Section 4: Hazard Identification and Risk Assessments

2016 Plan Update changes: This section combines Sections 6 and 7 into one section. Where possible, the content has been updated to reflect the best data available.

4.1 Introduction

During the 2016 Plan update many parts of the original County HMP were preserved. Where applicable, portions of the historical hazard data have been retained. This section addresses the specific requirements of the Interim Final Rule (IFR) and FEMA checklist requirements (Local Mitigation Plan Review Tool, October, 2011) with regard to hazards in the planning area. As required by federal planning guidelines, one of the key elements of the 2016 HMP update was to describe the events and effects of natural hazards on the County since the original version of the Plan was developed and adopted in 2010. In addition detailed risk assessments were completed for all hazards ranked high (hazards of concern) or medium by the 2016 Hazard Mitigation Planning Steering Committee (HMPSC).

The term "planning area" is used frequently in this section. This term refers to the jurisdictional limits of Middlesex County. The Risk Assessment section addresses the potential future damages from hazards on Middlesex County and its citizens.

4.1.1 Summary Description of the County's Vulnerability to Hazards

The DMA 2000 legislation and related FEMA planning guidance require mitigation plans to include discussion of community vulnerability to natural hazards. Vulnerability is generally defined as the damage (including direct damages and loss of function) that would occur when various levels of hazards impact a structure, operation or population. For example vulnerability can be expressed as the percent damage to a building when it is flooded, or the number of days that a government office will be shut down after a wind storm, etc., assuming there is sufficient detailed data available to support the calculations.

Because this Plan update includes many jurisdictions and data is often not detailed, it is not practical to complete vulnerability assessments on the many individual assets, operations and populations in individual jurisdictions. However, it is appropriate for participating municipalities to embark on a program of addressing these data deficiencies over the next five years in anticipation of the next Plan update.

As illustrated in the present section of the HMP update, Middlesex County is subject to numerous natural and manmade hazards, although in some cases the hazards have rarely impacted the area, or their effects have been relatively minor. As is the case with many parts of the mid-Atlantic, although relatively localized, flooding is the most frequent and most damaging natural hazard in central New Jersey and Middlesex County, However, it is important to recognize that several other hazards present significant risks (i.e. potential for future losses) to the County, even though they have occurred

infrequently in the past, or have not caused much damage.

In particular, earthquakes (although improbable) present risks to various communities within the County, because there are many relatively old structures that may be prone to failure if shaken by an earthquake. In order to accurately characterize vulnerabilities (and hence risks) at a local level, it will be necessary to study assets on a site-specific basis. There is also some vulnerability to wind in the County, mainly from hurricanes and tropical storms. While severe hurricanes are rare events in this area of the country, tropical storms and nor'easters are fairly common, and many structures in the communities are vulnerable to high winds. Most of the other hazards are either localized or improbable, and therefore, while various elements in the communities may be vulnerable to such hazards, the likelihood of them occurring in any specific location is very small.

4.2 Identification, History and Prioritization of Hazards

In accordance with IFR requirements, and as part of its efforts to support and encourage hazard mitigation initiatives, the 2016 HMPSC prepared this general assessment of the hazards that have potential to impact the County. The following subsections provide an overview of past hazard events in the County and descriptions of the potential for future losses. Under the subsection *Methodology for Prioritizing Hazards* beginning on Page 4-3 the hazards are ranked (high, medium, or low) based on the overall impact to the County. In addition, jurisdiction specific hazards have been identified and profiled for each municipality in Appendices 1-20. These hazards were identified by municipality point of contacts after a series of meetings and workshops held with each of the 25 jurisdictions. See Section 4 of the Plan update and the municipal appendices for additional details about the process for selecting these hazards and the hazard identified for each jurisdiction.

4.2.1 Overview of the Type and Hazards That Can Affect Middlesex County

In the initial identification process, the HMPSC catalogued potential hazards to identify those with the most chance to significantly affect the County. The hazards include those that have occurred in the past and may occur in the future. A variety of sources were used in the investigation. These included national, regional, and local sources such as emergency operations plans, the State Hazard Mitigation Plan, websites, published documents, databases, and maps, as well as discussion with the HMPSC.

In its early meetings related to this HMP update, the HMPSC reviewed the hazards included in the 2010 Hazard Mitigation Plan and identified a total of 15 hazards that have potential to affect the County. The 15 hazards include the addition of three new hazards that were not profiled in the 2010 Plan including Levee Failure, Power Loss and Nor'easters. Of the original 18 hazards profiled in the 2010 Plan only one is not included in the 2016 Plan update (Lightning). The 2016 HMPSC felt this hazard was covered under Severe Weather. The 15 hazards profiled as part of the 2016 Plan update are listed below.

1. Coastal Erosion
2. Dam/Levee Failure*
3. Drought
4. Earthquakes

5. Extremely High Temperatures
6. Extremely Low Temperatures
7. Flood (Riverine, Coastal, Storm Surge, local, and Sea Level Rise)
8. Geologic Hazards (Landslides, Subsidence, and Sinkholes)
9. Hazardous Materials (Fixed Sites, Rails, and Other Transportation)
10. Hurricanes and Tropical Storms
11. Nor'easters*
12. Power Outages*
13. Severe Weather (High Winds, Tornadoes, and Hail)
14. Wildfire
15. Winter Storm (Snow, Blizzards, and Ice Storms)

* New for 2016 Plan Update. Note that the Levee Failure portion of the Dam/Levee Failure hazard is new for the 2016 update.

4.2.2 Methodology for Prioritizing Hazards

The 2016 HMPSC reviewed these hazards (including the hazard profiles and risk assessments) and prioritized them as high, medium, or low based on the overall impact to the County. They considered factors such as how often the hazard occurred, degree of property and infrastructure damage, number of people impacted, and time of recovery.

The hazard prioritization table is provided below and describes the rationale for the hazard ranking. It also shows sources of information that were consulted for the determination. Although all 15 of the hazards are profiled in this section, the prioritization was used as a basis to focus vulnerability and risk assessment activities on those hazards with the most potential to negatively affect the County. Those hazards prioritized as high or medium by the HMPSC include more extensive discussions about vulnerability and risk than those with lower rankings. There is more information about location-specific hazards and vulnerabilities in the jurisdictional appendices.

The 2016 HMPSC identified 6 of the 15 hazards profiled as multi-jurisdictional or county-wide hazards of high concern (ranked high). As the regulations indicate, all of these identified hazards must be profiled, their vulnerability assessed, and mitigation actions developed for them. The remaining hazards were ranked medium or low. The high, medium and low rankings for the 15 hazards are shown below.

Table 4-1
Middlesex County (County-wide) Hazard Ranking Table
(Source: HMPSC)

Hazard	Level of Concern	Rationale	Sources
Flood (Riverine, Coastal, Storm Surge, Local, and Sea Level Rise)	High	Widespread impacts, history of occurrences in the county, significant annual damages	FEMA Flood Insurance Studies, FEMA Flood Insurance Rate Maps, FEMA Public Assistance records, FEMA National Flood Insurance Program claims data, US Army Corps of Engineers (USACE), and National Oceanographic and Atmospheric Administration (NOAA), studies and records, HAZUS.
Hurricanes and Tropical Storms	High	**Hurricanes:** Relatively low historic probability; potential for widespread impacts. **Tropical Storms**: Low to moderate probability; potential for widespread impacts.	NOAA and National Climatic Data Center (NCDC) records, New Jersey Department of Community Affairs - Division of Codes and Standards, New Jersey State Climatologist (Rutgers)
Nor'Easters	High	Moderate probability of more extreme events, potential for moderately widespread impacts.	NOAA and National Climatic Data Center (NCDC) records, New Jersey Department of Community Affairs - Division of Codes and Standards, New Jersey State Climatologist (Rutgers)
Winter Storm (Snow, Blizzards, and Ice Storms)	Medium	High annual probability, widespread impacts, but losses generally limited except in most extreme events.	NOAA-NCDC, National Weather Service (NWS), New Jersey State Climatologist (Rutgers)
Hazardous Materials (Fixed Sites, Rails, and Other Transportation)	High	High annual probability with impacts potentially severe in site-specific areas.	US Environmental Protection Agency, FEMA HAZUS (Hazards US) software, the Right-to - Know (RTK) Network, US Environmental Protection Agency (EPA).
Extremely Low Temperatures	Medium	Relatively high annual probability, but impacts are limited.	NOAA-NCDC, New Jersey State Climatologist (Rutgers), NWS
Extremely High Temperatures	Medium	Relatively high annual probability, but impacts are limited.	NOAA-NCDC, New Jersey State Climatologist (Rutgers), NWS
Dam/Levee Failure	High	Low annual probability based on historical data, but impacts potentially significant in site-specific areas.	New Jersey Department of Environmental Protection (NJDEP) - Dam Safety and Flood Control.
Drought	Medium	High annual probability, but impacts generally limited.	NOAA-NCDC; New Jersey State Department of Agriculture NJDEP
Coastal Erosion	Medium	Relatively high annual probability, but impacts are limited to northeastern coastal areas.	NOAA, The New Jersey Beach Profile Network (NJBPN), USACE
Power Outages	High	High annual probability, widespread impacts, but losses generally limited except in most extreme events.	JCP&L, PSE&G, Borough of South River
Severe Weather (High Winds, Tornadoes, Hail)	Medium	Moderate to high annual probability, widespread impacts, but losses generally limited except in most extreme events (such as Derechos, EF2+ Tornadoes, etc.).	NOAA-NCDC, New Jersey State Climatologist (Rutgers), NWS
Earthquakes	Low	Very low probability	United States Geologic Survey (USGS), New Jersey Geologic Survey (NJGS).
Geologic Hazards	Low	Very low probability with limited impacts	New Jersey Geologic Survey (NJGS).
Wildfire	Medium	High annual probability of site-specific events, but impacts generally limited.	U.S. Department of Agriculture, New Jersey Forest Fire Service, NJDEP.

Note: The data in this table is intended only to give a general sense of the significance of hazards in the county, relative to each other.

In addition to the hazards selected for the multi-jurisdictional or county-wide risk assessments, a subset of the 15 hazards included in the Plan update were also identified, profiled, and in some cases risk assessments completed for each participating municipality. One of the first steps in developing the jurisdictional appendices was for participating municipalities to review and prioritize the hazards that can affect them. Municipalities ranked the list of hazards as high, medium, low, or no concern. A high concern would be if the hazard occurs frequently or if the event is less frequent, but the potential damage/injuries/deaths would be high. Medium concern would be if the hazard occurs occasionally with minor property damage and few/no injuries. Low concern means it is unlikely the hazard will affect a community or if the event occurred it would cause little to no property damage and no personal injuries. The results of the municipal hazard rankings are shown below in Table 4-2. See municipality specific appendices for detailed hazard identification and risk assessments for select hazards of concern for each jurisdiction. Note that hazards of no concern are shown with a dash.

Table 4-2
Municipal Hazard Ranking Results
(Source: Municipal Interviews and Worksheets)

Municipality	Coastal Erosion	Dam/Levee Failure	Drought	Earthquakes	Extremely High Temperatures	Extremely Low Temperatures	Flood	Geologic Hazards	Hazardous Materials	Hurricanes And TS	Nor'Easters	Power Outages	Severe Weather	Wildfire	Winter Storm
Carteret Borough	L	L	M	L	H	L	H		M	H	H	H	H	L	M
Cranbury Township	L	L	L	L	L	L	L		L	M	M	L	L	L	L
Dunellen Borough	-	L	-	-	-	-	H		H	H	H	H	M	L	M
East Brunswick Township	L	H	M	H	M	M	H		M	H	H	M	M	L	M
Edison Township	-	L	L	L	M	M	M		H	M	M	M	M	L	M
Helmetta Borough	L	L	L	L	L	L	H		M	H	H	M	M	L	M
Highland Park Borough	L	L	M	L	H	L	H		M	H	H	H	H	L	M
Jamesburg Borough	L	H	L	L	M	L	H		M	H	H	H	H	L	H
Metuchen Borough	-	-	L	L	L	L	L		H	M	M	L/M	L	L	M
Middlesex Borough	-	H	L	L	L	M	H		H	H	H	H	M	L	M
Milltown Borough	L	M	L	L	L	L	H		L	H	H	H	M	L	H
Monroe Township	L	H	M	L	M	M	H		L	H	H	H	M	L	H
New Brunswick City	L	L	L	L	M	M	M		H	H	H	H	M	L	H
North Brunswick Township	L	L	L	L	L	L	L		M	M	M	M	M	L	M
Old Bridge Township	H	M	M	L	M	M	H		H	H	H	M	M	M	H
Perth Amboy City	H	-	-	L	M	M	H		H	H	H	H	M	-	H
Piscataway Township	M	M	L	L	M	L	H		H	H	M	H	M	L	H
Plainsboro Township	L	M	L	L	H	H	H		M	H	M	M	M	L	M
Sayreville Borough	L	L/M	L	L	M	M	H		H	H	H	M	M	L/M	L
South Amboy City	H	L	M	L	H	H	H		M	H	H	H	H	L	H
South Brunswick Township	-	L	L	L	L	L	L		L	M	M	L	M	L	M
South Plainfield Borough	-	-	M	-	M	M	H		H	H	H	M	-	-	M
South River Borough	L	L	L	L	M	M	H		L	H	H	M	M	L	M
Spotswood Borough	L	H	L	L	M	M	M		L	M	M	H	M	L	M
Woodbridge Township	-	-	L	L	M	M	H		L	H	H	M	L	-	M

4.2.3 Consistency with the 2014 New Jersey State Hazard Mitigation Plan

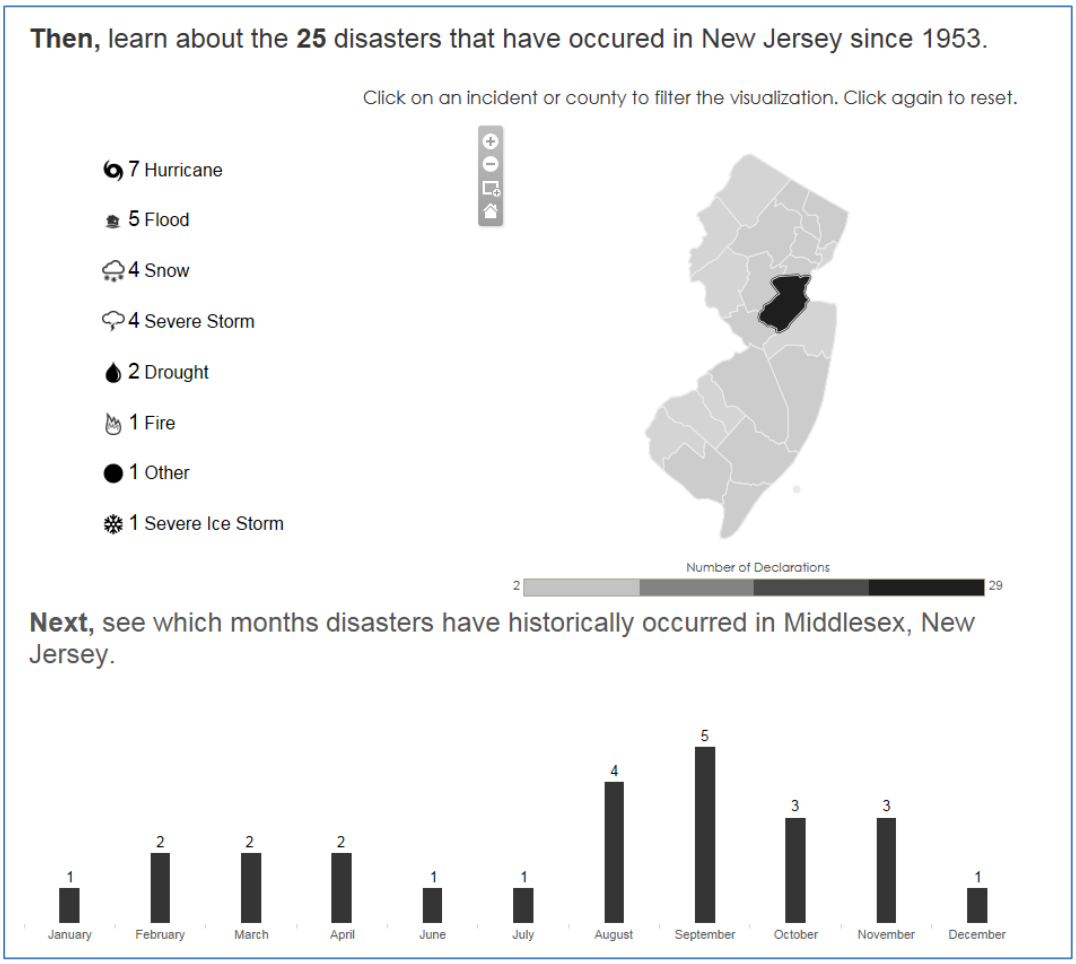
As part of the process of developing the Middlesex County Hazard Mitigation Plan Update, the planning team carefully reviewed the 2014 New Jersey State Hazard Mitigation Plan Update (SHMPU), with the goal of ensuring consistency between the two documents, primarily in the areas of hazard identification, risk assessment and mitigation strategy. The SHMPU comprises a shorter list of natural hazards (and does not include hazardous materials), but the most significant (natural) hazards statewide are part of both documents, and are generally prioritized in the same way.

4.3 Overview of Middlesex County's History of Hazards

Numerous federal agencies maintain a variety of records regarding losses associated with hazards. Unfortunately, no single source is considered to offer a definitive accounting of all losses. The Federal Emergency Management Agency (FEMA) maintains records on federal expenditures associated with declared major disasters. The U.S. Army Corps of Engineers and the Natural Resources Conservation Service collect data on losses during the course of some of their ongoing projects and studies. Additionally, the National Oceanic Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) database collects and maintains data about hazards in summary format. The data includes occurrences, dates, injuries, deaths, and costs.

One of the best sources to identify major natural disaster events that have impacted a county is FEMA's Disaster Database. FEMAs database indicates that as of June, 2015 Middlesex County has received 25 Disaster Declarations (both Emergency and Major Declarations) since 1953. Although seven hurricanes are listed, three of these were emergency declarations for the same event and another was related to evacuation victims from Hurricane Katrina. Deducting these events from the total there have been three Major Disaster Declarations related to Hurricanes (Floyd, Irene, and Sandy).

Figure 4-1
Summary by Hazard of Declared Disasters in Middlesex County, New Jersey, 1953 – June 2015
(Source: Federal Emergency Management Agency (FEMA), Disaster Declarations Database)



The more significant disaster declarations for Middlesex County are summarized below in Table 4-3 below.

Table 4-3
Significant Disaster Declarations Declared in Middlesex County, New Jersey
(Source: Federal Emergency Management Agency (FEMA), Disaster Declarations Database)

Disaster Number	Year	Declaration Date	Disaster Type	Incident Type	Title
205	1965	8/18/1965	DR	Drought	Water Shortage
245	1968	6/18/1968	DR	Flood	Heavy Rains and Flooding
310	1971	9/4/1971	DR	Flood	Heavy Rains and Flooding
402	1973	8/7/1973	DR	Flood	Severe Storms and Flooding
477	1975	7/23/1975	DR	Flood	Heavy Rains, High Winds, Hail and Tornadoes
528	1977	2/8/1977	DR	Severe Ice Storm	Ice Conditions
973	1992	12/18/1992	DR	Flood	Coastal Storm, High Tides, Heavy Rain, and Flooding
3106	1993	3/17/1993	EM	Snow	Severe Blizzard
1145	1996	11/19/1996	DR	Severe Storm	Severe Storms and Flooding
1088	1996	1/13/1996	DR	Snow	Blizzard of 1996 (Severe Snow Storm)
1295	1999	9/18/1999	DR	Hurricane	Hurricane Floyd
3181	2003	3/20/2003	EM	Snow	Snow
1694	2007	4/26/2007	DR	Severe Storm	Severe Storms and Inland and Coastal Flooding
1897	2010	4/2/2010	DR	Severe Storm	Severe Storms and Flooding
3332	2011	8/27/2011	EM	Hurricane	Hurricane Irene
4048	2011	11/30/2011	DR	Severe Storm	Severe Winter Storm
1954	2011	2/4/2011	DR	Snow	Severe Winter Storm and Snowstorm
4086	2012	10/30/2012	DR	Hurricane	Hurricane Sandy

Table 4-4 provides brief descriptions of particularly significant hazard events occurring in Middlesex County's recent history. This list is not meant to capture every event that has affected the area, rather lists some of the more significant events that have occurred here in the past. The more recent Declared disasters are included as part of the summary.

Table 4-4
Recent Hazards and Declared Major Disasters in Middlesex County, New Jersey, 1992 - 2015
(Source: FEMA)

Date & Disaster (DR)	Nature of Event
12/1992 (DR-973)	SEVERE STORMS AND INLAND AND COASTAL FLOODING – A major winter storm (Nor'easter) that caused considerable coastal flooding and beach erosion. A total of 12 counties in NJ included as part of the Presidentially Declared Disaster.
3/13/1993 (DR-3106)	SEVERE STORMS AND FLOODING – Event known as the "Storm of the Century" affected as many as 26 States from Florida to Maine, the Gulf Coast, and the Ohio Valley. One of the most intense nor'easters to ever effect the United States. The "storm of the Century" label was given to the event due to the record low pressure, wind speeds, temperature and snowfall. All 21 counties in New Jersey were included in the Presidentially Declared Disaster.
1/7/1996	BLIZZARD - A State of Emergency was declared for the blizzard that hit the State. Snowfall amounts ranged from 30 inches in the interior sections of the County to 14 inches along the coast. Road conditions were dangerous due to the high winds and drifts. Both government and contract snow plowing operations were running at a maximum. Local roads were impassable. This blizzard also brought on coastal flooding with the high tides of Sunday evening and Monday morning, and there were reports of damage to dunes and beaches from the heavy wave activity. More than 400 National Guard personnel were activated for transport assistance, primarily for medic missions. In Middlesex County snowfall totals ranged from 19-32 inches.
10/19/1996 (DR 1145)	Flash Flood – The flash flooding event caused an estimated $2.7 million in damages in Middlesex County. Flooding temporarily closed parts of US 1 and 9, several State routes, and the Garden State Parkway. In Dunellen 20 homes were damaged by the floodwaters.
11/19/1996	SEVERE STORMS AND FLOODING – This Nor'easter stalled for 8 hours over central New Jersey, causing heavy rainfall and street flooding in areas of Middlesex County.
9/16/1999 (DR -1295)	HURRICANE FLOYD – This downgraded fall hurricane put the entire Eastern Seaboard on flood watch, including every county in New Jersey. The storm lasted approximately 18 hours and caused an estimated $3.5 million in damages to public infrastructure in Middlesex County. In Middlesex County, floodwaters from the Raritan River caused severe flooding. As the Raritan River was rising, the incoming high tide during the early morning of the 17th prevented it from discharging into the bay. A total of 500 homes were damaged in Middlesex Borough. Residential damages were estimated at $6 million.
8/5/2003	SEVERE STORMS AND FLOODING – Thunderstorms with heavy rains caused flooding in the northwest part of the County. Rainfall totals from the storm were estimated at 2-5 inches and resulted in $250,000 in damages.
7/17/2005	SEVERE STORMS AND FLOODING – Flash flooding occurred in the Manalapan Brook Basin in southeastern Middlesex County impacting seven municipalities; East Brunswick, Jamesburg, Monroe, Spotswood, Helmetta, South River and Old Bridge. Collectively the flood damages to these areas totaled $9.7 million. A total of 308 homes, 25 apartments, 20 businesses and one industrial facility were damaged.
2/12/2006	SEVERE STORMS AND INLAND AND COASTAL FLOODING – A major winter storm (Nor'easter) that impacted the New Jersey shoreline with strong onshore winds that caused coastal flooding and beach erosion. In Middlesex County the area of South Amboy was impacted by coastal flooding.
4/15/2007 (DR -1694)	SEVERE STORMS AND INLAND AND COASTAL FLOODING – A 7-day Nor'easter deluged New Jersey with over 9 inches of rain, causing millions of dollars of damage and killing three residents. In Middlesex County nearly every municipality suffered flood damages or roads closed due to the extensive flooding.

