CHAPTER 8

PLACING THE RESULTS IN CONTEXT

Revisions of Sea Level Rise Scenarios

Long-range projections of physical, economic, and ecological systems often prove to be wrong, because they involve combinations of assumptions with varying degrees of certainty. Moreover, with a highly visible public policy issue such as climate change, the projections themselves can motivate people to take actions that render early projections obsolete (*e.g.*, projections of a 4˚C global warming could lead people to reduce emissions so that the warming is only 2˚C).

This report and other recent analyses suggest that sea level is likely to rise less than estimated by early reports on the subject (see Table 8-1).[1] The lower estimates have resulted from both a downward revision of future temperatures and an emerging consensus that Antarctica will probably not contribute to sea level in the next one hundred years.

Lower Global Temperatures. In the last decade, estimates of the global warming likely to occur by the year 2100 have been approximately cut in half. The 1983 reports by EPA and the National Academy of Sciences assumed that the radiative forcing equivalent of a CO_2 doubling was likely to occur by 2050. During the mid-1980s, several reports suggested that an effective CO_2 doubling could occur by the 2030s (*see e.g.*, Villach 1985). Thus, the EPA reports released in 1983 projected a warming of 3 to 9˚C by 2100, with CO_2 and other greenhouse gases accounting for equal amounts of warming (Hoffman et al. 1983; Seidel & Keyes 1983). The NAS (1983) report projected a warming of 1 to 5˚C from CO_2 alone and was thus viewed as being consistent with the EPA results (*see e.g.*, Chafee 1986). EPA's 1989 Report to Congress (Smith & Tirpak 1989) was based on similar assumptions, as shown in Table 8-2. For the most part, scenarios of sea level rise for the year 2100 were in the 50 to 200 cm range, with 100 cm being the most likely.

TABLE 8-1
CLIMATE CHANGE CONTRIBUTION
TO SEA LEVEL PROJECTED
BY VARIOUS STUDIES

A. Total Greenhouse Contribution to Sea Level by 2100 (cm)

	Low	Medium	High
EPA (1983)[a]	56	175	345
NAS (1985/1983[b])	50	100	200
NRC (1987)	50	100	150
IPCC (1990)	30	65	110
Wigley & Raper (1992)	15	48	90
This Report[c]	–1	34	104

B. Contribution to Thermal Expansion by 2100 (cm)

	Low	Medium	High
EPA (1983)[a]	28	72	115
NAS (1983)	24	30	36
NRC (1987)	—	—	—
IPCC (1990)	26	39	58
Wigley & Raper (1992)	22	33	44
This Report[c]	–1	20	58

[a] EPA (1983) refers to Hoffman et al. 1983.
[b] Thermal expansion from NAS 1983; glacial contribution from NAS 1985.
[c] Low and High refer to lower and upper 1 percent.

---

[1] Unlike some recent assessments by IPCC (1990, 1992) and Wigley & Raper (1992), this report still projects a significant risk that sea level will rise more than one meter by the year 2100; *i.e.*, our downward revision applies more to the "best estimate" than to the high end of the uncertainty range.

TABLE 8-2
GLOBAL WARMING PROJECTED BY VARIOUS STUDIES

A. Warming Over 1990 Levels

Report	2050 Low	2050 Medium	2050 High	2100 Low	2100 Medium	2100 High	CO_2 = 600 ppm Doubling Date
EPA (1983)[a]	0.7	2.4	4.5	2.1	5.0	9.0	2050
NAS (1983)[b]	—	—	—	—	4.5	—	—
NAS (1985)	—	—	—	1.5	3.0	4.5	2085
EPA (1989)[a]	—	3.0	—	—	—	—	2060
IPCC (1990)	1.3	1.6	2.5	2.3	3.7	5.7	2060
IPCC (1992)[c]	1.0	1.4	2.2	1.8	2.8	4.2	2060
Wigley & Raper (1992)[c]	0.8	1.2	1.7	1.7	2.5	3.8	2060
This Report[d]	–0.1	1.0	2.9	–0.1	2.0	6.3	2080

