Chapter One

PLANNING FOR SEA-LEVEL RISE

The threat of global climate change is one of the major issues confronting the world as it enters the 21st century. We are faced with a variety of predictions that indicate that the human race cannot continue to use up the earth's non-renewable resources at the current pace with impunity. Some experts hypothesize that the current pattern of resource consumption has set into motion a series of interactions which are causing global warming. One of the possible projected impacts of this human-induced global climate change is an accelerated rise in global sea level.

A very substantial international scientific research effort has been conducted during the last decade to try to verify the phenomenon and project the impacts of global climate change. Meanwhile, policy makers familiar with various impact projections are anxious to move beyond the problem-recognition stage to begin to develop constructive responses.

The critical issue is how best to develop specific responses when many scientific issues remain unresolved. This report asserts that meaningful preparations can take place now, despite scientific uncertainty, by carefully building upon what is already known. It utilizes the following approach:

- **at the outset, clearly identify what we know about sea-level trends in Maine**, what we know **about global climate change** and associated global sea- level change, and what we believe to be **the most likely impacts** associated with accelerated sea-level rise;
- **seek "no regrets" strategies** (which we will not regret even if there is no acceleration in the rate of sea-level rise) **which also address known threats and recognize that sea-level rise is just one factor affecting land loss.**
- **use a range of likely sea-level rise scenarios** to evaluate vulnerability and develop response strategies rather than limiting the analysis to a single projection;
- continue to **participate in appropriate emission reduction strategies** in an attempt to mitigate likely impacts;
- **assume that State and/or local governments will have primary responsibility** for mitigating local impacts of accelerated sea-level rise;

- build into the process **periodic review and adjustment** of anticipatory sea-level rise response strategies.

Each step in this approach is discussed in more detail below.

A. REVIEW WHAT WE KNOW ABOUT SEA-LEVEL TRENDS IN MAINE, GLOBAL CLIMATE CHANGE AND ASSOCIATED IMPACTS

1. Historical Rates of Sea-Level Rise in Maine

Sea level varies significantly in both its vertical and spatial position over time. Much of the variation, such as that caused by the tides, results in no net change in the position of the shoreline. However, geologists have recorded vertical movement of the sea between 25,000 years ago and the present greater than 100 meters as a result of the waxing and waning of continental glaciers.[1]

During the last fifty years, geodesists have observed tide gauges record a rise of the sea which has averaged 2.4 mm/yr in New England.[2] The exact reasons for this rise are still uncertain, but may be caused by melting of small glaciers,[3] thermal expansion of warming sea-surface water,[4] land subsidence,[5] or a combination of all of these factors.[6]

The Maine Geological Survey has used National Ocean Survey tide-gauge readings to estimate that Maine's rate of sea-level rise between 1940 and 1980 ranged from 1.1 mm per year in Kittery, to 2.3 mm per year in Portland, to 3.2 mm per year in Eastport.[7] If that rate continues unchanged into the future, it translates to increases *per century* of 11 cm (4 inches) in Kittery, 23 cm (9 inches) in Portland, and 32 cm (12 inches) in Eastport. Maine's coast is currently experiencing significant local submergence (decreased land elevation) due to lingering effects possibly caused by loading and unloading of receding ice sheets.[8] The rate of sea-level rise is supposed to be greatest in the Eastport area because of more rapid land subsidence in that area;[9] but this conclusion remains controversial.[10]

To keep this information about changes in sea-level in perspective, it is important to understand that a vertical increase of 11 to 32 cm (4 to 12 inches) in the level of the ocean will translate to a much larger horizontal migration of the high water line landward, depending upon the slope of the adjacent land surface and the type of shoreline. (*See Figure 1.1*) At a minimum, with a one foot rise, the shoreline will move at least as far inland as the previous one-foot topographic contour line. On a very gently sloping coast, that contour line will be much farther inland than on a steep coast.

However, while this simple method of estimating land loss from the slope of the land surface may be useful for sheltered estuaries or wetlands, it greatly underestimates land loss along eroding coastal bluffs or sandy shorelines. Coastal bluffs retreat at highly variable rates, depending on complex factors.[11] Sandy shorelines are also characterized by complex migration processes which result in land loss many times greater than the vertical rise in sea level;[12] some studies have estimated the landward movement of the shoreline per century to be in the magnitude of 100 to 300 times the vertical rise over that same period.[13] So, for example, a 23 cm (9 inch) vertical rise in sea level over the next century along a sand beach could translate into a movement of the shoreline landward in the magnitude of 23 to 69 meters (75 to 225 feet) per century.

