North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk

EMERGENCY COSTS

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US Army Corps of Engineers®

North Atlantic Coast Comprehensive Study
Emergency Costs

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Acronym List

C&D	construction and demolition
COLTs	cells on light trucks
COWs	cells on wheels
CY	cubic yards
DDF	depth-damage function
DMAT	Disaster Medical Assistance Team
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EMS	Emergency Medical Services
FDNY	Fire Department City of New York
FEMA	Federal Emergency Management Agency
FTA	Federal Transit Administration
GIS	geographic information system
HBLR	Hudson-Bergen Light Rail Line
HEC-FDA	Hydrologic Engineering Center Flood Damage Reduction Analysis
LIPA	Long Island Power Authority
LIRR	Long Island Railroad
MNR	Metro-North Railroad
MSW	Municipal solid waste
MTA	Metropolitan Transportation Authority
MTACC	MTA Capital Construction Division
MVD	Mississippi Valley Division
NACCS	North Atlantic Coast Comprehensive Study
NAD	North Atlantic Division
NAVD88	North American Vertical Datum of 1988
NED	National Economic Development
NICE	Nassau Inter-country Express
NJT	New Jersey Transit
NOAA	National Oceanic and Atmospheric Administration
NYCDOC	New York City Department of Corrections
NYCDOT	New York City Department of Transportation
NYCT	New York City Transit
NYPD	New York City Police Department
PANYNJ	Port Authority of New York and New Jersey
PATH	Port Authority Trans Hudson
PPDR	private property debris removal

RACM	regulated asbestos containing material
ROW-R	right of way – removal
SACM	suspected asbestos containing material
SECNY	U.S. Coast Guard Sector of New York
SLOSH	Sea, Lake, and Overland Surge from Hurricanes model
TSS	temporary storage sites
TSS-H	temporary storage sites – long haul
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture

1 Introduction and Purpose

The U.S. Army Corps of Engineers (USACE), North Atlantic Division (NAD) has prepared the North Atlantic Coast Comprehensive Study (NACCS), which is a multi-agency effort, to develop strategies that will reduce risk and increase resiliency for populations vulnerable to tidally influenced flooding and storm surge in areas within the boundaries of the USACE NAD.

As part of the overall NACCS, this Emergency Cost study was conducted in an effort to quantify the damages/costs related to emergency activities that could be included as part of the National Economic Development (NED) evaluation of coastal storm damage reduction alternatives. The purpose of the study was to understand depth-damage relationships to estimate the costs related to emergency activities conducted by the public and private sectors before, during, and after flood events.

The NAD of the USACE consists of five districts: New England, Baltimore, New York, Norfolk, and Philadelphia. This study focused specifically on areas that were most impacted by Hurricane Sandy and, thus, areas that had significant emergency costs associated with Hurricane Sandy's effects. Therefore, the study area focused on coastal areas of New Jersey and New York.

Data were collected by interviewing emergency service professionals in the study area, requesting completed questionnaires from organizations involved in emergency services, and reviewing relevant literature. It was difficult for emergency service professionals to estimate emergency cost information and especially costs related to different depths of flooding. General costs were obtained for most categories; however, not enough information was available to fully develop depth-damage functions (DDFs) that are typically used by the USACE when evaluating coastal storm and flood risk management projects. Although most emergency costs are specific to New York City, information gathered may be useful across the coastal/tidally influenced areas of Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, Maine, and the District of Columbia.

In 2012, the USACE, New Orleans District (Mississippi Valley Division [MVD]) published *Development of Depth-Emergency Cost and Infrastructure Damage Relationships for Selected South Louisiana Parishes* (MVD Report), which presented the background, workings, and results of an expert-opinion elicitation process to determine emergency costs for the Louisiana area. The results of this current study will ultimately be compared with the results of the MVD Report, and a similar study conducted by the USACE, Sacramento District titled *Valuation Report for Emergency Costs* (2010) to identify regional differences and similarities and form the basis for relationships that could be used nationally.

This study provides the methods for estimating emergency costs and describes how to develop DDFs. The information from this study may contribute to future NED analyses and be used as a basis for developing emergency cost DDFs for future studies.

1.1 Emergency Costs Defined

This study focused on estimating emergency costs, and when available, direct damages to infrastructure, utilities, and public service buildings. Direct damages are defined as the costs from the physical impacts of a coastal storm or riverine flood event (e.g., damage to structures and contents of buildings, infrastructure, and utilities). Emergency costs include:

- Actions taken by police, fire, and the other organizations to warn and evacuate floodplain occupants, direct traffic, and maintain law and order just before and during an event;
- Flood fighting efforts, such as sandbagging and building closures, taken to reduce damage;
- Costs of efforts, such as debris removal, establishing emergency shelters, and the provision of money, food, and clothing, to relieve the financial situation experienced by flood victims during and after an event;
- Evacuation costs for floodplain residents; and
- The administrative costs for public agencies and private relief agencies in delivering emergency services.

Information developed in this study regarding emergency costs and direct infrastructure damages may be used in further analysis of coastal storm and flood risk management alternatives. In accordance with USACE guidance, policy, and standard practices, this study does not consider nonuse values (meaning a value for a resource that may never be experienced or used) or monetization of human pain, suffering, or loss. No estimates of injuries or loss of life were made for this study.

Traditionally, NED flood analysis has focused on direct physical flood damage because the associated economic losses are easily traceable. For example, if a firm has a machine that is destroyed as a result of flooding, the direct economic loss is the depreciated value of the machine because it is a lost good in the economy that must be replaced. Indirect economic loss is not as easily traced through the economy. For example, if the employees of a firm lose income related to the lost production of a damaged machine or the inability of employees to perform work because of flooding, the indirect economic loss is only lost income that cannot be compensated for by postponement of an activity or transfer of the activity to other establishments. Additionally, if, during a flood event, emergency response activities take place to protect a firm’s machine and evacuate employees, the indirect economic loss is the increment of emergency response production for uses beyond normal, which is an emergency response loss. Emergency response organizations engage in activities and maintain employees in preparedness for emergency response during actual flood events. Emergency response losses are not necessarily incurred as a result of responding to a flood event and only include those expenses resulting from a flood that would not otherwise be incurred under normal conditions. This study attempts to quantify emergency costs from flooding and also includes direct damages for each category when available (as defined for this study).

The major loss type considered in this study is costs above those normally incurred that are not transfers. Some costs may not be clearly represented as losses. Therefore, for this study, the increased cost as a result of flooding is estimated. Data produced from this study may contribute to future NED analyses. Costs identified by emergency service professionals are costs under non-flood and flood conditions. The difference between these two expected costs approximates the NED loss. For this study, losses were categorized by economic activity associated with six groups: evacuation and subsistence, debris removal and cleanup, public utilities, infrastructure, public services patronized, and public services produced.

NED losses associated with public goods and services include some of the costs incurred as part of actions required to respond to a flood event. Costs that a public or private entity would incur that are not NED losses were not counted or detailed (e.g., emergency service program costs that would occur even if a flood did not take place). The types of costs that could be incurred and considered to be NED losses are those associated with the following activities that may employ staff and equipment:

- Temporary relocation of residents
- Subsistence (incremental costs above those that would be normally incurred)
- Cleanup
- Emergency response services

Data gathering for emergency costs focused on the following categories in six groups, as listed in **Table 1-1**.

Table 1-1: Emergency Cost Groups and Categories

Group	Category
1. Evacuation and Subsistence	1. Evacuation, Shelter and Food, and Reoccupation
2. Debris Removal and Cleanup	2. Debris Cleanup, Removal, and Disposal
3. Public Utilities	3. Natural Gas
	4. Electricity
	5. Telecommunications
	6. Sewage and Wastewater Treatment
	7. Water Supply
4. Infrastructure	8. Subway Lines
	9. Streets, Roads, and Highways

Group	Category
	10. Bridges
	11. Railroads
	12. Ports
	13. Airports
	14. Petroleum Wells and Land-Based Pipelines
5. Public Services Patronized	15. Daycares and Schools
	16. Public Agencies, Libraries, and Indoor Recreation
	17. Hospitals
	18. Eldercare Facilities
6. Public Services Produced	19. Police
	20. Fire
	21. Jail
	22. Government Judicial
	23. Government Legislative

1.2 Report Organization

Chapter 2 explains the economic theory of estimating emergency costs. Chapters 3 through 8 represent each of the six groups of emergency costs. Each of these chapters describes the emergency cost category, explains what happened during Hurricane Sandy, and discusses what data were collected and how. At the conclusion of each chapter, the method for estimating the emergency costs is described as well as any considerations for applying these methods in future studies. The last chapter explains how to develop DDFs for use in future NED analyses.

This emergency cost report is organized as follows:

- **Chapter 1** Introduction and Purpose
- **Chapter 2** General Method for Estimating Emergency Costs
- **Chapter 3** Group 1: Evacuation and Subsistence
- **Chapter 4** Group 2: Debris Removal and Cleanup
- **Chapter 5** Group 3: Public Utilities
- **Chapter 6** Group 4: Infrastructure

2 General Method for Estimating Emergency Costs

For this study, emergency costs were analyzed using the production function framework. The degree to which an input (labor or capital) is an economic loss was gauged by its potential to inhibit other production. How firms adjust production under flood conditions (routine production) was estimated in the analysis for this study. Flood production, or new production specifically for a flood (e.g., search and rescue), and direct physical damages were also estimated. All else except the flood was assumed to be constant. This allowed changes caused directly by a flood to be analyzed. Financial transfers of labor and capital were qualitatively discussed, while NED losses were quantified and monetized when possible.

Each of the emergency cost categories includes two types of production: production that existed before a flood (routine production) and production new and specific to the flood (flood production). All categories were viewed as simple production functions, where the quantity (Q) of output is a function (f) of labor (L) and capital (C) (all non-labor inputs), giving Q = f (L, C). Subscript R designates routine and subscript F denotes flood.

Routine Production Function: $Q_R = f_R (L_R, C_R)$

Flood Production Function: $Q_F = f_F (L_F, C_F)$

In this study, level of production (Q_R) was assumed constant before and after a flood to allow other parameters to vary to clearly identify an economic loss. Production Q_F begins as a response to the flood and ends when recovery is over. Economic loss was expected to be in the form of an increase in incremental production costs or opportunity costs (losses) created by flood-specific production. If Q_R decreased, there should be an NED loss. This loss was not monetized in the analysis.

Economic losses associated with incremental cost increases were represented by the consumption of L_R or C_R as inputs to maintain Q_R at its pre-flood level, when possible. Additional economic losses associated with opportunity costs are the consumption of L_F or C_F to produce any level of Q_F. When an f_R or f_F was identified as differing from pre-flood to post-flood conditions, the inputs were considered as possible sources of economic loss. The primary consideration for inclusion in the analysis as NED loss was the expectation of exclusion of use for other production purposes. This led to a similar treatment of all capital because of capital's ability to exclude common use in multiple productive capacities and its depreciable nature.

2.1 General Assumptions

Economic theory is built on basic simplifying assumptions. For this study, economic change was analyzed using the production function framework discussed in the previous section. The assumptions discussed below clarify what was and was not considered when estimating emergency costs:

- The status quo is the non-flood condition. This analysis assumes *ceteris paribus*, or all else equal. This means that aspects not discussed in the analysis were assumed to be the same pre-flood and post-flood.
- Society and market are defined as the United States for the NED account.
- Many costs associated with responding to a flood emergency and its aftermath are likely to be of local or regional concern, but are unlikely to affect the national level of economic production.
- Many costs of a disaster are transfers, not economic losses. A tax or a donation would be a transfer.
- The cost to use a good is at the normal market rental rate of the good.
- For clarity in this analysis, net economic loss associated with the possible loss of a public service was not monetized.
- An economic loss can be identified any time that the same quantity of production is produced less efficiently. For this reason, the emergency cost categories were simplified to the greatest extent possible to analyze a snapshot in time of how incremental costs would change during a flood-event.
- No shortages of labor or capital are expected. The quantity of labor and capital demanded and consumed by the flood would be small relative to the national market.
- The market has many buyers and sellers, and no one firm or consumer should be able to affect prices or quantities in the market.
- Price levels for this study are in 2014 dollars.
- This analysis is a short-run analysis. Labor would not have time to adjust and move into new markets. Therefore, most labor and capital used would be a loss to another market.

2.2 Data Collection

Interviews of emergency service professionals were conducted and questionnaires were distributed in an effort to collect emergency cost information from those that had direct experience with Hurricane Sandy. Emergency service professionals for each category were asked to provide a minimum, most likely, and maximum value for each depth of flooding. After the completion of the interviews, the data were reviewed and efforts were made to correct any discrepancies and validate the data. When necessary, data from other sources were used to supplement the collected data. During the interview process, emergency service professionals were sometimes unwilling or unable to provide information. Questionnaire data for most of the emergency cost categories were not obtained from the emergency service professionals that were contacted. When direct data from the interviews could not be obtained, efforts were made to supplement the data with information from the literature review. In addition, qualitative information on the impacts of Hurricane Sandy was included to provide a reference for types of emergency activities that were conducted.

For each category, the emergency costs are intended to be calculated per facility or structure type, per household, or per a specific unit of measure (e.g., emergency costs per mile of flooded subway track). These data may contribute to other planning studies that would include modeling emergency costs related to flood damage in the Northeast and Mid-Atlantic region.

The structure of the questionnaire required the emergency service professionals to consider each flood depth as an independent event in order to apply the estimated emergency costs to a wide variety of flooding events. Each cost was treated as an independent variable, and each cost was assumed to be independent of other costs, both in the same category and in other emergency cost categories. Correlation among emergency cost categories was not evaluated.

2.3 Literature Review

An extensive literature review was conducted throughout the study to identify potential emergency service professionals for interviews, identify emergency actions taken during Hurricane Sandy, and identify monetary damage estimates for the emergency actions. The literature reviewed included over 80 news articles, journal articles, trade publications, and government reports. Pertinent information from the articles was recorded to describe the impacts for each of the categories.

Notable publications include: *PlaNYC: A Stronger, More Resilient New York* report produced by New York City; the After-Action Report, and Progress Report: *Hurricane Sandy Recovery – One Year Later*, both published by Federal Emergency Management Agency (FEMA); *Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure*, published by the U.S. Department of Energy (DOE); and *Superstorm Sandy Public Transit Projects – Review of Cost Estimates*, published by the Federal Transit Administration (FTA). The PlaNYC report (NYC, 2013a) provided the most comprehensive and detailed description of the impacts experienced in New York following Hurricane Sandy, with chapters dedicated to utilities, liquid fuels, telecommunications, transportation, water, and wastewater. The FEMA reports offered broad overviews of Hurricane Sandy impacts, such as describing power outages that occurred across 20 States and the District of Columbia (FEMA, 2013a, 2013b). Similarly, the DOE report provided overall impacts to the electric grid that were not specific to one utility (DOE, 2013). Lastly, the FTA report was the source for the impacts to the railroads from Hurricane Sandy, including emergency cost information (FTA, 2013).

While extensive information could be found on the impacts and damages caused by Hurricane Sandy, much of the literature only provided qualitative descriptions of the impacts. The authors of relevant articles were contacted to determine whether they could provide additional information that may not have been published in the articles. These discussions often led to the authors providing the names of other people whom they felt were in a better position to help estimate the monetary damages related to emergency response.

3 Group 1: Evacuation and Subsistence

This section discusses losses associated with evacuation and subsistence. All emergency costs for this group are estimated per household. At the end of this section, the method for estimating emergency costs for this group for future studies is described.

3.1 Evacuation, Shelter and Food, and Reoccupation

Evacuation is one of the best ways to avoid injuries and fatalities during a flood event. Evacuation is the act of transporting people out of the floodplain, and its associated costs can take effect before, during, or after a flood event. Evacuation costs are usually relatively small compared to infrastructure damages and other emergency costs (Whitehead, 2005). Residents affected by a large flood either self-evacuate or are assisted by friends, family, public agencies, military, or non-governmental organizations, the largest of which is the American Red Cross.

Subsistence includes displacement costs (e.g., housing, storage) and necessities (e.g., food, bedding). During a flood event and its immediate aftermath, many displaced residents stay at shelters. Eventually, shelters close, and displaced residents can face long-term housing problems if their homes are extensively damaged. Until damaged houses are repaired or replaced, many residents relocate to other residences, not always in the vicinity of their previous homes. In an emergency, public labor and capital are used, but people also volunteer their time and resources for evacuation and reoccupation.

Inhabitants displaced during a large flood event are anticipated to eventually reoccupy the same area they left. Reoccupation costs include travel to settle insurance claims and repair residences. Displaced residents may make multiple visits to their properties to resolve home repair and insurance issues before they resettle. Evacuated populations may use their own resources along with assistance from public agencies, military branches, and non-governmental organizations, to transport their belongings from storage facilities and temporary housing.

Evacuation, Shelter and Food, and Reoccupation and Hurricane Sandy

The National Oceanic and Atmospheric Administration (NOAA) began issuing warnings for Hurricane Sandy on October 22, 2012. On Friday, October 26, FEMA deployed Incident Management Assistance Teams to aid the States that were expected to be impacted in the Northeast (FEMA, 2012). On Sunday, October 27, New Jersey Governor Chris Christie declared a state of emergency and ordered an evacuation of the barrier islands from Sandy Hook South to Cape May and the casinos of Atlantic City. The next day, New York City Mayor Michael Bloomberg ordered evacuations in low-lying areas of New York City. Mandatory evacuation orders are typically given when there is a possibility of injury and death during the storm and there are increased safety risks to first responders and law enforcement who might need to rescue stranded disaster victims (O'Neil, 2014). Despite these warnings and evacuation orders, a significant portion of the populations did not evacuate (O'Neil, 2014).

Findings

Questionnaire responses and other supporting data were used to estimate the temporary housing and assistance cost per household. Other evacuation and reoccupation costs were not estimated for Hurricane Sandy.

An emergency service professional from the evacuation, shelter and food, and reoccupation field was interviewed. That person did not have all the data associated with evacuation, subsistence, and reoccupation emergency costs but was able to provide the number of days temporary housing was required as a result of Hurricane Sandy and some costs associated with temporary housing. This information along with the General Services Administration Federal per diem rates were used to estimate the temporary housing and subsistence costs.

The standard rate for New York and New Jersey for the 2014 fiscal year is $83 per day for lodging and $46 per day for meals. According to the 2010 Census, the average household size for New York is 2.57 and 2.68 for New Jersey. The average of these two areas is 2.63 people per household. If the per diem rate is per person, then the temporary housing cost is estimated to be $218 per household per day. This validates the values obtained from the emergency service professional, ranging from $125 to $400, with a most likely value of $230 per household. The estimated temporary housing cost per household is the product of temporary housing cost and the number of displacement days provided by the emergency service professional.

The average cost of eating food at home was subtracted from the per diem value because people would still eat, whether or not they were displaced from their home. According to the U.S. Department of Agriculture (USDA), the cost of eating food at home ranges from $5 to $10 per person per day, with the average cost about $7 per person, per day. The adjusted subsistence cost ranges from $95 to $108 per household per day, with a most likely value of $101 per household per day. The method for estimating subsistence costs is consistent with the way FEMA estimates subsistence costs (FEMA, 2013d).

Using the number of days temporary housing was required after Hurricane Sandy according to the emergency service professional, the values in **Table 3-1** were estimated for temporary housing and subsistence per affected household.

Table 3-1: Summary of Temporary Housing and Subsistence Values for Hurricane Sandy

Category	Min	Most Likely	Max
Number of Displacement Days	15	122	422
Temporary Housing Cost per Household	$1,875	$26,581	$168,800
Subsistence Cost per Household	$1,422	$12,371	$45,394

3.2 Estimating Emergency Evacuation and Subsistence Costs

Flood-event-related economic losses associated with Group 1 include emergency costs related to displacement, search and rescue efforts, temporary housing, and subsistence. Displacement includes the costs associated with the time residents cannot reside in their household because of flooding. Search and rescue costs are based on the daily costs of search and rescue activities after a flood event. Temporary housing and subsistence assistance includes the costs of several temporary housing options and subsistence requirements (e.g., food, hygiene, water) for evacuees and displaced residents. These economic losses stem from two common loss types:

- Labor Diversion (flood-related)
- Capital Use (flood-related)

Associated subtype losses include the following:

- Travel Costs (flood-related)
- Temporary/Rental Structures (flood-related)

Specific *ceteris paribus* assumptions for this category are that the population number would remain the same (i.e., no deaths would occur) and that people would use least-cost alternatives and make rational decisions. The analysis for this category also assumes an orderly mandatory evacuation before a flood. Search and rescue activities would be conducted for un-evacuated persons. Un-evacuated persons would include individuals declining to evacuate and those who were not able to successfully evacuate during early evacuation efforts.

The cost diagram in **Figure 3-1** illustrates the data collection process and how these data can be used to calculate outputs. All costs are evaluated on a per-household basis. Flood-event-related economic losses associated with this group include transportation, displacement, temporary housing and subsistence assistance, and search and rescue costs. All costs must be associated with a specific level of flooding. If possible, at least three levels of flooding should be used for each emergency cost.

Transportation costs are the per-household costs associated with transportation needs in response to a flood event. These costs would be estimated by multiplying the estimated number of people that evacuate by their own means by the associated cost to evacuate. The unit of measurement and the cost per identified unit of evacuees would both need to be gathered from an emergency service professional or other reliable source. The evacuation transportation cost per household may be added to the other costs per household for this category. USACE provides guidance for estimating transportation costs in Appendix D of Engineer Regulation 1105-2-100 (USACE, 2000).

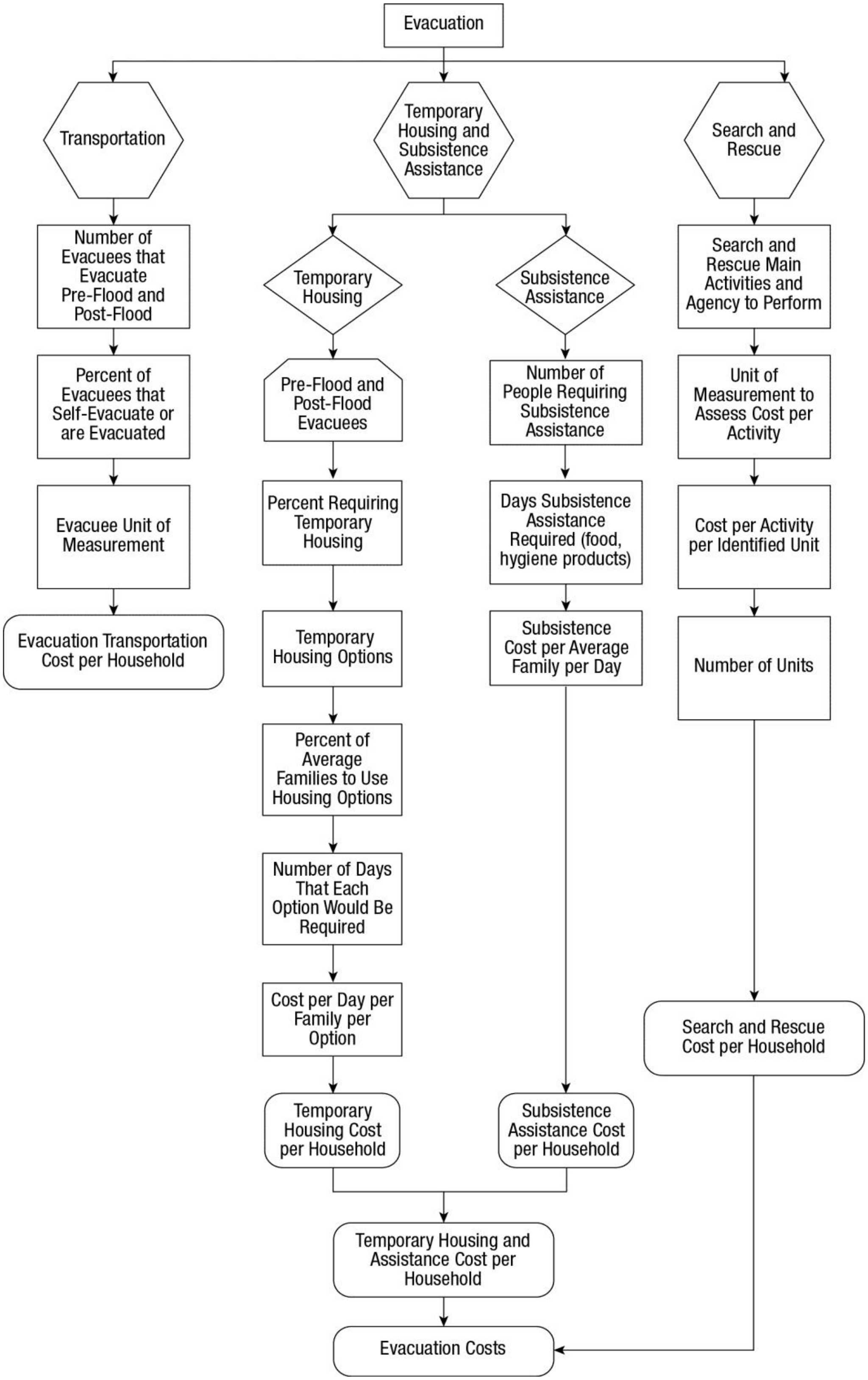


Figure 3-1: Evacuation and Subsistence Emergency Cost Diagram

Temporary housing and subsistence assistance costs are the per-household costs that may be based on several temporary housing options and subsistence requirements for evacuees and displaced residents. If the estimated number of people requiring temporary housing or the number of people utilizing a specific housing option is not known, but the estimated percentage of people is known, then the estimated percentage of people can be multiplied by the total number of people that evacuate as a result of a flood event to estimate the number of people. The number of people using each type of housing option would be multiplied by the number of days that each option would be required and by the cost per day per household for each option to estimate the total temporary housing cost per household. To estimate subsistence costs per household, the number of people requiring subsistence would be multiplied by the number of days subsistence assistance would be required and then multiplied by the cost per average family per day. The temporary housing cost per household can be added to the subsistence assistance cost per household to get the total temporary housing and subsistence assistance cost per household.

Search and rescue costs are the per-household costs of search and rescue efforts associated with a flood event. The unit of measurement to assess cost per activity and the cost per activity per identified unit would both need to be gathered from an emergency service professional or other reliable source. The product of the two would be the search and rescue cost per household.

An NED analysis compares the with-project to the without-project conditions, therefore only evacuation costs that would change (increase/decrease) with a coastal storm damage reduction project would have an impact on the NED analysis. While calculating the total evacuation emergency costs would give a better understanding of the full damages from a storm event, it is expected that some of the evacuation costs would remain the same with the implementation of a storm damage reduction project. Therefore, calculating the total evacuation cost may not be necessary. As a result, it is recommended that the analyst focus efforts on estimating emergency costs that would change as a result of a project.

Because of safety concerns, evacuation orders would be anticipated to occur with or without a coastal storm damage reduction project, but subsistence costs would vary depending on the number of residential structures impacted and the depth of flooding. Subsistence costs would be the additional costs above normal living expenses. For example, subsistence costs would include the additional cost for food above what is usually spent when residents are living in their homes. The increased daily costs of food and shelter would be multiplied by the number of days residents are displaced from their homes for each level of flooding. Search and rescue costs tend to be too unpredictable to estimate for future flood events; therefore, these costs are not likely to be included in an NED analysis.

4 Group 2: Debris Removal and Cleanup

This section discusses losses associated with debris removal and cleanup. All emergency costs for this group are estimated per structure type or per mile for roadway clearing. At the end of this section, the method for estimating emergency costs for this group for future studies is described.

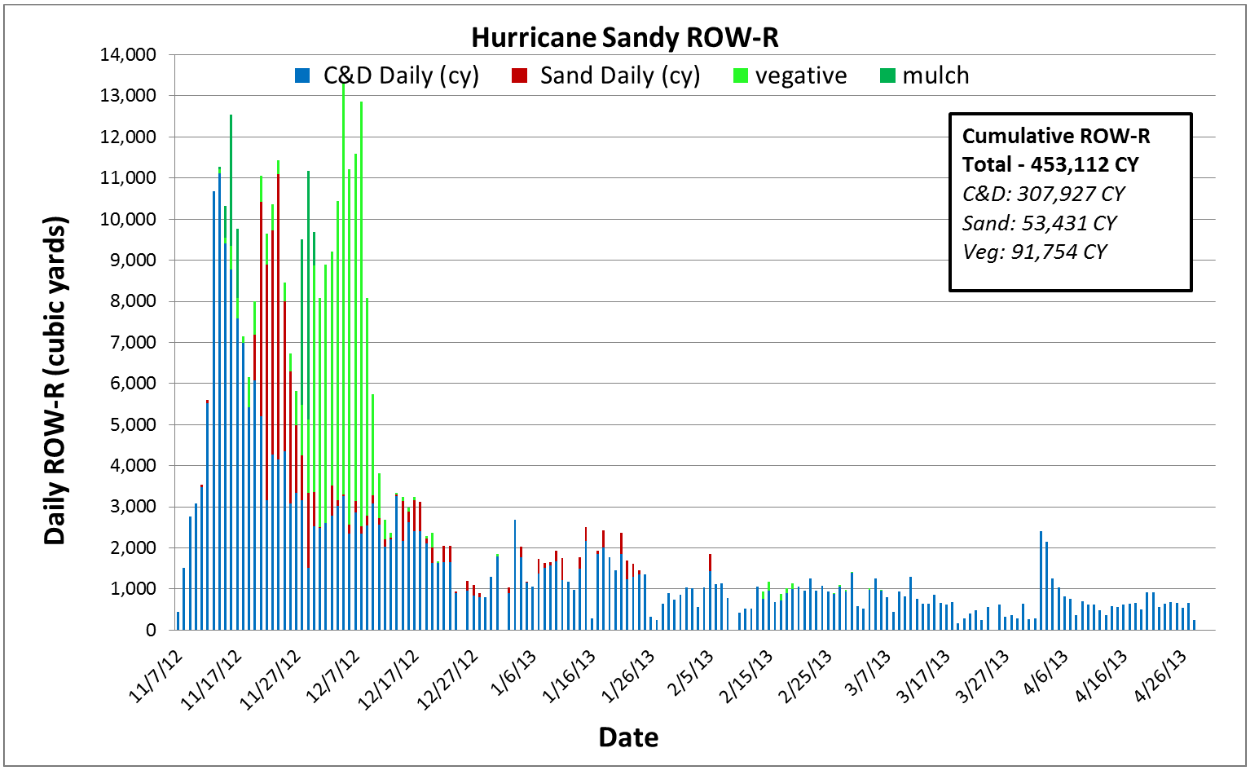
4.1 Debris Cleanup, Removal, and Disposal

After an emergency event that causes damage, the first activity that usually takes place is debris removal and cleanup. Debris removal and cleanup includes collection, processing, and disposal of debris material. These activities vary depending on debris material types and land use types. Debris cleanup is an important action that has both short-term and long-term considerations. In the short term, removal of debris is necessary to facilitate the recovery of a region, and in the long term, disposal methods of debris must be considered so that its management does not pose a future threat to human health or the environment (i.e., hazardous waste). Floods deposit large amounts of debris on roads, in yards and parks, and inside structures. Debris cleanup is necessary for functioning public services (e.g., fire, police, medical) and to support reoccupation.

