The Economic Cost of Greenhouse Induced Sea Level Rise for Developed Property in the United States

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THE ECONOMIC COST OF GREENHOUSE-INDUCED SEA-LEVEL RISE FOR DEVELOPED PROPERTY IN THE UNITED STATES*

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Abstract. Estimates of the true economic cost that might be attributed to greenhouse-induced sea-level rise on the developed coastline of the United States are offered for the range of trajectories that is now thought to be most likely. Along a 50-cm sea level rise trajectory (through 2100), for example, transient costs in 2065 (a year frequently anticipated for doubling of greenhouse-gas concentrations) are estimated to be roughly $70 million (undiscounted, but measured in constant 1990$). More generally and carefully cast in the appropriate context of protection decisions for developed property, the results reported here are nearly an order of magnitude lower than estimates published prior to 1994. They are based upon a calculus that reflects rising values for coastal property as the future unfolds, but also includes the cost-reducing potential of natural, market-based adaptation in anticipation of the threat of rising seas and/or the efficiency of discrete decisions to protect or not to protect small tracts of property that will be made when necessary and on the (then current) basis of their individual economic merit.

Early predictions of dramatic greenhouse-induced sea-level rise have given way over the past decade to more modest expectations. High projections settled around 1.5 meters in 1990 and converged to slightly more than 1 meter by 1992.[1] The mid-range best guess now stands at 64 cm. Widely cited work by Wigley and Raper (1992) nonetheless offers a mid-range estimate of 48 cm – a value that is nearly matched by the median value offered by Titus and Narayanan (1995) and a value that exceeds the largest of the most recent stable concentration mid-range estimates offered by Wigley (1995) by more than 20%.

The Wigley (1995) estimates for climate-induced sea-level rise, all of which assume stabilized concentrations, are recorded in Table I. Even though the oceans would continue to rise for centuries even if concentrations were stabilized in the interim, the highest middle value reported for 2100 is 40 cm. Recognizing, as well, that scenarios in which concentrations peak around the 750 ppm level are not all that uncommon,[2] it is clear that a new set of estimates of the economic cost of sea-level rise along lower trajectories should be constructed. This paper will report

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Table I
Sea-level consequences of greenhouse-gas concentrations[a,b]

(1) Stabilization level	(2) Year of stabilization	(3) Sea level rise at 2100			(4) Sea level rise at 2400		
		Low	Middle	High	Low	Middle	High
350	2050	0	16	39	–18	19	77
450	2100	4	26	56	–10	52	157
550	2150	7	32	65	–3	77	216
650	2200	9	36	72	2	96	261
750	2250	11	40	78	7	112	300

[a] Source: Table 2 in Wigley, op. cit. 1994.
[b] Sea-level rise is measured in cm along scenarios that reach the stabilization levels recorded in Column (1) by the date indicated in Column (2).

on the results of just such a computation for the United States. Economic costs are calculated as the sum of the value of lost property (values at the time of loss, net of market-based adaptation that might mitigate against this cost but including the cost of that adaptation) and the expense involved in protecting property that should not be abandoned.

Section 1 provides some context by reviewing past estimates of the potential cost to the United States of sea-level rise. A second section offers a description of the assumptions and methods that frame this work before results are reported in Section 3. Concluding remarks return to the historical context to argue that widely accepted base-case estimates are much too high. To be sure, past research has considered greenhouse-induced sea-level rise trajectories that reflect the lower expectations of the current wisdom, but most of the integrated assessment work that has incorporated the cost of sea-level rise into aggregate cost estimates have focused on the 100-cm trajectory that runs above the upper range of the current scientific consensus. Additionally, many of the past estimates have been constructed from analyses that miss both the cost-reducing potential of natural, market-based adaptation in anticipation of the threat of rising seas and the likelihood that decisions to protect or not to protect property will be made on the basis of economic merit. Correcting for both sources of error, baseline estimates for losses attributed directly to protecting or abandoning developed property will be seen to reduce past estimates by almost a full order of magnitude.

1. Historical Estimates of Cost

Schneider and Chen (1980) offered the first cost estimate along sea-level rise trajectories that the scientific community has long since dismissed, but their work certainly identified a global warming problem worthy of serious study.[3] They estimated, in particular, that the value of property in the United States that would be vulnerable to 15 feet and 25 feet of sea-level rise could be as high as $107.5 billion (1971$) and $146.9 billion (1971$), respectively. Inflated to 1990 dollars, their high estimate amounts to almost $474 billion.

Nearly a decade passed before here the U.S. Environmental Protection Agency undertook a systematic national study of the potential costs associated with rising seas as part of their 1989 Report to Congress. Nordhaus (1991) used their results to support including $2.4 billion in lost land value [published actually as $1.7 billion dollars (1980$) in annual rent lost but inflated here to 1990 dollars by the author] and $4.9 billion in protection cost [3.5 billion dollars (1980$) similarly inflated] in his estimate of the damage that the United States might expect to see in the year 2065. Nordhaus assumed, in making these calculations, that atmospheric concentrations of carbon dioxide would have doubled by that time and that seas would, as a result, rise by approximately 1 meter by the year 2100.[4]

Most recent assessments of the total damage pick 2065 to be the year associated with doubling of atmospheric concentrations and have reported larger estimates drawn from longer lists of contributing effects, but the absolute contributions of sea-level rise to those totals have remained remarkably stable. Except for Titus (1992), whose $5.9 billion (1990$) in annual costs are dominated by the value of lost forest land and pollution damage, sea-level rise consistently accounts for more than 10% of total damages; and all but Titus roughly agree with the early Nordhaus statistic in their contention that a doubling by 2065 will burden the late twenty-first century economy of the United States with from $7 to $9 billion (1990$) in lost land and the cost of protection.[5]

Of these totals, most of the cost estimates were generally informed by the same U.S. EPA Report that Nordhaus used, and so they are all built on the notion that something between $73 to $111 billion in cumulative protection costs would be incurred through 2100 to guard against a 1-meter rise.[6] Perhaps more importantly from an economic perspective, though, most of the estimates for the associated losses of abandoning developed property that should not be protected have been constructed from vulnerability measures of real estate losses. They express the potential total cost of abandoning property in terms of annual streams of constant economic rent that are computed so that their present values equal the total, current value of all of the real estate that might be lost to higher seas between now and the year 2100. This is a clever accounting practice, but it falls short in two regards. It is, first of all and by its very construction, static. It compares a snapshot of coastal property taken for the year 2100 with a snapshot of current development, but it expresses any differences between the two in terms of (average, annuitized) annual changes. The result shows change, but it does not portray the dynamics of that change. It approximates arbitrarily the rate of change in 2065, but it does not reflect accurately the transient nature of that property as it passes through 2065 along any specific sea-level trajectory. Put another way, this procedure applies the mean value theorem across a 110-year time span, and so it would offer the same picture for 2050, 2075, 2100, or any other year in its range. Integrated assessments that need to calibrate costs at some point in the future would prefer to employ 'transient costs' that are computed for that year rather than rough averages across a century or so.

