A PUBLIC HEALTH PERSPECTIVE ON SEA-LEVEL RISE: STARTING POINTS FOR CLIMATE CHANGE ADAPTATION

ROBIN KUNDIS CRAIG*

ABSTRACT

One of the widely acknowledged consequences of global climate change is sea-level rise. Sea-level rise has predictable impacts on human welfare and the environment and the oceans will continue to rise for some time, regardless of the climate change mitigation measures that the countries of the world decide to take. Therefore, some adjustment to sea-level rise—adaptation—is inevitable.

However, sea-level rise poses two challenges for leaders trying to formulate adaptation plans. First, sea-level rise is slow, measured in millimeters per year, and the full extent of climate change-driven sea-level rise is expected to take centuries to manifest. This is a planning horizon outside the political ken of most governmental bodies; indeed, planning horizons longer than a few decades are extremely rare. Second, scientists are still uncertain as to the extent of the problem. Specifically, how high will the oceans rise?

For both reasons, adaptation to sea-level rise requires some form of adaptive management—an ability to react to new information regarding the extent and speed of sea-level rise as that information becomes more certain and precise for different areas of the country. Moreover, an adaptive management approach to sea-level rise provides a means of avoiding government inaction because of uncertainty. Instead, recognition of the need for an adaptive approach necessarily counsels governments to implement initial adaptation measures that will be beneficial to coastal communities regardless of how far the oceans encroach and how fast they do so.

This Article suggests that taking a public health approach to sea-level rise can provide governments and planners with immediately implementable and "no regrets" adaptation measures that will be beneficial to coastal communities regardless of the eventual actual impacts of sea-level rise in particular areas of the country. Specifically, this Article suggests that planners should begin by looking at three specific concerns: (1) availability of drinking water supplies; (2) potential changes in disease exposure, with resultant changes in medical infrastructure and training needs; and (3) the potential for the toxic contamination of sea water as it comes ashore, with resultant changes in allowable land uses in the coastal zone.

* Attorneys' Title Professor of Law and Associate Dean for Environmental Programs, Florida State University College of Law, Tallahassee, Florida. My thanks to Jim May and the members of the *Widener Law Review* for inviting me to participate in this symposium. Comments may be directed to me by e-mail: rcraig@law.fsu.edu.

The ice we skate is getting pretty thin;
The water's getting warm, so you might as well swim.
--Smash Mouth, "All Star"

INTRODUCTION

One of the widely acknowledged consequences of global climate change is sea-level rise.[1] Sea-level rise has predictable impacts on human welfare and the environment. Moreover, these impacts are so potentially severe and disruptive that, in a policy briefing organized by the U.S. Geological Survey in March 2008, both federal and state officials advised Congress that "[c]oastal states should receive assistance from the federal government when planning for sea level rise and storms caused by climate change . . . ."[2]

James Titus has identified eight physical effects from sea-level rise. As he summarizes, "[a] rise in sea level would (1) inundate wetlands and lowlands, (2) erode shorelines, (3) exacerbate coastal flooding, (4) increase the salinity of estuaries and aquifers and otherwise impair water quality, (5) alter tidal ranges in rivers and bays, (6) change the locations where rivers deposit sediment, (7) increase the heights of waves, and (8) decrease the amount of light reaching the bottoms."[3] All of these physical results have potential impacts on humans.

Most basically, rising seas and eroding shorelines[4] displace coastal communities. Erosion actually makes the effects of sea-level rise worse. As Professor Titus has explained, "[i]n many areas the total shoreline retreat from a 1 m rise would be much greater than suggested by the amount of land below the 1 m contour on a map because shores would also erode."[5] Across the globe, the combined processes of sea-level rise and erosion could be devastating. "A 1 m rise in sea level would inundate 17% of Bangladesh. … Shanghai and Lagos—the largest cities of China and Nigeria—are less than 2 m above sea level, as is 20% of the population and farmland of Egypt."[6]

Indeed, human displacement as a result of the effects of climate change is already occurring, including in the United States. In late February 2008, the Inupiat Eskimo coastal village of Kivalina filed a public nuisance lawsuit against twenty-four oil and energy companies, seeking as damages up to four

1. *See, e.g.*, U.S. Environmental Protection Agency, Sea Level Changes, http://www.epa.gov/climatechange/science/recentslc.html (last visited Feb. 13, 2008) ("Sea levels are rising worldwide and along much of the U.S. coast") [hereinafter Sea Level Changes].

2. Federal Government Urged to Help States With Sea-Level Research, Flood Prevention, Daily Env't Rep. (BNA) No. 61, at A-1 (MAR. 31, 2008).

3. James G. Titus, *Greenhouse Effect, Sea Level Rise and Land Use*, 7 LAND USE POL'Y 138, 140 (1990).

4. *Id.* at 148; Orrin H. Pilkey & J. Andrew. G. Cooper, *Society and Sea Level Rise*, 303 SCIENCE 1781 (2004).

5. Titus, *supra* note 3, at 141.

6. *Id.* at 140 (citations omitted).

hundred million dollars necessary to relocate the village, because melting sea ice and thawing permafrost are eroding away the village's foundation.[7]

However, sea-level rise causes less obvious impacts as well. The process of inundation "refers to both the conversion of dry land to wetland and the conversion of wetlands to open water."[8] Inundation destroys coastal habitat and ecosystems,[9] which are generally some of the richest areas for biodiversity.[10] Also, when freshwater drinking supplies are located near the coast, in surface waters or aquifers, sea-level rise threatens those supplies with salt-water intrusion.[11] Finally, sea-level rise increases the destructive force of coastal storms.[12]

Given these effects, sea-level rise clearly requires coastal states and communities to plan for adaptation strategies. In climate change parlance, "adaptation" refers to the process of responding to climate change impacts.[13] Adaptation measures are contrasted to "mitigation" measures, which are measures designed to reduce the amount of carbon dioxide and other greenhouse gases entering the atmosphere.[14] According to the Intergovernmental Panel on Climate Change (IPCC) 2007 Report, "[a]daptation can reduce vulnerability [to climate change], both in the short and the long term."[15]

Sea-level rise is already occurring, as the U.S. Supreme Court acknowledged in *Massachusetts v. EPA*,[16] and the oceans will continue to rise for some time, regardless of the mitigation measures that the countries of the world decide to take.[17] Indeed, the IPCC recognized this fact quite forcefully:

---

7. Yereth Rosen, *Village in Alaska Sues Energy Companies over Erosion Linked to Warming Climate*, ST. ENV'T DAILY (Feb. 29, 2008), *available at* http://pubs.bna.com/ip/bna/sed.nsf/eh/A0B6D2P9D7.

