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Design For Rising Sea Levels

by **Kristina Hill and Jonathan Barnett**

A waterfront site for a single family house in Easthampton, New York, recently sold for more than $100,000,000. Condo development rolls onward over the barrier beaches along Florida's eastern shore. The Pudong district rises from the marshes in Shanghai as towers are constructed on newly formed islands off the coasts of Dubai and Abu Dhabi. The possible effects of storm surges, on top of a global rise in sea level, don't seem to be influencing how investors, governments, and tenants are making decisions about all this.

In the book version of *An Inconvenient Truth*, Al Gore shows illustrations of various urban areas under water ("In Shanghai and the surrounding areas, more than 40 million people would be forced to move"), and big parts of choice coastal real estate, like all of Florida south of Orlando, disappearing into the sea. These are projections of what could happen if the polar ice caps melt and produce a twenty-foot sea-level rise. These scenarios are dramatic; they get our attention; they help people understand the issues. But we don't know how to relate such apocalyptic visions to current problems. We are used to thinking of the environment as something that changes very slowly, if at all, and are confident that modern engineering can solve just about any problem. The problem is, no matter what happens now in the world of politics, sea levels are going to rise faster in our lifetimes than they have since before the first cities were built. How fast and how much? Our conclusion is that this will be an extremely significant challenge that our coastal regions will have to confront over the next fifty years.

Sea levels have been rising for thousands of years, since the last ice age, but so slowly that in the past natural systems have adjusted incrementally. We now know that sea levels will rise faster because of warmer water temperatures and accelerated melting of ice sheets, but we don't know enough about the physical processes that affect major ice sheets to know exactly how global temperature increases will affect them. The temperature increases that have already occurred have committed us to a faster rate of sea-level rise no matter what we do at this point. But how much more should we expect in fifty years, or 100, or

150? Could sea level change drastically within our lifetimes?

The blunt answer is “Yes.” Scientists who have studied the last great melting period between glaciations say that sea levels rose between thirteen and nineteen feet when parts of Greenland and the West Antarctic Ice Sheet melted. It’s more likely we’ll face increases on the order of a foot or two by 2050, with accelerated increases after that. We don’t know how long the more drastic melting will take, what its extent will be, and what we could still do to slow it down or prevent it. There are probably internal mechanisms that cause collapse in the ice sheets, but the climate models being used don’t include these mechanisms, so they don’t predict sea-level rise completely.[1] Sea level will rise faster than it has in the past, but at this point only careful monitoring of the actual ice can tell us the rate of acceleration that is due to the ice sheets. As designers and planners, our problem is whether we should design and plan for a very small change, a moderate change, or a very big change. And by when? Strategy decisions are made more difficult because we generally deal with trends that can be treated as linear. This one is going to be exponential.

In the late 1980s, one of us, Kristina, recalls having a discussion with an ecologist about our apparent inability to comprehend change that occurs not in dramatic steps, nor at a steady linear rate, but rather exponentially, starting out with a low slope that steepens over time. The biggest changes seem to happen almost overnight, because late in the process the curve is so abrupt. People want to believe that the flat part of the curve in the early phase of change is really linear, not the start of an exponential curve. And when the big changes occur later on, we often treat them as “sudden” disasters when, in reality, they were quite predictable.

Kristina was explaining this problem of human comprehension to a friend while walking on a beach. The tide was coming in. As she got to the part about change seeming to happen suddenly, even though it has been gradual, they realized that they were now (suddenly) walking on an isolated sand bar and would have to wade to shore. No more needed to be said.

