Report of the NJDEP Science Advisory Board

NJ Climate Change Charge Question

Prepared by the

Climate and Atmospheric Sciences Standing Committee

Approved by the
NJDEP Science Advisory Board

Dr. Judith Weis, Ph.D. (Chair)
Clinton J. Andrews, Ph.D., P.E.
John E. Dyksen, M.S., P.E.
Raymond A. Ferrara, Ph.D.
John T. Gannon, Ph.D.
Robert J. Laumbach, M.D., MPH
Peter B. Lederman, Ph.D., P.E.
Robert J. Lippencott, Ph.D.
Nancy C. Rothman, Ph.D.
Tavit Najarian, Ph.D.
Michael Weinstein, Ph.D
Anthony J. Broccoli, Ph.D.
Mark G. Robson, Ph.D.
David A. Vaccari, Ph.D., P.E.
Lily Young, Ph.D.

January 4, 2016

NJ Climate Change Charge Question

Prepared by the Climate and Atmospheric Sciences Standing Committee

Anthony J. Broccoli, Ph.D., Chairperson
Michael Aucott, Ph.D.
Mark J. Chopping, Ph.D.
Maurie J. Cohen, Ph.D.
Joann L. Held, M.S.
Philip K. Hopke, Ph.D.
Robin M. Leichenko, Ph.D.
William E. McMillin, M.E.E., P.E.
Gregory A. Pope, Ph.D.
David A. Robinson, Ph.D.
Alan Robock, Ph.D.
Richard Vaccaro, M.S.

***NJDEP Charge Question*:** Which aspects of climate change should be considered at this point to be inevitable, and how should NJ best adapt to these? What additional studies are indicated to assess statewide vulnerabilities to global warming and sea level rise, and how can these studies be linked to adaptive land use management practices, open space protection, and resource utilization?

Executive Summary

Rising carbon dioxide (CO_2) levels are very likely to cause continuing changes in climate for the foreseeable future unless there are aggressive policies to reduce CO_2 emissions that have yet to materialize. Based on the assumption that CO_2 levels will continue to rise, sea level rise, increased frequency of extreme high temperatures, decreased frequency of extreme low temperatures, lengthening of the frost-free season, and increased short-term hydrologic variability are robust responses to climate change that will very likely require adaptation efforts.

A substantial rise in sea level, estimated in a recent study to range from 30-71 inches over the course of the 21st century, will raise the baseline for coastal flooding. Days with maximum temperatures above 90° F will become more frequent. The frequency and intensity of cold spells is expected to decrease and the frost-free period (i.e., "growing season") is expected to lengthen by as much as one month during this century. Higher temperatures are expected to strengthen the hydrologic cycle, leading to more intense precipitation events but also greater evapotranspiration during dry spells, leading to increased seasonal drought risk in summer and fall. Climate change impacts will be felt among many sectors, including agriculture, fisheries, natural resources, transportation, water resources, coastal communities, public health, and utilities.

Coastal erosion is a chronic impact of climate change that is already being felt throughout the state. Beach replenishment has been undertaken to counteract coastal erosion, the costs of which have grown substantially as more sand has been required and the inflation-adjusted cost of sand has increased. Rising sea levels will likely lead to acceleration in the cost of beach replenishment, possibly threatening its feasibility. The SAB recommends that the Governor appoint a high-level panel to analyze the threats to New Jersey's beaches within the next 25 years from erosion in the light of current predictions of sea level rise.

Introduction

The magnitude and rate of future climate change over decadal to century time scales depends primarily upon the amount of greenhouse gases and climate-altering aerosol species that will be emitted in the future. Because the present climate is not in equilibrium with current concentrations of greenhouse gases and aerosols, there would be some additional change in climate even in the hypothetical situation in which atmospheric composition could be stabilized as it is today. This so-called "committed climate change" is associated with a further warming of global temperature of approximately 0.5-1° F (0.3-0.5° C) (IPCC 2013).

