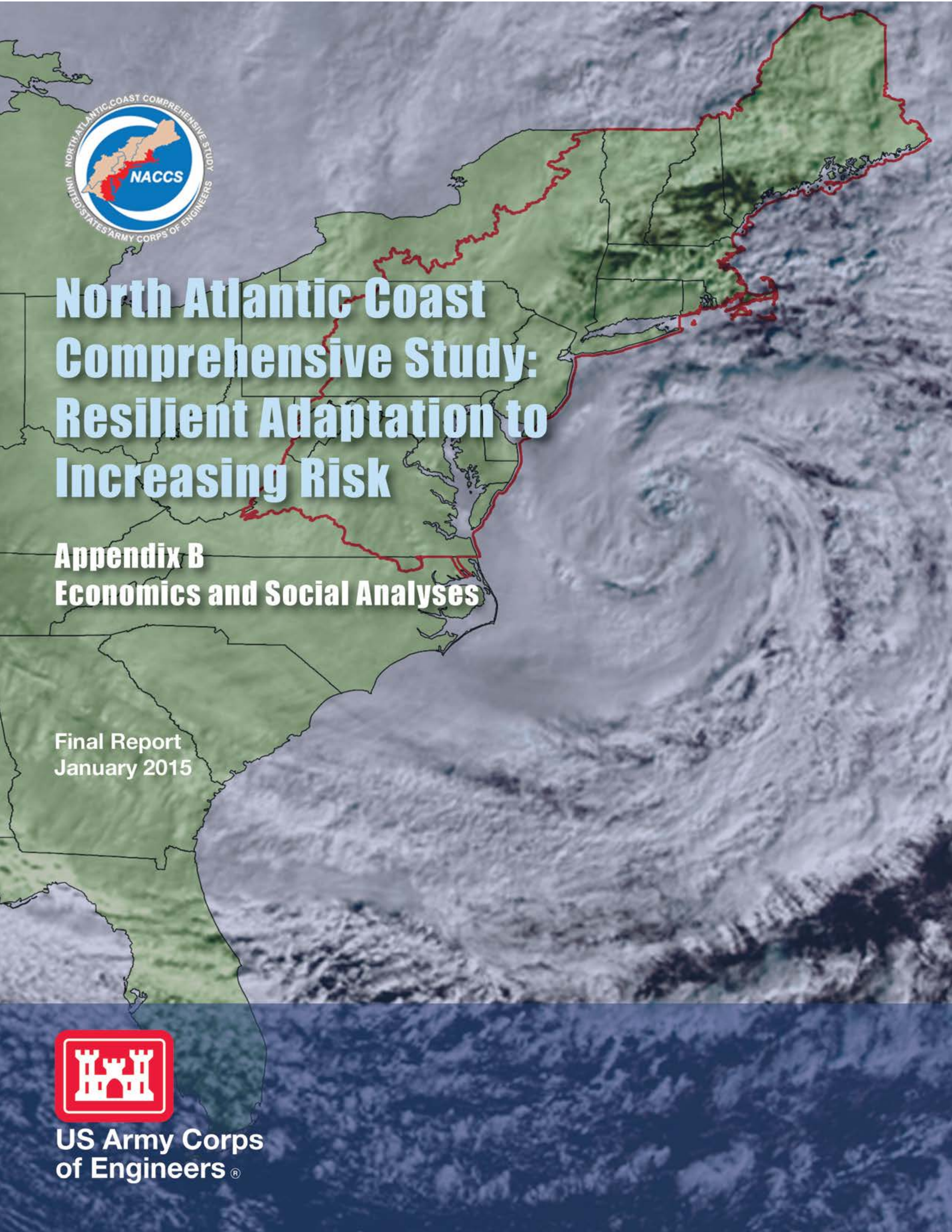

North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk

Appendix B
Economics and Social Analyses

Final Report
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APPENDIX B: ECONOMICS AND SOCIAL ANALYSES

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

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ECONOMIC ANALYSES

The economic analyses performed for the North Atlantic Coast Comprehensive Study (NACCS) consisted of two parallel efforts. The first effort was to develop a framework (referred to as the Coastal Storm Risk Management Framework) to characterize and compare the risk and vulnerability of coastal populations that is consistent with the direction of the Disaster Relief Appropriations Act, Public Law (PL) 113-2 (enacted January 29, 2013). The second effort was to incorporate information on Hurricane Sandy impacts into the procedures planners use to estimate the effects of future events. By doing so, decision-makers, stakeholders, and the public are better informed about the damage that such events can cause and the benefits to risk management strategies and measures. These two efforts are described in more detail below.

I. Risk and Vulnerability Assessments and Comparisons

Risk is an overarching concept that includes the components of hazard, exposure, performance of a system of flood risk management features (if applicable), subsequent consequences, and vulnerability. The exposure and risk assessments are part of an approach to evaluating flood peril along the North Atlantic Coast as a system. This approach incorporates the natural, social, and built systems as referenced in the National Oceanic and Atmospheric Administration's and U.S. Army Corps of Engineers *Infrastructure Systems Rebuilding Principles*.[1] As such, the exposure and risk assessments are planning processes that allow stakeholders to highlight risk areas. The NACCS Coastal Storm Risk Management Framework was applied on a macro-level to cover a large geographic area and its exposure and risk assessments focus on three criteria: population density and infrastructure, social vulnerability characterization, and environmental and cultural resources. The NACCS report includes an application of the Coastal Storm Risk Management Framework for the Rockaway Beach/Jamaica Bay study subreach as an example of the methodology for identifying and evaluating measures to reduce or manage the coastal flood risk.

[1] National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers). 2013. *Infrastructure Systems Rebuilding Principles* (NOAA and USACE, 28 February 2013), http://coastalmanagement.noaa.gov/resources/docs/infsysrebuildingprinciples.pdf (accessed June 2014).

