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Costs of Defending Against Rising Sea Levels and Flooding in Mid-Atlantic Metropolitan Coastal Areas: The Basic Issues

Nae man can tether time or tide. Robert Burns in "Tam o'Shanter," 1791

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Abstract. Rising ocean levels have resulted in increasingly severe flooding in numerous metropolitan coastal areas. What would it cost to minimize or eliminate such damage? Relatively little economic work has been done to provide an answer, at least partially because some authorities believe attempts to deal with flooding ultimately are futile. Further, discussions of funding always involve massive welfare transfers from the non-flooded to the flooded. The cost of erecting a single mile of new sea wall exceeds $35 million in 2009 dollars and annual maintenance costs range between 5 and 10 percent.

1. Introduction

If many Americans were not aware of the financial damage that could be imposed upon coastal metropolitan areas by flooding, then they learned some of the brutal facts after Hurricane Katrina hit the Gulf Coast in late August 2005. In the New Orleans metropolitan area, this hurricane was responsible for an estimated $500 billion in property damage (Robinson, 2009). An additional $1.5 billion in costs were incurred between 2005 and 2009 because the hurricane throttled regional economic activity. To wit, in 2004, the metropolitan area's real rate of economic growth was 8.9 percent; however, that rate declined to 3.3 percent in 2005 and plunged to -2.5 percent in 2006 (BEA, 2009; BLS, 2009a).

Hurricanes come and go along America's east and Gulf coasts, but when a really major storm such as Katrina appears, economic damage is almost inevitable. Recently, three other long-term influences have aggravated this circumstance. First, at least for the past century, ocean levels have been rising. Second, in many coastal locations such as Hampton Roads, Virginia (which I frequently will use as an example), the land is slowly sinking. Third, many more individuals now live in coastal areas than was true even 50 years ago. The combination of these three factors has accentuated flooding when hurricanes and nor'easter storms strike coastal communities and hence has increased financial damages.

From Philadelphia in the north to Miami in the south and stretching to Galveston in the west, at least a dozen major mid-Atlantic and Gulf Coast metropolitan areas face gradually increasing exposure to flooding. It is not puffery to observe that rising ocean levels and increased coastal flooding, and the costs of defending against such, unexpectedly may turn out to be the public policy issue of the 21st century for many mid-Atlantic and Gulf Coast metropolitan regions. Even the BP oil spill likely will have less of an economic impact than continually rising ocean levels and concomitant flooding.

In such a world, economists almost reflexively are conditioned to ask, "What would it cost to minimize or eliminate such damage?" This paper provides some "rule of thumb" answers to these questions.

Ultimately, of course, the economic approach to such a problem devolves into a benefit-cost analysis. Hence, what matters economically speaking is the present value of financial damage that would be incurred in absence of any preventive actions versus the present value of the cost of those preventive actions.

However, while there is prolific modeling and real time evidence available concerning both past and projected costs of water flooding (see Bosello, Roson and Tol, 2007, for a capable summary), much less has been written about the costs attached to mitigating or dramatically decreasing the flooding episodes. The old adage that an ounce of prevention is better than a pound of cure does not seem to have applied to the costs of rising water.

2. Setting the stage: the nature of the problem

Sea levels have been rising gradually along the Atlantic coast for a thousand years or more. For example, the overall rate of sea level rise in the Chesapeake Bay over the past thousand years has been about 0.56 mm/year (Kearney, 1996). This may not appear to be an impressively large number, but over a thousand years, it translates to a 566 mm rise in sea levels, 1.858 feet (22.3 inches). The weight of scientific evidence is that sea levels have risen more rapidly in recent years. Table 1 summarizes the predictions of the Chesapeake Bay Program's Scientific and Technical Advisory Committee. Since the 1920s, sea levels have risen from an average of 2.27 mm/year at Key West to 4.46 mm/year at Hampton Roads, Virginia.