Strictly speaking, only this committed climate change is inevitable from the standpoint of climate physics. There is little if any doubt, however, that atmospheric concentrations of greenhouse gases, primarily carbon dioxide (CO_2), will continue to rise for the foreseeable future because of the dominance of fossil fuel combustion as the primary source of energy. The Copenhagen Accord includes non-binding targets for reductions in CO_2 emissions with a goal of limiting global warming to 3.6° F (2° C), although there is doubt about whether the emissions reductions targeted in the Accord would even accomplish this goal (e.g., Nordhaus 2010). For the purpose of addressing this charge question, it will be assumed that future greenhouse gas emissions will be sufficient to raise global average temperature by at least 3.6° F (2° C), although it may be possible to keep future warming below this threshold if global emissions can be reduced more aggressively.

Projections of Future Climate Change

There is a vast literature on scientific projections of future climate change, including comprehensive assessment reports that integrate the relevant peer-reviewed scientific literature. Two recent assessment reports have been prepared by the Intergovernmental Panel on Climate Change (2013) and the United States Global Change Research Program (i.e., the National Climate Assessment, available at http://nca2014.globalchange.gov/). These reports are extensive and contain a great deal of technical detail, but each contains an executive summary that provides a wealth of information on the causes and consequences of climate change. We strongly recommend these documents as sources of information on climate change and we will not attempt to reproduce or summarize their content. Rather, we will briefly summarize the analyses of projected climate changes in the northeastern United States based on these assessment reports and identify the projected climate responses that may be most robust.

Robust Responses to Anthropogenic Climate Forcing

In the judgment of the SAB, some elements of the expected climate response to increasing greenhouse gases are more robust and thus will very likely require adaptation efforts. These include sea level rise, increased frequency of extreme high temperatures, decreased frequency of extreme low temperatures, lengthening of the frost-free season, and increased short-term hydrologic variability. A short summary of each of these elements is provided below. The primary source for these summaries is the section of the National Climate Assessment (2014) that focuses on climate change in the northeastern United States.

a) sea level rise

Sea levels along the New Jersey coast have risen more rapidly than the global average because the land is subsiding (Miller et al. 2013). The rate of sea level rise is especially rapid adjacent to the coastal plain where compaction of sediments contributes to greater land subsidence. At Atlantic City, where tide gauge records extend back to 1912, sea level has risen by an average rate of 1.5 inches per decade over the past 100 years, and will rise at a faster rate in the future.

The National Climate Assessment projects a rise in global sea level of 1-4 feet (30-122 cm) by 2100. The large range reflects the range of estimates of melting rates of the Greenland and Antarctic ice sheets. It also notes that "(s)ea level rise along most of the coastal Northeast is expected to exceed the global average rise due to local land subsidence, with the possibility of even greater regional sea level rise if the Gulf Stream weakens as some models suggest. Sea level rise of two feet (61 cm), without any changes in storms, would more than triple the frequency of dangerous coastal flooding throughout most of the Northeast."

Miller et al. (2013) projected future rates of sea level rise for the mid-Atlantic region. The projections are expressed relative to a 2000 baseline and include a best estimate as well as a range to account for uncertainties in future rates of global ocean warming and ice sheet melting. On the New Jersey coast, sea level is projected to rise by 30 to 71 inches (76-180 cm) by 2100, with a central estimate of 42 inches (106 cm). The implications of the projected sea level rise for coastal flooding will be substantial, as the baseline for future storm surge events will be raised accordingly. A recent study from scientists at the National Oceanic and Atmospheric Administration projects that coastal inundation equivalent to that from Hurricane Sandy will happen more frequently than every 20 years by 2100 if sea level rise is at the high end of the expected range (Sweet et al. 2013).