B. Year by Which Temperatures Warm 2˚C or 4˚C

Temperature Report	2˚C Low	2˚C Medium	2˚C High	4˚C Low	4˚C Medium	4˚C High
EPA (1983)[a]	2095	2040	2017	>2100	2085	2040
NAS(1983)[b]	2050	2030	2020	—	2080	—
NAS (1985)		2050		2050	>2100	>2100
EPA(1989)[a]	—	2035	—	—	2060	—
IPCC(1990)	2090	2060	2040	>2100	>2100	2085
IPCC (1992)[c]	2105	2075	2045	>2100	>2100	2095
Wigley & Raper (1992)[c]	>2100	2080	2060	>2100	>2100	>2100
This Report[d]	>2200	2099	2030	>2200	>2200	2065

[a] EPA (1983) refers to Seidel & Keyes (1983); EPA (1989) refers to Smith & Tirpak (1989).
[b] CO_2 only. Analyses based on assumption of 2˚C warming "a few decades into the 21st century" and 3 to 4˚C by 2080.
[c] IPCC (1992) and Wigley & Raper (1992) results use IPCC emissions scenario A.
[d] Low and High refer to upper and lower 1 percent.

Recent reports have gradually lowered the projections of future warming, primarily for three reasons. First, in the mid-1980s the fully halogenated CFCs were perceived as potentially responsible for about one quarter of the expected warming (*Cf. e.g.*, Ramanathan et al. 1985). These CFCs are no longer considered likely to contribute significantly to global warming by the year 2100[2]: The Montreal Protocol phases out their production. Moreover, the direct greenhouse effect from CFCs in the troposphere is partly offset because CFCs deplete stratospheric ozone, which is also a greenhouse gas. Although the partially halogenated HCFCs have not yet been regulated, IPCC has reduced its projections for these gases as well. For example, IPCC (1992) estimated that by the year 2100 the concentration of HCFC-22 will be 1.4 parts per billion, less than half the IPCC (1990) estimate of 3 ppb.[3]

Second, estimates of the concentrations of carbon dioxide have also been revised downward because of both lower emissions and revised carbon cycle models. The EPA studies released in 1983 assumed that CO_2 emissions were most likely to reach 70 gigatons per year by 2100. The IPCC (1992) Scenario A, by contrast, estimates about 20 Gt/yr; and even the high scenario E only projects 35 Gt/yr.[4] Thus, the IPCC (1990) and (1992) reports projected CO_2 concentrations of 825 and 800 ppm, respectively, well below the 1000 ppm projected by the early EPA studies.[5]

Recent revisions in carbon cycle models have also resulted in lower estimates of carbon dioxide concentrations. Wigley (1993) concluded that more carbon may be absorbed by the terrestrial biosphere than previously assumed; he estimated 678 ppm as the most likely scenario for 2100 if emissions follow the trajectory of IPCC (1992) Scenario A. IPCC (1994) applied several alternative carbon cycle models to IPCC Emissions Scenario A; all of the models project a CO_2 concentration between 650 and 725 ppm.[6] Our median estimate is 680 ppm.

Finally, temperature projections have declined because the early studies did not consider the cooling effect of atmospheric sulfates and other aerosols resulting from human activities. Since 1850, aerosols appear to have offset about one-third of the radiative forcing from greenhouse gases.[7] Because aerosols rapidly fall out of the atmosphere while greenhouse gases may accumulate for tens or hundreds of years, the relative contribution of aerosols will probably be less in the next century than it has been in the last century. Nevertheless, as discussed in Chapter 2, the IPCC emissions scenarios imply that sulfates are likely to offset about 8 percent of the increased radiative forcing from greenhouse gases over the period 1990–2100.[8]

In spite of the downward revisions in future temperature projections, one potential downward revision has *not* occurred: climatologists still generally accept the NAS (1979) estimate that, in equilibrium, a CO_2 doubling would raise global temperatures 1.5 to 4.5˚C. The cooling effect of aerosols offers a plausible explanation for why global temperatures have not risen as much as climate models would have suggested.[9] Wigley &

---

[2] For example, under IPCC's emissions scenario A, CFC-11 and CFC-12 are expected to contribute 0.2 W/m^2 by the year 2100, about 3 percent of the total radiative forcing from anthropogenic greenhouse gases. Because the current contribution of these two CFCs is about 0.22 W/m^2, IPCC scenario A implies a slight decrease in radiative forcing from CFC-11 and CFC-12. IPCC (1992) at 175.