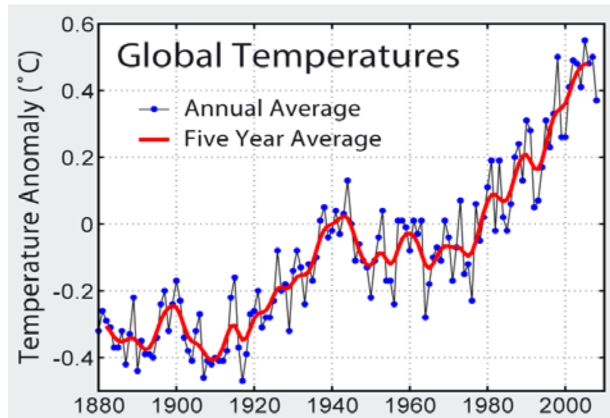
Table 1. Potential for shoreline changes due to sea-level rise along the U.S. Mid-Atlantic region.

Rates of Relative Sea-Level Rise for Selected Long-term Tide Gauges		
Station	**Rate of Sea Level Rise (mm/yr)**	**Time Span of Record**
Atlantic City, NJ	3.98 ±0.11	1922-1999
Philadelphia, PA	2.75 ±0.12	1900-1999
Lews, DE	3.16 ±0.16	1919-1999
Annapolis, MD	3.53 ±0.13	1928-1999
Solomons Island, MD	3.29 ±0.17	1937-1999
Washington, DC	3.13 ±0.12	1931-1999
Hampton Roads	**4.42 ±0.16**	**1927-1999**
Wilmington, NC	2.22 ±0.25	1935-1999
Charleston, SC	3.28 ±0.14	1921-1999
Miami, FL	2.39 ±0.22	1931-1999
Key West, FL	2.27 ±0.09	1913-1999

Note: A quarter-inch is approximately 3.175mm.
Sources: Woods Hole Science Center and U.S. Geological Survey

Unless these trends change, when 2050 arrives, these data predict that sea levels will be 3.66 inches higher in Key West and 7.20 inches higher in Hampton Roads. By 2100, sea levels will have risen 8.14 inches in Key West and 15.99 inches in Hampton Roads. The potential for large scale flooding is obvious, especially in periods of high tides.

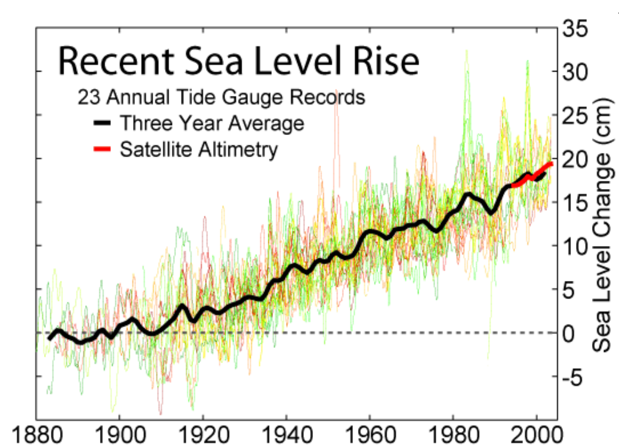
Why will sea levels rise? The direct answer is, gradual global warming. Reputable scientists can differ about precisely why global warming has been occurring, but it is indisputable that it has occurred over the past century.[1] Figure 1 illustrates these trends.



Source: Wandel (2007)

Figure 1. Rising global temperatures.

Gradually rising global temperatures, in turn, have two immediate impacts upon oceans. First, rising temperatures melt the polar ice caps. Second, warmer water occupies more space. The result is rising sea levels. Figure 2 illustrates this effect at 23 geologically stable sea level measuring points around the globe since 1880.



Source: NASA (2008)

Figure 2. Recent sea level rise.

[1] It is worth noting, however, that there is some evidence that global cooling has been occurring more recently. Whether or not this trend will continue is one of several trillion dollar questions.