The risk of coastal flood peril was defined using flood inundation mapping. Exposure to flood peril was defined as the presence of people, infrastructure, and/or environmental resources (receptors) affected by potential coastal flooding. Vulnerability is defined as the degree to which a system's receptors or assets are susceptible to, and unable to cope with, the adverse effects of coastal flooding over a period of time. It is a function of character and magnitude of a hazard (here, coastal storm flooding) to which the community is exposed, the sensitivity of the population, infrastructure, and environmental resources in the community, and the capacity of the community to bounce back and regain functional performance. The Coastal Storm Risk Management Framework presents an illustrative example and assessment of exposure and risk on a macro-level covering a large geographic area to assist in indentifying coastal flood hazards and proposes a method by which to identify and evaluate measures that could reduce or manage that risk. The extent of the flood hazard and what is exposed to flood peril help to define the problems and opportunities. The Framework describes the process to identify the flooding hazard from coastal storms as well as forecasted impacts from sea level and climate change, various assets exposed to the flood hazard, and the process to assess vulnerability.

Appendix C – Planning Analyses presents more information related to coastal flood inundation mapping and the development of the exposure assessment illustrated through the Coastal Storm Risk Management Framework. Performance, defined as how a system reacts to a hazard according to a specific set of metrics, along with various consequences, could not be evaluated at the regional scale within the time constraints to complete the study. However, performance analysis is warranted in more-detailed future studies.

An example of the application of the Coastal Storm Risk Management Framework is provided for each State in Appendix D – State and District of Columbia Analyses. Applying the Coastal Storm Risk Management Framework independently at a community level would allow users to complete more robust exposure and vulnerability assessments that consider the priorities and expectations of a more localized impact area.

I.1 Development of the NACCS Exposure Index

Hurricane Sandy and its aftermath demonstrated that coastal storms have the capacity to damage many of the things that members of society value. In some cases, that damage was fairly easily measured in terms of dollars; but in other cases, it was not. The damage is nevertheless both real and comparatively large even though the magnitude of the harm is not always easily or plausibly monetized. To evaluate a population's relative vulnerability to harm from coastal storms, it is necessary to compute a potential for harm, including potential harm that is easily measured in monetary terms and potential harm that is not easily measured. Use of an index allows for more complete measurement of the consequences of an event because it does not limit quantification of harm to one stream of values (e.g., monetary damages, lives lost). The NACCS uses an exposure index (EI) to accomplish this task.

The purpose of an EI is to measure the relative potential harm that can be done by a coastal storm in a given area. Several variables could be used to construct an EI, as long as the variables used result in an EI that is validated against past storm events and ensure that the spatial and temporal variations in the EI reflect historical conditions. All indexes compare the observation of a group of variables in one period or location to the observation of the same group of variables in a base period or base location. For instance, price indices compare how much money it would take to purchase a set of items in the current period to how much money it took to purchase the same set of items in the base period. Therefore, the current value of a price index reveals what current prices are relative to what prices were in the base period. Similarly, an EI reveals only the exposure to potential harm at one location relative to exposure to potential harm at another location.

The entire coast is exposed to the potential harm caused by coastal storms to one degree or another. The purpose of an EI is to illustrate to what degree a particular location is exposed relative to other locations. This purpose is accomplished through the choice of variables and their weightings.[2] This report presents the EI used for the NACCS; however, if another user of this EI were to view one of the criteria as more important for their purpose, that user could increase the relative weight allocated to that criterion.[3] As part of the NACCS Coastal Storm Risk Management Framework, the replication of the exposure assessment, with or without changes to weightings and inputs, can be accomplished at a smaller scale to incorporate the priorities and expectations of a more localized impact area.

A major consideration in selecting variables for inclusion in an EI is the preservation of comparability across the entire study area. This comparability is essential to be able (1) to compare the potential for harm that one area presents relative to another and (2) to use the EI, in conjunction with the frequency of occurrence of a given storm event and parametric costs, to get a single indicator of the relative coastal risk reduction per unit of implementation cost. The preservation of comparability across the large NACCS study area limited the choice of variables that could be included in any EI to those variables for which observations are available that (1) can be stated in a numerical form; (2) cover the entire NACCS study area; (3) are measured on the same basis; (4) were reported in a geographic information system (GIS) format; and (5) were reported in small enough geographic units that they could be aligned with the other elements of the NACCS EI. As individual study efforts proceed and the geographic extent under study is reduced, more variables will become available for inclusion in an EI while still preserving comparability. One variable that could be helpful to include in more focused studies would be evacuation time. Unfortunately, such statistics have not been generated for all areas within the NACCS study area, and in those areas that have such statistics, the statistics are not all estimated on the same basis or in the same units.

The NACCS used a series of exposure assessments to identify the various components of its EI. Again, the choice of variables that could be used for such a large study area is limited by the data available and comparably measured throughout that area. Ultimately, the NACCS developed an EI consisting of three component indices: population density and infrastructure, social vulnerability characterization, and environmental and cultural resources.

1. Population Density and Infrastructure Index[4]

Population density includes identification of the number of persons within an areal extent across the study area, and infrastructure consists of the critical infrastructure that supports the population and communities. These factors are combined to reflect the overall exposure of the built environment. Both population and infrastructure are used because Census Bureau population statistics alone would not give an appropriate representation of things to be damaged in the study area. For example, using

[2] The use of weights in some form in an index is unavoidable. Even the elimination of explicit weights is itself a scheme of implicit equal weighting. Moreover, the usual biases involved in Laspeyres or Paache weighting schemes are not an issue in this case because an EI is cross sectional, not a time series.