In addition, the data to which this annuitizing accounting procedure have been applied were drawn from current conditions. Since they were constructed from vulnerability estimates, more specifically, they ignore future development and land appreciation that can be expected even on vulnerable property in the intervening years. They miss any adaptation that might occur naturally within the market as new information emerges. They miss any policies that might be enacted to protect or abandon property in the context that market adaptation, *and* they miss the cost of protection that must be applied to property that should not be abandoned.

Correcting for most of these shortcomings can be expected to reduce the potential cost of sea-level rise, since adaptation would not occur unless costs were reduced. There is, nonetheless, some ambiguity that must be explored. Adaptation could reduce the cost of abandoning property, to be sure, but appreciation over the intervening years might increase the eventual cost of abandonment and thus the minimum acceptable cost of protection. In addition, while first best adaptive decisions that minimize cost may be made with adequate and timely information, it is perhaps more likely that worst case decisions that actually guarantee maximum cost might be made. The work reported here tries to account for all of this complication by bracketing the cost around best and worst case adaptation.

It should be noted that Titus (1992) produced cost estimates from a model that was more dynamic and adaptive than just described. He recorded the annual capital cost for developed areas that should be protected and for wetlands that should be restored on an annual basis. These were the result of 1991 capital cost estimates that were higher than those used previously. The annual rent notion described above was used only for undeveloped land that was abandoned. Barrier islands that were not developed in 1990 were not protected, and undeveloped mainland was developed at a rate dictated by the rate of economic growth. Assuming a 65-cm trajectory through 2100, the Titus cost estimate was lower than then existing estimates, and annual costs actually peaked.

2. Assumptions and Methods

Planning how to respond to rising seas along a developed coastline can be broken into two distinct decisions that are made in an effort to maximize discounted intertemporal welfare (i.e., the net benefits of any protection strategy minus the cost of its implementation).[7] The first is a decision to protect the coastline starting at some time t_0; and the second is a decision not to protect shoreline property (or to stop protection at time T). The (net) benefit side of a decision to protect a shoreline from time t_0 through time T can thus be modeled as the true opportunity cost of abandoning developed coastal property. Protection of undeveloped dryland has been considered by some, but neither its cost nor the loss associated with abandonment is reflected here.

Economic damage that might be attributed to future sea-level rise in the absence of any decision to protect threatened property is calculated here in terms of the value of that property at the (future) time of inundation and given any adaptation that might have occurred naturally and efficiently prior to flooding and abandonment. Satisfactory descriptions of how future development might affect coastline real estate values were derived from empirical market analyses of how property values might change as factors such as population and real income change. Abraham and Hendershott (1993), e.g., provide estimates of the form:

$$\mathrm{d}\{\ln(P_t)\} = \alpha_0 + \beta_L g_L + \beta_y g_y + \beta_{-1}\mathrm{d}\{\ln(P_{t-1})\}$$

were g_L and g_y represent the rates of growth of population and per capita income and P_k represents the real price of property in year k.[8] Planting externally drawn scenarios of how these 'driving socio-economic variables' might move as the future unfolds into accessible empirical studies produced historically based portraits of how real property values might change over the same time frame. Applied with care in the absence of any anticipated, fundamental structural change in the real estate marketplace, the resulting development trajectories offered reasonable portraits of the evolving context of the sea-level rise problem.

Satisfactory descriptions of how real estate markets might respond on a more micro, local level in the face of threatened inundation from rising seas were more difficult to create. On the one hand, the value of the land lost to rising seas should be estimated on the basis of the value of land located inland from the ocean. Any price gradient which placed higher values on parcels of land in direct correlation with their proximity to the ocean would, in a very real sense, simply migrate inland as shoreline property disappeared under rising seas. Ignoring what could be significant transfers of wealth for the purpose of computing economic cost, the cost of inundation was, therefore, taken to be the value of the land that will, in an economic sense, actually be lost – interior land equal in area to the abandoned and inundated property.[9] It should be emphasized, however, that adopting the cost-benefit paradigm that ignores transfers (or, more accurately, assumes some compensation for 'losers' derived from the efficiency driven surplus distributed to 'winners') masks components of what might be termed 'gross social cost' that could be enormous. Indeed, since protection decisions will likely be made at a local level where the political pressures brought might be most powerful, these components could lead to economically inefficient but socially and/or politically prudent efforts to protect coastline that the economic cost calculus would say should be abandoned.

On the other hand, the economic value of structures can be expected to depreciate over time as the threat of impending inundation and abandonment becomes known. Structures will be lost at the moment of inundation, of course, but their true economic value at that point could be zero if markets were equipped with enough advanced warning and with a complete understanding that the property would, indeed, be abandoned. Despite stories of individuals' reluctance to abandon threatened property in, for example, flood plains, investigations into how markets react to low probability– high cost events strongly supports the assertion that market-clearing real-estate prices do indeed decline over time in response to the pending cost of a growing threat.[10]

True economic depreciation (TED), modeled to start at some fixed time prior to inundation and to finish just when inundation would occur, was the appropriate representation of the maximally efficient market response to (known) risk of future sea-level rise.[11] TED is, by definition, a representation of how the value of an asset declines over time as it moves toward its retirement from service. Structures are thirty years assets in the view of the Internal Revenue Service, so thirty years of (certain) advanced warning was deemed to be sufficient. Its application here supports the position that the true economic cost of structures lost to rising seas could be as low as zero.

Uncertain abandonment, caused by uncertainty about the rate of future sea-level rise and/or a disbelief that existing property would actually be abandoned, would affect efficiency, of course. Either a source of imperfect information or an incomplete reaction to the threat of rising seas could, for example, shrink the time period over which markets could react to the threat of rising seas. The value of lost structures under these conditions would not be zero; it would, instead, equal the remaining value of (shoreline) structure at the time of inundation. [12] The worst case of imperfect information and uncertain abandonment would allow absolutely no warning and thus no time for any structural depreciation at all. Consideration of this case takes the lack of information to an extreme caused more by a sudden realization that the policy of abandonment would be followed than by a sudden realization that the oceans have risen; but it captures the situation in which the cost attributed to rising seas would be maximized. It therefore allows for the possibility that property that should have been abandoned (given maximum efficiency and perfect information) might actually be protected, instead. Indeed, the no-foresight case covers a more intuitive view of how the future might unfold with coastal property owners maintaining their structures to the bitter end. Protection is more likely, in this case, so the issue of wealth transfer noted above would be less likely to appear; when it does, however, the magnitude of the transfer is maximized and so exacerbates the problem.