As far as we can tell, most designers and planners aren’t thinking seriously about climate change in the U.S. unless they work closely with the insurance industry, which is dropping tens of thousands of East Coast customers and raising rates on the rest, in part as a result of climate predictions.[2] Ecologists all over the world also know that it’s a very big deal. The World Bank knows. But building and landscape architects, engineers, and planners don’t seem to have connected the dots. Jonathan, the other author of this article, worked on the first reconstruction plan for New Orleans after Hurricanes Katrina and Rita and saw the devastation from a storm surge that could have been prevented if the flood walls had been properly constructed. He became frustrated with the many comments from people outside New Orleans that the city had simply been built in the wrong location and ought to be a write-off, and he began to wonder what would happen if we applied the same standard to other places. Biloxi and other Gulf Coast cities also suffered severe damage from Katrina and Rita. Key West had flooding comparable to that in New Orleans from Rita. If we looked around the country at other vulnerable cities, we’d have to write off many more than New Orleans.

Few people realize that even without climate change, New York City is at risk from a hurricane that could drive a storm surge more than twenty feet above mean sea level over lower Manhattan and other coastal areas of the City, flooding subway and vehicular tunnels and putting Kennedy and LaGuardia Airports under water. The “Long Island Express,” a Category 3 hurricane that passed to the east of New York City in 1938, produced a twelve-foot storm surge and fifteen- to twenty-foot-high waves, striking the coast with a fast-moving wall of water about thirty feet high and resulting in 700 deaths and the destruction of 4500 homes along the coast.[3] Downtown Providence, Rhode Island, was under fifteen feet of water from that same storm. Galveston was destroyed by a hurricane in 1900. Other coastal cities like Charleston, Miami Beach, Miami, Baltimore, and Boston are also at risk from storm surges today, even without changes in sea level. Chronically under-maintained infrastructure across most of America, along with our very human ability to disbelieve what we have not personally experienced, leaves many cities vulnerable to life-threatening floods and extensive property losses. As the length of time between such disastrous storms increases, the number of vulnerable infrastructure elements, properties and people increases. If several cities suffered disasters on the scale of New Orleans within a few years of each other, there could be devastating national economic effects.

The Netherlands, where much of the land is below sea level, has been facing storm surge problems for centuries and is a leader in protection techniques. London and the Thames Estuary are other locations where substantial storm surge protection is already in place. Bangladesh, where much of the land is close to sea level, is unprotected from storm surge, and its problems become more serious as sea levels rise. Any inhabited delta, like New Orleans, is going to have to make major adjustments to deal with climate change; examples include, the Pudong skyscraper district of Shanghai, the Mekong Delta, the northern coast of Egypt. Low-lying island cities like Venice or Key West are also at high risk.

Other aspects of climate change add to the concerns about rising sea levels. Will there be more Katrinas in the Gulf than there have been in the past? More Hurricane Isabels and Floyds on the East Coast? That’s difficult to answer, because according to one recent modeling effort, sea surface temperatures and vertical wind shear could increase simultaneously; historically, increased vertical wind shear has been associated with diminished hurricane activity and intensity.[4] On the other hand, that model is so new that we might well want to wait and see if it is validated by others before accepting its results. Will the area designated as a 100-year floodplain become a ten-year floodplain in Boston[5] and in other cities where increased precipitation and a rising sea level are predicted? This outcome seems very likely, according to peer-reviewed studies cited in the Intergovernmental Panel on Climate Change's (IPCC) latest predictions for North America.[6] Will the Arabian Gulf get more Category 5 tropical cyclones, like the unprecedented one that occurred this past June, flooding homes and sucking SUVs into flash floods in the capital city of Oman? Is Dubai ready for cyclones that would flood its new palm-shaped artificial coastline of luxury homes? Although we don't know what will happen to the number and intensity of cyclones, we do know that in Dubai, the equivalent of billions of US dollars have been spent to put vulnerable housing on shallow spits of land where a hurricane of any size would cause substantial damage, and quick evacuation of residents would be very difficult.[7]

It is time to consider the effects of sea-level rise systematically and rigorously, and plan for what needs to be done about it. The IPCC Report released in February 2007 concludes that while sea levels have been rising at the rate of 1.8 millimeters per year from 1961 to 2003, from 1993 to 2003 the rate of sea-level rise was 3.1 millimeters per year. This report is edited by governments as well as scientists and went through paroxysms of edits before it was released, resulting in a conservative estimate of future risks. It is possible that the changes that have been observed are just normal fluctuations, but most scientists now believe they are evidence of a new trend. What is the trend?