[3] Doing so amounts to that user superimposing his or her own utility function into the $\Delta R/_{C}$ (change in risk over cost) indicator, which is envisioned here as a possible guideline for determining how best to allocate coastal storm risk management resources. The progression of the use of the NACCS EI to calculate a change in risk (ΔR) generated by an intervention that can be arrayed over the cost of that intervention (*C)* is discussed later in this chapter.

[4] The parallel to this component index in USACE planning terms would be National Economic Development (NED).

population statistics alone would provide a very low value for Wall Street in Manhattan, but we know from Hurricane Sandy that there is potential for exposure in that area.

The affected population and population density within the study area were identified as a measure of the coastal flood exposure. Population density for any location was calculated to identify the extent of population exposure. Because post-hurricane recovery time is directly proportional to the time it takes to restore interruptions in basic services, such services are necessary to ensure resilient communities. Critical infrastructure included sewage, water, electricity, academics, trash, medical, safety, and other considerations and services necessary to sustain a population. The evaluation of vulnerable infrastructure considered a wide range of facilities, including large facilities such as power plants, ports, and airports that serve large regional populations; moderate-sized facilities such as water and wastewater treatment plants that serve an entire community; and smaller facilities such as gas stations and pharmacies that serve specific neighborhoods. The Population Density and Infrastructure Index (PDII) used in the NACCS reflects a weighted summation of the population density and infrastructure that could be exposed to coastal flooding.

2. Social Vulnerability Characterization Index[5]

The social impacts of a storm event often fall disproportionately on the most vulnerable people in a society: the poor, the very young (or adults with very young children), the elderly, and those who do not speak English proficiently or who may need more support before, during, or after a storm event. Social vulnerability characterization provides an opportunity to meaningfully and comprehensively call attention to certain segments of the population that may have relatively more difficulty preparing for and responding to storm events.[6]

The NACCS Social Vulnerability Characterization Index (SVCI) utilized the U.S. 2010 Census and 2011 American Community Survey data on age, income, and characteristics to potentially identify those with limited English proficiency skills. Variables used in the SVCI were:

- **Percentage of People Age 65 and Over**

  The elderly are likely to have greater difficulty in evacuating than other age groups; have medical concerns; and may lack the ability, stamina, or resources to recover from the event. Also, the frail elderly may be in nursing homes or hospitals, which places the burden for their safety in a flood emergency on others.

- **Percentage of People Age 5 and Under**

  The very young require assistance to be removed from harm's way. Parents lose time and money caring for children when day-care facilities are affected by an event. The very young may also be more susceptible to flood-borne diseases.

- **Percentage of All People Whose Income in the Past 12 Months Is Below Poverty Threshold**

  Poorer households are more likely to occupy risky locations and to be in housing that is older and in substandard condition. Poorer households may lack resources, such as access to media, to prepare for an impending disaster and cars to evacuate in a flood emergency.

[5] The parallel to this component index in USACE planning terms would be Other Social Effects (OSE).
[6] See C. Mark Dunning and Susan Durden, *Social Vulnerability Analysis Methods for Corps Planning* (USACE Institute for Water Resources, May 2011)

Poorer households may also have less ability to absorb losses from a flood, less access to insurance, fewer resources to provide a cushion for a long recovery period, and less access to social networks that can lobby on their behalf for assistance.

- **Percentage of All People Who Speak a Language Other Than English and Do Not Speak English Very Well**

  Non-English speakers may not be able to understand warning information or be familiar with processes for obtaining relief or recovery information, both of which increase vulnerability.

These variables were chosen because they were seen to be the most prominent indicators of social vulnerability in prior USACE studies. Each of these variables was considered separately, but a combined value was developed to display as a visual illustration/representation. An additive means of combining the variables was determined to be the most appropriate method because previous social vulnerability studies have shown that an increase in all of these variables would result in an increase in overall social vulnerability. For example being over 65 makes one relatively vulnerable, but being over 65 and having low income (and therefore having relatively low consumption of things that contribute to storm preparedness, such as an auxiliary generator) makes one even more vulnerable than merely being over 65 and having higher income. Being over 65, having relatively low income and being unable to speak and understand English (and thus unable to receive the overwhelming bulk of emergency instructions or communicate that one is in trouble to the overwhelming bulk of emergency personnel) makes one even more vulnerable than merely being over 65 and of low income. The NACCS weighted all variables equally; however, the weighting scheme can be easily modified to better fit the characteristics of the focus area under consideration.

Because all variables were represented as a percentage, they were already normalized and could be added together without adjustment. An overall "score" was obtained for each of the census tracts based on the following formula:

$$SVCI = \%Age_{65+} + \%Age_{5-} + \%Income_{sub-poverty} + \%nonproficient\ English$$

Beyond their use in the NACCS EI, social vulnerability values were also mapped by Census tract using a classification based on the 10 naturally occurring breaks within the distribution. The higher the overall value, the more socially vulnerable the area was (Appendix C – Planning Analyses). The NACCS study team then focused its descriptions on the areas within the planning reaches with the highest values for overall social vulnerability. Generally speaking, those areas were characterized by higher levels of non-English speaking or poor populations. Even though some of the higher vulnerability values fell outside the areas highlighted for inundation during a major storm event, most of the higher vulnerability values were within the areas highlighted for inundation. This identification of high-vulnerability areas allowed a basis for comparison within the inundated areas and a logical progression for identifying the ultimately selected problem areas. The methodology outlined here can be used to ascertain similarities and differences in the relative levels of social vulnerability to assist decision-makers to pinpoint those factors that threaten the sustainability and stability of their communities.[7]

[7] Susan L. Cutter, Bryan J. Boruff, and W. Lynn Shirley, "Social Vulnerability to Environmental Hazards," *Social Science Quarterly,* Vol. 84, No. 2, June 2003, pp. 257-258.