The cost of protection from time t_0 through time T was easier to frame – it was simply the time trajectory of protection costs along the same specified sea-level rise scenario. Seven published studies were found that offered specific cost estimates for various protection structures.[13] For protecting against a 1-meter rise in sea level, review of this work suggested that the (fixed) cost of constructing dikes/levees range from \$150 to \$800 per linear foot while seawall and bulkhead construction costs range from \$150 to \$4000 per linear foot. Costs depend upon engineering and construction specifications as well as design standards and geological characteristics. The baseline results reported here were derived from a central estimate of $750 per linear foot for a generic hard structure, but their robustness was also tested in the extreme case where protection costs $4000 per linear foot.

Maintenance costs, modeled as the variable cost of protection, were also incorporated. Since the central fixed cost estimate was drawn from Gleick and Maurer, their representation of annual maintenance expenditure as a percentage of construction was adopted. Four percent per year was chosen as the central estimate, but ten percent was applied to hard structures that might be built along coastline open directly to the ocean.[14]

Structure and maintenance costs were changed for different scenarios, under the assumption that protection for the full measure of sea-level rise expected through 2100 would be constructed when it was needed. Weggle *et al.* (1989) and Sorenson *et al.* (1984) both indicate that construction costs increase geometrically with height, and Weggle offered a factor of 1.5. Nicholls and Leatherman (1994) as well as Sorenson offered more insight into the details of construction. They noted that hard structures are typically trapezoidal in shape with 1:2 slopes on the sides and with the width of the crown on top matching the height. This was enough information to compute a relationship between the cost of hard structures and their required height along 33-cm and 67-cm scenarios as fractions of the cost along a 100-cm scenario; and it supported a cost factor of nearly 2.

A different methodology was employed to characterize accurately the cost of protecting tracts of beachfront property and, to the extent possible, their fronting beaches. The basic idea conveyed by experts in the field was that beach nourishment alone would suffice provided that nourishment were an ongoing operation from the very start and as long as sea-level rise did not exceed some threshold; 33-cm was chosen to be that threshold. The cost of nourishment was computed from estimates of the requisite volume *and* regionally applicable supply curves for sand that related annual rates of sand extraction with estimates of its expected contemporary marginal cost.[15] Once the threshold was crossed, however, experts held that a hard structure constructed at the back of the beach would be required both to have any chance of preserving the nature of the beach and to protect interior property. The structure-cost assumptions just described with 10% annual maintenance costs were then applied; and protection was the preferred option only if the discounted beach and property protection benefits exceeded the discounted sum of all of these costs.

3. Results

The results presented here were derived by applying procedures informed by the observations outlined above to the same sample that supported the original vulnerability estimates published by Yohe; a description of the full sample is recorded in Table II. The results are, therefore, dependent upon interpolation of the same computer-based mapping capability with which inundation effects of various sea-level rise scenarios were displayed for each of the 30 sites in the vulnerability sample.[16] In those maps, each site was partitioned into square cells usually measuring 500 meters on each side, and a computer run for each provided cell-specific effects in five-year increments for designated sea-level scenarios defined not only by an assumed contribution from greenhouse warming, but also by a site-specific rate of natural subsidence. Sea-level rise in year t upon the shoreline of any Park site J along sea-level rise trajectory K was, more specifically, expressed by

$$SLR_{JK}(t) = S_J(t - t_J) + GH_K(t - t_J)^2$$

where t_J represent the year of initialization for site J, S_J represents the rate of local subsidence for site J, and GH_K represents a greenhouse-warming coefficient chosen to produce the chosen cumulative rise through 2100.[17]

Time series of the economic cost of future sea-level rise at each site were constructed as the sum of protection costs and abandonment losses under the assumption that decisions to protect or not were made on a cell-by-cell basis within any sample site. The sources of the protection cost data employed are described above. Abandonment losses given property appreciation and market adaptation were derived by applying the procedures described above to the same property value data that supported the original vulnerability estimates.[18] The resulting series, therefore, include the expense of protection or the cost (net of adaptation) of abandonment tuned not only to each specific sample site, but also to specific regions and areas within that site. There was, for example, no reason to require that all of the cells in any site that might eventually be threatened by rising seas be protected as soon as rising seas reached the first one or two cells. For each cell that might be threatened at some time t, in fact, a decision to protect or not was made on the basis of maximizing the present value of the total (net) benefit of protection with respect to t_0, the time when protection might start, and with respect to $T > t_0$, the time when protection might end. The cost trajectories reported here, therefore, include the cost of protection only during times when protection is warranted on a cell-by-cell basis; and they include the (net) cost of abandonment only at the time of that abandonment.

Table III displays results for each site under the baseline cost assumptions with and without foresight with 3% and 5% discount rates along three alternative sea level scenarios.[19] Table IV and Figure 1 reflect summary estimates that emerge from these data for the United States based upon the best available estimates of property-value appreciation, market adaptation, and protection costs for three sea-level trajectories under a variety of circumstances.[20] Estimates of the present value of the true economic cost of the indicated sea level trajectories are recorded in Column (2). They behave appropriately across the cases, showing larger estimates both for steeper sea-level rise trajectories and for circumstances of absolutely no foresight. Perfect foresight is, however, not as valuable as one might think, but the explanations for this small value are easy to explain. Notice, first of all, that column (5) shows that a majority of developed property is, in every case, protected

Table II
Subsample sites by region

Region	Identification[a]	Major municipality	Northern latitude	Western longitude	Natural subsidence[b]
Northeast (NE)	MEROCKLA	Rockland	44 07 30	69 07 30	1.0
	MAWESTPO	Westpoint	41 37 30	71 07 30	1.5
	RIWATCHH	Watch Hill	41 22 30	71 52 30	0.6
	CTBRIDGE	Bridgeport	41 15 00	73 15 00	0.9
	NJLONGBE	Long Beach	39 45 00	74 15 00	2.7
	MDEASTON	Easton	38 52 30	76 07 30	2.4
	VABLOXOM	Bloxom	37 52 30	75 37 30	1.9
	VANEWPOR	Newport News	37 07 30	76 30 00	3.1
Southeast (SE)	NCLONGBA	Long Bay	35 00 00	76 30 00	0.6
	SCCHARLE	Charleston	30 00 00	80 00 00	2.2
	GASEAISL	Sea Island	31 22 30	81 22 30	1.8
	FLSTAUGU	St. Augustine	30 07 30	81 30 00	1.8
	FLMIAMI	Miami	25 52 30	80 15 00	1.1
	FLKEYWES	Key West	24 37 30	81 52 30	1.0
	FLPORTRI	Port Richey	28 30 00	83 45 00	0.7
Gulf Coast (Gulf)	FLAPALAC	Apalachicola	29 45 00	85 07 30	1.2
	FLSTJOSE	St. Joseph	29 52 30	85 30 00	0.7
	MSPASSCH	Pass Christian	30 22 30	89 15 00	1.2
	TXPALACI	Palacios	28 45 00	96 15 00	2.8
	TXPORTLA	Portland	27 52 30	97 22 00	2.8
	TXGREENI	Green Island	26 30 00	97 22 00	3.9
	LAMAINPA	Main Pass	29 22 30	89 15 00	9.3
	LABARATA	Barataria	29 45 00	90 22 30	9.3
	LAGRANDC	Grand Chenier	29 52 30	93 00 00	8.5
West Coast (West)	CAALBION	Albion	39 15 00	123 52 30	0.0
	CAPTSAL	Point Sal	35 00 00	120 45 00	0.0
	CASANQUE	San Quentin	38 00 00	122 30 00	0.1
	ORYAQUIN	Yaquina	44 45 00	124 07 30	−1.0
	WAANACOR	Anacortes	48 45 00	122 45 00	0.2
	WATACOMA	Tacoma	47 30 00	122 30 00	0.8