Date & Disaster (DR)	Nature of Event
04/02/2010 (DR 1897)	SEVERE STORMS AND FLOODING - A slow moving storm moving north along the Atlantic coast produced heavy rains from March 12 - 15, 2010. Rainfall amounts were greatest in central and northeastern Event precipitation totals were 5.63 inches in South Brunswick, 5.25 inches in Metuchen and 5.14 inches in Piscataway. Damages were estimated in New Jersey at $30 million dollars as thousands of homes and businesses were damaged. It was the worst flooding in the Raritan Basin since April of 2007.
08/31/2011 (DR 4021)	HURRICANE IRENE - Hurricane Irene made landfall along the Outer Banks of North Carolina on August 27, 2011 as a Category 1 hurricane. The storm re-emerged over the Atlantic and made a second landfall as a tropical storm on August 28th in the Little Egg Inlet in southeastern New Jersey. In Middlesex County significant flooding occurred along parts of the Raritan River. The USGS reported that stream gages along the Raritan and Rahway recorded peaks greater than the 500-year recurrence interval (or 0.2% annual chance flood). The Middlesex County Flood Insurance Study (FIS) estimated overall damages in the County at $100 million.
October 29, 2011 (DR-4048)	SEVERE WINTER SNOWSTORM – A historic and unprecedented early-season winter storm impacted the area on Saturday, October 29, with more than one foot of heavy wet snow falling on interior portions of northeast New Jersey. This is the first time a winter storm of this magnitude has ever occurred in October. The heaviest snow fell across interior northeast New Jersey, with up to 18 inches of snowfall across higher elevations. Thousands of people across northeast New Jersey lost power during this event as heavy snow accumulated on trees that still had partial to full foliage during mid-autumn. This caused extensive felling of trees and limbs across the region and damage to power lines. In Middlesex County a significant number of trees came down due to the heavy wet snow. A Major Disaster Declaration was declared on November, 30, 2011, including Middlesex County.
10/30/2012 (DR 4086)	HURRICANE SANDY – In late October of 2012, Middlesex County was impacted by Hurricane Sandy, a late season hurricane. Sandy reached a peak intensity of 85 knots while it turned northwestward toward the mid-Atlantic states. Sandy weakened somewhat and then made landfall as a post-tropical cyclone near Brigantine, New Jersey with 70-knott maximum sustained winds. Because of its tremendous size, however, Sandy drove a catastrophic storm surge into the New Jersey and New York coastlines. In Middlesex County, the worst reported damage occurred in Woodbridge Township, Sayreville, South River and Old Bridge Townships. Most of this was related to tidal flooding in Raritan Bay and its ripple effects on the inland rivers including the Raritan.
04/10/2014	WILDFIRE - A major brushfire occurred on the Edison and Woodbridge municipal line near Olympic Drive near Raritan Center. A total of 194 acres were burned.
04/14/2014	SEVERE STORMS AND FLOODING – A slow moving low pressure system that caused major creek and river flooding along the Raritan River. Event precipitation totals averaged from three to six inches, with the highest amounts in central New Jersey. In Middlesex County very heavy rain caused considerable roadway flooding and also caused some brook flooding within the County. Nearly every major roadway in the County had flooding and many of them were closed. The Lawrence Brook at Weston Mills was above its 18 foot flood stage for roughly 12 hours. The NCDC estimated that in Middlesex County the event caused roughly $500,000 in property damages.

4.4 Hazard Profile and Risk Assessment

The following section includes the profile and risk assessment for the 15 hazards identified by the 2016 Middlesex County HMPSC. As part of the 2016 Plan new information was added to the hazard profiles for the period 2009 to June 2015. Entirely new sections were developed for the new hazards, Levee Failure, Power Loss and Nor'easters. For each hazard, the profile is followed by the risk and vulnerability assessment. Where data was available, each hazard's vulnerability was determined using Geographical Information System (GIS). Where feasible risk assessments were developed based on the GIS output. Additional details about the methodology and hazard data used are included in each hazard section.

Each of the 15 hazard-specific sections has five subsections. The subsections are listed below.

- ***Description of the Hazard***
- ***Location of the Hazard***
- ***Severity and Extent of the Hazard***
- ***Occurrence of the Hazard and***
- ***Risk and Vulnerability Assessment (Including Impact of the Hazard on Life and Property)***

For the 15 hazards profiled, links to websites have been included at the end of the *Description of the Hazard* subsection. These links provide additional information related to the general description of each hazard that can affect Middlesex County.

Coastal Erosion

Description of the Coastal Erosion Hazard

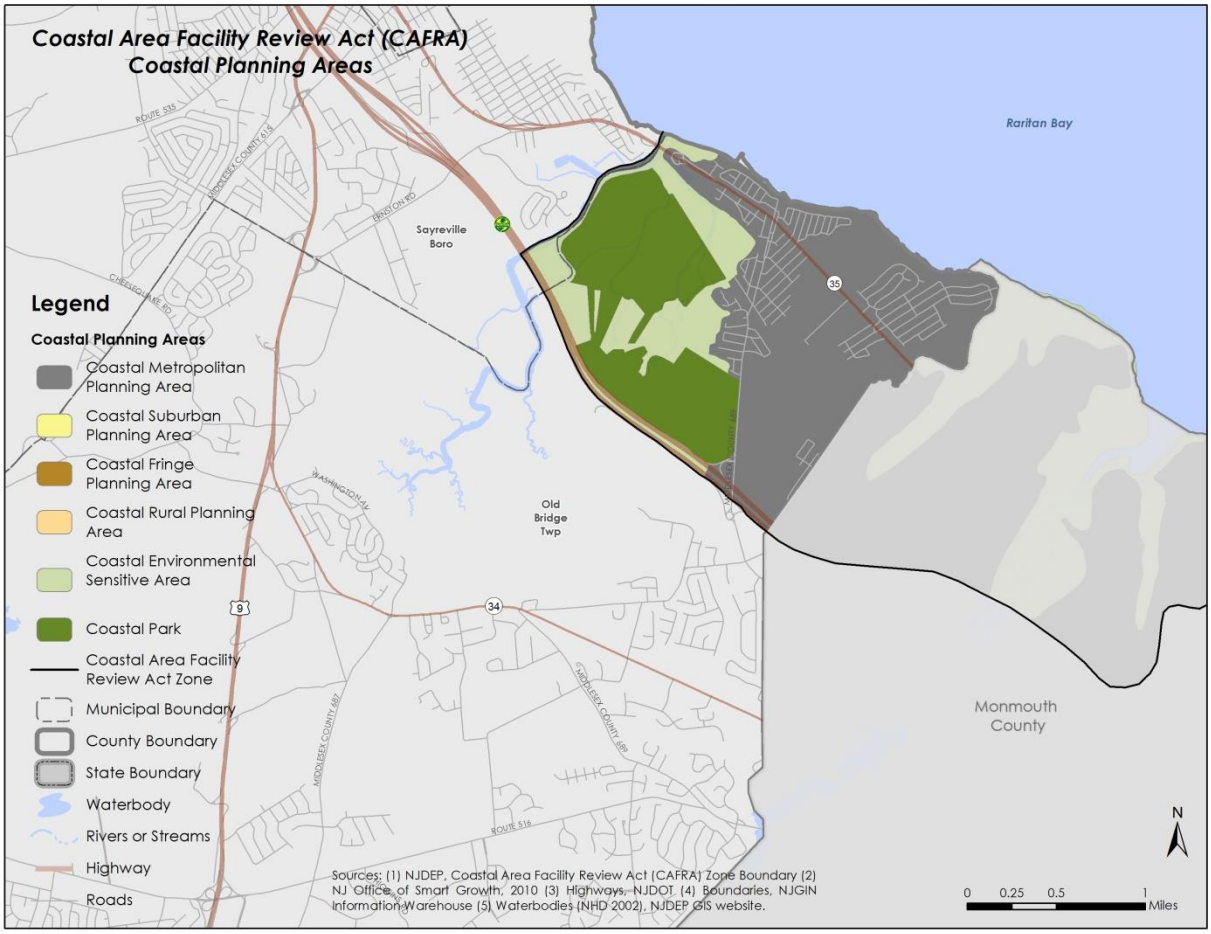
Coastal erosion is a dynamic process that is constantly occurring at varying rates along the coasts and shorelines of the U.S. Numerous factors can influence the severity and rate of coastal erosion including human activities, tides, the possibility of rising sea levels, and the frequency and intensity of hurricanes. Strong storms and hurricanes can erode large sections of coastline with a single event. The process of coastal erosion results in permanent changes to the shape and structure of the coastline. Human activities such as poor land use practices and boating activities can also accelerate the process of coastal erosion. For additional information about coastal erosion visit the National Oceanic and Atmospheric Administration's (NOAA) coastal hazards page.

Location of the Coastal Erosion Hazard

The State of New Jersey has over 130 miles of coastline, most of which is within close proximity to major metropolitan centers of the mid-Atlantic. Beach restoration and maintenance is an ongoing process for New Jersey. The state legislature provides $25 million annually for beach restoration and every beach on the Atlantic is currently under either a design, engineering or construction phase. In Middlesex County the erosion problem extends along the coast from the Borough of Carteret southward to the northern portion of Old Bridge Township. Along this area of the County there are mostly natural shores along the Raritan Bay with substantial dunes. Immediately inland of the beach area there are public roads bike paths and parks with residential development farther inland.

Within Middlesex County, a small portion of the southeastern corner within Old Bridge Township is located within the Coastal Area Facility Review Act (CAFRA) zone. This act limits development along coastal areas of New Jersey. The CAFRA includes coastal counties of New Jersey (non-tidal), and regulates certain development activities including residential, commercial, public or industrial development within the defined CAFRA planning areas. The remainder of the county is located outside of this zone. The CAFRA zone for Middlesex County is shown in Figure 4-2.

Figure 4-2
Southeastern Middlesex County Coastal Zone Area
(Sources: NJDEP, 2010, NJ Office of Smart Growth)



Severity and Extent of the Coastal Erosion Hazard

Episodic storm erosion generates the most significant erosion along the New Jersey coast. Typically these storms can impact the coast over periods of hours (tropical cyclones) to several days (nor'easters). Although the storm events are short-lived, the resulting erosion can be equivalent to decades of long-term coastal change. The actual quantity of sediment eroded from the coast is a function of storm tide elevation relative to land elevation, the duration of the storm and the characteristics of the storm waves. During severe coastal storms, it is not uncommon for the entire berm and part of the dune to be removed from the beach. The amount of erosion is also dependent on the pre-storm width and elevation of the beach. If the beach has been left vulnerable to erosion due to the effects of recent storms, increased erosion is likely. The time necessary for the beach to naturally recover from significant erosion can often be on the order of years to decades.

According to FEMA, coastal erosion is measured as the rate of change in the position or horizontal

displacement of a shoreline a period of time. Review of the *State of New Jersey 2014 Hazard Mitigation Plan Update* indicates a number of factors can determine whether a community experiences vulnerability to greater long-term erosion or accretion:

- Exposure to high-energy storm waves;
- Sediment size and composition of eroding coastal landforms feeding adjacent beaches;
- Near-shore bathymetric variations which direct wave approach;
- Alongshore variations in wave energy and sediment transport rates;
- Relative sea level rise;
- Frequency and severity of storm events; and
- Human interference with sediment supply (e.g. revetments, seawalls, jetties) (Woods Hole Sea 2003).[8]

Coastal erosion may be intensified by activities such as boat wakes, shoreline hardening, or dredging. Natural recovery after erosive events can take months or years. If a dune or beach does not recover quickly enough as a part of natural processes, coastal and upland property may be exposed to further damage in subsequent events. If severe enough coastal erosion can cause the destruction of buildings and infrastructure.

Occurrences of the Coastal Erosion Hazard

The NCDC database indicates there have been 22 coastal flooding events in Middlesex County between 1950 and June 2015. Of the 22 events, four resulted in property damage totaling $501 million (nearly all of which was related to Hurricane Sandy). Although not all 22 events resulted in property damage, most likely they all caused some amount of coastal erosion, particularly along the shoreline of the Raritan Bay and further inland along the Raritan River. Table 4-5 highlights some of the major events that have caused coastal erosion in Middlesex County. Coastal erosion events resulting in Presidential Disaster declarations include the disaster number below the event date.

[8] State of New Jersey 2014 Hazard Mitigation Plan Update, Section 5.2 Coastal Erosion and Sea Level Rise

Table 4-5
Major Coastal Erosion Events impacting Middlesex County (1990 – June 2015)
(Sources: FEMA, NOAA/NCDC)

Event date & Disaster (DR)	Erosion Event
12/1992 (DR-973)	SEVERE STORMS AND INLAND AND COASTAL FLOODING – A major winter storm (Nor'easter) that caused considerable coastal flooding and beach erosion. A total of 12 counties in NJ included as part of the Presidentially Declared Disaster.
3/16/1993 (DR-3106)	SEVERE STORMS AND INLAND AND COASTAL FLOODING – Event known as the "Storm of the Century" affected as many as 26 States from Florida to Maine, the Gulf Coast, and the Ohio Valley. One of the most intense nor'easters to ever effect the United States caused moderate coastal erosion along the New Jersey coastline. All 21 counties in New Jersey were included in the Presidentially Declared Disaster.
2/12/2006	SEVERE STORMS AND INLAND AND COASTAL FLOODING – A major winter storm (Nor'easter) that impacted the New Jersey shoreline with strong onshore winds that caused coastal flooding and beach erosion. In Middlesex County the area of South Amboy was impacted by coastal flooding.
9/1/2006	TROPICAL STORM ERNESTO – The combination of the remnants of Tropical Storm Ernesto and a large high pressure system over eastern Canada produced heavy rain, tidal flooding, and beach erosion in New Jersey. In Middlesex County erosion along the coast was widespread. In South Amboy sand eroded away from underneath the sidewalk at the Waterfront Park.
4/15/2007 (DR 1694)	SEVERE STORMS AND INLAND AND COASTAL FLOODING – A 7-day Nor'easter deluged New Jersey with over 9 inches of rain, causing millions of dollars of damage and killing three residents. In Middlesex nearly every municipality suffered flood damages or roads closed due to the extensive flooding.
11/3/2007	HURRICANE NOEL – The remnants of Hurricane Noel caused strong winds, minor tidal flooding and beach erosion along the New Jersey coast. In Middlesex County, in Old Bridge a four foot high dune was cut at its base for one-quarter of a mile from the municipal building to the police station.
08/31/2011 (DR 4021)	HURRICANE IRENE – Along the New Jersey coastline waves from Hurricane Irene were estimated to reach as high as 12 feet as offshore seas reached 25 feet. The NCDC indicates there were numerous reports of dune fence damage and sand overwashes onto streets and boardwalks. Along the Raritan Bay side of Middlesex and Monmouth Counties, most of the vertical cuts along the shoreline were less than two feet and no breaches were reported. About 3,000 county residents were evacuated along Raritan Bay.
10/29/2012 (DR 4086)	HURRICANE SANDY – One of the unique aspect of Sandy and unlike most tropical systems was the multi-tide cycle increase of onshore winds prior to landfall. This caused multiple high tide cycles with tidal flooding and also helped produce catastrophic wave action along the shoreline areas of New Jersey. The highest tide (and surge) along the ocean front and Raritan Bay was with the landfalling high tide cycle on the evening of the October 29th. The storm surge resulted in significant coastal erosion along parts of the Raritan Bay and Raritan River shoreline.

Review of other open sources indicates there have been several past erosion events in South Amboy City, Sayreville Borough and Old Bridge Township. Specifically portions of Paul's Beach in Old Bridge have repeatedly experienced significant shoreline erosion. Along the coastal shoreline of Sayreville Borough erosion from past coastal storms washed away large sections of beach, undermining and collapsing sections of a Bayfront walkway within the Raritan Bay Waterfront Park.[9]

As mentioned above, the coastal erosion problem is an ongoing problem along many areas of the Middlesex County coastline. It is difficult, if not impossible, to assign a probability to the near constant small ongoing erosion that may occur over a continuous period of time. However, a probability can be assigned to larger storm events such as nor'easters, hurricanes and coastal storms which can result in significant storm induced coastal erosion.

As shown above in Table 4-5, there were eight major nor'easters or downgraded hurricanes that caused erosion in Middlesex County between 1990 and June 2015. This translates to about one event every three years. In addition to the larger events noted above smaller nor'easters and other coastal storms cause erosion along the county coastline on average one to two times per year. The period of time over which this data is provided suggests the probability of coastal erosion will be about the same in the future, with year-to-year variations.

Coastal Erosion Risk and Vulnerability Assessment (Including Impacts on Life and Property)

Erosion from coastal storms has the potential to cause significant property damage particularly to more densely populated beach communities that are directly exposed to the Atlantic coast. Potentially billions of dollars of coastal development may be damaged or destroyed by the effects of erosion. Additionally the loss of beach shoreline can also have a negative impact on a community due to the potential loss of tourism dollars.

The coastal erosion problem is studied by various Federal, State and local agencies and organizations. The New Jersey Beach Profile Network (NJBPN) has been monitoring and surveying beach erosion along the New Jersey coastline since 1986. The survey data produced by the NJBPN includes cross-sectional profiles and quantitative measurements of volumetric changes along the profiles over time.

Because Middlesex County is primarily an inland jurisdiction, with limited coastline, information about the effects of coastal erosion is very limited. Although there is likely some erosion occurring (particularly in areas such as Perth Amboy, South Amboy and Old Bridge), there do not appear to be any studies or quantitative information on which to base a numerical risk assessment. Additionally, a significant part of the area that is directly exposed to erosion is privately-owned industrial land that likely has not been independently evaluated for erosion risks. There is no data about erosion-related damages in Middlesex County from Hurricane Sandy, which because of the significant surge associated with it, would likely have created erosion problems if the community was exposed to them.

[9] NJ.com, Middlesex County Officials Set to Restore Old Bridge Shoreline Damaged by Tides.

Dam/Levee Failure

Description of the Dam/Levee Failure Hazard

A dam is defined by the New Jersey Department of Environmental Protection (NJDEP) as any artificial dike, levee, or other barrier that is constructed for the purpose of impounding water on a permanent or temporary basis, that raises the water level five feet or more above the usual, mean, low water height when measured from the downstream toe-of-dam to the emergency spillway crest or, in the absence of an emergency spillway, the top-of-dam.

Dam failures can result from a variety of causes including lack of maintenance, seismic activity, improper design or construction, or the effects of large storms. Significant rainfall can quickly inundate an area and cause floodwaters to overwhelm a reservoir. If the spillway of the dam cannot safely pass the resulting flows, water will begin flowing in areas not designed for such flows and failure may occur. For additional information about dams in New Jersey and historical dam failures visit the NJDEP Bureau of Dam Safety and Flood Control website.

Dams are typically ranked by hazard classification, which is determined by the potential for infrastructure and property damages downstream if a dam failure were to occur. The three hazard classifications[10] include high, significant, and low and are defined as follows:

- **High hazard potential dams** - failure or operational failure will probably cause loss of life and/or significant infrastructure losses.
- **Significant hazard potential dams** - failure or operational problems are unlikely to cause loss of human life, but can cause economic loss, environmental damage, disruption of lifelines, or other concerns.
- **Low hazard potential dams** - failure would probably cause no loss of human life and only low economic and/or environmental losses, which would typically be limited to the dam owner's property.

To prevent, or reduce the probability of a failure, existing dams are periodically inspected by professional engineers on a regular basis. Table 4-6 summarizes the dam inspection schedule for New Jersey, including Middlesex County.

[10] New Jersey Administrative Code- Dam Safety Standards (NJAC: 7-20): Dam Classifications

Table 4-6
New Jersey Dam Inspection Schedule
(Source: NJDEP – Dam Safety and Flood Control)

Dam Class	Regular Inspection	Formal Inspection
Class I Large Dam	annually	once every 3 years
Class I Dam	once every 2 years	once every 6 years
Class II Dam	once every 2 years	once every 10 years
Class III Dam	once every 4 years	only as required
Class IV Dam	once every 4 years	only as required

A levee is a natural or artificial slope or wall, either earthen or concrete and often parallels the course of a river. Levee failure can occur in numerous ways but the most common is the breaching of a levee. The main purpose of a man-made levee is to prevent flooding to adjacent development or farmland.

A breach occurs when part of the levee actually breaks away, leaving a large opening for water to flood the land protected by the levee. A breach can be a sudden or gradual failure that is caused either by surface erosion or by a subsurface failure of the levee. Failure can also occur when water overtops the crest of a levee. This is known as overtopping, where floodwaters exceed the lowest crest of a levee, flooding the surrounding area. For additional information about levees see the United States Army Corp of Engineers Levee Safety Program.

Location of the Dam/Levee Failure Hazard

According to the United States Army Corp of Engineers (USACE) National Inventory of Dams (NID) there were 87,359 dams in the United States as of July 2015. Of this total, 825 are located in New Jersey. The NJDEP indicates there are a total of 39 dams in Middlesex County. The following table (Table 4-7) is a listing of all Middlesex County dams including the municipality name, hazard classification, the river or stream the dam is located along, the last inspection date and the name of the dam. The table is ordered by hazard classification which ranks the potential for infrastructure and property damages downstream if a dam failure were to occur.

In Middlesex County four dams are classified as high hazard by the NJDEP - Bureau of Dam Safety and Flood Control; Farrington Dam, Manalapan Lake Dam, Devoe Lake Dam and Regence and Monroe Pond Dam. The New Jersey Department of Environmental Protection database does not include the data points listed as “na” in the table.

Table 4-7
Inventory of Middlesex County Dams, ordered by Hazard Classification
(Source: NJDEP – Dam Safety and Flood Control, New Jersey Administrative Code – Dam Safety Standards)

Municipality Name	Dam Name	Hazard Class	River/Stream	Height (ft)	Length (feet)	Last Date Inspected
East Brunswick Township	Farrington Dam	H	Lawrence Brook	34	535	11/15/2013
Jamesburg Borough	Manalapan Lake Dam	H	Manalapan Brook	15	213	11/26/2013
Monroe Township	Regency Monroe Pond Dam	H	Offstream	14	780	7/18/2014
Spotswood Borough	Devoe Lake Dam	H	Manalapan Brook	15	290	5/31/2013
Cranbury Township	Brainerd Lake Dam	S	Cranbury Brook	12.5	382	8/27/2012
Edison Township	Roosevelt Park Dam	S	South Branch Rahway River	7.7	638	11/14/2013
Helmetta Borough	Helmetta Dam	S	Manalapan Brook	7	2000	11/26/2013
New Brunswick City	Weston's Arch Dam	S	Lawrence Brook	17	248	11/15/2013
New Brunswick City	Weston Mill Pond Dam	S	Lawrence Brook	15.5	309	11/15/2013
Old Bridge Township	Duhernal Dam	S	South River	13	878	3/18/2014
Piscataway Township	New Market Pond Dam	S	Bound Brook	7	300	1/23/2013
Plainsboro Township	Plainsboro Pond Dam	S	Cranbury Brook	10.62	500	12/2/2014
South Brunswick Township	Princeton Walk Dam	S	Carters Brook	16	400	11/20/2013
South Brunswick Township	Davidsons Mill Pond Dam	S	Lawrence Brook	9.5	135	11/15/2013
Woodbridge Township	Green Street Dam	S	Rahway River	8	755	12/3/2013
Edison Township	Silver Lake Dam	L	Raritan-TR	31	200	10/9/2013
Highland Park Borough	Pulte-Highland Park Dam	L	Raritan River-TR	16	286	
Middlesex Borough	Creighton Lake Dam	L	Ambrose Brook	10.8	200	3/16/2005
Milltown Borough	Mill Pond Dam	L	Lawrence Brook	7.5	200	8/30/2007
Milltown Borough	Ryders Crossing Regional Detention Basin	L	Lawrence Brook-TR	11.5	360	1/28/2000
Monroe Township	Monroe Hunt Pond Dam	L	Manalapan Brook-TR			6/27/2005
Monroe Township	Regency Monroe Pond No. 2 Dam	L	Offstream	10	900	
Monroe Township	Glen Rock Dam	L	Branch Manalapan Brook	9	250	4/23/2012
Monroe Township	Renaissance Dam	L	Offstream	20	200	1/22/2015
North Brunswick Township	Heritage Park Dam	L	Farrington Lake-TR	16	250	
North Brunswick Township	Hidden Lake Dam	L	6 Mile Run-TR	19	150	11/17/2001
Old Bridge Township	Deep Run Dam	L	Deep Run	10	1800	4/23/2008
Old Bridge Township	Tennents Brook Dam	L	Tennents Brook	9	600	8/22/2008
Old Bridge Township	Logan's Lake Dam at Cheesequake Village	L	Cheesequake Creek	30	170	5/24/2004
Old Bridge Township	Hooks Creek Lake Dam	L	Cheesequake Creek			3/16/2005
Old Bridge Township	Maiden Woods Dam	L	Tennents Brook-TR		800	
Piscataway Township	Piscataway Dam	L	Ambrose Brook-TR	8.1	380	
Piscataway Township	Lake Nelson Dam	L	Ambrose Brook	10.5	487	9/17/2011
Plainsboro Township	Bee Brook Detention Dam	L	Bee Brook	11	210	12/16/1991
Plainsboro Township	Walker Gordon Pond Dam	L	Devils Brook	8		9/29/1995

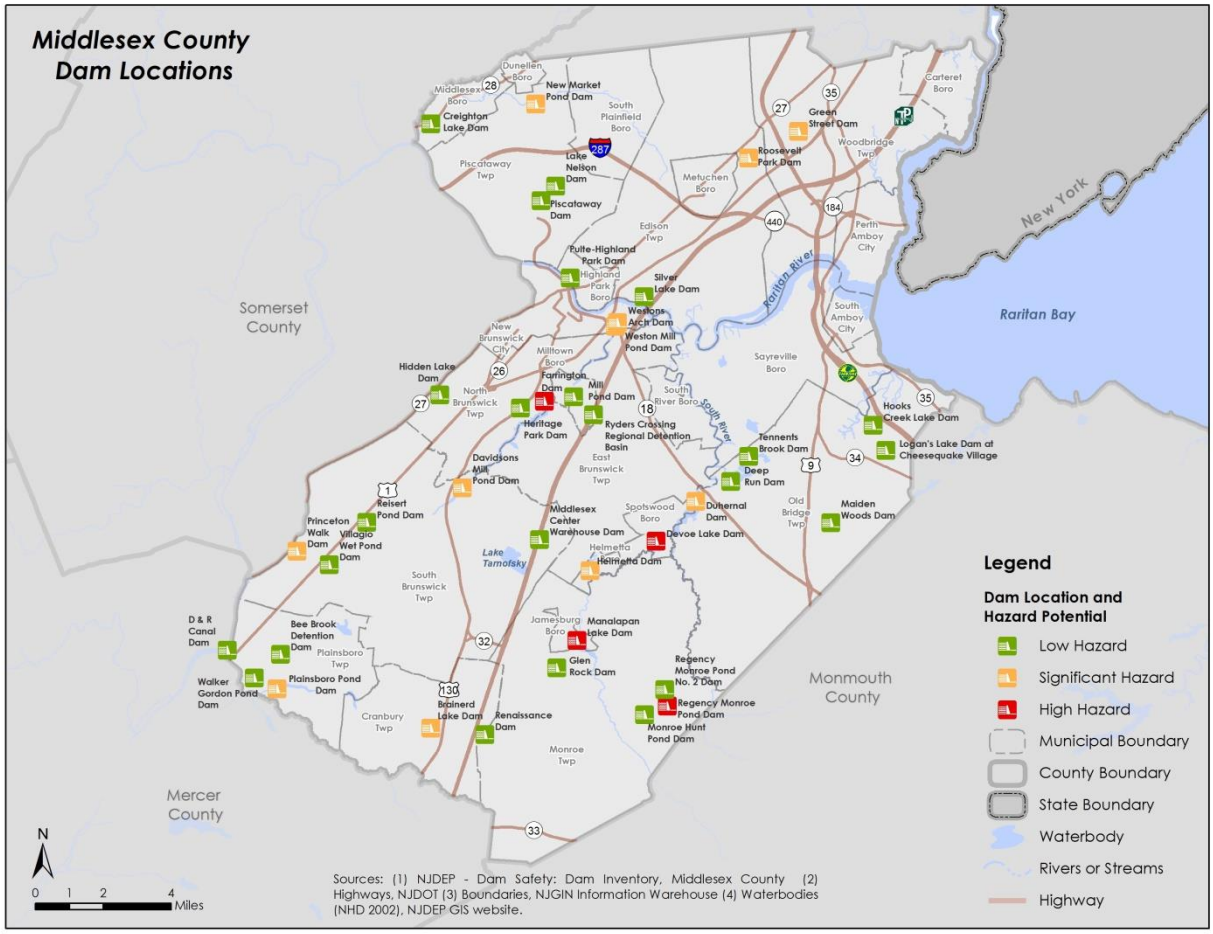
Municipality Name	Dam Name	Hazard Class	River/Stream	Height (ft)	Length (feet)	Last Date Inspected
Plainsboro Township	D & R Canal Dam	L	Millstone River		160	
South Brunswick Township	Middlesex Center Warehouse Dam	L	Offstream	10.5	1300	1/29/2007
South Brunswick Township	Reisert Pond Dam	L	Heathcote Brook	7	150	
South Brunswick Township	Villagio Wet Pond Dam	L	Heathcote Brook-TR	10	1140	3/14/2014

Hazard Classes (Source: New Jersey Administrative Code - Dam Safety Standards (NJAC: 7-20): Dam Classifications)

H = High Hazard: Loss of life likely (if failure were to occur)
S = Significant Hazard: Loss of life not likely, but the potential for significant property damage
L = Low Hazard: Loss of life not likely and minimal infrastructure and property damage other than the structure itself

The following map identifies the location for the 39 dams in Middlesex County. The inventory of dams was provided by the NJDEP - Bureau of Dam Safety and Flood Control in June 2015.