[3] HCFC-22 is by far the most important partially halogenated chlorofluorocarbon. IPCC (1992) estimates that the radiative forcing due to HCFC-22 will rise from close to zero today to approximately 0.2 W/m^2.

[4] *But see* Energy Modeling Forum (1995). Out of eight models considered, four models project emissions greater than the 26.6 Gt/yr assumed by IPCC's (1992) second highest scenario (F). Two of the models project emissions greater than IPCC's highest scenario (E); and one of the scenarios exceeds 55 Gt by the year 2090. *See Id.* at slide entitled "Modeler's Reference Case, World."

[5] The EPA and IPCC reports all projected concentrations of about 600 ppm for the year 2060. Because of the lags in the various processes, the divergence in assumptions for the post-2060 period has a modest effect on projections of sea level rise for the year 2100.

[6] *But see* Craig & Holmén (1995) (applying four different models for balancing the carbon budget to IPCC emission Scenario A results in CO_2 concentrations of 825, 725, 700, and 690 ppm for 2100).

[7] *See* IPCC (1994) at 167 (The direct radiative forcing from anthropogenic greenhouse gases released since preindustrial times is 2.4 W/m^2 ±15%; the mean direct radiative forcing from sulfates is –0.25 to –0.9 W/m^2; the mean direct radiative forcing from biomass burning is between –0.05 and –0.6 W/m^2).

[8] The IPCC scenarios do not assume that any governmental policies will be implemented to reduce SO_2 emissions, other than those already enacted before 1992. Just as the effects of SO_2 on plants and human health, and eventually acid rain, led the United States and other industrial nations to implement policies to reduce SO_2 emissions, developing nations may also choose to reduce their emissions, in which case the cooling effect of sulfates will be less than implied by the IPCC scenarios.

[9] The extent to which sulfates have offset greenhouse warming can be displayed by comparing world maps showing temperature trends with world maps showing estimated radiative forcing from sulfates. For example, the world map of estimated sulfate forcing, published in IPCC (1994) at 31, shows the greatest sulfate impacts over Europe, China, and the eastern United States. A world map of temperature trends shows that virtually all of the Northern Hemisphere has warmed by more than 1˚C in the last fifty years, except for Europe, China, and the Eastern United States (Kerr 1995 (citing Karl et al. (1995) at Figure 2)). *See also* Mitchell et al. 1995.

Raper (1992) showed that when sulfates are included, the historic change in global temperatures has been consistent with a climate sensitivity of 2.5 to 3.0˚C, which is near the middle of the 1.5 to 4.5˚C range.

The net effect of the various revisions is that the best-guess estimate for global warming by the year 2100 is about 2˚C—half the warming that was expected during the mid-1980s. Thus, even if there were no revisions in our understanding of the impact of global warming on sea level, one might reasonably expect the 50 to 200 cm greenhouse contribution to sea level rise to be cut in half. That appears to have happened: The Wigley & Raper estimate of 48 cm is almost exactly one-half the earlier best-guess estimate of 1 m; and their range of 15 to 90 cm is only slightly below the 25 to 100 cm range that would be expected if the sea level contribution was proportional to warming. Our 1%-high estimate of 1 m also reflects such a revision.