[a] Site identification codes reflect the state abbreviation in their first two letters and the major municipality in their last six letters.
[b] Rate of shoreline subsidence in mm per year.

even when the maximum efficiency (minimum abandonment cost) implications of perfect foresight are imposed; improved information has, in these cases, no effect on the ultimate decision of whether or not to protect, and it has no effect on the cost (of protection). Protection costs also limit the value of information because

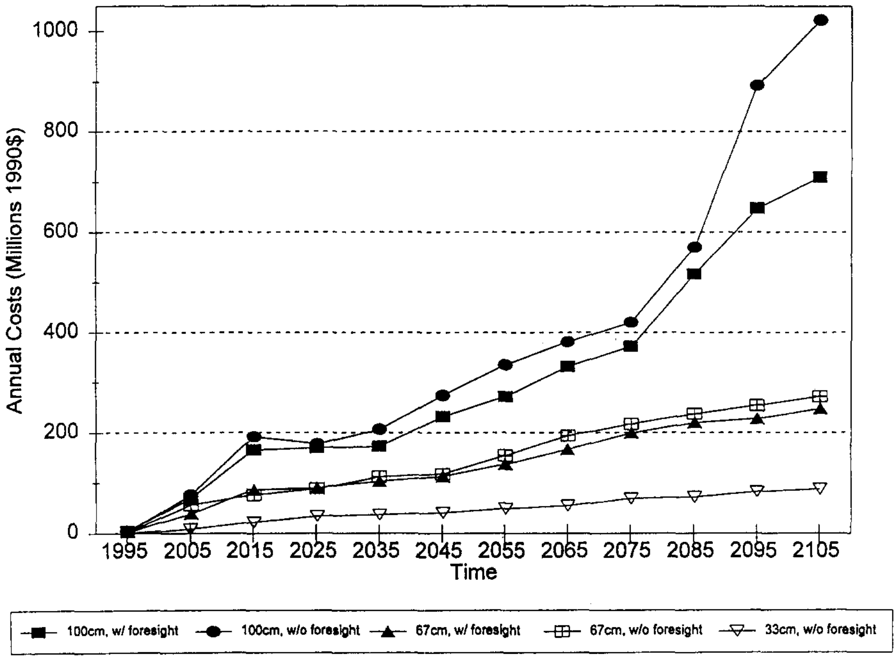

Figure 1. Annual cost estimates for several sea level rise scenarios. Values are annual averages based on decadal costs, and are undiscounted current year estimates in 1990 dollars.

they cap economic costs for the cells that would not be protected with perfect foresight but that would nonetheless be protected if the decision were made at the time of inundation with no advanced adaptation or market response. Finally, most of the protection decisions are made well into the future; and so differences in the discounted values of different decisions should be expected to be small.

Columns (3) and (4) of Table IV are most significant for comparing the results of previous estimates. Take, for example, the 100-cm trajectory with a 3% discount rate. Recall from Table IVa that discounted costs equal to $5.43 billion and $6.35 billion (1990$) were estimated with and without foresight, respectively. Column (3) shows estimates of annuitized costs equal to $163 million and $193 million based upon cumulative protection costs and the cumulative value of abandoned property equal to $36.1 billion and $45.4 billion, respectively. Column (4) meanwhile records transient costs for 2065 – undiscounted protection costs and lost property values actually expected in the year 2065. They are higher than the annuitized estimates that compare most directly with past protection/abandonment cost estimates, but even the $381 million estimate that emerges without foresight falls well short of previously published estimates of protection costs alone.

Original vulnerability estimates published by Yohe (1989) were derived from the same sample of sites; and cumulative vulnerability – the 1990-value of property threatened by rising seas – along the same reflection of a 100-cm trajectory put

Table IIIa
National and regional estimates for coastal protection strategy costs

Region/site name	100-cm SLR scenario (values expressed in $mil)				Strategy/notes
	3% discount rate		5% discount rate		
	30 yrs fore	0 yrs fore	30 yrs fore	0 yrs fore	
Northeast					
Rockland, ME	1.084	1.084	0.721	0.721	Protect
Westpoint, MA	3.831	3.831	1.797	1.797	Protect
Watch Hill, RI	9.817	9.817	5.115	5.115	Protect
Bridgeport, CT	6.215	7.136	3.243	3.585	No protect (30 yrs)/ protect (0 yrs)
Long Beach Island, NJ[b]	27.708	27.708	10.845	10.845	Protect
Easton, MD	6.105	6.105	2.437	2.437	Protect
Bloxom, VA	0	0	0	0	Zero inundation through 200-cm SLR
Newport News, VA[a]	31.189	31.38	16.687	16.738	–
Suffolk	0.254	0.445	0.073	0.124	No protect (30 yrs)/ protect (0 yrs)
Hampton	22.322	22.322	12.006	12.006	Protect
Norfolk	6.479	6.470	2.959	2.959	Protect
Portsmouth	2.134	2.134	1.649	1.649	Protect
Southeast					
Long Bay, NC	1.284	4.737	0.442	1.628	No protect
Charleston, SC[a]	8.62	17.69	3.922	5.936	–
Charleston City	0.746	0.746	0.18	0.18	Protect
Mt. Pleasant	4.058	6.29	2.641	3.392	No protect (30 yrs)/ protect (0 yrs)
Avondale	0.177	0.186	0.028	0.031	Partial protect
Dorchester	0.962	1.616	0.685	1.032	No protect
Sullivan's Island[b,c]	2.677	8.852	0.388	1.301	No protect
Sea Island, GA[b]	7.182	7.182	2.735	2.735	Protect
St. Augustine, GA[b]	2.26	2.83	1.271	1.679	No protect
Miami, FL[b]	15.675	15.675	6.142	6.142	Protect
Key West, FL[c]	11.634	11.634	4.134	4.134	Protect
Port Richey, FL[c]	3.972	3.972	2.396	2.396	Protect
Gulf coast					
Apalachicola, FL	0.082	0.303	0.013	0.045	No protect
St. Joseph, FL	0	0	0	0	Zero inundation through 180-cm SLR
Pass Christian, MS	1.326	1.901	1.011	1.423	No protect[b]
Palacios, TX	0.106	0.396	0.138	0.138	No protect
Portland, TX	0	0	0	0	Zero inundation through 180-cm SLR
Green Island, TX	0	0	0	0	Zero inundation through 200-cm SLR
Main Pass, LA	0	0	0	0	Zero inundation through 200-cm SLR