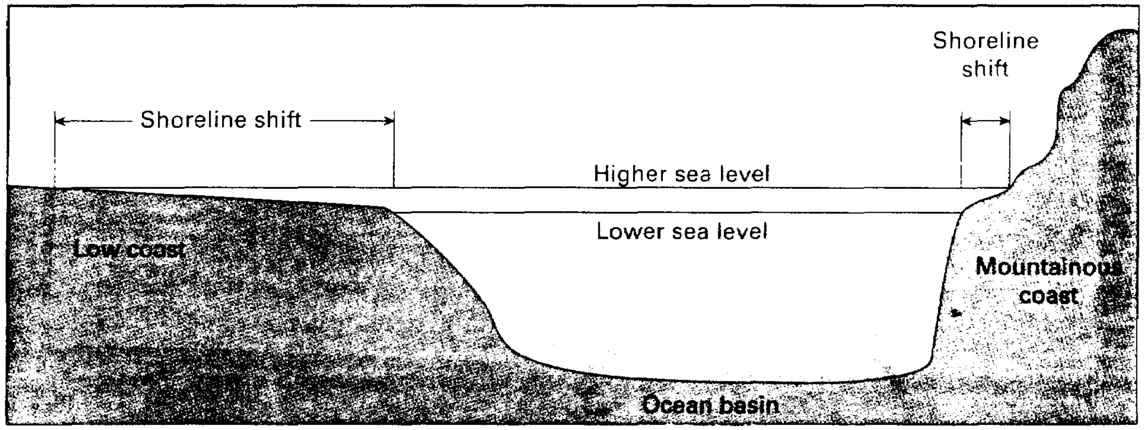

Figure 1.1. Small vertical changes in water level shift coastlines dramatically on gently sloping coasts but cause only minor shifts on steep coasts. Source: U.S. Geological Survey, COASTS IN CRISIS, Washington, DC (1990).

2. Accelerated Sea-Level Rise as a Result of Global Climate Change

The continued rise of the sea at the present rate (discussed immediately above) poses many problems along developed shorelines.[14] However, even greater concern has been raised for the potential impact of a still more rapid rise of the ocean than is presently occurring. Some scientists are predicting that the rate of sea-level rise will accelerate as a result of global climate change associated with the "greenhouse effect."[15]

The greenhouse effect, also referred to as *global warming*, is described as the presence of increased concentrations of human-induced gases, such as carbon dioxide and methane, in the atmosphere. These gases trap heat re-radiating from the earth's surface and raise the earth's atmospheric temperature. This, in turn, could increase the rate of sea-level rise due to further expansion of the sea's surface layer and glacial melting.[16] Thus to accurately project sea-level rise under conditions of global climate change, an additional increment must be added to local historical rates to reflect a *global* increase in ocean volume.

Scientific knowledge about possible global climate change and the associated increase in sea level is still at a very rudimentary stage. Recent studies tend to assume that best projections indicate a rise of approximately 1 to 3 feet by 2100, while earlier studies assumed a rise of 2 to 7 feet by 2100.[17] One of the more recent estimates put a "best guess" at 48 cm (approximately 1.5 feet) higher than present by the year 2100.[18] *(See Figure 1.2)*

Because there is still a wide range of uncertainty associated with projections of global climate change and resulting sea-level rise, scientists cannot provide coastal managers with a single number which represents the projected accelerated sea-level rise attributable to global warming. Instead, to assess possible impacts, coastal planners have to use a range of scenarios designed to be broad enough to encompass the range of likely outcomes. These scenarios are discussed in more detail in section C of this chapter.

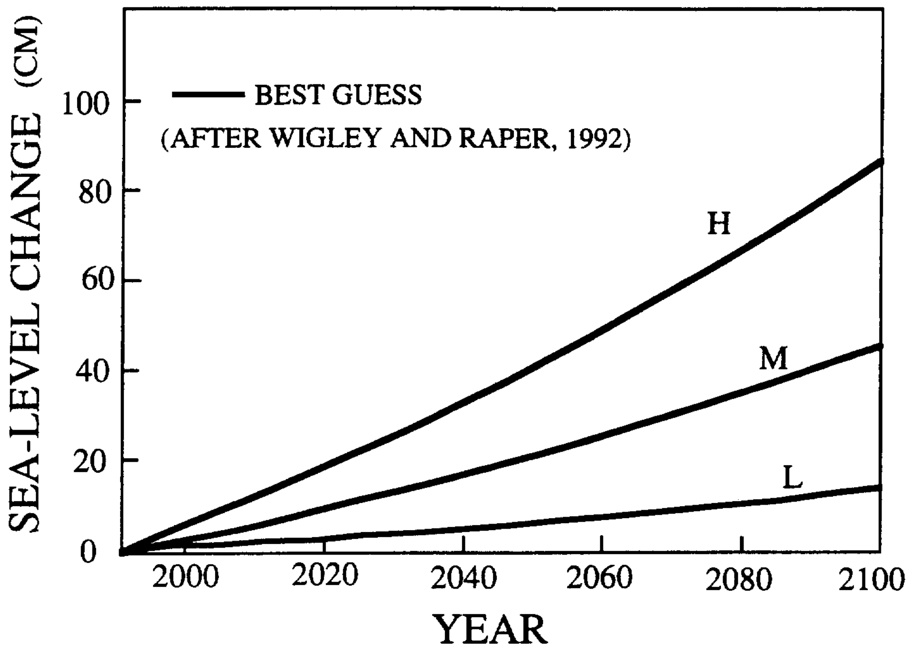

Figure 1.2. Estimates of future sea-level rise (modified from Wigley and Raper, 1992). L, M, and H refer to low, medium and high estimates of future sea levels.

3. Possible Impacts of Accelerated Sea-Level Rise

Given projected increases in sea level due to a combination of local and global changes, the next step of the analysis is to try to integrate possible scenarios with information about probable impacts. It is not yet possible to make precise predictions of the magnitude and specific array of future impacts of global warming.[19] However, researchers have begun to develop lists of possible impacts, and have begun to separate the probable from the merely possible. They have also begun to recognize that the baseline health of the coastal zone may have significant bearing on the ability of the region to adjust to a change in sea level.

