economic value is specified (e.g., the relationship between beach quality and distance from the shore, functional form, and content of the regression equation) and the way beach width is measured (e.g., in relation to tides and units of measurement), but each of these studies finds a positive and statistically significant marginal value for beach width. These studies, however, includes multiple years of sales data while utilizing an estimate of beach width from a single time period. Landry, Keeler, and Kriesel (2003) recognize potential bias in this approach given the dynamic nature of beaches and the possibility of periodic interventions due to beach replenishment operations; sales data should be matched with contemporaneous information on beach quality for accurate analysis.

Pompe and Rinehart (1999) use time-series beach quality data to address this problem. They produce marginal value estimates for South Carolina coastline that are generally lower than their previous estimates, but since average beach quality is higher this discrepancy could be consistent with diminishing marginal value. It is also possible that preferences (and thus economic value) are spatially or temporally distinct. While their approach addresses the problem of mis-measurement of beach width due to coastal dynamics and policy interventions, issues remain regarding interpretation of hedonic parameter estimates.

Table 1
Empirical estimates of marginal willingness to pay for beach quality derived from hedonic property price models

Study	Marginal WTP	Beach quality level	Notes
Pompe and Rinehart (1995); Surfside Beach and Garden City, SC	\$1,226/foot \$558/foot \$1,656/foot \$362/foot \$325/meter	79 feet—high tide 79 feet—high tide 79 feet—high tide 79 feet—high tide 76 meters—low tide	beachfront homes; log-linear f.f.* homes $\frac{1}{2}$ mile from beach; log-linear f.f.* beachfront vacant lots; log-linear f.f.* vacant lots $\frac{1}{2}$ mile from beach; log-linear f.f.* homes on Tybee Island; semi-log f.f.*
Landry et al. (2003); Tybee Island, GA			
Pompe and Rinehart (1999); Seabrook Island, SC	\$143/foot \$343/foot \$103/foot \$549/foot	228 feet—high tide 228 feet—high tide 325 feet—high tide 325 feet—high tide	homes on Seabrook Island; log-linear f.f.* beachfront homes; log-linear f.f.* vacant lots on Seabrook Island; log-linear f.f.* beachfront vacant lots; log-linear f.f.*
Landry and Hindsley (2011); Tybee Island, GA	\$640/meter \$553/meter \$587/meter \$357/meter \$1,440/foot [#] \$674/foot [#] \$8,800/foot [#] 4,211/foot [#]	26.5 meters—high tide 26.5 meters—high tide 76 meter—low tide 76 meters—low tide 95 feet—high tide 95 feet—high tide 95 feet—high tide 95 feet—high tide	island homes within 200 meters of the beach; semi-log f.f.* island homes within 300 meters of the beach; semi-log f.f.* island homes within 200 meters of the beach; semi-log f.f.* island homes within 300 meters of the beach; semi-log f.f.* beachfront homes; semi-log f.f.*; standard model beachfront homes; log-linear f.f.*; standard model beachfront homes; semi-log f.f.*; instrumental variables model beachfront homes; log-linear f.f.*; instrumental variables model
Gopalakrishnan et al. (2011); ten towns in coastal NC			

All value estimates reflect sample averages; *: f.f. = functional form of regression model; #: estimates from Gopalakrishnan et al. are not inflated because the study did not report whether the sales prices were normalized to a base year for estimation (sales data 2004–2007, so they are roughly comparable).

Market prices reflect the discounted present value of housing services, but beach quality is expected to change over time due to natural forces and may be manipulated via beach replenishment (or other policies). As such, the interpretation of marginal WTP for coastal resource quality depends on buyers' and sellers' knowledge of coastal processes and expectations of future coastal management actions. If they expect beach width to remain constant over time, either due to natural forces or regular beach replenishment, marginal WTP can be interpreted in the conventional manner. If, however, market participants expect beach width to decay over time, marginal WTP is an upper bound on the true marginal value associated with the observed level of beach quality (Landry and Hindsley 2011). On the flip side, if homeowners expect beach width to increase over time, these welfare estimates are lower bounds on the true value. In either case, the value estimates in Table 1 provide less accurate information about homeowner preferences than has been presumed.