Antarctic Contribution. Changing projections of future temperatures is not the only reason that sea level projections have been revised. Estimates of the likely contribution from Antarctica have also been revised downward. A decade ago, NAS (1985) projected that by 2100, Antarctica could contribute anywhere from −10 to +100 cm, with a contribution in the tens of centimeters most likely. More recent assessments, however, have generally concluded that the initial Antarctic contribution will probably be negative. Since NAS (1985), polar scientists have recognized the possibility that increased snowfall could at least partially offset any positive contribution to sea level from the Antarctic Ice Sheet's response to warmer temperatures. Since IPCC (1990), however, most studies have suggested that the ice sheet's response may be small and thus more than offset by increased precipitation, at least for the next century.[10]

Although a significant positive Antarctic contribution is not likely by 2100, such a contribution is still a risk that must be considered, both for calculating the likely rise by the year 2200 and for examining the 1%-high scenario. In the last fifty years, the Antarctic Peninsula has warmed 2˚C, causing the peninsula alone to contribute approximately 0.5 mm to sea level. (Drewry & Morris 1992). The Wordie and Prince Gustav Ice Shelves have largely disintegrated in the last few decades; around Larsen inlet, the ice shelf has retreated 10 to 15 km. In early 1995, an iceberg with an area of more than 2000 km^2 (the size of Rhode Island) broke away from the Larsen Ice Shelf. Until recently, James Ross Island was connected to the Peninsula by ice shelves; but now it is circumnavigable.

No one has demonstrated that these recent events around the Antarctic Peninsula were caused by global warming, nor that these events are a precursor to a disintegration of any of the other ice shelves. Nevertheless, these events lend some credence to the assumptions provided by the glaciology reviewers (Chapter 5), which generally imply that the NAS (1985) high estimate of a 100 cm contribution from Antarctica still has some validity, albeit for the year 2200 rather than 2100. Our attempts to quantify this risk should not obscure the primary reason for recognizing it: *The processes that determine warming of the circumpolar ocean, the melting of ice shelves, and the speed at which glaciers flow are very poorly understood*. The assessment that Antarctica will not make a major contribution is based on the assumption that the water intruding beneath the ice shelves will warm less than 1˚C in the next century; until there is a consensus among climate modelers on this point, one cannot reasonably rule out the possibility of a significant Antarctic contribution in the next century.

Changes in models of Greenland, mountain glaciers, and thermal expansion have also led to minor downward revisions of the sea level projections. Their combined impact, however, is small compared with the uncertainty regarding Antarctica and global temperatures.

How Should Sea Level Rise Scenarios Be Used?

In the last decade, coastal managers have increasingly incorporated information on sea level rise into decisionmaking. The gradual downward revision has not substantially reduced the use of these scenarios. Possible explanations include: the fact that most decisionmakers did not believe the high scenarios anyway; the existence of tidal gauge measurements—and recent satellite observations—

---

[10] The downward revision of the estimated ice sheet response has resulted partly from lower global temperature projections. The NAS (1985) analysis assumed a 4˚C global warming by 2050, whereas a 1.0 to 1.5˚C warming by that date now seems more likely. Although there is some disagreement among glaciologists whether a 4˚C warming would cause ice streams to accelerate, there is a general consensus that a 1˚C warming by 2050 would probably not cause a major impact by 2100.

showing that sea level is rising[11]; an increasing consensus that at least some sea level rise will result from global warming; and increased understanding among coastal scientists, engineers, and policy makers that even a small rise in sea level can have important consequences.

Sea level scenarios have been used to (1) encourage and guide additional research and modeling efforts; (2) justify modifications of engineering designs; (3) alter the land-use planning process to accommodate rising sea level; and (4) develop impact assessments to help national policymakers decide the appropriate level of attention warranted by the global warming issue.

Encouraging Additional Efforts. A draft by Hoffman et al. (1982) was the first effort by EPA or anyone else to estimate future sea level for specific years for the purpose of encouraging coastal decision makers to address rising sea level. A previous analysis by Schneider & Chen (1980) had examined the potential implications of a 5 to 8 m rise in sea level due to a collapse of the West Antarctic Ice Sheet, suggesting that such an occurrence could conceivably occur within several decades. But the purpose of that study was to alert society to the risks of CO_2 emissions, not to motivate coastal officials to change their own policies.