If the rate of change during the last ten years is projected forward as a straight line, it would result in only about a one-foot increase in sea level by 2100. Most people think we are seeing the base of an exponential curve, but there is still disagreement about the slope of the curve. As we noted earlier, some sea-level rise can be attributed to thermal expansion and some to melting glaciers and ice caps. Thermal expansion of the oceans depends on the predicted range of global temperature rise; the rate at which ice caps and glaciers are melting depends on interrelated variables that, in addition to ranges of potential air and water temperature change, include reduced reflectivity of the ice cap as it melts, which could cause melting to accelerate since the melted caps absorb more heat. Further complications: Some portions of the world's continents are subsiding and some are rising, and the point where oceans meet land fluctuates with daily and seasonal tides, making sea-level trends difficult to observe locally without consistent satellite data.

A mid-range prediction seems to be a worldwide average increase in sea level of about a foot by 2050 and three feet — almost a meter — by 2100. The Director of the Goddard Space Science Institute, James Hansen, has said recently that given observable trends in the melting of the ice sheets, "I just can't imagine that you could keep sea-level rise under a meter" by the end of this century.[8] Locally, that average could translate into bigger numbers or smaller numbers, depending on whether a section of coast is submerging or emerging, geologically speaking.[9] In Boston, for example, according to the *Boston Globe*, continental subsidence will add about six inches to sea-level rise this century.[10] Other influential global entities are moving ahead to make their own estimates of local risks. If you turn to a February 2007 World Bank report, *Impact of Sea Level Rise on Developing Countries*,[11] a one-meter rise by the end of the century is at the low end of their estimate. The Bank is estimating the upper end of the range by the end of the century as three meters in the countries they studied, and possibly as high as five meters if there is an "unexpectedly rapid break-up of the Greenland and West Antarctic ice sheets." Whether the global average ends up at one foot or sixteen feet by 2100, clearly some highly populated cities are in serious trouble, not just from rising seas but from the more severe effects of storm surges. Equally sobering is the fact that whatever the change is by 2050 or 2100, sea levels will continue to rise further for hundreds of years as the planet continues to warm, even if the rate of warming slows.

WHAT ARE THE CONSEQUENCES OF SEA-LEVEL RISE?

Whether or not climate change accelerates sea-level rise, our shorelines are having a quiet ecological crisis best known to people who fish. The near-shore aquatic environment is the nursery for many of species that are the mainstay of regional and global fishing economies. The U.S. fishing industry alone contributed more than $28 billion to the gross national product in 2001, and coastal habitats are critical to its future. But coastal marshes have been disappearing at a rate of 20,000 acres per year.[12] Over the last 100 years, Puget Sound in the Pacific Northwest has lost 73% of its original salt marshes; on the other side of the continent, Chesapeake Bay had already lost 90% of its submerged sea-grass meadows by 1990.[13] In the few estuaries, salt marshes, and sea-grass beds left, continuing urban development; nutrient runoff from parking lots, roofs, lawns, and farms; and transportation impacts are major threats. At our current growth rates, the coasts of North America are urbanizing so quickly that we can expect 25% of all coastal lands to be developed by 2025 — and to continue to develop beyond that level.[14] To a great extent, the fate of the near-shore environment determines the health of our oceans and the future of one of our most important food sources. Even as this complex world of birds, fish, crabs, and countless other life forms is squeezed and polluted from the land, it will be flooded from the sea. More water may not sound like a bad thing for fish, but even a six-inch increase in sea level could turn many of today's remaining shallow-water marshes into open water or sandy beaches, backed up against buildings, roads, and parking lots that used to be further inland. If that happens, we'll lose shrimp, crabs, salmon, and dozens of other economically important species, not to mention those that don't have a price tag at the grocery store.