3. Environmental and Cultural Resources Index[8]

The environmental and cultural resources exposure analysis identifies important habitat and environmental and cultural resources that would be affected by storm surge, winds, and erosion.

Impacts and recovery opportunities would vary depending on the resources affected and the time of year that the hazard occurs. The Environmental and Cultural Resources Index (ECRI) was also evaluated as it relates to exposure to the Category 4 maximum inundation. Data from national databases, such as the National Wetlands Inventory and The Nature Conservancy Ecoregional Assessments; data provided by the U.S. Fish and Wildlife Service, including threatened and endangered species' habitats and important sites for bird nesting and feeding areas; shoreline types; and historic sites and national monuments, among others, were used to assess environmental and cultural resource exposure. Properties with restricted locations (typically, archaeological sites) and certain other properties were omitted from the analysis because of site-sensitivity issues.

The NACCS Composite Exposure Index

The three independent EIs described above are summed together to develop one composite index that displays overall exposure, as presented below.

$$NACCS\ EI = 80\%\ \text{PDII} + 10\%\ \text{SCRI} + 10\%\ \text{ECRI}$$

Because the focus of the NACCS is on reducing risk to vulnerable coastal populations and the infrastructure that supports them, the population density and infrastructure exposure index was weighted much higher than the social vulnerability characterization and environmental and cultural resources indices as part of the development of the composite exposure index. Each index was multiplied by a relative weight, and the results were summed to develop the total index. Population density and infrastructure was assigned a weight of 80 percent, social vulnerability characterization was assigned a weight of 10 percent, and environmental and cultural resources was assigned a weight of 10 percent. The higher weight applied to the population density, and infrastructure exposure index reflects the NACCS interpretation of the mandate from Congress in PL 113-2 "to address flood risks of vulnerable coastal populations." This process is used to illustrate how the NACCS Coastal Storm Risk Management Framework could be applied based on a specific purpose or objective (here, reflecting the Congressional intent of the Hurricane Sandy Supplemental Appropriation). As noted previously, the framework could be adjusted to meet other objectives by applying refined data sets and/or resetting index weights.

A. Risk and Vulnerability, Getting from EI to ΔR

By its authorizing language, the NACCS is "a comprehensive study to address flood risks of vulnerable coastal populations in areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the Corps." To be sure that this study is fully responsive to this statutory direction, the terms *risk* and *vulnerable* need to be clearly defined. These concepts are intertwined to such an extent that only by having a clear definition of each can it be ensured that the analysis undertaken in the study is complete.

Risk is the product of the probability of occurrence of some event (i.e., the frequency with which it occurs) and the consequences of that event. A peril is a force that, if unchecked or not avoided, will cause harm. A hazard is a source of danger or peril to life, property, or assets. In light of its

[8] The parallel to this component index in USACE planning terms would be Environmental Quality (EQ).

authorization, the NACCS focuses on the flood peril. In the case of the flood peril, sea level change would be a hazard. Interventions such as construction of a seawall or the elevation of buildings could be viewed as hazard-reducing measures. In comparing the costs and benefits of a variety of measures, it will be necessary to consider both the progress of hazards arising in the future and the effects of existing and future hazard-reducing measures. Both affect the frequency with which any given area will be visited by the flood peril in the future.

Part of the risk calculation is the consequence of being visited by the flood peril, which is a function of exposure to the peril. For a given area, exposure to the peril depends on the presence of people, property, and resources to be harmed. Higher population density or higher density of development produces higher exposure to the flood peril. In this context, a program to reduce population density in near-shore areas, perhaps through buyouts or enhanced enforcement of land use regulation, could be seen as risk reduction through reduction in exposure to the peril. The NACCS developed its EI to approximate those items that are exposed to the flood peril in the event considered.

The full risk (R) presented by the flood peril, that is, *the vulnerability of the population* in any given reach, is the index of exposure multiplied by the probability of the occurrence of the flood peril, *P(f)*:

$$R = EI * P(f)$$

Note: For purposes of the study, exposure is used as a proxy for potential consequences, but additional analysis will be required to advance from exposure to actual consequence metrics.

Where there is some hazard-reducing measure already present in the without-project (*wop*) condition, the vulnerability of a given reach is reduced by the floods (*f*) that would be prevented by those in-place measures (f_{wop}).[9] Vulnerability in the without-project condition then becomes:

$$R_{WOP} = EI * P(f_{WOP})$$

The reduction in vulnerability (i.e., the benefit provided by any given measure) is the difference in the risk, *R*, between the with-project (*wp*) and without-project (*wop*) conditions. Thus, we can define ΔR for any given measure *j* as:

$$\Delta R_j = R_{wop} - R_{wp} = EI * \Delta P_j$$

where $\Delta P = P(f_{WOP}) - P(f_{WP})$.

Again, the peril is the flood, not the event causing the flood. The event, in the case of the NACCS, a coastal storm, will occur with or without measure *j* in place. What changes with measure *j* in place is whether the flood occurs or if it does, how severe it is. Alternatives that the USACE uses in its projects that change the frequency or severity of an event in a specific location include dunes, levees, and breakwaters. Alternatively, sea level change is likely to increase the probability of a flood event.

Up to this point, this document has treated EI as a constant; however, it is possible to relax that assumption. For instance, population growth or decline means that more or fewer people are exposed to the flood peril, respectively. Another way to decrease exposure to an event might be through strategic retreat from the areas where damages occur, including buying out homes. Table I-1 provides some examples of variables impacting exposure and probability.