Figure 4-3
Middlesex County Dams
(Source: NJDEP – Dam Safety and Flood Control)



According to the preliminary FEMA Flood Insurance Study (FIS) for Middlesex County (dated January 31, 2014) there are two levees in the County. FEMA specifies that all levees must have a minimum of 3-foot freeboard against 1% annual chance flooding to be considered a safe flood protection structure. None of the levees in Middlesex County are accredited as providing sufficient flood control by FEMA and therefore structures protected by levees still require flood insurance.

Of the two levees in the County, one levee is located in East Brunswick Township and the second is located in Woodbridge Township. The Woodbridge Township levee protects the area of Industrial Park on the north side of the South Branch Rahway River between Wood Avenue and the Garden State Parkway. The levee is designed to a 1% annual chance recurrence interval, but does not meet FEMA specifications.

Severity and Extent of Dam/Levee Failure Hazard

In 1921, the New Jersey Legislature created the Bureau of Dam Safety and Flood Control, which instituted laws relating to the construction, repair, and inspection of existing and proposed dam structures. The law was amended in 1981, and became known as the Safe Dam Act. New Jersey's Dam Safety program is administered by NJDEP's Division of Engineering & Construction, Dam Safety Section.[11] The severity of a dam failure event can depend on various aspects related to the size of the dam, the extent of the failure, and the velocity of the floodwaters released.

In addition to the characteristics described above, dam failure severity can also depend on additional factors such as the time of day when an event occurs, the extent of development within the inundation zone and whether the failure occurs during flooding or "sunny day" conditions. Dam failure during flooding conditions may result in more severe property damage than a failure during sunny conditions due to the volume and velocity of floodwaters. However, it's possible a failure during sunny conditions could be of a greater risk to people if a breach occurs with little or no warning time. See the *Risk Assessment – Dam Failure* sub-section for inundation zone map boundaries (or buffer zone) for all high hazard dams in the region and the number of housing units and population within census blocks intersecting each zone.

The severity of the levee failure hazard can range from minor cracks along the levee wall to complete breaching of the levee. The severity of failure can be influenced by a variety of factors, such as the topography of a region, population densities, volume, depth, and velocity of water released from behind the levee. The region's topography is relatively flat, allowing floodwater that might occur as a result of levee failure to potentially disperse over a wide area.

Occurrences of the Dam/Levee Failure Hazard

The NJDEP indicates there have been no previous catastrophic dam failures in New Jersey, but the number of small failures has risen over the past few years. This has been primarily due to a combination of lack of inspection and the number of dams nearing the end of their design life. Review of past damage inspection reports from the NJDEP – Bureau of Dam Safety identified the following dam failure occurrences.

- **September 20, 1989.** Heavy rains overtopped an area adjacent to the Manalapan Lake Dam which caused partial failure and severe flooding downstream.
- **October, 1999.** A partial dam breach at Logan's Lake Dam at Cheesequake Village caused water levels to drop between five to six feet from average levels. Inspection of the damages determined an embankment failure occurred without downstream damages. Preliminary design plans were submitted, reviewed and revised in 2002. The reconstruction permit was issued in 2004.

[11] NJDEP. Retrieved from http://www.state.nj.us/dep/

- **2005/August, 2011.** The Manalapan Lake Dam was damaged again in 2005 by heavy rains and Hurricane Irene in 2011. There were no specific details available about the damages that occurred to the dam. Since then, the dam has been repaired and routinely inspected.

- **Fall, 2011.** In the fall of 2011 the Glen Rock Dam was damaged (no specific details were available about the damage). Although the dam is still included as part of the NJDEP inventory, a request for dam removal was made in 2014 and was recently reviewed and approved.

With a total of five past partial dam failure events in Middlesex County between 1989 and 2015, the County experiences a partial dam failure on average roughly every five years. With one partial dam failure event every five years, there is a 20% annual probability of a future partial dam failure events occurring in Middlesex County. Note that these calculations and estimates are for minor partial dam failures. The likelihood of a major dam failure occurring in the future is considered very low.

Review of open source data indicates there has been no past levee failure occurrences in Middlesex County.

Dam/Levee Failure Risk and Vulnerability Assessment (Including Impacts on Life and Property)

Dam failure risks have several components, including the age and condition of the dam, antecedent conditions (extreme rainfall, seismic events), downstream topography, and the type and extent of populations and infrastructure downstream. Given the number of variables involved, it is never possible to state definitively the probability of dam failure, or the consequences. However, because the definition is partly based on life safety, one proxy for risk is the downstream population potentially exposed to flooding during a dam failure.

As part of the dam failure risk assessment the Steering Committee determined that the four dams in Middlesex County classified as high hazard would be selected for further analysis. These four State-designed high-hazard (potential) dams are defined by the State as those where failure or operational failure will probably cause loss of life and/or significant infrastructure losses. The Planning Team determined that the dam inundation zones from the Emergency Action Plans (EAP) would be used for high hazard dams where this information is available. NJDEP Division of Dam Safety provided the inundation zones for the four high hazard dams.

The inundation zone maps were provided in various electronic formats (.jpeg, .pdf, etc.). Several of the maps include more than one inundation scenario. The three inundation zone scenarios include the following:

- **Sunny Day -** dam failure occurs during non-flooding conditions
- **Flood – No Breach -** dam is overtopped by floodwaters with no breaching of the dam
- **Flood - Breach -** dam is breached by floodwaters as a result of a flood event

For dams that included all three inundation zones, the worst case scenario of "Flood – Breach" was used to complete the risk assessment.

As part of the risk assessment, the inundation zone maps were imported into GIS and the geo-referencing tool used to establish a projection and match the graphic with the existing political and waterbody boundaries to identify the inundation zone area identified downstream of the dam. Digitizing was then used draw a polygon matching the Flood - Breach inundation area from the original EAP inundation zone map. This method was repeated for each of the four high hazard dams. The inundation area was then used in combination with population and housing unit data per the US Census to determine the degree of exposure downstream.

Table 4-8 shows the population and housing units potentially exposed during a dam failure. The figures are derived via GIS analysis by establishing expected inundation limits and then determining the census blocks that intersect with these. The populations and housing units are for the entire census block, not only those within specific inundation limits. It should be noted that these figures are based on specific assumptions about inundation limits, which in turn must be estimated based on variables such as the amount of water impounded at the time of the failure, and the mode of dam failure, neither of which can be known with certainty.

Table 4-8
Middlesex County High-Hazard Dams, Populations and Housing Potentially Exposed to Floods during Dam Failure
(Source: NJDEP Dam Safety; U.S. Census Bureau)

Municipality	Dam Name	Population Exposed	Housing Units Exposed
Monroe Township	Regency Pond	NA (1)	NA (1)
Borough of Spotswood	DeVoe Lake	1,172	516
Borough of Jamesburg	Manalapan Lake	1,625	551
North Brunswick Township	Farrington	8,431	2,991

(1) The Regency Pond dam failure inundation area intersects only one census block, and no census block information was available at the time of this HMP update.

Note: that the appendices for the municipalities in the table include maps that show census blocks and flood inundation limits. It is important to note that the limits of the inundation zone areas are approximate and intended for general planning purposes only and generally used in the EAPs as a guide to help with establishing evacuation zones. Actual areas inundated will depend on actual failure or flooding conditions, and may differ from the areas shown.

As mentioned earlier there are two levees in Middlesex County identified from the preliminary FIS. A risk assessment was not completed for these two levees due to insufficient data needed to perform an analysis.

Drought

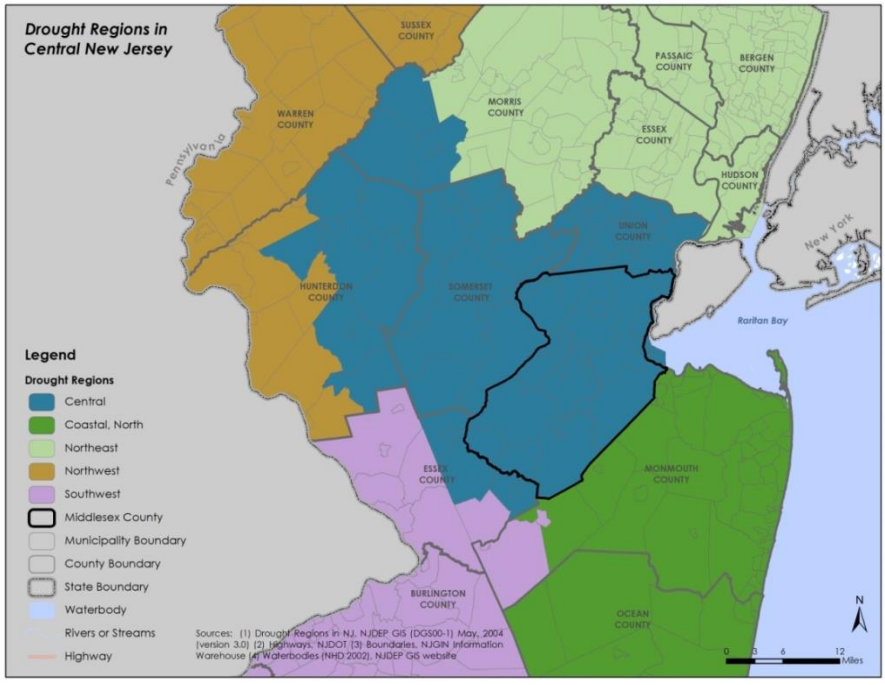
Description of the Drought Hazard

A drought is an extended dry climate condition when there is not enough water to support urban, agricultural, human, or environmental water needs. It usually refers to a period of below-normal rainfall, but can also be caused by drying bores or lakes, or anything that reduces the amount of liquid water available. Drought is a recurring feature of nearly all the world's climatic regions. For additional information about droughts visit the National Integrated Drought Information System (NIDIS) website.

Location of the Drought Hazard

Droughts may occur anywhere in the United States, and is possible throughout the planning area. Effects seen in different regions vary depending on normal meteorological conditions such as precipitation and temperature, as well as geological conditions such as soil type and subsurface water levels. The State of New Jersey is divided into six drought regions that provide a regulatory basis for coordinating local responses to regional water-supply shortages. The six drought regions are based on watershed and water-supply considerations and coincide with municipal boundaries. Each municipality in New Jersey is assigned to a drought region based on the watershed covering and supplying water to the municipality. The most recent version, shown in Figure 4-4, (Version 3.0, released in May, 2004) shows that all of Middlesex County is located in the Central Drought Region.[12]

Figure 4-4
New Jersey Drought Regions
(Source: NJDEP, Drought Regions)



[12] New Jersey Department of Environmental Protection (NJDEP), Division of Water Supply and Geoscience.

Severity and Extent of the Drought Hazard

A drought's severity depends on numerous factors, including duration, intensity, and geographic extent as well as regional water supply demands by humans and vegetation. The severity of drought can be aggravated by other climatic factors, such as prolonged high winds and low relative humidity. Due to its multi-dimensional nature, drought is difficult to define in exact terms and also poses difficulties in terms of comprehensive risk assessments.

One method used by scientists to calculate the severity and duration of a drought is the Palmer Drought Severity Index (PDSI). The PDSI indicates the prolonged and abnormal moisture deficiency or excess and indicate general conditions, not local variations caused by isolated rain. The PDSI is an important climatological tool for evaluating the scope, severity, and frequency of prolonged periods of abnormally dry or wet weather.[13]

The equation for the PDSI was empirically derived from the monthly temperature and precipitation scenarios of 13 instances of extreme drought in western Kansas and central Iowa and by assigning an index value of -4 for these cases. Conversely, a +4 represents extremely wet conditions. From these values, 7 categories of wet and dry conditions can be defined. Table 4-9 identifies the values used to define the PDSI.[14]

Table 4-9
Palmer Drought Severity Index (PDSI)
(Source: NOAA, NWS - Climate Prediction Center)

Palmer Drought Severity Index
-4.0 or less (Extreme Drought)
-3.0 or -3.9 (Severe Drought)
-2.0 or -2.9 (Moderate Drought)
-1.9 to +1.9 (Near Normal)
+2.0 or +2.9 (Unusual Moist Spell)
+3.0 or +3.9 (Very Moist Spell)
+4.0 or above (Extremely Moist)

Occurrences of the Drought Hazard

According to the NCDC database, Middlesex County has experienced 38 drought events in the period from 1950 to June 2015. All 11 events were between 1997 and June 2015. The database provides no indication as to why there are no events listed prior to 1997, although presumably occurrences follow the same pattern and frequency as shown in the NCDC list. The events are listed by month. For example, if a drought lasts several continuous months, it is listed in the database as separate events. If the

[13] NOAA. NWS. Climate Prediction Center. Drought Indices – Explanation.
[14] NOAA. NWS. Climate Prediction Center. Drought Indices – Explanation.

continuous months are combined into single events, the number of events is reduced from 38 to 11 events. The 11 events from the NCDC are summarized below in Table 4-10.

Table 4-10
Middlesex County Drought Events, 1950 – June 2015
(Source: NOAA/NCDC)

Location	Date	Injuries	Deaths	Property Damage	Crop Damage
countywide	6/30/1997	0	0	$0	$0
countywide	10/31/1997	0	0	$0	$0
countywide	6/30/1998	0	0	$0	$0
countywide	10/31/1998	0	0	$0	$0
countywide	12/14/1998	0	0	$0	$0
countywide	5/1/1999	0	0	$0	$0
countywide	10/31/2000	0	0	$0	$0
countywide	4/30/2001	0	0	$0	$0
countywide	10/30/2001	0	0	$0	$0
countywide	9/1/2005	0	0	$0	$0
countywide	9/1/2010	0	0	$0	$0
Grand Total	**----**	**0**	**0**	**$0**	**$0**

In addition to the NCDC, data from the Northeast Regional Climate Center (NRCC) was also reviewed to identify past drought events in southern New Jersey. The climate center provides historical data for severe and extreme droughts that are divided into three categories that include the Northern Climate Division, Southern Climate Division, and Coastal Climate Division. Considering the widespread impacts associated with droughts, the events listed within the Northern Climate Division were considered to impact the NJ4 HMP region. Table 4-11 lists the droughts within the Southern Climate Division between 1930 to June 2015 that were classified with a PDSI of severe or extreme (-3.0 to -4.0 or lower) for a period of two months or greater. The table shows there have been 10 significant drought events in the region between 1930 and 2013. Seven of these 10 events were also reported as part of the NCDC results. The additional six events reported in the NCDC query did not meet the PDSI threshold of severe or extreme (or two month timeframe), and therefore were not included as part of the NRCC results.

Table 4-11
Reported Droughts, Northern New Jersey (including Middlesex County), 1930 – June 2015
(Source: NOAA/NCDC, Northeast Regional Climate Center, Cornell University)

Drought Periods	Duration	Lowest PDSI	Lowest PDSI Month
8/1932 - 9/1932	2 months	-3.40	9/1932
11/1949 - 1/1950	3 months	-3.67	12/1949
9/1957 - 11/1957	3 months	-3.12	11/1957
8/1964 - 8/1966	25 months	-5.51	8/1966
12/1980 - 1/1981	2 months	-3.77	1/1981
3/1985 - 4/1985	2 months	-3.82	4/1985

Drought Periods	Duration	Lowest PDSI	Lowest PDSI Month
8/1995 - 9/1995	2 months	-3.43	8/1995
7/1999 - 8/1999	2 months	-4.15	7/1999
12/2001 - 5/2002	6 months	-4.57	2/2002
7/2002 - 9/2002	3 months	-3.28	8/2002

With a total of ten significant previous drought events (with a PDSI of severe or extreme) in Middlesex County between 1930 and 2015, the County experiences a significant drought event on average slightly more than once every eight years. Note that this average time period between events does not consider the additional six drought events reported by the NCDC that did not meet the PDSI severity threshold of severe or extreme and therefore were not included as part of the ten events. If the additional NCDC events were considered this would lower the average time period between events. With one event every eight years, there is roughly a 12% annual probability of a future significant drought event occurring in the region. Based on previous occurrences, it is reasonable to assume that droughts will continue in the region, but with no injuries, deaths, property, or crop damage the impact will continue to be reasonably low.

Drought Risk and Vulnerability Assessment (Including Impacts on Life and Property)

Droughts have the ability to impact many sectors of the economy, and reach well beyond the area experiencing physical drought. Drought impacts are commonly referred to as direct or indirect. Reduced crop productivity, increased fire hazard, reduced water levels, and damage to wildlife and fish habitat are a few examples of direct impacts. In rare cases, drought can cause damage to commercial and residential structure foundations, framing and walls, levees, roads, bridges, pipelines and other integral infrastructure. Indirect impacts of drought include increased prices for food, unemployment, and reduced tax revenues because of reduced supplies of agriculture products dependent upon rainfall.

While all residents of the region could be adversely affected by drought conditions, which could limit water supplies and present health threats, during summer drought (or hot and dry conditions) elderly persons, small children, infants and the chronically ill who do not have adequate cooling units in their homes may become more vulnerable to injury and/or death. The NCDC reported no known deaths, injuries or property damage from droughts in the region from any of the past events identified.

Limited water supplies during drought conditions could have an impact on availability of water for human consumption as well as reducing fire-fighting capabilities. New Jersey relies on reservoirs and groundwater as the main source of water. According to the State of New Jersey 2014 Hazard Mitigation Plan (Draft), New Jersey has created a water storage system that helps reduce the water supply's vulnerability to drought. The system of reservoirs allows for collection and storage of water for use

during dry periods. However, the majority of these reservoirs are located in the northern part of the state.[15]

The impacts of climate change will also have an effect on the drought hazard, resulting in more frequent and severe drought events. Climate change is expected to have a significant impact on agriculture in New Jersey. The report titled *Resilience – Preparing New Jersey for Climate Change* describes the following impacts to agriculture in New Jersey

- Decline in water availability requiring alterations to irrigation practices.
- Higher operational costs and unsuitable conditions for some current crops such as blueberries and cranberries

Perhaps the most significant potential impact from drought in New Jersey is crop damage or failure. Although urban and suburban areas dominate most of eastern New Jersey, agricultural uses are also present in many places. As such, drought presents some potential for crop loss even in more developed areas. Table 4-12 shows the types and values of agriculture in the State, and estimated as a proportion of State values based on the relative area of the County versus the State. There is no open-source information about agriculture products in Middlesex County, although it is assumed that data in the table are overestimates, based on the fact that Middlesex is very urbanized compared to many other Counties, particularly south and west of the jurisdiction. As such, these figures should be considered general and used only for comparisons with other quantified risks in the County. Note that a few common crops (such as tomatoes) are not on this list because growers would not provide information that they considered to be proprietary.

[15] State of New Jersey 2014 Hazard Mitigation Plan – Section 5.4 Drought

Table 4-12
Types and Values of Agricultural Products in New Jersey and Middlesex County
(source: http://www.stuffaboutstates.com/new.jersey/agriculture.htm)

Product	Statewide Value	Middlesex County Value
Greenhouse and nursery	$464,367,960	$17,183,051
Horses and mules	$137,340,000	$5,082,005
Blueberries	$57,493,800	$2,127,448
Dairy products	$40,708,080	$1,506,325
Chicken and eggs	$36,429,120	$1,347,990
Peaches	$29,206,800	$1,080,742
Soybeans	$27,953,100	$1,034,351
Cucumbers	$19,506,060	$721,785
Cranberries	$17,027,640	$630,075
Squash	$15,203,160	$562,564
Corn for grain	$14,666,400	$542,702
Hay	$11,959,920	$442,554
Lettuce	$10,281,600	$380,451
Cattle and calves	$9,646,560	$356,953
Cabbage	$8,158,500	$301,890
Apples	$7,246,260	$268,134
Eggplant	$6,773,760	$250,650
Sweet potatoes	$4,956,840	$183,418
Wheat	$4,609,080	$170,550

The next step is to simply estimate the potential annual damage to crops from drought. The next table (Table 4-13) is based on the assumption of a 5% annual chance of a drought significant enough to cause widespread damage to agricultural products, and that during such a drought, approximately 50% of the value of the products would be lost. As such, 2.5% of the annual crop value is assumed lost every year. This is purely an academic exercise for the purpose of including an assessment in this mitigation plan, and these results should be used only for planning and comparison purposes.

Table 4-13
Estimated Annual and 100-year Agricultural Drought Losses in Middlesex County, by Agricultural Product
(source: http://www.stuffaboutstates.com/new.jersey/agriculture.htm)

Product	Annual Drought Risk	100-year Drought Risk
Greenhouse and nursery	$429,576	$6,130,053
Horses and mules	$127,050	$1,813,005
Blueberries	$53,186	$758,967
Dairy products	$37,658	$537,381
Chicken and eggs	$33,700	$480,895
Peaches	$27,019	$385,555
Soybeans	$25,859	$369,005
Cucumbers	$18,045	$257,497
Cranberries	$15,752	$224,779
Squash	$14,064	$200,695
Corn for grain	$13,568	$193,609
Hay	$11,064	$157,881
Lettuce	$9,511	$135,726
Cattle and calves	$8,924	$127,343
Cabbage	$7,547	$107,699
Apples	$6,703	$95,657
Eggplant	$6,266	$89,419
Sweet potatoes	$4,585	$65,435
Wheat	$4,264	$60,844
Potatoes	$0	$2
Asparagus	$0	$2
Total	**$854,341**	**$12,191,449**

According to the source cited above, the total estimated 2015 value of agricultural products in Middlesex County is $34,173,649. The next table (Table 4-14) shows the acres of agriculture land uses in each Middlesex County jurisdiction, and uses the value data to estimate annual and 100-year drought losses. Annual drought losses are estimated by the same method as described above, and the 100-year losses are derived using a FEMA *present value coefficient* that produces values discounted using the FEMA/OMB rate of 7%.

Table 4-14
Estimated Annual and 100-year Agricultural Drought Losses in Middlesex County, by Jurisdiction
(source: http://www.stuffaboutstates.com/new.jersey/agriculture.htm)

Jurisdiction	Acres Agriculture	% of County Agriculture	Annual Drought Losses	100-year Drought Losses
Carteret Borough	0	0.00%	$0	$0
Cranbury Township	3,577	31.27%	$267,125	$3,811,880
Dunellen Borough	0	0.00%	$0	$0
East Brunswick Township	414	3.62%	$30,895	$440,877
Edison Township	24	0.21%	$1,761	$25,123
Helmetta Borough	0	0.00%	$0	$0
Highland Park Borough	0	0.00%	$0	$0
Jamesburg Borough	0	0.00%	$0	$0
Metuchen Borough	0	0.00%	$0	$0
Middlesex Borough	4	0.04%	$315	$4,496
Milltown Borough	0	0.00%	$0	$0
Monroe Township	3,188	27.87%	$238,103	$3,397,728
New Brunswick City	4	0.03%	$267	$3,803
North Brunswick Township	540	4.72%	$40,293	$574,975
Old Bridge Township	745	6.51%	$55,613	$793,603
Perth Amboy City	0	0.00%	$0	$0
Piscataway Township	41	0.36%	$3,094	$44,158
Plainsboro Township	980	8.57%	$73,193	$1,044,466
Sayreville Borough	29	0.25%	$2,164	$30,879
South Amboy City	0	0.00%	$0	$0
South Brunswick Township	1,891	16.53%	$141,243	$2,015,535
South Plainfield Borough	8	0.07%	$590	$8,420
South River Borough	0	0.00%	$0	$0
Spotswood Borough	0	0.00%	$0	$0
Woodbridge Township	0	0.00%	$0	$0
Total	**11,444**	**100%**	**$854,341**	**$12,195,942**

Earthquake

Description of the Earthquake Hazard

An earthquake is a sudden release of energy from the earth's crust that creates seismic waves. Tectonic plates become stuck, putting a strain on the ground. When the strain becomes so great that rocks give way, fault lines occur. At the Earth's surface, earthquakes may manifest themselves by a shaking or displacement of the ground, which may lead to loss of life and destruction of property. Size of an earthquake is expressed quantitatively as magnitude and local strength of shaking as intensity. The inherent size of an earthquake is commonly expressed using a magnitude. For additional information about earthquakes visit the United States Geological Survey (USGS), Earthquake Hazards Program located at http://earthquake.usgs.gov/.