8. Titus, *supra* note 3, at 140.

9. MMPB Fuentes et al., *Potential Impacts of Projected Sea-level Rise on Sea Turtle Rookeries*, 20:2 AQUATIC CONSERVATION: MARINE & FRESHWATER ECOSYSTEMS (forthcoming March/April 2010); National Wildlife Federation, Global Warming and Hawai'i 1 (2009), *available at* http://www.nwf.org/globalwarming/pdfs/Hawaii.pdf; Richard C. Daniels, Tammy W. White & Kimberly K. Chapman, *Sea-level Rise: Destruction of Threatened and Endangered Species Habitat in South Carolina*, 17:3 ENVTL. MANAGEMENT 373, 373-85 (May 1993).

10. U.S. EPA, Aquatic Biodiversity: Marine Ecosystems, http://www.epa.gov/bioindicators/aquatic/marine.html (last viewed March 3, 2009).

11. Titus, *supra* note 3, at 143-44.

12. *Id.* at 142-43.

13. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT 56 (2008) [hereinafter 2007 IPCC SYNTHESIS REPORT].

14. *Id.*

15. *Id.*

16. Massachusetts v. EPA, 549 U.S. 497, 521 (2007).

17. U.S. Environmental Protection Agency, Coastal Zones and Sea Level Rise, http://www.epa.gov/climatechange/effects/coastal/index.html (last visited Feb. 13, 2008) [hereinafter Coastal Zones and Sea Level Rise] (noting that "some processes affecting sea level have long (centuries and longer) time-scales, so that current sea level change is also related to past climate change").

> Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG [greenhouse gas] concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century . . . If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3 to 0.8m. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. These long-term consequences would have major implications for world coastlines. The long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries . . . .[18]

Therefore, some adjustment to sea-level rise—adaptation—is inevitable.

However, as the IPCC has also recognized, "more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change," and "additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades."[19] In particular, climate change-driven sea-level rise is likely to demand local and regional adaptation strategies, because the impacts of sea-level rise will vary considerably from location to location, depending on the slope of the coast, the extent and kind of existing coastal development, population densities, the local rate of sea-level rise, and pre-existing coastal management policies and local cultural norms.

Sea-level rise poses two fundamental challenges for community, state, and regional governments trying to formulate adaptation strategies. First, sea-level rise is slow, measured in millimeters per year,[20] and the full extent of climate change-driven sea-level rise is expected to take centuries to manifest.[21] This is a planning horizon outside the political ken of most governmental bodies; indeed, planning horizons longer than a few decades are extremely rare.

Second, scientists are still uncertain regarding the extent of the problem. Specifically, how high will the oceans rise?[22]

---

18. 2007 IPCC SYNTHESIS REPORT, *supra* note 13, at 67.

19. *Id.* at 56.

20. *See, e.g.,* U.S. CLIMATE CHANGE SCIENCE PROGRAM, COASTAL SENSITIVITY TO SEA LEVEL RISE: A FOCUS ON THE MID-ATLANTIC REGION 24, 25 (2009) (describing sea level rise averages of 1.7 millimeters per year worldwide and 2.4 to 4.4 millimeters per year for the Mid-Atlantic region of the United States), *available at* http://www.epa.gov/climatechange/effects/coastal/SAP%204.1%20Final%20Report%2001.15.09.pdf.

21. Titus, *supra* note 3, at 138-39 (citing estimates that "complete disintegration of the West Antarctic ice sheet" might take 200 to 500 years).

22. Pilkey & Cooper, *supra* note 4, at 1781 (noting that the extent of future sea-level rise is an "important unknown" in predicting the effects of global warming on society).

For both reasons, adaptation to sea-level rise requires some form of adaptive management—an ability to react to new information regarding the extent and speed of sea-level rise as that information becomes more certain and precise for different areas of the country. Moreover, an adaptive management approach to sea-level rise allows current government officials to avoid becoming stymied by the uncertainties and timeframes involved. Instead, recognition of the need for an adaptive approach necessarily counsels governments to implement initial adaptation measures that will be beneficial regardless of how far the oceans encroach and how fast they do so.

This Article suggests that taking a public health approach to sea-level rise can provide governments and planners with immediately implementable and "no regrets" adaptation measures that will be beneficial to coastal communities regardless of the eventual impacts of sea-level rise in particular areas of the country. Specifically, this Article suggests that planners should begin by looking at three specific concerns: (1) availability of drinking water supplies; (2) potential changes in disease exposure, with resultant changes in medical infrastructure and training needs; and (3) the potential for the toxic contamination of sea water as it comes ashore, with resultant changes in allowable land uses in the coastal zone.

Part I of this Article reviews the climate change-related causes of sea-level rise, predictions regarding the extent of that sea-level rise in the United States, and sources of uncertainty for adaptation planning. Part II examines the potential impacts of sea-level rise on coastal water supplies, while Part III discusses potential changes in disease exposure as a result of climate change generally and sea-level rise in particular. Using Hurricane Katrina's impact on New Orleans as a learning example, Part IV outlines the potential of sea-level rise to increase the destructiveness of storms and the potential toxicity of rising waters as a result of such destruction. The Article concludes by recommending a series of public health-based, "no regrets" adaptation measures that coastal states and local governments can begin to implement now.