Gopalakrishnan et al. (2011) examine the possibility that beach width at locations that engage in beach replenishment may be endogenous to the hedonic price function. This statistical problem would render basic regression estimates biased and thus unreliable for policy analysis. Their rationale is that housing values play a role in benefit-cost analysis of beach replenishment, and thus stretches of beach with more expensive housing are more likely to qualify for beach replenishment and more likely to receive higher volumes of beach sand during nourishment operations. Intuitively, this sort of positive feedback would lead to upward bias in estimates of marginal WTP. Using a technique known as "instrumental variables,"¹⁰ Gopalakrishnan et al. attempt to correct for endogeneity bias. Surprisingly, they find evidence of downward bias in standard regression estimates of marginal WTP (as indicated in the last four rows of Table 1). Economic values estimated by instrumental variables are around six times higher than standard estimates. They attribute this negative bias to increased erosion on replenished beaches (as they return to equilibrium profile) and measurement error in perceived beach quality (as discussed in Landry and Hindsley 2011).

The storm and erosion protection and recreation and leisure potential afforded by beaches are essentially a local public good.¹¹ The extent of their influence on coastal property values can be examined empirically, with clear implications for policy analysis and evaluation of beach management projects. Empirical evidence suggests that the value of beach quality declines with distance from the shore (Pompe and Rhinehart 1995, 1999). Landry and Hindsley (2011) find statistical support for the influence of beach width on property values within 300 meters for the ocean, with a distance of 200 meters providing the best fit to the data. Gopalakrishnan et al. (2011) find almost no influence of beach width on property values beyond 100 meters. Landry and Hindsley also find that housing values are positively influenced by dune width, while Gopalakrishnan et al. find no effect for the presence of dunes.

The estimates of marginal WTP in Table 1 are only point estimates. That is, they provide information about marginal value at one level of beach width. Under the standard assumptions and setup, the hedonic property model in Equation (5) is only capable of producing such point estimates. In order to recover the entire marginal value function, which could be extremely useful in policy analysis, more information must be obtained (typically derived from multiple housing markets) (Palmquist 2006). This has not been attempted for hedonic property models of beach quality. Landry, Keeler, and Kriesel (2003), Landry (2008), Smith et al. (2009), and Gopalakrishnan et al. (2011) use the parameterized hedonic price function to estimate property owner benefits attributable to beach width. This approach assumes that there is no heterogeneity in individual preferences for beach quality (Palmquist 2006).

In applied policy models, such as those employed by USACE, property values play a role in assessing project benefits for storm and flood protection. Unlike the aforementioned results that use property values to learn something about preferences for beaches, however, the applied policy models use the property values themselves, combined with estimates of storm damage, as measures of the benefit of storm protection. For flood-risk reduction projects, the USACE P&G require the use of “actual market values” as estimates of property value and provide guidance in assessing other benefits. In practice, however, estimates of value of existing structures are based on analysis of comparable properties or measured by replacement cost minus depreciation (Yoe 1993). Expected damages can be estimated using generalized damage data (based on damage data from similar areas) or site-specific damage data (based on historical damage data).

Under circumstances of risk and uncertainty, welfare economics defines benefits of protection as an aggregation of individual WTP, while P&G define property benefits as foregone storm damages. The different approaches to benefit estimation reflect the fundamental differences of the two conceptual models. Individual WTP for improved beach quality depends on expected storm and erosion protection, as well as perceived recreation benefit. Using sales prices to estimate WTP has advantages in that it is based on individuals’ subjective risk assessments (e.g., probabilities associated with different outcomes) and the perceived value of housing services in different states of the world (e.g., with and without storm losses). A potential disadvantage of this approach is that WTP will be downward biased if buyers are ignorant of or optimistic about storm and erosion risks or do not recognize the defensive potential of beach and dune sediments.

Focusing on foregone storm damages circumvents this potential problem, but ignores the role of risk preferences—describing how individuals are willing to tolerate changes in risk—in analysis of coastal protection. As recognized by the USACE (1983), analysis of foregone storm and erosion damages as a benefit criterion implicitly assumes risk-neutrality (neither risk averse nor risk seeking) on the part of coastal inhabitants. Moreover, failing to use market values in analysis of storm damage reduction can produce biased estimates of benefits. The validity of comparable values depends on the suitability of the comparison group (which can be limited by available data). Replacement values represent the costs of building coastal structures, not the benefit attributed to their occupation; the bias created through use of replacement value could be rather large and could be compounded by introducing a depreciation factor.¹²