During the last several decades, coastal regions of Maine have experienced very significant growth in the number of residents and recreational visitors.[20] This development pattern has resulted in a variety of problems including the degradation of coastal habitats, user conflicts resulting from spatial limitations, coastal pollution due to increasing volumes of municipal wastes and other point and nonpoint sources of water pollution, and coastal erosion and flooding due to insufficient allowance for natural coastal processes. Accelerated sea-level rise will tax those natural systems which provide protection against the sea (e.g., sand dune systems, wetlands) and will accentuate problems caused by or symptomatic of degradation of those systems.

In addition, depending upon the degree of sea-level rise and local conditions, scientists predict that new problems will be added to those already caused by intensive use of coastal areas. These new problems may include:

1) changes in the location of the terrestrial-aquatic boundary;

2) increased frequency and inland extent of flooding;
3) loss of coastal wetlands;
4) accelerated dune and beach erosion;
5) loss of significant habitat for commercially important species;
6) saltwater intrusion into groundwater; and
7) greater upstream intrusion of salt-water wedges.

In turn, these impacts on the natural environment may also:

1) destroy or undermine structures in developed areas;
2) damage the infrastructure; and
3) disrupt the local economy, particularly natural resource-dependent sectors.

The vulnerability to these possible impacts is assessed in greater detail in Chapters Two and Three of this report.

B. SEEK "NO REGRETS" STRATEGIES WHICH ALSO ADDRESS KNOWN THREATS AND RECOGNIZE THAT SEA-LEVEL RISE IS JUST ONE FACTOR AFFECTING LAND LOSS

Representatives of the United States Environmental Protection Agency, the United Nations Environment Programme, the World Meteorological Organization, and the international Intergovernmental Panel on Climate Change (IPCC), assert that despite scientific uncertainty about the global climate change, the magnitude of the potential negative impacts makes it incumbent upon governments to develop response strategies without waiting for conclusive proof of causation or complete unanimity in the scientific community. For example, the IPCC Coastal Zone Management Subgroup has adopted the following statement:

> It is urgent for coastal nations to begin the process of adapting to sea level rise not because there is an impending catastrophe, but because *there are opportunities to avoid adverse impacts by acting now*, opportunities that may be lost if the process is delayed. This is also consistent with good coastal zone management practice irrespective of whether climate change occurs or not.[21]

Due to the scientific uncertainty about global climate change and lag time before most impacts will be felt (if they occur at all) most of these representatives are not advocating immediate concrete steps to armor the shoreline or otherwise get ready for a change in sea level. Rather they emphasize relatively low-cost strategies which not only make sense to minimize any adverse impacts of accelerated sea-level rise, but which would also make sense (e.g., which the government would not regret taking) even if sea level does not rise at an accelerated rate. For example, these strategies may be justified because they increase the ability to survive coastal storm events of the intensity currently experienced with less damage or because they strengthen the resiliency of coastal resources. The focus of this report is on identifying these types of "no regrets" strategies.

In seeking these "no regrets" strategies, it is important to recognize that there are many interacting variables that can lead to coastal land loss. *(See Figure 1.3)* Projections of shoreline change as a result of sea-level rise caused by global climate change represent just one variable. The local impact will depend on the interactions of all of these variables. Furthermore, even if projections are wrong and global climate change does not cause a substantial rise in sea level, the other factors may cause significant land loss.