This phenomenon has particular relevance to Hampton Roads because anticipated sea level rises there are higher than for any other large Atlantic Coast metropolitan area (Table 1). Scientists from three federal agencies working for the U.S. Climate Change Science Program say that if this century's sea levels imitate those of the last century, then sea levels in Hampton Roads will rise between 16.77 and 18.03 inches by 2100 (EPA, 2009). There is yet another fly in the ointment for Hampton Roads (and several other metropolitan regions). Land in that metropolitan area gradually is sinking at a rate between 0.15 and 0.23 meters (5 and 7.5 inches) per century. This is occurring because of the "isostatic rebound" of the crust of the earth from the weight of long absent glaciers, groundwater removal, and slippage of the coast into the crater we now know as the Chesapeake Bay. The bottom line is that this "sinking land effect" must be added to the projected sea level rises we have just noted in order to determine the total tidal increase that we will observe in Hampton Roads and any other similarly impacted mid-Atlantic Coast metropolitan areas.

Because approximately 30 million people (about ten percent of the U.S. population) live in the mid-Atlantic Coast region on land less than one meter above monthly highest tides, the rising sea levels portrayed in Figure 2 combined with sinking land have serious economic implications. In Hampton Roads, for example, whether one accepts a lower bound estimate of a 20-inch problem in 2100, or a higher bound estimate of a 68-inch problem, it is difficult to avoid the conclusion that in the absence of preventive measures (dikes, levees, locks, breakwaters, etc.), a significant portion of that metropolitan area will be under water 100 years from now. Indeed, as Figure 3 illustrates, approximately one-half of that region already is in danger of being covered by water when a commonplace large storm strikes the area. A category four hurricane would result in water surges that would inundate areas as far as 20 miles away from the Atlantic Ocean. The Organization for Economic Cooperation and Development (OECD) asserts that Hampton Roads is the 10th largest coastal metropolitan area in the world in terms of total assets exposed to increasing flooding from rising sea levels (Koch, 2009).

Suffice it to observe, then, that in this century water inundation will not be an exotic problem confined to below sea level locations such as the Netherlands. The Netherlands, however, does provide us with some excellent examples how rising sea levels and storm surges can be restrained, if one is willing to spend enough money.

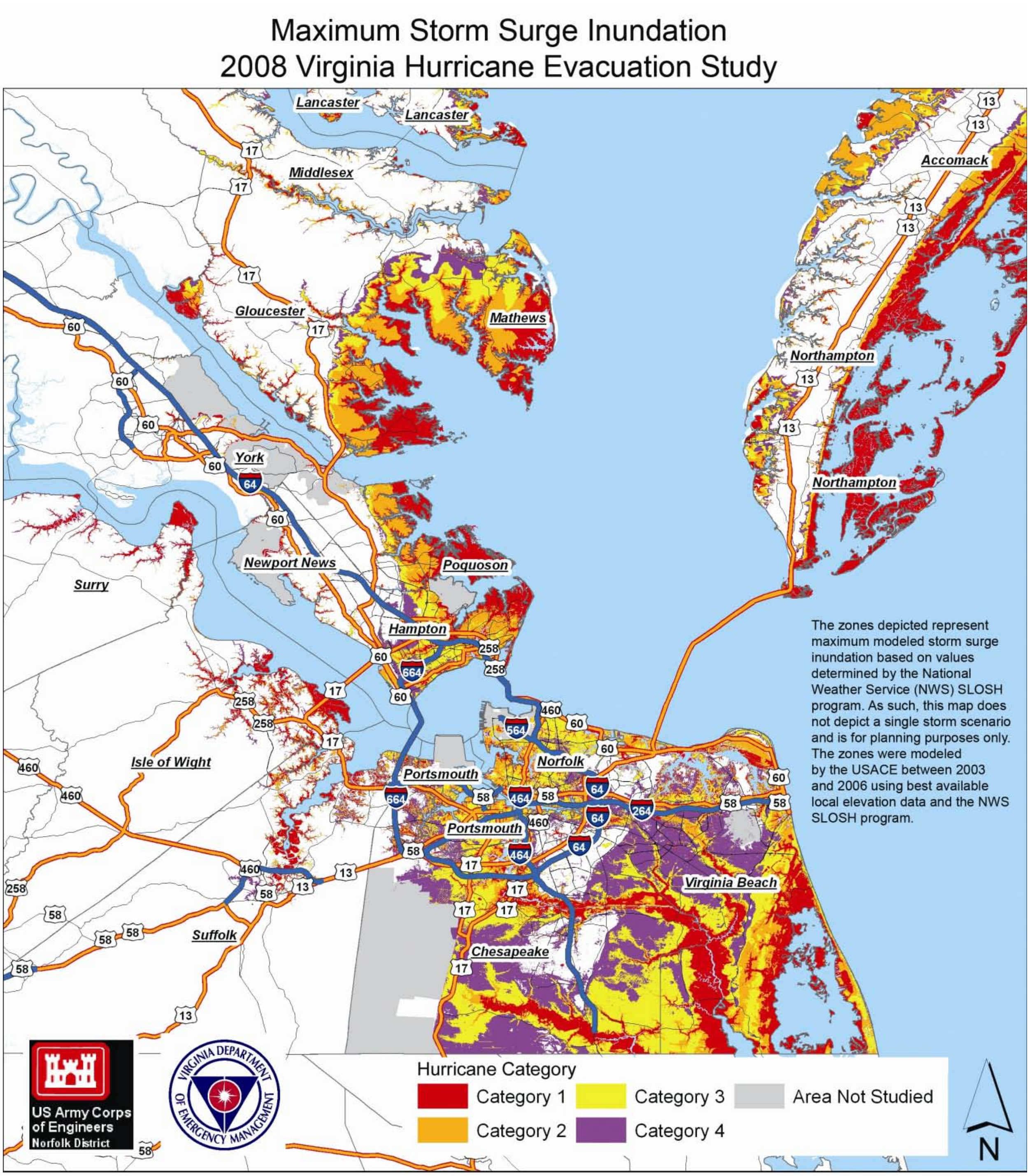
3. Means of defense: can we hold the sea back?