I. SEA-LEVEL RISE BASICS

Sea level has been rising worldwide for at least the last century, at a rate of about 12 to 22 centimeters (cm) (4.8 to 8.8 inches) per century,[23] or about one to two millimeters (mm) per year, on average globally. Nevertheless, focusing on global averages can obscure two important points. First, sea-level rise is not uniform throughout the world; instead, it varies from location to location. For example, in the United States, "[s]ea level has been rising 0.08-0.12 inches per year (2.0-3.0 mm per year) along most of the U.S. Atlantic and Gulf coasts."[24] However, location-specific rates actually vary from a rise of about ten millimeters (0.36 inches) a year in Louisiana, where the land is sinking, to

23. Sea Level Changes, *supra* note 1.
24. *Id.*

an actual drop in sea level in parts of Alaska, where the land is rising.[25] Second, the global average rate of sea-level rise appears to be accelerating.[26]

Climate change-driven sea-level rise occurs for two main reasons. First, water expands as it increases in temperature, and rising global air temperatures have been causing corresponding increases in ocean temperatures.[27] Second, hotter atmospheric temperatures are also causing ice caps and glaciers all over the world to melt, providing influxes of fresh water to the oceans and increasing the total volume of water that they hold.[28] According to researchers in this field, "[d]uring the past decade, ocean warming has contributed roughly half of the observed rate of sea-level rise, leaving the other half for ocean-mass increase caused by water exchange with continents, glaciers, and ice sheets."[29]

Nevertheless, many uncertainties complicate the implementation of adaptation strategies for climate change. Predicting how the world's oceans will behave is no easy task. First, uncertainty regarding future sea-level rise exists because of the potential effect of currently unenacted long-term mitigation measures (reduction in carbon dioxide and other greenhouse gas emissions).[30] Second, uncertainties exist because of the predictive nature of sea-level rise estimates, which depend on models and the assumptions within those models. Thus, in 2001, in its Third Assessment Report, the IPCC predicted that the global average sea-level rise by 2100 would be between nine and 88 centimeters,[31] or about 3.5 to 34.5 inches (almost a yard). In 2007, in its Fourth Assessment Report, the IPCC revised its estimates, predicting that average sea level would rise between 18 and 59 centimeters,[32] or about seven inches to almost two feet.

---

25. *Id.*

26. *Id.*

27. 2007 IPCC SYNTHESIS REPORT, *supra* note 13, at 32 fig.1.2; *See also*, *e.g.*, Michael Byrnes, *Southern Ocean Rise due to Warming, Not Ice Melts*, ENVTL NEWS NETWORK, Feb. 18, 2008, http://www.enn.com/top_stories/article/31325 (reporting that "[r]ises in the sea level around Antarctica in the past decade are almost entirely due [to] a warming ocean, not ice melting" as a result of a temperature increase of "three-tenths of a degree Celsius").

28. Pilkey & Cooper, *supra* note 4, at 1781 ("Eustatic rise from oceanic heating expansion and glacial [ice] melting is assumed to be one of the major fallouts from global warming that will have important impacts on our society."); *See also* Sea Level Changes, *supra* note 1 (citing both melting glaciers and warming ocean temperatures as primary sources of rising sea level).

29. Anny Cazenave, *How Fast Are the Ice Sheets Melting?*, 314 SCIENCE 1250, 1250 (2006); *but see also* Mark F. Meier et al., *Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century*, 317 SCIENCE 1064, 1065 (2007) (arguing that glaciers and ice caps "contribute about 60% of the eustatic, new-water component of sea-level rise").

30. 2007 IPCC SYNTHESIS REPORT, *supra* note 13, at 67.

31. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE REPORT 2001: SYNTHESIS REPORT 9 (2001).

32. 2007 IPCC SYNTHESIS REPORT, *supra* note 13, at 45 tbl.3.1.

However, the IPCC estimates did not take account of possible increases in the rates of ice melt.[33] The unexpectedly increasing pace of polar ice melt has added significant volatility to the art of sea-level rise prediction[34] and provides a third source of uncertainty in those estimates. Recent studies, for example, indicate that the Greenland ice sheet and Antarctic ice are melting faster than expected,[35] and an August 2007 study published in *Science* suggested "that future sea-level rise may be larger than anticipated and that the component due to GIC [glaciers and ice caps] will continue to be substantial."[36] If the Greenland ice sheet melts entirely, sea level will rise up to seven meters (23 feet.).[37] The West Antarctic Ice Sheet contains enough ice to raise sea level by five to seven meters (17-23 feet).[38] If all of Antarctica melts, sea level will rise approximately 60 meters, or almost 200 feet.[39] If both Greenland and Antarctica melt completely, sea level would rise about 65 meters,[40] or approximately 215 feet.

This range of sea-level rise estimates—from six or seven inches in the next century to a possibility of 215 feet in the next few centuries—invokes, at a purely physical level, a similarly wide range of potential adaptation needs. However, initial sea-level rise (say, over the next 50 years) is a problem mainly for already low-lying coastal areas. According to the U.S. Environmental Protection Agency (EPA), in the United States "about 5,000 square miles of dry land are within two feet of high tide."[41] Nevertheless, a two-foot sea-level rise which is close to the high end of the IPCC's current projections for the next century, even without the concern of faster-melting ice[42] will actually cover 10,000 square miles of land in the United States, an area about the size of Massachusetts and Delaware combined.[43] Moreover, the EPA estimated in a report to Congress that a two-foot increase in sea level could destroy 17 to 43 percent of the United States' coastal wetlands, with over 50 percent of that destruction occurring in Louisiana alone.[44] The IPCC has "suggest[ed] that by

33. *Id.* at 45.

34. Cazenave, *supra* note 29, at 1250-51 ("The greatest uncertainty in sea-level projections is the future behavior of the ice sheets.").

35. *Id.* at 1251; J.L. Chen, et al., *Satellite Gravity Measurements Confirm Accelerated Melting of Greenland Ice Sheet*, 313 SCIENCE 1958, 1958 (2006).

36. Meier, *supra* note 29, at 1066.

37. VIVIAN GORNITZ, GODDARD INSTITUTE FOR SPACE STUDIES, NASA, SEA LEVEL RISE, AFTER THE ICE MELTED AND TODAY (2007), http://www.giss.nasa.gov/research/briefs/gornitz_09/; *see also* U.S. Environmental Protection Agency, Future Sea Level Changes, http://www.epa.gov/climatechange/science/futureslc.html (last visited Feb. 13, 2008) (citing the same figure).

38. GORNITZ, *supra* note 37.

39. ANTARCTIC TREATY CONSULTATIVE MEETING XXIX, THE ANTARCTIC AND CLIMATE CHANGE 3 (2006), *available at* http://www.asoc.org/portals/0/pdfs/Climate%20Change%20IP.pdf.

40. Cazenave, *supra* note 29, at 1250.

41. Coastal Zones and Sea Level Rise, *supra* note 17.

42. 2007 IPCC SYNTHESIS REPORT, *supra* note 13, at 45 tbl.3.1.

43. Coastal Zones and Sea Level Rise, *supra* note 17.

44. *Id.* (citation omitted).