Location of the Earthquake Hazard

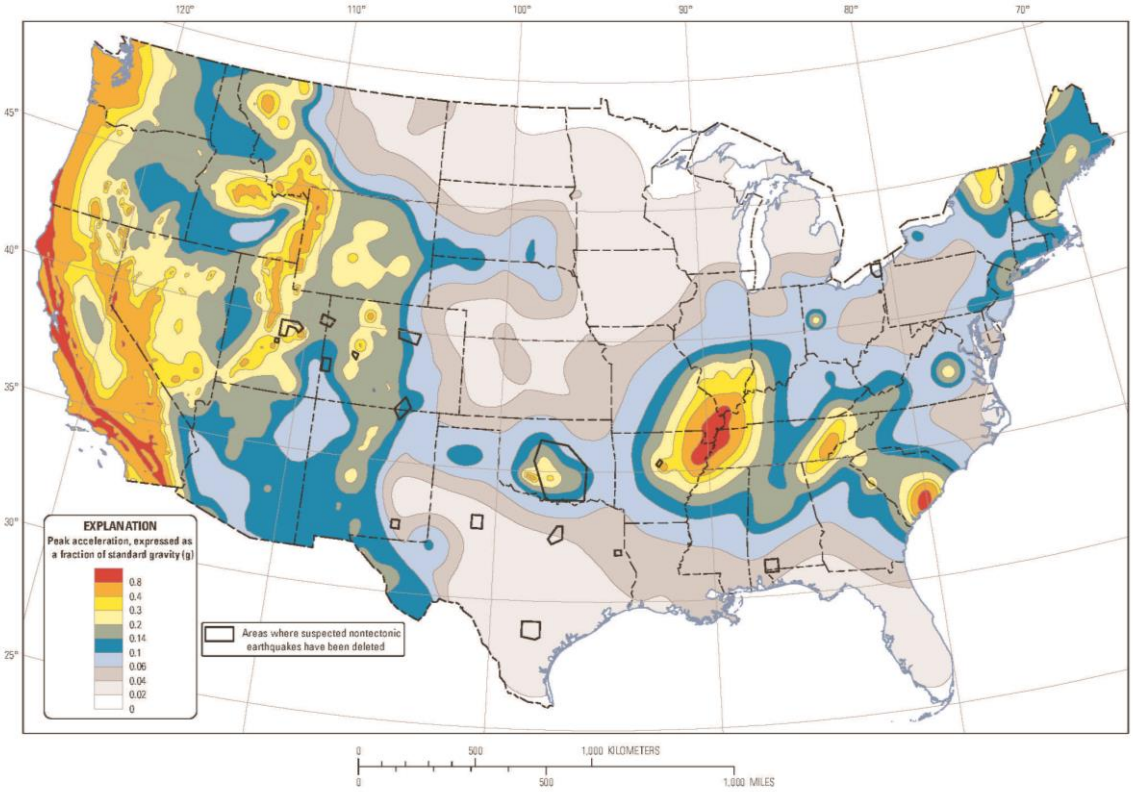
Review of the State of New Jersey 2014 Hazard Mitigation Plan (Draft) and other sources indicates that earthquakes are most likely to occur in the northern parts of the State (including Middlesex County) where significant faults are concentrated. The entire region is susceptible to the effects of earthquakes.

In 1996, the USGS produced probabilistic Seismic Hazard Maps for the United States. The USGS revises these maps roughly every six years to reflect newly published or thoroughly reviewed earthquake science and to keep pace with regular updates of the building code. The USGS maps were updated in 2002, 2008, and 2014. The 2014 USGS National Seismic Hazard Maps display earthquake ground motions for various probability levels across the United States and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy. The 2014 update of the maps incorporates new findings on earthquake ground shaking, faults, seismicity, and geodesy. The resulting maps are derived from seismic hazard curves calculated on a grid of sites across the United States that describe the frequency of exceeding a set of ground motions.[16]

The 2010 Middlesex County HMP included a USGS seismic hazard map from October 2002 showing peak ground acceleration (PGA) with a 10% chance of being exceeded over 50 years. PGA (peak acceleration) is a measure of earthquake acceleration on the ground and an important input parameter for earthquake engineering. It is a measure of how hard the ground shakes (or intensity) in a given geographic area. Figure 4-5 displays the most recent USGS National Seismic Hazard Map produced in 2014. The map shows PGA with a 2% chance of being exceeded over 50 years. The map shows that the PGA is highest in northeastern New Jersey (0.14 - 0.2%g) and decreases to the south (0.06 – 0.1%g). The map shows that the PGA in Middlesex County ranges from 0.14 – 0.2%g (shaded green).

[16] USGS. Documentation for the 2008 Update of the U.S. National Seismic Hazard Maps. Open File Report (2008-1128)

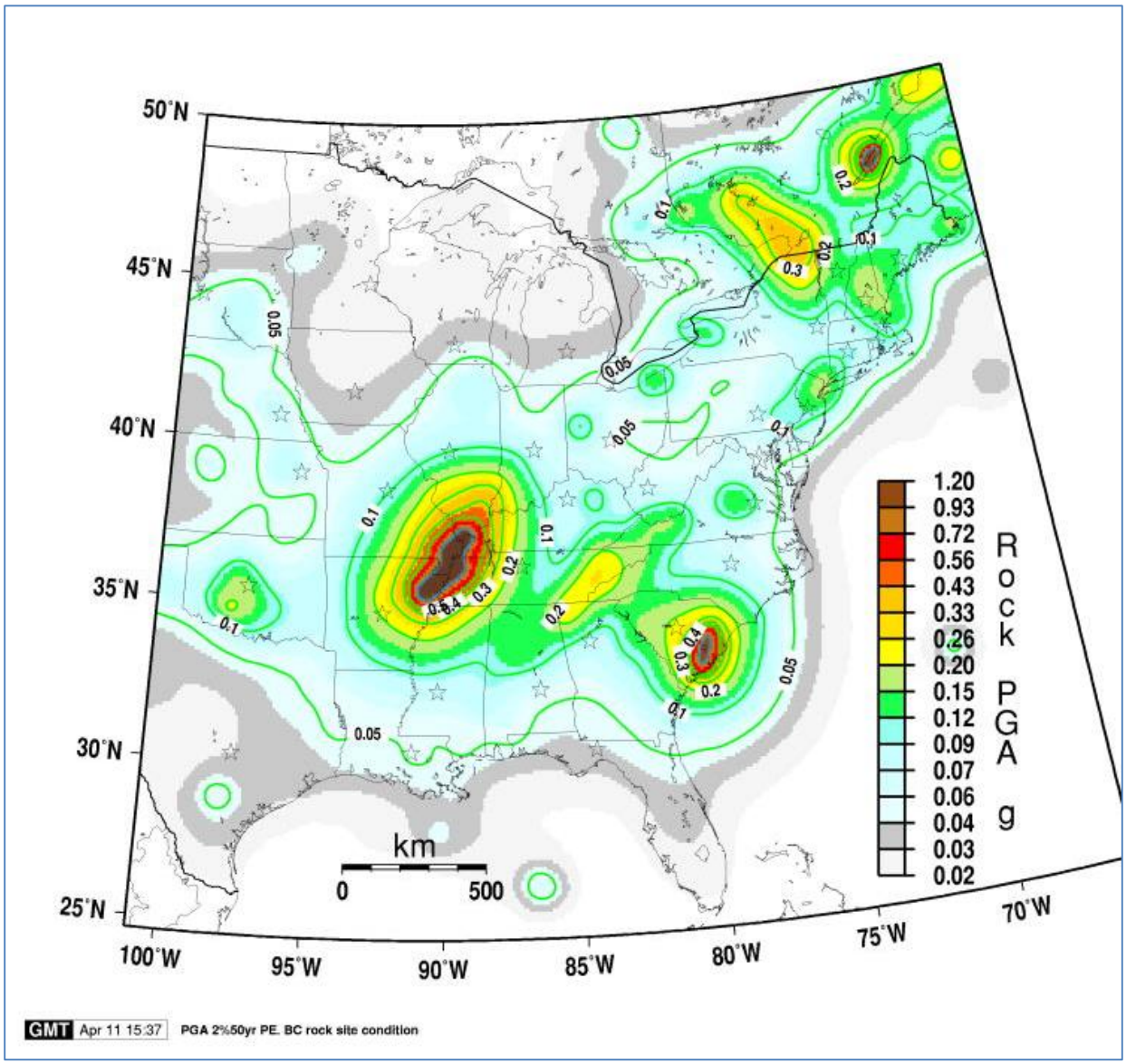
Figure 4-5
2014 US Seismic Hazard Map, showing Peak Ground Acceleration,
with 2% Probability of Exceedance in 50 Years
(Source: USGS, 2014 Update of the U.S. National Seismic Hazard Map)



Two-percent probability of exceedance in 50 years map of peak ground acceleration

In comparison to the 2008 Seismic Hazard Map, the 2014 version indicates a slight increase in risk in north-central New Jersey. Figure 4-6 is the 2008 USGS seismic hazard map for the central and eastern United States showing pga with a 2% chance of being exceeded over 50 years. The 2008 version shows Middlesex County in the 0.12g to 0.20g peak acceleration range. In Middlesex County, the lower range of the 2014 Seismic Hazard Map begins at 0.14g, a 0.02g increase from the 2008 version.

Figure 4-6
2008 US Seismic Hazard Map, showing Peak Ground Acceleration in Percent of *g*,
with 2% exceedance in 50 Years
(Source: USGS, 2008)

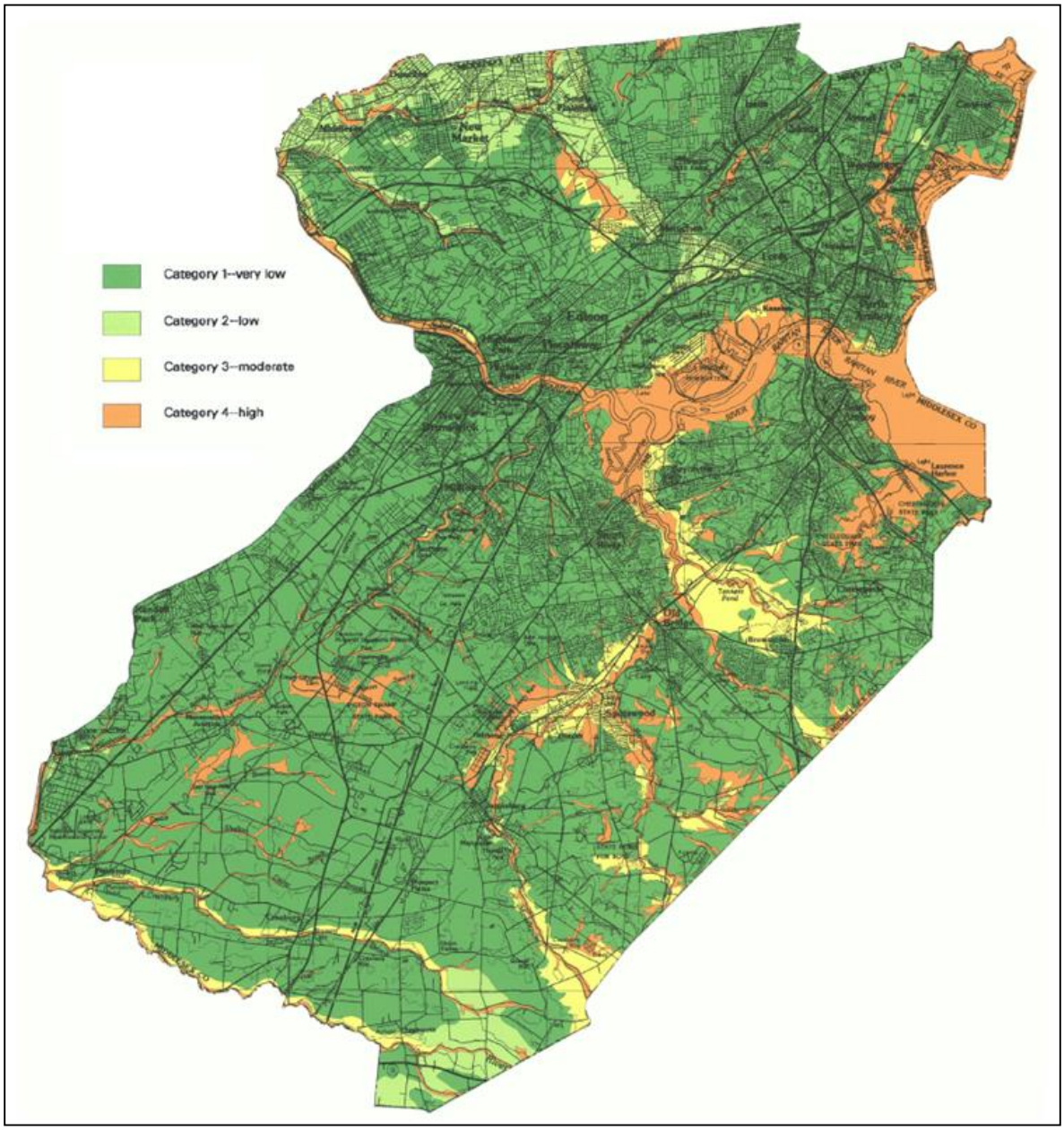


In 2003 the New Jersey Geologic Survey (NJGS) completed an *Earthquake Loss Estimation Study for Middlesex County.* The NJGS acquired and analyzed geologic, topographic and test-boring data in order to map seismic soil class, liquefaction susceptibility, and landslide susceptibility for Middlesex County. The soil class, liquefaction, and landslide susceptibility were then entered into the HAZUS model for each census track in the county.

The Study completed by the NJGS identified and mapped the distribution and thickness of 12 surface materials for Middlesex County. Mapping the soil type for each census track identifies areas that are susceptible to soil liquefaction. Figure 4-7 below is a soil liquefaction map for Middlesex County. The

map identifies the northeast County border and the Raritan River floodplain as the main areas of high susceptibility for soil liquefaction.

Figure 4-7
Middlesex County, New Jersey Soil Liquefaction Susceptibility
(Source: Earthquake Loss Estimation Study for Middlesex County, New Jersey: Geologic Component
(New Jersey Geologic Survey, 2003, page 123)



Severity and Extent of the Earthquake Hazard

Relatively low on magnitude and intensity scales for past events, Middlesex County has experienced few and minor earthquakes, on average, over the past 75-plus years. As shown in Figure 4-6, the probability of any severe earthquake in the area is moderate. The severity of earthquakes is influenced by several factors, including the depth of the quake, the geology in the area, and the soils. The severity of soil liquefaction is dependent on the soils grain size, thickness, compaction, and degree of saturation. [17]

The most common method for determining the magnitude of an earthquake is the Richter scale. The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions.[18] The Richter scale magnitudes are summarized in Table 4-15.

Table 4-15
Richter Magnitude Scale
(Source: USGS)

Richter Magnitude Scale	Earthquake Effects
2.5 or less	Usually not felt, but can be recorded by seismograph
2.5 to 5.4	Often felt, but causes only minor damage
5.5 to 6.0	Slight damage to buildings and other structures
6.1 to 6.9	May cause a lot of damage in very populated areas
7.0 to 7.9	Major earthquake; serious damage
8.0 or greater	Great earthquake; can totally destroy communities near the epicenter

Although numerous intensity scales have been developed in the past to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli (MM) Intensity Scale. Mercalli ratings use Roman numerals as categories range from I – XII. This scale is composed of increasing levels of intensity that range from imperceptible shaking to catastrophic destruction. It does not have a mathematical basis for the intensity rankings, but instead it is an arbitrary ranking based on observed effects. A low intensity earthquake, where few people feel the vibration (and there is no significant property damage), is rated as an I or II. The higher numbers (VII and above) of the scale are based on observed structural damages. The highest rating, a XII, is applied to earthquakes in which many structures are destroyed, the ground is cracked and other natural disasters, such as landslides or tsunamis, are initiated. Table RP.3-39 summarizes earthquake intensity as expressed by the Modified Mercalli scale.

[17] NJGS. Retrieved from http://www.state.nj.us/dep/njgs/geodata/dgs02-5.htm
[18] USGS – Definitions.

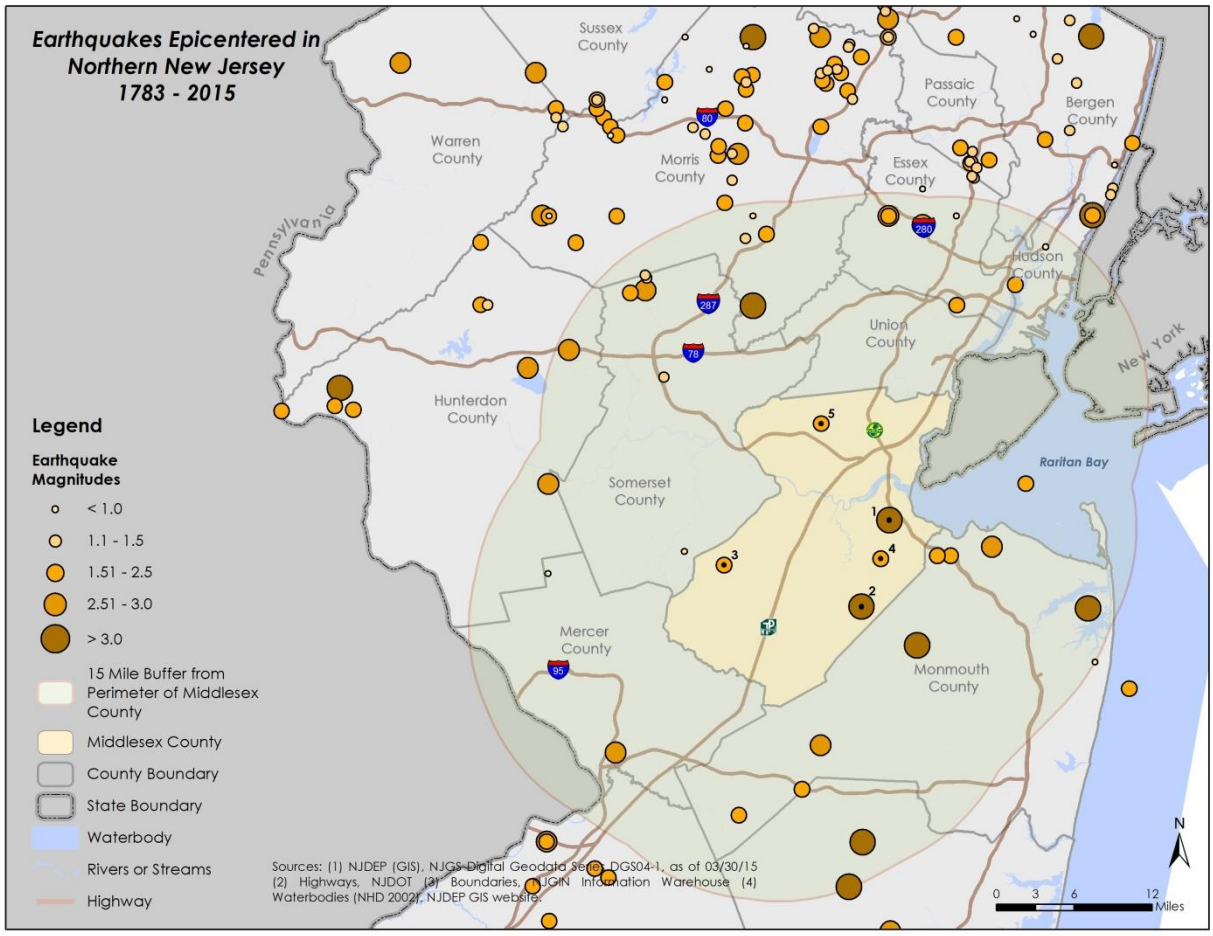
Table 4-16
Modified Mercalli Intensity Scale
(Source: USGS)

Intensity	Description/Damage
I	Not felt except by a very few under especially favorable conditions.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
II	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rail bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Occurrences of the Earthquake Hazard

To identify past earthquake occurrences that have potentially impacted Middlesex County, earthquake data from the NJDEP, New Jersey Geological and Water Survey (NJGWS) was reviewed. The NJGWS earthquake data indicates there have been 187 earthquakes with epicenters in New Jersey between 1783 and March 2015. During this 232 year time period most have been minor with magnitudes ranging from 0.4 to 5.3 and depths up to 25 km below sea level. Of the 187 earthquakes, five had an epicenter in Middlesex County. Figure 4-8 displays historical earthquakes with epicenters in northern New Jersey during this time period between 1783 and March 2015. The map also highlights earthquakes that have occurred within a 15 mile buffer extending out from the Middlesex County border. These earthquake epicenters are included within the area circled on the map. A total of 38 earthquake epicenters have occurred within this 15 mile buffer.

Figure 4-8
Earthquake Epicenters In Northern New Jersey
(Sources: NJDEP, New Jersey Geological and Water Survey, March 2015)



Note: This map was developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state-authorized.

Table 4-17 includes the five earthquakes with epicenters within Middlesex County between 1783 and 2015. Of the five earthquakes, the largest was a 4.1 magnitude event that occurred in September, 1895 in Sayreville Borough.

Table 4-17
Earthquakes in Middlesex County, 1783 – March 2015
(Sources: NJDEP, New Jersey Geological and Water Survey, May 2015)

Map ID	Event Date	Epicenter	Magnitude
1	09/01/1895	Sayreville Borough	4.1
2	1/9/1992	Old Bridge Township	3.1
3	7/15/1997	South Brunswick Township	2.3
4	6/6/2010	Old Bridge Township	2.3
5	6/9/2011	South Plainfield Borough	1.6

The following table (Table 4-18) shows the five most recent earthquakes within a 15 mile buffer of Middlesex County. The most recent event near Middlesex County occurred on December 13, 2014 when a 1.9 magnitude earthquake occurred in Millstone Township in Monmouth County, New Jersey.

Table 4-18
Five Most Recent Earthquakes within a 15 mile Buffer of Middlesex County
(Sources: NJDEP, New Jersey Geological and Water Survey, March 2015)

Event Date	Epicenter	County	Magnitude
12/13/2014	Millstone Township	Monmouth	1.9
7/8/2014	Kearny Town	Hudson	1.6
6/9/2011	South Plainfield Borough	Middlesex	1.6
6/6/2010	Old Bridge Township	Middlesex	2.3
2/21/2010	Bedminster Township	Somerset	2.3

Table 4-19 identifies the top five magnitude events within a 15 mile buffer of Middlesex County between 1783 and 2015. The table shows the largest earthquake within this radius was a 4.1 magnitude event in 1895 with an epicenter in Sayreville, New Jersey.

Table 4-19
Top 5 Magnitude Earthquake Events within a 15 Mile Buffer of Middlesex County, 1783- 2015
(Sources: NJDEP, New Jersey Geological and Water Survey, March 2015)

Event Date	Epicenter	County	Magnitude
09/01/1895	Sayreville Borough	Middlesex	4.1
8/23/1938	Jackson Township	Ocean	4
6/1/1927	Rumson Borough	Monmouth	3.9
8/23/1938	Jackson Township	Ocean	3.8
1/30/1979	Marlboro Township	Monmouth	3.5

With a total of 38 previous earthquakes having epicenters within 15 miles of the Middlesex County border between 1783 and 2015, the County experiences an earthquake event on average slightly more than once every six years. With one event roughly every six years, there is a 16% annual probability of a future earthquake events occurring in Middlesex County. Considering the impacts from the 38 past events have all been relatively minor, the 2016 Middlesex County HMPSC ranked earthquakes as a low risk hazard (See Table 4-1 for a complete list of hazard rankings).

Earthquake Risk and Vulnerability Assessment (Including Impacts on Life and Property)

The primary cause of earthquake damage to man-made structures is ground shaking. Depending on the severity of ground shaking, debris and falling building material can create a threat to life and property. Severe enough ground shaking, particularly for longer periods, can result in the complete collapse of some unreinforced or lightly engineered structures. The amount of ground-shaking depends on how soft and how deep the soil is, and on the type of bedrock lying beneath it. Also important is whether the soil type will lose strength, liquefy or slide downhill when shaken.