Debris Cleanup, Removal, and Disposal and Hurricane Sandy

Clearing debris on roadways and public rights of way is typically the first priority because debris blocking roadways, and thereby emergency vehicles and access to emergency facilities such as hospitals, is a threat to public health and safety. Public rights of way describe the areas adjacent to public streets and roads maintained by the local government and the area between the road edge and the utility poles. Once the debris from a flood event is collected, it would be sorted into piles of vegetative debris, construction and demolition (C&D) debris, and sediment (sand). C&D may include building materials, drywall, lumber, carpet, furniture, mattresses, and plumbing materials.

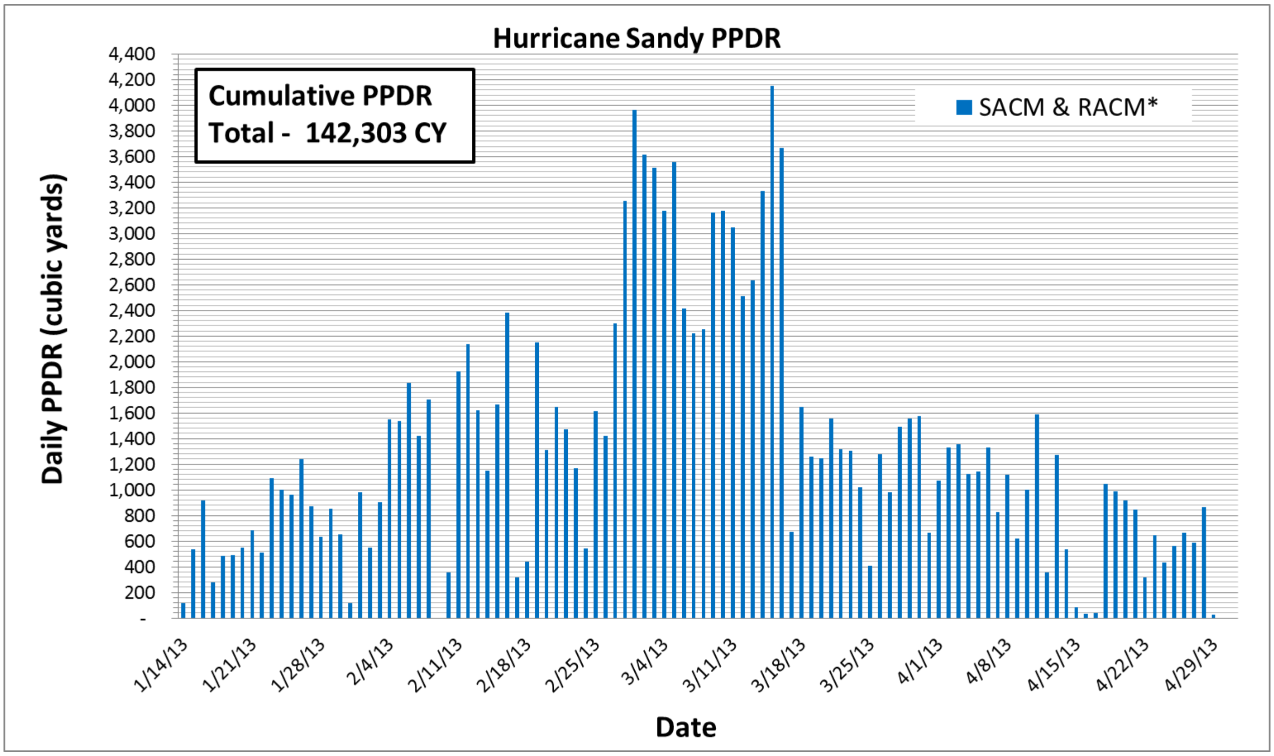
Quantities of rights-of-way debris collected following Hurricane Sandy (in cubic yards) are illustrated in **Figure 4-1**. A total of 453,112 cubic yards was collected by USACE; about 68 percent was C&D, approximately 20 percent was vegetative debris, and the remaining 12 percent was sediment (sand). If the total cost for road clearing was available, then the cost could be divided by the total number of cubic yards to estimate the cost per mile. Additionally, if the quantity of debris and cost could be estimated for different levels of flooding then a depth-damage relationship for street and highway clearing for emergency response could be established.



Note: ROW-R = Right of Way – Removal, C&D = construction and demolition, and CY = cubic yards

Figure 4-1: Quantity of Rights of Way Debris from Hurricane Sandy by Date

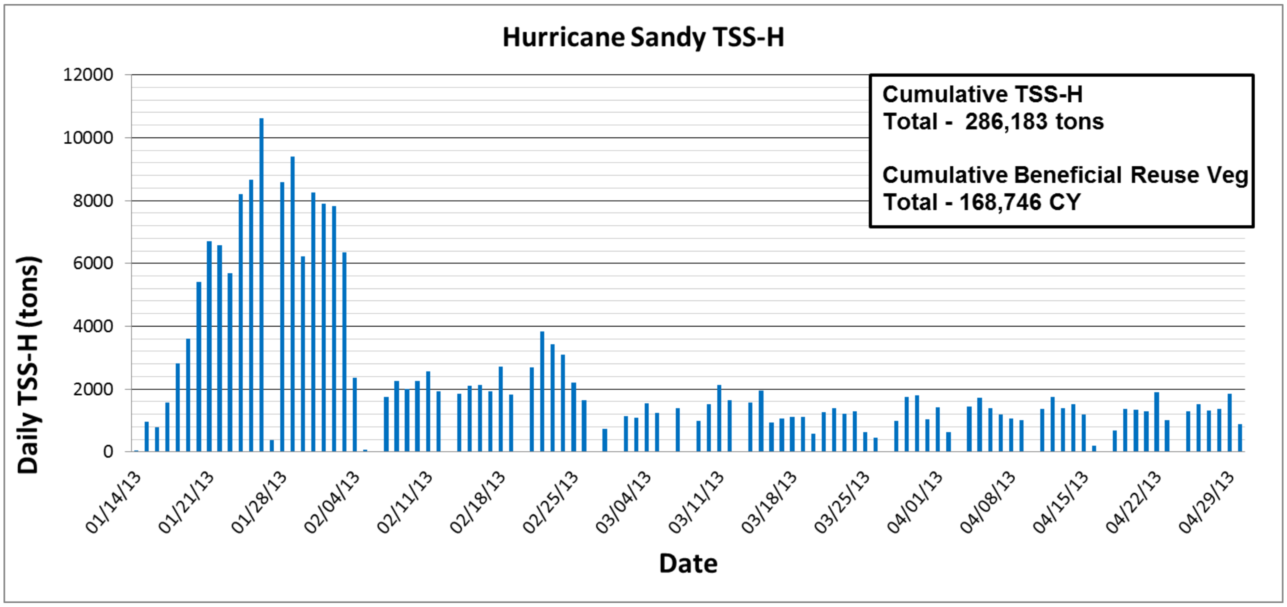
USACE private property debris removal (PPDR) totaled 142,303 cubic yards, including regulated asbestos containing material (RACM) and suspected asbestos containing material (SACM) (see **Figure 4-2**).



Note: PPDR = private property debris removal, SACM = suspected asbestos containing material, RACM = regulated asbestos containing material, and CY = cubic yards

Figure 4-2: Quantity of Private Property Debris Removal from Hurricane Sandy by Date

Some debris was sent to temporary storage sites (TSS). These TSS allowed some waste sorting and processing prior to transporting the debris to disposal sites. Some vegetation debris could be reused as wood chips after meeting USDA invasive species requirements. A total of 168,746 cubic yards of vegetation could be reused (see **Figure 4-3**). Once sand was tested and cleaned of storm debris, it could also be reused. Sand was tested, screened, and then reused to replenish eroded beaches. Household hazardous waste was separated and collected by U.S. Environmental Protection Agency contractors at many of the TSS. From the TSS, barging operations were used to transport storm debris to upstate disposal facilities.



Note: TSS-H = temporary storage site – long haul, CY = cubic yards

Figure 4-3: Quantity of Debris from Hurricane Sandy at Temporary Storage Sites by Date

Both New York and New Jersey hired private contractors in addition to support from the USACE. About 305,000 housing units were damaged or destroyed in New York and 346,000 in New Jersey. USACE estimated total debris cleanup, removal and disposal costs of $196 million for New York and New Jersey, including vegetative debris, sand, concrete, SACM, RACM, restoration of TSS, and other USACE costs.

Findings

The cost for debris collection and disposal was obtained from the questionnaire and other supporting data according to structure type. Originally, residential structures were divided into six types: mobile home, one-story slab home, one-story pier home, two-story slab home, two-story pier home, and multi-family residence. Non-residential structures were divided into seven types: eating or recreation facility, grocery store or gas station, professional office, public or semipublic facility, retail business, repair or home-use facility, and warehouse or construction facility.

An emergency service professional from the debris cleanup, removal, and disposal field submitted responses to a questionnaire but was not interviewed. The emergency service professional provided values for residential structures and could not provide any data for non-residential structures. Costs were estimated to be the same for one-story and two-story homes with pier or slab foundations. Costs were provided for white goods, electronic goods, and hazardous waste. These costs are presented in **Table 4-1**. Costs were not provided for content debris, sediment, vehicles, vessels, and tires.

Table 4-1: White Goods, Electronic Goods, and Hazardous Waste Costs per Residential Structure

Category	4 Feet Less than Sandy			2 Feet Less than Sandy			Hurricane Sandy		
	Min	Most Likely	Max	Min	Most Likely	Max	Min	Most Likely	Max
Mobile Home	$33	$210	$566	$60	$414	$595	$420	$785	$1,150
One-Story Residential Home	$45	$275	$680	$100	$480	$760	$460	$845	$1,300
Two-Story Residential Home	$130	$325	$735	$325	$585	$850	$735	$1,165	$1,800

Another emergency service professional explained that computing a precise unit cost for each waste stream is difficult because of the complexity of debris operations at every stage of the cleanup effort. After Hurricane Sandy, the urgent nature of the initial response coupled with limited contracting capability at the onset of the effort drove up costs. Therefore, costs associated with right-of-way, TSS, and PPDR volumes were not available.

Because there did not appear to be much difference in costs from previous studies, the six residential structure types and seven non-residential structure types were revised to five total types: residential with basement, residential without basement, single-wide mobile home, double-wide mobile home, and non-residential structures.

Supporting documents were used to estimate the emergency costs associated with debris removal and disposal for residential structures. Debris removal costs are based on the type of residence and landfill tipping fees. The landfill tipping fees come from a National Solid Wastes Management Association study (2005), which surveyed 800 municipal solid waste landfills and 120 incinerators around the country and grouped the tipping fees into seven regions. The average tipping fee estimated for the Northeast and Mid-Atlantic regions is $71.14 per ton (2014 dollars). The debris quantity is provided by FEMA Publication 329, the Public Assistance *Debris Estimating Field Guide*. The debris per structure type and cost per structure (the product of the debris tons and the tipping fee) are provided in **Table 4-2**. The quantities and costs can be applied to structures that would be damaged more than 50 percent.

Table 4-2: Debris Tonnage and Cost by Structure Type

Type of Residence	Debris (CY)	Debris (tons)	Tipping Fee Cost
Residence without basement	25-30	6.875	$489
Residence with basement	45-50	11.875	$845
Destroyed mobile home (single-wide)	290	72.5	$5,157
Destroyed mobile home (double-wide)	415	103.75	$7,380

Note: CY = cubic yards

About 305,000 housing units were damaged or destroyed in New York and 346,000 in New Jersey. The Census Housing Survey (2011) provided the composition of the housing supply. Then, the number of structures for each structure type was multiplied by the total cost estimated from the tipping fee (**Table 4-2**). Because 40 percent of the buildings that were flooded in Nassau and Suffolk Counties were damaged more than 50 percent or completely destroyed, 40 percent of all the flooded housing units were assumed to also be damaged more than 50 percent or completely destroyed. When this percentage was applied to the structures, the total cost calculated for the debris ($173.8 million) was about 11 percent less than the total debris cost estimated by the USACE ($196 million). This estimate does not include sediment, vehicles, vessels, and debris from non-residential structures, which may make up the remaining 11 percent.

In New Jersey, Union Beach was devastated by Hurricane Sandy. Of the 2,400 homes in Union Beach that were damaged, 1,800 were flooded with 4 to 8 feet of water, and 240 homes were demolished. Of the total debris, an estimated 90 percent was from damaged residential homes and 10 percent was from municipal damages. Representatives from Union Beach estimated a debris removal cost of $6 million; roughly, $2,250 per home.

Using the New Jersey estimate of $2,250 per home would overestimate the debris costs by over seven times the USACE cost estimate. Therefore, the tipping fee method seems more reasonable when complete data estimates are unavailable.

For non-residential debris removal from Hurricane Sandy, costs varied from $34 per cubic yard to $102 per cubic yard. Debris removal from bridges was about $40 per cubic yard on average. The amount of debris on bridges ranged from 373 cubic yards to 1,388 cubic yards per bridge, with an average of 920 cubic yards per bridge. Debris removal from airports ranged from $34 per cubic yard to $92 per cubic yard, with an average of $63 per cubic yard. The amount of debris at airports ranged from 124 cubic yards to 3,800 cubic yards, with 1,455 cubic yards of mixed debris at airports on average. Debris removal from ports had the greatest variability from $38 per cubic yard to $102 per cubic yard. It cost $38 per cubic yard to remove a trailer that was destroyed. It cost up to $102 per cubic yard to remove 6,479 cubic yards of scattered mixed debris from several ports. On average it cost $11 per cubic yard to pick up, load, and haul the debris and $80 per cubic yard for disposal.

Spill Response and Cleanup and Hurricane Sandy

In addition to debris described above, there were a number of oil spills. For example, thousands of field tanks, cylinders, boats, and vehicles were sources of oil pollution. A representative from the U.S. Coast Guard (USCG) Atlantic Strike Team was interviewed about oil spill emergency response. The Atlantic Strike Team is an expert authority in preparation for and response to the effects of oil discharges, hazardous waste releases, and other emergencies. Immediately following Hurricane Sandy, oil spill response in New York and New Jersey was their primary responsibility.

In the New York City metropolitan area and coastal areas of New Jersey, many facilities prepared for a 13.5-foot storm surge situation, but the storm surge was about 2 feet higher than expected. As a result, the containment areas that surround tanks filled with floodwater. In one situation, 350,000 gallons of low-grade sulfur diesel spilled. In another, enough oil was spilled to fill a swimming pool. In addition to spills from tanks, oil used for heating is typically stored in the basements of buildings. Some oil tanks in schools and apartment buildings spilled between 10,000 and 30,000 gallons of oil. More damage and spills tend to occur when the oil tanks are not full. When oil tanks are full, they are typically more secure and can withstand the pressure from flooding.

In many inundated areas, chemical and oil spill assessments had to be done on foot, by boat, or by helicopter. A lot of spills were submerged and difficult to manage, so the response effort was focused on land. Many items were washed up on shore, including recreational boats. Many of these boats leaked fuel and oil. At some sites, boats were piled on top of other boats because the storm surge carried them all to one area.

Findings

The Atlantic Strike Team was authorized $11.5 million in mission assignments; $8 to $8.5 million for New York and $3 to $3.5 million for New Jersey. About $6.5 million of the appropriated funds were spent in 45 days following the storm, cleaning up 589 sites and utilizing 145 Federal responders (about $11,000 per site). There were thousands of instances where residents and corporations were proactive in cleaning up their own sites. For example, Nissan proactively cleaned up 50,000 cars that were damaged on the dock. Private companies spent approximately $220 million for oil cleanup at three sites.

4.2 Estimating Emergency Debris Removal and Cleanup Costs

Flood-event-related economic losses associated with Group 2 include street and highway clearing for emergency response, structure-related debris cleanup, and other types of debris cleanup. Street and highway clearing for emergency response can be evaluated as a per-mile cost generated by collecting, processing, and disposing of debris material from roadways during the emergency response phase after a flood event. Costs for structure-related debris include costs associated with debris collection, processing, and disposal, and landscaping repairs associated with structure-related debris caused by flooding and not wind. Structure-related debris types are listed in **Table 4-3**. Other costs associated with debris removal relate to collection, processing, and disposal of vehicles, vessels, tires, and sediment. Costs related to debris cleanup can be based on the structure type and level of flooding. Also, the quantity of other debris per household, caused by flooding and not wind, is considered to calculate other debris cleanup costs per residential structure. These economic losses stem from two common loss types:

- Labor Diversion (flood-related)
- Capital Use (flood-related)

Associated subtype losses include the following:

- Travel Costs (flood-related)
- Temporary/Rental Structures (flood-related)

Specific *ceteris paribus* assumptions for this category are that no goods would be removed from residences when occupants were evacuated, and no special measures would be taken to reduce debris generation. Another assumption is that changes in routine production activities would be minimal and/or transferred to other places (e.g., routine garbage service would temporarily decrease in the floodplain, yet increase in areas where evacuees would be relocated, resulting in no net routine production losses). Travel needs would increase during a flood because debris material would need to be transported to destination facilities. Also, temporary structures, such as debris staging areas, would be created for flood response.

Debris from residential and non-residential structures was grouped into nine types. **Table 4-3** shows the nine types of debris considered in this study and includes examples of debris type and their destination facility. Destination facilities include landfills and recycling centers, although in some cases, debris could be processed and reused. For example, vegetative debris could be chipped for landfill composting, erosion control, or cover.

Debris materials that could be disposed of at landfills or recycled were assumed to be recycled to minimize further stress to landfill capacities. Although vehicles, vessels, and tires are combined into one category, they would each be evaluated separately.

Table 4-3: Debris Types

Debris Types	Examples of Debris Types	Destination Facility
Vegetative debris	Trees, shrubs, other woody debris	Municipal solid waste (MSW) landfill, composting facility
Sediment	Sand from sandbags, levees, mud, other soil	MSW landfill
Contents	Non-structural and non-toxic contents, such as furniture	Construction and demolition landfill or MSW landfill
Hazardous waste	Cleaning products, fertilizers, pesticides, flammables, medical waste	Hazardous waste facility
White goods	Refrigerators, freezers, air conditioners, washing machines, stoves, heaters	Metal recycling facility (after removing Freon and other fluids from items)
Electronic goods	Televisions, microwaves, computers, stereo equipment	Electronics recycling facility
Vehicles, vessels, and tires	Boats, heavy machinery, small motorized equipment	Auto recycling facility

The cost diagram in **Figure 4-2** describes the data collection process and how this data can be used to calculate outputs. Flood-event-related economic losses associated with this group include street and highway clearing, structure-related debris, other debris types, and oil and spill response. All costs must be associated with a specific level of flooding. If possible, at least three levels of flooding should be used for each emergency cost.

Street and highway clearing for emergency response are the per-mile costs generated by collecting, processing, and disposing of debris material from roadways during the emergency response phase after a flood. The quantity of debris per mile of roadway, caused by flooding and not wind, would be multiplied by the applicable cost to obtain the total street and highway clearing cost per mile of roadway.

Structure-related debris costs are the debris collection, processing, and disposal, and landscaping repair costs associated with structure-related debris caused by flooding, not wind. The costs associated with each structure-related debris type are based on a unit of measurement that would be provided by an emergency service professional or other reliable source. The quantity of structure-related debris per household, caused by flooding and not wind, would be multiplied by the applicable cost to obtain the total structure-related debris cost per household.

Other debris types include vehicles, vessels, tires, and sediment and the costs related to collection, processing, and disposal. The costs associated with other debris types are based on a unit of measurement that would be provided by an emergency service professional or other reliable source. The quantity of other debris per household, caused by flooding and not wind, would be multiplied by the applicable cost to obtain the total other debris cost per household.

Oil spill and response costs include the collection, processing, and disposal costs per structure. The costs associated with oil spill and responses are based on a unit of measurement that would be provided by an emergency service professional or other reliable source. The quantity of oil spills caused by flooding, and not wind, would be multiplied by the applicable cost to obtain the total oil spill and response cost per structure.

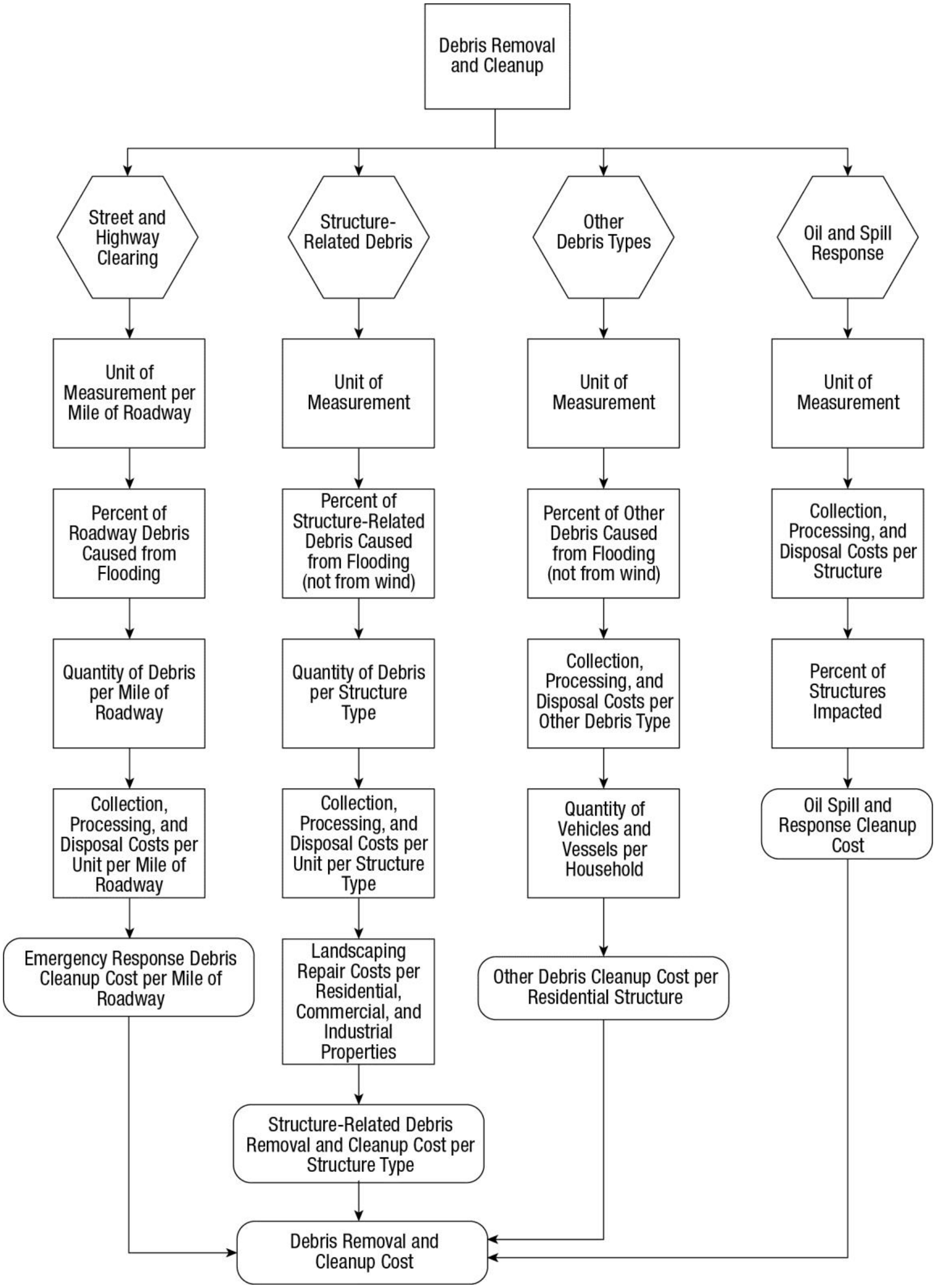


Figure 4-4: Debris Removal and Cleanup Emergency Cost Diagram

Debris removal and cleanup costs can be related to each structure type. Thus, all structures in a category would have the same emergency debris removal expenditures due to flooding. The collecting, processing, and disposal cost per unit (e.g., cubic yard) of debris could be estimated based on the amount of debris per unit for a prototypical structure size for each structure category or occupancy for commercial structures. These costs would then need to be referenced to first floor elevation and depth of flooding. Use caution when using a debris DDF in conjunction with generic DDFs, which may also include debris removal and cleanup costs.

5 Group 3: Public Utilities

Flood inundation may damage standard public utility infrastructure and interrupt services. This section discusses losses associated with five public utility service categories analyzed in this study: natural gas, electricity, telecommunications, sewage and wastewater treatment, and water supply. Some public utility losses would be estimated per residential, commercial, and industrial structure types, while other public utility losses would be estimated per specific components of each public utility system. At the end of this section, the method for estimating emergency costs for this group for future studies is described.

5.1 Natural Gas

For the natural gas system, the biggest risk a flooding event with storm surge poses is to the distribution infrastructure. If water enters pipes, natural gas service can be compromised. The low-pressure system is particularly vulnerable to floodwater, whereas typically gas can continue to flow if water inundates a city gate or regulator station.

During a flood event, the ability of gas utilities to provide service may be compromised. Total economic losses could vary greatly depending on the extent, severity, and duration of damage that may cause gas utility system outages. Repairs to damaged gas utility infrastructure would require the use of private labor and capital.

Natural gas is typically used for cooking, drying clothing, and heating, ventilation, and air conditioning units. Temporary measures can be used in place of natural gas to perform the same functions (e.g., camping stoves, hanging clothes outside to dry, portable heating units, fans). Emergency costs related to natural gas include labor and capital costs that the utility would incur to prevent flood damage (e.g., flood fighting activities) and restore the natural gas system, and costs for temporary measures that would be needed until the natural gas service was repaired.

Natural Gas Service and Hurricane Sandy

Public Service Electric and Gas (New Jersey's largest provider) provides service to 1.8 million customers and had 10,000 outages. New Jersey Natural Gas reported the most damage: $30 million to $40 million in Sandy-related repair and restoration efforts (Friedman, 2013). About 31,000 of New Jersey Natural Gas's 500,000 customers lost service, mostly in Monmouth and Ocean Counties. Crews re-pressurized or replaced 270 miles of gas main and rebuilt or replaced 51,000 gas meters. After the storm, restoration of service to Long Beach Island's 14,000 customers took about a month and restoration of service to most of Seaside Peninsula's 17,000 customers took about 2 months (see **Figure 5-1**).

Figure 5-1: Location of Seaside Heights Peninsula

In New York City, parts of the natural gas distribution network were inundated with floodwater. Approximately 80,000 National Grid and 4,000 Con Edison customers lost natural gas service (see **Figure 5-2** for location of service territories) (NYC, 2013a). Natural gas fuels about 65 percent of heating in New York and fuels more than 98 percent of New York City electricity production by power plants (NYC, 2013a). Four privately owned pipelines transport natural gas into New York City. Con Edison owns and operates the natural gas system in Manhattan, the Bronx, and parts of Northern Queens, and National Grid owns and operates the natural gas system in the rest of New York City. Con Edison completed restoration of service 12 days after the storm, and National Grid completed restoration of service a week after the storm, except for customer-side outages (NYC, 2013a).

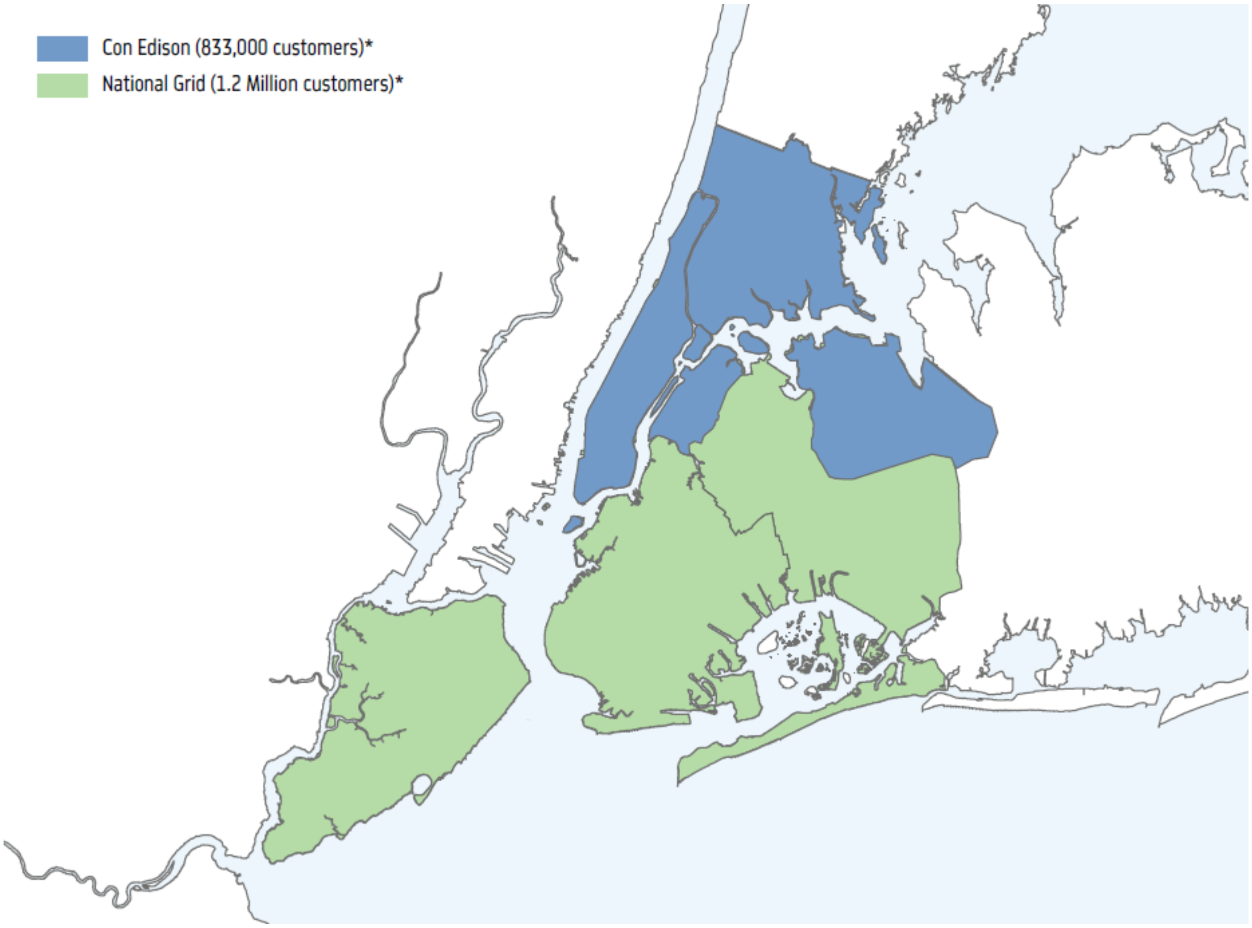


Figure 5-2: Natural Gas Service Territories[1]

Before Hurricane Sandy's final approach into New York City, both utilities isolated some low-lying parts of their networks to limit the effects from floodwater. The utilities also shut down several regulator stations before the storm. Con Edison and National Grid shut down more sections of their respective distribution systems during the storm as floodwater continued to rise. In some parts of the low-pressure distribution system, the pressure of floodwater quickly exceeded the pressure inside the gas mains, which caused water to enter the pipes. Also, in the high-pressure distribution system, floodwater entered some customer service lines. After the storm, gas service was lost in a number of city neighborhoods, including Coney Island, Howard Beach, the Rockaways, Edgewater Park, Locust Point, City Island, and portions of the East Village and South Street Seaport. Additionally, some of Con Edison's gas control and monitoring equipment ceased operating as a result of the loss of power and telecommunications services.