2080, sea level rise could convert as much as 33 percent of the world's coastal wetlands to open water."[45] Most barrier islands along the Gulf of Mexico and Atlantic coasts of the U.S. climb only five to ten feet above high tide, and the bay sides are often less than two feet above high water.[46] As a result, these islands, and the storm protection that they provide, are immediately vulnerable to sea-level rise.

Human and social uncertainties also complicate the planning of adaptation strategies. As noted in the Introduction, the full extent of climate change-related sea-level rise is unlikely to occur for centuries. However, any attempt to engage in centuries-long planning is unlikely to be practical. Say, for example, that most of the effects of climate change with respect to sea-level rise occur over the next three centuries, a reasonable prediction.[47] A 300-year horizon puts planners in 2008 in approximately the same predicament that colonial land use planners would have faced in 1708, had they tried to engage in 300 years of planning for the continental United States to reach the present day. Had the colonists tried such an ambitious undertaking, we would have undoubtedly seen that many of their prescriptions and predictions turned out to be grossly inappropriate for conditions in 2008. It would be the height of hubris to assume that today's governments could do much better in prescribing comprehensive adaptation measures to govern American societies into the 24th century.

Nevertheless, it is reasonable to assume that certain basic human requirements and desires will persist over the centuries. For example, although the exact sources, methods of treatment, and regulations governing use may change over time, humans of whatever century will need secure sources of potable fresh water to support their lives and various industrial, municipal, and agricultural activities. Similarly, it is reasonable to assume that humans will continue to desire protection from disease, both in the senses of preventing infection and of having access to adequate and proper treatment. Finally, humans will presumably prefer to live in a relatively toxic-free environment and to continue to enjoy, to the extent that sea-level rise allows at all, the ecosystem goods and services that a healthy coast can provide—fresh fish and shellfish, protection from storms, and recreational opportunities.

Climate change-induced sea-level rise will impact each of these public health-related issues in predictable ways. Moreover, some adaptation measures to address the effects of sea-level rise on these amenities will provide salutary benefits even if the seas do not rise at all. Therefore, water supply, disease prevention and treatment, and reduction of coastal toxic vulnerability

---

45. *Id.* (citing 2007 IPCC SYNTHESIS REPORT, *supra* note 13).

46. *Id.*

47. Titus, *supra* note 3, at 138-39 (citing estimates that "complete disintegration of the West Antarctic ice sheet" might take 200 to 500 years).

should become three relatively uncontroversial starting points for a sea-level rise adaptation strategy.

II. SEA-LEVEL RISE AND COASTAL WATER SUPPLIES: ADAPTING TO SALT-WATER INTRUSION

Salt-water intrusion is the invasion of seawater into fresh water and brackish areas. The salt-water intrusion that occurs as a result of sea-level rise will have important ecological effects. For example, "[i]n estuaries the gradual flow of fresh water toward the oceans is the only factor preventing the estuary from having the same salinity as the ocean,"[48] and it is this decreased and fluctuating salinity that helps induce estuaries' high levels of biodiversity. Sea-level rise thus has the potential to interfere with coastal ecosystems and, in particular, to greatly reduce or destroy estuarine biodiversity.

However, from a public health perspective, it is the effects on public water supply that are the most important consequences of salt-water intrusion. The coastal communities most vulnerable to sea-level rise often depend on local sources of fresh water. These water supplies can come from either surface sources, such as lakes and rivers, or from underground aquifers, accessed through wells. Both sources of coastal fresh water are vulnerable to salt-water intrusion as the seas rise.[49]

As the EPA has noted, salt-water intrusion already threatens the surface water supplies of important coastal cities. For example,

> New York City, Philadelphia, and much of California's Central Valley obtain some of their water from portions of rivers that are slightly upstream from the point where water is salty during droughts. If sea level rise pushes salty water upstream, then the existing water intakes might draw on salty water during dry periods.[50]

In addition, certain coastal aquifers are also already at risk from salt-water intrusion. As the EPA noted, "[t]he freshwater Everglades currently recharge Florida's Biscayne aquifer, the primary water supply to the Florida Keys. As rising water levels submerge low-lying portions of the Everglades, portions of the aquifer would become saline."[51] Similarly, increasing salinity in the Delaware River as a result of sea-level rise would threaten aquifers in New Jersey.[52]

As sea level rises, additional aquifers will become threatened by salt-water intrusion. Indeed, James Titus has predicted that "[t]he impact of sea level rise on groundwater salinity could make some areas uninhabitable even before they

---

48. *Id.* at 143-44.

49. Coastal Zones and Sea Level Rise, *supra* note 17 (noting that "[r]ising sea levels . . . increase the salinity of rivers, bays, and groundwater tables").

50. *Id.*

51. *Id.*

52. *Id.*

were actually inundated, particularly those that rely on unconfined aquifers just above sea level."[53] In such aquifers, generally, a freshwater "lens" floats on top of heavier salt water, and "if the top of the aquifer is one meter above sea level the interface between fresh and salt water is forty meters below sea level."[54] If fresh water is plentiful, the unconfined aquifer will simply rise with the rising sea level.[55] However, if drought or wells deplete the fresh water in the aquifer, then existing wells will be too deep and will draw brackish or salt water instead of fresh water.[56]

Fresh water management authorities currently deal with the threat of salt-water intrusion by storing fresh water in reservoirs and then releasing it during droughts, preventing saline water from creeping upstream.[57] However, as sea level rises, this solution may become impracticable, both because of rising salinity tables and the potential for decreased water supply, reducing areas' ability to store excess water in reservoirs.

Instead, water managers in coastal states should begin to evaluate seriously the potential impact on fresh-water supplies of a range of sea-level rise scenarios, taking into account the region's population dynamics as well. In Florida, for example, spurred by Governor Crist's climate change executive orders, the regional Water Management Districts are beginning to engage in long-term water planning, with a century-long horizon.[58] In areas like Florida where salt-water intrusion is already a threat to water supplies, and even in areas where sea-level rise of a meter or less will lead to salt-water intrusion, managers should at least begin to plan for, and perhaps begin to implement, water conservation measures, including changes to water pricing. In addition, water managers should identify and, where fiscally and politically possible, secure alternative sources of water supply. Finally, managers and the relevant government should begin to identify and plan for potential water supply infrastructure needs (*e.g.*, transportation, desalination, water treatment) for a range of sea-level rise scenarios.