Table IIIa
(Continued)

Region/site name	100-cm SLR scenario (values expressed in $mil)				Strategy/notes
	3% discount rate		5% discount rate		
	30 yrs fore	0 yrs fore	30 yrs fore	0 yrs fore	
Barataria, LA	11.416	16.631	7.356	10.799	No protect[b]
Gran Chenier, LA	2.664	7.818	1.394	3.667	No protect[b]
West					
Albion, CA	0	0	0	0	Zero indundation through 200-cm SLR
Point Sal, Ca	0	0	0	0	Zero inundation through 200-cm SLR
San Quentin, CA	4.332	5.336	2.175	2.493	No protect (30 yrs)/ protect (0 yrs)
Yaquina, OR	1.9	1.9	0.712	0.712	Protect
Anacortes, WA	2.375	4.052	1.169	1.766	Protect
Tacoma, WA	5.324	5.343	2.793	2.798	No protect (30 yrs)/ protect (0 yrs)
National estimates (in $mil)	$5,426	$6,352	$2,569	$2,931	
Regional estimates (in $mil)					
Northeast	$2,808	$2,844	$1,334	$1,347	
Southeast	$1,654	$2,082	$687	$805	
Gulf coast	$509	$884	$324	$525	
West coast	$455	$543	$224	$254	

National and regional estimates are calculated by applying a weight of 32.667 (980/30) to each site.
All values assume a rate of 4% was used for variable costs of protection, unless otherwise specified.
[a] Values are taken as a sum of all subsites analyzed at that site.
[b] A site involving a beach nourishment strategy.
[c] A site using 10% variable protection cost instead of 4%.
[d] Using a 1% variable protection cost induced a protect strategy.

$321 billion (inflated to 1990$) at risk. Recall the previously mentioned U.S. EPA (1989) estimate that protecting developed property against 100 cm of greenhouse induced sea-level rise would cost between $73 and $111 billion through 2100. Cline (1992) assumed $240 billion in cumulative expenditure on protection alone to support (annuitized) annual costs of $1.2 billion. These estimates are clearly and significantly different from the ones produced here; and their difference lies not only in the details of the underlying analyses, but also on the timing of protection expenditures.

Perhaps the most comparable evaluation, and thus the most fruitful place to turn for detailed consideration of the differences, is Fankhauser (1994a, b). His work supports a benchmark estimate for protection costs drawn from a relatively careful analysis based upon smooth inundation patterns that were taken to be proportional in area to assumed rates of sea-level rise. Proportional inundation is an oversim-

Table IIIb

National and regional estimates for coastal protection strategy costs

Region/site name	67-cm SLR scenario (values expressed in $mil)				Strategy/notes
	3% discount rate		5% discount rate		
	30 yrs fore	0 yrs fore	30 yrs fore	0 yrs fore	
Northeast					
Rockland, ME	0.476	0.476	0.317	0.317	Protect
Westpoint, MA	1.383	1.383	0.71	0.71	Protect
Watch Hill, RI	3.717	3.717	2.153	2.153	Protect
Bridgeport, CT	2.851	2.851	1.444	1.444	Protect
Long Beach Island, NJ[b]	18.331	18.331	7.205	7.205	Protect
Easton, MD	2.358	2.358	0.964	0.964	Protect
Bloxom, VA	0	0	0	0	Zero inundation through 200-cm SLR
Newport News, VA[a]	10.577	10.577	6.29	6.29	–
Suffolk	0	0	0	0	Zero inundation with 67-cm SLR
Hampton	7.511	7.511	4.383	4.383	Protect
Norfolk	1.727	1.727	0.876	0.876	Protect
Portsmouth	1.339	1.339	1.031	1.031	Protect
Southeast					
Long Bay, NC	0.803	2.617	0.254	0.846	No protect (30 yrs)/ protect (0 yrs)[d]
Charleston, SC[a]	3.562	4.025	1.969	2.061	–
Charleston City	0.157	0.157	0.022	0.036	Protect
Mt. Pleasant	2.607	2.647	1.367	1.445	Partial protect (30 yrs)/ protect (0 yrs)
Avondale	0	0	0	0	Zero inundation with 67-cm SLR
Dorchester	0.798	1.221	0.58	0.58	No protect
Sullivan's Island[b,c]	0	0	0	0	Zero inundation with 67-cm SLR
Sea Island, GA[b]	4.579	4.579	1.771	1.771	Protect
St. Augustine, GA[b]	1.548	2.216	0.874	1.314	No protect
Miami, FL[b]	10.386	10.386	4.085	4.085	Protect
Key West, FL[c]	3.212	3.212	1.733	1.733	Protect
Port Richey, FL[c]	1.747	1.747	1.055	1.055	Protect
Gulf coast					
Apalachicola, FL	0	0	0	0	Zero inundation with 67-cm SLR
St. Joseph, FL	0	0	0	0	Zero inundation through 180-cm SLR
Pass Christian, MS	0.954	0.954	0.637	0.637	Protect
Palacios, TX	0.074	0.271	0.02	0.074	No protect
Portland, TX	0	0	0	0	Zero inundation through 180-cm SLR
Green Island, TX	0	0	0	0	Zero inundation through 200-cm SLR

Table IIIb
(Continued)

Region/site name	67-cm SLR scenario (values expressed in $mil)				Strategy/notes
	3% discount rate		5% discount rate		
	30 yrs fore	0 yrs fore	30 yrs fore	0 yrs fore	
Main Pass, LA	0	0	0	0	Zero inundation through 200-cm SLR
Barataria, LA	8.744	9.532	5.469	6.347	No protect (30 yrs)/ protect (0 yrs)
Gran Chenier, LA	1.916	5.117	0.902	2.304	No protect
West					
Albion, CA	0	0	0	0	Zero indundation through 200-cm SLR
Point Sal, Ca	0	0	0	0	Zero inundation through 200-cm SLR
San Quentin, CA	2.056	2.056	1.012	1.012	Protect
Yaquina, OR	0.602	0.602	0.268	0.268	Protect
Anacortes, WA	1.412	1.484	0.662	0.704	Protect
Tacoma, WA	2.274	2.274	1.21	1.21	Protect
National estimates (in $mil)	$2,730	$2,965	$1,339	$1,454	
Regional estimates (in $mil)					
Northeast	$1,297	$1,297	$623	$623	
Southeast	$844	$940	$384	$420	
Gulf coast	$382	$519	$230	$306	
West coast	$207	$210	$103	$104	

National and regional estimates are calculated by applying a weight of 32.667 (980/30) to each site.
All values assume a rate of 4% was used for variable costs of protection, unless otherwise specified.
[a] Values are taken as a sum of all subsites analyzed at that site.
[b] A site involving a beach nourishment strategy.
[c] A site using 10% variable protection cost instead of 4%.
[d] Using a 1% variable protection cost induced a protect strategy.

plification for any rugged coastline that could easily produce overestimates of the area of land that is actually threatened. While that may be an open question, careful review of Table IV shows no discernable patterns of inundation or protection decisions. Concern over that assumption notwithstanding, the Fankhauser methodology is widely applicable and offers (in Table (a) of Appendix 3 in Fankhauser (1994a)) $62.59 billion (1990$) as an estimate of cumulative protection cost (total cost with zero percent utility discounting and an effective discount rate equal to the rate of growth of percapita GDP – approximately 1.6% averaged through the year 2100) for the United States along a 100-cm trajectory. The corresponding annuitized cost of protection alone (using the average 1.6% discount rate) is something close to one billion dollars.