If you're thinking we could just do without shrimp, consider the water we drink. The fate of the underground aquifers and freshwater rivers many cities depend on for drinking water depends on sea level as well. One to three feet could impact groundwater supplies that support New York City, New Jersey, and Long Island, the Delaware River freshwater intake for

Philadelphia, and the cities and farms of California that depend on the Sacramento and San Joaquin River systems for drinking and irrigation water.[15]

Then there's the flooding. Coastal roads, subway tunnels, drainage pipes, housing, and just about everything else we've built along the coast are extremely vulnerable to higher high tides and storm surges. The impacts to transportation infrastructure aren't just expensive; they actually jeopardize the logistics of evacuation routes, which can have a direct impact on human survival rates. Sewer outfall pipes that are affected by tides could back up and cause severe new flooding far from the edge of the sea itself when sea levels rise. Entire districts of some coastal cities could end up being below sea level, and all coastal cities become more vulnerable to flooding from the higher storm surges that result from rising oceans.

INSURANCE AS A BELLWETHER

Since accelerated sea-level rise is already a reality, we should expect to see the private sector paying close attention and getting mobilized to protect its assets. Indeed, if we consider the insurance industry, that's exactly what we find. Media reports state that Allstate recently stopped accepting customers for homeowners insurance along the coasts of New Jersey, Connecticut, Delaware, and in the five boroughs of New York City, where they also won't renew policies for 30,000 of their 600,000 residential customers. While this isn't news in the Gulf Coast states, homeowners all along the mid-Atlantic and northeast Atlantic coast are watching their insurance premiums and deductibles increase by two and three digits. Their insurers are pointing to the risks of climate change as the reason.[16]

The institutional and private investors who own shares in these large insurance companies have been urging their Boards of Directors to consider the risks of climate change and to incorporate those risks into their business practices. The pension funds of Florida and California, for example, have joined a group called the Investor Network on Climate Risk, which pressures publicly held companies to tell shareholders how they are dealing with the financial risks and opportunities of climate change and its impacts. The Florida State Board of Administration manages $180 billion in assets, with $140 billion of that coming from the Florida Retirement System. The California equivalent, CalPERS, has a fund with a market value of $245 billion. Globally, insurance is the world's largest industry, with a total market value of $3.4 trillion. And out of all the $374 billion in payouts that industry has made around the world from 1980 to 2004, more than 70% has been driven by storms, with an additional 5 to 10% driven by flooding. According to Evan Mills, a scientist who specializes in insurance and climate change at Lawrence Berkeley National Laboratory, the ratio of losses to premium revenues is increasing as a result of weather-related losses.[17] The upshot is that the insurance industry is likely to increasingly shift the costs of sea-level rise and more damaging storm patterns to governments and individuals. For example, the Association of British Insurers actively advised the British government to make the massive investments in flood defenses that were constructed in the Thames River Estuary after severe floods affected central London in the 1950s.

Some insurance companies are also looking farther into the future and are influencing builders and other market agents to do more to mitigate climate change. Fireman's Fund recently offered the first premium credits for "green" building elements and added requirements to rebuild green as well. Allianz is funding sustainable block-scale residential building experiments in Germany, where the goals are to generate more energy than is used and drastically reduce water use. Insurance Australia is offering online automobile carbon-offset services to its customers. Travelers is offering discounts to drivers of hybrid vehicles. One of the world's largest insurers of insurance companies, Swiss Re, has identified corporate director's and officer's insurance as a vulnerable area now that companies that emit greenhouse gases are being sued by various U.S. states. Rather than let these corporate board members off the hook, they have begun to require companies to detail the corporate practices that will allow them to take climate change risks into consideration.[18]

By working with large insurance companies, government regulators could encourage rationality when either the private sector or public agencies make major investments in coastal urban futures. Important dialogues could begin about how to share the significant investment costs of adapting coastal areas to sea-level rise and new flooding patterns. Because they would bring insurers and institutional leaders together, these new investment and cost-sharing discussions provide a way to allow flexible design and planning solutions to emerge that would be insurable, politically feasible, and recognize the need for social equity in how citizens are protected from immediate and longer-term dangers.