[9] "With-project condition" and "without-project condition" are commonly used terms in USACE civil works studies. USACE planning, guided by U.S. Army Corps of Engineers, *Engineer Regulation 1105-2-100: Planning Guidance Notebook (USACE, 22 April 2000)*, makes use of these terms to understand the consequences of their interventions. Although this report is not a classic USACE study, the use of such concepts is still useful for current purposes.

Table I-1.Variables Impacting Exposure and Probability			
EXPOSURE INDEX		**PROBABILITY**	
Variables that would increase exposure	**Variables that would decrease exposure**	**Hazard Increasers**	**Hazard Decreasers**
Population growth	Population reduction	Sea level change	Installation of structural projects in the without-project condition
Increased development	"Retreat" policies, such as a program of buyouts, building elevations, and enforcement of land use restrictions	Increased frequency or intensity of storms due to climate change	Decreased frequency or intensity of storms due to climate change
Demographic changes resulting in higher social vulnerability	Demographic changes resulting in lower social vulnerability	Degradation of natural protection features such as dunes due to shoreline erosion	A buildup of natural protection features such as dunes due to sediment aggradation

Calculating ΔR for each measure *j* (or combinations of measures, *j, k, and l*) would give a relative estimate of benefits of project implementation, although that relative estimate would not be denominated in dollars.

B. Change in Risk as a Screening Tool for Alternative Measures

To be useful to decision-makers, ΔR_j would have to be compared with a relative estimate of the implementation costs of that measure, which we will call C_j. This relative estimate does not need to be measured in dollars because all that is required is a cost estimate that reveals the relative change in cost associated with changing the scale of each type of measure considered. The idea is to produce, for each type of measure, an equation that shows the relationship between the scale of production of the measure and the total cost to produce that scale. The relevant scales would be those corresponding to the water surface elevation associated with $P(f_{WP})$.

Once the necessary C_j estimates are produced, finding $\frac{\Delta R_j}{C_j}$ would produce a number that represents the relative net benefits of implementing a measure *j*. The resulting number would only have meaning in comparison with similarly found numbers for other projects (e.g., *k, l, m, n*). These numbers, although analogous to net present value, are not benefit-to-cost ratios. Thus, there is nothing significant about the value of $\frac{\Delta R_j}{C_j}$ being greater than or less than one. The significance of $\frac{\Delta R_j}{C_j}$ lies only in whether it is greater than or less than $\frac{\Delta R_k}{C_k}$. If $\frac{\Delta R_j}{C_j} > \frac{\Delta R_k}{C_k}$, then project *j* produces more reduction in vulnerability to the flood peril per dollar invested than project *k* does.

If the objective of the planning process is to optimize the allocation of a given level of expenditure across competing uses in the form of project implementation, then the rule to follow is to always allocate the next dollar to the project that offers the highest $\frac{\Delta R}{C}$. This decision rule is implied by the equimarginal principle.[10]

Although the equimarginal principle is a mathematical description of optimizing behavior subject to a constraint, it is not the same thing as a benefit-to-cost ratio (BCR) either. Although the equimarginal principle tells us how to allocate resources so as to get the largest total benefit (whether that benefit takes the form of utility, output, revenue, etc.) from a given level of expenditure, it tells us nothing about whether the total benefit is more than, less than, or equal to the total expenditure (much less cost) that must be incurred to obtain it. The BCR tells us whether total benefits exceed total costs (BCR > 1), are less than total cost (BCR < 1), or equal total cost (BCR = 1). When we start considering projects that incur costs and yield benefits over more than one period, the BCR would be the ratio of the present value of the stream of benefits to the present value of the stream of costs. The BCR in such a case has some limitations that are not frequently acknowledged, among them the fact that the BCRs of alternatives of different scales cannot validly be compared to one another. Because it is a comparison of marginal ratios, project scale is already accounted for in the application of the equimarginal principle.

C. Conclusions

The use of an EI to discuss the things that can be damaged in a flood event allows a planner to account for those things that both can and cannot be monetized, all of which have value. The EI is based on characteristics that can be measured in the same way across the entire scale and scope of the study. In keeping with the direction of the study legislation (PL 113-2), the NACCS EI focuses on population density and the infrastructure that supports it. The EI also includes social vulnerability characterization and environmental and cultural significance component indices, but these are weighted far lower in the composite. The NACCS indexing system can be scaled to reflect increased levels of detail for particular areas of interest and weighted to reflect the specific goals and priorities of individual decision-makers.

The definition of risk has two components. One of these is the things that can be damaged, which in the NACCS is measured by the EI. The other is the probability of the damaging event (P). In the case of the NACCS, the damaging event is the flood that occurs as a result of a coastal storm. The *product* of the *EI* and the *probability* of the event is the *risk* associated with the event. The change in risk from any intervention or series of interventions can come from either a change in the exposure or a change in the probability of the flood occurring. Examples of interventions that could change the EI would be elevating buildings or moving people out of a floodplain. Examples of interventions that could change the probability of the flood occurring could be construction of breakwaters, dunes, or wetlands that decrease the severity of the flood in the area.