Let us take it as given that: (1) sea levels are slowly rising; (2) coastal land is sinking in many regions; (3) the combination of these two influences render many coastal areas in the mid-Atlantic area vulnerable to flooding from storm surges; (4) when flooding does occur due to storm surges, it often causes severe financial damage; and, (5) flooding damage consists primarily of damage to physical assets (real estate, property), plus diminished economic activity. What can be done to combat these circumstances and what will it cost?

Many reputable authorities have concluded that in the long-run, there is very little that human beings can do to deter the oceans. Bruun (1972) and Charlier (2003) are among those who imply that in the long-run, attempts to hold back the oceans are fools' errands. As Charlier put it, "...history has proven that only the sea will decide, if this metaphor is allowable, which town will drown – and scores of them have..." (p. 875). Pilkey (1998) has become well-known for arguing that the oceans ultimately will have their way. That is, barring stupendously large expenditures, the earth's oceans will overcome nearly any set of strategies, structures, and coastal defense strategies that men and women can devise.

Charlier (2003) reports that the ancient Egyptians built dikes in Alexandria prior to the birth of Christ, but that coastal protection activities actually go back 3,000 years. These attempts to discipline the oceans neatly divide into offshore devices designed to channel or repel water and onshore devices and programs designed to reduce water erosion and damage. Offshore devices often feature breakwaters composed of sundry materials ranging from rocks and timber to vehicle tires, but also can include groins, dikes and locks. Onshore devices and programs include dredging, dunes, dikes, beach replenishment, and beach protector mats. Beach replenishment (for example, with sand imported from another location) is a temporary palliative that sometimes can be reversed completely by a single storm.

Nevertheless, beach replenishment remains a popular remedy in tourist locations, not the least because affected metropolitan areas usually are able to extract major financial support for replenishment from the U.S. Government. Hence, virtually every Atlantic Coast beach area from New Jersey to Key West has received federal funding to help replenish their beaches. The State of New Jersey alone has received an estimated $450 million from the U.S. Government since 1985 to enable it to restore its beaches.



Sources: U.S. Army Corps of Engineers, Virginia Department of Emergency Management

Figure 3. Maximum storm surge inundation, Hampton Roads, Virginia

This constituted 65 percent of New Jersey's total expenditure on beach replenishment (Adubato, 2009).