[1] Source: NYC, 2013a

As floodwater receded, natural gas restoration required the removal of water from distribution mains, equipment and pipe inspections, and the re-lighting of customers' appliances. New York City's Rapid Repairs program was instrumental in assisting homeowners with making repairs to damaged boilers and heating systems. New York City Rapid Repairs is an innovative program, funded by FEMA, for homeowners affected by Hurricane Sandy to make essential emergency repairs so residents could return home quickly. Emergency repairs include restoration of heat, power, and hot water. Although restoration work began immediately after the storm, damage to some system components was extensive. For example, in the weeks following the storm, National Grid had to rebuild 13 miles of gas mains serving Breezy Point (which had also been damaged by fire) and New Dorp (NYC, 2013a).

Emergency costs associated with natural gas service include costs to restore service and additional operating costs incurred by the utility (e.g., flood fighting costs). Loss of service consists of the daily cost of substitute service and the daily cost of other temporary actions used to restore service. These costs would be multiplied by the average number of days of an outage of service for each depth of flooding. Additional operating costs for the utility include overtime or costs incurred for employing additional utility workers above what is normally required. Costs associated with direct damage to the physical infrastructure would also be collected when possible. Direct damage costs could be related to specific components of the utility system and depth of flooding at which damage would occur.

5.2 Electricity

An electric utility company generates and/or distributes electricity, whereas regional transmission organizations or independent system operators administer the transmission grid on a regional basis. Electricity is indispensable to factories, commercial establishments, schools, homes, and even some recreational facilities. Flooding may disrupt electrical service to many areas, including areas not actually inundated, because substations, power poles, and other electrical infrastructure become physically damaged and, thus, impair electricity distribution. Floodwater may also cause electrical shorts and other problems. Losses of electrical service would affect homes, businesses, public buildings, street lighting, and other facilities. Many critical facilities, such as hospitals, have backup power systems (e.g., onsite generators), but even these are subject to failure during floods if they are located in low-lying areas. Residents and businesses may use smaller generators as a temporary measure.

Emergency cost impacts of lost or reduced electric service vary widely, depending on extent and duration of flooding, degree of physical damage to substations and other distribution infrastructure, and types of homes and businesses in affected areas. Private labor and capital would be required for repair of damaged infrastructure. Emergency costs associated with electricity include the additional operating costs an electric utility would experience because of a flood event (e.g., flood fighting costs). Calculated costs would be based on anticipated additional actions taken by the electric utility when flooding occurs and the expected length of time that these actions would be necessary. Emergency costs would also include the daily cost of temporary measures taken by residents and businesses to substitute the loss of electricity.

Electric Service and Hurricane Sandy

Following Hurricane Sandy, power outages impacted approximately 8.5 million customers, including commercial and industrial customers, across 20 States and the District of Columbia, from North Carolina to Maine and as far west as Illinois and Wisconsin (FEMA, 2013b). An additional 150,000 outages were caused by the November 7, 2012, nor'easter that hit the region during the Sandy recovery. About 70,000 workers were deployed using executed mutual aid agreements, the largest ever dispatch of utility workers (FEMA, 2013a). In Nassau and Suffolk Counties, there was flood damage to 44 power substations or other electrical facilities (Bleyer, 2013).

During and after Hurricane Sandy, one-third of New York City's generating capacity was temporarily lost. Five major transmission substations were flooded and shut down. More than 800,000 customers were without service (representing over 2 million New Yorkers), which is five times higher than the number that lost power during Hurricane Irene, the second most disruptive storm in recent history (NYC, 2013a). Electric service was restored within a few days of the storm for most of the city; however, areas of the Rockaways and Staten Island had outages that lasted for weeks.

Long Island Power Authority (LIPA) provides electric service to Long Island and the Rockaways (see **Figure 5-3**); Con Edison provides service to the rest of New York City (see **Figure 5-4**). Most Con Edison customers had service restored within 4 days after the storm; however, some customers' service was not restored for almost 2 weeks—the longest-duration outage in Con Edison's history. LIPA's electric service restoration in the Rockaways took about 14 days, with some customers enduring outages much longer. LIPA experienced damage to 50 substations, 2,100 transformers, and 4,500 utility poles during Hurricane Sandy, compared with damage to 22 substations, 1,000 transformers, and 900 utility poles from Hurricane Irene (DOE, 2013).

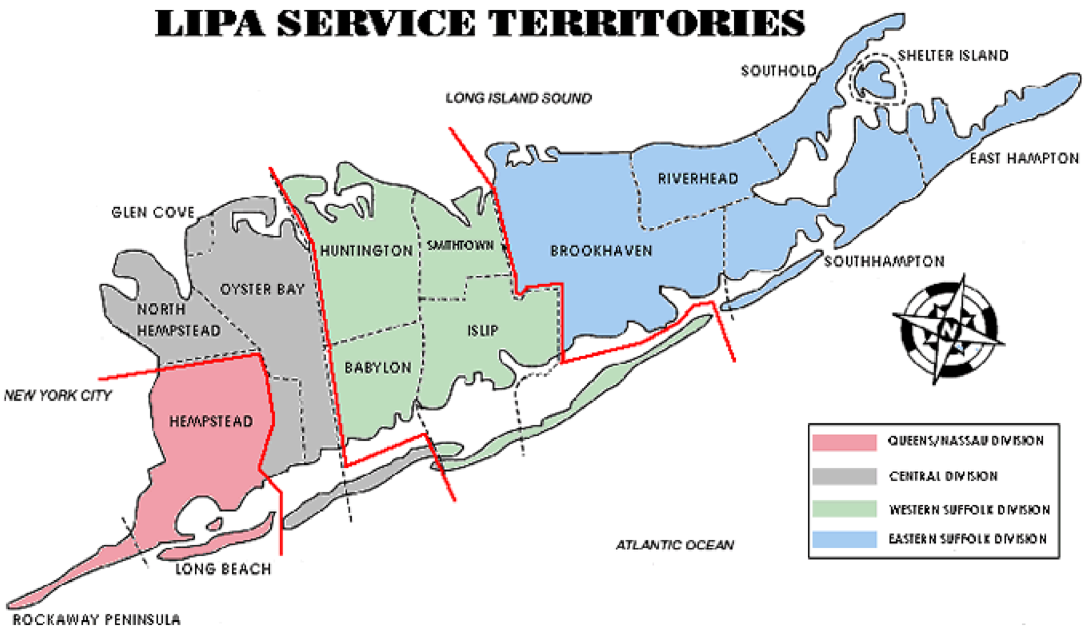


Figure 5-3: Long Island Power Authority Service Territories[2]

Figure 5-4: Con Edison Service Territory in New York[3]

As indicated, even when power was restored to the electrical grid, some customers could not use that power in their homes and businesses, mostly because of significant flood damage to

[2] Source: Long Island Power Authority

[3] Source: Consolidated Edison Company of New York

customer-side equipment. In these cases, the Rapid Repairs program made licensed electricians available to repair customer-side electrical damage. By the time it ended 5 months after Hurricane Sandy, the Rapid Repairs program had helped restore service to about 20,000 homes (NYC, 2013a).

In the days leading up to Sandy, the utilities took preventive measures to minimize potential interruption of service by protecting their infrastructure. For example, the utilities protected critical facilities with sandbags, plywood, and other temporary barriers. Then, on the night the storm arrived, Con Edison proactively shut down three networks, namely the Bowling Green and Fulton networks in Lower Manhattan and the Brighton Beach network in Brooklyn. The networks were shut down to prevent catastrophic flood damage to several clusters of underground distribution equipment and customer equipment. Con Edison also prepared to shut down feeders at key underground transformer vaults threatened by flooding in other areas. Because of the way the distribution system is configured, sometimes these preventive measures caused the loss of electricity not only to customers in areas anticipated to be flooded but also to many customers that were expected to be outside of those areas.

The surge from the storm exceeded projections, which negated many pre-storm preparations. Flooding forced several power plants and transmission lines that import electricity from New Jersey to shut down, leaving New York City more dependent on electricity generated from within the city and transmitted from upstate New York. Some facilities were damaged severely by Hurricane Sandy's surge, while other facilities were disconnected temporarily because of impacts to the transmission system. Several key substations were affected by storm surges that were not expected to be impacted based on surge forecasts before the storm. For instance, all four LIPA substations were knocked out by floodwater in the Rockaways, resulting in widespread power failures throughout the peninsula. Although Hurricane Sandy significantly disrupted electricity supply, the impacts would have been more severe if the storm arrived during the summer, when air conditioning is more vital.

The storm surge flooded a substation in Lower Manhattan and surpassed temporary protective barriers at Con Edison's East 13th Street complex in Manhattan, flooding two transmission substations and leading to an electric arc that could be seen from across the East River (NYC, 2013a). The saltwater damaged critical control equipment and made the substations inoperable, knocking out power to most of Manhattan south of 34th Street (with one notable exception being Battery Park City, which is supplied with electricity from a transmission substation in Brooklyn) (NYC, 2013a). Flooding of a transmission substation in Staten Island caused a grid-level shutdown in the western part of the borough. Each of these damaged substations impacted tens or hundreds of thousands of customers. In all, approximately 370,000 electric customers in New York City lost power as a result of network shutdowns and substation flooding in Manhattan, Brooklyn, Queens, and Staten Island (NYC, 2013a). Once a substation was repaired, service to the tens of thousands of customers could be turned on immediately.

LIPA took 11 days after the storm to restore distribution and a few additional days beyond that for complete restoration of service, except for customer-side outages (NYC, 2013a). Con Edison was not able to restore service until 2 weeks after the storm, and even afterward there were still outages in flood-damaged areas, primarily because of customer equipment (NYC, 2013a).

Substation disruptions affected New York City's bulk transmission system, which caused additional power outages. For example, a day after the storm, two flooded transmission substations in Brooklyn and Staten Island and the disconnection of the Arthur Kill generating facility caused a transmission system overload. These factors coupled with the loss of imported power from New Jersey caused the remaining transmission line capacity from northern parts of the city to be inadequate for servicing parts of Brooklyn and Staten Island. As a result, Con Edison was forced to terminate service to 140,000 customers. This situation persisted for 2½ hours, until the Arthur Kill generating units could be brought back online (NYC, 2013a).

In addition to the outages caused by substation disruptions, intense wind and wind gusts reaching 90 miles per hour sent trees and branches onto power lines. Hurricane Sandy caused damage to 140 miles of overhead lines, 1,000 poles, and 900 transformers in Con Edison's system that had to be replaced or repaired. As a result, approximately two-thirds of New York City's customers (or 390,000 people) lost power (NYC, 2013a).

In heavily flooded areas, approximately 55,000 customers lost power, primarily as a result of damage to electrical equipment in their buildings. In many cases, these customers endured much longer outages because of the extensive repairs needed.

After the storm, the utility companies began identifying system outages using grid monitoring technology, customer complaints, and special assessment teams in areas of heavy damage. The efforts to restore electric service were focused on repairs to damaged transmission infrastructure and local distribution system equipment. Once the utility companies assessed the location and extent of damage, restoration of service was prioritized to the extent possible for facilities necessary for critical care and public safety, infrastructure, and then individual customers (NYC, 2013a).

Even after the restoration of substations, there was still a lot of work needed to restore service. Con Edison pumped hundreds of flooded underground vaults dry. In addition to dewatering, Con Edison needed to repair many components that were damaged by flooding. Inspections were also required prior to reenergizing.

Utilities from around the country sent crews under mutual aid agreements to assist in this restoration effort. For example, Con Edison brought in nearly 3,400 overhead line workers (as well as over 400 underground workers) from as far away as California (NYC, 2013a). As a result of these efforts, electric service was restored to most customers in less than a week. Given the sheer volume of damage across the system, restoration of power to all of Con Edison's customers who could accept it took another week (NYC, 2013a).

In LIPA's territory, the situation in the Rockaways was worse. Several substations were so badly damaged that a mobile substation unit had to be put in place while longer term repairs were conducted (NYC, 2013a). It was 11 days after Sandy passed before LIPA could begin to reenergize its grid and 3 days later power was restored to 10,000 customers, predominantly in portions of Far Rockaway where homes were built on higher ground (NYC, 2013a). The majority of customers in Rockaway neighborhoods (i.e., Belle Harbor, Rockaway Beach, and Arverne) had significant flood damage to electrical equipment in their homes and businesses, which further delayed service restorations (NYC, 2013a).

New York City deployed about 230 generators to hospitals, nursing homes, large multi-family buildings, and New York City Housing Authority developments in the days following the storm (NYC, 2013b). New York City found that it was less expensive to provide generators to private facilities and apartments than it was to relocate residents, prompting a change in response for the emergency distribution of generators. New York City representatives also noted that a premium was paid for the rental of the generators due to demand resulting from the scale of damages.

Emergency costs associated with electricity service include costs to restore service and additional operating costs incurred by the utility (e.g., flood fighting costs). Loss of service consists of the daily cost of substitute service and the daily cost of other temporary actions used to restore service. These costs would be multiplied by the average number of days of an outage of service for each depth of flooding. Additional operating costs for the utility include overtime or costs incurred for employing additional utility workers above what is normally required. Costs associated with direct damage to the physical infrastructure would also be collected when possible. Direct damage costs could be referenced to specific components of the utility system and depth of flooding at which damage would occur.

5.3 Telecommunications

Emergency costs related to telecommunication service include labor and capital costs that the utility would incur to prevent flood damages and restore the telecommunication service and costs for temporary measures that would be needed until the telecommunication service was repaired. Private labor and capital would be required for repair of damaged infrastructure. Costs may be separated by residential, commercial, and industrial telecommunication customers.

Telecommunications Service and Hurricane Sandy

In areas that were heavily damaged by storm surge from Hurricane Sandy, telecommunication lines were either washed away or waterlogged underground. In Mantoloking, NJ, the local utility provider, Verizon, replaced the phone lines with a wireless alternative because they do not expect to have enough customer demand to justify the cost of replacing landline service (Wyatt, 2013). However, the wireless service is not as reliable as landline service during emergency events when electricity may not be available to power the service and 9-1-1 calls may not go through during times of congestion.

About 25 percent of the region's wireless cell towers were out of service after the storm and some 9-1-1 emergency call centers were not operational, according to Julius Genachowski, chairman of the Federal Communications Commission. According to James Ratcliffe, an analyst at Barclays, the storm could cost cable and telephone network operators $550 million to $600 million in cleanup and repair costs. He estimated Sandy would cost Verizon about $306 million. Verizon took about 2 weeks to restore service to most of its customers. Verizon employees involved in the recovery were scheduled to work 12-hour days, 7 days a week to fix the network, when normally they would only work a 40-hour week (Carew, 2012).

During Sandy, telecommunications outages followed the pattern of utility power outages and flooding. When utility power went out, it knocked out cable and Internet services in homes and businesses immediately. These power-driven telecommunications outages affected the greatest number of customers and were generally short term. However, flood damage at critical facilities, in individual buildings, and to telecommunication infrastructure led to longer-term outages.

About 300 Verizon central offices were affected by power outages but most did not lose service (Kwasinski, 2013).The loss of electric power required the use of backup power at central offices in Southern Manhattan, Staten Island, Southern Brooklyn, and the Rockaways. At critical facilities in Southern Manhattan, Red Hook, and the Rockaways, flood damage to equipment and backup power systems caused service to go out in the areas they served (NYC, 2013a). The pumps used to remove floodwater from these facilities were not adequate for the volume of saltwater, resulting in a delay up to 5 days to remove the water out of some central offices and motivating some companies to redesign their facilities entirely.

Longer-term telecommunications outages in the city were primarily caused by flood damage to commercial and residential buildings. Flooding of 1 to 3 feet or more usually resulted in damage to basement and exterior telecommunications equipment, affecting an estimated 35,800 buildings across the city (NYC, 2013a). In high-rise buildings, flooding often destroyed telecommunications equipment, including electronics and copper distribution frames, and electrical switchgear that distributed power. To restore telecommunications service, buildings needed access to power and space at higher elevations for new equipment, which further delayed service restoration in some cases.

Cell service outages were largely caused by loss of power (most significant factor), loss of backhaul service, and/or physical damage to antennas. Where possible, cell providers responded to network outages by connecting generators to existing cell sites. In areas where service could not be quickly restored, providers used cells on wheels (COWs) and cells on light trucks (COLTs), mobile cell sites that can be deployed after a disaster. Most of the

COWs and COLTs were deployed shortly after the hurricane passed and at least one was deployed 5 days after the storm (Kwasinski, 2013). Both Verizon and AT&T and even some private organizations provided charging stations where people could charge their phones (Kwasinski, 2013). Because many cell sites in New York are affixed to private buildings, in many cases, cell sites could not be restored until power to the buildings and connection to backhaul circuits were fully restored. After power returned, telecommunication providers began restoring landline connections. These landline reconnections caused the longest delays in restoring full cell service (NYC, 2013a).

Hurricane Sandy revealed the weaknesses of the telecommunications system. Generally, most telecommunications equipment and facilities were not designed for power outages and flooding. Many critical facilities were not prepared for the storm; notably, backup generators were located below anticipated flood heights. Telecommunications equipment located in basements was flooded too easily, causing significant damage even at relatively low floodwater heights. Another problem was that standard battery backup for cell towers of 4 to 8 hours proved insufficient during the extended outages caused by Hurricane Sandy (NYC, 2013a). Many parts of the telecommunications network were not built with redundancy. Where these vulnerabilities exist, one cut cable or flooded facility could result in an outage for a few thousand customers (NYC, 2013a). In buildings that were wired with multiple telecommunications providers, residents and businesses were able to switch service to the providers that restored service fastest. However, most residents had limited or no secondary provider options (NYC, 2013a).

Emergency costs associated with telecommunications service include costs associated with loss of service and additional operating costs incurred by the utility (e.g., flood fighting costs). Loss of service comprises the daily cost of substitute service and the daily cost of other temporary actions used to restore service. These costs would be multiplied by the average number of days of an outage of service for each depth of flooding. Additional operating costs for the utility include overtime or costs incurred for employing additional utility workers above what is normally required. Costs associated with direct damage to the physical infrastructure would also be collected when possible. Direct damage costs could be related to specific components of the utility system and the depth of flooding at which damage would occur.

5.4 Sewage and Wastewater Treatment

Sewage and wastewater treatment is the process of removing contaminants from household sewage and from wastewater associated with stormwater runoff and commercial/industrial activities. It includes physical, chemical, and biological processes to remove contaminants. Flooding may disrupt sewage and wastewater treatment services for a service area. This disruption could occur because pumps may not work, conveyance systems may be damaged, or treatment plants may be overrun. Disruptions to sewage and wastewater treatment would affect homes, businesses, public buildings, and other facilities. Some of these facilities could operate without sewage and wastewater treatment for a period of time, and some might be able to provide onsite storage, but these actions would only be temporary.

Sewage and Wastewater Treatment Service and Hurricane Sandy

New York State estimates the sewage and wastewater system repair and recovery costs for Hurricane Sandy to be about $1.9 billion. The New Jersey Department of Environmental Protection plans to allocate $2.6 billion dollars for water infrastructure damaged by the storm. Of that, $342 million will go to recovery, $553 million will be spent on repairs, and the remaining $1.7 billion will be spent on building resilience into the system.

Emergency cost impacts of lost or reduced sewage and wastewater treatment service could vary widely, depending on extent and duration of flooding; degree of physical damage to pumping stations, pipelines, and other distribution infrastructure and treatment facilities; and types of homes and businesses in affected areas. Private labor and capital would be required for repair of damaged sewage and wastewater treatment infrastructure. Emergency costs related to lost or reduced sewage and wastewater treatment service include labor and capital costs that the wastewater treatment plant would incur to prevent flood damages and to restore sewage and wastewater treatment, and costs for temporary measures that would be needed until the sewage and wastewater treatment was repaired.

Two wastewater treatment plant professionals were interviewed together and submitted one questionnaire. Another wastewater treatment plant professional submitted the New York City Wastewater Resiliency Plan from the New York City Department of Environmental Protection. The estimated emergency costs provided include the cost per wastewater treatment plant for temporary flood barriers at critical locations, standby generators, dewatering, and additional operating costs (e.g., flood fighting costs). There was not a distinction among the costs for each flood depth (i.e., Hurricane Sandy, 2 feet less than Hurricane Sandy, and 4 feet less than Hurricane Sandy). **Table 5-1** summarizes the costs. These costs are significantly higher than the costs estimated in the USACE Sacramento District study and MVD Report, by about two orders of magnitude.

Table 5-1: Sewage and Wastewater Treatment Emergency Cost Summary

Category	Mean	Standard Deviation
Temporary Flood Barriers at Critical Locations	$1,000,000	$204,125
Standby Generators	$91,666,667	$7,168,640
Dewatering	$26,670,052	$7,730,621
Additional Operating Costs	$5,695,000	$1,960,017
Total	**$125,031,719**	**$10,708,880**

Although emergency costs were provided for a wastewater treatment plant that would be affected by a storm similar to Hurricane Sandy, the specific depth of flooding associated with the costs was not available. Depth of flooding associated with emergency costs is essential for applying these costs in future planning studies. Also, costs associated with direct damage to the physical infrastructure would also be collected when possible. Direct damage costs could be related to specific components of the wastewater treatment plant and depth of flooding at which damage would occur.

5.5 Water Supply

Disruptions of municipal water supply systems may occur as a result of flooding. Floodwater may damage treatment plants, cause pipe breakage, or cause inoperable pumps because of lost electricity. Contaminated floodwater could enter groundwater aquifers, pipes, and wells that supply drinking water to much of the region. Resulting economic losses could affect businesses and residences and force business owners and residents to evacuate, close, or use clean water from other sources, such as bottled water. After a disaster, access to clean potable water is a high priority because it is basic to human survival.

Typically, under flood conditions, widespread water shortages are likely until floodwater recedes. Residential water use is considered in terms of use categories: consumption (e.g., cooking, washing dishes, brushing teeth), hygiene use (e.g., hand washing, bathing, laundry), and outdoor use (e.g., irrigation, car washing). During flood conditions, restrictions on certain uses are typically enforced by local water utilities. For instance, nonessential water use is either discouraged or not allowed. Examples of nonessential water usage include outdoor irrigation and car washing.

Total losses could vary greatly, depending on extent, severity, and duration of damage that may cause outages to water distribution systems. Private labor and capital is typically required for repair of damaged water supply infrastructure, and temporary replacement measures, such as the use of bottled water may also be necessary.

Water Supply and Hurricane Sandy

Hurricane Sandy impacts to the water supply were minimal. In fact, Mayor Bloomberg stated that the New York City water supply was not affected by Hurricane Sandy (Salzman, 2012). All of New York City’s drinking water treatment and distribution facilities remained operational and supplied potable water throughout the storm. New York City’s water quality testing system confirmed water quality by sampling locations in the watershed and nearly 1,000 stations across the five boroughs during and after Sandy (NYC, 2013a).

Although the water supply system fared well overall during Hurricane Sandy, there were some localized impacts. Many high-rise buildings throughout the city were unable to pump water to residents on upper floors because there was not electricity to power their pumping systems. In Breezy Point, fires caused significant disruption to the neighborhood’s private water distribution system. Although some water main breaks were reported, there was no significant spike citywide, and for these individual cases it took the New York City

Department of Environmental Protection an average of 5 hours to restore water service (NYC, 2013a).

Emergency costs associated with water supply include costs associated with loss of service and additional operating costs incurred by the utility (e.g., flood fighting costs). Loss of service comprises the daily cost of substitute service and the daily cost of other temporary actions used to restore service. These costs would be multiplied by the average number of days of an outage of service for each depth of flooding. Additional operating costs for the utility include overtime or costs incurred for employing additional utility workers above what is normally required. Costs associated with direct damage to the physical infrastructure would also be collected when possible. Direct damage costs could be related to specific components of the utility system and depth of flooding at which damage would occur.

5.6 Estimating Emergency Costs for Public Utilities

Flood inundation may damage standard public utility infrastructure and interrupt several services. This section discusses losses associated with five public utility service categories analyzed in this study, including natural gas, electricity, telecommunications, sewage and wastewater treatment, and water supply. Some public utility losses were estimated per residential, commercial, and industrial structure types, and other public utility losses were estimated per specific components of each public utility system.

Analyzed flood-event-related economic losses associated with public utilities stem from two common loss types:

- Labor Diversion (routine- and flood-related)
- Capital Use (routine- and flood-related)

No subtype losses were analyzed for this category.

Specific *ceteris paribus* assumptions for this category are that demand for utility services would remain the same before and after a flood, all households would use this category's infrastructure, and people within the flooded area without service would be evacuated.

The diagram in **Figure 5-5** outlines the calculation of expected flood emergency costs per utility system components or per residential, commercial, and industrial structures. Flood-event-related economic losses associated with this group include damage to physical infrastructure, loss of service and additional operating costs (e.g., flood fighting costs). All costs must be associated with a specific level of flooding. If possible, at least three levels of flooding or more should be used for each emergency cost.

Damages to physical infrastructure are costs generated by flood damage to utility system components. Each damaged utility system component generates labor and capital costs. The quantity per residential, commercial, and industrial structures, price, current depreciation, and labor cost to replace each utility system component are inputs to calculating value of damage to a utility system's physical infrastructure with consideration of the location of each component. Direct damage to a public utility is calculated and presented when available.

Loss of service is the combination of the probability of a service outage and length of time a service outage is expected to last. Daily costs of actions to restore service inside a flooded area, and cost to supplement lost utility services outside the flooded area, are the basis of estimated costs. The sum of the daily cost of temporary actions and the daily cost of substitute services would be multiplied by the average number of days of an outage of service to get the loss of service cost per structure type.

Additional operating costs mean additional operating costs that a utility system would experience because of a flood event. Calculated costs are based on anticipated additional actions taken by a utility system when flooding occurs (e.g., flood fighting) and expected length of time that the actions would be necessary. The combined value of additional operating costs per day would be multiplied by the number of days the additional operating costs are expected to occur to get the total additional operating costs for each flood depth.

Emergency costs are aggregated into utility system flood emergency costs per residential, commercial, and industrial structures. Direct damages to the utility system may be calculated as the cost per specific utility system components. All costs must be associated with a specific level of flooding. If possible, at least three levels of flooding or more should be used for each emergency cost.

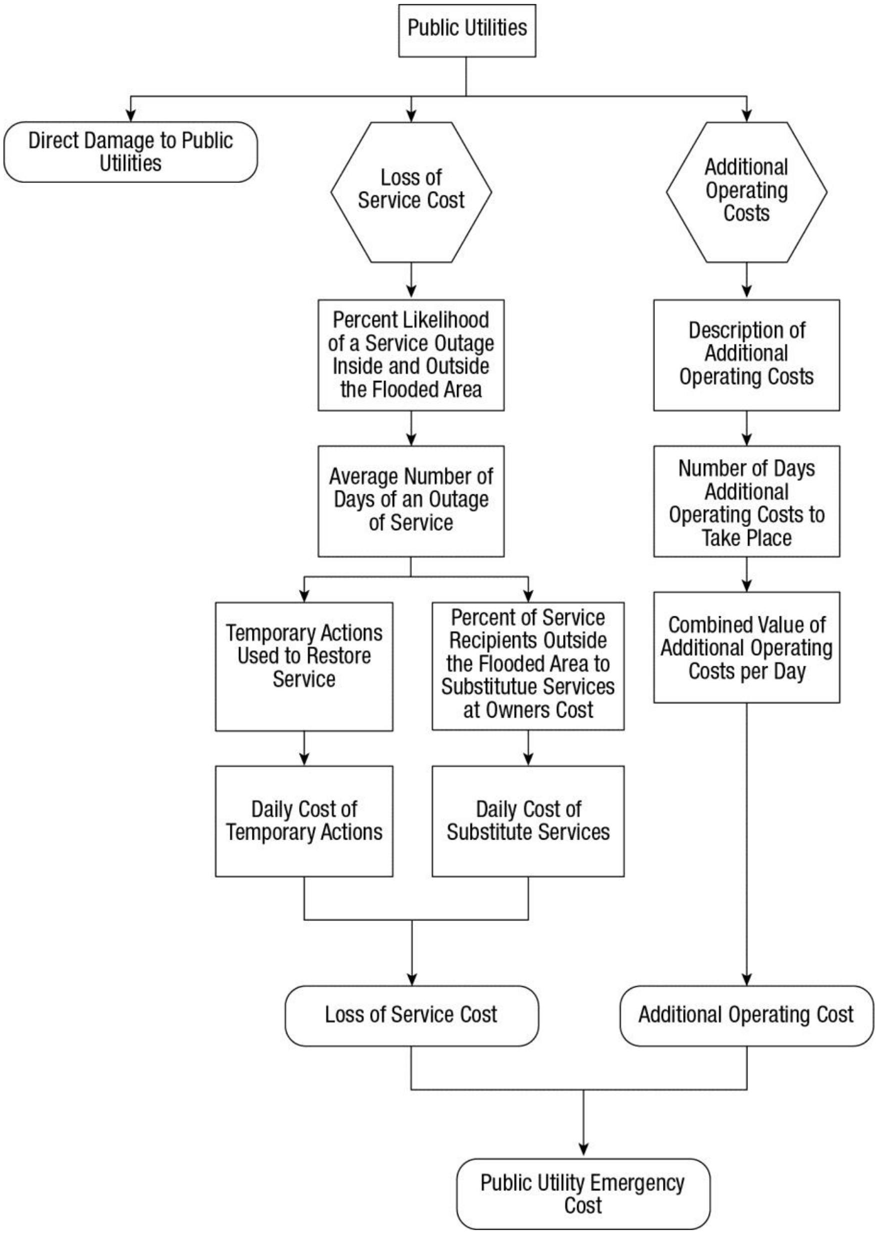


Figure 5-5: Public Utility Emergency Cost Diagram

Estimating emergency costs associated with utilities is difficult because the way the utility network is structured, a component damaged by flooding may cause a loss of service in an area outside the inundated area. Conversely, damage to utility equipment at the customer site could cause an outage for that customer but not necessarily the area surrounding the site.