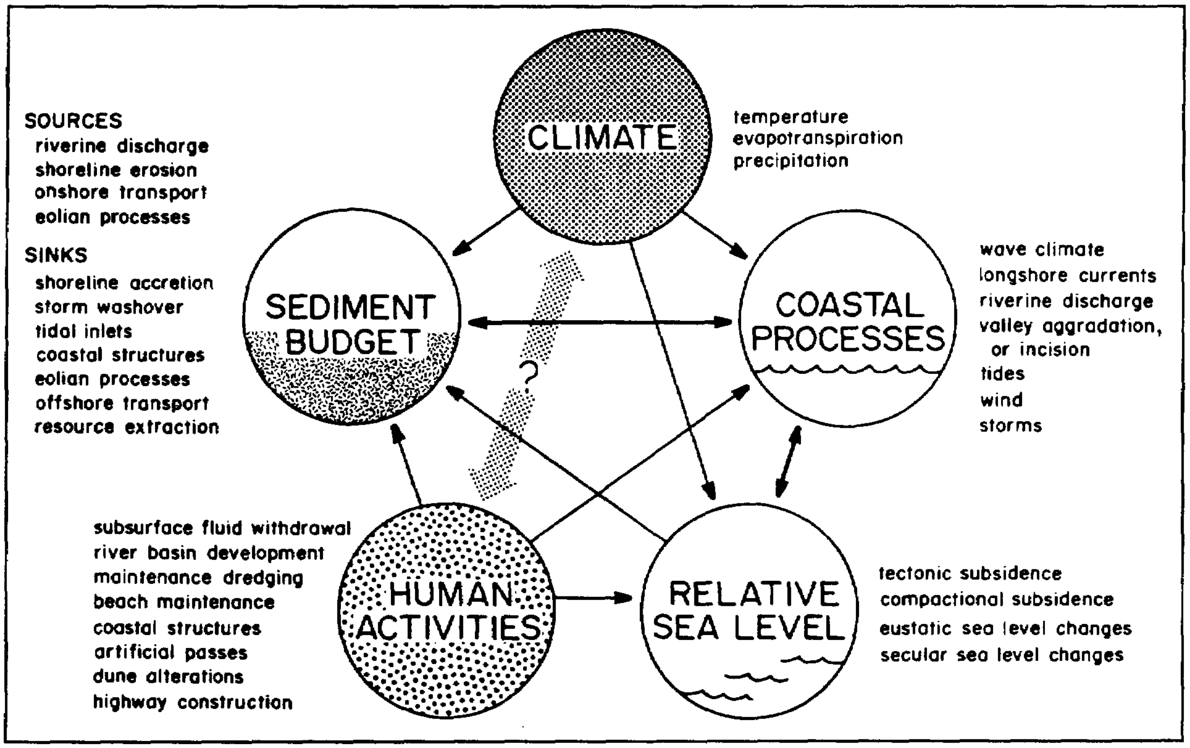

Figure 1.3. Interaction of agents affecting land loss. Arrows point toward the dependent variables. The number of arrows originating from or terminating at a particular agent indicates the relative degree to independence or interaction. For example, human activities are independent of other agents, but they affect sediment budget, coastal processes, relative sea level conditions, and perhaps climate (from Morton [1977]).

Source: O.H. PILKEY, ET AL. COASTAL LAND LOSS. (Wash., DC: American Geophysical Union, 1989) at 6.

The factors affecting land loss are identified as:

1) **relative sea-level changes** (including not only eustatic (world-wide) sea-level changes which might be attributable to global climate change, but also tectonic and compactional subsidence and oceanographic sea-level changes);

2) **coastal processes** (waves and currents, with highest and most intense levels of wave and current energy affecting the coast during intense storms such as hurricanes and northeasters);

3) **alterations in the sediment budget** (affecting sandy shores, with supplies from coastal rivers interrupted by natural decreases, river containment or diversion, dam construction);

4) **climate** (temperature and precipitation indirectly influencing land loss by affecting decomposition of rocks, vegetated cover, and upland runoff); and

5) **human activities** (such as coastal construction projects, fluid production, and resource extraction promoting alterations and imbalances in the sediment budget, coastal processes and relative sea level).[22]

The multi-factored, interactive nature of the land loss process highlights two important considerations in any anticipatory planning process:

- Coastal land loss is a natural phenomenon, perhaps increasingly exacerbated by human activities. It does not become a "problem" until humans try to hold back natural processes of land migration.

- Coastal land loss may result from factors other than eustatic sea-level rise attributable to global climate change, with coastal storms and human activities which disrupt the sediment budget being prime factors. Thus, it is important that any anticipatory plan be responsive to these land loss factors as well.

Since these factors are so interrelated, it may be possible to develop "no regrets" strategies which address sea-level rise, but will also minimize coastal land loss from other factors.

C. COMPENSATE FOR SCIENTIFIC UNCERTAINTY BY USING A RANGE OF SEA-LEVEL RISE SCENARIOS

While the scientific models and current knowledge are sufficiently developed to identify a potential problem on a global scale, they can not yet accurately predict the timing and magnitude of sea-level rise on a local scale.[23] It is thus prudent to use a range of possible scenarios to assess vulnerability and evaluate response options.

For at least the last decade, the international research community has used an assumption of a one meter rise in sea level over the next century to study possible impacts. During that time, specific research projects have developed other high, medium and low scenarios, illustrated in Figure 1.2 (p. 1-4) and Figure 1.4, on the following page.

In its sea-level rise studies, the U.S. Environmental Protection Agency (EPA) has generally continued analyzing the National Research Council's 1985 scenarios of a rise of 50, 100 and 200 cm (½, 1 and 2 meters) by 2100. According to the EPA, the primary reason for using the 50, 100 and 200 cm scenarios is not that it expects these precise results to unfold, but rather that they are "round numbers" that seem to "bracket the range" and serve its goal of being a bit wider of the mark so they cover every contingency.[24] EPA asserts that the extra-high scenario (200 cm) is useful to project what might happen in the very long run (perhaps 200 years or longer) since there is no reason to expect the effects of global warming to stop in 2100. EPA suggests that the extra-high scenario is also useful for identifying which areas are at any risk, even though small, of being affected by accelerated sea-level rise over the next century to assist with siting facilities that would be severely impacted by coastal erosion, such as a hazardous waste disposal facility.