The Hoffman et al. (1982) draft was sent to every U.S. coastal state, as well as one hundred scientists. That draft and the final EPA report quickly spurred three panels of the National Academy of Sciences to consider how to project sea level for specific years. In the NAS Climate Research Board's 1983 report, *Changing Climate*, Roger Revelle estimated that, in the course of a century, Greenland and small glaciers could each add 12 cm to sea level if the Earth warms 3 to 4˚C; he estimated that a 70 cm rise in one hundred years was most likely. Two years later, the NAS Polar Research Board, assisted by the U.S. Department of Energy, provided the first detailed assessment of the potential glacial contribution to sea level (NAS 1985); that report adopted EPA's convention of estimating sea level through the year 2100. Recognizing the superior expertise of the Polar Research Board, EPA impact studies immediately adopted the 50 to 200 cm range implied by the Polar Research Board report,[12] suggesting that a 1 m rise was most likely.

Meanwhile, the National Academy of Engineering's Marine Board commissioned a panel to examine the engineering implications (NRC 1987), assisted by the Army Corps of Engineers. The wide range of uncertainty of the EPA scenarios led the Marine Board panel to recommend that engineers consider scenarios ranging from 50 to 150 cm by the year 2100.

Engineering Design. Rising sea level may sometimes justify designing coastal structures differently than would be appropriate if sea level was stable. In 1985, EPA examined the implications of accelerated sea level rise for the beach at Ocean City, Maryland (Titus 1985). The report noted that while groins *may* curtail erosion due to alongshore transport of sand, they do not curtail erosion due to sea level rise. Therefore, because sea level was already rising and was expected to accelerate, it would be advisable to shift from groins to placing sand onto the beach. That message was presented at dozens of public meetings and private briefings of state and local officials. Shortly thereafter, the State of Maryland decided to shift from groins to beach nourishment (*see* Associated Press (1985)).

The prospect of sea level rise was not the only reason that the state chose to shift strategies. Many geologists doubted that the groins would work anyway; and the U.S. Army Corps of Engineers was already on record as supporting beach nourishment. But sea level rise helped to provide a political environment in which the issue could be reconsidered. First, the issue prompted a series of articles in a Baltimore newspaper, which explained how barrier islands naturally respond to rising sea level, and questioned the state's then-current erosion control strategy. Second, the issue could be viewed as "new information," which made it possible to advocate beach nourishment without impugning the original decision to build groins.

Like many of the policy changes motivated by the accelerated sea level scenarios, the shift to beach nourishment was justified by *current* sea level trends. Thus, the fact that the sea level scenarios were (in retrospect) too high had little or no impact.

---

[11] *See* Chapter 9 for a sample of U.S. tide gauge trends. Recent satellite estimates suggest that global sea level rose approximately 4 mm/yr over the last three years (Nerem 1995).

[12] *See* Table 8-1, *supra*. After 1984, no EPA study used the Hoffman et al. (1983) high scenario. A few studies that were initiated before the NAS report but published later made reference to the Hoffman et al. scenarios; but accompanying text generally made it clear that the range of 50–200 cm was to be preferred. The 50–200 cm range was also used in a 1989 report to Congress (Smith & Tirpak 1989) and in EPA-funded studies of Senegal, Nigeria, Venezuela, Argentina, and Uruguay (*e.g.*, IPCC 1995).

More recently, a number of design standards have added an extra 30 to 100 cm to account for future sea level rise. By 1987, California's Bay Area Conservation and Development Commission (BCDC) was requiring an additional one foot of elevation on any newly reclaimed land in San Francisco Bay, based on a scenario of a one-foot rise in fifty years. Perhaps if it had waited for improved scenarios, the BCDC might have chosen to require only an additional nine inches of elevation; but given the long lifetimes of land reclamation projects, it seems just as likely that the Commission would have employed the same standard while citing a longer time horizon. Reclamation in Hong Kong also includes a safety margin for accelerated sea level rise, as do the design of new seawalls in eastern Britain and the Netherlands (Nichols & Leatherman 1995).