The benefits of living on the coast are best estimated by the market value of coastal property; in a competitive market environment, property market values will reflect individual WTP for occupancy of property, and will include values associated with access to the recreational beach, coastal view and ambiance amenities, and rental income. There are, however, complications associated with employing sales values for benefit estimation in applied policy analysis: (1) not all properties have changed hands recently (so no information on current sales value is available); (2) prices include value of both structure and land (so it can be difficult to separate the two for analysis of storm damage and erosion); and (3) market values reflect all characteristics of the property, and if these characteristics change over the course of analysis (e.g., second row home becomes beach front; distance to the shoreline or beach width changes) the housing values need to be adjusted. Regression models employing hedonic property price analysis can be used to address each of these problems. A properly specified regression model can be used to estimate current market value, can be used to estimate the value of a vacant lot (if there are data on lot sales), and can predict the change in housing value associated with changing characteristics (Landry,

Keeler, and Kriesel 2003; Parsons and Powell 2001). Alternatively, assessed values (from tax collector records) can be used to proxy for market values.

Beach Visitors

Beach visitors include tourists and locals that do not own property at the beach. Recreation demand models can be used to estimate the economic value of visitors' access to beach sites, and how these economic values change with alterations in the natural environment (such as increases in beach width). Recreation demand models recognize recreation trips as economic goods that are produced by individual households using purchased commodities (e.g., automobile, gasoline, automobile maintenance) and personal travel time. These elements determine the cost of a recreation trip (travel cost), which is used as a price instrument to examine the tradeoff that visitors make between the number of recreation trips, the quality of recreation trips (as reflected in site characteristics), and other economic goods and services.

All else being equal, we expect those that live further away from recreation sites to take fewer trips (due to the higher travel costs) than visitors who live closer. This is the basic rationale behind the "single-site demand" and "system of demand equations" approaches. In application, these models employ regression analysis to examine the relationships between the numbers of recreation trips to one or more sites, travel costs, income, household characteristics, and other factors. The single-site demand model looks at trips to a single site and includes travel costs to substitute sites as covariates in the regression equation. The system of demand equations model looks at trips to an array of recreation sites within a multiple regression equation framework and can include site characteristics (e.g., beach quality, amenities) as covariates. Each of these models is capable of producing estimates of net economic value of beach visitation—that is economic value over and above the costs incurred in visitation. The system of demand equations approach also has the capability of valuing site characteristics.

Site characteristics play a more prominent role in the "site choice model"—another common framework for analysis of recreation demand. The intuition behind this model is that site choice is primarily influenced by the array of characteristics (including travel distance) at available recreation sites. For example, if an individual selects a trip to a faraway site, this reflects a preference for characteristics of that site vis-à-vis other sites in the "choice set," all else being equal.¹³ The discrete choice model (also known as "random utility model" [RUM]) provides the regression framework, and model covariates are site characteristics (and sometimes individual or household attributes). This model is capable of producing estimates of economic value of access to one or more sites and value estimates for site characteristics.

Table 2 displays net economic value estimates for consumption of beach recreation; all values have been converted to constant 2010 dollars using the consumer price index. Estimates of the economic value of a beach day derived from the single-site model range from \$10 to \$95, per person, per day, for sites in North Carolina and Georgia (Bin et al. 2005; Landry and McConnell 2007). Consistent with diminishing marginal value, the findings of Bin and colleagues (2005) suggest that the average value of a beach day is generally lower for overnight visitors relative to those that take primarily day trips. Estimates from California produced with site choice models are of a similar magnitude, \$27 to \$29 per household (Lew and Larson 2009). Seasonal value estimates range from \$68 per household (Rehoboth, DE; von Haefen, Phaneuf, and Parsons 2004) to \$1,104 per household (all NC beaches; Landry et al. 2010). Lew and Larson (2009) estimate the value of beach recreation

Table 2
Economic value estimates for consumption of beach recreation (constant 2010 dollars)

Study	Economic value	Unit	Model
Bin et al. (2005); Pea Island, NC	\$13—day trip; \$49—overnight	per person, per day	Single-site demand
Bin et al. (2005); Fort Macon, NC	\$21—day trip; \$15—overnight	per person, per day	Single-site demand
Bin et al. (2005); Wrightsville Beach, NC	\$26—day trip; \$18—overnight	per person, per day	Single-site demand
Bin et al. (2005); Cape Hatteras, NC	\$71—day trip; \$13—overnight	per person, per day	Single-site demand
Bin et al. (2005); Cape Lookout, NC	\$82—day trip; \$24—overnight	per person, per day	Single-site demand
Bin et al. (2005); Rachel Carson, NC	\$94—day trip; \$29—overnight	per person, per day	Single-site demand
Bin et al. (2005); Topsail Island, NC	\$95—day trip; \$17—overnight	per person, per day	Single-site demand
Landry and McConnell (2007); Jekyll Island, GA	\$10	per person, per day	Single-site demand
Landry and McConnell (2007); Tybee Island, GA	\$23	per person, per day	Single-site demand
Lew and Larson (2009); San Diego, CA	\$27 to \$29	Per household, per day	Site Choice
von Haefen, Phaneuf, and Parsons (2004); Rehobeth, DE	\$1,652 to \$1,779	Per household, 2 month period	Site choice
	\$68 to \$100	per household, per season	System of demand equations
von Haefen, Phaneuf, and Parsons (2004); all Northern Delaware beaches	\$140 to \$208	per household, per season	System of demand equations
Landry et al. (2010); all NC beaches	\$1,104	per household, per year	Single-site demand