b) increased frequency of extreme high temperatures

The National Climate Assessment (Walsh et al. 2014) discusses the response of extreme high temperatures in the northeastern United States under two scenarios for future anthropogenic emissions. The high emissions scenario projects continuing increases in CO_2 emissions while the low emissions scenario assumes that emissions will stabilize toward the middle of the 21st century and slowly decrease thereafter. The response of extreme high temperatures is described as follows. "Under both emissions scenarios, the frequency, intensity, and duration of heat waves is expected to increase, with larger increases under higher emissions. Much of the southern portion of the region, including the majority of Maryland and Delaware, and southwestern West Virginia and New Jersey, are projected by mid-century to experience many more days per year above 90° F (32.2° C) compared to the end of last century under continued increases in emissions. This will affect the region's vulnerable populations, infrastructure, agriculture, and ecosystems."

c) decreased frequency of extreme low temperatures

Nighttime minimum temperatures have trended upward through much of the world, with fewer low temperature records occurring. Future projections generally extend this trend, as discussed in the National Climate Assessment (Walsh et al. 2014). "The frequency, intensity, and duration of cold air outbreaks is expected to decrease as the century progresses, although some research suggests that loss of Arctic sea ice could indirectly reduce this trend by modifying the jet stream and mid-latitude weather patterns." The evidence for the latter hypothesis is quite controversial and more research will be required to confirm it.

d) lengthening of the frost-free season

A concise discussion of past and projected changes in the length of the frost-free season is provided in the National Climate Assessment (Walsh et al. 2014). "The frost-free season length has been gradually increasing since the 1980s. The last occurrence of 32°F (0° C) in the spring has been occurring earlier in the year, and the first occurrence of 32°F (0° C) in the fall has been happening later. During 1991-2011, the average frost-free season was about 10 days longer than during 1901-1960."

Their projections of future changes in the length of the frost-free season indicate that increases of a month or more are expected over most of the U.S. by the end of the century under the higher emissions scenario, with smaller but still substantial increases under the lower emissions scenario. Future increases in the length of the frost-free season "are projected to be much greater than the normal year-to-year variability experienced today."

e) general warming of marine and terrestrial environments

In addition to the specific warming effects discussed in items b), c), and d) above, generalized warming of the land and water bodies, including coastal waters, will occur throughout the state. This warming can be expected to impact vulnerable ecosystems and wildlife populations in a variety of ways. These may include deleterious impacts to anadromous fish in the Delaware River Estuary (Weinstein, et al., 2009). Other impacts could include an increase in vector-borne diseases that could result, for example, from prolonged mosquito seasons.

f) increased short-term hydrologic variability

Higher temperatures are expected to strengthen the hydrologic cycle, leading to more intense precipitation events but also greater evapotranspiration during dry spells. According to the National Climate Assessment, the heaviest rainfall events in the United States have become heavier and more frequent (Walsh et al. 2014). "The amount of rain falling on the heaviest rain days has also increased over the past few decades. Since 1991, the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains – more than 30% above the 1901-1960 average. There has also been an increase in flooding events in the Midwest and Northeast where the largest increases in heavy rain amounts have occurred."

Regarding future changes in precipitation, the National Climate Assessment noted that the recent trend towards increased heavy precipitation events is expected to continue. Specifically for the northeastern United States, "(t)he frequency of heavy downpours is projected to continue to increase as the century progresses. Seasonal drought risk is also projected to increase in summer and fall as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt.

An important implication of the expected changes in precipitation is that hydrologic statistics can no longer be assumed to be stationary (Milly et al. 2008). In other words, it is not appropriate to assume that future hydrologic statistics, such as return periods for extreme precipitation events, can be determined from past history alone.