Direct damage to physical infrastructure could be estimated if costs are available for utility components according to the level of flooding. It would require using a geographic information system (GIS) to locate components and to determine depth of flooding for each component in a study area.

6 Group 4: Infrastructure

In his testimony on December 20, 2013, before the U.S. Senate Committee on Banking, Housing and Urban Affairs on Hurricane Sandy, Peter M. Rogoff, Administrator, FTA, stated that "Hurricane Sandy triggered the worst transit disaster in U.S. history. On the Tuesday morning following the storm, more than half of the nation's daily transit riders were without service." This included Amtrak service along the Northeast corridor, as well as intra-city mass transit systems and commuter lines in Washington, D.C., Baltimore, Philadelphia New York City, and Boston. About 20,000 flights were cancelled as a result of flooding, power outages, and other storm-related problems at the airports. Motorists experienced gridlock due to closures of bridges and tunnels and also as a result of the limited mass transit availability. The most severely impacted areas were New York and New Jersey.

Overall damage estimates to the New Jersey Transit System were around $400 million, with estimates of total damage to the entire transit, road, and bridge system in the State reaching $2.9 billion. During the days immediately after the storm, New Jersey Transit offered free park-and-rides, shuttle buses, and ferries into Manhattan to help mitigate the congestion on the open bridges and tunnels.

The transit network, which services nearly 8.5 million people on a normal weekday, experienced a temporary suspension of service and most sustained serious, widespread damage. The most heavily damaged transit agencies and notable impacts included:

- Metropolitan Transportation Authority (MTA)
  - MTA New York City Transit (NYCT) – stations and tunnels in Lower Manhattan and the Rockaway line
  - MTA Bus Company (MTA Bus)
  - MTA Metro-North Railroad (MNR) – Hudson Line and New Haven Line, including the New Canaan Branch in Connecticut
  - MTA Long Island Railroad (LIRR) – West Side Yard, Long Beach Branch, and East River tunnels (owned by Amtrak but used by LIRR)
  - MTA Capital Construction Division (MTACC)
- New York City Department of Transportation (NYCDOT) – ferry slips and terminals
- Port Authority of New York and New Jersey (PANYNJ), which operates Port Authority Trans Hudson (PATH) service – PATH right-of-way, substations, rolling stock, tunnels beneath the Hudson River and many stations
- New Jersey Transit (NJT) – Hoboken Terminal, North Jersey Coast Line, Meadowlands Maintenance Facility, Hudson-Bergen Light Rail system, the Newark City Subway and rolling stock

- Other smaller agencies and providers, including the City of Long Beach and Nassau Inter-country Express (NICE); Putnam, Rockland, and Westchester counties; and the New York State Department of Transportation

In addition, all of the rail systems experienced damage to communication and signal systems, substations, and power systems. Extensive dewatering efforts to tunnels, stations, storage yards, and other facilities were required. Flooding was the primary cause of damage; however, a major removal effort was needed as a result of downed trees and other wind-borne debris. Also, latent damage from corrosive saltwater is still being discovered.

This section discusses losses associated with seven infrastructure categories analyzed in this study, including subway lines, streets, bridges, railroads, ports, airports, land-based pipelines, and petroleum wells. Some infrastructure losses would be estimated per mile, while other infrastructure losses would be estimated per infrastructure facility (e.g., per airport or per port). At the end of this section, the method for estimating emergency costs for this group for future studies is described.

6.1 Subway Lines

The New York City subway system includes hundreds of miles of infrastructure and thousands of individual assets, including (but not limited to) subway cars, passenger stations, track, switches, signals, fan plants, pump rooms, communications equipment, circuit breaker houses, substations, power and communications cables, tunnel lighting, maintenance and overhaul shops, employee facilities, and rail yards. The features of these asset types vary significantly, in accordance with a system that has evolved over 110 years, as an amalgamation of three separate privately-run subway systems. Collectively, these various components allow for the safe and efficient provision of service to 1.7 billion riders (in 2013), including 5.5 million daily weekday riders on over 8,000 scheduled trips per day. Subway ridership has grown significantly over the past two decades and is now at its highest levels in 55 years.

Subway Lines and Hurricane Sandy

Service was suspended in advance of Hurricane Sandy on Sunday, October 28, 2012, with the storm reaching New York City on October 29. Although very limited service resumed in some non-flooded areas on November 1st, pumping and emergency repair work continued for several days in most locations. NYCT's flooded under-river tubes were pumped out over the course of the subsequent week, with the final tube (the Montague Tube) flooded until November 9. Service disruptions extended far beyond this time period, with R train service suspended through the Montague Tube until September 15, 2014, for repairs, A train service suspended across the Rockaway Flats until May 30, 2013, and one train service to destroyed South Ferry Terminal remaining diverted while the station and its right-of-way infrastructure is being reconstructed over several years.

Because of the diverse nature of NYCT's subway infrastructure (in terms of geography, location at or below grade, type of equipment, and construction, etc.), damage severity varies significantly across the system depending on the nature of flooding and the type and location of particular components. Generally speaking, damage to right-of-way equipment begins once saltwater reaches the rail bed, by degrading and corroding track and switch components, signals, ducts, and associated cables (for signals, power, and communications) as floodwater increases in height. Similarly, yard infrastructure begins to see salt water-induced degradation once flooding surpasses the base of the rail. Public and private labor and capital may be required for repair of damaged subway infrastructure and temporary replacement measures may be needed.

Emergency costs associated with subway lines include the additional operating costs incurred by the transit authority because of a flood event. Calculated costs are based on additional actions taken by the transit authority when flooding occurs and the expected length of time that these actions would be necessary. Emergency costs also include the daily cost of temporary measures taken by residents and businesses to substitute the loss of transportation mode.

Findings

A professional from NYCT was interviewed and provided estimated costs for measures to avoid flood damage, the repair cost per track mile, temporary actions, and additional operating costs. The professional was unable to provide information on flood events less severe than Hurricane Sandy at this time. Current agency planning and response efforts are generally based on a Hurricane Sandy–level storm as a minimum severity.

Depth of flooding is measured differently at the surface and underground. At the surface, as it relates to at-grade facilities and ingress points leading to underground facilities, depth of flooding is measured using the North American Vertical Datum of 1988 (NAVD88) as feet above ground level. Underground flooding is measured in feet above the base of rail. Flood depths underground are generally grouped into three different ranges (above base of rail):

- 0–4 feet: at this height, water does not reach the subway station platform
- 4–14 feet: at this height, water reaches above the platform and potentially up to the ceiling of the station platform level
- Above 14 feet: at this height, water reaches facilities and areas at levels above the platform level

Significant impacts to the subway system based on critical depths of flooding are described in **Table 6-1**.

Table 6-1: Significant Impact to the Subway System

Significant Impact Description	Critical Depth of Flooding in Feet	Damages Expected at or Beyond Critical Depths of Flooding
Right-of-way flooding	0–4 feet from base of rail	Saltwater damage to track, switches, signal equipment, duct banks, cables, etc. (corrosion expected; would result in increased rates of failure and reduced asset lifespan). Service disruption likely to last several days to weeks, assuming expeditious interim repairs are made.
Platform level flooding	4–14 feet from base of rail	Water damage to stations, including turnstiles, token booths, fare equipment, and station facilities; significant damage to right-of-way equipment expected (including complete loss of some assets). Service disruption likely to last several weeks to months.
Beyond-platform level flooding	14+ feet from base of rail	Complete loss of station equipment and majority of right-of-way assets; would likely require significant reconstruction and could result in a loss of subway service for several years while undergoing capital construction project.
Flooding of above-grade facilities	0–20+ feet above surface	Damage to equipment likely to occur at 0–4 feet of flooding; at excessive flood heights, the structures of some above-grade facilities may succumb to hydrostatic pressure, resulting in the total loss of these facilities and all related equipment.

NYCT is pursuing numerous resiliency projects aimed at (1) preventing water from entering the subway system, (2) protecting critical facilities and equipment within the system, and (3) addressing floodwater within the system and improving any associated emergency response. NYCT analysis has identified approximately 40 stations, 30 fan plants, 30 substations, 10 yards, and hundreds of additional facilities that are located in the SLOSH (Sea, Lake, and Overland Surge from Hurricanes model) Category 2 flood zone, and are currently being scoped for storm resiliency measures. As dozens of specific measures are being pursued by NYCT at this time, a summary of high-level NYCT resiliency projects are listed in **Table 6-2**. This list is not exhaustive and does not include various small-scale measures or operational response improvements, which are also under NYCT consideration. Among the most common measures is water ingress protection at all various forms of street-level openings, perimeter protection and drainage improvements at yards, and watertight sealing and protection of critical equipment in various facilities both at and below grade.

NYCT's design standard is to protect the subway system up to a Category 2 flood level, plus 3 additional feet (to account for sea level rise, wave action, etc.). This intentionally high standard exceeds flood heights experienced during Hurricane Sandy to account for the future possibility of both greater and more frequent storms. As such, the estimated costs of each resiliency measure, provided below, are based on protection to this Category 2 + 3 feet standard.

Table 6-2: Measures to Avoid Flood Damage for Subway Lines

Measure	Description	Cost
Measure 1	Sealing of Street Level Openings (protection of stairways, vents, manholes, hatches, etc.)	$401M
Measure 2	Tunnel Sealing: Portals and Internal Walls (barriers to prevent water ingress and/or cross-flooding)	$58M
Measure 3	Hardening of Vent Plants (water ingress protection, structural hardening, etc.)	$127M
Measure 4	Flood Mitigation at Yards (perimeter protection, drainage improvements, etc.)	$1,504 M
Measure 5	Pumping System Improvements (backup power, pump trains and mobile pumps to increase capacity)	$75M
Measure 6	Substation Hardening (water ingress protection, structural hardening, etc.)	$106M
Measure 7	Right-of-Way Equipment Hardening (protection of signal/pump facilities and equipment)	$85M
Measure 8	Internal Station Hardening (protection of signal and communications rooms within stations)	$26M
Measure 9	Flood Mitigation of the Rockaway Line (protection of stations, right-of-way, other components)	$182M
Measure 10	Flood Mitigation of Staten Island Railway Facilities (protection of Clifton Shop and St. George Terminal)	$206M
Measure 11	Emergency Communications Enhancements (upgrades to emergency systems, control centers, etc.)	$100M
Measure 12	Flood Mitigation of Other NYCT Facilities (protection of various administrative/support facilities)	$32M

For a flood event such as Hurricane Sandy, it is expected to take anywhere from 4 to 54 days for the subway lines to resume full service. Various forms of emergency repairs would be performed to restore service, ranging from simple inspections, cleaning, and testing of equipment, to temporary "quick fix" repair measures, to full equipment replacement by in-house forces. Following Hurricane Sandy, track, signals, and rolling stock were painstakingly inspected to be in proper working order before restoring any service. Stations and communication equipment were reactivated on emergency generator power and with power pulled from the 3rd rail traction power.

Additional provisions to operate modified service include (but are not limited to) makeshift terminals, new turn-back locations where train service through tubes is suspended, suspension of express train service and modification to local service schedules, and temporary suspension of fare collection.

Transportation in the New York metropolitan area was substantially compromised in the days following Hurricane Sandy. Without subway service and the 5.5 million daily rides it provides, as well as a shortage of available gasoline, gridlock consumed much of the region. Where possible, NYCT offered expanded bus service, including free "bus bridges," which replaced suspended subway service between downtown Brooklyn and midtown Manhattan using exclusive lanes on the East River bridges. These bus services were heavily used, but did not have nearly the capacity of Brooklyn-Manhattan subway services. Following Hurricane Sandy, NYCT spent approximately $6 million operating "bus bridges" (just during the 3-day free-fare/limited subway service period); however, this is considered a very small fraction of the overall cost to disrupted service recipients and to the regional economy. In response to the tremendous increase in personal vehicular travel, the city imposed high-occupancy vehicle restrictions on various river crossings, which is believed to have caused a marginal increase in bicycling, walking, carpooling, and telecommuting.

In total, $54 million in operating charges were attributed to Hurricane Sandy in the 54 days between the storm's landfall and the restoration of the Montague Tube. Of these, internal operating and maintenance groups (primarily responsible for repairs) spent $41 million, while other support forces (supplying, planning, and management functions, logistics, etc.) charged $13 million. In addition, NYCT incurred an additional $23 million in charges between December 21, 2012, and October 25, 2013, attributable to ongoing Hurricane Sandy–related maintenance and operational issues.

Although a significant portion of NYCT's emergency operating costs would be incurred in the immediate weeks and months following a storm, residual Hurricane Sandy–related operational challenges and associated costs still persist after 18 months. Consequently, operating costs from a Hurricane Sandy–level storm can be expected for an indefinite period of time (at least several years). In terms of direct operational charges, NYCT attributed additional operating costs to Hurricane Sandy for approximately 365 days after the storm.

As evidenced during Hurricane Sandy, the subway's under-river tubes are particularly vulnerable to flood damage, as they are generally low points in elevation and collect floodwater entering via various waterfront surface openings. In addition, the Sea Beach Line is particularly vulnerable to flood-related costs (as it is located in an open cut in a low-lying area), as are several of NYCT's coastal yards (most notably, Coney Island Yard, 207 St Yard, and Clifton Yard, which house a variety of critical subway car maintenance and overhaul functions) (see **Figure 6-1**). The vast majority of NYCT's operating and capital costs post-Sandy are attributable to damage in these locations. Moreover, because of the interconnected nature of the subway system, several lines are susceptible to cross-flooding at key transfer locations (including West 4th Street on the Sixth Avenue Eighth Avenue Lines, South Ferry / Whitehall Street on the Seventh Avenue and Broadway Lines, Lexington Avenue / 59 Street on the Lexington Avenue and Broadway Lines, and Metropolitan Avenue / Lorimer Street on the Crosstown and Canarsie Lines).

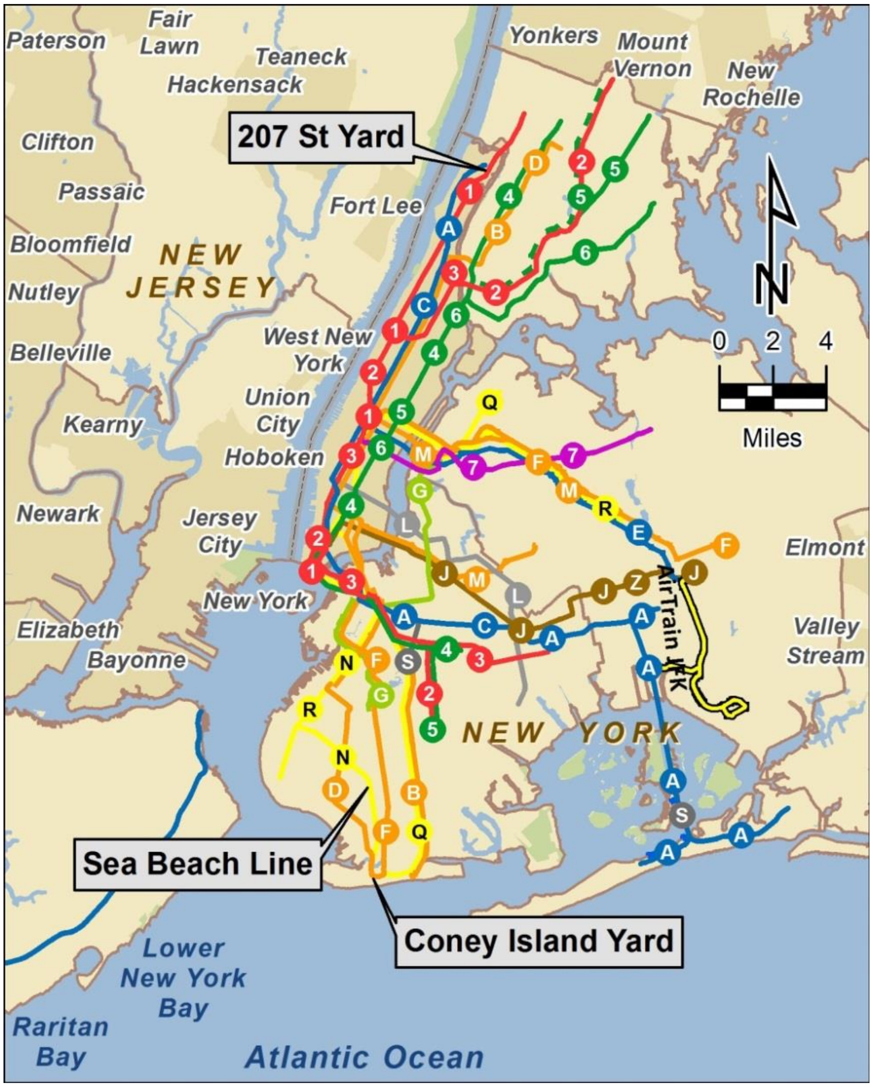


Figure 6-1: Location of New York Subway Lines

Table 6-3 summarizes emergency costs associated with the subway lines. Only the maximum cost was provided for the measures to avoid flood damage (e.g., flood fighting activities) and only the most likely value was offered for additional operating costs. A subway professional only provided emergency cost estimates for the Hurricane Sandy flood depth. These costs could not be compared with the costs estimated in the USACE Sacramento District study and MVD Report because those studies did not include a category for subway lines.

Table 6-3: Summary of Emergency Costs for Subway Lines

Category	Minimum	Most Likely	Maximum	Mean	Standard Deviation
Measures to avoid damage	N/A	N/A	$1,548,000,000	N/A	N/A
Repair cost per track mile	$79,260	$295,486	$416,815	$263,854	$69,805
Temporary Actions	$3,028,000	$5,549,000	$41,378,000	$16,651,668	$8,757,260
Additional Operating Costs	N/A	$77,000,000	N/A	N/A	N/A

Note: N/A = not available
Source: NYCT

Although emergency costs were provided for a subway system affected by a storm similar to Hurricane Sandy, the specific depth of flooding associated with the costs was not available. Depth of flooding associated with emergency costs is essential for applying these costs in future planning studies. Additionally, costs based on the New York City subway system may not be easily transferred to a subway system in another city because of the diverse nature of NYCT's subway infrastructure (in terms of geography, location at or below grade, type of equipment, and construction, etc.).

6.2 Streets, Roads, and Highways

When streets, roads and highways are flooded or damaged, sometimes detours can avoid impassable areas. Detours typically require more time and distance to reach the destination. Measures may be taken before a flood event to avoid flooding, such as embankment stabilization. During or immediately after a flood event, traffic control and pump operations may be necessary. All of these additional operating costs (e.g., flood fighting activities) are considered emergency costs. Calculated costs would be based on anticipated additional actions taken when flooding occurs and the expected length of time that these actions would be necessary. Emergency costs associated with streets, roads, and highways can be aggregated for each functional road class category as the cost per distance of roadway. Traffic control costs would already be captured in the police category, since police officers typically perform these duties.

Street, Roads, and Highways and Hurricane Sandy

A few days after the storm, people attempted to resume daily routines. Because the public transportation system was still partially out of service, some former mass transit riders resorted to bicycles (30,000 bike commuters on November 1 – triple the typical number) (Public Radio International , 2012), bus shuttles, ferries, and walking or some combination, while others used automobiles. As a result, there was gridlock on roads and bridges heading into Manhattan, such as the Lincoln Tunnel, the Brooklyn-Queens and Gowanus Expressways, the Long Island Expressway, and Queens Boulevard. The average highway speeds dropped by as much as 71 percent relative to speeds on normal weekdays (NYC, 2013a). Traffic was backed up for miles in Brooklyn, Queens, and New Jersey; 4-hour backups were reported at the Lincoln Tunnel. To ease gridlock, Mayor Bloomberg implemented HOV3 carpooling restrictions (requiring 3 or more passengers) on most entry points to Manhattan, with the exception of the George Washington Bridge (Miller, 2012). Average travel speeds recovered after this temporary measure went into effect.

No matter which alternative transportation option was used, all transportation options were more time-consuming ways to travel immediately following the storm. The New York University Rudin Center’s survey of 315 commuters (about half typically took the subway to work) revealed the increase in commute time due to Hurricane Sandy. The travel times and frustration index for those commuting to work (not telecommuting) on November 1 and 2 are shown in **Table 6-4** (Kaufman et. al., 2012). The frustration level is a scale from 1 to 10, with 10 being the most frustrated and 1 being the least.

Table 6-4: Average Commute Time and Frustration Level After Hurricane Sandy

Residence Location	Pre-Sandy Commute Time (minutes)	Commute Time Nov. 1–2 (minutes)	Percent Change (%)	Average Frustration Level
Brooklyn	42	86	105	3.93
Manhattan	29	52	79	2.97
Queens	45	47	4	3.00
Bronx	41	63	54	2.14
Staten Island	84	240	186	7.00
New Jersey	52	69	33	5.67
Northern Suburbs	73	61	-16	2.40
Long Island	85	85	0	2.00

Commute times by automobile for survey respondents nearly tripled, from an average of 47 minutes before Hurricane Sandy to an average of 115 minutes post-Sandy (Kaufman et. al., 2012). An estimated 4.2 million drivers were impacted by the shutdown of various transportation systems (NYC, 2013a).

Findings

After Hurricane Sandy, floodwater receded within 12 hours. About 60 lane miles of roadways were damaged severely; otherwise, most flooded roadways in affected areas were undamaged or sustained only minor damage. USACE estimated 355.16 lane miles were damaged by Hurricane Sandy for a total cost of $297 million for repair (either resurfacing or reconstruction), a cost of about $836,000 per mile. Flooding also damaged traffic signals of nearly 700 intersections when signal control boxes and underground conduits and cables were exposed to salt water.

Although direct damage costs were provided for streets, roads, and highways affected by Hurricane Sandy, the specific depth of flooding associated with these costs was not available. Depth of flooding associated with emergency costs and direct damage costs is essential for applying these costs in future planning studies.

Emergency costs associated with streets, roads, and highways are the additional operating costs incurred by the owner of the infrastructure. Additional operating costs may include overtime or other costs incurred for emergency services above what is normally required. Emergency services may include setting up detours, traffic control, erosion control, and other preventative activities to avoid damage (e.g., flood fighting activities).

6.3 Bridges

Depending on the height and design of a particular bridge, infrastructure spanning bodies of water are at particular risk during flood events. Much of the Nation’s bridge infrastructure is outdated and not up to current structural codes, exacerbating the risk of damage during an event. The major risk to bridges during flood events centers on debris within floodwater that can be washed into the structures, causing extensive damage. Additionally, flood and storm surge like that observed during Hurricane Sandy can cause extensive erosion that would normally occur over a long period of time to occur instantly, further compromising the structural integrity of a bridge.

Bridges and Hurricane Sandy

During Hurricane Sandy, bridges were closed throughout the New York and New Jersey metro area. The PANYNJ and the MTA closed the lower level of the George Washington Bridge immediately, with the upper levels of the Whitestone Bridge, the Throngs Neck Bridge, the Verrazano-Narrows Bridge, the George Washington Bridge, the Henry Hudson Bridge, the Tappan Zee Bridge, and the Cross Bay Veterans Memorial Bridge following suit (Donohue, 2012). The City of New York also closed four East River bridges, including the Brooklyn, Manhattan, Williamsburg, and Ed Koch Queensboro Bridges, with the city Transportation Department closing the Joseph P. Addabbo Memorial Bridge in Queens in coordination with the MTA’s closure of the Cross Bay Bridge (Donohue, 2012). Major bridges were able to reopen within 12 hours after the storm following safety inspections by engineers.

Findings

Damage to bridges in the metropolitan area surrounding New York City was extensive. The USACE estimated that 25 bridges were damaged by Hurricane Sandy with a total cost estimated at $44.1 million for repairs, or an average cost of about $1.8 million per bridge. Hurricane Sandy flooded the Carroll Street Bridge up to 30 inches above the deck and FEMA has committed $1 million to repair electrical and hydraulic equipment to make the bridge operable for marine traffic (Musumeci, 2013). Additionally, exemplifying a key risk to bridges during a flooding event, the Morgan Drawbridge on the North Jersey Coast Line in South Amboy sustained damage from boats and a trailer that collided into the bridge (Mass Transit, 2012). While some bridges were damaged, others had to be demolished. After Hurricane Sandy battered one of two remaining sections of the old Ponquogue Bridge, the 83-year-old section will have to be demolished as a section more than 30 feet long in the middle of the old span was completely washed away by waves, leaving 200 feet of the decommissioned structure in shambles and cut off from land (Wright, 2013).

The George Washington Bridge serves both New Jersey and New York equally by transporting goods across the State lines via vehicular equipment from Fort Lee, NJ, to the upper west side of Manhattan, NY. During Hurricane Sandy, a 24-hour-per-day work force was implemented at the George Washington Bridge until the bridge was eventually shut down and traffic was diverted on both sides of the bridge. Because of the severity of the storm, the bridge was shut down in stages for approximately 22 hours. The Port Authority Police assisted in redirecting traffic at the bridge and along the New Jersey Parkway. Emergency costs for the George Washington Bridge totaled about $250,000, including 2,070 hours of overtime; hotels and food for staff doing long shifts; Port Authority Police services; materials and equipment, such as electrical components used to “sure-up” and preserve the electrical integrity of the bridge, generators, salt, and vehicles; and direct administrative costs for document development, processing, and verification.

Hurricane Sandy caused widespread debris throughout the access roads at the three Staten Island bridges: Outerbridge Crossing, connecting Staten Island, NY, with Perth Amboy, NJ; Goethals Bridge, connecting Staten Island, NY, with Elizabeth, NJ; and Bayonne Bridge, connecting Staten Island, NY, with Bayonne, NJ. Outerbridge Crossing had 1,388 cubic yards of debris, Goethals Bridge had 1,000 cubic yards of debris, and Bayonne Bridge had 373 cubic yards of debris, for a total of 2,761 cubic yards of debris. Debris removal costs for all three bridges totaled about $110,000 for labor, equipment, materials, and direct administrative cost. The average cost was $40 per cubic yard of debris. Weighting the costs according to the amount of debris, Outerbridge Crossing would account for about half the cost, $55,000, Goethals Bridge would account for about $40,000, and Bayonne Bridge would account for about $15,000 for debris removal.

In addition, emergency protective measures were taken immediately prior to and during the storm at the three Staten Island bridges to lessen or prevent damage from high winds, tidal conditions, and storm surge. Emergency measures included sandbagging, securing and powering down vulnerable electrical equipment, moving vehicles to higher ground, and supplying temporary electrical power. The Port Authority Police had 77 hours of overtime for setting up road barricades and controlling traffic. This cost was split evenly among the three bridges and was included in the emergency protective measures cost. A summary of the emergency costs for the three Staten Island bridges is provided in **Table 6-5**.

Table 6-5: Bridges Emergency Cost Summary[4]

Bridge	Debris Removal	Emergency Protective Measures	Total
George Washington Bridge	-	$250,000	$250,000
Outerbridge Crossing	$55,000	$71,000	$126,000
Goethals Bridge	$40,000	$33,000	$73,000
Bayonne Bridge	$15,000	$94,000	$109,000

Although direct damage and emergency costs were available for bridges affected by Hurricane Sandy, the specific depth of flooding associated with these costs was not available. Depth of flooding associated with emergency costs and direct damage costs is essential for applying these costs in future planning studies.

6.4 Railroads

Railroad infrastructure throughout New York and New Jersey is particularly susceptible to flooding events (see **Figure 6-2**). Legacy infrastructure underneath rivers and the close proximity of assets to bodies of water contributed to the devastating effect of Hurricane Sandy on railroads. In anticipation of a storm event that may result in flooding preparation efforts consist mainly of securing tunnel entrances, relocating capital assets to higher ground, and phasing down service toward system shutdown.

[4] The data shown are taken from project worksheets drafted between December 2012 and November 2013. The figures shown are estimates. Determination of actual costs is in progress and pending review. Disclaimer: Figures shown will change based on pending coordination between PANYNJ and FEMA.