III. CLIMATE CHANGE, SEA-LEVEL RISE, AND CHANGES IN DISEASE PATTERNS: ADAPTING TO NEW MEDICAL NEEDS

In early April 2008, the World Health Organization (WHO) reported that "[c]limate change is one of the factors causing an increase in the incidence of

---

53. Titus, *supra* note 3, at 144.
54. *Id.*
55. *Id.*
56. *Id.*
57. Coastal Zones and Sea Level Rise, *supra* note 17.
58. FLORIDA CLIMATE CHANGE TASK FORCE ADAPTATION WORKING GROUP, DRAFT POLICY FRAMING TEMPLATE: ADP-4 WATER RESOURCE MANAGEMENT 1 (2007), *available at* http://www.flclimatechange.us/ewebeditpro/items/O12F18335.pdf.

diseases like malaria and dengue fever."[59] As one of the effects of climate change, sea-level rise will contribute to the spread of these and other diseases and health problems in several ways.

A. Sea-Level Rise and Mosquito-Borne Diseases

In combination with higher temperatures in many coastal areas, sea-level rise will contribute to the expected resurgence of certain mosquito-borne diseases such as malaria and the introduction of new mosquito-borne diseases, such as dengue fever, in the United States. As James Titus has noted, "[b]y deepening shallow bodies of water, a sea level rise could cause them to stagnate."[60] Warm, stagnant bodies of brackish water are perfect breeding grounds for disease-bearing mosquitoes. Worldwide, malaria and dengue fever are spreading, both by emerging into new areas and by returning to areas where the diseases had been under control. For example, WHO reported in April 2008 that "[m]alaria kills at least 100,000 people each year" worldwide, and it noted that malaria-carrying mosquitoes are now found in areas where malaria has never existed before.[61] Moreover, malaria has returned to countries like Peru, largely as a result of climate change and deforestation. In Peru, malaria was almost eradicated 40 years ago, but this year 64,000 cases have been registered in the country, half in the Amazon region. It is thought there are many more unregistered cases deep within the massive and humid rainforest, where health authorities find it almost impossible to gain access.[62]
Malaria is also endemic in the United States, if currently essentially eradicated;[63] thus, the resurgence of the disease in Peru provides a cautionary note for Americans.

"WHO also estimates that there may be 50 million cases of dengue infection around the world every year, of which half a million will require hospitalization. About 12,500 of the cases will be fatal."[64] Dengue fever epidemics are currently spreading through South America,[65] and the disease has spread up both coasts of Mexico to the United States border, with a small number of noted cases in South Texas.[66] Indeed, the Centers for Disease Control and Prevention (CDC) have already warned health officials in Texas

59. Raju Gopalakrishnan, *Climate Change a Factor in Deaths from Disease: WHO*, ENVTL. NEWS NETWORK, Apr. 7, 2008, http://www.enn.com/top_stories/article/29980.

60. Titus, *supra* note 3, at 145.

61. Gopalakrishnan, *supra* note 59.

62. Andrés Schipani & John Vidal, *Malaria Moves in Behind the Loggers*, THE GUARDIAN, Oct. 30, 2007, http://www.guardian.co.uk/world/2007/oct/30/environment.climatechange.

63. Centers for Disease Control and Prevention, Eradication of Malaria in the United States (1947-1951), http://www.cdc.gov/malaria/history/eradication_us.htm (last visited April 9, 2008).

64. Gopalakrishnan, *supra* note 59.

65. Marcela Valente, *South America: Climate Change Fuels Spread of Dengue Fever,* INTER PRESS SERVICE, Mar. 19, 2007, http://ipsnews.net/news.asp?idnews=36994.

66. Centers for Disease Control and Prevention, Dengue Fever, http://www.cdc.gov/ncidod/dvbid /dengue (last visited April 12, 2008).

to look for the disease's emergence there.[67] Sea-level rise in the Gulf of Mexico could thus help to provide the breeding grounds that will introduce dengue fever to the United States.

B. Sea-Level Rise and Sea-Borne Diseases

The sea itself is a reservoir of disease bacteria and viruses, and rising sea levels could expose new and more extensive populations to these diseases. For example, cholera outbreaks are "associated with drinking or bathing in unpurified river or brackish water" but also appear to be linked to climate and temperature.[68] Moreover, the cholera bacterium (*Vibrio cholerae*) has a sea stage, during which copepods (a type of tiny animal, or zooplankton) act as host organisms. According to researchers investigating the link between climate change and cholera, "[c]limate, seasonal weather changes and seasonal changes in ocean currents affect the growth of copepods."[69] Thus, researchers hope that by measuring ocean parameters such as temperature and plankton blooms, they will be able to provide "an early warning system for cholera, enabling an effective deployment of resources to minimize or prevent cholera epidemics . . . ."[70]

Cholera-carrying copepods "live[] in salt or brackish waters, including rivers and ponds, and travel[] with currents and tides. Copepods harbour both dormant, nutrient-deprived and culturable *Vibrio*. The bacteria can survive as an inactive sporelike form—dormant but still infectious—in the gut and on the surfaces of copepods in between epidemics."[71] Moreover, ships transport a very large number of copepods—and other disease organisms—in ballast water.[72]

Evidence indicates that "cholera outbreaks occur shortly after sea-surface temperature and sea-surface height are at their zenith."[73] Thus, sea-level rise, in connection with changes in currents and sea temperatures, could promote the spread of cholera. Moreover, cholera spreads through drinking water and, as has already been discussed,[74] one consequence of sea-level rise is contamination of drinking water supplies. Perhaps not coincidentally, therefore, in this decade—that is, within the same time-frame that climate

67. *Dengue Fever a Risk in South Texas, CDC Says*, REUTERS, Aug. 9, 2007, http://www.reuters.com/article/domesticNews/idUSN0925073120070809.

68. Brad Lobitz et al., *Climate and Infectious Disease: Use of Remote Sensing for Detection of Vibrio Cholerae by Indirect Measurement*, 97 PROC. NAT'L ACAD. SCI. 1438, 1438 (2000).