Land Use: Planning and Regulation. The early EPA studies helped to motivate two states to alter their land use regulations in the coastal zone. EPA's first case study (Barth & Titus 1984) examined Charleston, South Carolina, and provided maps showing the areas that would be permanently inundated or periodically flooded with various sea-level scenarios ranging from 30 to 350 cm. At a conference presenting the results, an official from the Chamber of Commerce stated that he "wished EPA had studied Savannah [Georgia] instead," fearing that the prospect of sea level rise might scare away business. But businesses do not generally base relocation decisions on potential flooding that might occur in the year 2100, especially in areas that are currently vulnerable to hurricanes.

The State of South Carolina was concerned, however, about its eroding beaches. The State Legislature appointed a "Blue Ribbon Panel," which examined the risks to the shoreline. Motivated in part by EPA's projection that sea level could rise one foot in the next thirty years, the panel recommended that no new structures be allowed within the area most vulnerable to erosion, which it defined as a line landward of the primary dune by a distance equal to forty times the annual erosion rate. The South Carolina Legislature enacted these recommendations in a new Beachfront Management Act.[13]

Shortly thereafter, a developer named Lucas, whose lots were entirely seaward of the setback line, challenged the law as an unconstitutional taking of private property without compensation. In one of the most celebrated cases on property rights, *Lucas v. South Carolina Coastal Council*,[14] the U.S. Supreme Court agreed that he was entitled to compensation. Meanwhile, Hurricane Hugo had prompted the Legislature to slightly revise the law, so that the setback only applied to lots that had room for a house landward of the setback line. People in Lucas' situation are now allowed to build, but subject to a "rolling easement" or "special permit", which requires them to remove their structure if the beach erodes enough to put the house in harm's way.[15]

Did EPA's erroneously high estimate of a one-foot rise in thirty years prompt the Legislature to enact hasty legislation? There is little evidence that this occurred. The forty-year setback is somewhat less stringent than the sixty-year setback in neighboring North Carolina. Moreover, the Beachfront Management Act was passed four years after the EPA case study was published, and only after the extra deliberative step of a Blue Ribbon Panel. Because of the importance of *Lucas*, the Beachfront Management Act has been analyzed by dozens of legal commentators, none of whom has suggested that any flaws in the legislation resulted from unrealistically high sea level scenarios.[16] As with the Ocean City study, the Blue Ribbon Panel's analysis was not precise enough to distinguish between a one-foot rise in thirty years and one foot over sixty years.[17]

Maine's regulations are more closely linked to the sea level rise scenarios: The state's Coastal Sand Dune Rules explicitly presume the mobility of any structures that would interfere with the landward migration of sand dunes or wetlands with a rise in sea level of up to three feet.[18] Considerable technical

---

[13] S. C. Code §48-39-250 *et seq.*

[14] 112 S.Ct. 2886, 34 E.R.C. 1897 (1992).

[15] For additional details on the "Takings" implications of policies in response to sea level rise, *see* J.G. Titus, 1994, "Rising Seas, Coastal Erosion, and the Takings Clause" (draft).

[16] *See e.g.*, Richard A. Epstein, "Lucas v. South Carolina Coastal Council: A Tangled Web of Expectations", 45 *Stanford Law Review* 1369, 1377 (1993) ("The Court has provided an effective blueprint for confiscation....").

[17] For a more detailed discussion of the implications of sea level rise for the South Carolina law, *see* J. G. Titus (1994), "Rising Seas, Coastal Erosion, and the Takings Clause" (draft).

[18] "If the shoreline recedes such that the coastal wetland...extends to any part of the structure, including support posts, for a period of six months or more, then the approved structure...shall be removed and the site shall be restored to natural conditions within one year." Coastal Sand Dune Rules. Code Me. R § 355(3)(B)(1) (1987).

discussions took place as the state debated whether to use the EPA or NAS scenarios. This illustrates an information-transfer problem: by the time the regulations were issued in 1987, EPA was recommending the use of the NAS scenarios anyway.

Do the lower scenarios (if accurate) imply that even a three-foot rise was too much to plan for? As discussed in the following chapter, our analysis suggests a 7 percent chance that sea level will rise three feet along the U.S. Atlantic coast by the year 2100, and a better than fifty-fifty chance that such a rise will occur during the next two hundred years. The benefits of this regulation (if the sea does rise three feet) would have to be greater than the cost of the restrictions, which must be borne whether or not the sea rises.