Understanding and communicating the change in risk associated with reduction in vulnerability is integral to the post–Hurricane Sandy planning process. When considering multiple alternative risk-reduction strategies and measures, arraying the decrease in risk coming from a proposed measure

[10] This principle might strike some readers as being a new concept. In fact, it is a straightforward application of what is called the equimarginal principle, which goes back to at least 1854 in a formal mathematical way in the form of the second of Gossen's three laws (see, e.g., Julio Segura and Carlos Rodriguez Braun, *An Eponymous Dictionary of Economics* [Cheltenham, UK: Edward Elgar Publishing Limited, 2004], pp. 94–95) and much further than that as a logical proposition. Thus, Adam Smith wonders about it in Book 1, Chapter 4, of *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776) in his discussion of the diamond-water paradox, although he does not quite fully work out the principle involved and it did not have a formal name at that time. Today, the equimarginal principle is so universally recognized as a fundamental concept in economics that it appears in almost every introductory text (see, e.g., William Baumol and Alan Blinder, *Economics: Principles and Policy*, 12th ed. [Cengage South-Western, 2011], pp. 101-06.).

over the cost of that measure quantifies the risk reduction per resource spent, how much of the risk remains with each measure, and allows alternatives to be compared on a relative basis. Again, neither the numerator nor the denominator of the $\frac{\Delta R}{C}$ needs to be denominated in monetary terms. Although like a BCR, comparing $\frac{\Delta R}{C}$ allows a planner to see optimal use of resources, unlike a BCR, $\frac{\Delta R}{C}$ is a comparison of marginals, so a hurdle of "1" is irrelevant. Using this type of equimarginal analysis provides the decision-maker with relative comparisons of cost efficiency and the relative effectiveness of each measure in reducing total risk.

II. Economic Depth-Damage Function Development

The justification of USACE coastal storm risk management (CSRM) projects is based on cost-benefit analysis. That cost-benefit analysis is used to compare alternatives at a project site. The BCR generated by that cost-benefit analysis also follows an approved project through the USACE budgeting process and is fundamental in determining which authorized projects are funded for construction.

The 1983 Principles and Guidelines for Water and Land Related Resources Implementation Studies P&G and USACE planning regulations require USACE to estimate with- and without-project expected annual damages to determine the benefits of potential flood risk management and CSRM projects. The benefit of a proposed project is the difference between the estimated annual damages that would occur if that project was in place versus the estimated annual damages that would occur without the project or, otherwise stated, the reduction in damages between the with- and without-project conditions. That estimated reduction in damages is based on the modeling of future storms that are expected to occur over the life of the project. Each of these storms is anticipated to produce specific levels of damages depending on the frequency of the event. Those damages are aggregated over the project life, and expected annual damages are estimated for both the with- and without-project conditions. The difference between the with- and without-project benefit streams is the benefit attributable to the project. The average annual cost of the proposed project is subtracted from the benefits estimate—that is, the change in expected annual damages—to generate average annual net benefits. The benefits estimate is arrayed over the average annual cost of the proposed project to generate the BCR.

USACE classifies benefits into four streams: NED, Regional Economic Development (RED), Environmental Quality (EQ), and Other Social Effects (OSE). As dictated by the P&G, "…the Federal objective of water and related land use project planning is to contribute to NED, and such projects are to be formulated to alleviate problems and contribute to this objective". The P&G defines NED as "…increases in the net value of the national output of goods and services." Since the publication of the P&G in 1983, USACE has also begun to quantify RED, EQ, and OSE; however, the vast majority of CSRM benefits used to justify projects are NED benefits.

NED benefits for CSRM projects can be defined as any benefit that increases productivity or value on a national net basis. NED benefits commonly used for economic justification of USACE CSRM projects include damages avoided to structures, contents, automobiles, and infrastructure and avoided transportation delay costs, as they are relatively easy to measure and monetize. Until the passage of the Water Resources Development Act of 2007 (PL 110-114), which amended 33 United States Code (U.S.C.) 2281 to specifically require relevant USACE planning studies to address life safety, potential decrease in loss of life was not generally quantified in the justification process for USACE projects, and until recently that quantification has been limited to fluvial flood reduction planning and dam safety efforts.

Although difficult to definitively measure, NED benefits include the emergency costs incurred as a result of a storm event that might not have been incurred or been so large if a USACE project had been in place. Among these NED benefits are costs for debris cleanup, personnel, and services that are used in the event of an emergency. Finally, there are NED losses that occur as a result of a storm event that the USACE would define as secondary and tertiary effects of such an event. These are often extremely difficult to measure, but they contribute to NED losses and generally go uncaptured in USACE economic analysis. An example of these would be the damages to the petroleum distribution system beyond the primary form that might be considered infrastructure damages but that would have the secondary and tertiary effects of limiting the ability of people to get to work and children to get to school. Those lost work and school days that might have been prevented if a USACE project was in place are NED benefits.

As part of the NACCS effort, the study team determined that an important element of the Coastal Storm Risk Management Framework to “address flood risks to vulnerable coastal populations impacted by Hurricane Sandy” would be to gather missing data and refine the analyses that USACE uses to estimate benefits for CSRM projects. The NACCS study team began a year-long effort to capture and document the actual economic damages that occurred in Hurricane Sandy to provide field teams with the data they need to properly assess the benefits in the future. Better quantifying the actual effects of the event will also help planners to adequately and cogently discuss and communicate risk and, when applicable, residual risk.

This data collection effort focused on four subcategories of NED benefits, namely:

- Assessment of damages to structures and their contents
- Loss-of-life projection
- Emergency costs
- Secondary and tertiary effects

A. Assessment of Damages to Structures and Their Contents

To estimate the damages that would occur in different events, USACE studies are directed by planning guidance (*Engineer Regulation* [ER] *1105-2-100*, [USACE 2000, Appendix E]) to apply depth-damage relationships to determine the amount of damage as a percentage of the structure or content value by depth of inundation.

Although in some cases those relationships might be readily available, in most cases, they are not, and USACE economists use generic depth-damage relationships produced by USACE’s Institute for Water Resources (IWR). These generic relationships have been developed through the USACE Flood Damage Data Collection Program by post-flood surveys and expert elicitation. These generic damage functions are focused on fluvial flood events and limit damages to those caused by inundation. Coastal storms are different from riverine ones in that they have the added damage mechanisms of wave attack and erosion. Using fluvial damage curves to measure the effectiveness of coastal interventions disregards the damages that occur from waves and erosion and may undercount the benefits to those interventions.