69. Rita R. Colwell, *A Voyage of Discovery: Cholera, Climate, and Complexity*, 4 ENVTL. MICROBIOLOGY 67, 67 (2002).

70. Lobitz, *supra* note 68, at 1438.

71. Colwell, *supra* note 69, at 68.

72. *Id.*

73. *Id.*

74. *Id.* at 67.

change has begun to affect ocean temperatures and ocean currents—cholera has re-emerged in epidemic form in the coastal areas of Southeast Asia, Central America, and South America.[75]

A related species, *Vibrio vulnificus*, is another sea-dwelling bacterium that can cause disease in humans. These bacteria, found in most ocean waters around the United States, "colonize filter feeding animals such as oysters, crabs and mussels, but can also be found free-living in seawater."[76] While "[m]ost people become infected with *V. vulnificus* through eating raw shellfish," the bacterium "can also cause wound infections where an open wound is exposed to seawater."[77] In addition to unpleasant but less serious effects, septicemia leading to amputation or death is one potential outcome from either route of infection.[78]

The disease potential of *Vibrio vulnificus* appears to be linked to sea temperature, and through the 20th century most identified infections occurred along the very warm Gulf of Mexico, especially in Florida. However, the emergence of *Vibrio vulnificus* disease in other parts of the world, notably Israel, has been linked to climate change and increasing temperatures.[79] Similarly, in the United States in the early 21st century, there has been an increase in the number of *Vibrio vulnificus* infections along the Atlantic coast, stretching as far north as Delaware, New Jersey, and Rhode Island, linked to increasing sea temperatures.[80] Sea-level rise, in concert with this temperature increase, will expose new populations of humans to the *Vibrio vulnificus* bacterium, potentially increasing the disease's incidence throughout the United States.

C. Other Sea-Related Health Problems

Contaminated sea water is already the source of increasingly frequent toxic algae blooms. A variety of factors spur marine algae blooms, including temperature, nutrients from agricultural run-off, and other oceanic properties.[81] Some of these algae produce toxic chemicals, and when the algae are present in high concentrations, these toxins can affect humans and other animals. For example, sea lions in California have died when blooms of

---

75. *Id.*

76. CARINA BLACKMORE, FLORIDA DIVISION OF DISEASE CONTROL, VIBRIO VULNIFICUS (1999) http://www.doh.state.fl.us/Disease_ctrl/epi/htopics/reports/vib_vul.pdf.

77. *Id.*

78. *Id.*

79. S. Paz et al., *Climate Change and the Emergence of Vibrio vulnificus Disease in Israel*, 103 ENVTL. RES. 390, 390-91 (2007).

80. Jessica Forres, *Vibrio Bacteria a Bigger Threat to Swimmers than Sharks as Northern Waters Warm*, STORIES THAT MATTER, May 23, 2007, http://www.storiesthatmatter.org/index.php?option=com_content&task= view&id=123.

81. *The Rising Tide of Ocean Plagues: How Humans are Changing the Dynamics of Disease,* EUREKALERT, Feb. 17, 2006, http://www.eurekalert.org/pub_releases/2006-02/s-trt021206.php.

certain marine algae produce domoic acid.[82] As with *Vibrio vulnificus* disease, sea-level rise will take these public health threats inland to new populations.

Even melting ice could potentially expose people to long-forgotten diseases. In 2006, Dr. Scott Rogers, a Bowling Green State University biologist, reported "the potential for long-dormant strains of influenza, packed in ice in remote global outposts, to be unleashed by melting and migratory birds."[83] As a result, melting ice could expose human populations to strains of flu, such as the virus that caused the 1918 flu pandemic, against which human immunity has died out.[84] Dr. Scott contends this "information could be used to help develop inoculation strategies for the future."[85]

D. Disease-Related Adaptation Measures

The connection between sea-level rise and disease suggests another set of adaptation strategies that coastal states and local governments might pursue: public health preparedness. The medical profession in the United States is generally unaccustomed to dealing with malaria, dengue fever, and cholera, especially in epidemic proportions, and *Vibrio vulnificus* and algae blooms are already presenting new medical challenges to many coastal communities. Therefore, training medical personnel in these communities to recognize and treat these diseases and other sea-related health issues would seem to be an appropriate adaptation strategy. Such training, moreover, will help to ensure that coastal medical communities recognize these diseases if and when they emerge, allowing public health officials to implement control measures and to engage in larger-scale public health preparation in case of epidemics.

IV. SEA-LEVEL RISE AND TOXIC LAND USES: REDUCING CHEMICAL CONTAMINATION AS THE WATERS RISE

As every tide pooler or beachcomber caught out by the incoming high tide learns, it's not the creep that gets you—it's the surge. Similarly, many of the public health dangers of sea-level rise derive not from the year-to-year millimeter-by-millimeter increases in average sea level, but rather from the increased destructive potential of storms.

---

82. *Id.*

83. *Flu Can Bide Time in Icy Limbo Before Re-Emerging, Biologist Believes*, SCIENCE DAILY, Nov. 28, 2006, http://www.sciencedaily.com/releases/2006/11/061127210430.htm.

84. *Id.*

85. *Id.*

A. Sea-Level Rise and Storm Damage

According to James Titus, sea-level rise provides "a higher base upon which storm surges could build; if sea level rises 1 m[eter], an area flooded with 50 cm [centimeters] of water every 20 years today would then be flooded with 150 cm every 20 years; [and] surges would also penetrate farther inland."[86] "The higher base for storm surges would be particularly important in areas where hurricanes are frequent," such as the southeastern United States.[87] In addition, as sea level rises, the sea erodes coastal shores and submerges protective features such as barrier islands, beaches, and dunes, which would otherwise protect coastal property and infrastructure.[88] Loss of wetlands, mangroves, and marshes means that storm surges travel faster and with less friction through estuaries, increasing coastal flooding from storms.[89] Finally, sea-level rise also increases the coast's vulnerability to flooding from rain storms and river surges because of decreased drainage.[90] As a result, according to the EPA, "existing development in the U.S. Coastal Zone would experience a 36-58 percent increase in annual damages for a 1-foot rise in sea level, and a 102-200 percent increase for a 3-foot rise."[91]

Storm-related complications are particularly likely to impact the southeast. In 2000—before the hurricane years of 2004 and 2005—the first *National Assessment of the Potential Consequences of Climate Variability and Change* had already noted that "[t]he US experienced 42 weather-related disasters over the past 20 years that resulted in damage/costs in excess of $1 billion each; 23 of these occurred in the Southeast, mostly in the form of floods and hurricanes."[92] The assessment specifically recognized that "[p]rojected sea-level rise could increase the risk from flooding to low-lying coastal counties from the Carolinas to Texas, which could adversely impact human health, threaten lives and cause extensive economic damage."[93] Thus, this hurricane-prone area of the country should be particularly interested in adaptation measures that could reduce the public health impacts of storms.