Table IIIc
National and regional estimates for coastal protection strategy costs

Region/site name	33-cm SLR scenario (values expressed in $mil)				Strategy/notes
	3% discount rate		5% discount rate		
	30 yrs fore	0 yrs fore	30 yrs fore	0 yrs fore	
Northeast					
Rockland, ME	0.087	0.087	0.049	0.049	Protect
Westpoint, MA	0.209	0.209	0.094	0.094	Protect
Watch Hill, RI	0.618	0.618	0.315	0.315	Protect
Bridgeport, CT	0.252	0.252	0.133	0.133	Protect
Long Beach Island, NJ[b]	8.945	8.945	3.531	3.531	Protect
Easton, MD	0.278	0.278	0.101	0.101	Protect
Bloxom, VA	0	0	0	0	Zero inundation through 200-cm SLR
Newport News, VA[a]	2.162	2.162	1.362	1.362	–
Suffolk	0	0	0	0	Zero inundation with 33-cm SLR
Hampton	1.591	1.591	0.991	0.991	Protect
Norfolk	0.25	0.25	0.116	0.116	Protect
Portsmouth	0.321	0.321	0.255	0.255	Protect
Southeast					
Long Bay, NC	0.244	0.244	0.06	0.06	Protect
Charleston, SC[a]	1.003	1.118	0.621	0.671	–
Charleston City	0	0	0	0	–
Mt. Pleasant	0.407	0.407	0.199	0.199	Protect
Avondale	0	0	0	0	Zero inundation with 33-cm SLR
Dorchester	0.596	0.711	0.422	0.472	No protect
Sullivan's Island[b,c]	0	0	0	0	Zero inundation with 33-cm SLR
Sea Island, GA[b]	2.171	2.171	0.855	0.855	Protect
St. Augustine, GA[b]	0.649	1.417	0.342	0.772	No protect
Miami, FL[b]	5.238	5.238	2.093	2.093	Protect
Key West, FL[c]	0.543	0.543	0.314	0.314	Protect
Port Richey, FL[c]	0.322	0.322	0.162	0.162	Protect
Gulf coast					
Apalachicola, FL	0	0	0	0	Zero inundation with 33-cm SLR
St. Joseph, FL	0	0	0	0	Zero inundation through 180-cm SLR
Pass Christian, MS	0.177	0.177	0.098	0.098	Protect
Palacios, TX	0.024	0.024	0.004	0.004	Protect
Portland, TX	0	0	0	0	Zero inundation through 180-cm SLR
Green Island, TX	0	0	0	0	Zero inundation through 200-cm SLR
Main Pass, LA	0	0	0	0	Zero inundation through 200-cm SLR

Table IIIc
(Continued)

Region/site name	67-cm SLR scenario (values expressed in $mil)				Strategy/notes
	3% discount rate		5% discount rate		
	30 yrs fore	0 yrs fore	30 yrs fore	0 yrs fore	
Barataria, LA	1.761	1.761	0.981	0.981	Protect
Gran Chenier, LA	0.558	0.558	0.228	0.228	Protect
West					
Albion, CA	0	0	0	0	Zero indundation through 200-cm SLR
Point Sal, Ca	0	0	0	0	Zero inundation through 200-cm SLR
San Quentin, CA	0.275	0.275	0.125	0.125	Protect
Yaquina, OR	0.079	0.079	0.029	0.029	Protect
Anacortes, WA	0.224	0.224	0.087	0.087	Protect
Tacoma, WA	0.388	0.388	0.181	0.181	Protect
National estimates (in $mil)	$856	$885	$384	$400	
Regional estimates (in $mil)					
Northeast	$410	$410	$182	$182	
Southeast	$332	$361	$145	$161	
Gulf coast	$82	$82	$43	$43	
West coast	$32	$32	$14	$14	

National and regional estimates are calculated by applying a weight of 32.667 (980/30) to each site. All values assume a rate of 4% was used for variable costs of protection, unless otherwise specified.
[a] Values are taken as a sum of all subsites analyzed at that site.
[b] A site involving a beach nourishment strategy.
[c] A site using 10% variable protection cost instead of 4%.
[d] Using a 1% variable protection cost induced a protect strategy.

These estimates are higher than the ones presented here for a number of reasons. First of all, his work suggests (in Tables (c) and (d) of Appendix 2 in 1994a) that 99% of U.S. cities and 98% of U.S. harbors would be protected. These values are considerably higher than the proportions recorded for developed property in Column (5) of Table IV; and they are driven by relatively high property values. Even with no foresight, 70% is the highest proportion protected along a 1-meter scenario – a proportion that may itself be exaggerated because the method applied here makes protection decisions not on a city-by-city basis, but on a cell-by-cell basis. Moreover, Fankhauser employs unit cost estimates that are enormous; his $9250 per linear foot for harbors and cities (Table (d) of Appendix 1) is a full 12 times the $750 per foot baseline used here and more than twice the $4000 per foot extreme explored briefly.

These significant differences notwithstanding, it is important to recognize that variance in the frequency and cost of protection do not explain completely why the aggregate estimates differ so widely. The statistics recorded in Table IV include not

Table IV
Economic cost – damage plus protection (millions of 1990$)[a]

Scenario	(1) Discount rate	(2) Present value	(3) Annuitized annual cost	(4) Transient cost (2065)	(5) Percent protected
100 cm (perfect)	3%	$5426	$163	$331	55%
100 cm (none)	3%	$6352	$191	$381	70%
100 cm (perfect)	5%	$2569	$128	$331	55%
100 cm (none)	5%	$2931	$147	$381	70%
67 cm (perfect)	3%	$2730	$82	$166	72%
67 cm (none)	3%	$2965	$89	$193	83%
67 cm (perfect)	5%	$1339	$67	$166	72%
67 cm (none)	5%	$1454	$73	$193	83%
33 cm (perfect)	3%	$856	$26	$55	93%
33 cm (none)	3%	$885	$27	$55	93%
33 cm (perfect)	5%	$384	$19	$55	93%
33 cm (none)	5%	$400	$20	$55	93%

[a] Annuitized costs are annual costs that produce the same discounted value as the cumulative calculation. Transient costs are NOT discounted. They represent the sum of actual protection cost expenditures in 2065 and the value of developed property expected to be abandoned in 2065; but they ARE dominated in 1990 dollars.

only the expense involved in protection when they are warranted, but also the value of abandoned property when it is abandoned. Of the $331 million in transient cost recorded for 2065 under the assumption of perfect foresight in Table IV, in fact, only $199 million reflect protection expenditure. The appropriate 'apples-to-apples' comparison shows that the transient estimate reaches only 15% of comparable $1.2 billion quoted by Cline and 20% of Fankhauser's more recent calculations.