Specific Impacts of Climate Change Anticipated for New Jersey

There are a wide array of impacts associated with climate change, as documented in reports of the Intergovernmental Panel on Climate Change (2013b) and the National Climate Assessment (Walsh et al. 2014). A discussion of climate impacts specific to New Jersey and their implications has been developed by the New Jersey Climate Adaptation Alliance in six working briefs available at http://njadapt.rutgers.edu/climate-impacts-in-new-jersey. Highlights from these working briefs and additional information based on expert judgment of the SAB members are listed in the remainder of this section.

a) agriculture and fisheries

- Higher temperatures will lengthen the growing season for crops suited for warm conditions, such as melon, okra and sweet potato.
- Conversely, the growing season will shorten for crops that are better suited for cooler conditions, such as potato, lettuce, broccoli and spinach.
- Some fruit crop species that require long periods of winter chill may become unsuitable for cultivation.
- Higher temperatures can cause decreases in yield and quality for some crops that are sensitive to heat at critical stages of growth.
- Many insect pests and plant diseases will benefit from higher temperatures, particularly those insect pests that have historically been unable to survive cold winters.
- Weeds will benefit from higher temperatures and elevated atmospheric carbon dioxide levels. Some herbicides used to control them may lose effectiveness as carbon dioxide levels increase.
- Increases in temperature will allow better survival of pathogens and parasites affecting livestock.
- Changes in ocean temperatures will affect the distributions of fish and invertebrates.
- Water requirements for crops, ornamental plants, and lawns will increase in a warming climate, increasing demand for irrigation during dry periods.
- More intense rainfall events will increase the likelihood of crop damage and root diseases, delay planting, and inhibit field work.
- Increased heavy rains will cause more runoff into freshwaters, coastal waters and estuaries, causing more sediment, nitrogen, phosphorous and other nutrient discharges into surface waters that will increase the frequency and extent of eutrophication, causing more fish kills.
- Additional freshwater discharges into estuarine waters will affect salinity regimes and alter aquatic vegetation and fishery species diversification.
- Sea level rise may damage bivalve habitat as salt water extends farther into estuaries.
- Rising sea levels will increase the baseline for coastal flooding, increasing the likelihood of saltwater inundation of coastal agricultural lands.
- Ocean acidification from increasing carbon dioxide can affect shell-building in marine organisms by reducing the availability of carbonate.

b) built infrastructure: transportation

- Sea level rise will increase water levels during times when astronomical tides are unusually high (e.g., "king tides"). Low-lying areas, roads and transportation corridors that currently floods only on king tides will occur more frequently, from a couple of times annually to monthly.
- Sea level rise will increase the probability of flooding of airports, roads, rail lines, and tunnels, mainly in conjunction with storm surge events. The impacts would be particularly serious in New Jersey, where much critical transportation infrastructure is close to sea level.
- Higher sea levels will increase the likelihood of erosion of road beds and undermining of bridge supports.
- Sea level rise and higher storm tides may affect navigability of shipping channels.
- Increased summer heat can compromise road pavement (i.e., softening and rutting of asphalt), deform rails, and expand bridge joints.
- Extreme heat can adversely affect air transportation by buckling runways and reducing lift (due to reduced density of air), necessitating longer runways or service disruptions.
- Higher winter temperatures will reduce impacts from snow and ice (e.g., fewer potholes).
- More frequent flooding from intense rainfall events will lead to increases in transportation disruptions and delays.
- Damaged transportation infrastructure will affect the transportation of food, fuel and other necessities across the state, especially in coastal communities.

c) built infrastructure: water resorces

- The rapid filling and then lowering of water supply reservoirs will cause water shortages. Such situations already have occurred; water systems have had to impose water use restrictions more frequently in the past decade.
- Water quality in the reservoirs could deteriorate as a result of rapid runoff and then long periods without normal inflow.
- More frequent and intense rainfall will increase the discharge of sediments, metals, nutrients and other constituents into reservoirs and source waters that will cause more stresses on water treatment plants.
- More frequent and intense rainfall will cause more siltation in reservoirs, thus reducing their capacities.
- Streams/rivers could experience wide ranges of flows that might impact both supply and raw water quality.
- Recharge of aquifers could be reduced; more precipitation falling in heavy rainfall events can be expected to lead to a greater percentage of precipitation leaving the local system via surface runoff
- Sea level rise will increase the frequency of inundation and damage of low-lying utility infrastructure.
- More frequent intense precipitation events can directly damage infrastructure (e.g., shifting of distribution pipes, erosion of access roads).
- More frequent and intense rainfall will cause additional stresses on stormwater and combined sewer collection systems, and wastewater treatment plants necessitating increased operational maintenance costs that will be passed on to ratepayers.