PROTECTING COASTAL DEVELOPMENT

There are essentially three ways of dealing with the effect of rising seas on coastal development.

1. Development can be moved away from the shore, and the shoreline can be restored to a state that will accept the fluctuations of rising tides and storm surges. This may be the best alternative for individual houses in vulnerable locations, but it would be the last resort for whole cities.

2. Development can be raised above flood levels, in its current place. Individual houses raised a story or more above ground are becoming a familiar sight in coastal locations. This is not a great design strategy in denser areas, where it would make more sense to raise the streets and buildings for an entire district. FEMA regulations permit parking to be below flood levels, so both parking and utilities could remain at today's grade level; future utilities and parking would actually cost less with that approach, since it is cheaper to build parking and utilities up from grade than to excavate. Street levels and side sewer lines were raised in the mid-19th century in entire districts of Chicago and Seattle to improve drainage. Raising the elevation of a whole urban district can work, although it is obviously expensive and

requires the coordination of public and private investment.

3. Protect coastal cities with a combination of wetlands restoration, flood walls, and pumps. A version of this strategy, minus significant wetland restoration, failed in New Orleans; although the walls should have worked, their construction turned out to be faulty. After devastating storm surges from North Sea storms in 1953, the governments of Great Britain and the Netherlands invested in major engineering protection against flood surges. The Thames estuary protection includes barriers across the approximately 1,600-foot width of the Thames River to protect central London. These retractable steel barriers rest on the river bottom in sections between five-story towers and swivel upward and sideways to hold back a flood surge. They have been used many times since completion in 1983, and more often recently. At a cost of more than 500 million pounds in 1983 (which today would exceed a billion pounds and equal about $1.9 billion USD), the project was paid for primarily by public taxation and was designed to last until 2030. The centerpiece of storm surge protection in the Netherlands is a much larger estuary-mouth barrier, the Oosterscheldekering, built from 1976 to 1986 just south of Rotterdam. That behemoth is 5.6 miles long and mostly fixed in place, with movable gates along slightly less than half its length to allow tidewaters and boats to pass through in fair weather. Built at a cost of 2.5 billion euros (or about $3.4 billion USD), the dam was designed to last 200 years. These are expensive investments, but even these big numbers are much smaller than the property values protected: New York, for example, has more than $1 trillion in insured coastal property.[19]

While some governments and their engineers are thinking in terms of enormous barriers, some architects have been thinking of altering buildings instead. The Rotterdam Architecture Biennale of 2005 brought together a cross section of architectural ideas in an exhibit specifically on water and cities. Using the past as a point of departure and displaying extreme real-world examples of constructed coastlines such as the Palm Jumeirah in Dubai, the exhibit was in some ways a valuable eye-opener. But when design concepts for dealing with climate change were requested from various practitioners around the world, the proposals that came back were more about shock than strategy. Perhaps that was the intent of the organizers. But the idea that glass-fronted buildings could and should detach from stilt-like supporting piers and float during floods won't exactly appeal to insurance companies: Under what weather and terrain circumstances would floodwaters come without significant winds, waves, and debris?

Architects, engineers, landscape architects, urban designers, and planners owe the public a serious discussion of how to deal concretely with the effects of sea-level rise up to at least 2060, as well as a look beyond to protections that would last until the end of the century.

LANDSCAPE AS COASTAL INFRASTRUCTURE

In the more complex third strategy we described above that includes mechanical barriers and pumps as well as wetlands, the open question is how landscape can form an infrastructure for coasts.