Table 3
Economic value estimates for loss of beach sites (constant 2010 dollars)

Study	Economic value
McConnell and Tseng (2000); Chesapeake Bay beaches	\$2.38 [#] to \$4.51 [#]
Parsons, Massey, and Tomasi (2000); Popular beach sites in Maryland, Delaware, and New Jersey	\$4.29 to \$22.98
Parsons, Massey, and Tomasi (2000); Unpopular beach sites in Maryland, Delaware, and New Jersey	\$0.00 to \$0.19
Lew and Larson (2009); San Diego, CA	\$0.01 to \$0.50

All estimates are per household, per trip, derived from site choice models. #: estimates from McConnell and Tseng are inflated assuming that 2000 is the base year of travel costs.

over a two-month period in San Diego, California at around \$1,700 per household. The wide variation in these estimates can reflect differences in spatial aggregation (single site vs. multiple sites), modeling framework, abundance of existing substitute sites, and preferences of the studied population.

Site choice models are especially well suited to estimate the value of lost site access, while explicitly controlling for substitution possibilities. These types of estimates can be useful for damage assessment in cases of pollution or loss of beaches. Table 3 presents economic value estimates for lost access to beach sites (all values in constant 2010 dollars). Loss of sites within a choice set have smaller impacts on economic welfare than the estimates in Table 2 might lead one to expect because of substitution possibilities. As indicated in the last two rows of Table 3, loss of sites that are not frequently visited has very small impacts on economic welfare of recreational users.

Site choice models, systems of demand equations, and single-site demand models that make use of panel data¹⁴ are capable of producing estimates of the economic value attributed to changes in site characteristics. Some of these estimates are displayed in Table 4 (all values converted to constant 2010 dollars). Economic values for preventing erosion have been estimated at \$7.88 to \$14.81 per household, per trip for Delaware beaches (Parsons, Massey, and Tomasi 2000), and \$46.01 to \$78.09 per household, per year for all beaches in Virginia, Maryland, and Delaware (von Haefen, Phaneuf, and Parsons 2004). Focusing on southern North Carolina beaches, Whitehead, et al. (2010) estimate \$3.57 per individual, per trip, and \$8.32 to \$17.84 per household, per year for a 100-foot increase in beach width. Parsons, Massey, and Tomasi (2000) and Whitehead et al. (2010) find evidence that beach length has positive influence on site choice, indicating a preference for longer beaches.

Increases in beach area provide additional space for coastal recreation and leisure activities, and may enhance economic value by (1) improving scenic and aesthetic amenities, (2) allowing for increased utilization of beach resources (i.e., accommodating more people), (3) decreasing congestion for existing users, or all three. The last two rows of Table 4 present economic value estimates for improvements in beach width derived from an SP approach called the Contingent Valuation Method (CVM). CVM elicits WTP for hypothetical increases in public goods using a simulated referendum or market exercise (i.e., would you vote for a policy to improve beaches if it increased taxes by \$X per year? Or, would you purchase a beach pass at \$Y per trip if beaches were wider?). Using this approach, modest improvements in beach width in Georgia are valued at \$8.87 to \$13.00 per household, per trip for current beach users (Landry, Keeler, and Kriesel 2003). In

Table 4
Economic value estimates for changes in site characteristics (constant 2010 dollars)