- More frequent and intense rainfall will increase the discharge of sediments, metals, nutrients and other constituents into reservoirs and source waters that will cause more stresses on water treatment plants, necessitating costly process upgrades and increasing their maintenance and operational costs that are passed on to rate payers.
- More frequent and intense rainfall will cause more siltation in reservoirs thus reducing their capacities to store water when it will be most needed during more frequent and extended droughts.
- More frequent low streamflow periods due to droughts and warmer temperatures may cause more frequent water quality impairments that may result in an increased burden on wastewater utilities to improve their effluent quality beyond their current effluent limits. Total Maximum Daily Loads in the Passaic River and other critical waterbodies will become obsolete, require recalculation, and costly planning and permitting process to reduce pollutant discharges to achieve compliance with the Clean Water Act. Capital investments and increased operational and maintenance costs will be required at the expense of ratepayers.
- Low flows can allow saltwater intrusion to adversely affect water supplies by encroaching on surface water intakes.
- Higher sea levels may increase salt water intrusion in coastal areas and threaten drinking water wells.

d) coastal communities

- Loss of land due to inundation and increased erosion from sea level rise
- Increased vulnerability to flooding due to higher storm tides caused by sea level rise
- Damage to public and private property and diminished tourism and tax revenues from more frequent inundation and increased erosion
- Risk to human life and public health from more frequent coastal flooding events and their consequences
- Risk to public health from water contamination from excessive runoff in the aftermath of extreme precipitation events

e) natural resources

- Ocean acidification from increased atmospheric carbon dioxide concentrations can impact plankton and shellfish with possible risks to the food web.
- Loss of beach and wetland habitats from inundation due to sea level rise and erosion or destruction due to more frequent intense precipitation events.
- Increases in temperature can cause changes in coastal salinity and circulation, with implications for estuarine structure and the biota.
- Increases in frequency of intense precipitation and accompanying runoff can lead to increased sedimentation and decreased water quality.
- Rising temperatures can increase the frequency of wildfires and vulnerability of forests to pests.
- Rising temperatures can cause changes in forest tree species and increase their susceptibility to disease.

f) public health

- More frequent extreme high temperatures lead to an increase in heat-related mortality and morbidity from heat stress and exacerbation of pre-existing chronic conditions
- Greater risk of pulmonary and respiratory diseases from increases in ground-level ozone and particulate matter associated with more frequent episodes of air stagnation and increased energy use during high temperature periods
- Increase in asthma and allergenic diseases due to a longer pollen season and greater pollen potency
- Consumption of contaminated food and water as a result of more frequent flooding and its consequences (e.g., power outages, displaced populations)
- More frequent flood-related damage to low-lying health care facilities and infrastructure
- Exposure to mold, mildew, and toxic contamination from flooding, including flooding of hazardous or contaminated sites
- Expanded ranges of vector-borne diseases such as Lyme disease, and West Nile virus in a warming climate
- Increase in food-borne pathogens such as salmonella and vibrio caused by increasing temperatures
- Flood-related increases in population of waterborne parasites such as Cryptosporidium and Giardia, which cause gastroenteritis

g) built infrastructure: power utilities

- More frequent extreme high temperatures can degrade performance of thermal power plants, cause equipment failures (e.g., electrical transformers), and lead to more frequent power failures due to increasing energy demand.
- Longer dry spells can lead to reduced cooling capability at inland power plants from decreased water levels and flows.
- Higher temperatures and longer heat waves will cause increased demand on power generation and transmission and increase the risk of blackouts thus necessitating increased generating capacity, transmission, and operation and maintenance costs.
- Backup power capabilities used by water, wastewater, telecommunications and other utilities will be employed more frequently in the future.