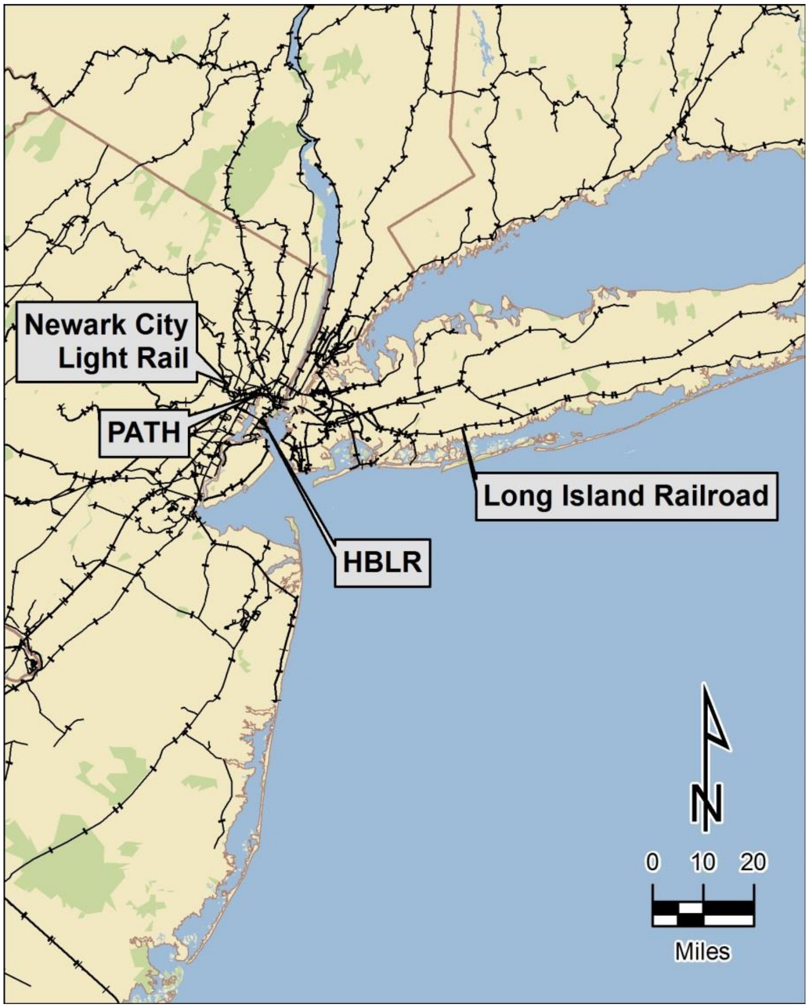


Figure 6-2: Location of New York and New Jersey Railroads

Recovery efforts immediately following a storm include removing water from inundated tunnel infrastructure, debris removal from tracks, and restoration of power. Amtrak shut down all services for 3 days following the storm while debris was removed from the tracks, tunnels were dewatered (which was a major effort), and signals and tracks were repaired. Amtrak was the first to resume service after Hurricane Sandy. About 910 Track employees, 455 Bridge & Building employees, and 405 Electric Traction employees were involved in the restoration efforts at Amtrak (BMWED, 2013). Before recommencing service, inspections were required to ensure it was safe to operate the trains. Although temporary repairs allowed service, corrosive salt water continues to degrade the signaling system and Amtrak is still finding damage.

NJT, which provides commuter train service to New York City and within the State, suffered extensive damage to its rail cars and engines, which delayed restoration of service. The agency had shut down service pre-emptively and moved trains to less flood-prone areas in preparation of the storm, but the storm still caused significant damage. Line erosion, hundreds of downed trees, and recreational boat debris were observed across many lines, while additional debris downed power lines along rails. NJT described the very significant types of damage from the storm being primarily wind related, such as the destruction of the overhead catenary system, which comprises the electric wires that provide traction power to the electric trains (FTA, 2013).

The NJT rail operations center in Kearny was flooded by up to 7 feet of water, damaging 74 locomotives and 294 rail cars, and required several weeks of repairs before rail services resumed. The flooding also damaged backup power supply systems, the emergency generator, and the computer system that controls the movement of trains and power supply.

NJT's Hudson-Bergen Light Rail Line (HBLR) connects Bayonne and western Jersey City with Jersey City's Exchange Place and Newport Center and Hoboken Terminal. HBLR vehicles were moved to two higher-elevation locations before the storm and, consequently, were not damaged. HBLR facilities and infrastructure had extensive damage from flooding and high winds. Repair and restoration of the HBLR totaled $8,298,313 (FTA, 2013).

The Newark City Light Rail system has a line across the greater Newark area. Floodwater damaged station operational facilities and equipment, track and signal equipment, station power and station ventilation, and smoke evacuation systems. Repair and restoration of the Newark City Light Rail system totaled $12,592,413 (FTA, 2013).

A subsidiary of the PANYNJ, PATH operates about 28 miles of interstate heavy rail rapid transit with an average weekday ridership of over 265,000 passenger trips (FTA, 2013). PATH connects Newark, Jersey City, and Hoboken with lower and mid-town Manhattan via two pairs of tunnels beneath the Hudson River. The storm surge flooded passenger stations and tunnels, which are more than 100 years old. Flooding of PATH's tunnels and stations caused severe damage to its signal, communications, and power systems in addition to station facilities, equipment, the maintenance facility, and rolling stock. Because of the age of the system, many of the system components that were damaged by the storm are obsolete, requiring specially designed and fabricated replacement parts. Also, 85 rail vehicles stored at the Harrison Car Maintenance Facility were submerged and suffered significant damage. PATH was unable to resume any service until November 6 (FTA, 2013). Normal service was restored gradually, but direct service between Hoboken and Lower Manhattan remained suspended until January 30, 2013 (FTA, 2013).

The historic Hoboken Station, which serves more than 50,000 people per day with multiple modes of transportation, namely the NJT commuter rail, PATH, MNR line, various bus lines, the Hudson-Bergen Light Rail, and NY Waterway-operated ferries, was one of the hardest hit stations. Because of the loss of the signal system, operating staff teams of 18 were used to manually communicate train positions in between Exchange Place and the World Trade Center through partial system operations during the earliest recovery periods (FTA, 2013). Repair and restoration of the Hoboken Terminal is estimated to be $3,556,250.

PATH operation and maintenance costs, including labor, attributed to Hurricane Sandy total $32,200,000 (FTA, 2013). Recovery and restoration projects include the signal system ($26,350,000), automatic train control project delays ($30 million), escalator and elevators ($9 million), rail vehicles ($38,974,000), Harrison Car Maintenance Facility ($2 million), fare collection equipment ($3.6 million), station platforms ($4 million), security and communications ($3,250,000), tunnel pumps ($1 million), World Trade Center Station ($403,234,164), emergency repair work performed by contractors ($5 million), track repairs and drainage ($100,649,100), and permanent station repairs ($41,230,000) (FTA, 2013). Resiliency projects based on identified needs for preventative measures total $1,396,262,500, including replacing damaged assets with those in a state of good repair (FTA, 2013).

The MNR is the busiest commuter railroad in the country, operating on 775 miles of track with a daily ridership of 280,000 passengers and serving 121 stations in seven counties in New York and two counties in Connecticut (FTA, 2013). Hurricane Sandy caused the most extensive damage on the Hudson Line, which parallels the Hudson River on its east bank. Flooding of the NJT’s Hoboken Terminal caused significant disruptions to West of Hudson service in addition to rail damage. Portions of the New Haven Line were also impacted by the storm. Five capital projects identified by MNR to meet restoration requirements total $231.3 million; operating and revenue impact expenses for pre-storm and immediate post-storm activity and recovery costs are estimated at $8 million; and $812 million of resiliency projects have tentatively been identified (FTA, 2013). These estimates were made soon after the storm, and long-term damage from salt water may not be immediately known.

The LIRR system comprises over 700 miles of track, 124 stations, and 735 daily trains serving over 80 million customers each year, an average of 301,000 customers each weekday (FTA, 2013). Before the storm, LIRR suspended services and moved more than 1,000 train cars to less flood-prone areas. Additionally, LIRR secured hundreds of grade crossings over 700 miles of track and was able to restore limited service 2 days after Sandy initially made landfall.

Hurricane Sandy caused the most extensive damage to LIRR substations, traction power and yard equipment on the Long Beach Branch, a 5.7-mile line from Lynbrook to Long Beach crossing the Reynolds Channel. Four East River Tunnels shared with Amtrak and NJT also experienced damage from flooding. Surge waters flooded the West Side Storage Yard in Manhattan and the Long Island City Storage Yard. The West Side Storage Yard operations include undertaking inspections, repairs, maintenance, and cleaning for the railroad’s fleet. The project to repair the West Side Storage Yard involves replacing switch machines, signal components, third-rail components, switch heaters, and fire alarm systems.

Six capital projects identified by LIRR to repair the system total $267 million; operating and revenue impact expenses for pre-storm and immediate post-storm activity and recovery costs are estimated at $18 million; and $488 million of resiliency projects have tentatively been identified (FTA, 2013).

The FTA’s new Public Transportation Emergency Relief Program allocated $20.9 million to the LIRR to repair infrastructure and revitalize the transit system (Brown et. al., 2014). The Program allocated $138 million to restore substations and power infrastructure along LIRR and MNR and

$88.1 million to repair communications and signal equipment for LIRR's Long Beach branch and Westside storage yard. (Callegari, 2014).

Findings

Emergency costs associated with railroads include additional operating costs that the railroad industry would experience because of a flood event (e.g., flood fighting activities). Calculated costs would be based on additional actions taken by the railroad industry when flooding occurs and expected length of time these actions would be necessary. **Table 6-6** summarizes the direct damage and emergency costs from the MNR, LIRR, and PATH railroads. Light rail costs were not included because the damage to them was caused predominantly by wind.

Table 6-6: Summary of Railroad Emergency Costs

Railroad	Repairs and Restoration	Increased Operating Costs Due to Flood	Resiliency Projects
Metro-North Railroad (MNR)	$231.3 million	$8 million	$812 million
Long Island Railroad (LIRR)	$267 million	$18 million	$488 million
Port Authority Trans Hudson (PATH)	$668.3 million	$32.2 million	$1.4 billion

Although direct damage costs and emergency costs were available for railroads affected by Hurricane Sandy, the specific depth of flooding associated with these costs was not available. Depth of flooding associated with emergency costs and direct damage costs is essential for applying these costs in future planning studies.

6.5 Ports

Ports are critical for growth and prosperity of a country. Cargo includes essential items, such as petroleum, grain, steel, automobiles, and commercial goods. Port usage leads to economic and employment growth. U.S. Ports handle about $3.8 billion worth of goods each day and ports-related employment in the United States is estimated at 13 million people (AAPA, 2013). However, by their inherent proximity to waterfront areas, ports are highly susceptible to the direct threats from storm events and flooding (Becker et. al., 2013). Storms events and resulting flooding interrupt port operations, damage infrastructure, and can cause the release of hazardous chemicals into the waterways.

Ports and Hurricane Sandy

Hurricane Sandy caused widespread disruption to maritime operations and facilities in ports along the coast. Prior to the landfall of Hurricane Sandy, the USCG was tracking the storm and continually issuing Marine Safety Information Bulletins to alert all port authorities. Adhering to its Hurricane and Severe Weather Plan, the USCG closed the Port of New York and New Jersey at 6 pm on October 28 (Smythe, 2013). The USCG provides guidance in the form of Storm Preparation Checklists of tasks to complete prior to a storm occurring. Preparedness efforts include securing marine equipment and vessels, moving applicable equipment to higher elevations, establishing emergency command centers, and inspecting operations as necessary. NOAA assists in hydrologic surveys and its Office of Coast Survey activated and prepositioned National Response Teams to be able to respond quickly to Hurricane Sandy (Pounds, Ward, & Forsythe, 2013). The USCG also activated its Maritime Transportation System – Recovery Unit in the New York Sector.

The Port of New York and New Jersey, the largest port on the east coast handling 5.4 million shipping containers, 745,000 automobiles, and 37 million tons of bulk cargo annually, was the hardest hit of any port during the storm. Following initial closure on October 28, the port did not reopen until November 4, and even then some operations were further delayed (Smythe, 2013). Hurricane Sandy brought an extraordinary 14-foot storm surge that caused oil and hazardous material incidents, swept debris into shipping channels, severely damaged marine terminals including destroying berths and pier faces, and flooded corrosive salt water into computers, power transformers, cargo control systems, electric cranes, fuel oil pumps, and transportation infrastructure (Sturgis, Smythe, & Tucci, 2014). The PANYNJ reported estimated damages of $170 million with $130 million of that being capital costs, while the U.S. Coast Guard Sector of New York (SECNY) reported damages of $76 million (Smythe, 2013).

Impact and response effort costs varied:

<u>Power/Electrical Infrastructure</u>

- Widespread and prolonged power outages meant of a loss of communications, requiring the use of personal devices and increased physical presence on location (Smythe, 2013).
- Loss of security systems necessitated fencing lots of imported cars and providing guards (Smythe, 2013).
- Traffic lights were down at 17 intersections, causing safety issues in returning to normal operations (Wakeman & Miller, 2013).
- Saltwater flooding damaged electrical systems in operations centers and also in marine equipment, such as the large cranes used to move cargo (Smythe, 2013).
- Container cranes with electric motors were flooded with saltwater, making them inoperable. Repair costs were estimated at $160,000 each (Wakeman & Miller, 2013).

<u>Fuel</u>

- No power meant that gas station pumps could not operate necessitating gas import from elsewhere (Smythe, 2013).
- Similarly, petroleum terminals were damaged and without power, causing an inability to move product (Smythe, 2013).

Personnel

- USCG and NOAA activated response teams prior to landfall, requiring extra man power. Around-the-clock surveys covered 34 square nautical miles and 100 linear nautical miles of waterways in the Port of New York and New Jersey (Sturgis, Smythe, & Tucci, 2014).
- Transportation and roadways restricted staff access to port facilities, while other personnel had evacuated or were dealing with personal issues that prevented them from reporting to work (Smythe, 2013).

Debris Removal/Environmental Cleanup

- Port traffic was closed for 3 to 5 days while underwater surveys were completed (Sturgis, Smythe, & Tucci, 2014).
- The USACE had significant damage to its waterfront facility at Caven Point, which supports its harbor survey and marine debris removal operations. The New York District fleet's drift collection vessels collected 40 percent of its annual target in the 3 weeks post-Hurricane Sandy (212,000 cubic feet of debris was collected compared to the annual 530,000 cubic feet) (Gardner, 2013).
- USACE contracted three tugs and 19 barges to speed transport of debris to permanent landfills (Army Corps employs barges to move storm-damage debris out of NYC, 2012).
- Oil storage tanks and piping at petroleum terminals were damaged, causing approximately 500,000 gallons of fuel oil to be released into the Arthur Kill waterway. The USCG Marine Transportation System-Recovery Unit was in charge of coordinating responders to avoid disturbing containment booms (Sturgis, Smythe, & Tucci, 2014).
- Sewage lift stations flooded, and sewage spilled into public and terminal areas and had to be removed before people could return to the port (Wakeman & Miller, 2013).

Transportation

- An estimated 4,500 commercial trucks and hundreds of railcars were destroyed (Sturgis, Smythe, & Tucci, 2014).
- Without power at the Nuclear Detection Portals, terminal gates could not operate and trucks could not return to terminals or remove containers (Wakeman & Miller, 2013).

Findings

A storm surge of 4 to 5 feet from Hurricane Sandy inundated the New Jersey Marine Terminal facilities at Port Elizabeth, Port Newark, Port Jersey North, Port Jersey South, and the Auto Marine Terminal. Tidal surge flooded buildings and equipment, dislodged and damaged equipment and infrastructure, and caused power outages. Emergency protective measures that were taken include storm preparations, securing and protecting equipment and facilities, moving vehicles to higher ground, emergency power generation, conducting safety inspections, emergency clean up and recovery, and providing additional security. Overall, emergency protective measures cost $344,000 for 2,476 hours of overtime, contractors, materials, equipment, and direct administrative costs. The emergency protective measures cost also includes temporary repairs to the Port Newark Warehouse, which were necessary to make the facility safe for the tenants and to reduce the possibility of further damage until permanent repairs could be completed.

The building housing the Maintenance Department and the Port Authority Police Department at Port Newark was flooded with 3 to 4 feet of water. Temporary trailers were used onsite for 3 months until the facility was restored. Removal of a flooded trailer (16 cubic yards) cost $600. At Port Jersey South, storm surge flooding severely damaged the building occupied by the Resident Engineer Office, which is responsible for essential functions related to protecting and preserving property and public health and safety. Temporary modular office units were installed, operated, and removed. The cost for the temporary facilities at Port Newark and Port Jersey was $205,000.

The New York Marine Terminal facilities at Brooklyn Piers, Red Hook Container Terminal, and Howland Hook/Port Ivory were also inundated by a storm surge of 4 to 5 feet. The tidal surge flooded buildings and caused power outages that dislodged and damaged equipment and infrastructure, creating hazardous conditions. Emergency protective measures that were taken include storm preparations, securing and protecting equipment and facilities, moving vehicles to higher ground, emergency power generation, emergency clean up and recovery (including oil spills), Port Authority Police Department water search and rescue operations, making temporary repairs, and installing protective fencing. Overall, emergency protective measures cost about $3,161,000 for contractors, 932 hours of overtime, materials, rented equipment, and direct administrative costs. Strong winds and heavy rain from Hurricane Sandy scattered 6,479 cubic yards of mixed debris throughout Howland Hook Marine Terminal on Staten Island, which cost $663,000 to remove. The New York Marine Terminal Administration Office facilities were flooded and temporary facilities were needed. The temporary facilities cost $53,000.

A summary of the data that were available for the New Jersey Marine Terminal facilities and New York Marine Terminal facilities is provided in **Table 6-7**.

Table 6-7: Summary of Emergency Costs for New York and New Jersey Terminal Facilities[5]

Description	NJMT	NYMT
Emergency Protective Measures	$344,000	$3,162,000
Debris Removal	$600	$663,000
Temporary Facilities	$205,000	$53,000
Total	**$549,600**	**$3,878,000**

Note: NJMT = New Jersey Marine Terminal facilities
NYMT = New York Marine Terminal facilities

[5] The data shown are taken from project worksheets drafted between December 2012 and November 2013. The figures shown are estimates. Determination of actual costs is in progress and pending review. Disclaimer: Figures shown will change based on pending coordination between PANYNJ and FEMA.

The Greenville Yard is a dedicated barge-to-rail transfer facility. This facility is used to transfer train railcars onto and off of specially equipped rail barges called car floats for transport across the Hudson River between New Jersey and New York City. Greenville Yard has a railcar float operation between Jersey City, NJ, and Brooklyn, NY, that moves 1,500 railcars a year. The Greenville Yard is under a Federal mandate to operate this facility. Storm surge, high winds, and a runaway construction work barge impacted the existing wood and steel rail-to-barge loading bridges and demolished them. The runaway construction work barge damaged all lift bridges and operating equipment and put the entire facility out of operation. To maintain the continuity of operations, two barges were relocated and partially site adapted to the Greenville Yard. Additionally, two steel pontoons were relocated to hold the cantilevered end of a relocated steel pontoon bridge. The temporary bridge cost $2,459,000 and is being used to continue operations until a permanent two-lift bridge facility can be constructed.

The severe flooding from Hurricane Sandy storm surge and heavy rains damaged Greenville Yard office trailers, a crew trailer, and tool containers beyond repair. Temporary facilities were leased for $25,000 until permanent trailers could be installed. It cost $206,000 to remove an estimated 2,779 tons of mixed debris that was deposited throughout the Greenville Yard from the storm surge. The flood waters inundated the electrical utilities, including recently installed electrical and communication controls that served the entire rail-to-barge facility. The electrical equipment had to be removed because of operational safety concerns caused by the storm. Temporary electrical repairs and temporary equipment was installed at a cost of $293,000. The temporary electrical equipment will be decommissioned and removed once the permanent replacement for the demolished rail-to-barge facility is constructed and new electrical controls are installed. The total emergency costs for the Greenville Yard were $2,983,000. A summary of the Greenville Yard emergency costs is provided in **Table 6-8**.

Table 6-8: Summary of Greenville Yard Emergency Costs[6]

Description	Cost
Temporary Pontoon Bridge	$2,459,000
Temporary Electrical Repairs	$293,000
Debris Removal	$206,000
Temporary Facilities	$25,000
Total	**$2,983,000**

An emergency service professional from the port industry was interviewed and provided the following information. Measures taken to prevent flood damage included placing sandbags around substation and low lying building entrances; moving trucks, machinery, and trailers to

[6] The data shown are taken from project worksheets drafted between December 2012 and November 2013. The figures shown are estimates. Determination of actual costs is in progress and pending review. Disclaimer: Figures shown will change based on pending coordination between PANYNJ and FEMA.

higher ground; surrounding outlying buildings with containers to shield from wind and debris; tightening up container piles; and removing crane motors. Damage begins to occur between 1 and 4 feet of flooding. If these critical flood depths are exceeded, a port would close from an estimated 2 to 7 days (most likely 4 days) after the storm as a result of flooding. After Hurricane Sandy, the Port of New York and New Jersey would have been operational 3 days after the storm if it wasn't for the loss of electricity. Descriptions of impacts to ports associated with different levels of flooding are presented in **Table 6-9.**

Table 6-9: Significant Impacts to Ports

Significant Impact Description	Critical Depth of Flooding in Feet	Damages Expected at or Beyond Critical Depths of Flooding
Electrical Infrastructure	1 Feet	Varies greatly. Crane motors will have to be re-spun; substations all impacted. Possible replacement required of underground cabling that was submerged. Rail switching stations, refrigerated warehouse coolers, and other electrical components exposed to salt water.
Trucks and Container Handling Equipment	2 Feet	Forklifts and other low-profile equipment will be totaled. All tires and brakes will need to be pulled and reconditioned. Trucks will be totaled if any of the electrical components were exposed to water. Container handling equipment will be a complete loss.
Buildings/furniture/ computers	1 Foot	Remediation of all mold/water to ensure buildings are safe to return to once repaired. Replacement of flooring and sheetrock as well as some electrical components. Furniture replacement if precautions not taken to relocate to a location not susceptible to flooding. Trailers used regularly for housing on facilities may be total losses.
Containers/Cargo	6 inches	Standard pallet height is 5 to 7 inches. Water higher than this will result in cargo damage. Containers are not meant for submersion. Most cargo exposed to floodwater will be deemed a total loss.
Storeroom/Spares/Tools	6 inches	All spares stored on bottom shelf will be totaled. Any machinery or electrical tools on bottom shelf or floor (i.e., arc welders) will also be total losses. Paper records in bottom drawers may be saved at a large cost.

Source: Port Emergency Service Professional

Emergency costs associated with ports include additional operating costs a port would experience because of a flood event (e.g., flood fighting activities). Calculated costs would be based on any additional actions taken by a port when flooding occurs and the expected length of time these actions would be necessary. **Table 6-10** presents the estimated costs of temporary actions used to restore service (not including permanent repairs). These are general estimates for future flood events that could be applied to any port in the study area.

Table 6-10: Estimated Cost of Temporary Actions to Restore Service at Ports

Description	Min	Most Likely	Max
Fuel & Surcharges	$10K	$25K	$50K
Cleaning Buildings/Restacking Containers	$700K	$1M	$1.2M
Crane/Equipment Repair	$65K	$250K	$350K
Facility Maintenance	$50K	$150K	$300K

Source: Port Emergency Service Professional

The most important factors affecting extent of flood damage are the location and design of the ports. For example, NYCT is built on a natural grade. The administrative building is higher in the yard than the area by the pier. The port was flooded from the pier face and also the surrounding rivers. Conversely, Conley Terminal in Boston is located in a relatively sheltered harbor and the smaller buildings are elevated. Global Container Terminals proved vulnerable because of its location on a peninsula. RoRo (roll-on/roll-off) terminals have much less infrastructure (e.g., buildings, cranes, electric wiring) than the other ports in the study area, but they also are less able to move as many cars prior to the arrival of a storm.

The emergency service professional from the port industry estimated emergency costs for each port to be about 5 to 10 percent of the total damages each port claimed from Hurricane Sandy. The infrastructure damage sustained is estimated between $34 and $52 million in capital costs, plus an additional $5.1 million in operating costs and $1.2 million in lost revenue from port operations (HUD, 2013).

Although direct damage costs and emergency costs were available for ports affected by Hurricane Sandy, the specific depth of flooding associated with these costs was not available. Depth of flooding associated with emergency costs and direct damage costs is essential for applying these costs in future planning studies.

6.6 Airports

Airports are economic engines for their regions and play a strategic role in economic development of local communities. Benefits of airports can be attributed to direct and indirect impacts. Direct impacts are economic activities carried out at airports that are directly involved in aviation. Indirect impacts are economic activities generated by non-airport businesses, such as hotels, travel agencies, or restaurants.

Airports and Hurricane Sandy

John F. Kennedy, LaGuardia, and Newark airports (see **Figure 6-3**) were all closed during and the day after the Hurricane Sandy, but opened within 2 days of the storm. About 20,000 flights were cancelled as a result of flooding, power outages, and other storm-related problems at these airports and the Philadelphia, Washington D.C., and Boston airports as well. The cancellation of flights east also backed up operations at major hubs, such as Denver, San Francisco, Detroit, Chicago, Atlanta, and Dallas airports (Forbes, 2012). LaGuardia had extensive damage from the storm.

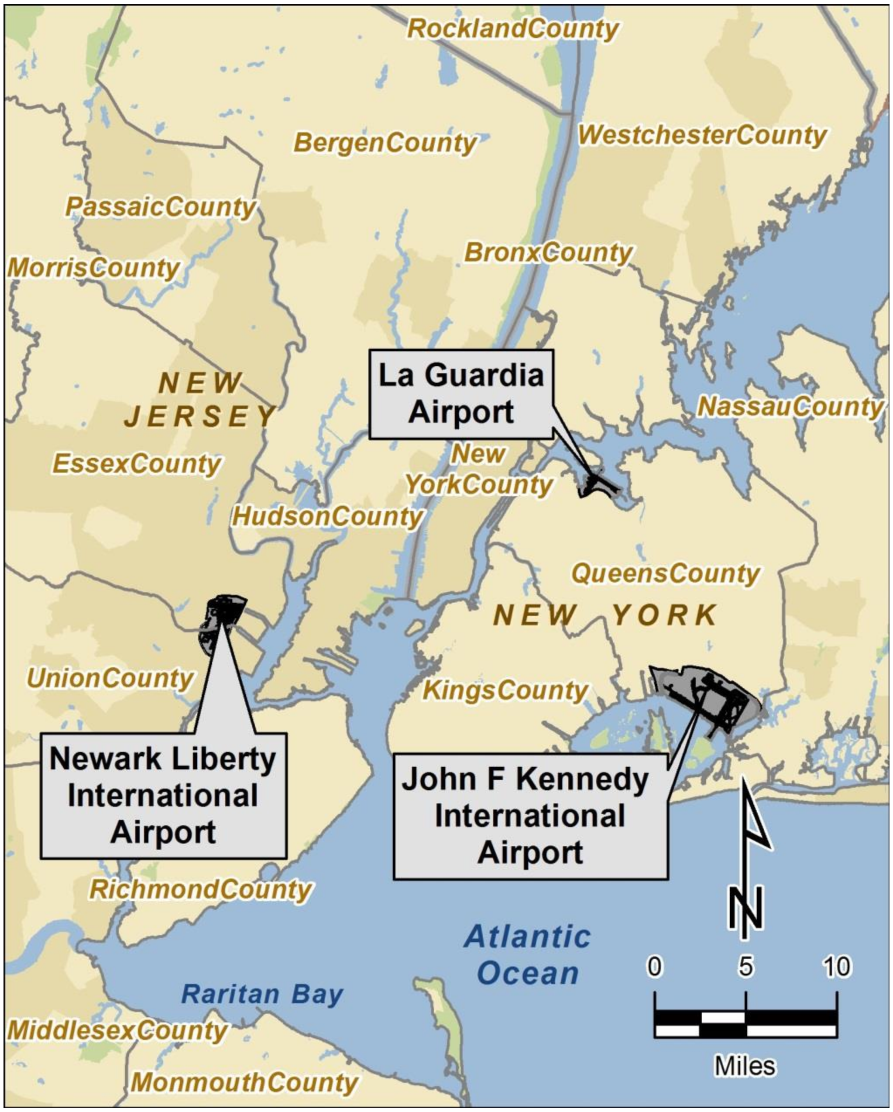


Figure 6-3: Location of Major Airports near New York City

Findings

An airport professional submitted some information from a flood damage assessment that was completed for the New York City Climate Change Adaptation Task Force. Repair and replacement costs were estimated, but emergency costs were not included. Emergency measures were identified, but the costs associated with these measures were not provided.

Table 6-11 summarizes the repair and replacement costs for LaGuardia Airport. Because these costs do not include all emergency costs, they could not be compared with the costs estimated in the USACE Sacramento District study and MVD Report.

Table 6-11: Estimated Repair and Replacement Costs for Airports

Category	1 foot of Salt Water Flooding	2.5 feet of Salt Water Flooding	4 feet of Salt Water Flooding
Total cost per airport	$15,590,000	$29,565,000	$48,785,000

At the John F. Kennedy Airport, storm surge from Hurricane Sandy flooded the south and east perimeter of the airport. The storm surge also backed up the storm drain outfalls, flooding some interior areas of the airport. The cut and cover tunnel flooded, perimeter security fencing was destroyed, security monitoring systems were damaged, buildings flooded, power and lighting systems were damaged, roadways flooded, signs blew down, doors and windows were damaged, and passengers were stranded. Emergency protective measures were implemented, such as moving and securing equipment and vehicles to safer locations, sandbagging, securing active construction sites and equipment, and making temporary repairs. Temporary repairs were made to security fencing, power and lighting systems, traffic lights, signs signals, damaged doors and windows, roofing, parking lot gates, and controllers. These emergency protective measures cost $875,000, which was mostly for contractors, overtime, and Port Authority Police service, but also for materials, equipment, and direct administrative costs.

Strong winds, heavy rains, and storm surge brought in an estimated 3,800 cubic yards of mixed debris throughout the John F. Kennedy Airport property. The total cost for debris removal was $348,000 for overtime, equipment, dumpsters, and direct administrative costs. Tidal surge of 4 to 5 feet flooded runways and taxi ways, causing damage to signal and lighting systems. The signal circuits and lighting that were damaged by saltwater had to be repaired temporarily to restore and sustain safe flight operations. These temporary repairs cost $466,000, mostly for materials, but also for overtime and direct administrative costs.

A 12-foot peak storm surge combined with peak tide in Flushing Bay flooded the LaGuardia Airport runway and associated taxiways. The depth of flooding varied on the airfield with a maximum depth of about 6 feet. Emergency protective measures were instituted, including sandbagging to protect critical facilities, assisting stranded passengers, providing additional security personnel, and dewatering the airfield. These emergency protective measures totaled $790,000, mostly for contractors, overtime, and Port Authority Police service, but also for materials and direct administrative costs.