Most design thinking for coastal protection explores options in the vertical plane: walls, mechanical barrier arms, levees, and houses on stilts. The alternative is to think horizontally. If we could design a living coastal infrastructure that would support marine ecosystems and also absorb some wave energy and flood water and allow that new coastal infrastructure to migrate inland as sea levels rise, we would have the kind of solution that engineers sometimes call a belt-and-suspenders approach. In New Orleans, a statistic widely quoted was that every five miles of coastal wetlands restored could reduce storm surge by about a foot. When storm surges are expected to exceed twenty feet, coastal wetlands alone don't seem an immediate practical solution. Sandy barrier islands like those found at the mouth of New York harbor or Virginia's eastern shore can move by ten feet in a single year. Clearly, like mechanical barriers and pumps, landscape strategies have to be used very carefully to achieve significant long-term benefits. The designs must address the specific limiting factors that exist in ecosystems and human systems.

Two of the most significant limiting factors for the growth of shallow-water sea grass beds that nurture fish and crabs are insufficient light, since rays of sunshine are blocked by turbid water that suspends sediments and pollution in storm-water runoff. Artificial islands and reefs of various kinds can make deep water shallower, creating places where sea grasses can grow, as long as we simultaneously continue to improve the quality of water running off cities, suburbs, and farmlands. If the artificial islands and reefs are built to float in a submerged position, rather than fixed in place on the bottom of bays or beaches, we can move them inland as the sea rises to form a flexible new marine edge. These structures could be built with select materials from the industrial waste stream, and by recycling some materials from buildings that are being torn down and replaced. The questions of cost and modularity will be important, along with the ability of these floating structures to absorb wave energy or create flood storage on the freshwater side.

There are three critical reasons to consider these horizontal approaches: first, they are the best solution for supporting coastal ecosystems short of simply removing big sections of coastal cities along their waterfronts and restoring pre-development habitat; second, in most coastal building situations the value of the assets being protected will not justify billions of dollars in investment in vertical coastal barrier systems. And third, if we don't pay what it takes for new barriers to make sure they are built to open mechanically, they will contribute to more severe problems for aquatic ecosystems. The simpler strategies of decamping or raising the floor levels of buildings may be viable options in low-density development, but the more comprehensive solution to protect lower-density urbanization as well as ocean ecosystems is to unpack our vertical strategies and reconsider systems that can operate in the horizontal zone.

BARRIER METHODS FOR PROTECTING DEVELOPMENT FROM SEA-LEVEL RISE

The Thames and Eastern Scheldt barriers provide templates that can be applied to comparable situations where the value of property is so high that it could justify these investments. Structures analogous to the Thames Barrier could be placed across the Narrows, the entrance to New York Harbor, and across the passage from Long Island Sound, roughly where the Throgs Neck Bridge is located, to protect many vulnerable locations from storm surges.[20] The outer reaches of New York's waterways could be protected by a barrier on the model of the Eastern Scheldt in the Netherlands, connecting barrier beaches from Sandy Hook to Coney Island. If such a barrier were needed, it would be part of a system of seawalls that would protect the barrier beaches themselves. An early version of such a seawall is the one built on Galveston Island after the 1900 hurricane. Boston Harbor could be protected by a series of seawalls along the coast and something like the Eastern Scheldt barrier across its opening. An installation like the Thames Barrier across the Shanghai River might protect Shanghai's Pudong district from storm surges, and perhaps a barrier even longer than the one across the Eastern Scheldt could protect the whole Arabian Gulf.

PLANNING, DOLLARS, AND SENSE

In the United States we need engineering and planning studies of every coastal city to look at the type of coastal protections that may be possible and what their effect would be on future development. We also need new financial strategies that would make these investments affordable for our cities, which already struggle and often fail to fund new infrastructure and maintenance. Federal and state dollars will be essential components of any plan to provide equal protection to citizens at all income levels.