Adaptation to Climate Change; Extreme Events

The aspects of climate change that have been highlighted in this report have been the focus of a substantial body of work on adaptation to climate change. The New Jersey Climate Adaptation Alliance (NJCAA) (http://njadapt.rutgers.edu/), a network of policymakers, public and private sector practitioners, academics, and NGO and business leaders that is facilitated by Rutgers University, seeks to build climate change preparedness capacity in New Jersey. It has recently released a comprehensive report that identifies a broad variety of adaptation measures (NJCAA, 2014). In addition, extensive work has been conducted by the City of New York and its New York City Panel on Climate Change to characterize the changing climate, make forecasts for the local region, identify the threats and potential risks, and identify potential adaptation strategies to improve resilience. The work is updated now on a biannual basis. The City's 2007 *PlaNYC*, its 2013 *A Stronger More Resilient New York* and many more companion reports prepared by its individual public service departments provide examples of adaptation strategies and specific mitigation measures across all public sectors. Due to the proximity of New York City, much of the information in this analysis is relevant to New Jersey. Numerous federal resources are available from FEMA, the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, etc. Lessons will also be learned from the HUD-funded Rebuild by Design efforts in Hoboken and the Meadowlands.

All of these studies and informational resources indicate that climate change will make extreme events, including floods, heat waves, and droughts, more likely. They stress the need to build capacity at the local, regional, and state level to develop and institutionalize strategies to cope with extreme events. Detailed recommendations on steps to build this capacity are presented in the reports. The NJCAA report (NJCAA, 2014) identifies five broad recommendations, and lists and discusses a number of specific actions associated with each of these areas. These recommendations are:

> 1) Strengthen climate change preparedness and adaptation in New Jersey through the establishment of a statewide climate adaptation policy that is designed to significantly reduce New Jersey's vulnerabilities to a changing climate. This would be implemented by directing integration of science-based standards into state policies, programs and regulations and directing actions consistent with the statewide policy be taken by State agencies, regional and local planning authorities and commissions, municipal and county government.
>
> 2) Implement standards, regulations and policies that apply a risk management approach to identify people, places and assets (including natural capital) most at risk to climate stressors and direct investment to risk reduction efforts as well as uses that are compatible with a changing climate.
>
> 3) Rely on existing governance structures and programs, to the greatest extent possible, and build partnerships with community-based organizations, as a means to integrate climate change adaptation and preparedness rather than create new programs.
>
> 4) Explore and implement creative strategies to generate stable funding for climate change adaptation and preparedness activities, favoring strategies that also result in reductions of emissions that cause climate change.
>
> 5) Promote education, training, outreach and innovative partnerships to better inform the public, decision makers and practitioners about climate change impacts and adaptation strategies to foster adaptation and preparedness capacity.

The SAB recommends that these resources be used to provide general guidance on climate change adaptation, and stresses that developing capacity to adapt to extreme events such as floods and other storms, heat stress, and drought, before they happen is very likely significantly more cost-effective than attempting to adapt to extreme events after they happen. The SAB further stresses that although their timing cannot be predicted, it is virtually certain that extreme climate change-related events will occur with increasing frequency.

Chronic Impacts of Climate Change: Sea Level Rise

The SAB finds that, even in the absence of extreme events, which could be considered acute manifestations of climate change, chronic impacts of climate change are already occurring.