The PL 113-2 direction to “address flood risks to vulnerable coastal populations” and the resources provided by that legislation presented USACE with the opportunity to produce generic depth-damage relationships specific to coastal damage mechanisms. These depth-damage relationships are based on survey and physical data gathered by USACE, the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), local governments, and academic institutions in the aftermath of Hurricane Sandy to generate depth-damage relationships for residential, non-residential, and public property, including structures, contents, vehicles, and public infrastructure. The empirical data collected were presented to a panel of coastal storm damage experts, which included structural engineers, appraisers, restorers, and catastrophe modelers from the insurance industry, for a three-day elicitation to generate storm-damage functions. This working meeting produced several damage curves that captured the damages that occurred during Hurricane Sandy and that are anticipated to be predictive of the damages that would be incurred in future coastal events in the without-project condition accounting for densely populated coastal areas, including high-rise residential structures. These new curves close a data gap of being appropriate to densely populated coastal metropolitan areas.

B. Loss of Life Projection

Hurricane Sandy was responsible for at least 286 direct and indirect deaths across the United States, the Caribbean, and Canada, of which at least 159 deaths took place in the United States. Of these, 72 direct deaths occurred in the United States as consequences of Hurricane Sandy (e.g., wind, flood, structural collapse). At least 87 deaths were indirectly caused by Hurricane Sandy (e.g., in situations in which the disaster led to unsafe conditions, such as hazardous roads or disruption of usual services that contributed to the deaths). About 50 of the 87 deaths were the result of extended power outages during cold weather, which led to deaths from hypothermia, falls in the dark by senior citizens, or carbon monoxide poisoning from improperly placed generators or cooking devices. The remaining deaths were mostly from storm cleanup efforts, including removing fallen trees and car accidents. Storm surge was responsible for most of the U.S. deaths, with 41 of the 72 fatalities attributable to drowning as a result of storm surge. Some 32 of the 41 drowning victims were in New York. Of these, 30 lived in homes within New York City's Mandatory Evacuation Zone. Twenty of those victims died in flooded homes while the others drowned while trying to flee their homes.

Section 2033 of the Water Resources Development Act of 2007 (PL 110-114) requires that USACE calculate the residual risk of loss of human life and human safety with a proposed project in place. Traditionally, life loss is calculated in a three-step process. First, the population-at-risk is estimated. Second, the population exposed to peril—following evacuations—is forecasted. And third, fatality rates attributable to the peril are applied to the exposed population. The USACE yet to be approved model to estimate life loss is the Hydrologic Engineering Center–Flood Impact Analysis (HEC-FIA). At present, this software is configured to estimate damages from sudden events that generally have little, if any, evacuation time (*e.g.*, dam breaks); however, this post-Sandy effort provides the information required to allow this model to be configured for coastal situations.

In response to the direction of PL 113-2, the NACCS team led an extensive survey effort to predict human response to coastal storms, determine the regional characteristics for compliance with evacuation orders, and understand the obstacles to evacuation. The purpose of this data gathering was to fulfill the second step described above. This step preceded the life loss estimation, which was necessary to determine the fatality rates from the hazard (step 3), and so that HEC-FIA could be reconfigured for use in coastal situations. This calibration of the model is particularly important given that post–Hurricane Sandy projects are moving quickly and individual model approval for use by project is time consuming and onerous. The survey used in this effort gave special emphasis to the obstacles to evacuation, as the sample was limited to the New York metropolitan area, where most people are reliant on public transportation and many do not own automobiles, which makes evacuation more complicated. The survey data and reconfigured application of the HEC-FIA model will be applied to estimate the with- and without-project conditions as individual coastal storm risk management projects move forward in anticipation of additional Hurricane Sandy–like events.

C. Emergency Costs

Among the risks to vulnerable coastal populations are the additional emergency costs that would be incurred during a coastal event. USACE guidance specifies that emergency costs should remain separate from damage functions and should be determined based on local factors. In 2012, USACE, New Orleans District published “Development of Depth-Emergency Cost and Infrastructure Damage Relationships for Selected South Louisiana Parishes,” which presented the background, workings, and results of an expert elicitation process to determine emergency costs for the area (USACE 2012). This effort builds on the framework of the New Orleans effort and a prior effort by the USACE Sacramento District to generate similar depth-emergency cost relationships to be used in planning studies for the North Atlantic region.

The data-gathering for this effort focused on six categories of emergency costs that are incurred during storm events. These were:

- **Evacuation and associated subsistence costs** are those costs incurred by individuals who self-evacuate or evacuate as part of assisted evacuations (Red Cross, locality).

- **Debris removal and cleanup costs** include the costs associated with the collection, processing, and disposal of debris materials to facilitate the recovery of the region.

- **Public services utilized (*e.g.,* schools, hospitals, libraries).** In Hurricane Sandy, New York City metropolitan area hospitals and medical facilities were severely impacted by the storm, and emergency evacuation of nearly 2,000 hospital patients was required. Elder-care facilities also required evacuations, which taxed the working hospitals at a time when their resources were already over-burdened. Schools and libraries served as shelters and community centers, taxing their resources to help those they served.

- **Public services provided (*e.g.,* police, fire).** During a major event, these resources are generally diverted to the immediate demands of the flood response. Significant overtime duties are required. This cost is incurred because of the event; the avoidance of this cost could be considered a benefit to a measure that would lessen the severity of the impact of that event.

- **Public utilities.** During a flood event, the ability of utilities to provide service is compromised, and there are economic losses to both the utility and the users from that disruption. In the case of Hurricane Sandy, there were areas of Long Island, New York, that had no power for more than 2 weeks after the storm. This utility disruption had primary effects quantified as part of this effort and secondary and tertiary ones discussed in the secondary and tertiary effects section of this document, below.