But realistically, what arguments or evidence will mobilize those dollars and raise significant new revenues for disasters that have not yet occurred in a society in which relatively low taxes are perceived as too high?

The Interstate Highway System enjoys widespread political support because it provides benefits in every state, creates a great many jobs — as well as profits for big construction companies — and has a dedicated source of funding, a federal gasoline tax. Protecting coastal development from sea-level rise will be a problem in many states, and a high proportion of the U.S. population lives in them. Protection ought to be seen as a bi-partisan, national issue, providing plenty of potential work for the construction industry. There could be substantial resistance from states far from a coast unless new fund allocations would also pay for expanded reservoirs and aqueduct systems in the arid West or new river flooding protections in the Midwest.

It is difficult to think of a funding source that has the beautiful simplicity of the gasoline tax. The most likely place to look for fiscal solutions may be in partnership with the insurance industry. Perhaps insurance companies would buy long-term government bonds to finance coastal protections that would make these areas insurable. But this is only cash-flow management, since the government would still be paying the interest on the bonds. Some kind of fail-safe government guarantee of these insurance policies may be needed. In Great Britain and the Netherlands the national interest was enough to justify public expenditure on coastal defense. Could that happen in the U.S.?

Since a secure source of federal government funding was available for the interstate highways, planning at first was seen as solely about engineering, and for a long time it did not occur to decision-makers that local communities should be consulted. We all know our Jane Jacobs stories about the harm new highways did to inner-city neighborhoods. We live with the decentralized development that highways have facilitated as an unplanned side effect. As we adapt to sea-level changes, we'll need to avoid making the same kind of mistake. Social equity, above and beyond broader cultural and economic health, must be a top priority when public funds are used.

Deciding what to protect and how to protect it is going to require rational leadership if we want to come to conclusions that are truly in the public interest. The voices of influential people with houses in locations that probably do not justify the costs of protection will have to be balanced against the future of low-lying, low-income neighborhoods where protection could be effective but political clout is small — after hurricane Katrina, George W. Bush famously was able to imagine himself sitting on Trent Lott's rebuilt front porch but had no such vision for New Orleans' devastated Ninth Ward.

The science of coastal defense is still developing. Some groins and seawalls have turned out to actually cause more erosion, and we may fail in some of our experiments to support coastal ecosystems. But the no-action alternative includes the loss of many ecosystems. Lack of certainty does not justify complacency.

There is time, measured in decades, before the effects of sea-level rise make coastal dangers significantly worse. But we are going to need to use all the time we have. It took Britain and the Netherlands from 1953 to the mid-1980s to put key flood barrier systems in place for exceptionally valuable landscapes. We will need a process of public education and participation. We will need extensive studies to determine the scope of the problem, the range of potential solutions, their cost, and ways of managing those costs. Leadership will need to come from state and federal governments, but the design professions can and must help set the strategic direction. □

NOTES

1. According to Dr. Vivien Gornitz, a top NASA scientist who has been studying climate change and its implications for sea level since the late 1980s, a global average temperature increase of 1.9 to 4.6 degrees. C could cause major changes in these massive ice reservoirs. That increase could be reached by 2100 in the IPCC's SRES A1B scenario. In this scenario, global economic and population growth continues but new and more efficient technologies for energy use are assumed to be in use. It also assumes balanced growth in fossil and non-fossil fuel use, which is not yet the

case. It's not a worst-case greenhouse gas emissions scenario, but it is sufficient to produce the kind of warming that historically caused large parts of the world's massive ice sheets to melt and raised sea levels by sixteen to twenty-three feet. Gornitz calls the IPCC's latest estimate that sea level could rise by half a foot to two feet by 2100 "probably a very conservative estimate" in part because "current computer models do not yet include many of these dynamic ice processes." (Email to Kristina Hill, June 19, 2007.)