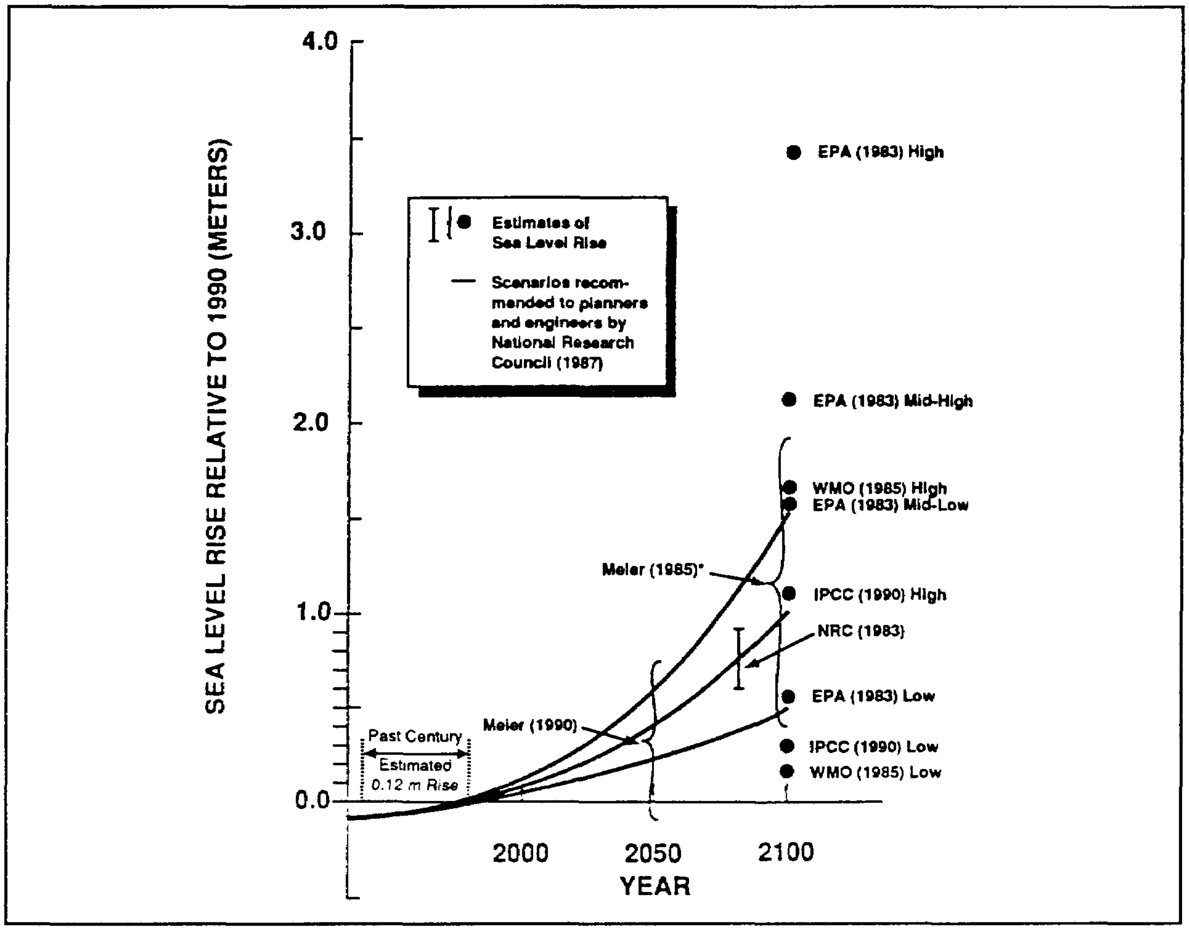

Figure 1.4. Estimate of future sea level rise. Source: J.G. Titus, et al., *Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea* 19 COASTAL MANAGEMENT 171-204 (1991) at 176.

EPA does not equate these scenarios with projections of the most likely outcomes. Recent EPA uncertainty analyses, now cite the 50 cm scenario as the median estimate by 2100. This analysis gives 200 cm a less than 0.5% chance of happening by the year 2100 and a 10% chance of happening by 2200. The mid-level 100 cm scenario is given a 5% chance of happening by 2100, but a 50% chance of happening by 2200.[25]

Despite these probabilities, the EPA continues to advocate that all areas examine their sensitivity to at least the one meter rise scenario, because that builds in some precautionary room for error and probably has the effect of extending the analysis beyond 2100. EPA has recommended that communities add the local historical rate of sea-level change (positive or negative) attributable to subsidence to the 50, 100 or 200 cm adjust for local conditions.

In 1990, the Intergovernmental Panel on Climate Change (IPCC) reaffirmed this general approach when it developed its best estimates of future sea-level rise. It predicted that by the year 2100 there will be a global rise in sea level in the range of 33 to 110 cm, with a most likely rise of 66 cm.[26]

Other researchers have subsequently made adjustments to these sea-level rise projections based on revised International Panel on Climate Change emissions scenarios. These revisions place the global low-, mid- and high-level scenarios at 15 centimeters, 48 centimeters and 90 centimeters, respectively.[27]

*Table 1.*1 summarizes historical change and various scenarios or projections, using a measured historical rise in Portland as the base. Thus, depending on the assumptions used, sea-level rise predictions or scenarios combining both local subsidence and global change range from a low of 24 to 59 cm, to a high of 104 to 214 cm, with a mid range of 60 to 112 cm.

***Table 1.1*. Predicted Sea-Level Rise in Portland, Maine, 2100**

	Low	Mid	High
Historical (Maine Geological Survey)	21 cm	24 cm	26 cm
Local Historical (historical less eustatic rise component)	9 cm	12 cm	14 cm
Global Sea-Level Rise Scenarios	50 cm	100 cm	200 cm
Forecast Rise 1 (local historical plus global scenarios)	59 cm	112 cm	214 cm
1990 IPCC Sea-Level Rise Estimate	33 cm	66 cm	110 cm
Forecast Rise 2 (local historical plus 1990 IPCC estimate)	42 cm	78 cm	124 cm
Adjusted IPCC After Revised Emissions	15 cm	48 cm	90 cm
Forecast Rise 3 (local historical plus adjusted IPCC)	24 cm	60 cm	104 cm

Source: Adapted from Maine Geological Survey, First Year Report on Hazard Mapping Project, 1993.[28]

In mapping shoreline change based on accelerated sea-level rise scenarios, this project opted to map scenarios of sea level of 50, 100, and 200 cm above present sea level in the year 2100. This was the equivalent of using typical global scenarios without adding an additional increment for local change. For the low- and mid-level scenarios, it was substantially equivalent to using 1990 IPCC projections of global change plus local change. While recognizing the importance of local change as a factor, the project opted not to add local change to global scenarios for purposes of mapping change in shoreline position because: 1) local historical sea-level rise varies over the study area; 2) local change is relatively small in relation to the global scenarios; and 3) adding local historical change to the global scenarios would cause the mapped assumptions to deviate even more from IPCC 1990 projections and later revised projections of sea-level rise based on revised emission projections. It was felt that use of these 50, 100 and 200 cm scenarios incorporated the requisite margin for error and worst-case scenarios that must be factored in when planning to mitigate severe adverse coastal impacts.