Study	Economic value	Units	Resource change scenario	Model
Parsons, Massey, and Tomasi (2000); Maryland, Delaware, and New Jersey	\$7.88 to \$14.91	per household, per trip	all Delaware beaches eroding to a width of less than 75 feet	Site-choice
von Haefen, Phaneuf, and Parsons (2004); Virginia, Maryland, and Delaware	\$46.01 to \$78.09	per household, per year	all beaches eroding to width of 75 feet or less	System of demand equations
Whitehead et al. (2008); Southern NC beaches	Positive, but statistically insignificant	per household, per year	100-foot increase in beach width	Single-site demand (panel data)
Whitehead et al. (2010); Southern NC beaches	\$3.57	per individual, per trip	100-foot increase in beach width	Site-choice
	\$8.32 to \$17.84	per household, per year	100-foot increase in beach width	Single-site demand (panel data)
Landry, Keeler, and Kriesel (2003); Tybee Island, GA	\$8.87 to \$13.00	per household, per trip	modest improvements in beach width	Contingent valuation
Silberman and Klock (1988); Northern NJ beaches	\$0.61	per individual, per day	improvements in beach width	Contingent valuation

contrast, improvements in beach width in northern New Jersey are valued at only \$0.61 per individual, per day (Silberman and Klock 1988), but this study finds a large impact on anticipated visitation. Focusing only on current users, Silberman and Klock estimate a 65% net increase in visitation across all New Jersey beaches when the northern New Jersey beaches undergo replenishment.

Notably, neither of these two papers explicitly controls for congestion in their evaluation of changes in beach value attributable to replenishment. In an application of CVM to valuation of Rhode Island beaches, McConnell (1977) finds that an increase of 100 people per acre decreases the average economic value by 25%. Since beach replenishment increases beach area, one might expect a decrease in congestion. For the use of federal funds, however, the USACE requires enough parking spaces to accommodate peak demand and access points every quarter mile. The increase in accessibility, combined with the possibility of greater regional appeal, could possibly lead to an increase in overall beach congestion. The relationship between beach area, available parking and access, visitation levels, congestion, and economic value remains an important area for future research.

Treatment of recreation values in applied policy analysis requires empirically based estimates that reflect current and projected characteristics of the resource and user population under consideration (USACE 1983). As studies of recreation demand can be expensive and time consuming, practical application often relies on the use of “unit day value” estimates of visitors WTP for beach recreation. Tables of unit-day values are available in USACE reference documents, and these values adjust for site quality, visitor types, and other factors. The use of unit-day values is essentially an application of “benefit transfer,” which employs existing empirical estimates to approximate values in a different situation. There are more robust forms of benefit transfer, however, that employ regression analysis to make adjustments. Still, the method can be inaccurate and unreliable, and a more robust methodology for transferring existing estimates to new projects under consideration is desirable. Structural benefit transfer methods that make use of existing valuation results within a theoretically consistent economic framework (Van Houtven and Poulos 2009) are a promising alternative for assessment of recreational benefits. Perhaps reflecting uncertainty in recreation benefits estimation, current USACE guidelines permit recreation benefits to make up at most 50% of total project benefits. This limitation is apparently arbitrary and has no basis in welfare economics.

Non-Use Values and Economic Impact

Stakeholders may harbor value for beaches that are independent of their own current use of beach resources. Examples of non-use values include: (1) *option value*—WTP to ensure beaches are available for future personal use; (2) *vicarious use value*—WTP to ensure beach exists for use of others; (3) *bequest value*—WTP to ensure beaches are available for future generations; and (4) *existence value*—WTP to ensure beaches exist for natural or intrinsic purposes. As non-use values can be independent of resource utilization, SP methods (such as CVM) must be employed to produce empirical estimates.

Silberman, Gerlowski, and Williams (1992) use CVM to attempt to estimate “existence value” for users and non-users of New Jersey beaches; their focus is primarily on preserving recreation use for others, so the value concept is more in line with vicarious use value described above. Using onsite and mail survey data, they estimate vicarious use values from one-time voluntary payments for beach replenishment in New Jersey to be on the order of \$19 to \$40 per household (converted to 2010 dollars). They note the difficulty in trying to separate use from non-use values for those that intend to use replenished

beaches. Using CVM, Shirlani, Letson, and Theis (2003) compare estimates of WTP for beach width, both with and without identifying improvements in sea turtle habitat as an additional benefit (presumably reflecting existence value). They estimate an approximately 25% greater WTP when sea turtles are identified as additional beneficiaries of the beach nourishment project (\$2.22 vs. \$2.78 per household, per visit (converted to 2010 dollars)). Aside from these studies, there has been little empirical research on non-use values for beaches.