Given the fact that movable structures are allowed in this area, the additional cost of the restriction may be small. The benefits depend both on (1) how soon the shore reaches a house (or the location where it would have been built without the regulation) and (2) the reduction in the cost of moving the structure as a result of having designed it to be moved (or the additional time it takes to reach the structure because it was built farther from the shore).[19] Although evaluating the impact of revised sea level rise scenarios on the regulation is beyond the scope of this report, a recent study by the State of Maine suggests that the regulation has greater benefits than costs even if a 50 cm rise in sea level is most likely (Maine 1995).

Impact Assessments. Finally, sea level scenarios have been used to illustrate the implications of sea level rise for policymakers and members of the general public who need to know whether or not global warming is important, as well as people who are simply curious. Our previous estimate of the cost of a one meter rise in sea level was about twice as great as the cost of a 50 cm rise in sea level (Titus et al. 1991). Both estimates suggest that coastal communities will eventually have to develop a stable mechanism for funding coastal protection. But because the sole use of those national estimates is to gain a rough feel for the issue, not to set an appropriation, there is no practical difference between what must be done today if we expect an eventual cost of $200 billion and what we must do if the cost will only be $100 billion.

Finally, there have and will continue to be strong reasons to consider the one meter sea level rise scenario. In the United States, most maps show the 5 ft contour, which is typically about one meter above high tide. Regardless of which scenario one expects, impact analysis would be much easier if finer-resolution topographic maps were available in coastal areas. Nevertheless, it is wise to analyze a wide variety of possible scenarios.

References

Associated Press. 1985. “Doubled Erosion Seen for Ocean City.” *Washington Post*, November 14 (Maryland Section).

Barth, M.C., and J.G. Titus (eds). 1984. *Greenhouse Effect and Sea Level Rise: A Challenge for This Generation*. New York: Van Nostrand Reinhold.

Chafee, Senator John H. 1986. “Our Global Environment: The Next Challenge.” In: Titus, J.G. (ed). *Effects of Changes in Stratospheric Ozone and Global Climate.* Washington, DC: U.S. Environmental Protection Agency and United Nations Environment Programme.

Craig, S.G., and K.J. Holmén. 1995. “Uncertainties in Future CO2 Projections.” *Global Biogeochemical Cycles* 9:139-52.

Dean, R.G., et al. 1987. *Responding to Changes in Sea Level*. Washington, DC: National Academy Press.

Drewry, D.J., and E.M. Morris. 1992. “The Response of Large Ice Sheets to Climatic Change.” *Phil. Trans. R. Soc. London* B338:235-242.

Energy Modeling Forum. 1994. “EMF14: Integrated Assessment of Climate Change Models for Which Second Round Scenario Results Have Been Received as of May 10, 1995.” Stanford, CA: Energy Modeling Forum. (Available from John P. Weyant, Stanford University, Stanford, CA, 94305-4022.)

Hoffman, J.S., D. Keyes, and J.G. Titus. 1983. *Projecting Future Sea Level Rise*. Washington, DC: U.S. Environmental Protection Agency.

Hoffman, J.S., et al. 1982 (draft). *Projecting Future Sea Level Rise*. Washington, DC: U.S. Environmental Protection Agency.

Intergovernmental Panel on Climate Change. 1995. *Global Climate Change and the Rising Challenge of the Sea*. Proceedings of the International Workshop Held on

---

[19] The greatest cost savings of the regulation may be institutional cost avoided. Abandoning neighborhoods to an eroding shore is politically problematic. Without an advance understanding that such a retreat is part of the rules of the game, it may be politically infeasible to prohibit property owners from rebuilding; as a result, natural wetlands and beaches may be replaced by bulkheads. *See* Titus (1991).

Margarita Island, Venezuala, March 9–13, 1992. Silver Spring, MD: National Ocean Service, U.S. Department of Commerce.

Intergovernmental Panel on Climate Change. 1994. *Climate Change 1994. Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios*. Cambridge and New York: Cambridge University Press.