One such chronic impact is coastal erosion, driven in part by the steady pressure of sea level rise. As noted above, at Atlantic City, the sea has risen approximately 15 inches since the early 1900s. A variety of efforts have been made to counter coastal erosion. Historically, New Jersey built sea walls, groins and jetties as a defense against beach erosion. Today, in most cases, beach nourishment is preferred to hard structures such as seawalls and bulkheads. Beach nourishment is replenishment of beaches with sand pumped or dredged from bay areas and from the ocean floor. It began on New Jersey beaches and others in the Northeast U.S. in 1930s. The quantities of sand placed on beaches since the 1930s, and the associated costs, have been cataloged for beaches throughout the nation (Program for the Study of Developed Shorelines, 2014).

The SAB has reviewed beach replenishment data for New Jersey and finds that both the quantities of beach fill placed on New Jersey beaches and their costs have grown from approximately $100 million to $200 million per decade from the 1950s through the early 1990s to over $600 million in the decade spanning 2005 through 2014 (Figure 1). This cost increase has been driven both by increasing quantities of sand used, which has grown from between 10 and 20 million cubic yards per decade in the 1950s through the early 1990s to over 40 million cubic yards per decade in the most recent two decades, and by increasing costs per cubic yard. The latter costs, in 2013 dollars, were in the range of $8 to $12 per cubic yard from the mid-1960s through 2004, but rose to over $16 per cubic yard in the most recent decade. In part, this cost increase reflects an increasing lack of availability of suitable sand (Gillis, 2014).

Extrapolation of the existing trend of increasing cost of beach replenishment suggests that the cost per decade could reach over $1 billion within the next 20 years. Steadily rising seas, coupled with the likely increasing difficulties in obtaining sand, suggest that the trend of increasing costs could accelerate. Currently, much of the funding for replenishment is federal; there is no guarantee that this will continue at its present level. At some point, perhaps sooner than later, replenishment of at least some of New Jersey's beaches may cease to be feasible.

The SAB recommends that the Governor appoint a high-level panel to analyze the threats to New Jersey's beaches, coastal ecosystems, and coastal communities that are expected to develop within the next twenty five years from sea level rise and associated coastal erosion, and to develop a plan to rationalize and coordinate protection efforts for coastal communities, coastal ecosystems, and beaches, including the acquisition of sufficient funding.