The economic values in Tables 1–4, and those discussed earlier, are estimates of net economic value that resides with users (and non-users) of natural resources. Welfare estimates derived from hedonic property price models indicate implicit economic value for homeowners; estimates produced by recreation demand models indicate net economic value for visitors, and estimates from SP models, like CVM, reflect economic value of those surveyed. Improvements in beach quality can also affect local businesses, by increasing their profitability. We are unaware of any existing research on economic benefits of beach maintenance accruing to local businesses. Economic welfare estimates do not include changes in transfer payments, such as increases in property and sales tax revenues or the impact of tourists' travel expenditures. Local and state governments, however, are often concerned about these measures of economic impact. Input–output models (such as IMPLAN) can be used to quantify the direct, indirect, and induced impact of tourist expenditures on local and regional economics.

Economic Costs of Coastal Erosion Management

Economic costs of erosion management include: (1) direct monetary costs (e.g., expenditures on equipment, personnel, energy for beach replenishment); (2) transaction costs associated with permitting and planning; (3) opportunity costs stemming from the use of resources owned by agency or contractor conducting operations (i.e., costs that would not show up as direct expenditures, but nonetheless entail the use of scarce resources and must be counted from an economic perspective); and (4) external environmental costs (e.g., negative impacts of replenishment activities on the nearshore environment). We consider beach replenishment costs, but the basic approach could be applied to other erosion management actions. Consider a production function for replenishment sand (N):

$$N = N(k, l, e; \lambda), \quad (6)$$

where k represents the level of capital equipment, l represents the amount of labor, e represents the amount of energy, and λ is an index representing the availability of beach-quality sand. Equation (6) could include additional inputs. We assume all inputs have positive and diminishing marginal product: $\partial N / \partial j > 0$; $\partial^2 N / \partial j^2 < 0$ for $j = k, l, e$. The λ index can be thought of as a measure of distance to beach quality sand reserves, with $\partial N / \partial \lambda < 0$.

The objective of a rational project manager is to minimize the costs of producing any quantity of replenishment sand, which gives rise to a “private” economic cost function:

$$C(r, N; \lambda) = \min FC + r_k k + r_l l + r_e e \quad \text{subject to } N = N(k, l, e; \lambda), \quad (7)$$

where FC represents fixed costs of beach replenishment, which include expenditures on mobilization/demobilization of equipment, permits and fees, and environmental impact statement (EIS); r is a vector of exogenous input prices; and N is the desired level of sediment.¹⁵ The cost function in Equation (7) is labeled “private” because it does not

reflect external environmental costs (which are borne by the public at large). The vector r input prices are appropriate measures of opportunity cost only if the inputs are traded in competitive markets. All resources that go into conducting beach replenishment should be included in Equations (6) and (7).

Empirical estimates of Equation (7) can be derived from data on project expenditures, input price levels, sand quantities, and sand “borrow area” depth and distance (reflecting λ). Western Carolina University’s *Program for the Study of Developed Shorelines* (PSDS) has archival data on monetary costs of beach replenishment (as well as sediment quantities and shoreline lengths) for the majority of beach projects extending back to the early 1960s. Monetary costs typically include direct expenditures and some types of transaction costs. It is unclear whether the archived cost data include opportunity costs of capital equipment. The PSDS data do not include information on inputs utilized, input prices, or other details of replenishment operations (such as details on borrow area).

Landry, Keeler, and Kriesel (2003) use historical data on beach replenishment at Tybee Island, GA to produce a rough average estimate of approximately \$1.394 million per year (converted to 2010 dollars) to maintain beach width. Landry (2008) uses the historical PSDS data to estimate a “reduced form” cost equation for beach replenishment [based only loosely on the structure in Equation (7)]. Pooling data for mid-Atlantic, southeast, and Gulf beach replenishment projects, he estimates a panel data model with state-level fixed effects, sediment quantity (in quadratic form), and a time trend. His results suggest that costs are increasing and convex in sediment quantity (indicating increasing marginal cost) and that real costs (controlling for inflation) are trending upward over time. Landry speculates that the increasing time trend could reflect dwindling reserves of high quality beach fill sand in close proximity to the shore.

In order to account for all costs associated with beach replenishment, the economic cost function should also include external costs imposed on the environment. The social cost function is thus:

$$\tilde{C}(r, N; \lambda) = C(r, N; \lambda) + EC, \quad (8)$$

where EC represents external costs of beach replenishment. External environmental costs can include damages at the mine/borrow site (damage to habitat and benthic communities), the target beach (increased turbidity in water or compaction of sediments), or adjacent communities (Greene 2002). Speybroeck et al. (2006) provide a detailed account of possible ecological impacts at the target site and consider differential impacts of competing beach replenishment technologies. Limited empirical information exists on environmental costs of beach replenishment. Using the SP approach known as choice experimentation (CE), Huang, Poor, and Zhao (2007) estimate the costs of wildlife impacts (disturbance of habitat with no threat of extinction) due to beach replenishment. They find that New Hampshire and Maine residents are WTP \$4.23 to \$6.33 per household (converted to 2010 dollars) to prevent these impacts.