Hurricane Sandy storm surge caused floodwaters from Newark Bay to back up in the Newark Liberty International Airport Peripheral Canal, overtopping its banks near the City of Newark

Pump Station and causing flooding of some of the airport facilities. Emergency protective measures were implemented prior to the storm, during the storm, and after the storm. Emergency repairs (included as emergency protective measures) were performed to protect the health and safety of the public and to reduce the threat of significant damage to improved property. Emergency protective measures included sandbagging and storm preparations, constructing a temporary berm, erecting a perimeter fence, performing soil erosion temporary repair, dewatering Hotel Road Overpass area, relocating vehicles to higher elevations and securing equipment, establishing and operating an Emergency Command Center to respond to conditions as they developed, and providing increased security and supplemental staffing. Of the $672,000 cost for emergency protective measures, most was for contractors and overtime, but also for materials, treatment of a sewage contaminated area, equipment, and direct administrative costs. Additionally, $15,000 was spent removing 441 cubic yards of vegetative debris (about $34 per cubic yard).

Hurricane Sandy caused flooding and power outages at Teterboro Airport. To protect the health and safety of personnel and passengers, to protect airport buildings and equipment, and to maintain continuity of airport operations, emergency protective measures were taken. These measures included establishing and operating an Emergency Operations Center, sandbagging low-lying buildings, moving vehicles to higher ground, securing equipment, instituting a 24-hour fire watch during the period that the fire alarm control was not operational, renting generators, and performing a temporary repair of an electrical transformer that was needed to maintain the operational status of the airport. These measures cost $45,000, more than half was for the fire watch at the hangars, but the cost also covers overtime, generator rentals, and temporary electrical transformer repair. In addition, $8,000 was spent to remove 124 cubic yards of mixed debris that was deposited throughout Teterboro Airport (about $65 per cubic yard).

At Stewart International Airport, Hurricane Sandy caused flooding in basements at various facility-wide locations and power outages. Downed trees and telephone poles blocked roads around the airport. To ensure public safety and maintain continuity of airport operations, emergency protective measures were taken, including utilizing generators and sump pumps to dewater basements, and providing traffic detours and lighting for blocked roads. Contractors and overtime accounted for half of the total cost of the emergency preventative measures. The cost also covered materials, lodging for laborers, and equipment.

A summary of the emergency costs for the John F. Kennedy Airport, LaGuardia Airport, Newark Airport, Teterboro Airport, and Stewart Airport is provided in **Table 6-12**.

Table 6-12: Summary of Emergency Costs for Airports[7]

Airport	Emergency Protective Measures	Debris Removal	Repairs	Total
John F. Kennedy Airport	$875,000	$348,000	$466,000	$1,689,000
LaGuardia Airport	$790,000	-	-	$790,000
Newark Airport	$672,000	$15,000	-	$689,000
Teterboro Airport	$45,000	$8,000	-	$53,000
Stewart Airport	$12,000	-	-	$12,000

Although direct damage costs were available for airports affected by Hurricane Sandy, the specific depth of flooding associated with these costs was not available. Depth of flooding associated with emergency costs and direct damage costs is essential for applying these costs in future planning studies.

6.7 Land-Based Pipelines and Petroleum Wells

Land-based pipelines are vital for energy flow. Pipelines carry needed energy resources, such as oil and natural gas, to different regional areas, and any disruption in pipelines affects the supply of energy to those areas, thereby increasing energy prices throughout the country (General Electric, 2009).

The New York Metro area is the largest liquid fuels hub on the East Coast with product supplied by regional refineries, pipelines to Gulf Coast refineries, and marine tankers bringing product from global refineries. Pipelines provide between 35 and 40 percent of New York City's petroleum supply (NYC, 2013a). In order for pipelines to move these products continuously, a steady supply is necessary to push forward what is already in the pipeline, as well as electric power to run the pumps that move the product along (Hurricane Response and Market Effect, 2014).

Land-Based Pipelines and Hurricane Sandy

The Colonial pipeline (see **Figure 6-4)** is the major conduit from the Gulf Coast to the primary hub in Linden, NJ, with a maximum capacity of 37 million gallons a day (NYC, 2013a). The Buckeye pipeline then delivers fuel from the Colonial pipeline and regional refineries and terminals to New York City and Long Island terminals, as well as regional airports (NYC, 2013a). Preparedness efforts for pipelines are heavily dictated by the surrounding supply chain infrastructure. In anticipation of Hurricane Sandy, refineries and terminals significantly curbed or all together halted operations. From a pipeline perspective, this necessitates lowering

[7] The data shown are taken from project worksheets drafted between December 2012 and November 2013. The figures shown are estimates. Determination of actual costs is in progress and pending review. Disclaimer: Figures shown will change based on pending coordination between PANYNJ and FEMA.

throughput on the pipeline to prevent a backup and line burst. Throughput on pipelines is maintained by pumping stations running off of electricity. Mitigation for these stations involves securing and refueling backup generators.

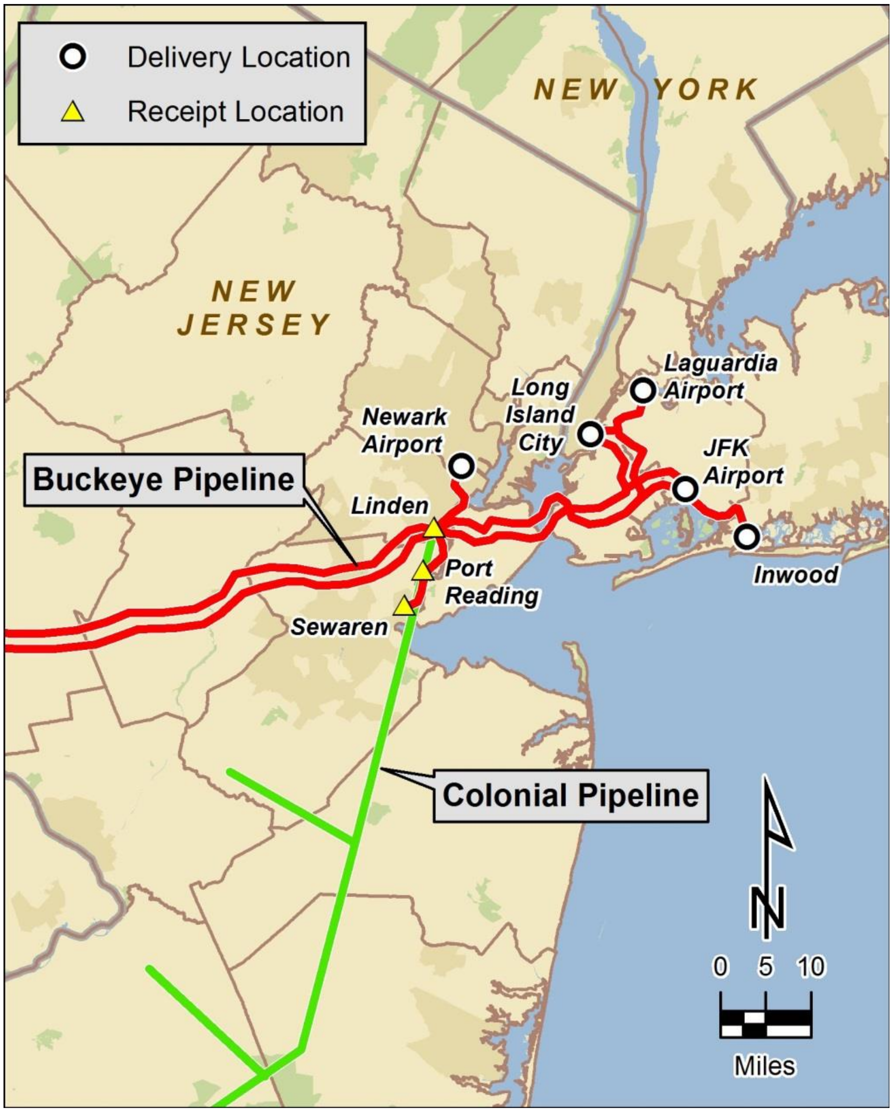


Figure 6-4: Location of Major Pipelines near New York City

Following Hurricane Sandy, both the Colonial and Buckeye pipelines had no direct damage but were impacted by power loss and damage to refineries and terminals. Power outages affected pumping stations, refineries, and terminals, and generators were deployed to alleviate these issues. Even after commercial power had been restored, Colonial pipeline and several terminals continued to lose power as utilities struggled to repair power infrastructure (US Energy Information Administration, 2012). Power issues were severely compounded by impacts from damages to refineries and terminals. The flow of fuel through the Colonial and Buckeye pipelines did not reach pre-storm levels for several days because of bottlenecks at their terminals (NYC, 2013a). Terminals could not return to functional operations until after dock inspections and underwater surveys had been completed and generators were delivered to provide power. Specifically, the outage of the Linden terminal of the Colonial pipeline for 5 days seriously impeded product throughput (Office of Electricity Delivery and Energy Reliability, 2013). **Figures 6-5, 6-6, and 6-7** provide the operational status of refineries and terminals following Hurricane Sandy.

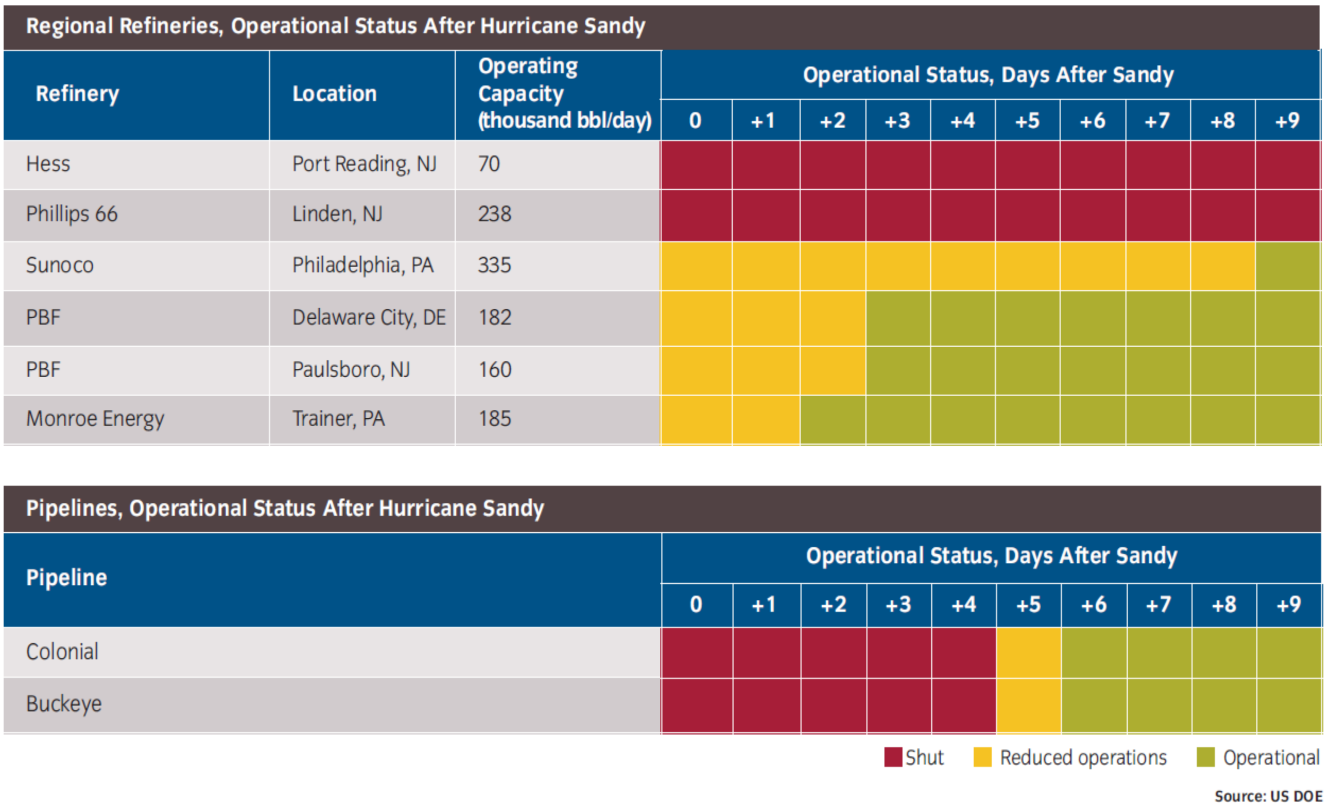


Figure 6-5: Operational Status of Refineries and Terminals (Source: NYC, 2013a)

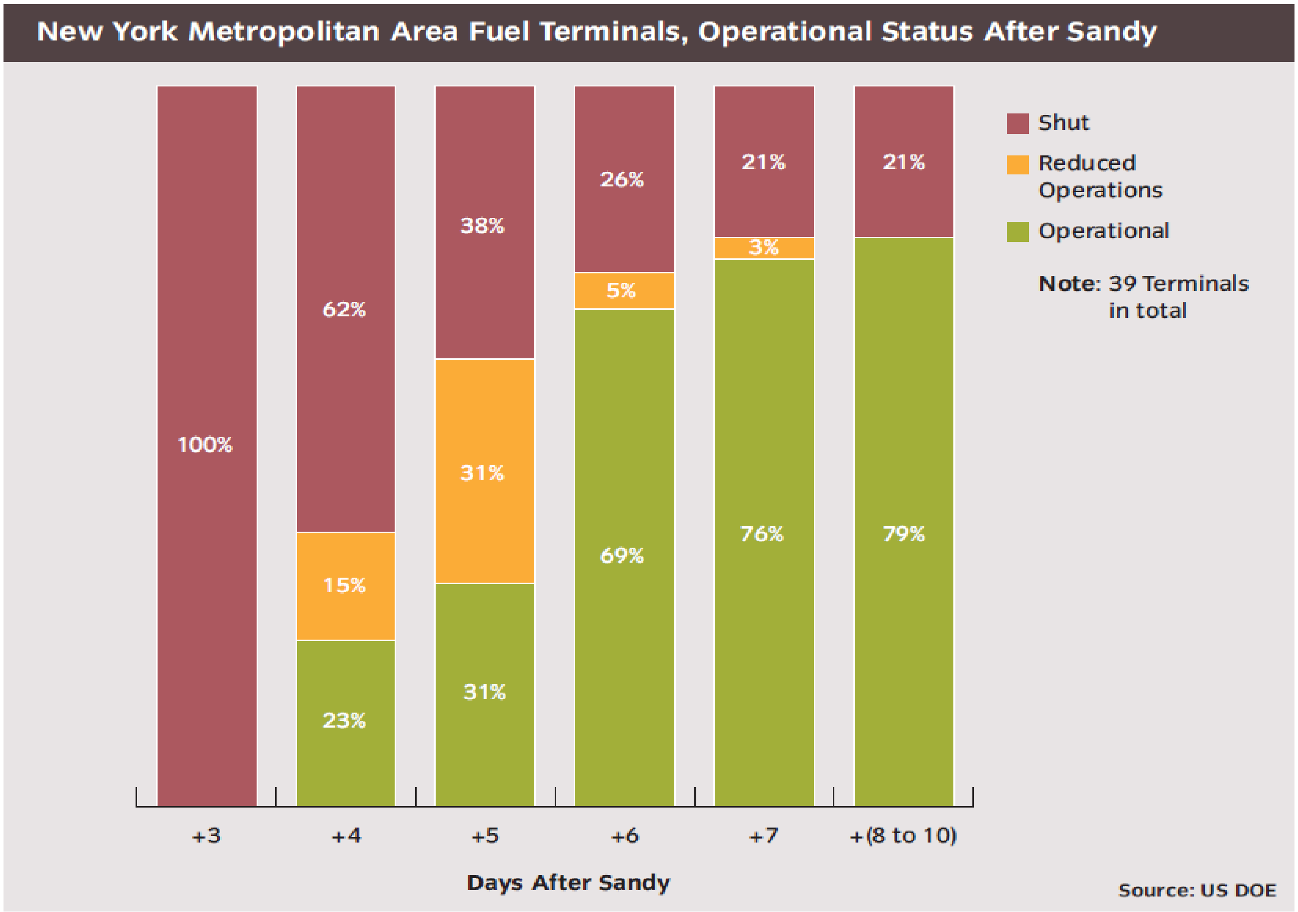


Figure 6-6: Operational Status of New York Metropolitan Area Fuel Terminals (Source: NYC, 2013a)

Summary of Product Flows

	Receipts (Inflows)			Deliveries (Outflows)		
	Pre-Storm	Post-Storm Nov. 7-13 Average	Post-Storm Percent of Pre-Storm	Pre-Storm	Post-Storm Nov. 7-13 Average	Post-Storm Percent of Pre-Storm
Gasoline	941	597	63%	838	605	72%
Distillate	281	184	65%	317	176	56%
Other (Jet, Ethanol)	197	136	69%	192	38	20%
Total	1,419	917	65%	1,347	819	61%

Summary of Flows by Transportation Mode

	Receipts (Inflows)			Deliveries (Outflows)		
	Pre-Storm	Post-Storm Nov. 7-13 Average	Post-Storm Percent of Pre-Storm	Pre-Storm	Post-Storm Nov. 7-13 Average	Post-Storm Percent of Pre-Storm
Tanker/Barge	523	307	59%	563	253	45%
Pipeline	753	573	76%	346	179	52%
Truck	12	7	58%	438	387	88%
Other	131	31	24%	-	-	0%
Total	1,419	918	65%	1,347	819	61%

Note: Thousands of barrels per day except as noted

Figure 6-7: Summary of Product Flows and Flows by Transportation Mode[8]

Flooding from Hurricane Sandy damaged much of the petroleum product supply and delivery systems around the New York Harbor area, including both of the refineries in northern New Jersey and many of the terminals. The New York Harbor area is a major distribution hub for petroleum delivery to consumer markets in New England, New York, and New Jersey. With the terminals nonoperational, product supply into the region stopped. Some New York Harbor terminals were badly damaged, but others were able to return to full or partial operation within a month after the storm using generator power after dock inspections, underwater surveys, and electrical equipment was replaced (EIA, 2012).

Petroleum Wells and Hurricane Sandy

Days in advance of a tropical storm or hurricane moving toward drilling and production operations, petroleum and gas companies evaluate the situation and make decisions on preparedness efforts (Hurricane Response and Market Effect, 2014). Concerning petroleum and natural gas wells, the major mitigating measure is to shut-in wells via remote access. Remote shut-in capability for oil and gas wells are a safety feature whereby wells shut-in during an emergency do not continue to release oil and gas if piping or other equipment is damaged

[8] Source: EIA, 2012

(Lepore, 2014). Preparedness difficulties can be exacerbated by wells not capable of remote shut-in because remote locations are difficult to access under storm event conditions. Additionally, equipment and storage tanks often on site with wells must be securely anchored prior to flooding events or sufficiently elevated, as it is primarily loose equipment and debris that damage well heads causing spills. Prior to the Front Range flooding in Colorado in September 2013, the Colorado Oil and Gas Association oversaw private sector companies as they evacuated drill sites, removed onsite equipment, shut-in more than 1,900 wells, and setup emergency command centers (Schuller, 2014). Before Hurricane Sandy hit the Northeast region, natural gas company Spectra Energy Corporation shut in a compressor station and a meter station (Hurricane Sandy Causes Minimal Disruption in Marcellus, 2012). Other petroleum and natural gas sector private companies followed suit as applicable.

Much of the petroleum and natural gas well infrastructure in the Northeast is situated away from the coastline and not vulnerable to a storm surge event, such as Hurricane Sandy. As a result, Hurricane Sandy and the prolific storm surge that caused widespread flooding did not significantly impact petroleum and natural gas wells in the area. Chesapeake Energy indicated that there had been minimal impact on their drilling operations and that, prior to the storm, they had checked environmental controls (Marcellus Shale Producers Ensure Environmental, Worker Safety Throughout Hurricane Sandy, 2012).

Post-storm operations for petroleum companies normally involve inspections both on site and aerial helicopter surveys, geologic surveying to identifying any soil shifts, as well as cleanup from any spills that may have occurred. Much of the Hurricane Sandy response work involved monitoring wells for damage and well sites for possible soil shifts. Chevron indicated they were monitoring erosion controls at well sites because of continued rain and that, prior to landfall, they had drawn down water impoundments at natural gas hydraulic fracturing sites (Marcellus Shale Producers Ensure Environmental, Worker Safety Throughout Hurricane Sandy, 2012).

Much of the impact for the petroleum sector was felt in damaged terminals and refineries, as well as pipelines with lost power. Hurricane Sandy’s storm surge damaged port areas leading to refinery and terminal damages that significantly impacted the petroleum sector. Philadelphia refineries were not significantly affected; however, two northern New Jersey refineries were closed for extended periods and had shut down facilities prior to landfall, eliminating 35 to 40 percent of the region’s petroleum supply capacity (NYC, 2013a).

The disruption of refinery and pipeline operations led to the immediate loss of gasoline and diesel production. This shortage coupled with power outages at some gas stations resulted in long lines at gas stations. The U.S. Energy Information Administration (EIA) reported that two-thirds of New York metro area stations were without fuel on November 2 following the storm; EIA estimated that on November 9, 28 percent of stations still did not have gas for sale (EIA, 2012b). New York and New Jersey both implemented temporary gas rationing to discourage drivers from buying fuel out of panic and reduce lines. Sales were restricted to cars with even-numbered license plates on even days and odd-numbered license plates on odd days. Plates ending with a letter were treated as odd-numbered. New Jersey ended gas rationing on November 13 and New York ended gas rationing on November 24 following the storm.

No emergency costs or direct damages were available for the petroleum wells and land-based pipelines affected by Hurricane Sandy. Damage to the physical infrastructure could be measured according to the distance or length of the pipeline and the associated depth of flooding. The depreciated value of the pipelines and petroleum wells should also be considered when estimating the direct damage cost. Emergency costs are the additional operating costs incurred as a result of flooding (e.g., flood fighting activities). These costs may include overtime and other preventative activities to avoid damage. The additional daily operational costs would be multiplied by the number of days that the additional operating costs would be experienced before and following a flood event.

6.8 Estimating Emergency Costs for Infrastructure

Flood inundation may damage infrastructure and generate economic losses. Infrastructure categories include subway lines, streets, roads and highways, bridges, railroads, ports, airports, land-based pipelines, and petroleum wells.

Analyzed flood-event-related economic losses associated with infrastructure stem from two common loss types:

- Labor Diversion (routine-related)
- Capital Use (routine-related)

No subtype losses were analyzed for this category.

Specific *ceteris paribus* assumptions for this category are that the infrastructure have already been built to completion, are in a stage of depreciation, and that all emergency flood costs can be associated per a certain amount of miles (i.e., per mile of roadway, subway line, railway line) or per infrastructure type (i.e., per airport, per port, per bridge, per petroleum well).

The diagram in **Figure 6-8** outlines the calculation of expected flood emergency costs per a distance specific to each type of infrastructure. Economic loss categories include damage to physical infrastructure and direct industry losses. Damage to physical infrastructure includes costs generated by flood damage to infrastructure components. Each damaged component incurs labor and capital costs. A reference distance or length specific to the infrastructure type would be used to assess component costs at different depths of flooding. Depreciated capital costs should also be considered. All costs must be associated with a specific level of flooding. If possible, at least three levels of flooding or more should be used for each emergency cost.

Direct industry losses are additional operating costs that the infrastructure industry would experience because of a flood event. Emergency costs would be calculated by multiplying the cost of anticipated additional actions taken by the infrastructure industry when flooding occurs by the expected length of time that actions would be necessary. These costs may be assessed based on a reference distance or length specific to the infrastructure type. These emergency costs can be aggregated into a single flood emergency cost per a distance specified or infrastructure type to facilitate further flood analyses.

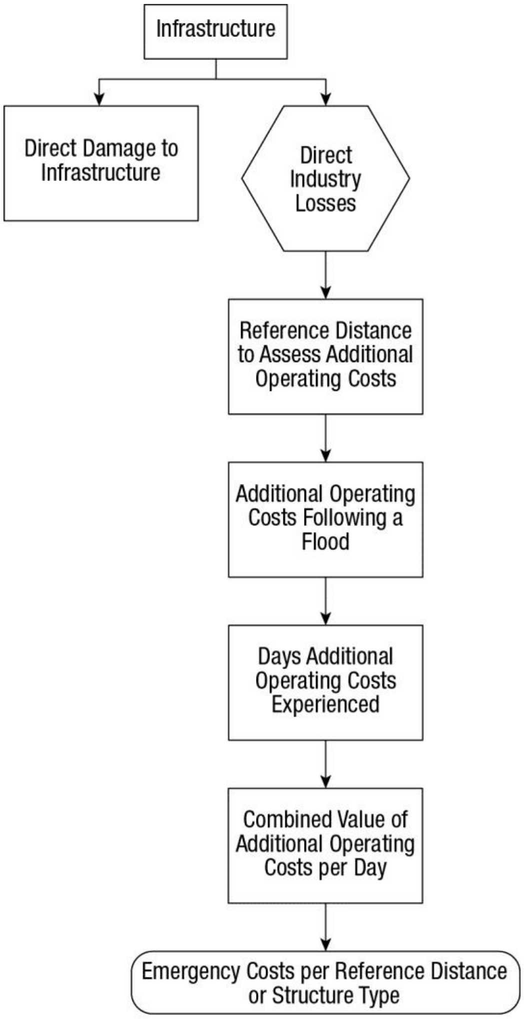


Figure 6-8: Infrastructure Emergency Costs Diagram

Flooding can temporarily hinder transportation in an inundated area. For New York City, the temporary loss of the public transportation system along with detours in place for roads and bridges that were flooded, damaged, or covered with debris contributed to gridlock on the roads that were open. Traffic rerouting costs associated with closed roads and bridges would be based on the additional operating cost for each vehicle (including depreciation, maintenance, and gasoline) per mile of detour and the traffic delay cost per passenger. These costs may be included in an NED analysis and would be calculated separate from the emergency costs associated with streets, roads, highways, and bridges. USACE provides guidance for estimating transportation costs in Appendix D of Engineer Regulation 1105-2-100 (USACE, 2000).

7 Group 5: Public Services Patronized

This section discusses losses associated with four public services patronized categories analyzed in this study, including daycares and schools; public agencies, libraries, and indoor recreation; hospitals; and eldercare facilities. At the end of this section, the method for estimating emergency costs for this group for future studies is described.

7.1 Daycares and Schools

Primary, secondary, and university school facilities could close for days, weeks, or months if a flood occurred, depending on degree of required cleanup and repairs. Whether a specific school or facility would be affected, and to what degree, would depend on the type of services it provides to the public. If a flooded school or facility would not be available to provide education or childcare services, alternatives may be needed.

Daycares and Schools and Hurricane Sandy

A professional with childcare expertise was interviewed and was able to offer a better understanding of how childcare facilities and families requiring childcare were affected by Hurricane Sandy.

In Nassau County, there are 979 regulated childcare programs, only a few of the 209 center-based programs and 121 school-aged programs were impacted by Hurricane Sandy. For home childcare facilities, 123 are home-based with 6 to 8 kids and 526 are group family childcare (meaning they are home-based with additional staff) with 8 to 36 kids. The in-home daycare providers were the hardest hit by Hurricane Sandy and these types of providers usually care for children under the age of 5 years old.

For about 3 months after Hurricane Sandy, families needed assistance finding childcare. All childcare facilities had to be inspected and deemed safe before they could resume childcare service. If any mold was found, the facility was completely shut down for remediation. If programs had excess licensed capacity after Hurricane Sandy, they added kids that didn’t have a place to go but they didn’t usually accept additional staff. School-based programs were closed for months after Hurricane Sandy, so those programs typically relocated to another facility. After Hurricane Sandy, lost service days varied from a week to 10 months.

Most childcare facilities are leased, not owned, so they are not in a position to implement measures to avoid flood damage. Childcare providers in leased facilities are more likely to either relocate after significant flooding or close completely.

Emergency costs associated with daycares and schools include costs associated with loss of service and additional operating costs incurred by the facility. Loss of service comprises the daily cost of substitute service and the daily cost of other temporary actions used to restore service. Additional operating costs for the facility may include overtime, costs associated with evacuation or transferring students to another facility, and costs associated with a temporary location. These daily costs would be multiplied by the average number of days a loss of service or additional operating costs would occur for each depth of flooding. Costs associated with direct damage to the facility would also be collected when possible. Care should be taken to ensure that direct damage costs are not already included in the structure inventory for the study (e.g., home daycares may already be accounted for as residential structures).

7.2 Public Agencies, Libraries, and Indoor Recreation

Public agencies include all local, State, and Federal agencies located in the study area, except agencies that are specific to another emergency cost category. During and immediately following a flood, services from public agencies that are not critical would likely be temporarily suspended in an inundated area.

During a flood, library services in an inundated area would likely become unavailable. After floodwater has receded, the timing for reestablishing library services would largely depend on the extent of damage to library structures and materials and to the area where they are located. Depending on the location of libraries relative to an inundated area, some of these services may be lost entirely as a result of power loss, blocked access routes, and displaced staff.

Indoor recreation services refer to not-for-profit community indoor recreation facilities supported by public taxes and serving all residents of a specific area. These types of facilities serve the public's general recreation needs and may provide some or all of the following activities: indoor sports (basketball, volleyball, swimming), cultural events (concerts, plays), public meetings, banquets, dance (instruction or dances), and youth activities. After a flood event, some indoor recreation centers would be directly affected and forced to close, and others might be affected by staff absenteeism and may not have sufficient staff to deliver their services. During a flood, indoor recreation services in an inundated area would likely become unavailable.

Libraries and Hurricane Sandy

A library professional was interviewed and was able to offer a better understanding of how libraries were affected by Hurricane Sandy.

Libraries include facilities with State archives, public libraries, museums, and any other facility with archives and collections. Public libraries can vary significantly from repurposed buildings to modern facilities designed as a library. Library buildings are typically multi-storied, Americans with Disabilities Act compliant, have public use rooms (sometimes the only public meeting place for smaller communities), and have basements that are used by the public; however, most are converting basement use for more replaceable items instead of collections. Libraries can be used in non-traditional ways (e.g., job searches) and can be located within historical societies and museums.

After Hurricane Sandy, book mobiles were used in place of libraries, which were under repair. Some libraries provided story time and movies for kids, offered a place to recharge electronics (areas with power outage), and provided assistance with public funding for disaster assistance.