The result is a massive welfare transfer from all taxpayers (including those in diverse locations such as Bemidji, Minnesota and Fort Worth, Texas) to the states, localities and individuals that receive these funds. Is this a good thing, economically speaking, for these receiving parties? Absolutely. A study of beach replenishment in Virginia Beach (Virginia's largest city) revealed not only that it was a winning financial proposition for that city to replenish its beaches with federal funds, but also that state sales and income tax receipts grew. Local hotels, motels and restaurants prospered and local property owners even up to ten miles away from the beach benefitted from increased property values (Koch, 2005). Indeed, a property value gradient exists in Virginia Beach whereby property values gradually decline the farther away one is from the Atlantic Ocean (ceteris paribus).

From a societal point of view, however, there is no free lunch to be eaten. If a massive majority of the benefits from beach replenishment go to the metropolitan areas and states where the beaches actually are located, then it is not clear why taxpayers from around the country should subsidize such a welfare transfer. Some weakly offer that other regions also benefit from their own preferred varieties of welfare transfers, for example, emergency funding to deal with river flooding, forest fire fighting, and tornado damage funding, and the like, and so it all comes out in the wash. Thus, they argue that the societal welfare transfers often balance out. A rigorous analysis of this assertion has not been performed, but on the face of it, the validity of such a notion is suspect.

The general suspicion that welfare transfers such as sand replenishment are questionable public policy applies to many (though not all) attempts to restrain the ocean and reduce flooding. Exceptions include those situations connected to national defense and those that generate significant external diseconomies because, for example, a busy port could be shut down by flooding and this adverse effect then would ripple through the economic structure of other regions.

There are other effects to be considered as well. McQuarrie and Pilkey (1998) catalog six adverse environmental and beach impacts associated with 20 different offshore devices and 22 different onshore devices and programs designed to restrain the ocean or redirect it. For example, "beach saver" offshore reefs cause erosion of down drift beaches, have negative effects on water quality, and endanger swimmers, while onshore wave busters tend to erode both down drift and fronting beaches and are hazardous to individuals.

Rising sea levels are not a new phenomenon. What is different now, opines Evans (2009) is that "humans have congregated along the shoreline without much awareness of how much or how soon the sands might shift."

If there were an award for successful national actions taken to defend against flooding, then clearly that recognition would go to the Netherlands, a country where 27 percent of the area and 60 percent of the population is below sea level (Wikipedia, 2009a). In 1953, the Dutch experienced severe flooding that resulted in 1,800 deaths and this led them to stimulate a rest of the century, $5 billion dollar program of flood protection and water diversion that is touted as reducing the probability of major flooding damage to less than 1 in 10,000 annually. Project Delta, as it is usually called, involves 10,250 miles of dikes, dams, storm surge barriers and moveable sluices (Watson and Finkl, 1990). It will suffice to say that nothing of this magnitude ever has reached credible public consideration in the United States, though the next few decades might change this circumstance. One reason for this could be the high costs associated with sea defense mechanisms (more about this below).

What might we anticipate in the United States? Table 2 reports daunting financial cost numbers that are based upon a 2009 study conducted by the California Climate Change Center, which has received funding for its work from the Lawrence Berkeley National Laboratory, the University of California, the National Center for Atmospheric Research and the California Air Resources Board. The Center reports that building a new levee already cost $1,500 per linear foot in 2000; if those costs increased at the same rate as the CPI-U, then they would have risen to $1,922 per linear foot by 2009. Similarly, 2009 average costs per linear foot are estimated to be $679 for raising a levee and a stratospheric $6,789 per linear foot for an entirely new seawall. On a per mile basis, these costs extrapolate to $10.1 million, $3.5 million and $35.8 million for new levees, raised levees, and new seawalls, respectively.

Table 2. Estimated costs of building defenses against rising sea levels.