USACE P&G on estimation of project costs recognizes basic principles of economic theory of costs. All resources utilized in structural and non-structural alternatives should be valued at their opportunity cost—the value that is sacrificed when a decision on use of a scarce resource is made. Under competitive market conditions, marginal opportunity costs of resources correspond with market prices, while price signals will provide biased signals of opportunity cost under conditions of market power, or in the presence of price controls, taxes, or subsidies. Under these conditions, P&G recommend proxy or surrogate measures of opportunity cost be used.

The P&G organize economic costs into three categories: implementation costs, or explicit costs associated with project execution (incurred by federal agencies and cooperating entities); other direct costs, including the value of resources devoted to project execution, but for which direct outlays are not made (including use of resources with are owned by the implementing authority, value of donated facilities, and the value of positive or negative externalities); and associated costs that stem from execution of the project (and are necessary to achieve benefits) but that are paid by other agents (USACE 1983).

Implementation costs should include the value of resources used to minimize adverse impacts and/or mitigate fish and wildlife habitat losses as required under federal law, and direct costs associated with salvage or preservation of historical and cultural resources. Interest during construction is an “other direct cost” that is always added to project costs in order to put construction costs on the same base year as benefits; since benefits may not begin to accrue until after the project is completed, construction costs must be inflated to reflect this time lag and to render benefits and costs comparable in real terms. Moreover, as water resource projects typically involve a significant time horizon, project costs must be assigned to the appropriate time period in which they will be incurred, expressed in terms of the expected price level, and appropriately discounting in order to make then comparable to present discounted value of benefits. The USACE P&G requires that benefits and costs be expressed as annuities, commonly referred to as “average annual equivalent values.”

Yoe (1993) provides a detailed account of economic cost estimation procedures required by USACE. The approach is generally in accord with the economic theory outlined above [in Equations (6)–(8)]. In practice, specialized software programs are used to implement cost estimation. This author is not sufficiently familiar with these programs to provide a thorough review of their accuracy or suitability. Nonetheless, cost estimation remains a potentially fruitful area for future research.

Conclusions

Applied policy models for coastal erosion management have developed simultaneously alongside of theoretically derived models in natural resource economics. The structure of applied models is influenced by statutory guidelines and practical considerations. For example, Congressional mandates require the use of storm damage reductions as primary evaluation criterion, prohibit the consideration of erosion benefits not associated with storms, and limit the magnitude of recreational benefits that may be used for project justification. Budget limitations often prevent primary data collection for analysis of recreational benefits, necessitating some form of benefit transfer.

While the USACE Principles & Guidelines recommends the use of “actual market values” in the inventory and valuation of existing structures, comparable values or replacement costs (minus depreciation) are typically employed (Yoe 1993). This may bias the benefits of storm protection downward (especially in the case of replacement costs), and it has implications for the validity of hedonic price estimates. Since market values are not typically used in analysis of beach replenishment, the concerns of Gopolo Krishnan et al. (2011) over endogeneity may not be well founded (at least for historical data). Nonetheless, their results indicate some anomalies are present in beach width and coastal housing price sales data. These anomalies deserve further exploration.

Dynamic optimization models originating in natural resource economics incorporate information on economic benefits and costs with representations of coastal dynamic processes, like erosion, storms, and sea-level rise. These models can address optimal beach replenishment rotations in the short term, as well as coastal protection in the long run.

Employing the framework of the dynamic optimization models, an optimal long term strategy depends on the degree of erosive pressure (i.e., sea-level rise), how this affects management costs, and the benefits of preserving the current shoreline. Long run applications of the models can examine whether beach replenishment is a tenable management practice over a long time horizon, given assumptions about sea-level rise and costs and benefits. A termination of beach replenishment in the long run implies a policy of shoreline retreat, which would entail gradual migration of barrier islands and associated losses in property and infrastructure. A primary goal of the broader research agenda on coastal erosion management should be estimation of the optimal timing of such a transition and an exploration of factors that influence this timing. Information on the optimal timeline of shoreline retreat could be instrumental in allowing the market value of threatened properties to properly adjust to the risk of sea-level rise and invaluable for coastal planning and investment purposes.