Some facilities did not have power, were pumping water out of basements, or were inaccessible for a week or so because they needed structural engineers to evaluate the facility before entering. Security systems were down because of a lack of power. Flooding was only experienced for a few days in Nassau County but libraries were closed for weeks, if not months, because they required mold remediation. Salt water is very corrosive and created more damage than would a freshwater flood.

To avoid flood damage, libraries may relocate items that are not easily replaced from basements, back up electronic information off site, move collections before a flood event, and/or purchase electric generators. Most likely, more effort would be expended to save special collections than general library collections, which could be replaced (e.g., microfiche or microfilms are easily replaced). For typical library branches, less than 5 percent of the collections are high value, non-replaceable books. The Queens Research Center has valuable collections, but was not affected by Hurricane Sandy. Smaller libraries typically have insufficient staff to relocate materials prior to a flood event. Usually, libraries get more help after a flood event.

Following Hurricane Sandy, the libraries that were open played a significant support function for the community. Often these libraries were the only facility in the community that had electricity and was accessible to the public. The libraries supported the communities by:

- Providing a gathering place
- Offering current news and information on storm recovery efforts
- Providing assistance with public funding for disaster assistance
- Providing story time and movies for kids
- Offering a place to recharge electronics (in areas with power outage)

Emergency costs associated with public agencies, libraries, and indoor recreation facilities include costs associated with loss of service and additional operating costs incurred by the facility (e.g., flood fighting activities). Loss of service comprises the daily cost of substitute service (e.g., book mobiles) and the daily cost of other temporary actions used to restore service. Additional operating costs for the facility may include overtime, costs associated with a temporary location, or extended hours of operation. These daily costs would be multiplied by the average number of days a loss of service or additional operating costs would occur for each depth of flooding. Costs associated with direct damage to the facility would also be collected when possible.

7.3 Hospitals

Hospitals typically provide emergency services, general and specialty-based diagnosis and treatment services, screening, inpatient and outpatient services, pharmaceutical services, rehabilitation, a range of therapeutic treatments (e.g., physical, occupational, speech, psychological), corpse intake and processing, and many different health education and outreach programs. During and shortly after a major flood, the ability of a hospital to perform services would be degraded because personnel, equipment, facilities, and vehicles normally used to perform these services are redirected to immediate demands of emergency flood response. Depending on the location of medical facilities relative to the inundated area, some of these services may be lost entirely for some period of time. A Disaster Medical Assistance Team (DMAT) facility, which is a rapid-response facility, can be used to supplement local medical care during a disaster or other event.

For areas with limited or no inundation, most hospitals have backup systems to provide power and other essentials during an emergency. Many hospitals are multilevel structures that could allow patients to be moved to higher floors if lower floors were to flood. Significant loss of function and service would still be expected, particularly because emergency generators for the facilities are often on the ground floor. After floodwater recedes, the timing for reestablishing medical services would largely depend on the extent of damage to structures in which services are housed and areas in which they are located.

Hospitals and Hurricane Sandy

New York City Metropolitan area hospitals and medical facilities were severely impacted by Hurricane Sandy. Across New York City, five acute care hospitals and one psychiatric hospital closed. This resulted in the emergency evacuation of nearly 2,000 patients. Three hospitals closed in advance of the storm, New York Downtown (Manhattan) closed after notice of a potential pre-emptive utility shutdown, while the Veterans Affairs New York Harbor Hospital (Manhattan) and South Beach Psychiatric Center (Staten Island) closed as a result of concerns about flooding. Three other hospitals—New York University’s Langone Medical Center (Manhattan), Bellevue Hospital (Manhattan), and Coney Island Hospital (Brooklyn)—evacuated during or after Sandy because of the failure of multiple electrical and mechanical systems, including emergency power systems. In the immediate aftermath of Sandy, hospital bed capacity was down 8 percent citywide.

Despite power outages and/or limited flooding in basement areas, 10 hospitals remained open. In the week after the storm, Beth Israel in Manhattan—powered only by backup generators as a result of the area-wide power outage— saw a 13 percent increase in emergency room use.

New York City hospitals incurred an estimated $1 billion in costs associated with emergency response measures taken during and immediately after Hurricane Sandy, including the costs of staff overtime, patient evacuations, and emergency repairs of equipment. Damaged hospitals are projected to spend at least another $1 billion on repairs and mitigation. In addition, permanent revenue loss for hospitals citywide is estimated to have been nearly $70 million per week in the immediate aftermath of the storm.

Findings

Two hospital professionals were interviewed. These professionals represented hospitals that were significantly different in size so the emergency costs were not aggregated. Instead, emergency costs were calculated for hospitals that may be considered small (e.g., 150-bed capacity) and hospitals that may be considered large (e.g., 1,000-bed capacity).

Only the most likely values were provided for each flood depth. DMAT costs were not available. **Table 7-1** summarizes the emergency costs. If the hospital ceases operations entirely, all of the inpatients are assumed to be transported to another hospital. The costs for the small hospital decrease as flood depths increase because once all of the patients are transferred to another hospital, all operations at the small hospital would cease entirely, so the emergency costs are associated with evacuation and closure of the hospital. Therefore, for a small hospital, it appears to be more expensive to continue operations during a flood event than to close the hospital entirely, whereas for a large hospital, it may be less expensive to continue operations during a flood event than to transport all patients to another hospital.

Only the emergency costs estimated for a small hospital for Hurricane Sandy were comparable with the emergency costs estimated in the USACE Sacramento District study and the MVD Report. The emergency costs estimated for a large hospital and for the other depths of flooding for the small hospital were significantly higher than the other studies.

Table 7-1: Summary of Hospital Emergency Costs

Category	4 feet Less than Sandy	2 feet Less than Sandy	Hurricane Sandy
	Most Likely	Most Likely	Most Likely
Small Hospital (150 beds)			
Continue operations in current facility	$7,520	$3,760	$0
Add temp structures onsite	$75,200	$37,600	$0
Transport to another hospital	$0	$0	$0
Cease operations entirely	$0	$14,883	$29,767
Total Cost per Small Hospital	**$82,720**	**$56,243**	**$29,767**
Cost per bed	**$551**	**$375**	**$198**
Large Hospital (1,000 beds)			
Continue operations in current facility	$76,667	$0	$0
Add temp structures onsite	$0	$0	$0
Transport to another hospital	$0	$447,222	$447,222
Cease operations entirely	$0	$0	$0
Total Cost per Large Hospital	**$76,667**	**$447,222**	**$447,222**
Cost per bed	**$77**	**$447**	**$447**

Although direct damage costs and emergency costs were estimated for hospitals affected by Hurricane Sandy, the specific depth of flooding associated with these costs was not available.

Depth of flooding associated with emergency costs and direct damage costs is essential for applying these costs in future planning studies.

7.4 Eldercare

Eldercare facilities are often single-story structures and would likely require evacuation of patients for even shallow flooding. In the aftermath of a flood, an eldercare facility could close for days, weeks, or months while cleanup and repairs occur. The duration of this functional downtime would be determined by the extent of damage and by how facilities are prioritized for repair relative to other types of damaged structures and lost services. During downtime, those who use these services would probably seek substitutes. Depending on the severity of flooding, an affected eldercare facility could transfer residents to a host eldercare facility, an alternative sheltering facility, or to home or family care.

Transferring eldercare services with each of these actions may result in economic losses. Residents who are transferred to host and alternative facilities may incur additional above-normal costs to obtain the same service. Transferring services to family elder care would result in losses to the person(s) paying for such services. Losses would include an annual income decrease that a family would experience because of increased family elder care responsibilities. After floodwater recedes, the timing for reestablishing eldercare services would largely depend on the extent of damage to structures in which services are housed and to areas where the structures are located.

Eldercare and Hurricane Sandy

Hurricane Sandy’s impact on residential providers was also significant. Sixty-one nursing homes and adult care facilities were in areas impacted by power outages and/or flooding. Half of these providers continued to operate—some because they sustained minimal or no damage, others because they had effective emergency plans. But within a week of the storm, 26 facilities had to shut down, and another 5 partially evacuated, reducing citywide residential capacity by 4,600 beds and leading to the evacuation of 4,500 residents who had to be transported to other facilities or Special Medical Needs Shelters, which were staffed by personnel from the New York City Health and Hospitals Corporation and DMATs. These closures affected hospitals as well, preventing them from discharging patients to nursing homes, as they normally would have done. Instead, hospital beds that could have been available for new patients remained occupied by existing patients who had nowhere else to recover after treatment.

Findings

An eldercare professional was interviewed and was able to offer some information about how eldercare facilities and families requiring eldercare were affected by Hurricane Sandy.

For future flood events, the majority of the residents in skilled nursing facilities would need to be transferred to another skilled nursing facility if there was flood damage. In previous evacuations, residents were sent to stay with their families, which caused problems because residents need assistance with ambulating, feeding, bathing, dressing, grooming, and other medical needs. The cost to transport each resident would be about $80 on average. Ambulettes cost between $200 and $800 per trip, depending on patient acuity, and some residents could be transferred by a chartered bus. For Hurricane Sandy, the evacuation costs were over $25,000 for a skilled nursing facility that had a 278-bed capacity. Because these costs did not include all emergency costs for eldercare facilities, they could not be compared with the costs estimated in the USACE Sacramento District study and MVD Report.

The New York City Department for the Aging estimated that it spent $90,000 for overtime, compensation, and fringe benefits while providing services during and after Hurricane Sandy.

Although some emergency costs were provided for eldercare facilities affected by Hurricane Sandy, the specific depth of flooding associated with the costs was not available. Depth of flooding associated with emergency costs is essential for applying these costs in future planning studies.

7.5 Estimating Emergency Costs for Public Services Patronized

Public services patronized are services primarily provided by the government that usually require consumers to visit a location to obtain the service. In the public services patronized group, the following categories were analyzed: daycares, schools, public libraries, public agencies, indoor recreation facilities, hospitals, and eldercare.

Analyzed flood-event-related economic losses associated with public services patronized stem from two common loss types:

- Labor Diversion (routine-related)
- Capital Use (routine-related)

Associated subtype losses include the following:

- Travel Costs (routine-related)
- Temporary/Rental Structures (routine-related)

Specific *ceteris paribus* assumptions for this category are that the number of people that require the public services patronized in the area does not change, nor does demand for the public services patronized, and that lost service days are kept to the minimum of time necessary (no bureaucratic hindrances are expected).

The diagram in **Figure 7-1** outlines the calculation of expected flood emergency costs per average public services patronized facility. Economic losses for this group are derived primarily from estimated evacuation and relocation costs. Direct damage costs to these public service facilities would also be included when available. All costs must be associated with a specific level of flooding. If possible, at least three levels of flooding or more should be used for each emergency cost.

Set-up costs or transfer administrative costs and incremental daily operating expenses of each action are considered. Duration of repair and rehabilitation is the basis for applying daily emergency costs per facility. Additional daily operating expenses would be multiplied by the number of days the facility would be closed for repairs. The number of days of additional costs would be associated with the depth of flooding above first floor elevation for these types of public service facilities.

Evacuation of patients from hospitals and eldercare facilities or possibly children from schools and daycares may be required. These evacuation costs per person or another unit of measure (e.g., per 100 patients) would be multiplied by the average cost to transport these people to another location, using the same unit of measurement. Set-up costs or transfer administrative costs would be added to this cost to arrive at the total evacuation cost per facility.

GIS would be needed to locate these types of public service facilities and assign elevation levels in order to calculate the associated emergency costs. Evacuation and relocation costs that would occur with or without a flood risk management project would not be considered an NED benefit.

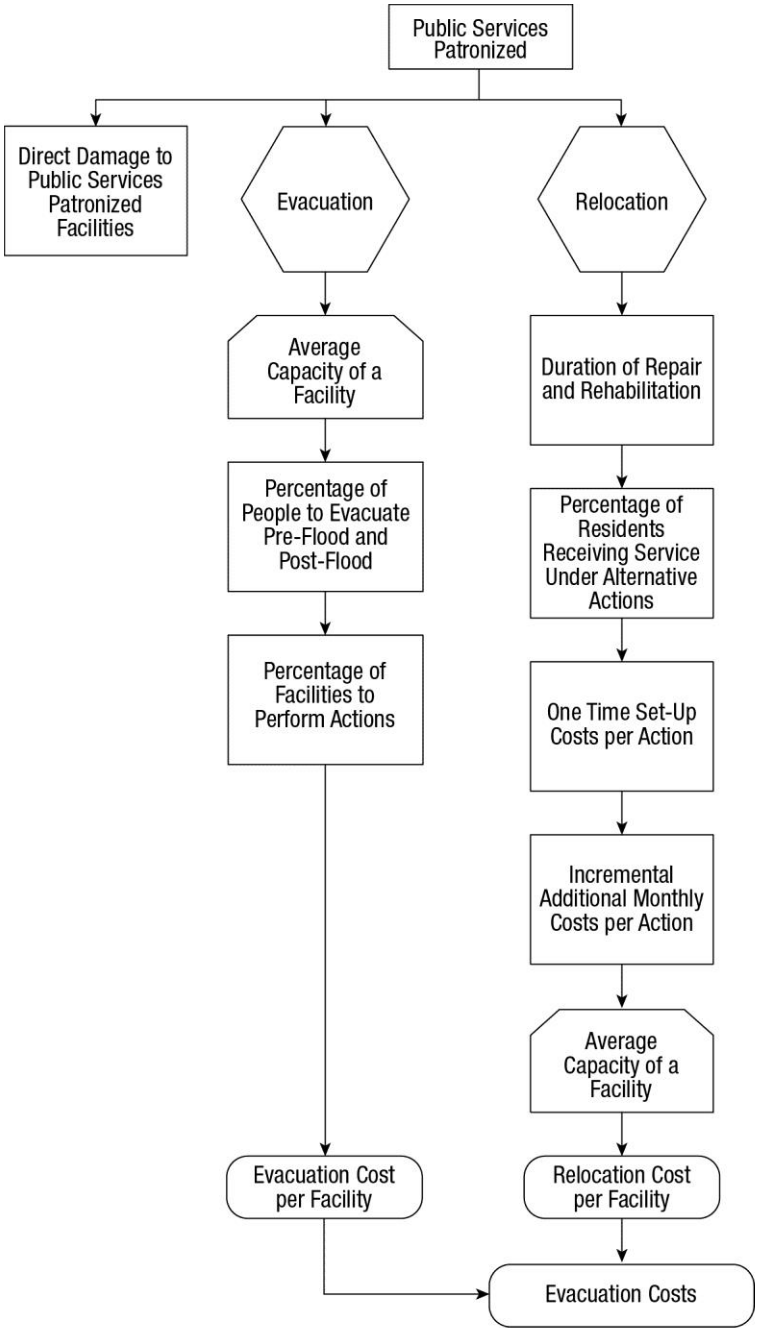


Figure 7-1: Public Services Patronized Emergency Cost Diagram

8 Group 6: Public Services Produced

This section discusses losses associated with five public services produced categories analyzed in this study: police, fire, jail, government judicial, and government legislative. At the end of this section, the method for estimating emergency costs for this group for future studies is described.

8.1 Police

During and after a major flood, almost all police services and resources would be redirected to the immediate demands of emergency flood response. Police officers would perform a number of services, including search and rescue, flood fighting, road closures, traffic and crowd control, and prevention of widespread panic and looting. There would be significant amounts of overtime and call-in hours to perform these duties. During a flood, routine-related and flood-related police costs would typically increase. If a police station flooded, all of its routine costs would also change.

Police and Hurricane Sandy

Police command and response personnel were organized before Hurricane Sandy made landfall and remained on duty both during and after the storm. Extra officers and dispatchers were brought in prior to the storm to ensure adequate personnel were available if needed. Police officers were expected to be on call and work extended shifts. The Summit Police Department was advised to be prepared to bunk at the headquarters (City of Summit, 2012).

During Hurricane Sandy, police performed search and rescue operations for residents in inundated areas and assisted with evacuations. After the storm, police combatted looting and break-ins and assisted residents that were still present in areas hit by the storm. The New York City Police Department (NYPD) was critical for enforcing temporary transportation regulations throughout the city, such as the HOV3 rule and gas rationing. Police officers were stationed at every gas station in the city to prevent fighting and regulate orderly lines (Kaleem and Kavner, 2012).

Some police stations in New York and New Jersey lost electric service. Most stations had emergency generators designed to provide power for full functionality during power outages. At stations where emergency power was not available or generators failed as a result of inundation, mechanical, electrical, and communications systems became partially or completely unusable. At some locations, generators were elevated but still failed because components of the emergency power system (e.g., transfer switches or pumps) were located below flood levels. In stations that experienced flooding, damaged equipment included electrical service equipment, distribution panels, generators, transfer switches, boilers/furnaces, and hot water heaters (FEMA, 2013c).

Police stations that did not have emergency generators, or had generators that failed, experienced the longest downtimes. Police stations that were significantly damaged were forced to evacuate and relocate, which severely affected their operations. In some cases, mobile command trailers or other local accommodations (such as a local motel) were used for operations because of damage to the primary facility. Stations with functioning generators and minimal mechanical and electrical damage were mostly able to remain operational during or immediately after the floodwater receded (FEMA, 2013c).

Findings

For Hurricane Sandy, USACE found the NYPD had 1,497,293 hours of overtime costing $154 million. About $20 million was spent using NYPD vehicles and other equipment. Temporary relocation costs totaled $4 million for 25 damaged NYPD facilities sustaining $10 million in flood damages. In addition, 460 NYPD vehicles were damaged and 276 required full replacement, costing $10 million. It is estimated there are 34,500 NYPD officers and about 305,000 housing units were damaged or destroyed. The police emergency costs are summarized in **Table 8-1**.

Table 8-1: Police Emergency Costs for Hurricane Sandy

Category	Cost	Cost Per Officer	Cost Per Household
Overtime	$154 million	$4,464	$505
Equipment Use	$20 million	$580	$66
Vehicle Damage	$10 million	$290	$33
Facility Damage	$10 million	$290	$33
Temporary Relocation	$4 million	$116	$13
Total	**$198 million**	**$5,739**	**$649**

Associating a depth of flooding is difficult for these types of emergency costs because police jurisdictions may cover a large area where flood depths vary significantly, as was the case with Hurricane Sandy. It is also important to consider whether these emergency costs would change with the implementation of a flood risk management project. Also, determining what proportions of the emergency costs are related only to flooding, and not wind, is difficult.

8.2 Fire

During a flood, the ability of a fire department to perform many of their regular services would be diminished, and the personnel and vehicles normally used to perform the services would be redirected to the immediate demands of emergency flood response. During an emergency, a fire department can be called to do search and rescue, flood fighting, road closures, and traffic and crowd control, and to prevent widespread panic. Many fire departments now require their firefighters to be at least emergency medical technicians, if not full paramedics. Firefighters also provide hazardous materials mitigation services.

Firefighter emergency activities before a flood event include determining special needs for storm preparations within their response area; contacting other City agencies within their response areas to determine resource needs and/or resources or services available during storm emergencies (e.g., gasoline and fuel oil vendors, supplies, equipment); completing lists of streets and roads in their response areas that could be subject to flooding and could become impassable; creating plans to determine where to station backup apparatus and resources if the response area becomes isolated; pre-positioning resources to respond to vulnerable areas and communities (the fire department may deploy reserve units, command sites, and staging areas); testing all equipment that would be necessary during and after a flood (i.e., dewatering pumps, chainsaws, generators, etc.); surveying area hospitals, health care facilities (i.e., nursing homes), and infrastructure in low-lying flood-prone areas; maintaining a list of hydrants that could become submerged during a flood; reviewing GIS-based borough storm maps and identifying challenges as conditions change; and ensuring fire department property is properly stored, protected, and/or relocated to mitigate risk of water damages.

Fire and Hurricane Sandy

During Hurricane Sandy, the Fire Department City of New York (FDNY) conducted hundreds of swift water and search and rescue operations for residents in low-lying neighborhoods. Rescue companies, Squads, Cold Water Rescue units, and Special Operations Command units are equipped with life preservers and cold water rescue suits. Firefighter's aid in the evacuations of people trapped in homes or motor vehicles. As call volume and demand increased during Hurricane Sandy, Emergency Medical Services (EMS) were called upon to assist in coordinating emergency evacuations of Bellevue, New York University, and Coney Island hospitals. EMS continued to provide emergency medical services throughout the storm. At the peak of Hurricane Sandy, firefighters were battling several large, multi-alarm fires that covered dozens of blocks in the Rockaway Peninsula in Queens. During Hurricane Sandy, to deal with the rise in fire activity as well as search and rescue operations, additional fire and EMS units, and dedicated rescue task forces, were deployed to established flood zones.

A fire department would increase its force deployment as much as possible during and after a flood. Meeting increased demand for these services under the fire category would require significant amounts of overtime and call-in hours. Economic losses may also occur if a fire department must relocate one or more department headquarters, squad rooms, or other bases of operations. If relocation also causes a decrease in the quality of service provided—if, for example, response time is longer—there could be an added loss. Fire departments would have across-the-board increases in flood and routine costs. When a fire station is flooded, all of its routine costs would change and it would need temporary supplies to carry out its routine mission.

Findings

A fire department professional from FDNY was interviewed and provided estimated costs for flood events. The total relocation cost per station for each depth of flooding was estimated for future flood events. Only the most likely value for the additional labor cost per firefighter for Hurricane Sandy was provided. Additional labor cost per firefighter is the overtime costs associated with Hurricane Sandy. **Table 8-2** summarizes the estimated emergency costs. The station relocation costs are significantly higher than the costs estimated in the USACE Sacramento District study and MVD Report, which ranged from $1.4 million to almost $10 million.

Table 8-2: Fire Emergency Costs Collected by Interview

Category	4 feet Less than Sandy			2 feet Less than Sandy			Hurricane Sandy		
	Min	Most Likely	Max	Min	Most Likely	Max	Min	Most Likely	Max
Relocation Cost per Station	$900,000	$3.05M	$12.2M	$2.9M	$5.85M	$17.8M	$8.5M	$14.25M	$29M
Additional Labor cost per Firefighter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$2,095	N/A

Note: M = million, N/A = not available

Trees, vegetation, and sand were moved in New York City to clear blocked streets and to allow emergency vehicles access to protect the health and welfare of residents. The FDNY incurred overtime costs in the amount of $8.8 million (including fringe benefits) to carry-out Category A-related Debris Removal Operations. From October 28, 2012, through November 24, 2012, the FDNY performed emergency protective measures to protect life and safety (500 swift water rescues, evacuations, de-watering, fire suppression, and emergency medical operations). The FDNY incurred overtime costs in the amount of $13.8 million (including fringe benefits) to carry-out Category B-related Emergency Protective Measures.

Several FDNY firehouses, EMS stations, vehicle shops, and other critical facilities were damaged during Hurricane Sandy. Over 30 specialized vehicles were damaged beyond repair. Salt water has a detrimental effect on all of the apparatus onboard electrical systems, as well as the brakes and seals. Equipment, tools, uniforms, and supplies were destroyed beyond repair (estimated to be over $2 million). The FDNY sustained damages to marine infrastructure, including floating docks, piers, wave screens, wave attenuators, facilities, and utilities.

For Hurricane Sandy, total overtime cost was estimated to be $22.6 million. About $4 million was spent using FDNY vehicles and other equipment. There were 29 FDNY facilities damaged sustaining $107.6 million in flood damages. In addition, 112 FDNY vehicles were damaged, costing $20 million. It is estimated that there are 10,200 FDNY firefighters and about 305,000 housing units were damaged or destroyed. The fire emergency costs are summarized in **Table 8-3,** including the most likely relocation cost for Hurricane Sandy.

Table 8-3: Fire Emergency Costs for Hurricane Sandy

Category	Cost	Cost Per Officer	Cost Per Household
Facility Damage	$107.6 million	$10,549	$353
Overtime	$22.6 million	$2,216	$74
Vehicle Damage	$20 million	$1,961	$66
Temporary Relocation	$14.3 million	$1,397	$47
Equipment Use	$4 million	$392	$13
Total	**$168.5 million**	**$16,515**	**$552**

Associating a depth of flooding is difficult for these types of emergency costs because fire jurisdictions may cover a large area where flood depths vary significantly, as was the case with Hurricane Sandy. It is also important to consider whether these emergency costs would change with the implementation of a flood risk management project. Also, determining what proportions of the emergency costs are related only to flooding, and not wind, is difficult.

8.3 Jail

During and after a major flood, adult jails/prisons and juvenile halls would likely become inundated and unavailable. Therefore, prisoners housed in these facilities would need to be relocated. Different transportation modes would be required to evacuate inmates with specific security measures, resulting in economic losses. Alternative facilities accepting the relocated prisoners would also experience increased costs. In addition, economic losses would occur after the floodwater subsided and inmates return to their original detention facility. These losses would be associated with increased consumption of capital and travel costs.

Jail and Hurricane Sandy

Overall, there was little impact on the jail systems in the areas impacted by Hurricane Sandy. The New Jersey State Department of Corrections ordered the evacuation of inmates from one low-lying prison in Cumberland County: Southern State Correctional Facility in Delmont. Although the facility has some buildings capable of withstanding the storm conditions, many inmates are housed in trailers that are vulnerable to flooding. This facility houses more than 2,300 inmates. Corrections spokeswoman Deirdre Fedkenheuer said, “to err on the side of caution, we will relocate inmates from that area.” For security reasons, further specifics of the evacuation were not disclosed (Mueller, 2012).

Rikers Island, home to New York City's most renowned jail, is located in the East River between the boroughs of Queens and The Bronx. The 400-acre island houses an average of 12,000 inmates daily as well as 7,000 staff members employed by the city and 1,000 civilian employees. It is only accessible via the Francis R. Buono Memorial Bridge from the Steinway neighborhood of Queens by either bus or private car.

Prior to Hurricane Sandy making landfall in New York City, Mayor Michael Bloomberg designated evacuation zones based on vulnerability to Hurricane Sandy floodwater. Rikers Island was designated as a "no flood zone" and only a small portion of the perimeter of the island was considered to be in Zone C, the least vulnerable to flooding. No jail facilities are located on this portion of the island (Rothenberg, 2014).

New York City Department of Corrections (NYDOC) spokeswoman, Robin Campbell, reported "given its elevation, Rikers Island can withstand any storm up to and including a Category 4 hurricane." Because Hurricane Sandy was a category 1 storm, Campbell stated it would be "extremely unlikely" that the facility would need to be evacuated. Furthermore, Campbell reported at no point was Rikers Island under any threat from the storm; there were no power outages or flooding. No inmates of Rikers Island were evacuated as a result of Hurricane Sandy (Rivas, 2012).

NYCDOC Deputy Commissioner Matthew Nerzig provided a statement the morning after Hurricane Sandy made landfall in New York City, stating, "No power outages on Rikers last night. No significant flooding or disruption of our operations. The Commissioner [DOC Commissioner Dora Schriro] spent the night there." Prior to Hurricane Sandy, the NYCDOC posted notice that the staff will remain on Rikers Island and the facility is a full self-sustaining entity, prepared to operate and care for inmates in an emergency (Ridgeway, 2012).

Emergency costs for jail facilities are related to evacuation, relocation, and reoccupation. Direct damages to jail facilities may also be collected when available. Evacuation costs are the actual cost of transporting inmates to another facility. Once the jail is safe and any repairs have been completed, inmates would return to the jail. Any additional labor costs due to the evacuation and reoccupation of the inmates are also considered emergency costs.

8.4 Government Judicial

The judicial branch of the government is responsible for interpreting and applying laws and resolving legal conflicts. The judicial system is composed of trial courts, consisting of the superior courts (e.g., County Courts and Supreme Court) and the inferior courts (e.g., District Courts and City Courts), and the appellate courts (e.g., Court of Appeals). Following a major flood event, law offices and courthouses may be temporarily closed causing a major disruption to the legal system.

The judicial flood emergency costs include additional judicial facility or courthouse actions in the event of a flood. Incremental facility rental costs and increased security costs would be evaluated for each action. All costs would be evaluated per average judicial facility or per average courthouse basis.

8.5 Government Legislative

The legislative branch is the body of the government that makes and passes the laws governing a city, State, or the country depending on the jurisdiction of the legislative branch. Following a major flood event, legislative facilities may be temporarily closed causing a disruption to the legislative system.

The flood emergency costs associated with the government legislative category include relocation costs, incremental facility rental costs, costs associated with prioritizing interrupted services, and legislative facility actions taken in the event of a flood.

Findings

A government legislative professional was interviewed and was able to offer some information about how government legislative facilities were affected by Hurricane Sandy.

To prevent flood damages, flood walls and gates could be constructed around government legislative facilities for about $40,000. Most documents are stored on the second level of facilities in the study area, but in the event of an emergency evacuation order, documents are typically relocated to a higher level. Document recovery costs could range from $25,000 to $50,000 if there is not an emergency evacuation order because the staff would likely not be able to move sensitive documents in time.

8.6 Estimating Emergency Costs for Public Services Produced

Public services produced are services primarily provided by government that do not usually require consumers to visit a location to obtain the service. The following categories were analyzed in this group: police, fire, jail, government judicial, and government legislative.

Analyzed flood-event-related economic losses associated with public services patronized stem from two common loss types:

- Labor Diversion (routine- and flood-related)
- Capital Use (routine- and flood-related)

Associated subtype losses include the following:

- Travel Costs (routine- and flood-related)
- Temporary/Rental Structures (routine- and flood-related)

Specific *ceteris paribus* assumptions for these categories are that routine missions will not be interrupted by a flood, extra labor will be used to carry out flood missions, and prices for goods used in either mission are not expected to increase post-flood.

Figure 8-1 outlines the calculation of expected flood emergency costs per facility and per household. Economic losses associated with public services produced include direct damages to facilities, relocation costs, equipment costs, and additional operating costs (e.g., labor). Evacuation transportation costs for this group are only relevant for the jail category.

Relocation costs include actions that a facility would take to continue providing services (e.g., occupying an alternative facility). The additional daily costs per relocation action would be multiplied by the number of days that the relocation actions would be required for each depth of flooding and then any set-up or other one-time costs would be added to develop the relocation cost per facility.

Emergency equipment costs are calculated by multiplying the duration of use by the daily costs of using ancillary equipment. The number of days that the ancillary equipment would be required should correspond to each depth of flooding.