---

86. Titus, *supra* note 3, at 142.
87. *Id.* at 143.
88. *Id.* at 142-43.
89. *Id* at 143.
90. *Id.*
91. Coastal Zones and Sea Level Rise, *supra* note 17; *see also* EZRA MILLSTEIN, IMPACTS OF CLIMATE CHANGE IN THE UNITED STATES: SOUTHEAST, AN OVERVIEW (1999) http://www.climatehotmap.org/impacts/florida.html ("The impact from storm surge will intensify as sea level rises and natural coastal defenses deteriorate. Thus, even if hurricanes do not become more frequent and intense, they are likely to cause more damage.").
92. MILLSTEIN, *supra* note 91.
93. *Id.*

B. Post-Storm Contamination and the Lessons of Hurricane Katrina

If Hurricane Katrina taught us anything, it's that what matters isn't just the volume and the force of the seawater itself, but also what the seawater brings with it. During that storm, according to engineers who studied New Orleans, "[s]everal chemical plants, petroleum refining facilities, and contaminated sites, including Superfund sites, were covered by floodwaters. In addition, hundreds of commercial establishments, such as service stations, pest control businesses, and dry cleaners, may have released potentially hazardous chemicals into the floodwaters."[94] In addition, the soils around industrial New Orleans were already contaminated with metals, and construction lumber in the area was "preserved with creosote, pentachlorophenol, and arsenic."[95] Flooding added oil and gasoline (from about 400,000 flooded vehicles) and biological wastes (i.e., feces and sewage) from both humans and animals.[96] According to the EPA and CDC, as reported in the *New York Times* ten days after Hurricane Katrina hit New Orleans, "[t]ests of water covering New Orleans showed excessive levels of E. coli bacteria and lead, . . . providing the first confirmation that the floodwaters caused by Hurricane Katrina are posing health risks for emergency response workers and residents who have remained in the city."[97]

As will be the case with sea-level rise, floodwaters in New Orleans did not recede immediately, worsening the spread of toxics and contagions. "Floodwaters were present in the city from the passage of the storm on August 29, 2005, until the city was declared dewatered by the U.S. Army Corps of Engineers on October 11."[98] In 2007, two Tulane University sociologists reported as follows:

> We now know that at a minimum, the floodwaters contained a complex mixture of contaminants. Some areas of the city soaked for weeks in a bath of heavy metals such as arsenic, lead, mercury, and zinc along with *Escherichia coli* and fecal coliforms, overcoated by a thin layer of petroleum-based volatile organic compounds (VOC).[99]

---

94. Danny D. Reible et al., *Toxic and Contaminant Concerns Generated by Hurricane Katrina*, 36 THE BRIDGE No. 1, Spring 2006, http://www.nae.edu/NAE/bridgecom.nsf/weblinks/MKEZ-6MYQQP?OpenDocument.

95. Reible, *supra* note 94.

96. *Id.*

97. Michael Janofsky, *Level of Bacteria is Found Unsafe*, N.Y. TIMES, Sept. 8, 2005, *available at* http://www.nytimes.com/2005/09/08/national/nationalspecial/08enviro.html?_r=1&adxnnl= 1&oref=slogin&adxnnlx=1207761485-xTuY4rRcfCFIrvcDjEOT/A.

98. Reible, *supra* note 94.

99. For example,

Most directly relevant to the immediate spread of human disease, testing of the floodwaters revealed bacterial concentrations of "great concern."[100] The EPA and CDC were initially concerned only about lead and *E. coli* levels, both of which they found present at concentrations ten times those considered safe.[101] Such concerns were, of course, warranted. *E. coli* is a common species of fecal coliform, and if it contaminates drinking water, it can cause serious illness and even death. Other post-Katrina testing in New Orleans revealed that fecal coliform concentrations were 50 times greater than primary contact water quality standards would allow.[102] That testing also revealed high concentrations of *Aeromonas* pathogens, which cause wound infections and diarrhea, in the floodwaters, fresh waters, and soil.[103] Moreover, according to the Natural Resources Defense Council (NRDC):

> In the days immediately following the storm as many as 185 of the 683 drinking water facilities in the state were unable to provide clean, safe water to residents. In New Orleans, the storm ruptured more than 20,000 water pipes and there were published estimates of 100 million gallons of water per day leaking underground throughout the system during the months following the flooding.[104]

Thus, New Orleans arguably narrowly avoided a water-borne illness disaster.

Even after the floodwaters receded, soil contamination remains, creating longer-term risks of poisoning. Shortly after Katrina, levels of arsenic, iron, lead, and polycyclic aromatic hydrocarbons (PAHs) exceeded EPA Region 6's Human Health Specific Screening Levels, measures used to evaluate health risks from soil contamination.[105] Moreover, risks from toxic contamination have continued to linger. In March 2007, the NRDC, as part of a continuing testing program in New Orleans, reported that "nearly 25 percent of the 35

> When Hurricane Katrina tore through New Orleans in August 2005, the levee failures inundated the city—particularly its most vulnerable neighborhoods—with a hazardous sea of fuel, sewage, and chemicals. Floodwaters containing pathogens from raw sewage and toxic contaminants from oil spills, pesticides, and hazardous waste poured into neighborhood streets, leaving behind thick sediment inside homes, in parks, and on lawns.

Scott Frickel & M. Bess Vincent, *Hurricane Katrina, Contamination, and the Unintended Organization of Ignorance*, 29 TECH. IN SOC'Y 181, 182 (2007); *see also* LESLIE FIELDS ET AL., NATURAL RESOURCES DEFENSE COUNCIL, ARSENIC-LACED SCHOOLS AND PLAYGROUNDS PUT NEW ORLEANS CHILDREN AT RISK 4 (Aug. 2007), *available at* http://www.nrdc.org/health/effects/wake/wake.pdf.

100. Reible, *supra* note 94.

101. Janofsky, *supra* note 97.

102. Reible*, supra* note 94 (reporting median concentrations of 10^4 MPN/100 mL when the primary contact water quality standard is 200 MPN/100 mL).

103. *Id.*

104. FIELDS, *supra* note 99, at 5 (citation omitted).

105. *Id.* at 4.