D. Participate in Appropriate Emission Reduction Strategies

While the emphasis of the preceding discussion has been on adaptation strategies, the State should not lose sight of the fact that one way to reduce the extent of sea-level rise is to reduce emission of greenhouse gases. Clearly the problem of increased concentrations of greenhouse gases is global in scope. International attempts are being made to negotiate reductions in emissions of particular trace gases. While hopes are high for a joint international agreement, similar efforts suggest that progress will probably be slow and incomplete.

But the State of Maine does not have to wait for a coordinated international response. In the United States, a variety of state and local governments have developed their own partial emission reduction strategies. For example, responses have included:

- comprehensive studies/plans to reduce greenhouse gas emissions and per capita nonrenewable energy consumption;
- utility regulation strategies (e.g., choices regarding fuels, conservation initiatives, preference to conservation, and demand-side management measures);
- building codes (e.g., requiring buyers to make conservation investments when they purchase a house);
- small scale demonstration projects (e.g., reduced energy use by state agencies, transportation policies to reduce automotive use, efficiency investment in new buildings);
- attempts to incorporate environmental costs of nonrenewable energy sources into prices through tax policies; and
- participation in EPA's Green Lights program to install energy efficient equipment when it is profitable and does not compromise lighting quality.[29]

Admittedly, these state and local programs can only make a small incremental contribution to reducing the global emission problem. But adaptation planning and emission reduction efforts should both be pursued by the State.

E. Assume State/Local Governments Will Have the Primary Responsibility for Mitigation of Sea-Level Rise Impacts

With emission reduction strategies, there is a misguided, but nevertheless strong, temptation to wait for national or international bodies to adopt the laws or negotiate the treaties that will put in place a coordinated global response. In contrast, whether it likes it or not, the State will probably bear the burden and the responsibility to formulate the local, adaptive response to this global problem. The impacts of global climate change will be felt locally, the costs will generally be borne locally and, in the United States, since land use controls are generally a function of state or local governments, the responsibility for much of the response planning will fall on those governments.[30] Thus, even if state and local governments have little direct control over reducing global greenhouse gas emissions, they will have a major responsibility for planning to adapt to potential adverse impacts.

F. Utilize a Process Which Incorporates Periodic Review and Updating of the Adaptive Response Strategy

Given scientific uncertainty and rapidly evolving scientific knowledge, coastal managers are not in a position to make decisions now about a definitive adaptive response strategy for the next century. Rather policy decisions will have to be made now based on the best available knowledge, with the express intent of reviewing these policies periodically (e.g., every five to ten years) as scientists refine their predictions. It will be an iterative process.

Despite the scientific uncertainty and complexities discussed above, there are certain affirmative statements that can be posited as a starting point for Maine's anticipatory planning for sea-level rise:

1. Despite some scientific uncertainty about causation and extent of global climate change, the magnitude of the potential negative impacts makes it incumbent upon governments to develop response strategies without waiting for conclusive proof of causation or unanimity in the scientific community;

2. Even though negotiations are being conducted to reduce emissions of greenhouse gases, due to forces already set into motion, it is essential to simultaneously develop local adaptation strategies in preparation for potential impacts of future global climate change;

3. In coastal communities, adaptation strategies should first focus on the possible impacts of sea-level rise associated with global climate change since that will have the most direct impact on natural resources and human development.

4. In the United States, it is appropriate for States to take the lead in developing local sea-level rise adaptation strategies since they will be most directly responsible for coping with the local impacts. States already possess a range of land use, zoning, development regulation, public investment, economic incentive, and similar tools to use in developing anticipatory strategies.

5. Due to the inherent complexities of predicting impacts of global climate change and the first, second, and higher order impacts of relative sea-level change, and the interconnections between those impacts, the initial analysis should be a first-cut at determining the most likely impacts and the general magnitude of those impacts within very broad parameters. If further refinement of the assessment of vulnerability of particular localities or resources is needed to develop adaptation strategies, additional detailed scientific studies will be required.

6. Developing adaptive response strategies will be an iterative process that will require decisions to be based on the best available information at the time. Anticipatory response plans should be reviewed and updated as scientific knowledge increases, projections of magnitude of global sea-level rise are refined, and experience with governmental response strategies increases.

7. The State should retain and improve on existing policies (supplemented as necessary by new policies) which strengthen the State's position with regard to the known, measurable threats already posed by a continuation of the historical rate of sea-level rise, but are also sufficiently flexible to respond to accelerated sea-level rise, if it occurs. These "no regrets" strategies will be justified (and the State will not regret implementing them) even if the global warming theories are incorrect and the State does not experience any change in the rate of coastal erosion or change in shoreline position attributable to the greenhouse effect.

The detailed results of the mapping and vulnerability assessment components are contained in the next two chapters. The remaining chapters explore anticipatory response options from economic and legal perspectives.

G. ENDNOTES

1. R.G. Fairbanks, *A 17,000 Year Glacio-Eustatic Sea-Level Record: Influence of Glacial Melting Rates on the Younger Dryas Event and Deep-Ocean Circulation*, 342 NATURE 637-642 (1989) and J.T. Kelley, S.M. Dickson, D.F. Belknap & R. Stuckenrath, *Sea-Level Change and the Introduction of Late Quaternary Sediment to the Southern Maine Inner Continental Shelf*, *in* QUATERNARY COASTS OF THE UNITED STATES, at 23-24 (J. Wehmiller & C. Fletcher, eds., Soc. Econ. Paleo. and Mineralogists, Spec. Pap. 48, 1992).