Labor includes additional labor costs based on the quantity of additional working hours a facility would incur because of flooding multiplied by the associated wage rate. Costs are either evaluated on per average public service produced facility or per household.

Evacuation costs may depend on the type of transportation used to move inmates and the costs associated with each type. The number of inmates evacuated via each transportation type would be multiplied by the associated cost. USACE provides guidance for estimating transportation costs in Appendix D of Engineer Regulation 1105-2-100 (USACE, 2000). The inmate evacuation may also increase labor costs for guards. To calculate the labor costs from the inmate evacuation, the duration of the evacuation (in hours) would be multiplied by the average wage rate of the guards, but only if these costs are additional labor costs that would not have occurred otherwise. The sum of the evacuation costs would then be divided by the total number of inmates to determine the average evacuation cost per inmate.

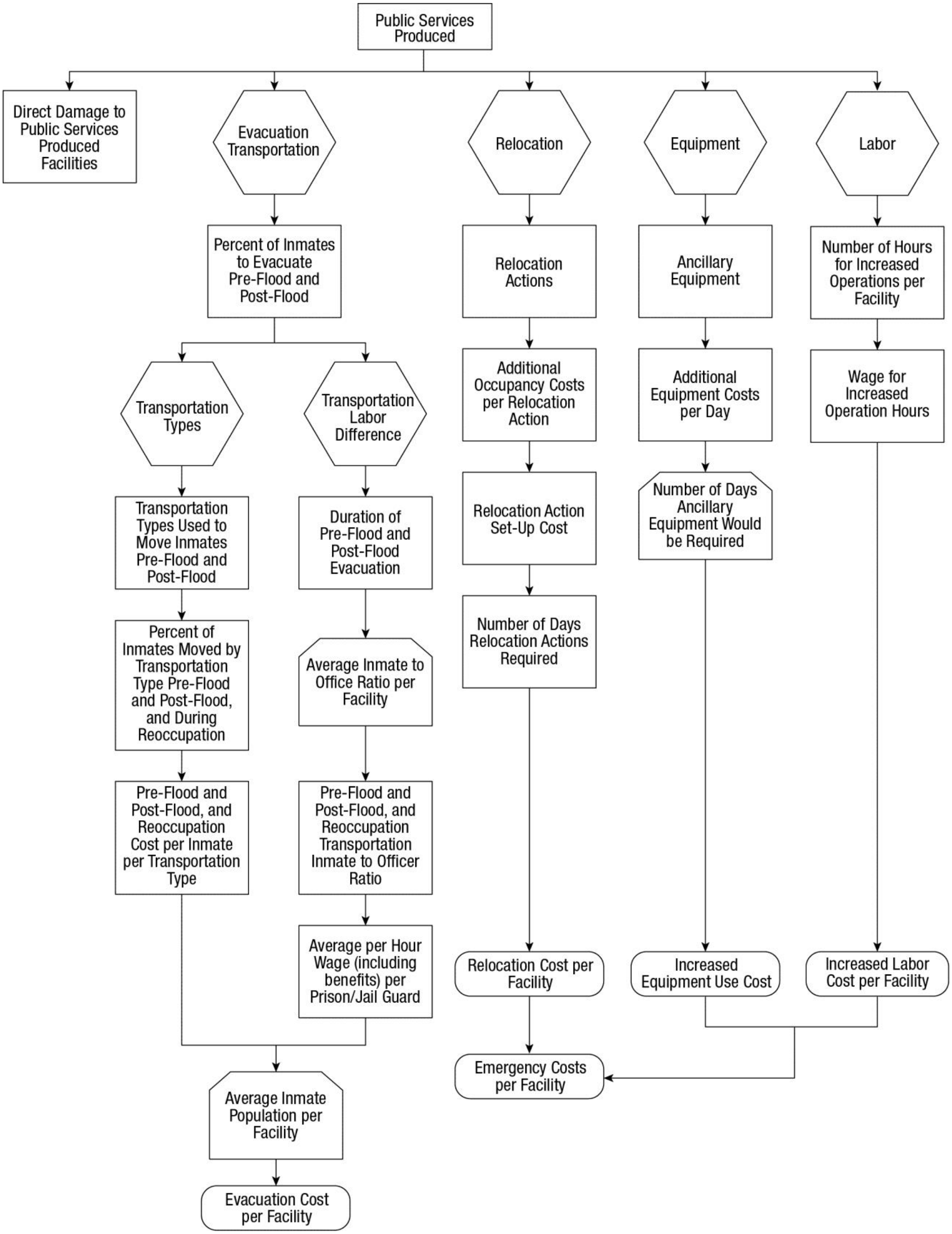


Figure 8-1: Public Services Produced Emergency Costs Diagram

Emergency costs for public services produced categories are primarily overtime costs. Other emergency costs include relocation costs and other increased daily operational costs. GIS would be needed to locate these types of public service facilities and assign elevation levels in order to calculate the associated emergency costs. The increased daily operational costs from a flooding event could be multiplied by the number of days these costs would be incurred. The number of days of additional costs would be associated with the depth of flooding above first floor elevation for these types of public service facilities. Relocation and evacuation costs that would occur with or without a flood risk management project would not be included in an NED analysis.

Only evacuation costs that would change with a coastal storm damage reduction project should be included in an NED analysis. Because of safety concerns, evacuation orders may be anticipated to occur with or without a coastal storm damage reduction project.

9 Application

The Federal government, in cooperation with the States and local entities, seeks to contribute to NED while protecting the environment. The 1936 Flood Control Act explains that the Federal government may participate in flood risk management projects "if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected." Subsequent acts have expanded the scope of the Federal interest in floodplain management to include consideration of all alternatives by reducing the susceptibility of property to flood damage and relieving human and financial losses. Typically, a benefit-cost analysis is used to evaluate the economic efficiency of flood damage reduction alternatives and assist in the decision-making process. The benefit-cost analysis results include the net benefits and the benefit-cost ratio. The net benefits are the total benefits minus the costs. The benefit-cost ratio greater than 1 indicates that the benefits outweigh the costs. There are other considerations in addition to benefit-cost analysis results, such as environmental quality impacts, regional economic development, and other social effects.

Most benefits from flood risk management projects come from the reduction of inundation damages. These benefits include avoiding structure and content flood damages, alleviating cleanup costs, reducing production losses, and decreasing evacuation and traffic rerouting. The application of DDFs can be used to calculate physical damages for planning studies. DDFs include generalized curves, project-specific curves (sometimes estimated from field surveys), or site-specific relationships.

Inundation reduction benefits can be categorized as physical damage or non-physical damages. Physical damage includes structural damage to buildings, loss of contents of the building, raw materials, materials used in processing, processed material, and damage to infrastructure (e.g., streets, railways, bridges, sewers, and substations). Physical damage is usually the largest share of benefits from flood risk management projects. Non-physical damages include emergency costs, income losses, flood-proofing costs, restoration of land market values, and the modified use of floodplain property. Physical damage to public utilities, infrastructure, and other facilities should be included for each relevant category when available. Emergency costs are considered non-physical damages and are incurred only in the event of a flood or when flooding is imminent enough to warrant emergency action.

When conducting a benefit-cost analysis, the flood risk management alternatives are compared to the conditions if the project did not take place (i.e., the without-project condition). This comparison is necessary to isolate the changes that are expected to occur as a result of the project from changes that would occur if the project was not undertaken. The without-project condition is an assessment of the flood problem, assuming no action is taken to alleviate it.

Flood damages for the without-project existing conditions are imperative to analyze the project and alternatives. Flood damages are expressed in terms of expected annual damages. Expected annual damages is the monetary value of a physical loss that can be expected in any given year based on the magnitude and probability of losses from all possible flood events. In order to calculate the expected annual damages, DDFs must be developed. DDFs are based on how much damage occurs at various flood elevations. The preferred method for developing DDFs is by gathering information on damages that occurred during a recent flood.

DDFs predict either direct-dollar loss or the percent of value lost through a flood event. DDFs can be applied to structures on an individual basis or applied over a large number of structures with similar vulnerability. Hydrologic variables, structural variables, and institutional factors (such as an evacuation order) can influence the depth-damage relationship. Hydrological variables include velocity, duration, sediment, and frequency of flood events. Structural variables include the building materials, inside construction, condition, age, and content location.

The damage-frequency relationship is represented by the probability that could be associated with any level of flood damage. By applying a frequency interval to each level, a weighted average for each flood event can be calculated. The average annual damages are calculated by computing the area under the damage-frequency curve (the integral of the function).

Planners may use the USACE HEC-FDA[9] software to perform an integrated hydrologic engineering and economic analysis during the formulation and evaluation of flood risk management alternatives. DDF can be entered into HEC-FDA and predict damage as a function of the depth of inundation at the structure. Damage is expressed as a percentage of total value and depth is measured relative to the first floor elevation of a structure. The percent damage would be multiplied by the structure value, content value or "other" value to get a unique DDF at the structure. Emergency costs would fall under the "other" category.

When available, damage estimates for each category should be translated into DDFs by converting each value to a percentage of the average maximum estimated value. The average maximum value is represented by 100 (100 percent). The percent damages between data points is linearly interpolated and then linearly extrapolated to zero feet of flooding unless the depth where damage begins is known. These percentages for each flood depth can then be entered into HEC-FDA.

For categories with multiple estimated values for a certain flood depth, the data can be aggregated by averaging the minimum, most likely, and maximum values that were provided by the emergency service professionals. Then, an aggregated triangular distribution could be developed using the average minimum, most likely, and maximum values. The skew of the triangular distribution is set by the size of the most likely value relative to the minimum and maximum values. The probability distribution illustrates the range of possible values and their likelihood of occurrence.

A Monte Carlo simulation can be used to generate a range of outputs (the possible outcomes) and the likelihood of occurrence, represented by a probability distribution. The selection of values from the triangular distributions is called sampling. Each calculation of the spreadsheet is called

[9] Hydrologic Engineering Center Flood Damage Reduction Analysis

an iteration. For each iteration of the simulation, a random sampling of a set of single values from the triangular distribution functions and fixed values is used to calculate single-valued results. The output distributions are a consolidation of all the single-valued results from all the iterations. Then, the results of the Monte Carlo simulation can be translated into a DDF for each emergency cost category.

Some categories are not associated with point data, such as a structure, but rather linear data (e.g., roads). Categories based on linear data are linked to a grid cell. The grid cell size can be specific to the project, with each grid cell having a centralized point with attributed length characteristics. To calculate the inventory value associated with each individual grid point, the average maximum value is multiplied by the length, in miles, in each cell.

Example

The following example of developing a DDF for the streets, roads, and highways category is provided to illustrate the process.

Emergency costs associated with streets, roads, and highways are the additional operating costs incurred by the owner of the infrastructure. Additional operating costs may include overtime or other costs incurred for emergency services above what is normally required such as setting up detours, traffic control, erosion control, and other preventative activities to avoid damage.

To calculate the streets, roads, and highways emergency cost per mile per day, the cost of additional operations per mile is multiplied by the number of days the additional costs are experienced.

$$C_O = D_{op} * C_{op}$$

Where: C_O = Cost of additional operations per mile

D_{op} = Number of days experiencing additional costs

C_{op} = Operating costs per mile per day

Information is gathered for additional operating costs for at least three depths of flooding. If multiple estimates are available for one depth of flooding, they can be aggregated by averaging the minimum, most likely, and maximum values (see **Table 9-1**). Then, an aggregated triangular distribution can be developed using the average minimum, most likely, and maximum values as depicted in **Figure 9-1**. This process is repeated for each depth of flooding.

Table 9-1: Example of Data Aggregation

Source	Minimum	Most Likely	Maximum
Source 1	$50	$75	$100
Source 2	$40	$80	$120
Source 3	$60	$85	$125
Average	**$50**	**$80**	**$115**

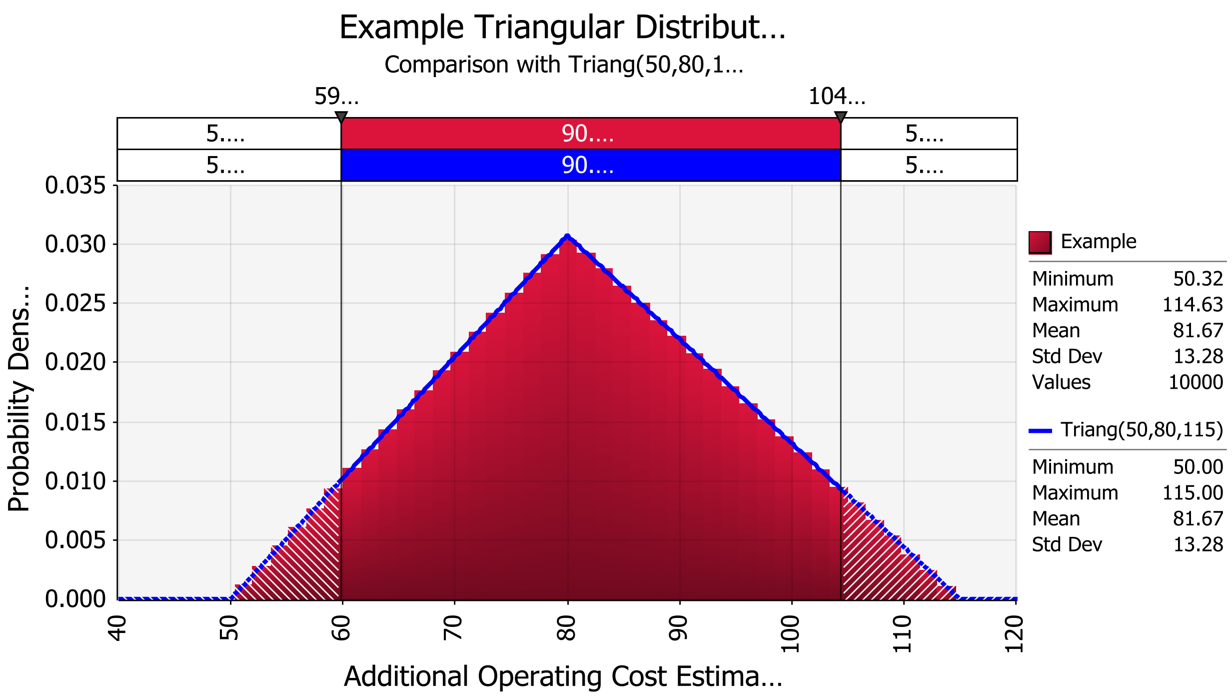


Figure 9-1: Example of Triangular Distribution

The emergency cost estimates can be translated into a DDF by converting each mean value for each flood depth to a percentage of the average maximum estimated value. The average maximum value is represented by 100 (100 percent). **Table 9-2** contains example data values and **Table 9-3** illustrates how those data values are translated into a DDF. The percent damages between data points is linearly interpolated and then linearly extrapolated to zero feet of flooding unless the depth where damage begins is known. These percentages for each flood depth can then be entered into HEC-FDA.

Table 9-2: Example of Data Values

Additional Operating Costs (per Mile)			
Flood Depth	2 Feet	5 Feet	10 Feet
Mean	$82	$150	$300
Standard Deviation	$13	$20	$41

Table 9-3: Example of Converting Data Values into a Depth-Damage Function

Depth-Damage Percentages			
Flood Depth	2 Feet	5 Feet	10 Feet
Mean	27.3	50	100
Standard Deviation	4.3	6.7	13.7

Conclusion

Understanding how to apply emergency cost information in an NED analysis is critical. Emergency costs are generally variable costs that are incurred at the time of a flood event. The fixed costs of emergency programs, such as maintaining the administrative staff and equipment needed in typical daily operation, are only considered if there is a reasonable possibility that these costs could be reduced by a project. Similarly, if evacuation of an area is still expected whether the actual flood depth is 1 foot or 12 feet (for example), then the emergency costs associated with evacuation do not change between the without project and with project alternative; therefore, these costs would not be included in an NED analysis. Also, only incremental changes attributed to flooding and not wind, which can be difficult to distinguish in some cases, should be considered for an NED evaluation of coastal storm damage reduction alternatives.

Data were collected based on experience with Hurricane Sandy. In most cases, these costs were not specific to a depth of flooding because they typically covered large areas where peak storm tide elevation in New York and New Jersey varied from 3.5 to 19 feet above NAVD88 (McCallum, 2013). As a result, emergency service professionals had difficulty estimating costs according to levels of flooding. Another difficulty encountered was that some organizations did not track emergency costs. For future planning studies, it is imperative that public and private organizations have an understanding of emergency costs and track these costs for future flood events.

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Appendix B: Interview Process

This section defines and describes the methods used to collect emergency cost information. Data were collected by interviewing emergency service professionals in the study area and reviewing relevant literature. The primary focus was obtaining information directly from emergency service professionals that had experience with Hurricane Sandy and when this was not possible or data were missing, literature was used to supplement the data.

Identification and Selection of Emergency Service Professionals

To gather the necessary data and represent all emergency cost categories, a list of emergency service professionals was developed. The initial list of emergency service professionals was compiled using news articles, studies, and reports focusing on Hurricane Sandy, archival literature, technical societies, governmental organizations, scholarly journals, and other knowledgeable professionals. The target number of emergency service professionals interviewed for each category was between one and five.

Emergency service professionals who represent a wide range of backgrounds were targeted for participation. For example, the contacts for the schools and daycares category were selected from schools that were impacted by Hurricane Sandy and representatives that were interviewed or acknowledged in Hurricane Sandy reports. Additional contacts for the categories were solicited during initial calls and during interviews, as well as from contacts developed through other studies, such as Mitigation Assessment Team reports completed for the Federal Emergency Management Agency (FEMA). The resulting selection maintained a balanced and broad spectrum of technical viewpoints, expertise, and organizational representation.

Efforts were focused on identifying emergency service professionals with broad and detailed engineering or technological knowledge; however, not all emergency service professionals are necessarily engineers or economists. Efforts were made to include emergency service professionals with backgrounds in management; knowledge of equipment, components, consequences; and expertise with safety, administrative, and logistic aspects of operations. Larger, management agencies rather than smaller, individual businesses were targeted for participation to avoid contacts being unable to respond to questions regarding “typical” facility-level information.

Questionnaire Development

To ensure consistency between the current study and the MVD Report, a questionnaire for each of the categories was developed based on the MVD Report. The questionnaires, with revised scenarios and questions, were provided to the larger study team and USACE representatives for review and concurrence.

Similar to the MVD Report, the questionnaires included two scenarios to which all the subsequent questions applied:

Scenario 1 description:

> *"A saltwater flood event occurs as the result of rainfall, storm surge, and wave impacts consistent with Hurricane Sandy conditions. A mandatory evacuation order of the study area was issued in the 48 hours preceding landfall of the storm. Two other depths of flooding will also be considered. The first is a storm event with flooding 2 feet less than the flood depths experienced during Hurricane Sandy (which in the New York City area would be similar to the 1992 Nor'easter) and flooding 4 feet less than the depths experienced during Hurricane Sandy (slightly higher than Hurricane Irene)."*

Scenario 2 description:

> *"A saltwater flood event occurs as the result of rainfall, storm surge, and wave impacts consistent with Hurricane Sandy conditions. No mandatory evacuation order of the study area was issued. Two other depths of flooding will also be considered. The first is a storm event with flooding 2 feet less than the flood depths experienced during Hurricane Sandy (which in the New York City area would be similar to the 1992 Nor'easter) and flooding 4 feet less than the depths experienced during Hurricane Sandy (slightly higher than Hurricane Irene)."*

Interviewing Emergency Service Professionals

Once a list of emergency service professionals to be targeted for interviews was developed, a cover letter, detailing the purpose of the study, interview process, and expectations was sent to the emergency service professionals. Those who responded were sent their respective questionnaire prior to scheduling an interview. If the emergency service professional agreed to move forward with the interview, a telephone interview was scheduled. Contacts who did not agree to participate in the interview were asked if they knew of another emergency service professional who might be willing to participate in the study. In some cases, responses for several categories were coordinated through one agency contact, who would distribute the questionnaires to the appropriate personnel.

Participation of emergency service professionals was more difficult than originally estimated. Emergency service professionals had many reasons to decline participation, including limited time availability, questionnaire seemed daunting, or they believed that they lacked the information/experience needed to participate. For several of the categories, the emergency service professional claimed they did not incur any emergency costs and so the questionnaire was not appropriate for their organization. Additionally, many emergency service professionals thought the questionnaire was not appropriate for their position and offered to forward the information on to other colleagues in their offices who might have more relevant information. This offer frequently fell through as the original emergency service professionals claimed they could not find anyone willing or able to take on this task. Many people claimed the interview was low on their list of priorities and did not have sufficient time to devote to the questionnaire and/or interview, which is entirely understandable given that efforts were still underway and accounting for the event was incomplete. Another obstacle encountered was that many emergency service professionals thought multiple people in their organization would need to collaborate to gather all of the requested information in the questionnaire. They perceived the questionnaire and interview as being difficult and time consuming, which discouraged them from participating.

After several months of unsuccessful scheduling for interviews, revisions were made to the questionnaires in an attempt to make them less overwhelming. Seemingly unnecessary questions were removed and only questions essential to the depth-damage relationships remained in an attempt to decrease the amount of effort required. After receiving feedback that the scenarios were either too confusing, or did not apply to their situation, the scenarios were removed from the questionnaires.

Efforts to get completed questionnaires for each category included:

- Repeated telephone calls
- Repeated email correspondence
- Weekly team meetings troubleshooting ideas to increase participation
- Weekly team meetings for brainstorming additional contacts and supplemental data sources to collect
- Direct contact with the potential respondents by the USACE study manager
- Questionnaire modifications to simplify the process

Interview Quality Review

Questionnaire responses were reviewed to identify potential errors and data gaps. When possible, the emergency service professional was contacted to verify responses that were inconsistent with other responses or that did not seem reasonable based on knowledge gained through research, similar studies, and/or engineering estimates. During the discussion, the interviewer would elaborate on the intent of the question so the emergency service professional could explain the logic behind a seemingly unreasonable response. If it was not possible to resolve the discrepancy with the emergency service professional because they were unavailable, the study team excluded the questionable data from subsequent data processing and analysis.

During the interview process, if the emergency service professional was unable to answer a question, the question was rephrased and additional information was given to help the emergency service professional understand what data were needed. Still, some emergency service professionals were unable to provide responses to all of the questions. In some cases, the emergency service professional could only provide information for questions relating to Hurricane Sandy and was not comfortable providing estimates for specific depths of flooding. If possible, missing values were set equal to values provided for the most similar flood depth.

In some cases, emergency service professionals completed the questionnaires and did not want to participate in the interview, while in other cases the emergency service professionals did not want to complete the questionnaires and relied on the interviews to convey the information to the study team. Although significant efforts were put forth to get participation, interviews and/or questionnaires (some only partially complete) were not obtained for all of the categories.

Appendix C: Agencies and Organizations Contacted

Attempts to get participation in the study took place over a year. Although it was difficult to find the appropriate contact, individuals who participated in the study were very helpful and made every effort to provide any relevant information that they could. The project team appreciates the efforts of all the agencies and individuals that contributed to this study. **Table C-1** lists the variety of agencies and organizations that were contacted for this study.

Table C-4: Agencies and Organizations Contacted

Agency or Organization	Agency or Organization
American Red Cross	New Jersey School Boards Association
Aqua New Jersey, Inc.	New Jersey Schools Insurance Group
AshBritt Environmental	New Jersey State League of Municipalities
Atlantic City Electric	New Jersey State Police, Emergency Management
Atlantic City Sewerage Company	New Jersey Transit
Atlantic County Library, Brigantine Branch	New Jersey Transit Police Department
Atlantic County Utilities Authority	New Jersey Transportation Trust Fund Authority
Bay Head Municipal Court	New York Academy of Medicine
Beach Haven Municipal Court	New York City Department for the Aging
Beach Terrace Care Center	New York City Department of Buildings
Bellevue Hospital Center	New York City Department of Education
Bergen County Courthouse	New York City Department of Environmental Protection
Berlin Borough Water Department	New York City Department of Health and Mental Hygiene
Borough of Highlands, New Jersey	New York City Department of Parks and Recreation
Borough of Park Ridge Water Department	New York City Department of Sanitation
Borough of Union Beach, New Jersey	New York City Department of Transportation
Carteret Public Library	New York City Health and Hospitals Corporation
Catholic Charities Neighborhood Services of Brooklyn and Queens	New York City Housing Authority
Center for Children’s Initiatives	New York City Human Resources Administration
Child Care Council of Nassau, Inc.	New York City Transit Authority
Child Care Council of Suffolk, Inc.	New York City’s Health and Hospitals Corporation, Bellevue Hospital

Agency or Organization	Agency or Organization
Child Development Support Corporation	New York City's Medical Reserve Corps
City of Bordentown, New Jersey	New York Downtown Hospital
City of New York Department of Correction, Rikers Island	New York Fire Department
Clinton, New Jersey Water and Sewer Utility	New York Police Department
Columbia University, National Center for Disaster Preparedness	New York Southern Bankruptcy Court, Manhattan
Con Edison	New York Southern Bankruptcy Court, Poughkeepsie
Coney Island Hospital	New York Southern Bankruptcy Court, White Plains
Council of Senior Centers and Services of New York City, Inc.	New York State Department of Health
Daniel Patrick Moynihan U.S. Courthouse	New York State Division of Code Enforcement and Administration
Daycare Council of New York, Inc.	New York State Division of Homeland Security and Emergency Services
Dover, New Jersey Water Commission	New York State Library
Elizabethtown Gas	New York State Office for the Aging
Encore Community Services	New York State Office of Children and Family Services
Environmental Disposal Corporation	New York University Langone Medical Center
Fayson Lakes Water Company	Oakwood Village Sewerage
FEMA, Region II	Ocean County Library
FEMA Hazard Mitigation Assistance	Office of Emergency Management, Long Island
Forest Lakes Water Company	Office of Emergency Management, New Jersey
Francis Stewart Agency	Office of Emergency Management, New York City
Gordon’s Corner Water Company	Office of Health Emergency Preparedness
Grandell Rehabilitation and Nursing	Orange Rockland Electric
Heritage Preservation	Palisades Medical Center
Highlands Fire Department	Passaic Valley Sewerage Commission
Hoboken Public Library	Pinelands Wastewater Company
Hoboken University Medical Center	Port Authority of New York and New Jersey
Jersey Central Power & Light	PSE&G

Agency or Organization	Agency or Organization
Jersey City Free Public Library	Queens Library
Jewish Association Serving the Aging	Riggins, Inc.
Joint Meeting of Essex and Union County	Roxbury Water Company
Lake Lenape Water Company	Roxiticus Water Company Inc.
Lifespan	Sayreville Public Library
Long Beach Medical Center	SB Water and Sewer Company
Long Island Power Authority	Sea Bright Borough
Mantoloking Court	Sea Bright Library
Meals on Wheels, Henry Street Settlement	Sea Crest Health Care Center
Metropolitan Transportation Authority	Seaside Park Police Department
Middlesex County Courthouse	Seaview Harbor Water Company, LLC
Middlesex County Utilities Authority	ServiceMaster Recovery Management
Middlesex Water Company	Shore Water Company Inc.
Midtown Water Company	Shorelands Water Company
Monmouth Beach Library	Simmons Water Company
Monmouth County Library, Oceanport Branch	South Jersey Gas
Montague Water and Sewer Company	Southern State Correctional Facility
Mount Olive Villages Water Company	Suffolk Cooperative Library System
Nassau County, Area Agency on Aging	Suffolk County Office for the Aging
National Association of Home Builders; Palisades Home Improvement	The Administrative Office of the N.J. Courts
National Institute of Health	The Department of Children and Families for New York State
National Library of Medicine, Disaster Information Management Research Center	The Federal Alliance for Safe Homes
Naturally Occurring Retirement Community/Vladeck Cares, Henry Street Settlement	The New York Southern District Court (Federal)
New Jersey American Water Company	The New York State Coalition for the Aging
New Jersey Association of Homes and Services for the Aging, LeadingAge New Jersey	The Ocean County Road Department
New Jersey Department of Community Affairs; Sandy Recovery Division	Trenton Water Utility
New Jersey Department of Education	U.S. Customs and Border Patrol

Agency or Organization	Agency or Organization
New Jersey Department of Environmental Protection, Emergency Management	U.S. Department of Health and Human Services, Administration for Children and Families
New Jersey Department of Human Services	Union Beach Fire Department
New Jersey Department of Transportation	Union Beach Sewer Department
New Jersey Department on Aging and Elder Services	United Water, New Jersey
New Jersey District Court, Newark	United Water, New York
New Jersey Division of Fire Safety	U.S. Department of Transportation, Regional Emergency Transportation Coordinator Program
New Jersey Hospital Association	Verizon New Jersey, Inc.
New Jersey Library Association	Verizon New York, Inc.
New Jersey Natural Gas Company	Village of Ridgewood Water Department
New Jersey Office of Homeland Security and Preparedness	Wallkill Sewer Company
New Jersey Primary Care Association	Yonkers Wastewater Treatment Plant

Appendix D: Cover Letter Delivered to Identified Emergency Service Professionals

Mr./Ms. _____,

The North Atlantic Coast Comprehensive Study is a multi-agency effort to develop a strategy that will reduce risk and increase resiliency to populations affected by Hurricane Sandy and those areas vulnerable to tidally-influenced flooding and storm surge in areas within the boundaries of the United State Army Corps of Engineers (USACE) North Atlantic Division. As part of the Comprehensive study, the USACE is collecting data to determine emergency costs associated with coastal storms.

To complete the analysis, the USACE has contracted with the International Coastal Solutions Partnership ("ICSP", a Joint Venture partnership between Moffatt Nichol and URS). ICSP team members will be interviewing willing respondents and collecting data regarding emergency costs associated with Hurricane Sandy. You have been identified as an emergency service professional in your field and we are asking for your participation in this study. While participation in this interview is voluntary it is hoped that you will be willing to talk with our ICSP representative and complete a questionnaire. Your responses are strictly confidential and will not be disclosed outside of the immediate study team. Reports released to the public will only show results aggregated by broad categories, and will not contain any identifying information.

Your participation is greatly appreciated. The information you provide will help us to develop strategies for mitigating future storm impacts. An ICSP team member will be contacting you to set up a time for an interview or you can respond to this email with your availability. If you feel that there is someone else from your organization that is better suited to provide emergency cost information, please respond with the contact information for this individual.

Thank you,