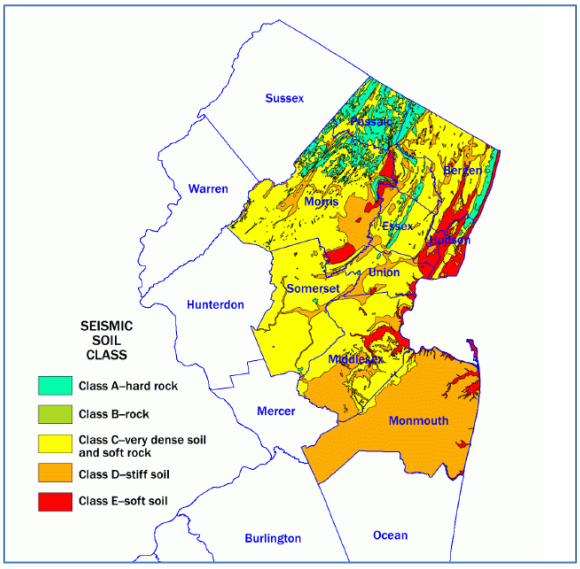
Damage can be increased when soft soils amplify ground shaking. FEMA's National Earthquake Hazard Reduction Program (NEHRP) developed five soil classifications defined by their shear-wave velocity that impact the severity of an earthquake. The soil classification system ranges from A to E, as noted in Table 4-20, where A represents hard rock that reduces ground motions from an earthquake and E represents soft soils that amplify and magnify ground shaking and increase building damage and losses.

Table 4-20
NEHRP Soil Classifications
(Source: FEMA)

Soil Classification	Description
A	Hard Rock
B	Rock
C	Very Dense soil and soft rock
D	Stiff soils
E	Soft soils

Figure 4-9 identifies the NEHRP soils for New Jersey counties located in the northeast quadrant the State. The map was produced by the New Jersey Geologic and Water Survey (NJGWS) as part of the Earthquake Loss Estimation Study for New Jersey. The majority of Middlesex County falls within Class C – Very Dense Soil and Soft Rock (shaded yellow). Approximately 25% of the area is located within Class D – Stiff Soil (shaded orange). The far eastern part of the County (and areas inland along the Raritan River) is located within Class E – Soft Soil (shaded red).

Figure 4-9
Seismic Soils in Northeastern New Jersey
(Source: New Jersey Geological and Water Survey)



There are no known deaths or injuries from earthquakes in Middlesex County. Some of the past earthquake events were severe enough to cause minor property damage such as broken windows or contents falling from shelves. The effects on life and property in the area could be significant if a large earthquake were to occur, because of the nature of the built environment. However, the very low probability of an event suggests that potential for these impacts is minimal.

HAZUS Earthquake Risk Assessment

To ascertain risks from seismic hazard in Middlesex County, our team performed Level 1 analysis using Earthquake Module of FEMA HAZUS v2.1 tool. HAZUS is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. Analysis was performed for the probabilistic event, where HAZUS model used available relevant seismic records in its database. Annual estimation was performed using ground motion predictions for eight return periods (100, 250, 500, 750, 1000, 1500, 2000, and 2500 years).

The geographical size of the Middlesex County is 313.58 square miles and it contains 177 census tracts. There are over 265 thousand households in the County which has a total population of 750,162 people (2002 Census Bureau data, used by HAZUS 2.1). There are an estimated 234,852 buildings in the County with a total building replacement value (including contents) of $119,948,782 (millions of dollars). Approximately 91 % of all the buildings and 59% of the total building exposure are associated with residential housing. Table 4-21 details the total exposure for each municipality in the County, per each of the seven general occupancy classes.

Table 4-21
Middlesex County Building Count by Occupancy Class
(Source: HAZUS- MH 2.1 Earthquake Module, August 2015)

Municipality Name	Residential	Commercial	Industrial	Agricultural	Religious	Government	Education	Total Exposure
Carteret Borough	$1,622,359	$873,694	$316,623	$3,906	$48,970	$9,098	$48,074	$2,922,724
Cranbury Township	$462,472	$339,815	$366,318	$7,606	$11,624	$5,986	$4,672	$1,198,493
Dunellen Borough	$642,159	$226,142	$30,254	$936	$25,032	$5,734	$8,496	$938,753
East Brunswick Township	$5,139,342	$2,160,403	$493,414	$21,020	$126,546	$59,644	$129,282	$8,129,651
Edison Township	$10,008,005	$10,006,868	$1,445,575	$36,088	$160,548	$714,677	$319,068	$22,690,829
Helmetta Borough	$193,919	$18,332	$3,513	$1,714	$4,170	$284	$1,428	$223,360
Highland Park Borough	$1,231,360	$471,921	$30,627	$2,266	$49,640	$5,404	$44,978	$1,836,196
Jamesburg Borough	$626,915	$133,537	$29,006	$3,742	$18,140	$9,028	$22,636	$843,004
Metuchen Borough	$1,479,025	$573,212	$161,312	$4,008	$96,060	$10,219	$46,776	$2,370,612
Middlesex Borough	$1,293,559	$437,762	$348,746	$7,992	$51,030	$9,021	$31,844	$2,179,954
Milltown Borough	$759,844	$229,233	$46,644	$1,494	$26,836	$6,179	$9,264	$1,079,494
Monroe Township	$3,366,465	$645,036	$153,086	$45,136	$43,248	$35,873	$23,490	$4,312,334
New Brunswick	$3,288,507	$1,683,662	$757,667	$3,570	$180,836	$99,934	$235,982	$6,250,158
North Brunswick Township	$3,322,388	$1,095,251	$487,410	$11,098	$80,696	$5,934	$102,162	$5,104,939
Old Bridge Township	$5,882,717	$1,038,924	$281,145	$17,328	$104,094	$24,739	$97,100	$7,446,047
Perth Amboy	$2,974,746	$1,093,046	$370,686	$4,372	$119,490	$30,856	$44,552	$4,637,748
Piscataway Township	$4,916,517	$1,670,591	$739,165	$115,852	$138,304	$33,223	$358,605	$7,972,257
Plainsboro Township	$2,361,452	$875,422	$846,773	$2,950	$38,240	$41,862	$24,640	$4,191,339
Sayreville Borough	$3,839,884	$939,126	$420,778	$5,472	$35,526	$21,921	$40,992	$5,303,699
South Amboy	$699,597	$149,875	$31,708	$706	$25,798	$12,787	$17,452	$937,923
South Brunswick Township	$3,990,942	$2,125,733	$999,556	$16,596	$88,354	$43,121	$48,058	$7,312,360
South Plainfield Borough	$2,267,893	$1,345,764	$1,538,514	$12,628	$36,684	$9,850	$165,086	$5,376,419
South River Borough	$1,336,161	$320,762	$121,216	$3,504	$46,302	$14,529	$12,808	$1,855,282
Spotswood Borough	$726,954	$162,881	$20,251	$6,680	$11,724	$1,486	$13,862	$943,838
Woodbridge Township	$8,868,009	$3,671,012	$984,120	$19,120	$139,192	$66,394	$142,522	$13,890,369
Totals	**$71,301,191**	**$32,288,004**	**$11,024,107**	**$355,784**	**$1,707,084**	**$1,277,783**	**$1,993,829**	**$119,947,782**

The total annualized economic loss estimated for the earthquake is $1.63 million. Table 4-22 presents the annualized losses in Middlesex County, also per each occupancy class and a municipality.

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses (or Capital Stock Losses) are the estimated costs to repair or replace the damage caused to the building and its contents. In Table 4-23, these losses are contained within three subcategories: Building, Contents, and Inventory loses. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake. In Table 4-23, these losses are defined in four sub-categories: relocation cost, business income loss, rental loss, and lost wages. The total annualized building-related losses were $1.63 million; 17 % of the estimated losses were related to the business ($0.29 million). The projected losses over the 50-year and 100-year horizons were $22.48 million and $23.24 million, respectively. Projected losses were calculated using conversion factors of 13.801, and 14.269, which were based on FEMA discount rate of 7%.

Table 4-22
Middlesex County Annualized Seismic Losses by Occupancy Class (Source: HAZUS- MH 2.1 Earthquake Wind Module, August 2015)

Municipality Name	Residential	Commercial	Industrial	Agricultural	Religious	Government	Education	Annualized Loss
Carteret Borough	$21,850	$16,720	$4,580	$50	$810	$170	$780	$44,960
Cranbury Township	$4,220	$5,390	$4,120	$90	$140	$90	$60	$14,110
Dunellen Borough	$7,550	$4,420	$440	$10	$380	$100	$130	$13,030
East Brunswick Township	$52,790	$39,610	$6,460	$260	$1,770	$990	$1,840	$103,720
Edison Township	$119,040	$180,330	$20,130	$490	$2,460	$12,200	$4,900	$339,550
Helmetta Borough	$2,010	$330	$40	$20	$60	$0	$20	$2,480
Highland Park Borough	$14,770	$9,110	$410	$30	$730	$90	$660	$25,800
Jamesburg Borough	$6,180	$2,300	$360	$40	$230	$140	$300	$9,550
Metuchen Borough	$16,650	$11,530	$2,360	$60	$1,490	$180	$720	$32,990
Middlesex Borough	$14,160	$8,260	$4,820	$100	$760	$160	$480	$28,740
Milltown Borough	$7,730	$4,370	$620	$20	$380	$100	$130	$13,350
Monroe Township	$32,050	$10,510	$1,800	$510	$540	$540	$300	$46,250
New Brunswick	$44,790	$32,940	$10,180	$40	$2,640	$1,720	$3,490	$95,800
North Brunswick Township	$35,960	$20,020	$6,180	$130	$1,130	$90	$1,450	$64,960
Old Bridge Township	$61,740	$19,370	$3,600	$200	$1,470	$370	$1,380	$88,130
Perth Amboy	$39,720	$21,170	$5,320	$50	$1,820	$530	$670	$69,280
Piscataway Township	$56,630	$31,390	$10,170	$1,560	$2,060	$560	$5,360	$107,730
Plainsboro Township	$23,140	$13,470	$9,250	$30	$470	$620	$310	$47,290
Sayreville Borough	$42,740	$17,610	$5,710	$70	$510	$370	$600	$67,610
South Amboy	$8,310	$3,040	$450	$0	$390	$220	$260	$12,670
South Brunswick Township	$38,620	$34,030	$11,670	$190	$1,130	$650	$630	$86,920
South Plainfield Borough	$26,460	$25,750	$21,730	$180	$570	$170	$2,510	$77,370
South River Borough	$14,610	$5,910	$1,600	$40	$670	$240	$190	$23,260
Spotswood Borough	$7,500	$2,840	$260	$80	$160	$20	$190	$11,050
Woodbridge Township	$109,040	$73,070	$14,060	$280	$2,190	$1,220	$2,250	$202,110
Totals	**$808,260**	**$593,490**	**$146,320**	**$4,530**	**$24,960**	**$21,540**	**$29,610**	**$1,628,710**

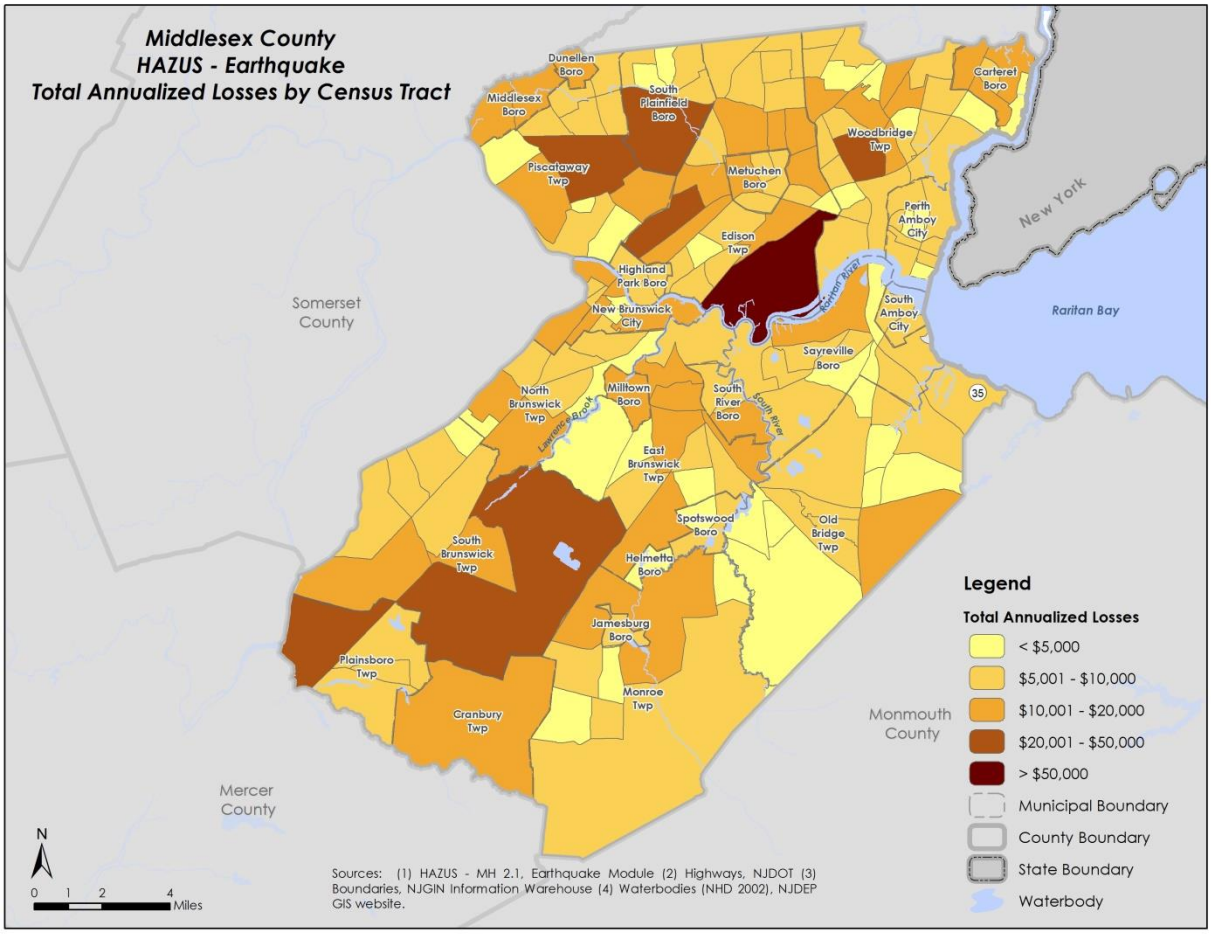
Table 4-23

Annualized Seismic Losses by Occupancy Class and Overall Risk for 50-year and 100-year Horizons (Source: HAZUS- MH 2.1 Earthquake Wind Module, August 2015)

Municipality Name	Building Damages	Contents Damages	Inventory Loss	Relocation Cost	Business Income Loss	Rental Loss	Lost Wages	Total Annualized Loss	50-year Risk	100-year Risk
Carteret Borough	$27,650	$9,660	$390	$3,260	$920	$2,090	$1,050	$44,980	$620,769	$641,820
Cranbury Township	$8,150	$3,230	$300	$850	$470	$470	$640	$14,100	$194,594	$201,193
Dunellen Borough	$8,140	$2,610	$70	$920	$330	$530	$460	$13,040	$179,965	$186,068
East Brunswick Township	$63,030	$21,310	$590	$7,070	$3,460	$3,860	$4,430	$103,720	$1,431,440	$1,479,981
Edison Township	$198,800	$72,130	$1,930	$25,930	$11,060	$17,000	$12,710	$339,500	$4,685,440	$4,844,326
Helmetta Borough	$1,710	$480	$0	$150	$40	$80	$40	$2,490	$34,364	$35,530
Highland Park Borough	$15,780	$4,970	$40	$1,870	$740	$1,320	$1,070	$25,800	$356,066	$368,140
Jamesburg Borough	$6,110	$1,850	$30	$640	$230	$360	$320	$9,550	$131,800	$136,269
Metuchen Borough	$20,060	$6,970	$200	$2,310	$970	$1,160	$1,340	$33,010	$455,571	$471,020
Middlesex Borough	$17,700	$6,260	$330	$1,980	$610	$1,000	$850	$28,740	$396,641	$410,091
Milltown Borough	$8,220	$2,670	$60	$890	$480	$460	$560	$13,350	$184,243	$190,491
Monroe Township	$30,300	$9,100	$180	$3,090	$850	$1,580	$1,170	$46,280	$638,710	$660,369
New Brunswick	$56,030	$19,210	$620	$6,650	$3,340	$4,410	$5,540	$95,810	$1,322,274	$1,367,113
North Brunswick Township	$40,240	$13,190	$470	$4,410	$1,790	$2,540	$2,380	$64,980	$896,789	$927,200
Old Bridge Township	$57,350	$17,650	$260	$5,600	$1,830	$2,990	$2,500	$88,170	$1,216,834	$1,258,098
Perth Amboy	$42,470	$13,780	$360	$4,940	$1,740	$3,590	$2,420	$69,300	$956,409	$988,842
Piscataway Township	$67,150	$22,800	$720	$7,420	$2,490	$3,930	$3,250	$107,740	$1,486,920	$1,537,342
Plainsboro Township	$29,420	$10,270	$520	$2,870	$1,040	$1,990	$1,170	$47,310	$652,925	$675,066
Sayreville Borough	$43,030	$13,850	$450	$4,290	$1,480	$2,450	$2,010	$67,590	$932,810	$964,442
South Amboy	$7,990	$2,520	$30	$910	$280	$540	$410	$12,680	$174,997	$180,931
South Brunswick Township	$53,140	$18,460	$940	$5,990	$2,220	$3,370	$2,850	$86,950	$1,199,997	$1,240,690
South Plainfield Borough	$44,970	$18,100	$1,490	$5,040	$2,090	$2,660	$3,040	$77,350	$1,067,507	$1,103,707
South River Borough	$14,820	$4,710	$130	$1,640	$480	$900	$580	$23,260	$321,011	$331,897
Spotswood Borough	$7,210	$2,150	$30	$820	$210	$380	$250	$11,060	$152,639	$157,815
Woodbridge Township	$124,050	$41,880	$1,160	$13,700	$6,010	$8,550	$6,770	$202,170	$2,790,148	$2,884,764
Totals	**$993,520**	**$339,810**	**$11,300**	**$113,240**	**$45,160**	**$68,210**	**$57,810**	**$1,628,930**	**$22,480,863**	**$23,243,202**

The total annualized damages, broken down by the census tract are depicted in the HAZUS-MH output. The map shows that census tracts in southern Edison Township and southwest Middlesex County and have the highest annual losses.

Figure 4-10
Estimated Earthquake Risk to Middlesex County, Total Annualized Losses per Census Tract
(Source: HAZUS- MH 2.1 Earthquake Module, August 2015)



Extremely High Temperatures

Description of the Extremely High Temperatures Hazard

Temperatures that are significantly above normal are considered extreme temperatures. There is no specific point when air temperatures are defined as significantly above normal. However, the NWS will initiate alert procedures such as special weather statements when the heat index is expected to exceed 105˚F-110˚F (depending on local climate), for at least two consecutive days.[19] Heat stress can be indexed

[19] NOAA-Heat Wave Description

by combining the effects of temperature and humidity. For information about extreme hot temperatures see the NWS Extreme heat page at http://www.nws.noaa.gov/os/heat/index.shtml.

Location of the Extremely High Temperatures Hazard

The entire planning area is subject to the hazards associated with extreme high temperatures. Therefore, in general, all people and structures are equally exposed to extreme temperatures.

Severity and Extent of Extremely High Temperatures

The severity of extreme heat events is measured by temperature, duration, and humidity. Most events are less than a week in duration. In the northeastern U.S., periods of warmer than normal temperatures typically occur several times a summer. Extreme heat waves may occur about once every five years or so where maximum daily temperatures exceed 100°F for an extended period of time. The passing of a cold front usually moderates temperatures after a few days to a week.

Heat kills by pushing the body beyond its limits. Under normal conditions an internal thermostat produces perspiration that evaporates and cools the body. The human body dissipates heat by varying the rate and depth of blood circulation, by losing water through the skin and sweat glands, and as a last resort, by panting, when blood is heated above 98.6°F. Sweating cools the body through evaporation. However, high relative humidity retards evaporation, robbing the body of its ability to cool itself. When heat gain exceeds the level the body can remove, body temperature begins to rise, and heat related illnesses and disorders might develop.

Most heat disorders occur because the victim has been overexposed to heat or has over-exercised for his or her age and physical condition. The ***Heat Index*** (HI) is the temperature the body feels when heat and humidity are combined. Table 4-24 and 4-25 illustrate the heat index and its potential effects on the human body.

Table 4-24
Temperature Versus Relative Humidity
(Source: NWS)

Temperature (F)	Relative Humidity (%)					
	90%	80%	70%	60%	50%	40%
80	85°	84°	82°	81°	80°	79°
85	101°	96°	92°	90°	86°	84°
90	121°	113°	105°	99°	94	90°
95		133°	122°	113°	105°	98°
100			142°	129°	118°	109°
105				148°	133°	121°
110						135°

*This chart is based upon shady, light wind conditions; exposure to direct sunlight can increase the HI by up to 15°F.
** Due to the nature of the heat index calculation, the values in the table have an error +/- 1.3F.

Source: National Weather Service: http://www.crh.noaa.gov/pub/heat.htm

Table 4-25
Heat Index Versus Possible Effects
(Source: NWS)

Hi Temperature	Possible Heat Disorder
80°F - 90°F	Fatigue possible with prolonged exposure and physical activity.
90°F - 105°F	Sunstroke, heat cramps and heat exhaustion possible.
105°F - 130°F	Sunstroke, heat cramps, and heat exhaustion likely, and heat stroke possible.
130°F or greater	Heat stroke highly likely with continued exposure.

Source: National Weather Service: http://www.crh.noaa.gov/pub/heat.htm

Occurrences of Extremely High Temperatures

The NCDC database indicates there have been 76 recorded heat events and 14 excessive or extreme high temperature events in Middlesex County during the period 1950 – June 2015. Although the query results begin in 1950, the first reported event was in 2001. There are most likely additional extreme heat events prior to 1996 that are not captured in the NCDC database. The database provides no indication as to why there are no events prior to 2001, although presumably occurrences follow the same pattern and frequency as shown in the NCDC list. Table 4-26 lists the extreme heat events from the NCDC for Middlesex County from 2001 to June 2015.

Table 4-26
Reported Excessive Heat Events, Middlesex County, 2001 – June 2015
(Source: NOAA/NCDC)

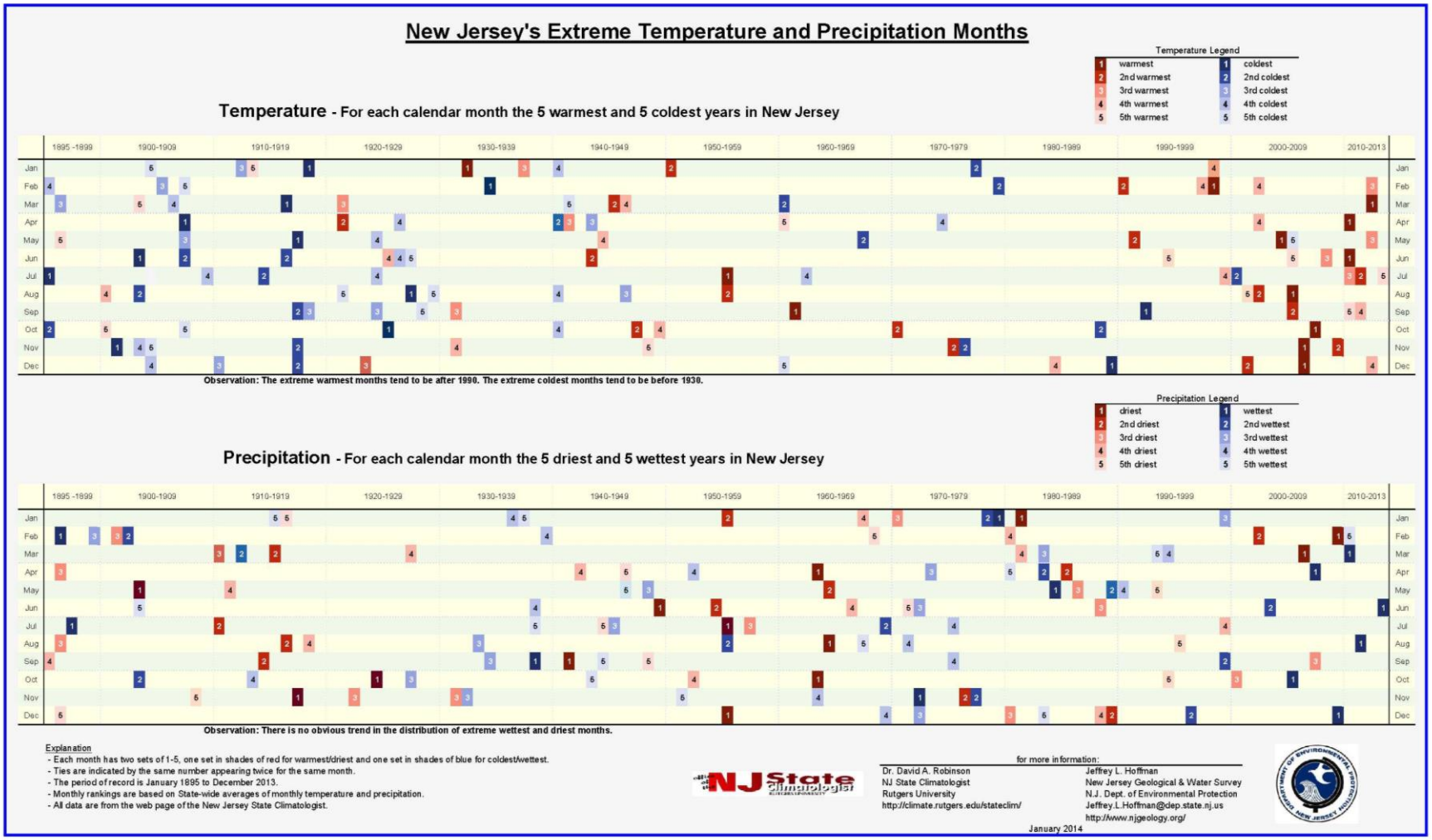
Start Date	End Date	Injuries	Deaths	Property Damage
5/02/2001	5/04/2001	0	0	0
6/26/2007	06/28/2007	0	0	0
7/09/2007	07/10/2007	0	0	0
8/08/2007	8/8/2007	0	0	0
8/25/2007	8/25/2007	0	0	0
6/07/2008	6/10/2008	0	0	0
7/16/2008	7/22/2008	0	0	0
8/10/2009	8/10/2009	0	0	0
6/27/2010	6/28/2010	0	0	0
7/05/2010	7/07/2010	0	0	0
7/23/2010	7/25/2010	0	0	0
7/21/2011	7/24/2011	3	0	0
7/18/2012	7/18/2012	0	0	0
7/18/2013	7/19/2013	0	0	0
Grand Total	**----**	**3**	**0**	**0**

Although not reported as an excessive heat event (reported as a heat event) in the NCDC, one of the worst extreme heat events occurred in July, 1999. A very strong and oppressive high pressure system resulted in a brutal heat wave in New Jersey that included the entire Independence Day weekend. High temperatures reached the 90s for the first time on the 3rd, but sweltering humidity and record breaking maximum temperatures of around 100 degrees Fahrenheit occurred from Independence Day through the July 6th. More recently an excessive heat event occurred from July 21st – July 24th, 2011 where temperatures reached around 105 degrees. The most oppressive day was July 22nd when the combination of temperature and dew points pushed many afternoon heat index values to 110F to around 120F.[20] The NCDC indicated this was one of the more oppressive heat waves since July, 1995.