The news is even more striking along the more likely 33-cm scenario. Annuitized estimates of average cost of protection and abandonment run from $19 to $26 million per year, and transient costs for 2065 both round off to $55 million. The 67-cm scenario paints an intermediate case, of course, with transient costs reaching $193 million. With the best guess sea-level trajectory somewhere in between these two cases, it would therefore seem that present estimates are at least one order of magnitude too high.

These results hinge on protection cost, of course, so Table V records the results of some robustness explorations using the highest protection cost estimate available – $4000 per linear foot estimated for a project in San Francisco Bay by Gleick and Maurer (1990).[21] The summary statistics noted there bracket current sea-level rise expectations. They continue to reflect efficient protection decisions made on a cell-by-cell basis with and without foresight, but the fixed and variable costs of protection are now *5.33* times higher than the base case. Note that the percentage

Table V

Economic cost – maximum damage plus protection[a] (millions of 1990$; 3% discount rate)

Scenario	(1) Discount rate	(2) Present value	(3) Annuitized annual cost	(4) Transient cost (2065)	(5) Percent protected
33-cm trajectory					
Perfect; base	3%	$856	$26	$55	93%
None; base	3%	$885	$27	$55	93%
Perfect; ×5.33	3%	$1817	$54	$99	56%
None; ×5.33	3%	$2157	$65	$109	80%
67-cm trajectory					
Perfect; base	3%	$2730	$82	$166	72%
None; base	3%	$2965	$89	$193	83%
Perfect; ×5.33	3%	$4889	$147	$297	17%
None; ×5.33	3%	$7528	$225	$490	63%

[a] Maximum damages are calculated to construction costs equal to $4000 per linear foot; they therefore increase both fixed and va riable cost by a multiplicative factor of 5.33.

of sites that are protected falls dramatically in all cases, and that moving from foresight to no foresight makes a big difference. Both of these effects should have been expected. Note, too, that annuitized and transient cost estimates rise, but not by a factor of 5.33. The value of threatened land and, in the case of no foresight, structure now cap the cost estimates.

The largest value recorded in Table V is $490 million, the transient cost with no foresight along the 67-cm trajectory, but it corresponds to a sea-level trajectory that is well on the high side of current expectations. The data produced for Table V can, however, be used to suggest maximum cost estimates for a 50-cm trajectory – a trajectory that reflects the Wigley and Roper middle case without stabilization and the Titus median. A quadratic trajectory that reaches 50 cm by 2100 reaches 23 cm by roughly 2065 – a level reached along the 33-cm trajectory in 2080. As a direct result, that transient costs along the 33-cm trajectory amount to $72 million with and without foresight in 2080 (with the best guess protection cost) and $121 million and $139 million with and without foresight, respectively, in 2080 even with the 5.33 cost factor included. Actual costs could be lower than these values, if some property that might be protected along the slower path were abandoned along the more rapid path, but they could be no higher. A linear 50-cm trajectory would reach 34 cm around 2065 (the end of the 33-cm trajectory). Transient costs reflecting maximum protection costs could therefore be as high as $142 and $159 million with and without foresight, respectively; but the baseline guess is approximately $87 million.

Table VI
The potential cost of sea-level rise along the developed coastline of the United States (billions 1990$)

		Amortized	Cumulative	Transient (2065)
4.6 m				
Schneider and Chen (1980)	Vulnerability	n/a	347	n/a
7.6 m				
Schneider and Chen (1980)	Vulnerability	n/a	474	n/a
100 cm				
Yohe (1989)	Vulnerability	n/a	321	1.37
EPA (1989)	Protection	n/a	73–111	n/a
Nordhaus (1991)	Protection	4.9	n/a	n/a
Cline (1992)	Protection	1.2	240	n/a
Fankhauser (1994a)	Protection	1.0	62.6	n/a
Yohe (present)	Protection and	0.16	36.1	0.33
	abandonment	0.19	45.4	0.38
50 cm				
Yohe (1989)	Vulnerability	n/a	138	n/a
Cline (Smith 1995)	Protection	3.6	120	n/a
Fankhauser (1994b)	Protection	0.57	35.6	n/a
Yohe (present)	Protection and abandonment	0.06	20.4	0.07

All of the cumulative estimates but Fankhauser's are undiscounted; his are discounted effectively by the annual rate of growth of per capita GNP (expected to average approximately 1.6% for the US through 2100).

It should be noted that the most recent work published by Fankhauser (1994b) can be read to offer estimates along a 50-cm sea-level rise trajectory. It suggests $35.6 billion (1990$) in cumulative protection cost for the United States, again with utility discounted a 0%. This corresponds to an annuitized annual value on the order of $0.57 billion. Smith (1995) meanwhile has reworked Cline's estimate to correspond to a 50-cm scenario. For a 3% discount rate, his base cost estimate for protection costs alone converts at 3% to an annual cost of $3.6 billion.

4. Concluding Remarks

The results reported here, carefully cast in the appropriate context of protection decisions for developed property, can offer considerable insight into the potential cost to the United States of greenhouse induced sea level rise. Table VI records the various estimates cited above. Even casual review of estimates published prior to 1994 suggests that those estimates of the cost of protecting or abandoning developed properties in the face of rising seas are more than an order of magnitude higher than the ones offered here. Why? Because those estimates missed the cost-reducing potential of natural, market-based adaptation in anticipation of the threat of rising seas and/or the efficiency of discrete decisions to protect or not to protect small tracts of property that will be made when necessary and on the (then current) basis of their individual economic merit. Fankhauser has, to be sure, worked to incorporate these effects, but his 1994 estimates are still an order of magnitude higher than the ones offered here. This difference is not methodological, though; it finds its sources in the fact that his protection costs are higher and that his more macro decisions methodology nonetheless finds it efficient to protect more developed land.[22]

Finally, much of the work on the cost of greenhouse induced sea-level rise has been criticized by workshop participants and by referees for stopping at the year 2100 when all of the underlying natural science shows that seas will continue to rise even if concentration limits were imposed by the middle of the next century. Indeed, that is the message of Table I; and it could easily be a significant message along the quadratic trajectories described here. Moving from a 100-cm to a 50-cm scenario offers a transient cost 'tail', though, that can be used to suggest protection and/or abandonment costs through, say, 2145 along a quadratic 50-cm path. Without foresight, for example, approximately $25 billion (1990$) in cost would be distributed beyond 2100. Applying a 3% discount rate to this highest cost case, moving 45 years past 2100 would add approximately $490 million to the present value of costs – an increase of something like 33%. This could be significant, but even this total falls 50% short of the $6.3 billion present value associated with the 100-cm scenario through only 2100.