2. K. Breslau, "The Insurance Climate Change," *Newsweek*, January 9, 2007, <www.msnbc.msn.com/id/16720746/site/newsweek/>.

3. The historical record of hurricanes leaves the New York area with a 150-year "return interval" for a Category 3 storm like the Long Island Express of 1938. For more details about that storm, see: <www2.sunysuffolk.edu/mandias/38hurricane/damage_caused.html>. As climate change and sea-level rise occur, this rate of occurrence may not reflect the region's new realities, which could be worse. New York's vulnerability is assessed by insurers as a function of the magnitude and likelihood of storms, but also in terms of the amount of insured property along the coast. New York has more than $1 trillion in insured coastal property, putting it a close second to Florida in terms of vulnerability and far outpacing other U.S. states.

4. G. A. Vecchi and B. J. Soden, "Increased tropical Atlantic wind shear in model projections of global warming," *Geophysical Research Letters* 34, L08702, doi:10.1029/2006GL028905, April 2007.

5. See the final report at <www.tufts.edu/tie/climb/>.

6. A draft of the North American impacts chapter is available at <www.climatesciencewatch.org/file-uploads/Ch14.pdf>.

7. Images and descriptions of this artificial coastline can be found at <www.thepalm.ae/jumeirah/>.

8. R. Kerr, "Pushing the Scary Side of Global Warming," *Science*, June 8, 2007, 1412 – 1415.

9. This is why it is impossible to simply draw a line at some elevation above sea level to identify urban areas that could be impacted by sea level rise. Impact maps must consider local subsidence by adding it to the predicted global average for sea-level rise, as well as the erosive impacts of waves (including typical as well as storm-driven waves). The so-called "Brunn's Rule" in coastal geomorphology is often interpreted to mean that every centimeter of sea-level rise corresponds to fifty to eighty centimeters of horizontal beach erosion. Applying that rule means that a three-foot rise in sea level would correspond to 150 to 240 feet of shoreward erosion of a sandy beach.

10. Illustration for a climate change simulation, *Boston Globe* website, April 2007 <www.boston.com/news/multimedia/interactive_bostonflood/>.

11. Susmita Dasgupta, Benoit Laplante, Craig Meisner, David Wheeler, and Jianping Yan, "The Impact of Sea-Level Rise on Developing Countries: A Comparative Analysis," World Bank Policy Research Paper 4136, February 2007, <http://ideas.repec.org/p/wbk/wbrwps/4136.html>.

12. Pew Oceans Commission, "America's Living Oceans: Charting a Course for Sea Change," Pew Trusts, 2003, <www-ocean.tamu.edu/GOOS/GSC8/ nowlin.ppt>.

13. More information about trends in estuary environments can be found at <www.estuaries.org>.

14. D. Beach, "Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States," Pew Oceans Commission, Arlington, Virginia, 2002, <www.pewtrusts.com/pdf/env_pew_oceans_sprawl.pdf>.

15. About a third of New York City's water customers depend on the Long Island aquifer for water, which is vulnerable to intrusion by salt waters as sea levels rise. New York's emergency water source has been the Hudson River, which was accessed at the Chelsea pumping station in the late 1980s during a major drought. This emergency intake is vulnerable to the movement of salt water up the Hudson as sea levels rise. For more detailed information about water supply in these areas and its vulnerability to climate change, see D. Major and R. Goldberg, "Water Supply," *Metropolitan East Coast Water Sector Report* (New York: Columbia University Center for Climate System Research, 2001), <www.epa.gov/climatechange/effects/coastal/SLRDelaware.html>;
Knowles and D. Cayan, "Potential Effects of Global Warming on the Sacramento/San Joaquin Watershed and the San Francisco Estuary," *Geophysical Research Letters* 29: 18, 2002.

16. Breslau.

17. Concise and accessible information on this subject can be found in E. Mills, "Insurance in a Climate of Change," *Science*, August 12, 2005, 1040 – 1044.

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