In addition to querying the NCDC for past excessive heat events in New Jersey, data from the Office of the New Jersey State Climatologist was also reviewed. Figure 4-11 below shows months with both hot and cold temperature extremes over the 100-years for the State of New Jersey. The data shows that the extreme warm months over the past 100-years tend to occur after 1990. This New Jersey trend is consistent with scientific evidence of rising global temperature averages over the past 20 years.

[20] NOAA – NCDC, Storm Events Database, Excessive Heat –Middlesex County

Figure 4-11
New Jersey's Extreme Temperature and Precipitation Months, 1895–2013
(Source: Office of the New Jersey State Climatologist (ONJSC))



Based on the 14 extreme heat events between 1996 and June 2015, on average, an extreme heat event occurs approximately once every 1.3 years. Based on the historical data from the NCDC database, extreme heat events will continue to occur in the county about every one to two years. With one event every 1.3 years, there is roughly a 75% annual probability of a future extreme heat event occurring in Middlesex County. Considering the 14 past events over the past 19 years, the 2016 Middlesex County HMPSC ranked extreme temperature (heat) as a high risk hazard (See Table 4-1 for a complete list of hazard rankings).

Extremely High Temperatures Risk and Vulnerability Assessment (Including Impacts on Life and Property)

The NCDC database indicates there have been five deaths and four injuries from heat or excessive heat-related events. Of the five reported deaths in Middlesex County three were from one event that occurred from July 4 - 6, 1999. The combination of the temperature and humidity produced heat indices of around 110 degrees Fahrenheit during the afternoon of each day. Most of the deaths occurred to elderly persons in poor health, with no air-conditioning and inadequate ventilation.[21] In addition to the three deaths, 160 people were injured in the central New Jersey region. Damages from the extreme temperature hazard are generally confined to effects on humans, although occasionally there may be relatively minor effects on infrastructure such as electric grids, railroads, and airports.

Table 4-27
Reported Deaths and Injuries from Heat and Excessive Heat, Middlesex County, 1950 – June 2015
(Source: NOAA/NCDC)

Start Date	End Date	Event Type	Injuries	Deaths	Property Damage
7/04/1999	7/06/1999	Heat	4	0	0
7/16/1999	7/19/1999	Heat	1	0	0
6/09/2011	6/09/2011	Heat	0	1	0
7/21/2011	7/24/2011	Excessive Heat	0	3	0
----			**5**	**4**	**0**

The risk from extreme high temperatures will likely increase over the next 20 to 50 years as a result of climate change. The report titled *Resilience – Preparing New Jersey for Climate Change* supports the graphic above (Figure 4-11) indicating nine of the ten warmest calendar years in New Jersey have occurred since 1990. This is consistent with the long-term upward trend of temperatures in New Jersey increasing by an average of 2.2 degrees Fahrenheit per century. The report found that the past 25 years have been characterized by many more unusually warm months in New Jersey than unusual cold months. The Resilience report defines unusual warm and cold months as the five warmest and coldest, respectively, for each calendar year. [22]

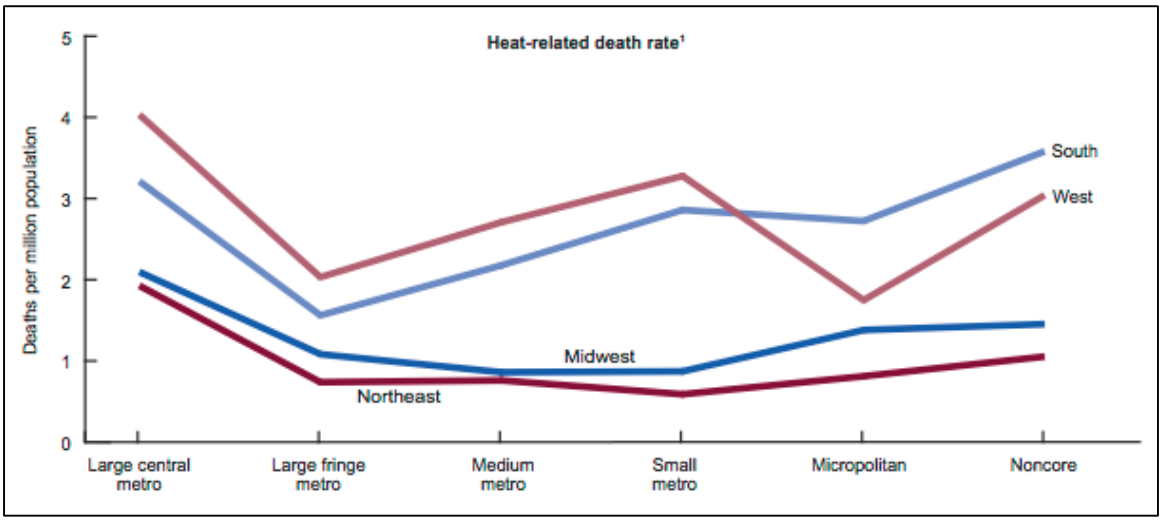
[21] NOAA. NCDC. Storm Events Database. July 4-6, 1999 Heat Event in Middlesex County.

[22] Resilience. Preparing New Jersey for Climate Change, December, 2013.

As result of climate change future extreme high temperature events will become more frequent and severe due to the impacts from climate change. Climate change and the increase in average temperatures will have the greatest impact on vulnerable populations including the poor, undocumented immigrants, the elderly, and those with physical and mental disabilities.[23]

Although it is never possible to accurately predict extreme weather events, there are nevertheless statistics that can be used to generate simple risk projections based on heat- and cold-related mortality. In July, 2014 the U.S. Centers for Disease Control and Prevention (U.S. Department of Health and Human Services) produced a reported entitled *Deaths Attributed to Heat, Cold and other Weather Events in the United States, 2006-2010.* The report includes national- and regional-level statistics on mortality related to extreme heat and cold. Heat-related deaths are strongly related to age, with deaths among citizens 75 years and older being at least twice as much as most other age groups. There are also differences among regions nationally (the report divides the country into South, West, Midwest and Northeast) and among different kinds of environments (large, central metro, medium metro, etc.). As shown in Figure 4-12, the northeast is consistently lower than all other regions with respect to heat-related deaths.

Figure 4-12
Heat-Related Mortality in the United States, 2006-2010, by Region and Metro Type
(source: U.S. Department of Health and Human Services *Deaths Attributed to Heat, Cold and other Weather Events in the United States*)



Nationally, the number of heat-related deaths from 2006 to 2010 was 3,332, an annual figure of 666. Risks of mortality from extreme heat in Middlesex County are then calculated by proportioning the national statistics to the local level via population. The basis of the calculation is the current figure FEMA uses to value loss of life in benefit-cost analysis ($6,412,265).

[23] Resilience. Preparing New Jersey for Climate Change, December, 2013.

Table 4-28 shows the expected annual number of heat-related deaths by jurisdiction in Middlesex County, as well as the projected losses over 50- and 100-year planning horizons. The 50- and 100-year losses are based on annualized values that are discounted to present day using the FEMA standard discount rate of 7%.

Table 4-28
Expected Mortality and Risk from Extreme Heat Events in Middlesex County, 50- and 100-year Planning Horizons

Jurisdiction	Population	Annual Loss	50-year Loss	100-year Loss
Edison	99,967	$1,351,174	$18,646,203	$19,281,254
Woodbridge	99,585	$1,346,011	$18,574,951	$19,207,576
Old Bridge	65,375	$883,622	$12,193,979	$12,609,281
Piscataway	56,044	$757,502	$10,453,527	$10,809,553
New Brunswick	55,181	$745,838	$10,292,558	$10,643,101
Perth Amboy	50,814	$686,812	$9,478,009	$9,800,811
East Brunswick	47,512	$642,182	$8,862,108	$9,163,934
South Brunswick	43,417	$586,833	$8,098,294	$8,374,106
Sayreville	42,704	$577,196	$7,965,303	$8,236,585
North Brunswick	40,742	$550,677	$7,599,344	$7,858,162
Monroe	39,132	$528,916	$7,299,041	$7,547,631
South Plainfield	23,385	$316,076	$4,361,854	$4,510,410
Plainsboro	22,999	$310,859	$4,289,856	$4,435,960
Carteret	22,844	$308,764	$4,260,945	$4,406,064
South River	16,008	$216,367	$2,985,869	$3,087,562
Highland Park	13,982	$188,984	$2,607,973	$2,696,795
Middlesex	13,635	$184,293	$2,543,249	$2,629,867
Metuchen	13,574	$183,469	$2,531,871	$2,618,101
South Amboy	8,631	$116,658	$1,609,885	$1,664,714
Spotswood	8,257	$111,603	$1,540,125	$1,592,579
Dunellen	7,227	$97,682	$1,348,006	$1,393,916
Milltown	6,893	$93,167	$1,285,707	$1,329,496
Jamesburg	5,915	$79,948	$1,103,287	$1,140,863
Cranbury	3,857	$52,132	$719,421	$743,923
Helmetta	2,178	$29,438	$406,248	$420,084
Total	**809,858**	**$10,946,204**	**$151,057,612**	**$156,202,328**

Extremely Low Temperatures

Description of the Extremely Low Temperatures Hazard

Temperatures that are significantly below normal are considered extreme cold temperatures. The consequences of extreme cold on humans are intensified by high winds which increase the rate of heat loss and has the effect of making it feel colder than the actual air temperature. Extreme low temperatures combined with high winds can lead to frostbite, permanent damage to the body, or even death. . For additional information about extreme low temperatures visit the National Weather Service (NWS) Winter Storm Safety website.

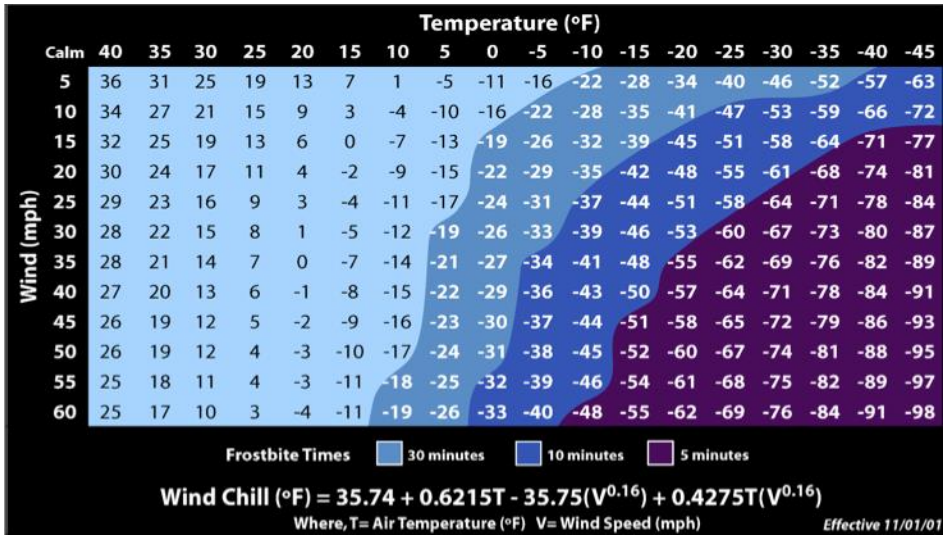
Location of the Extremely Low Temperatures Hazard

The entire planning area is subject to the hazards associated with extreme cold temperatures.

Severity of Extremely Low Temperatures

The severity of extreme low temperature events are measured by temperature, duration, and humidity. Most events are of less than a week in duration but can occasionally last for longer periods up to several weeks. Another measure of severity is the wind chill, how cold people and animals feel when outside. Wind chill is based on the rate of heat loss from exposed skin caused by wind and cold. As the wind increases, it draws heat from the body, driving down skin temperature and eventually the internal body temperature.[24] The NWS indicates that the wind chill is defined for temperatures at or below 50°F and wind speeds above 3 mph. A wind chill chart is produced by the NWS for temperatures below 50°F. The chart is shown in Figure 4-13. The potential for frostbite is calculated when temperatures reach 10°F with winds of 60 mph.

Figure 4-13
NWS, Wind Chill Chart
(Source: NWS, Winter Safety)



[24] NOAA – NWS, Winter Safety

Occurrences of Extremely Low Temperatures

The two categories within the NCDC database related to cold temperatures include Cold/Wind Chill and Extreme Cold. The NCDC database indicates there have been 24 Cold/Wind Chill events and two Extreme Cold/Wind Chill events in Middlesex County during the period 1950 – June 2015. Although the query results begin in 1950, the first reported event was in 1996. There are most likely additional extreme cold events prior to 1996 that are not captured in the database. No indication is given in the database as to why there are no events identified prior to 1996, although the pattern is most likely similar to the 19 year reporting period. Table 4-29 lists the cold and extreme cold temperature events from the NCDC for Middlesex County from 1996 – June 2015.

Table 4-29
Reported Cold and Extreme Cold Events, Middlesex County, 1996 – June 2015
(Source: NOAA/NCDC)

Date	Hazard Type	Injuries	Deaths	Property Damage
2/4/1996	Cold/Wind Chill	0	0	0
1/17/1997	Cold/Wind Chill	0	0	0
4/9/1997	Cold/Wind Chill	0	0	0
5/31/1997	Cold/Wind Chill	0	0	0
7/31/2000	Cold/Wind Chill	0	0	0
7/31/2001	Cold/Wind Chill	0	0	0
1/14/2003	Cold/Wind Chill	7	1	0
1/9/2004	Cold/Wind Chill	0	0	0
1/15/2004	Cold/Wind Chill	0	0	0
12/20/2004	Cold/Wind Chill	0	0	0
1/18/2005	Cold/Wind Chill	0	0	0
1/23/2005	Cold/Wind Chill	0	0	0
1/28/2005	Cold/Wind Chill	0	0	0
1/26/2007	Cold/Wind Chill	0	0	0
2/5/2007	Extreme Cold/Wind Chill	0	0	0
2/6/2007	Extreme Cold/Wind Chill	0	0	0
3/6/2007	Cold/Wind Chill	0	0	0
1/16/2009	Cold/Wind Chill	0	0	0
1/4/2014	Cold/Wind Chill	0	0	0
1/7/2014	Cold/Wind Chill	0	0	0
1/22/2014	Cold/Wind Chill	0	0	0
1/7/2015	Cold/Wind Chill	0	0	0
2/13/2015	Cold/Wind Chill	0	0	0
2/15/2015	Cold/Wind Chill	0	0	0
2/20/2015	Cold/Wind Chill	0	0	0
2/24/2015	Cold/Wind Chill	0	1	
Grand Total		**7**	**2**	**0**

As mentioned in the Occurrences subsection of the Extremely High Temperatures section, data from the Office of the New Jersey State Climatologist was also reviewed to identify historical heat events. Figure 4-11 (on page 4-52) shows months with both hot and cold temperature extremes over the 100-years for the State of New Jersey. The data shows that the extreme cold months over the past 100-years tend to occur before 1930.

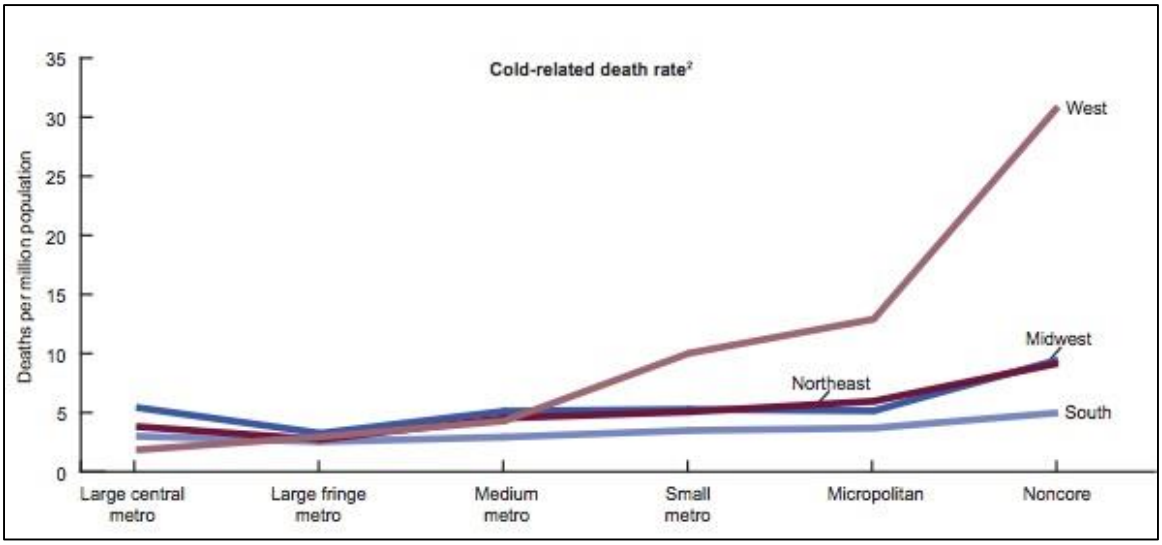
Based on the 26 events between 1996 and June 2015 a cold temperature event occurs approximately once or twice per year (1.3 events per year on average). However, this estimate includes both the cold and extreme cold events from the NCDC. If the annual estimate is limited to the two extreme cold temperature events an event occurs roughly every ten years. Based on the historical data from the NCDC database, extreme cold temperature events will continue to occur in the region every couple of years. With one event every 1.3 years, there is a 100% annual probability of a future cold event occurring in Middlesex County. Considering the 26 past events over the past 19 years, the 2016 Middlesex County HMPSC ranked extreme temperature (heat) as a medium risk hazard (See Table 4-1 for a complete list of hazard rankings).

Extremely Low Temperatures Risk and Vulnerability Assessment (Including Impacts on Life and Property)

The NCDC database indicates there have been one death and seven injuries from cold/wind chill events or extreme cold events. The one death and seven injuries occurred from a cold/wind chill event that occurred from January 13 – 29, 2003. During this event low temperatures were reported near or below zero. In Middlesex County a 20-year-old man was found frozen to death at a Garden State Parkway rest stop in Woodbridge. Damages from extreme cold temperatures are generally confined to effects on humans (described above), although occasionally there may be relatively minor effects on infrastructure such freezing pipes or electric grids.

Although it is never possible to accurately predict extreme weather events, there are nevertheless statistics that can be used to generate simple risk projections based on heat- and cold-related mortality. In July, 2014 the U.S. Centers for Disease Control and Prevention (U.S. Department of Health and Human Services) produced a reported entitled *Deaths Attributed to Heat, Cold and other Weather Events in the United States, 2006-2010.* The report includes national- and regional-level statistics on mortality related to extreme heat and cold. Heat-related deaths are strongly related to age, with deaths among citizens 75 years and older being at least twice as much as most other age groups. There are also differences among regions nationally (the report divides the country into South, West, Midwest and Northeast) and among different kinds of environments (large, central metro, medium metro, etc.). As shown in Figure 4-14, the northeast is about average among the four regions for cold-related mortality.

Figure 4-14
Cold-Related Mortality in the United States, 2006-2010, by Region and Metro Type
(source: U.S. Department of Health and Human Services *Deaths Attributed to Heat, Cold and other Weather Events in the United States*)



Nationally, the number of cold-related deaths from 2006 to 2010 was 6,652, an annual figure of 1330. Risks of mortality from extreme cold in Middlesex County are then calculated by proportioning the national statistics to the local level via population. The basis of the calculation is the current figure FEMA uses to value loss of life in benefit-cost analysis ($6,412,265).

Table 4-30 shows the expected annual number of cold-related deaths by jurisdiction in Middlesex County, as well as the projected losses over 50- and 100-year planning horizons. The 50- and 100-year losses are based on annualized values that are discounted to present day using the FEMA standard discount rate of 7%.

Table 4-30

Expected Mortality and Risk from Extreme Cold Events in Middlesex County, 50- and 100-year Planning Horizons

Jurisdiction	Population	Annual Loss	50-year Loss	100-year Loss
Edison	99,967	$2,697,482	$37,225,252	$38,493,068
Woodbridge	99,585	$2,687,174	$37,083,004	$38,345,976
Old Bridge	65,375	$1,764,061	$24,344,042	$25,173,151
Piscataway	56,044	$1,512,276	$20,869,407	$21,580,177
New Brunswick	55,181	$1,488,989	$20,548,047	$21,247,872
Perth Amboy	50,814	$1,371,151	$18,921,884	$19,566,325
East Brunswick	47,512	$1,282,051	$17,692,300	$18,294,864
South Brunswick	43,417	$1,171,552	$16,167,423	$16,718,052
Sayreville	42,704	$1,152,313	$15,901,919	$16,443,506
North Brunswick	40,742	$1,099,371	$15,171,319	$15,688,023
Monroe	39,132	$1,055,927	$14,571,794	$15,068,080
South Plainfield	23,385	$631,014	$8,707,999	$9,004,576
Plainsboro	22,999	$620,599	$8,564,262	$8,855,943
Carteret	22,844	$616,416	$8,506,544	$8,796,259
South River	16,008	$431,955	$5,960,985	$6,164,005
Highland Park	13,982	$377,286	$5,206,553	$5,383,878
Middlesex	13,635	$367,923	$5,077,339	$5,250,262
Metuchen	13,574	$366,277	$5,054,624	$5,226,774
South Amboy	8,631	$232,897	$3,213,972	$3,323,433
Spotswood	8,257	$222,805	$3,074,704	$3,179,422
Dunellen	7,227	$195,011	$2,691,157	$2,782,812
Milltown	6,893	$185,999	$2,566,784	$2,654,203
Jamesburg	5,915	$159,609	$2,202,601	$2,277,617
Cranbury	3,857	$104,076	$1,436,252	$1,485,168
Helmetta	2,178	$58,771	$811,034	$838,656
Total	**809,858**	**$21,852,985**	**$301,571,199**	**$311,842,102**

3.3.7 Flood

(Includes Riverine, Coastal, Storm Surge, Local, and Sea Level Rise)

Description of the Flood Hazard

Flooding is defined as the accumulation of water within a water body and the overflow of excess water onto adjacent floodplain lands. The floodplain is the land adjoining the channel of a river, stream, ocean, lake, or other watercourse or water body that is susceptible to flooding.

Hundreds of floods occur each year in the United States, including overbank flooding of rivers and

streams and shoreline inundation along lakes and coasts. Flooding typically results from large-scale weather systems generating prolonged rainfall. Flooding in Middlesex County can be the result of the following weather events: hurricanes, thunderstorms (convectional and frontal), storm surge or winter storms. For additional information about floods visit NOAA's Flood Monitor webpage.

Storm surges are caused by hurricanes, nor'easters, and tropical storms that impact coastal areas. Surge is simply water that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the hurricane storm tide, which can increase the mean water level 15' or more. In addition, wind driven waves are superimposed on the storm tide. This rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with the normal high tides.[25] In addition to flooding coastal areas, storm surge can also reach further inland impacting lakes and rivers.

Storm surges are particularly damaging when they occur at the time of a high tide, combining the effects of the surge and the tide. This increases the difficulty of predicting the magnitude of a storm surge since it requires weather forecasts to be accurate to within a few hours. For additional information about storm surge visit NOAA's Storm Surge Overview webpage.

Global sea level is the average height of all the Earth's oceans. "Global Sea Level Rise" refers to the increase currently observed in the average global sea level, which is primarily attributed to changes in ocean volume due to two factors: ice melt and thermal expansion. Long-term variations in sea level occur over various time scales, from monthly to several years, and may be repeatable cycles, gradual trends, or intermittent anomalies. Seasonal weather patterns, variations in the Earth's declination, changes in coastal and ocean circulation, anthropogenic influences (such as dredging), vertical land motion, and the El Niño Southern Oscillation are just a few of the many factors influencing changes in sea level over time. When estimating sea level trends, a minimum of 30 years of data are used in order to account for long-term sea level variations and reduce errors in computing sea level trends based on monthly mean sea level. Accounting for repeatable, predictable cycles, such as tidal, seasonal, and interannual variations allows computation of a more accurate long-term sea level trend.[26] For additional information about coastal erosion and sea level rise, visit the National Oceanic and Atmospheric Administration's (NOAA) coastal hazards page.