Dynamic optimization models also have shortcomings. Up to this point, representations of coastal processes have been fairly simplistic, but recent work has sought to incorporate longshore spatial effects (Slott, Smith, and Murray 2008). The array of management options considered is also limited, as only one policy “control”—beach replenishment—is considered with other options only implicitly introduced (shoreline retreat in case of Landry 2008). Economic applications that have compared a broader array of erosion management options (e.g., Parsons and Powell 1999; Landry, Keeler, and Kriesel 2003) have been *ad hoc*, not explicitly incorporating natural dynamics. Further research should examine ways to incorporate diverse management options within a dynamic optimization framework.

Lastly, given their explicit focus on beach replenishment, the dynamic optimization models discussed in this paper are mathematically complex. They do not readily lend themselves to heuristics or rules-of-thumb that could be applied by state and local governments in analysis of beach replenishment projects. Future research should focus on end-user applications that could be used for policy analysis.

Notes

1. Whether general tax revenue, user fees, or local property or sales taxes should be used to pay for beach replenishment is an important question that is beyond the scope of this article.

2. The manuscript can be downloaded from the Department of Economics (<http://www.ecu.edu/cs-educ/econ/upload/ecu1011-Landry-CoastalErosion.CMJ.pdf>) or Center for Natural Hazards Research (<http://www.ecu.edu/cs-cas/hazards/upload/Coastal-Erosion-Landry.pdf>) at East Carolina University.

3. Examples of dynamic models for natural resource management include Faustmann’s (1849) model of optimal rotation of forest stock, Hotelling’s (1931) model of optimal mineral extraction, and Gordon’s (1954) fisheries model.

4. If a prior entitlement exists, willingness-to-accept (WTA) compensation for sacrifice of the resource is the appropriate measure of economic value.

5. Fixed costs are independent of the level of output (in this case, the amount of beach fill).

6. That is, an instantaneous benefit is realized each period and depends on the level of beach quality.

7. The approach of backward recursion is based on Bellman’s Principle of Optimality, which states that an optimal policy must constitute an optimum with regard to the remaining periods regardless of preceding decisions. As such, one can solve the problem by working backward.

8. In addition to net economic benefit, project evaluation must also focus on environmental quality, regional economic development, and other social effects (collectively referred to as “output

and effects"). The P&G require evaluation of with- and without-project output and effects along each of the four criteria (completeness, efficiency, effectiveness, and acceptability) for each alternative, while allowing for some flexibility in the level of analytical detail (with appropriate justification).

9. Numerous studies have empirically tested for the influence of environmental amenities on coastal housing markets, including proximity to water (Shabman and Bertelson 1979; Milon, Gressel, and Mulkey 1984; Pompe and Rinehart 1995, 1999; Earnhart 2001; Parsons and Powell 2001; Landry, Keeler, and Kriesel 2003; Bin, Kruse, and Landry 2008; Pompe 2008) and water view (Kulshreshtha and Gillies 1993; Lansford and Jones 1995; Benson et al. 1998; Pompe and Rinehart 1999; Bin et al. 2008).

10. They use topological characteristics of the shore profile—distance to the continental shelf and presence of dune scarps—as instruments for beach width; each of these geographic features should be correlated with coastal erosion but may be uncorrelated with housing values (conditional on a given level of beach quality).

11. Public goods can be distinguished from conventional private goods in that their provision engenders benefit to multiple households simultaneously, and once these goods are provided potential beneficiaries cannot be excluded from their consumption. As such, the existence of public goods can lead to situations in which free and competitive markets do not perform well. Public goods comprise a major component of research in public economics.

12. If the housing stock is old, depreciated replacement costs may value many parcels at close to zero dollars (depending on the age of the structure and depreciation method employed). Land on barrier islands and along the coast is scarce, and competition among buyers and sellers can be significant. When market demand is strong (as has been the case on the east coast for the past 10–15 years, last couple of years excepted), market values can exceed replacement cost, as coastal parcels earn scarcity rents. Competition will affect the value of land more than structure, but since the two are linked market structure values can exceed replacement cost.

13. Other factors that can influence site choice, such as proximity to family and friends, and the relationship between recreation and other trip objectives, must be carefully considered during data collection.

14. Panel data usually have cross-sectional and time series dimensions. In non-market valuation, some panel data combine RP and SP data to create a quasi-temporal dimension.

15. Under standard assumptions: $\partial C/\partial r > 0$; $\partial C/\partial N > 0$; and $\partial C/\partial \lambda > 0$.

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