- **Infrastructure.** Beyond the direct costs of physical damages to infrastructure, additional costs occur because of the disruption. For example, when public transportation infrastructure is damaged, people must rely on alternative forms of transportation, which can strain those resources. Furthermore, there are extensive labor market losses when people cannot get to their jobs. The primary effects of infrastructure disruption are quantified as part of this discussion. The secondary and tertiary effects of infrastructure disruption are discussed in the secondary and tertiary effects section, below.

Data gathering for the development of emergency costs consisted of a series of interviews with service providers and experts from each of the categories listed above. The data collected during those interviews were used as inputs to develop emergency costs for various depths of flooding by coastal storm events for each category, with triangular probability distributions to quantify risk. These depth-damage curves for the New York City metropolitan region will be published for use by USACE economists or other stakeholders needing such information at the completion of the NACCS. Also, a report is being developed to discuss the differences between the results of this work and the New Orleans and Sacramento efforts. The methodology concerning the quantification and application of these benefits will be discussed in a technical report. Some of these effects may not be applicable to all USACE feasibility studies. Their applicability and policy compliance should be determined on a case by case basis. However, these quantities may assist others, to include local sponsors and stakeholders, in evaluating their own objectives and needs.

D. Secondary and Tertiary Effects

Hurricane Sandy revealed that there are many indirect but nonetheless significant second- and third-order consequences associated with a storm event. Second- and third-order effects are things that are two or three links into the chain of causation. Oftentimes, the indirect impacts from a storm event in the chain of causation have effects on the economy and society. In an attempt to quantify one such measure of the effects that the storm incurred, the U.S. Department of Commerce prepared a report that with a focus to measure the impact of disruption of economic activity caused by Hurricane Sandy, which could be negative in terms of spending losses in travel and tourism, or positive in terms of the potential for increased economic activity from reconstruction efforts (U.S. Department of Commerce, 2013). Other potential impacts on society observed following Hurricane Sandy include damages to petroleum infrastructure that led to gas shortages, and gas shortages led to people not being able to reach their places of employment. In other cases, subway disruptions led to many non-parent caregivers for the very young not being able to reach their places of employment, and school closures occurred because teachers could not get to the schools. With no childcare or school, parents who work outside of the home and who are not reliant on mass transit or gas could not get to their places of employment. In these cases, the subway disruption caused secondary and tertiary effects of lost work days for caregivers, teachers, and parents and lost school days for the children. In these cases, the NED losses were not limited to the initial damage to the subway or fueling system, but also affected the labor reliant on those systems.

In other cases, the magnitude and impact area of Hurricane Sandy itself compounded damages. For instance, there are many densely populated neighborhoods on the southern shore of Nassau County, New York where heat is generated from basement boilers. An October storm in the northeast, flooding a few basements and requiring several boiler replacements is an entirely different problem than a storm that floods 30,000 basements and requires that many replacement boilers. The latter type of event puts a strain on the nation's boiler supply because there is not likely to be enough residential boilers in inventory at any one point in time; nor is there likely to be enough installers to perform the work of installing them even if enough boilers were available and could be moved to where they were needed overnight. Indeed, many people were displaced for extended periods because boilers were hard to come by, and November weather in the northeast United States is cold enough to require them. This type of strain was also seen in the automobile market, as many people lost cars in the storm and tried to replace them at the same time.

Although traditional economic analyses quantify direct effects, such as property damages, the second- and third-order effects that occur as a result of direct damages from a storm are not typically identified. The aftermath of Hurricane Sandy made it evident to the NACCS team that “addressing flood risks to vulnerable coastal populations in areas impacted by Hurricane Sandy” would require cogent discussion of such effects. To that end, the team developed a method to begin to estimate the secondary economic effects associated with storm events. The methodology concerning the quantification and application of these benefits will be discussed in a technical report. Some of these effects may not be applicable to all USACE feasibility studies. Their applicability and policy compliance should be determined on a case by case basis. However, these quantities may assist others, to include local sponsors and stakeholders, in evaluating their own objectives and needs.

This effort began with identification of significant end-point impacts that could be measured (*e.g.*, loss of productivity) and their causes (*e.g.,* employees cannot get to work, no electricity). Beyond labor market and productivity losses, impacts to health, tourism, tax revenue, recreation days, disruption of the rental housing market, and fishing harvests were identified as potentially quantifiable. These damage pathways were displayed diagrammatically to show the connections between the physical storm effect (flooding, wave impacts, wind damage, and erosion) and the resulting economic or social impacts. For example, people may be unable to work due to many causes such as the subway was not working (due to flooding or power loss), the place of business was closed (due to flooding or power loss), the employee’s residence was damaged (due to flooding or wind), or the schools or day care were closed (due to damage or lack of staff). When available, the costs of such disruptions during Hurricane Sandy were allocated to their causes. A proposed method for evaluation and monetization of such effects was then identified. This method included defining the criteria to measure the impacts (*e.g.,* population impacted, types of impact, duration of impact) and proposing metrics to evaluate these criteria (*e.g.,* $/person, $/facility, a ratio based on total structure/content damages). The method was tested using basic assumptions to evaluate the results against actual events.

E. Conclusions

Improving the analysis used to measure damages from coastal storm events goes beyond providing more accurate BCRs. Understanding the damages that actually occur as a result of coastal events and the damages that might be avoided if an alternative is in place, allows USACE and other decision-makers to better describe the residual risk associated with proposed projects. Each of the activities described in this effort have their own products that are published and available through the NACCS website: www.nad.usace.army.mil/CompStudy.

III. References

USACE (U.S. Army Corps of Engineers). 2012. “Development of Depth-Emergency Cost and Infrastructure Damage Relationships for Selected South Louisiana Parishes.” USACE, New Orleans District, 2012.

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