Location of the Flood Hazard

The topography of the county consists of marshes and wetlands along coastal and floodplains in the east. Numerous areas within Middlesex County are susceptible to localized flooding from excess rain events, stormwater runoff, local drainage problems, overbank flooding and other sources. This section highlights several of the significant flood areas throughout Middlesex County. All of the municipalities within the County experience some degree of flooding. Past history of flooding in Middlesex County indicates that flooding of varied origin may be experienced in any season of the year since New Jersey lies within an area that can experience the impacts of major storm tracks including hurricanes and

[25] NOAA – storm surge description
[26] NOAA. Tides and Currents. Sea Level Trends

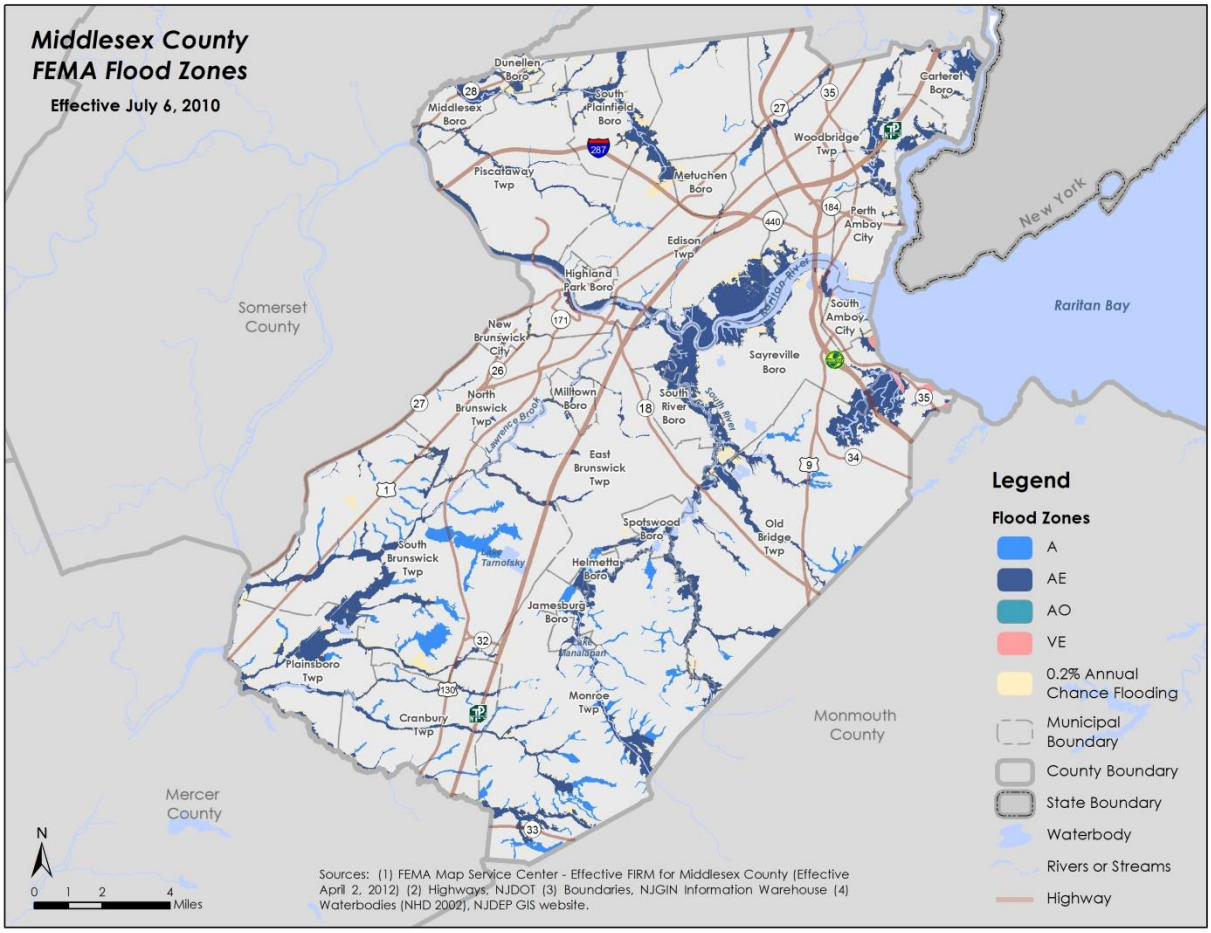
nor'easters. Within the County, the low-lying areas along streams are subject to periodic flooding. The more extensive floods have occurred in late summer and fall, usually associated with tropical disturbances moving northward along the Atlantic Coast.[27] Specific details about areas vulnerable to flooding in each community can be found in the individual municipality appendices.

One of the best sources for determining flood risk for an area is review of the Flood Insurance Rate Maps (FIRMs) produced by FEMA. The FIRM is the official map of a community on which FEMA has delineated both the special flood hazard areas (1% annual chance of flooding) and the risk premium zones applicable to the community.[28] The effective FIRM for Middlesex County is dated July 6, 2010.

Figure 4-15 shows various flood zones in Middlesex County (see flood zone descriptions following the map) from the effective FIRM. The 100-year floodplain includes areas with a 1% annual chance of flooding and includes zones A, AE and AO (various shades of blue). The 1% annual chance flooding covers 46.25 square miles (or 14.60%) of the County. The majority of the 1% annual chance flooding areas follow the major rivers in Middlesex County including the Raritan River and its tributaries, South River, Woodbridge River, Manalapan Brook, and the Arthur Kill River. The 500-year floodplain includes areas with a 0.2% annual chance of flooding. The 0.2% annual chance flooding is shown on the map below in yellow and represents the areas between the limits of the 100-year and 500-year floodplains. Note that the effective FIRM is included as part of the Flood hazard overview for historical context, however the most recent flood hazard data is the Preliminary FIRM dated January 30 2015. The new flood hazard data is presented later in this subsection.

[27] Middlesex County FEMA - Flood Insurance Study (FIS), January 31, 2014
[28] FEMA online - Floodplain Management. Flood Insurance Rate Map (FIRM) definition

Figure 4-15
Effective FIRM of Middlesex County
(Sources: FEMA Map Service Center, Effective FIRM July 6, 2010 and NJDEP)



The flood zone designations are defined as follows:

- **Zone A.** Shaded light blue. Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
- **Zone AE.** Shaded dark blue. Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. In most instances, base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
- **Zone AO.** Shaded aqua. River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
- **X500.** Shaded yellow. Represents areas between the limits of the 1% annual chance flooding and 0.2% chance flooding
- **Zone VE.** Shaded pink. Coastal areas with a 1% or greater chance of flooding and an additional

hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

During its fiscal year 2009, FEMA began transitioning to a new approach to floodplain mapping. The Risk Mapping, Assessment, and Planning (Risk MAP) activities built on the pre-existing map modernization program to leverage state, local, and tribal expertise to enhance quality data and further public awareness. Prior to Sandy in 2012, FEMA had begun a coastal flood study to update Flood Insurance Rate Maps (FIRMs) and Flood Insurance Study (FIS) reports for portions of New York and New Jersey, including Middlesex County, using improved methods and data to better reflect coastal flood risk. The re-study included new analyses, GIS mapping, creating a new Digital Flood Insurance Rate Map (DFIRM) and an updated Flood Insurance Study (FIS) for the county. The project includes at least a portion of the following 11 municipalities in Middlesex County.

- Carteret Borough
- Edison Township
- Highland Park Borough
- New Brunswick City
- Old Bridge Township
- Perth Amboy City
- Sayreville Borough
- South Amboy City
- South River Borough
- Spotswood Borough
- Woodbridge Township

After Sandy, FEMA released Advisory Base Flood Elevation (ABFE) maps for certain communities (including the regional region) based on the partially completed flood study that was designed to help with rebuilding and recovery efforts. The ABFEs are updated estimates of the 1% chance flood elevations derived from new coastal flood analysis and data. As part of the ongoing flood study the flood hazard maps are updated in several phases. Prior to release of the final updated FIRMs for a community, the phases include (1) ABFE maps (2) Preliminary Work Maps (PWMs), and (3) Preliminary FIRMs. The PFIRMs created for certain New Jersey and New York communities are an interim product created by FEMA in the development of new FIRMs. FEMA is currently in the process of releasing PFIRMs showing coastal flood hazard data in certain communities in New Jersey and New York.

In Middlesex County the most recent flood hazard data at the time of the Plan update (as of summer 2015) is the Preliminary FIRM (PFIRM). The PFIRM data was released by FEMA on January 30, 2015 and replaced the PWMs to update the flood hazard data for all of the county and not just the coastal regions. Once approved, this updated flood hazard data will replace the current effective FIRM and FIS. As part of the FEMA flood study existing flood hazard data was updated throughout portions of the

county. This most recent flood data was used to complete the flood hazard analysis and risk assessment. Figure 4-16 identifies the area of analysis that was studied to update the flood hazard data in Middlesex County. A total of 25 miles was studied along the major rivers (and tributaries) located in central and eastern Middlesex County.

Figure 4-16
Middlesex County Coastal Analysis
(Source: Middlesex County Flood Hazard Mapping Status Report for Property Owners)

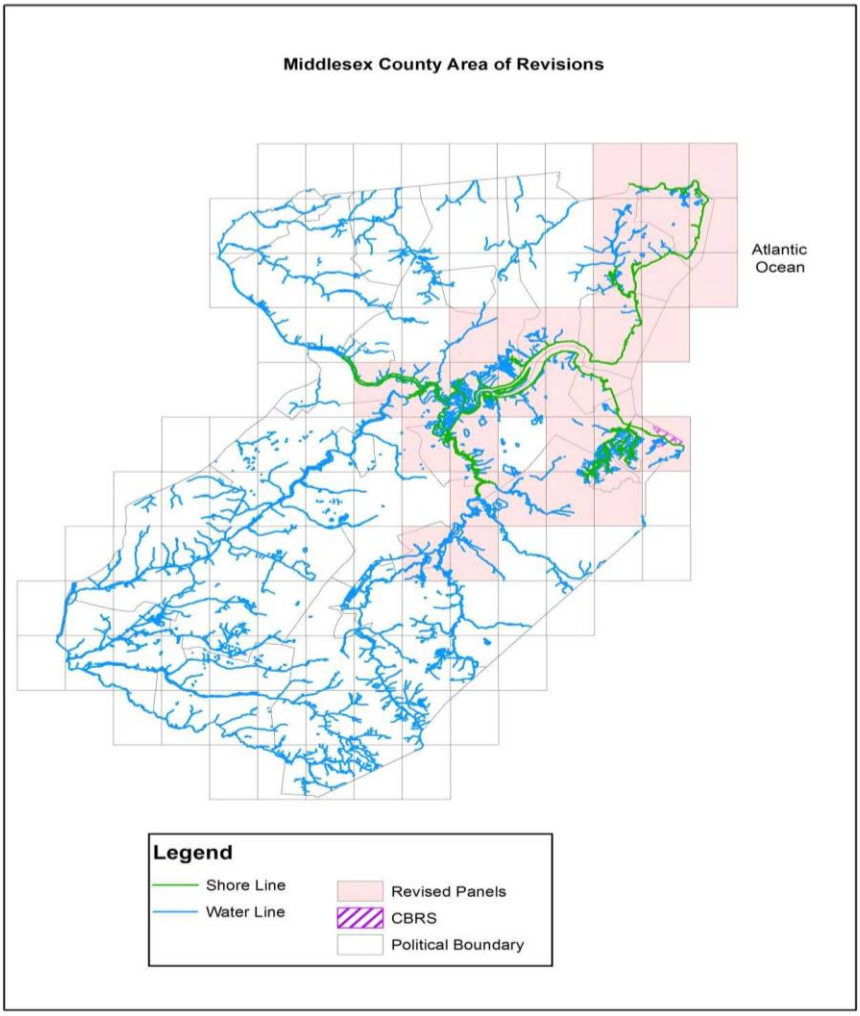
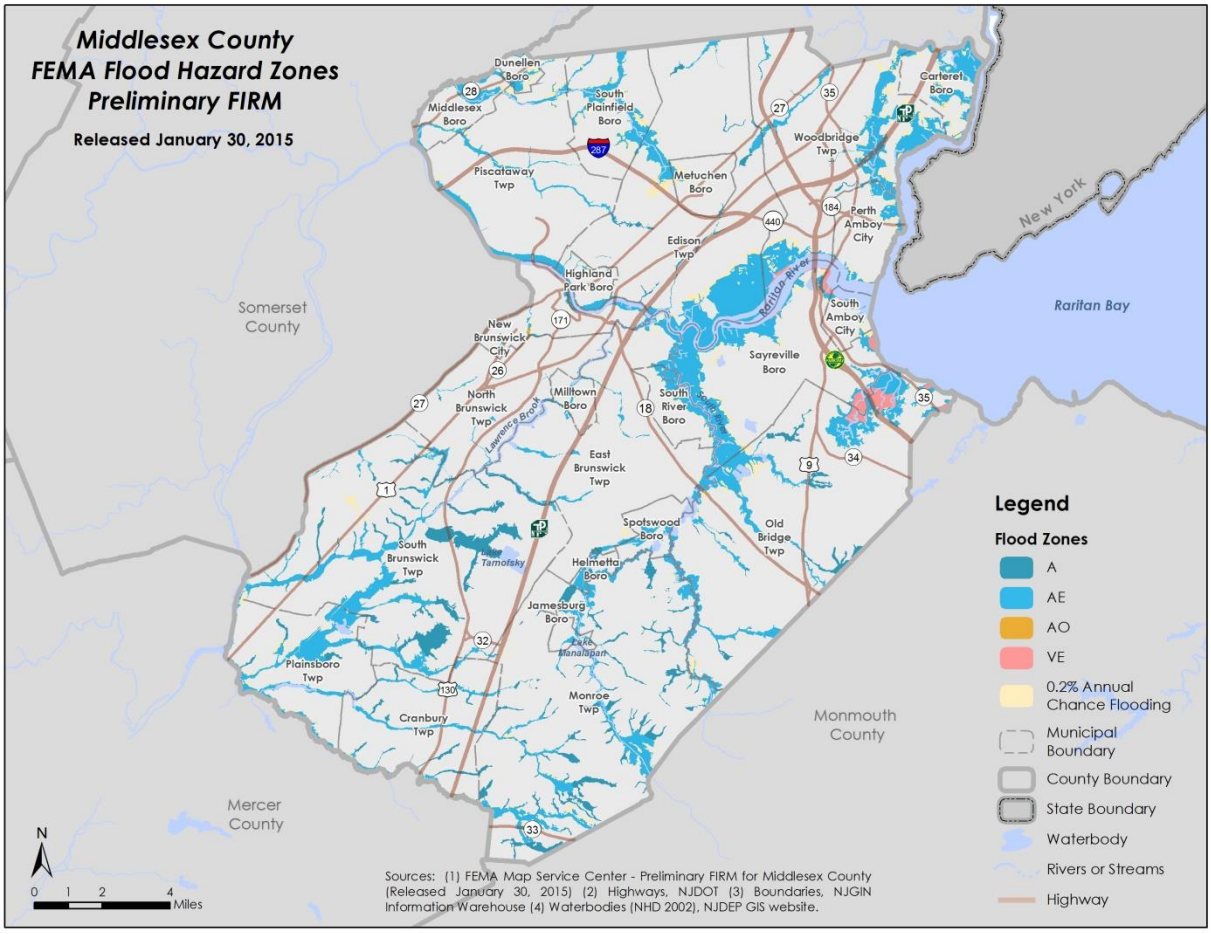


Figure 4-17 identifies the PFIRM flood zones for Middlesex County. This map includes five flood zones including Zone A, AE, AO, VE and 0.2% annual chance flooding (500-year floodplain). The area of 1% annual chance flood for the PFIRM covers 50.32 square miles or 15.88% of the land in the County. This is an increase of 4.07 square miles compared to the effective FIRM (See Table 4-31 for specific areas of increase). Although not shown on the County map below, the municipality PFIRM maps include the Limit of Moderate Wave Action (LiMWA). The LiMWA identifies areas that will be affected by waves with a 1.5 foot wave height or greater within the coastal A Zone. While FEMA currently does not require special

floodplain management standards or flood insurance purchase requirements based on LiMWA delineations, it is likely that properties and structures within the LiMWA will receive substantial damage from wave action during a one-percent-annual-chance flood event.[29]

Figure 4-17
Middlesex County Preliminary FIRM
(Source: FEMA Region II, Coastal Analysis and Mapping, Preliminary FIRM, January 30, 2015)



Flood maps identifying the PFIRM for each community can be found in the individual municipality appendices (See Appendices 1-20). Flood mapping and analyses in this section of the Plan update utilizes PFIRM data, the most recent flood hazard data available.

To assist communities interpret the new flood hazard data FEMA has developed various flood risk tools (also referred to as Risk MAP non-regulatory products). As of summer 2015, the flood risk tools were in development by FEMA and various county-wide data available for certain New Jersey Counties.[30] In some of these counties, including Middlesex County, FEMA has identified the proposed changes in flood

[29] FEMA Region II Coastal Analysis and Mapping - Coastal Mapping Basics
[30] See FEMA Region II Coastal Analysis and Mapping website for additional information about Flood Risk Tools http://www.region2coastal.com/community-officials/flood-risk-tools/tool-descriptions

zones and developed a map described by Risk MAP as the Changes Since Last FIRM (CSLF). The CSLF dataset compares information shown on the preliminary FIRM with that of the effective FIRM. This includes a comparison of the floodplain boundaries and zones, Base Flood Elevation (BFE) changes, and where applicable, the regulatory floodway. The CSLF also includes information about why changes are happening in particular areas and indicates where no changes are occurring as well. It can be used to help explain map changes to residents and to identify areas newly mapped in high-risk flood zones where outreach efforts may need to be focused. It can also be used to inform planning decisions and to prioritize mitigation measures.

Figure 4-18 identifies the CSLF for the areas studied within Middlesex County. As with other counties in New Jersey, the updated coastal flood zones in Middlesex County extend further inland with higher flood elevations than the Special Flood Hazard Areas (SFHA) shown on the current effective FIRMs. The PFIRM proposes significant expansion of the SFHA along the Raritan River, particularly in Edison Township, Highland Park Borough, New Brunswick City and Sayreville Borough (areas shaded red). In addition, the PFIRM map proposes changing a portion of the flood zone in eastern Old Bridge from Flood Zone AE to a V Zone (Shaded brown). At this map scale it is difficult to interpret some areas of changes, particularly along the shoreline of the Raritan Bay and Arthur Kill River.

More detailed CSLF maps for Carteret Borough, Woodbridge Township, Perth Amboy City, South Amboy City, and Old Bridge Township can be found in the individual municipality appendices.

Figure 4-18
Middlesex County Changes since Last FIRM (CSLF)
(Source: FEMA Region II, Coastal Analysis and Mapping, Flood Risk Tools, Middlesex County, December 2014)

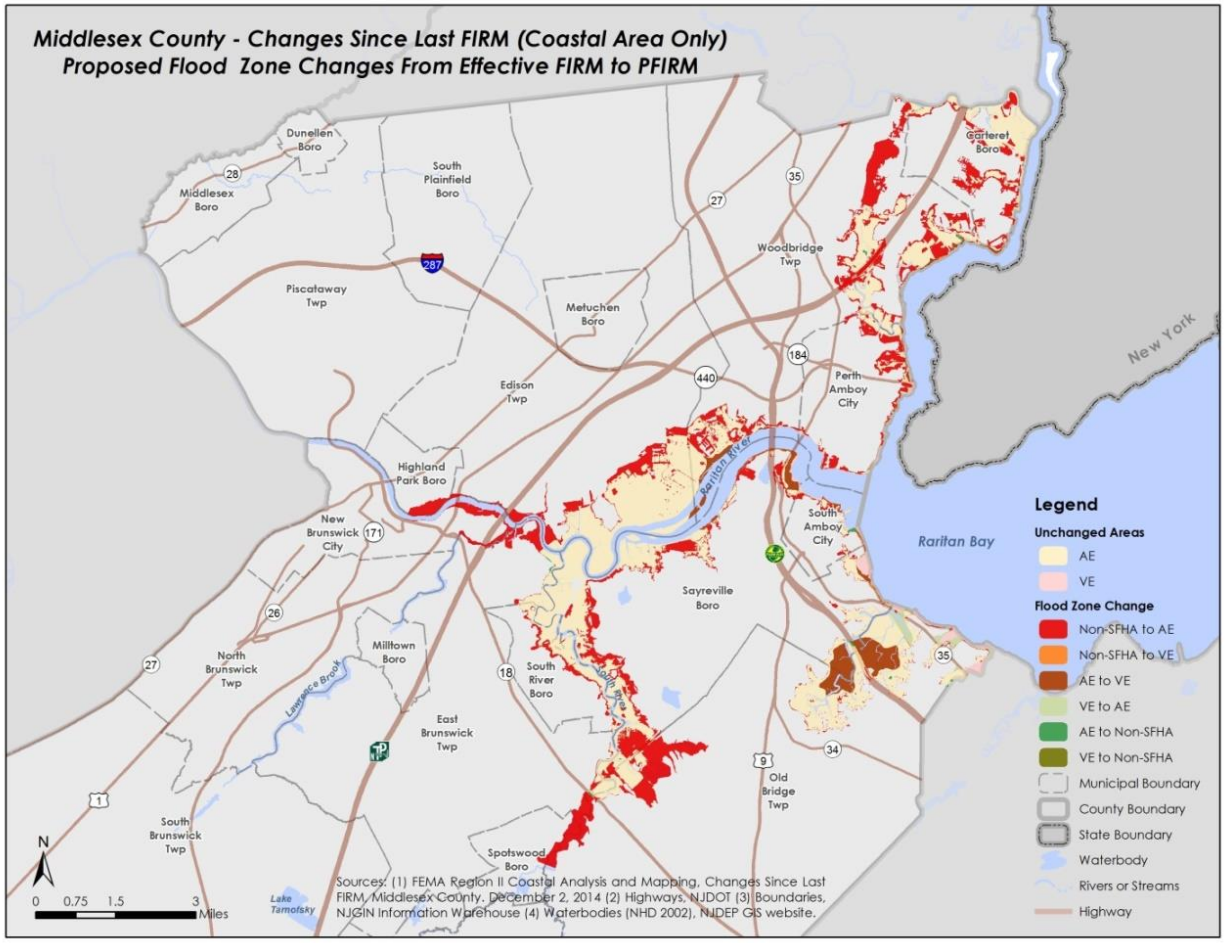


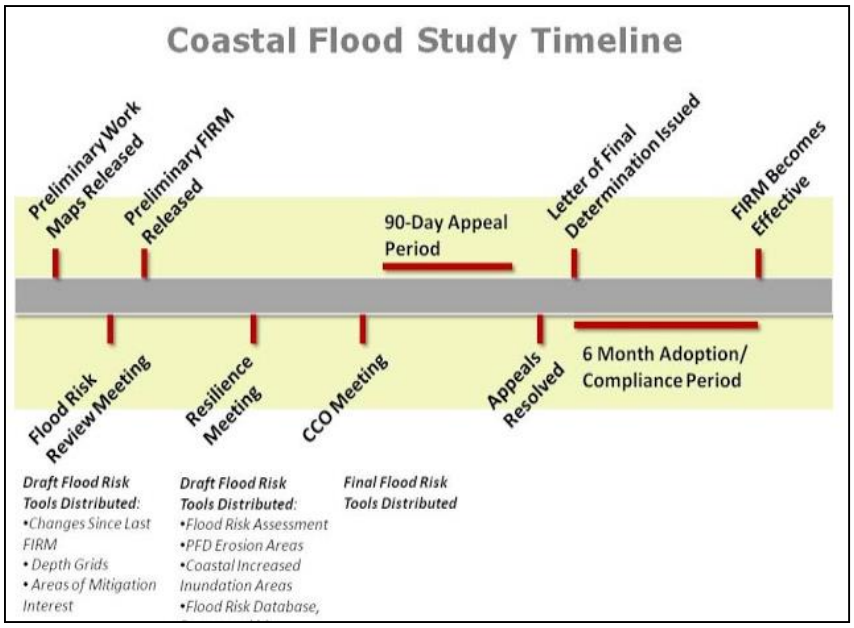
Table 4-31 below compares the square miles of floodplain from the effective FIRM to the PFIRM for each municipality in Middlesex County. The table is ordered by the number of square miles within the 1% annual chance flood (or SFHA) from the PFIRM. The table shows the municipality with the highest land area of floodplain is located in South Brunswick Township (6.40 square miles). The highest increase in the SFHA is found in Woodbridge Township, adding 1.12 square miles of floodplain as part of the proposed PFIRM.