	Cost Per Linear Foot, 2000	Cost Per Linear Foot, 2009	Cost Per Mile, 2009
New Levee	$1,500	$1,922	$10,145,520
Raise Levee	$530	$679	$3,584,750
New Seawall	$5,300	$6,789	$35,847,504

Source: Herberger et al. (2009)

The projected costs of defending a coast line against the sea outlined in Table 2 may seem high, but they are consistent with other rough estimates of the cost of erecting significant sea defenses. After Houston was ravaged in 2008 by Hurricane Ike (the third most destructive hurricane ever to hit the American coast), the Houston area began to consider erecting a 17-foot seawall at the entrance to Galveston Bay, accompanied by 1,000 foot floodgates. The estimated cost of this is $2-4 billion for the 60 miles involved (Casselman, 2009). If we adopt a midpoint estimate of $3 billion in overall costs for this massive project, then the expected cost is $50 million per mile.

Note that the costs outlined in Table 2 are for construction only and do not include costs of maintenance, which average five to ten percent per year (Herberger et al., 2009). Further, they do not include costs associated with environmental degradation that result when sea barriers are erected, for example, the loss of beaches and wetlands. Additional costs connected to the loss of ocean front recreational space must be weighed as well. In some studies, these additional considerations add approximately 25 percent to cost estimates. The unavoidable bottom line with respect to the costs of sea defense mechanisms is that they are expensive, much more expensive than in years past when ocean front areas were not so heavily populated and environmental considerations took a back seat. Prior to the economic recession of 2008-2009, the State of Louisiana had proposed to spend $14 billion on restoring coastal sea barriers along the Mississippi River Delta (Evans, 2009).

Are such public expenditures economically justifiable or not? Sea defense mechanisms (such as groins, levees and seawalls) clearly have public good properties because of the externalities they emit (positive and negative), significant indivisibilities, and the inability of those who pay for the sea defense mechanisms to exclude many bystanders from the benefits. However, sea defense mechanisms certainly are not pure public goods because they also can be purchased by individuals who are able to corral a healthy portion of the benefits (for example, benefits derived from sand replenishment or a groin).

In any case, those individuals and assets located near the ocean typically are affected far more by flooding and flood protection than those located inland. Consequently, when a vital question is asked – "Who benefits, who is damaged and hence who should pay?" – the air is thick with arguments concerning the identities of the beneficiaries and victims. Emotional treatises about taxation fairness also are certain to follow. With respect to these issues, the sand replenishment discussion reviewed earlier has continued relevance with respect to other sea defense mechanisms, though the financial stakes are larger for sea defenses than for sand replenishment.

Consider as an instructive example one contentious corner of sea defense discussions. If lives are saved (or lost) by sea defenses (or their absence), then how should we value a life on average? In 2008, economists in the Netherlands placed a € 2.2 million value on a human life in their deliberations about the benefits and costs of sea defenses. At December 2009 exchange rates, this equated to $3.25 million, an estimate that resides at the higher end of values adopted by the Victim Compensation Fund to pay the relatives of those killed in the September 11, 2001, terrorist attacks (*USA Today*, 2002). However distasteful the process of valuing lives may be to some, economists realize that virtually all economic processes at least implicitly place a value on life, and therefore it must be done in the case of sea defenses as well. To not do so is to generate a flawed analysis. The relevant question is "What is the value of a life?"

The ultimate conclusions about the virtue of sea defenses rise or fall on the basis of such assumptions about the values of lives, beaches, and wetlands. Because God is in the details of such assumptions, all involved would be well advised to cast skeptical eyes on any benefit-cost analysis of sea defenses, regardless of conclusions. Small changes in assumption are capable of generating huge changes in conclusions.

4. Approximating water defense costs: the case of Hampton Roads, Virginia

Hampton Roads, Virginia, is the nation's 35th largest metropolitan area and has a population of 1.7 million. It boasts approximately 30 miles of high quality ocean beach front and several cities such as Norfolk, Portsmouth, Hampton and Newport News whose urban cores directly face the ocean or its direct tributaries. Altogether, there are at least 100 miles of water front that already are being impacted by rising sea levels.