2. S.D. Lyles, L.E. Hickman, & H.A. Debaugh, SEA-LEVEL VARIATIONS FOR THE UNITED STATES 1855-1986 (National Ocean Services, National Oceanic and Atmospheric Administration, Office of Oceanography and Marine Assessment, Rockville, MD, 1988).

3. M.F. Meier, *Contribution of Small Glaciers to Global Sea Level*, 226 SCIENCE 1418-1421 (1984).

4. D. Reommich, *Ocean Warming and Sea-Level Rise Along the Southwest U.S. Coast*, 257 SCIENCE 373-375 (1992).

5. D. AUBREY & K.O. EMERY, SEA LEVELS, LAND LEVELS, AND TIDE GAUGES, (New York, NY: Springer Verlag 1990).

6. W.R. Peltier, *Global Sea Level and Earth Rotation*, 240 SCIENCE 148-1421 (1988).

7. D.F. Belknap, B. Andersen, et al., LATE QUATERNARY SEA-LEVEL CHANGES IN MAINE, at 71-75 (Soc. Econ. Paleo. and Mineralogists, Spec. Publ. 41, 1987).

8. W.R. Gehrels & D.F. Belknap, *Neotectonic History of Eastern Maine Evaluated from Historic Sea-Level Data and C-14 Dates on Salt-Marsh Peat*, 21 GEOLOGY 615-618 (1993).

9. W.A. Anderson, et al., *Crustal Warping in Coastal Maine*, 12 GEOLOGY 677-680 (1984).

10. R. Reilinger, *Reanalysis of Crustal Warping in Maine*, 15 GEOLOGY 998-961 (1987); W.R. Gehrels & D.F. Belknap, *supra* note 8, at 615-618.

11. HANDBOOK OF COASTAL PROCESSES AND EROSION (P.D. Komar ed., Boca Raton, FL: CRC Press 1983).

12. O.H. PILKEY, R.A. MORTON, J.T. KELLEY & S. PENLAND, COASTAL LAND LOSS, (Wash., DC: American Geophysical Union 1989).

13. NATIONAL RESEARCH COUNCIL, MANAGING COASTAL EROSION (Wash., DC: National Academy Press 1990).

14. W. KAUFMANN & O. PILKEY, THE BEACHES ARE MOVING: THE DROWNING OF AMERICA'S SHORELINE (Duke Univ. Press 1983) (1979); J.T. KELLEY, A.R. KELLEY & O.H. PILKEY, LIVING WITH THE COAST OF MAINE (Duke University Press, 1989); and O.H. Pilkey, J.T. Kelley, R.A. Morton & S. Penland, *supra* note

15. There are two basic indicators of global climate change: global mean temperatures and global mean sea level. Evidence exists that global mean surface temperatures have increased by 0.3 to 0.6° C over the last 100 years. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, WORKING GROUP I, 1992 IPCC SUPPLEMENT: SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE 4 (J.T. Houghton, et al., eds., 1992) [hereinafter 1992 IPCC SUPPLEMENT]. Global mean sea level is correlated with temperature and has apparently increased by 10 to 20 cm during the last century as well. V. Gornitz, S. Lebedeff & J. Hansen, *Global Sea Level Trend in the Last Century*, 215 SCIENCE 1611-1614 (1982).

One theory advanced to explain the observed global warming is that the measurable increase in greenhouse gas concentrations during the last century has trapped solar heat. Scientists theorize that these trace gases (such as carbon dioxide and methane) which are believed to result in large part from human activities (e.g., burning of fossil fuels, deforestation, certain agricultural practices) delay the escape of infrared radiation from the earth's atmosphere. This trapped heat causes a warming of temperatures. According to this theory, it also causes a rise in sea level due to the thermal expansion of sea-surface water and, melting of small glaciers. M.F. Meier, *Contribution of Small Glaciers to Global Sea Level*, 226 SCIENCE 1418-1421 (1984); W. Peltier, *supra* note 6, at 895-901.

Changes in global surface temperature and concentrations of greenhouse gases that were observed during recent years are consistent with the greenhouse theory, but most scientists take the position that a definitive cause/effect relationship has not yet been demonstrated. Too few and too widely dispersed temperature observations, and sea-level measurements biased by a concentration of tide gauges in subsiding, formerly-glaciated regions preclude definitive statements yet on the status of global climate change.

In addition while most scientists acknowledge that the greenhouse gas theory is consistent with the evidence of global temperature changes and changes in mean sea level, most scientists agree that another viable theory exists which also explains those temperature and sea-level rise observations: natural internal variability. P. Stone, *Global Climate Change: Causes, Evidence and Prediction in* AIP CONFERENCE PROCEEDINGS: THE WORLD AT RISK: NATURAL HAZARDS AND CLIMATE CHANGE SYMPOSIUM (Rafale Bras, ed., Cambridge, MA: MIT Center for Global Change Science and Industrial Liaison Program, 1992) [hereinafter THE WORLD AT RISK] and 1992 IPCC SUPPLEMENT, *supra* at 4. These scientists note that the observed global warming is still within the range that could be explained by natural variations in climate based on historical natural climate variations. Until the data proves that the observations exceed historical variations, the greenhouse gas theory cannot be validated. It is not expected that observations which support the theory of enhanced greenhouse effects will provide unequivocal information for at least a decade. 1992 IPCC SUPPLEMENT, *supra* at 4.