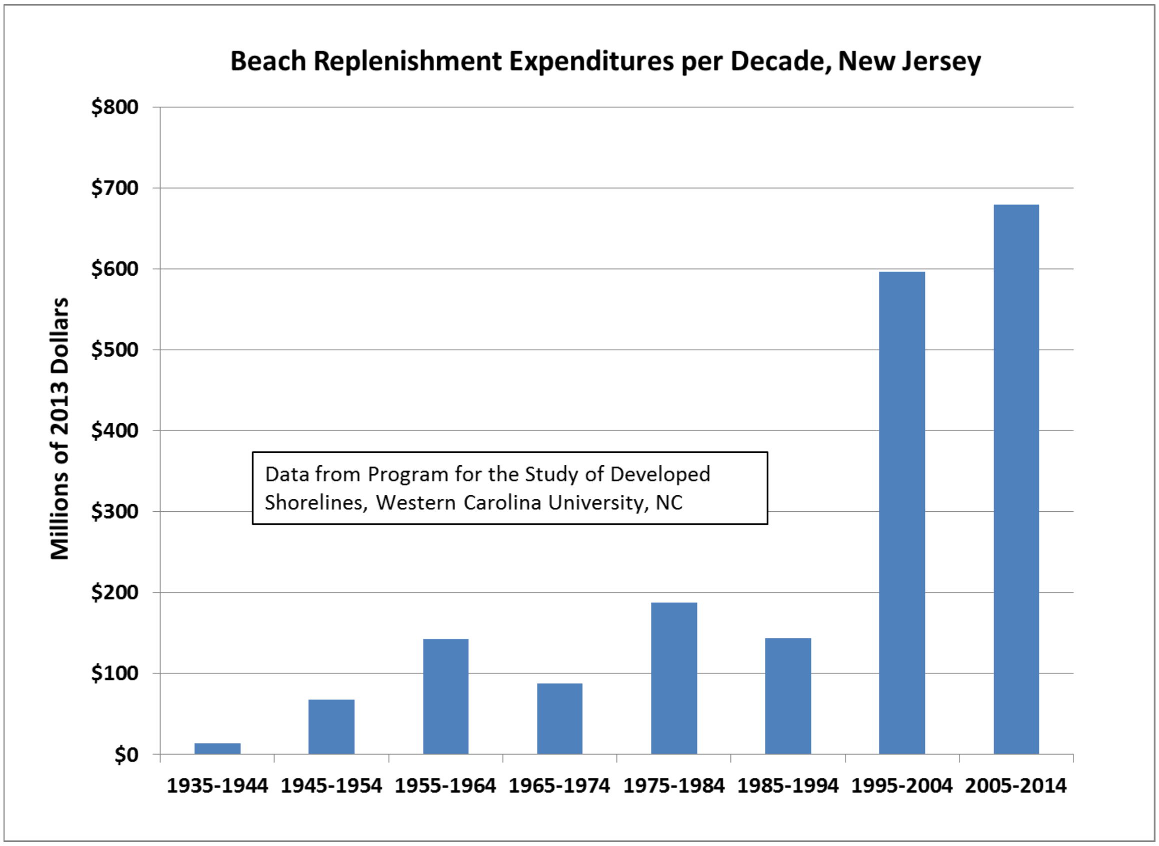

Figure 1

References

Gillis, John, 2014, Why Sand is Disappearing, *The New York Times*, November 4th, 2014, http://coastalcare.org/2014/12/why-sand-is-disappearing-by-john-r-gillis/ (accessed 12/21/14)

IPCC, 2013: *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Miller, K. G., R. E. Kopp, B. P. Horton, J. V. Browning, and A. C. Kemp, 2013: A geological perspective on sea-level rise and impacts along the U.S. mid-Atlantic coast. *Earth's Future*, DOI:10.1002/2013EF000135.

Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, Z. W. Kundzewicz, D. Lettenmaier, and R. J. Stouffer, 2008: Stationarity is dead: Whither water management? *Science*, **319**, 573-574, DOI:10.1126/science.1151915.

New Jersey Climate Adaptation Alliance (NJCAA). 2014. Resilience: Preparing New Jersey for Climate Change: Policy Considerations from the New Jersey Climate Adaptation Alliance. Edited by Matt Campo, Marjorie Kaplan, Jeanne Herb. New Brunswick, New Jersey: Rutgers University.

New York City, 2007. *plaNYC, A Greener Greater New York.*

New York City, 2013. *plaNYC, A Stronger, More Resilient New York.*

Nordhaus, W. D., 2010: Economic aspects of global warming in a post-Copenhagen environment. *Proc. Nat. Acad. Sci.*, **107**, 11721-11726, DOI:10.1073/pnas.1005985107.

Program for the Study of Developed Shorelines, Western Carolina University, 2014, Beach Nourishment, http://psds.wcu.edu/projects-research/beach-nourishment/ and beach nourishment data, https://docs.google.com/spreadsheet/ccc?key=0Ai5L0L8AX-QAdExmRmNrY203UXZWVndzNlg4aFBILUE&usp=sharing (accessed 12/18/14).

Sweet, W., C. Zervas, S. Gill and J. Park, 2013: Hurricane Sandy inundation probabilities today and tomorrow [in "Explaining Extreme Events of 2012 from a Climate Perspective"]. *Bull. Amer. Meteor. Soc.*, **94**, S17-S20.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014: Ch. 2: *Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.

Weinstein, M.P., S. Y. Litvin, V. G. Guida, and R. C. Chambers, 2009, Is global climate change influencing the overwintering distribution of weakfish Cynoscion regalis? *J. Fish Biology,* **75**, 693–698.