Consider Norfolk as an illustration. It is the financial, medical and cultural center of the region, but the downtown area which contains these assets faces the Elizabeth River, which flows into the Atlantic Ocean. This waterfront is about 7 miles. Norfolk also contains Navy Base Norfolk, the largest navy base in the world (water front about 10 miles) and the Lambert's Point Coal Pier, which is the largest coal import/export facility in the United States (water front 1 mile). Finally, there are two public universities enrolling about 30,000 students whose campuses have water frontage (about 2 miles).

Suppose the City of Norfolk decided to replicate the sea defense suggestions being bandied about for the Houston region. Then, if only these water front areas were protected, and the cost per mile ranges between $36 million to $50 million, this will cost the City of Norfolk between $720 million and $1.0 billion. This still would not relieve Norfolk from flooding that would come in from unprotected areas, but it would be a start.

The case of neighboring Virginia Beach is more complicated. Virginia Beach boasts a very long and attractive white sand beach, behind which stand numerous hotels, restaurants, and tourist attractions.

Suppose this city chooses to ignore rising sea levels. This means that its beaches progressively will be eaten away and the ocean gradually will creep toward the hotels and other attractions. Massive sand replenishment is capable of retarding beach erosion, but seldom deters it permanently. Alternatively, Virginia Beach could construct groins, levees and sea walls to defend it against rising ocean levels. However, this would destroy much of the city's attractiveness to tourists because its lovely white beaches would be defaced by sea walls and the like. If the sea defenses are constructed close to the ocean, experience elsewhere indicates that this actually may accelerate beach erosion, which would be economically destructive to Virginia Beach. In 2008, Virginia Beach hosted 2.47 million overnight visitors, who made $864 million in direct expenditures in the city and were directly and indirectly responsible for 13,600 jobs (Yochum and Agarwal, 2009). Clearly, it has vital interests in sustaining this economic activity. Were the city to opt for a less costly, though practical levee solution (costing about $10.1 million per mile according to Table 2), then this visually unattractive solution would involve approximately $303 million in costs if it builds levees along its entire 30 miles of prime beachfront.

Virginia Beach is caught on the horns of a dilemma. If it ignores rising sea levels, then in the space of a few decades, its beaches will be eaten away and major physical assets such as hotels and restaurants will be damaged or destroyed. On the other hand, if it directly addresses rising sea levels by means other than sand replenishment, then it likely will make its beaches less attractive and progressively damage itself economically speaking

By contrast, Norfolk's problems are more straightforward. While that city has some attractive beaches, its major assets are its downtown business and cultural core, its medical center and universities, its coal pier and the naval base. Further, it benefits from the fact that the U.S. Government could become a major financial contributor to a sea defense solution. The same cannot be said for Virginia Beach.

These examples might be labeled the "Tale of Two Cities" because they underline the extent to which all ocean frontage, even that which is urban, varies dramatically insofar as efficient sea defense solutions are concerned. While Norfolk and Virginia Beach adjoin each other, their problems and solutions differ dramatically.

5. Final observations

The doubts of some scientists and economists about the precise causes of global warming, a very recent trend toward global cooling, and the tendency of many economists to deflate future benefits and costs by applying high rates of discount have caused some policy makers to look past the future economic challenges posed by rising sea levels and (in some locations) sinking coastal land surfaces. Regardless of one's ideological or scientific position on issues relating to climate change and global warming, rising sea levels constitute a reality that cannot be dismissed. Sea levels have been rising and some coastal lands have been sinking. The result has been increased flooding, and if trends continue significant portions of coastal land in the United States will either be permanently submerged with water or periodically covered by storm surge water.

The focus of this paper has been to elucidate the nature of the challenge and to sketch approximate costs attached to defending coastal lands against flooding. These costs (in 2009 dollars) range from about $10 million to $50 million per mile if significant, credible sea defenses are initiated de novo. Maintenance costs average 5 to 10 percent of these amounts and environmental costs attached to such actions augment these costs as well. Almost needless to say, significant economic benefits are required for such expenditures to be economically viable. Ordinarily, this means that significant economic externalities are required if those outside affected coastal areas are to be expected to help pay for sea defenses.

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