16. J.G. Titus, *Greenhouse Effect, Sea-Level Rise and Barrier Islands*, 18 COASTAL MANAGEMENT 1-20 (1990). An increase in sea level may result through one or more of the following: 1) thermal expansion of ocean water (the same amount of water takes up more space as its temperature increases above 4° C); 2) increased melting of mountain glaciers; 3) melting of Greenland glaciers; and 4) introduction of portions of massive Antarctic glaciers into the ocean. W.R. Peltier, *supra* note 6.

17. THE POTENTIAL EFFECTS OF GLOBAL CLIMATE CHANGE ON THE UNITED STATES, (J.B. Smith & D.A. Tirpak, eds., Wash., D.C.: Hemisphere Publishing Corporation, 1990) and J.G. Titus, *The Cost of Holding Back the Sea*, 19 COASTAL MANAGEMENT 171 (1991).

18. T.M.L. Wigley & S.C.B. Raper, *Implications for Climate and Sea Level of Revised IPCC Emission Scenarios*, 357 NATURE 293-300 (1992).

19. There are several reasons for a lack of precision in predicting the range and magnitude of impacts. These include the inherent unpredictability of climate, the unpredictability of other events that could affect the global climate (e.g., volcanic activity, solar emissions), the unpredictability of rates of increases in

greenhouse gases which may be driving the warming (e.g., negotiated reductions in emissions, public education altering emissions), and inherent limitations of current climate models. P.H. Stone, *Forecast Cloudy: The Limits of Global Warming Models*, THE WORLD AT RISK *supra* note 15, at 143-149. There is also continuing debate over the list of expected impacts. Small differences in assumptions make major differences in projected impacts. Nevertheless, it is important to note that sea-level rise is one of the major impacts of global climate change that is projected with a relatively high level of confidence. If the planet is in fact experiencing human-induced global climate change, global sea-level rise is one of the most likely impacts. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE: THE IPCC SCIENTIFIC ASSESSMENT (J.T. Houghton, G.J. Jenkins & J.J. Ephraums, eds., Cambridge University Press, 1990). Since it is one of the less speculative impacts, this report focuses on sea-level rise. Some other projected impacts with potential bearing on the coastal region are mentioned in the report as well.

20. J.R. KELLEY, A.R. KELLEY & O. PILKEY, LIVING WITH THE COAST OF MAINE (Duke University Press 1989).

21. *Appendix A: Conclusions from the 1990 IPCC First Assessment Report*, *in* GLOBAL CLIMATE CHANGE AND THE RISING CHALLENGE OF THE SEA (L. Bijlsma, J. O'Callaghan, et al., eds., Rijkswaterstaat, The Netherlands, Report of the Coastal Zone Management Subgroup, Intergovernmental Panel on Climate Change, Response Strategies Working Group, May 1992).

22. O.H. PILKEY, R.A. MORTON, J.T. KELLEY & S. PENLAND, *supra* note 12.

23. There is a significant discrepancy in the scales used by scientists and the needs of the local policy makers. Modelers of climate change are usually working on a scale of thousands of miles. Policy makers, in contrast, are often hoping to narrow the findings to a particular municipality, county or state. While some scientists have attempted to use scientific methodologies to convert from a regional global circulation model to local predictions, the effort is very complex and results can suffer from significant limitations. J.P. Hughes, D.P. Lettenmaier & E.F. Wood, *An Approach for Assessing the Sensitivity of Floods to Regional Climate Change, in* THE WORLD AT RISK, *supra note 15, at 112.* Even though some impacts are predicted on a global scale, they will affect different parts of the world differently. For example, increased global mean temperature is a change that is predictable with some degree of certainty, but the extent of the increase is still the subject of much debate. Attempts to move from the global scale to the local scale to predict changes in local air temperature have not been successful because local air temperatures will be affected by changes in rainfall and wind patterns (among other things). While able to give a general indication of the likely direction of change on a larger regional scale, global circulation models are not yet able to predict changes in rainfall and winds with accuracy on a local scale. J.C. Pernetta & D.L. Elder, *Climate, Sea Level Rise and the Coastal Zone: Management and Planning for Global Changes*, 18 OCEAN AND COASTAL MANAGEMENT 1, 136 (1992).

24. Correspondence from James G. Titus, Office of Policy, Planning and Evaluation, United States Environmental Protection Agency, June 6, 1994, on file with the Maine State Planning Office.

25. *Id.*

26. *E.g.*, a rise of 13 to 43 inches, with a most likely rise of 26 inches. 1992 IPCC SUPPLEMENT, *supra* note 15.

27. T.M.L. Wigley & S.C.B. Raper, *supra* note 18.

28. Historical rates based on tide gauge readings were uniformly adjusted to find "local change" by subtracting 12 cm. This amount was subtracted to account for the portion of the historical change attributable to a eustatic (worldwide) rise in sea level because the historical change already includes a past rise in worldwide sea levels. The figure of 12 cm is an estimate only, based on other estimates ranging from 10 to 18 cm. Titus, *supra* note 24.

29. P. Wexler & S. Conbere, *States Fight Global Warming*, 18 EPA JOURNAL 4, 18 (Sept./Oct. 1992).

30. J. Nigg, *Societal Response to Global Climate Change: Prospects for Natural Hazard Reduction*, *in* THE WORLD AT RISK, *supra* note 15, at 289.