Intergovernmental Panel on Climate Change. 1992. *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment*. Cambridge and New York: Cambridge University Press.

Intergovernmental Panel on Climate Change. 1990. *Climate Change: The IPCC Scientific Assessment*. Cambridge and New York: Cambridge University Press.

Karl, T.R., R.W. Knight, G. Kukla, and J. Gavin. 1995. "Evidence for Radiative Effects of Anthropogenic Sulfate Aerosols in the Observed Climate Record." In: Charlson, R., and J. Heintzenberg (eds). *Aerosol Forcing of Climate*. Chichester: John Wiley and Sons (in press).

Kerr, R.A. 1995. "Study Unveils Climate Cooling Caused by Pollutant Haze." *Science* 268:802.

Maine, State of. 1995. *Anticipatory Planning for Sea-Level Rise Along the Coast of Maine*. First printing. Augusta: Maine State Planning Office.

Maine, State of. 1995. *Anticipatory Planning for Sea-Level Rise Along the Coast of Maine*. Second printing. Washington, DC: U.S. Environmental Protection Agency (Climate Change Division).

Mitchell, J.F.B., R.A. Davis, W.J. Ingram, and C.A. Senior. 1995. "On Surface Temperature, Greenhouse Gases, and Aerosols: Models and Observations." *Journal of Climate* (in press).

National Research Council. 1987. *Responding to Changes in Sea Leve*l. R.G. Dean, Chairman. Washington, DC: National Academy Press.

National Academy of Sciences. 1985. Mark Meier, Chairman. *Glaciers, Ice Sheets, and Sea Level*. Washington, DC: National Academy Press.

National Academy of Sciences. 1983. *Changing Climate*. Washington, DC: National Academy Press.

National Academy of Sciences. 1979. *CO_2 and Climate: A Scientific Assessment*. Washington, DC: National Academy Press.

Nerem, R.S. 1995. "Global Mean Sea Level Variations from TOPEX/POSEIDON Altimeter Data." *Science* 268:708-10.

Nichols, R.J., and S.P. Leatherman. 1995. In: McGregor, D., and D. Thompson (eds). *Geomorphology and Land Management In a Changing Environment*. Chichester: John Wiley and Sons.

Ramanathan, V., R.J. Cicerone, H.B. Singh, and J.T. Kiehl. 1985. "Trace Gas Trends and Their Potential Role in Climate Change." *Journal of Geophysical Research* 90:5547-66.

Schneider, S.H., and R.S. Chen. 1980. "Carbon Dioxide Flooding: Physical Factors and Climatic Impact." *Annual Review of Energy* 5:107–40.

Seidel, S., and D. Keyes. 1983. *Can We Delay a Greenhouse Warming?* Washington, DC: U.S. Environmental Protection Agency.

Smith, J., and D. Tirpak (eds). 1989. *Potential Effects of Global Climate Change on the United States*. Report to Congress. Washington, DC: U.S. Environmental Protection Agency.

Titus, J.G. 1991. "Greenhouse Effect and Coastal Wetland Policy: How Americans Could Abandon an Area the Size of Massachusetts at Minimum Cost." *Environmental Management* 15:1:39-58.

Titus, J.G. (ed) 1985. *Potential Impacts of Sea Level Rise on the Beach at Ocean City, Maryland."* Washington, DC: U.S. Environmental Protection Agency.

Titus, J.G., R.A. Park, S. Leatherman, R. Weggel, M.S. Greene, M. Treehan, S. Brown, C. Gaunt, and G. Yohe. 1991. "Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea." *Coastal Management* 19:3:171-204.

Villach. 1985. *International Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts*. Conference Statement. Geneva: United Nations Environment Programme.

Wigley, T.M.L. 1993. "Balancing the Carbon Budget: Implications for Projections of Future Carbon Dioxide Concentration Changes." *Tellus* 45B:409-25.

Wigley, T.M.L., and S.C.B. Raper. 1992. "Implications for Climate and Sea Level of Revised IPCC Emissions Scenarios." *Nature* 357:293-300.