Notes

1. See J. S. Hoffman, D. Keys and J. G. Titus (1983) as well as IPCC (1992).
2. The baseline case reported by Yohe to Energy Modeling Forum –14 peaks around 770 ppm just past 2200. Two of the six IPCC emissions scenarios (IS92c and IS92d) achieve stabilization around 750 ppm. Concentrations that peak around 750 ppm generally reach 625 ppm by 2100; uncertainty analysis reported in Nordhaus (1994) puts the cumulative probability that concentrations in 2100 fall short of 625 ppm around 40%.
3. While 'mainstream' estimates of greenhouse induced sea-level rise are now relatively small, it should be noted that some concern has been raised recently about Antarctic warming and the collapse of the East Antarctic Ice Sheet. Collapse of that sort is, in late 1995, generally rated as

a 'high consequence – low likelihood' event; but impressions may have changed between 1995 and now – when you are reading this.

4. The U.S. EPA estimates were based, in part, on estimates of U.S. vulnerability produced for the EPA from a 30 site sample and reported in Yohe (1990).
5. There is a perception that these early estimates of cost were dominated by drylands and wetlands loss. As indicated by the Nordhaus (1991) calculus in which a full two-thirds of the cost attributed to sea-level rise in the United States were protection costs, this perception is false. It was only later, see e.g., Cline (1992), that the relative contribution of protection cost expanded.
6. These estimates are from Titus and Green (1989). Subsequent work by Titus *et al.* (1991) assumed that all property with a population above an arbitrary threshold would be protected and put protection costs for one meter at between $143 and $305 billion.
7. This is precisely the decision rule followed in the United States by, for example, the Army Corps of Engineers when it evaluates a shore-protection project. Other rules may, in fact, be more applicable in other countries or regions.
8. See Abraham and Hendershott (1993). Their full sample results showed a constant of −0.006 with population and income elasticities of 0.313 and 0.565, respectively, and a lagged price inertia coefficient of 0.402.
9. See Yohe (1989) or Yohe, Neumann and Amaden (1995) for a complete description of the methodology employed here. The exception to this procedure occurs when rising seas threaten a barrier island where the property-value gradient encroaches from two sides. It is still possible to use the value of interior land to reflect costs, but care must be taken to note when interior values begin to reflect the higher values which define both gradients from the inside out.
10. Brookshire, Thayer, Tschirart and Schulze (1985) examined the validity of the expected utility hypothesis as a model of homeowner behavior in the face of low probability-high severity risk – earthquakes in this case. They found evidence to support the hypothesis in peoples' response to expert and legal descriptions of risk even when the same people did not respond privately by purchasing disaster insurance. The Brookshire work reinforced similar conclusions offered by MacDonald, Murdoch and White (1987) after an analysis of homeowner behavior in the face of the treat of flooding. All of this work offers evidence to suggest that market values should accurately process information provided by experts on low probability natural hazards. The assumption made here extends that conclusion and argues that property prices should, over the very long term in the face of gradual manifestations of global warming, internalize the threat of rising seas given some validating informational authority (provided perhaps an informally as some loosely documented history of sea level rise).
11. See Samuelson (1964) or Stiglitz (1986) for descriptions and derivation of true economic depreciation TED – the rate at which the present value of an economic asset declines over time as it moves toward obsolescence.
12. True economic depreciation takes a mirror-image trajectory over time when compared with the more familiar concept of accelerated depreciation. The actual trajectory depends upon the discount rate, but ten (twenty) years of depreciation against a 30-year-time horizon would, for all positive rates, mean that more than 67% (33%) of the true economic value of the structure would remain.
13. See Weggel *et al.* (1989), Sorenson *et al.* (1984), Gleick and Maurer (1990), URS Consultants (1991), San Francisco BCDC (1988), Leatherman (1989), and Nicholls and Leatherman (1994).
14. See Gleick and Maurer (1990) and Nicholls and Leatherman (1994) for descriptions of why maintenance costs can be represented as a proportion of original construction cost.
15. Private communication with Stephen Leatherman, a coastal geologist from the University of Maryland, Robert Hallermeier, a coastal engineer at Dewberry and Davis, Inc., and Dennis Dare, city manager and coastal engineer for Ocean City, MD, provided estimates of the annual quantities required along the beaches captured by the sample. Their input corroborated estimates published by Leatherman (1989). Supply curves were drawn from the Titus and Green (1989) application of the Leatherman (1989) cost function; unit costs across the various locations climbed from lows that seldom fell below $4 per cubic yard for nearby sand up to $10 to $15.25 per cubic yard for sand that would have to be transported more than 5 miles.

16. The mapping technology was created for the 1989 EPA Report by Richard Park, then at Holcomb Research Institute. Results are reported in Park *et al.* (1989). The technology allows 50, 100, 150, 200 and 300-cm scenarios to be applied to each of 98 sites chosen systematically from the 980 USGS half-minute cites around the United States that have some coastline. The work reported here interpolates from these scenarios to get data for the 33-cm and 67-cm trajectories.
17. The sea level trajectories employed here are quadratic. They supported the original EPA work for the United States. The IPCC draws linear trajectories, of course, but robustness tests suggest that the differences are not enormous and quite predictable. Losses are larger early along linear trajectories, but the value of foresight is diminished later because seas are rising less rapidly.
18. These data are described in Yohe (1990).
19. The underlying data and spreadsheet-based methodology (Quattro-Pro) are available from the authors, and may now be available on-line through CIESIN.
20. Aggregate statistics were produced as they were in the original analysis – up by simple multiplication to achieve the national scale from the 30-site sample. Figure 1 shows five trajectories: with and without foresight along 100-cm and 67-cm trajectories, and without foresight along the 33-cm scenario. The foresight version along 33-cm is, at the scale of Figure 1, indistinguishable from the no foresight case.
21. The Gleick and Maurer (1990) estimate is for new bulkheads and sea walls and lies at the high end of their \$750–\$4000 per foot range. This robustness exercise applies this maximum value everywhere.
22. To see that these two effects carry enough weight to explain the difference, note that something like 70% of the cost estimated here can be attributed to protection. That means that the ratio between the annuitized protection cost estimates published by Fankhauser (1994b) and those recorded here for a 50-cm trajectory is $(0.57/0.7 \times 0.061) = 12.45$. Fankhauser's protection costs are (\$9250/\$750) times higher than the baseline gleaned here from published work, and the ratio of protected property is (93%/88%). Multiplying these two factors, alone, produces the expectation that the Fankhauser estimate should be $(925/75)\ (93/88) = 13.03$ times higher. The difference is certainly 'within the noise'.

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