New Orleans playgrounds and schoolyards tested two years after Katrina may be classified as arsenic 'hot spots.'"[106] As the NRDC further explained:

> Arsenic is toxic to humans and is known to cause cancer; no amount is considered fully safe. Many scientific studies, including numerous reviews by the National Academy of Sciences, have determined that arsenic can cause cancer of the bladder, skin and lungs; likely causes other cancers; and can cause a variety of other serious health problems, including birth defects, cardiovascular disease, skin abnormalities, anemia, and neurological disorders.[107]

The soil contamination levels are significantly higher than the arsenic soil contamination levels before Katrina,[108] testifying to the continuing legacy of the contaminated floodwaters.

C. Public Health-Based Adaptation Measures

The public health threats created by Hurricane Katrina and its flooding suggest several sea-level rise adaptation measures that coastal states and local coastal governments should consider, especially in areas subject to hurricanes and other violent storms, the effects of which sea-level rise will likely intensify. At a minimum, the contamination caused by Katrina counsels city engineers and the drafters of state and local building codes to demand that potentially toxic and/or biologically contaminative facilities—sewage treatment plants, solid and hazardous waste disposal facilities, chemical manufacturers, power plants, oil and gas facilities, military facilities, etc.—meet stringent design and maintenance requirements intended to seal potential contaminants within sea water-proof buildings and containers when storms occur. In addition, expedited cleanup of existing and new contaminated sites—federal Superfund sites and their state and unofficial equivalents—should be a priority in all coastal areas.

More ambitious coastal states and communities might also consider new siting requirements for facilities that could cause contamination, in addition to design and maintenance requirements. Such requirements, for example, might mandate that all new potentially contaminating facilities be built above a certain sea-level elevation. Governments should key the elevation mandated to the expected life of the facility and the high end of the projected sea-level rise in that locality over that expected facility life (with margins of safety added to each estimate). For example, if a facility is expected to last sixty years and sea-level rise estimates for the locality over the next seventy-five years range

106. *Id.*
107. *Id.* at 5.
108. *Id.* at 10 fig.1.

from six inches to five feet, the state or local government might mandate that the facility be built at least eight to ten feet above current sea level.

The most ambitious coastal states and local governments could use the public health threats from Katrina as the justification for initiating a coastal retreat policy. Such a policy might mandate that, as potentially contaminating facilities within the coastal zone close in the course of normal economic turnover, the owner completely dismantle the facility and restore the property to clean and relatively "natural" conditions. The property would then be subject to an eminent domain purchase by the state. The Takings Clause of the Fifth and Fourteenth Amendments to the U.S. Constitution likely prohibits states and local governments from requiring abandonment without compensation, although at some point public necessity and quarantine-/vaccination-/forced immunization-like public health arguments may obviate the need for payment.[109] However, in the near term, the existence of forced clean-up laws, such as the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[110] and the corrective action provisions of the federal Resource Conservation and Recovery Act (RCRA),[111] probably eliminate the need for governments to pay full commercial market value for those properties.

Importantly, all of these measures are immediately beneficial to storm-prone coastal communities. As Katrina demonstrated, coastal communities already face significant risks from storm-based contamination, regardless of how high seas eventually rise, how fast they encroach, or how much additional destruction sea-level rise causes. The contemporary benefits of implementing measures to reduce the toxicity and disease potential of coastal storms could render these building code, clean-up, and land use measures politically palatable now as well as beneficial for future climate change adaptation.

CONCLUSION

Despite its relatively slow progress and uncertainties, climate change-related sea-level rise is occurring, and it appears to be occurring more rapidly and to a greater potential height than originally expected. Given the extensive development of and humanity population density within most coastal areas in the United States, climate change-driven sea-level rise creates enormous public policy issues. Among the most important "is whether to retreat or hold back the sea."[112] To date, neither the United States as a whole, nor individual coastal states, have provided definitive answers regarding this most basic of choices. Moreover, either choice requires significant political will and large

109. *See, e.g.*, Michael A. Hiatt, *Come Hell or High Water: Reexamining the Takings Clause in a Climate Change Future*, 18 DUKE ENVTL. L. & POL'Y F. 371, 381 (2008) (noting that "the government should not have to pay to regulate behavior or land use that is harmful to the public health. . .").

110. 42 U.S.C. § 9607(a).

111. 42 U.S.C. § 6924(t)-(v).

112. Titus, *supra* note 3, at 150.

amounts of money to be implemented rationally and in an environmentally protective way.[113] However, reduced fresh water supplies in the coastal zone may force a default position of haphazard and environmentally detrimental abandonment, if water supplies become insufficient to support the coastal population.

While the politicians and the public choose to ignore rather than debate that ultimate choice—and I happen to fall on the side of retreat—there are still steps worth taking to protect the public health from some of the more predictable effects of sea-level rise. Salt-water intrusion into coastal surface waters and aquifers is already occurring and will only increase. As a result, public water supply agencies should be working to ensure adequate supplies of clean drinking water for coastal residents before the lack of such water becomes a public health problem. Sea-level rise will create new reservoirs of warm, brackish, stagnant water, perfect for breeding mosquitoes that can transmit malaria, dengue fever, and a host of other tropical mosquito-borne diseases, while the warming sea will itself harbor increasing concentrations of opportunistic viruses and bacteria such as cholera and *Vibrio vulnificus* and promote increasing numbers of harmful algae blooms. Some of these diseases, such as malaria, represent the return of health problems long thought vanquished in the United States; others, like dengue fever, represent entirely new disease for the American medical community. Preparation for these diseases should begin now, including training for medical staff in coastal areas and, as it becomes appropriate, public education regarding avoidance, control, signs and symptoms, and treatment. Finally, Hurricane Katrina taught us that the coastal zone can become a toxic soup when storms and high seas strike. Given the interaction of sea-level rise, projected increases in the severity of storms as a result of climate change, and the increase destructive potential resulting from this combination, coastal communities should at least impose siting and construction restrictions with respect to power plants, chemical factories, waste treatment and disposal facilities, sewage treatment plants, coastal septic systems, and similar facilities, and perhaps begin to engage in limited retreat from the sea.

---

113. As several researchers have noted, "coastal ecosystems could migrate inland; however, in many cases human development poses an obstacle to that migration." MILLSTEIN, *supra* note 91.