Table 4-31
Floodplain Land Area Comparison for Effective FIRM to PFIRM, Ordered by the Number of Square Miles Within the 1% Annual Chance Flood Hazard of the PFIRM
(Sources: FEMA Map Service Center, Effective FIRM, April 2, 2012, PFIRM, January 30, 2015)

Municipality	Square Miles	SQ Miles With SFHA (Effective FIRM)	SQ Miles Within SFHA (PFIRM)	Increase or Decrease in SFHA (SQ Miles)	SQ Miles within 0.2% Floodplain (500-yr) (PFIRM)	% of Land Area Within SFHA (PFIRM)
South Brunswick Township	41	6.40	6.40	0.00	0.59	15.60%
Monroe Township	42.16	6.31	6.31	0.00	0.70	14.96%
Old Bridge Township	38.68	5.76	6.20	0.44	0.75	16.03%
Sayreville Borough	17.58	4.34	5.16	0.82	0.65	29.37%
Edison Township	30.64	4.25	4.74	0.49	0.77	15.48%
Woodbridge Township	24.01	3.42	4.54	1.12	1.18	18.93%
Plainsboro Township	12.11	2.76	2.76	0.00	0.45	22.79%
East Brunswick Township	22.41	1.66	1.74	0.08	0.26	7.76%
Carteret Borough	4.5	1.01	1.62	0.61	0.46	35.92%
Piscataway Township	18.95	1.54	1.54	0.00	0.41	8.13%
Cranbury Township	13.43	1.48	1.48	0.00	0.19	11.05%
South Plainfield Borough	8.32	1.26	1.26	0.00	0.57	15.18%
New Brunswick City	5.75	0.99	0.99	0.00	0.16	17.27%
Middlesex Borough	3.51	0.97	0.96	-0.01	0.23	27.35%
Perth Amboy City	5.17	0.55	0.93	0.38	0.22	17.94%
South River Borough	2.92	0.57	0.74	0.17	0.16	25.21%
Spotswood Borough	2.41	0.58	0.58	0.00	0.03	23.96%
North Brunswick Township	12.28	0.55	0.55	0.00	0.07	4.47%
Helmetta Borough	0.87	0.45	0.45	0.00	0.01	52.27%
South Amboy City	1.97	0.47	0.44	-0.03	0.10	22.30%
Dunellen Borough	1.06	0.30	0.30	0.00	0.16	27.85%
Highland Park Borough	1.82	0.28	0.28	0.00	0.05	15.32%
Metuchen Borough	2.83	0.13	0.13	0.00	0.10	4.46%
Milltown Borough	1.59	0.12	0.12	0.00	0.04	7.78%
Jamesburg Borough	0.89	0.10	0.10	0.00	0.01	11.14%
Grand Totals	**316.86**	**46.25**	**50.32**	**4.07**	**8.30**	**15.88%**

The next phase in developing updated flood hazard for Middlesex County will be the release of the new effective FIRMs. The PFIRMs are intended to help communities and property owners understand current flood risk and likely flood insurance requirements in the future. The release of this information will also provide local officials an opportunity to review and comment on areas in their community where they believe risks are inappropriately mapped (understated or overstated).[31] The effective FIRM will replace the PWMs (and PFIRM) that were prepared for Middlesex County to assist with rebuilding and recovery efforts in the aftermath of Sandy as the most recent data available from FEMA. The PFIRMs were released to the public beginning in early 2014 and scheduled to be delivered on a rolling community/county basis. Figure 4-19 shows the New Jersey Coastal Flood Study timeline from the point of releasing the PWMs. As of June 2015 FEMA has not provided an anticipated release date for the new effective FIRMs in Middlesex County.

Figure 4-19
New Jersey Coastal Flood Study Timeline (From Release of PWMs)
(Source: FEMA Region II, Coastal Analysis and Mapping, Flood Risk Tools for New Jersey Communities)



The following subsections highlight several of the major flood areas throughout Middlesex County. These include areas of the Raritan River and flooding in parts of Helmetta, Jamesburg, and Spotswood. See the individual municipality appendices for additional details related to specific flood characteristics each municipality.

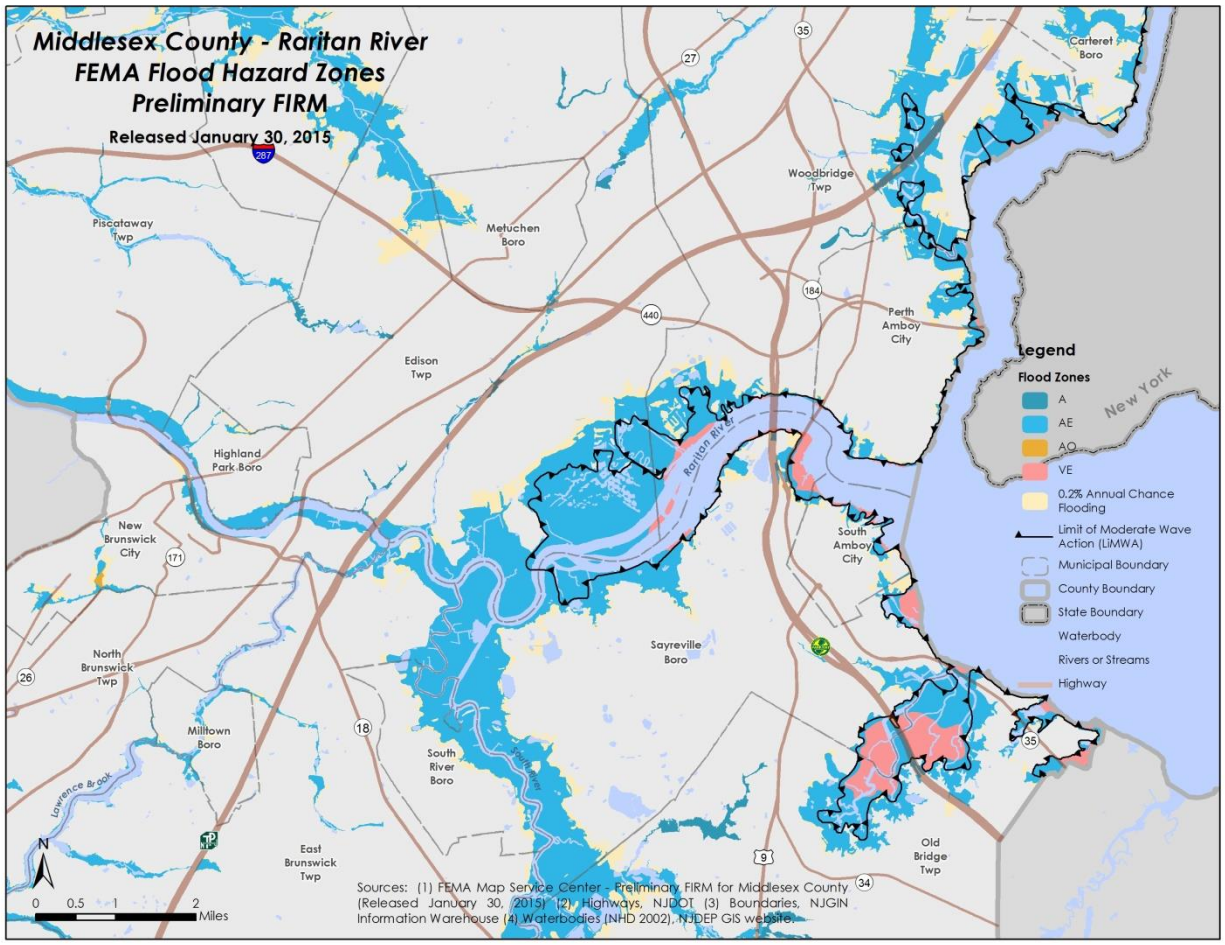
[31] FEMA Region II Coastal Analysis and Mapping

Raritan River Floodplain

The County is roughly bisected southwest to northeast by the Raritan a major river in central New Jersey. The watershed of the Raritan River covers roughly 1,100 square miles and collects most of the runoff from the mountainous areas of the central portion of the State. The Raritan forms at the confluence of the North Branch and South Branch just west of Somerville, New Jersey and empties into the western edge of Raritan Bay along the Atlantic Ocean. It flows for approximately 16 miles before slowing in tidewater at New Brunswick. Its estuary extends for another 14 miles until reaching the Raritan Bay at South Amboy.[32]

In the past, the Raritan River has experienced significant flooding problems when excessive rain from storms affects the river basin. Figure 4-20 is a map of the Middlesex County portion of the Raritan River with the 100-year floodplain included from the PFIRM.

Figure 4-20
Middlesex County Portion of the Raritan River
(Sources: FEMA and NJDEP)



[32] Sierra Club New Jersey. Raritan Valley Group. Raritan River description.

Certain areas of the Raritan River are susceptible to overbank flooding. In the past there have been repeated flood events along certain parts of the River. Portions of the Raritan River have seen major flooding events in 1996, 1999, 2007, 2011, and 2012.

The flooding event on October 19th, 1996 caused an estimated $2.7 million in damages throughout Middlesex County. A Federal Disaster Declaration (DR-1145) was declared in five New Jersey counties, including Middlesex. In Dunellen the damages were estimated at $500,000 including 20 residential homes that were damaged by flooding from the Raritan River. Of the 20 homes damaged, floodwaters caused serious structural damage to about half including one that was moved from its foundation[33] .

In September of 1999 Hurricane Floyd caused widespread damage from South Carolina to as far north as Maine. The storm had been downgraded by the time it reached New Jersey but still dumped as much as nine inches of rain on parts of the state causing flooding along the Raritan. A total of 12 counties in New Jersey received a Presidential declaration (DR-1295). The total estimated FEMA Public Assistance was just over $2.3 million.

In Middlesex County overbank flooding from the Raritan caused significant flooding in New Brunswick and other communities along the River flowing out to the Raritan Bay. As the Raritan River was rising, the incoming high tide during the early morning of the September 17th, 1999 prevented it from discharging into the bay. The floodwaters caused an estimated $6 million in damages to 500 homes in Middlesex Borough. In Woodbridge, flooded stores were not expected to be reopened for weeks. In Piscataway where damage estimates reached $5 million, the Riverside, Mayflower and Birchview Apartment Complexes were severely flooded. Parks near the Raritan River were also badly damaged[34].

In Edison, low water pressure problems associated with the Elizabethtown Water Treatment Plant resulted in little or no water for the township for the first four days following Hurricane Floyd. During this time the National Guard provided water for the township. Numerous streams flooded throughout the county and by the afternoon of the September 19th an estimated 30 to 40 roads throughout the county were already closed with numerous water rescues from car tops taking place. In Dunellen over 100 homes were damaged by flooding[35].

The New Brunswick area flooded again as a result of overbank flooding from the Raritan during the April 2007 flood event. Parts of Route 18 were closed due to the flooding.

[33] NOAA/NCDC Database
[34] NOAA/NCDC Database
[35] NOAA/NCDC Database

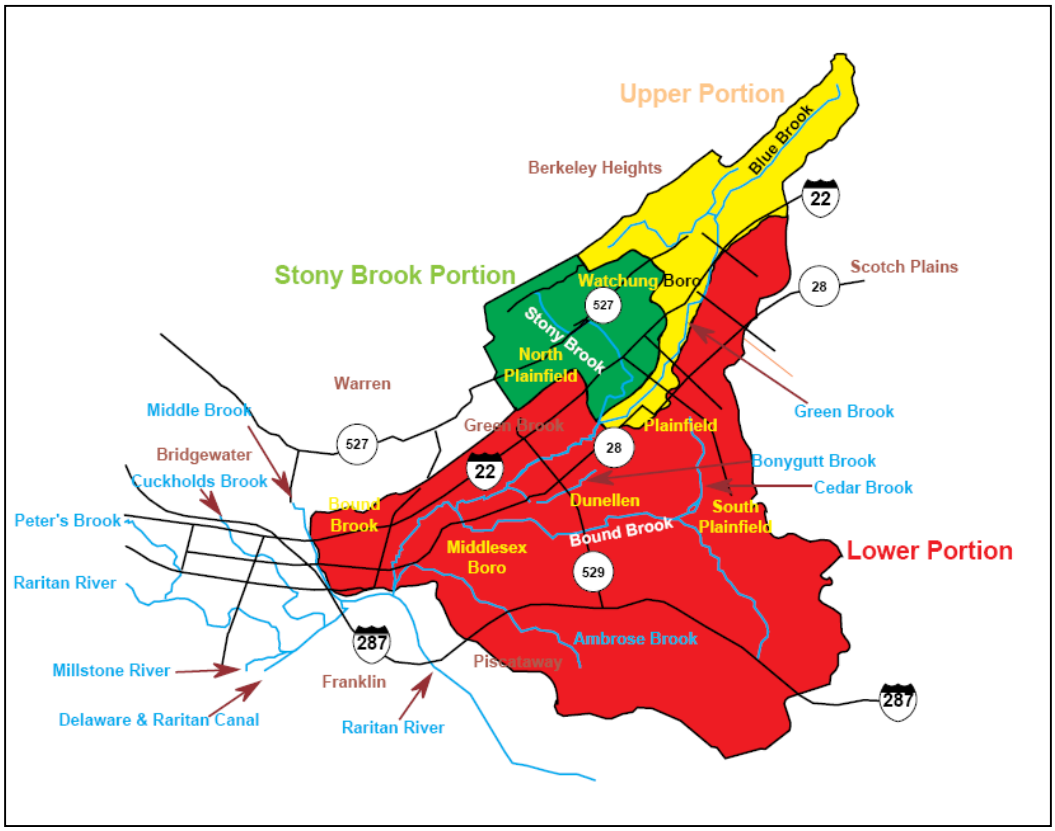
Figure 4-21
Raritan River flooding in New Brunswick, NJ; April 2007 Flood Event
(Source: The Star-Ledger; April 16, 2007)

In the northwestern portion of Middlesex County the Raritan and its tributaries flow through Middlesex Borough, Dunellen and Plainfield. This portion of the county is part of the Green Brook Sub Basin which covers an area 65 square miles and includes portions of three counties and 13 municipalities. In the past, the Green Brook Sub Basin has experienced severe and sometimes devastating flood damages. In response to the 1971 and 1973 floods, the Green Brook Flood Control Commission was authorized by the State of New Jersey. The Commission is comprised of representatives from Middlesex, Somerset, and Union counties and is comprised of volunteer representatives appointed by the flood-affected municipalities and counties, as well as the State.

The U.S. Army Corps. of Engineers (USACE) – New York District has studied this area extensively in the past and has completed several flood control projects within the Basin with additional projects currently in progress as of 2015. Figure 4-22 is a map which divides the basin into three areas; Upper Portion, Stony Brook Portion, and the Lower Portion. The majority of the Lower Portion (shaded red) is within Middlesex County and has been impacted in the past by major flood events in 1973, 1996, and 1999[36]. The Lower Portion includes portions of Middlesex Borough, Dunellen Borough, Piscataway Township and South Plainfield Borough.

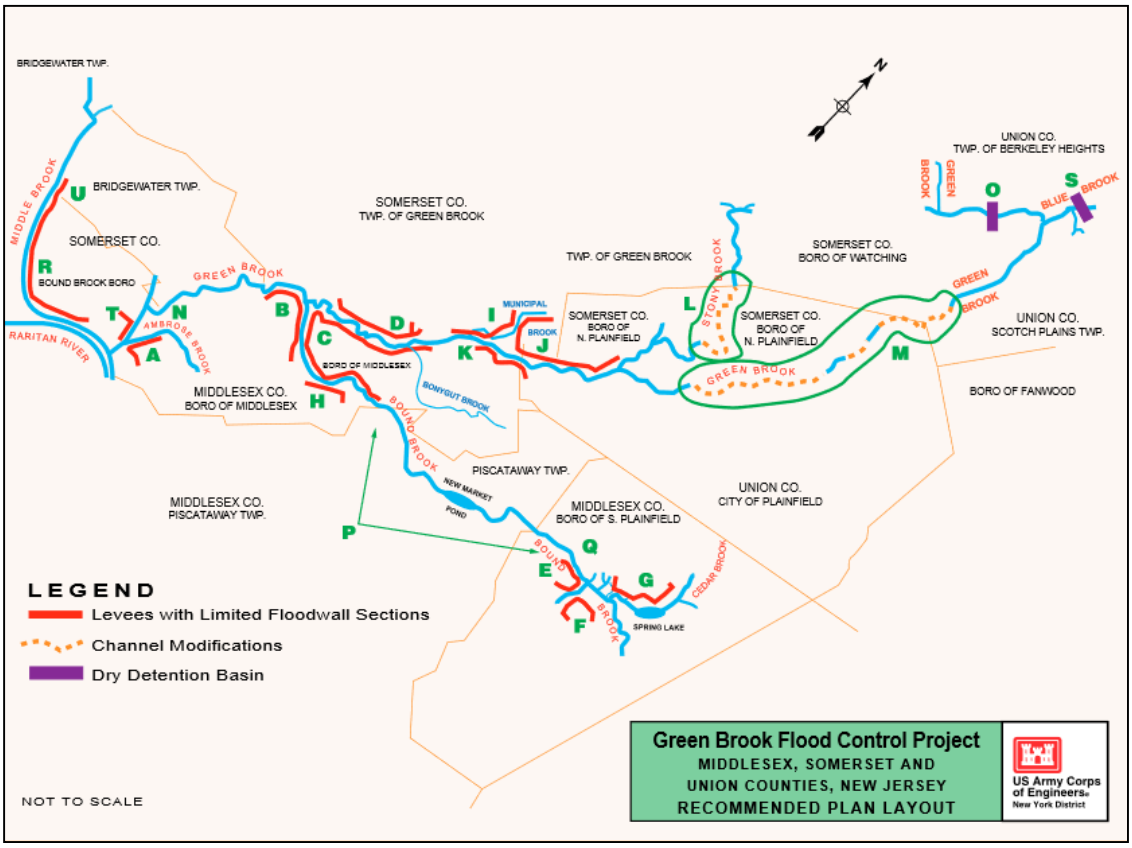
[36]USACE – New York District

Figure 4-22
Green Brook Sub Basin: Upper Portion, Stony Brook Portion, and the Lower Portion
(Source: USACE – New York District)



The USACE objectives of the project are to provide comprehensive flood protection to areas vulnerable to flooding within the Green Brook Sub Basin by protecting homes, businesses, critical facilities and other infrastructure. The overall estimated cost of the project is $362 million and construction is estimated to take approximately ten years. The recommended plan layout is shown in Figure 4-23.

Figure 4-23
Green Brook Sub Basin: Recommended Plan Layout
(Source: USACE – New York District, Green Brook Sub Basin – Recommended Plan)



The USACE recommended plan for the Lower Portion includes providing flood protection up to the 150-year event by installing levees, floodwalls, pump stations, and making modifications to existing channels. The project is summarized below in Table 4-32.

Table 4-32
Green Brook Sub Basin – Lower Portion
(Source: USACE – New York District, Green Brook Sub Basin – Recommended Plan)

Lower Portion Improvements	Quantity/Unit
Levees/Floodwalls	78,000 Linear Feet (LF)
Bridge and Road Modifications	11
Channel Modifications	3,300 LF
Closure Structures	8
Floodproofed Structures	162
Pump Stations	16

As of spring 2015, several components of the flood control project have been completed in Middlesex Borough including the Segment B1 Sebrings Mills Bridge Raising, Levee, Pump Station and Floodwall. Additional portions of the project within Middlesex (specifically Segments identified by the USACE as B3 & B4) are currently nearing design completion with Segment B3 scheduled to begin by September 2015[37].

Helmetta, Jamesburg, Spotswood area Flooding

In September of 2005 the County created the South Central Middlesex County Flood Control Commission and appointed representatives to address the problem of flooding in the Helmetta, Jamesburg, and Spotswood area. The commission was formed after the July 2005 flood event and is studying a 44 square mile area. Half of the study area is in Middlesex County and other half is located in Monmouth County.[38]

The July 2005 flood event caused significant flooding in the towns of Helmetta, Jamesburg, Spotswood, and other surrounding areas. In these three towns floodwaters from the event inundated and damaged a total of 440 residential homes and 20 businesses. In Jamesburg a total of 7-8 inches of rain fell within a period of several hours. The excess rainfall in such a short period of time resulted in flash flooding in Jamesburg that inundated approximately 75 residential homes and 12 businesses causing an estimated $3.4 million in damages. Flooded areas within the City included West Railroad Avenue, East Church Street, Pergola Avenue, Willow Street, Forsgate Drive, and Gatmzer Avenue[39]. The storm also caused significant infrastructure damages in Jamesburg including a 60 inch drainpipe that collapsed near the intersection of Forsgate Drive and West Railroad Avenue. The collapsed drainpipe created a 20 foot sinkhole undermining the roadway and causing an estimated $600,000 in damages[40] . In Spotswood and Helmetta the damages from the event were estimated at $2.2 million and $750,000 respectively [41].

[37] USACE Fact Sheet – Green Brook Sub Basin, February 2015
[38] Sentinel News – September 1, 2005
[39] Jamesburg.net
[40] Middlesex County – Engineering Department
[41] Sentinel – July 28, 2005

Figure 4-24
Jamesburg, New Jersey during the July 2005 Floods
(Source: Jamesburg.net/flood2005)

In August of 2011 Hurricane Irene again caused significant flooding in these municipalities as well. Additional information about Hurricane Irene can be found in the "Occurrences of the Hazard" (Page 4-135) subsection as well as the individual appendices for Helmetta, Jamesburg, and Spotswood.

Location of the Flood Hazard (Storm Surge)

The storm surge hazard associated with hurricanes and other severe storms are responsible for coastal flooding and erosion along the New Jersey coastline. Storm surge vulnerability is closely related to elevation relative to sea level and proximity to the coast, the lower the elevation, and closer to the potential sources of flooding; the more likely it is that an area will be negatively impacted by surge. Surge can come directly from the Atlantic Ocean and various bays in the state, and also can occur as a result of backwater effects on rivers. The northeastern coastline of Middlesex County is at greatest risk from the storm surge hazard. In addition to flooding coastal areas, storm surge can also reach further inland impacting lakes and rivers, particularly along the Raritan River and its tributaries. Storm surge in Middlesex County is primarily the result of hurricanes and nor'easters that travel north parallel to the Atlantic coastline.

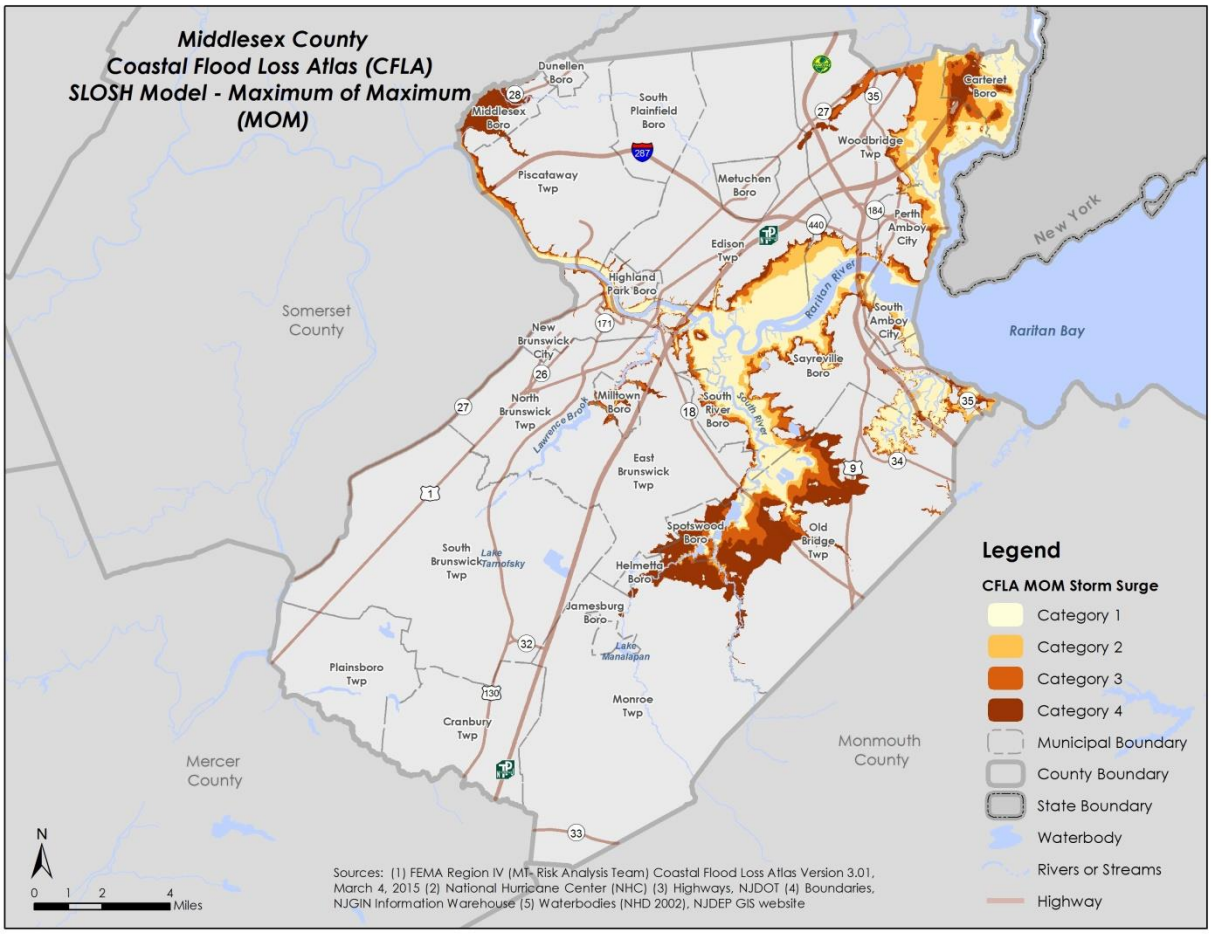
In 2007, FEMA's Risk Analysis Team with Region IV (Atlanta, Georgia) developed the Coastal Flood Loss Atlas (CFLA) to better assess and properly mitigate the risks and vulnerabilities associated with storm surge. The CFLA unites the National Hurricane Center's (NHC) Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model with FEMA's loss estimation model, HAZUS (Hazards US), creating an easily and readily accessible atlas of possible coastal flood conditions and losses to support pre- and post-hurricane landfall strategies.

The Risk Analysis Team developed storm surge inundation (i.e. water depth over land) grids in GIS

format from SLOSH Maximum of Maximums (MOMs) outputs per hurricane category. These outputs are considered the worst case storm surge scenarios for each Saffir-Simpson hurricane category (1 through 5) under perfect storm conditions. Local emergency management officials use MOMs to delineate storm surge evacuation zones, and the CFLA complements FEMA HES to achieve the goal of comprehensive risk and vulnerability assessments for all hurricane storm surge scenarios and evacuation zones. The CFLA establishes a baseline level of coastal flood risks and vulnerabilities that can be further assessed for better, more comprehensive understanding of coastal hazards and disasters.

Figure 4-25 shows the maximum storm surge extent for hurricane categories 1through 4 in Middlesex County. Note that the Category 5 extent is not included on the map. The CFLA summary indicated that Category 5 MOM SLOSH models have not been produced for FEMA Region II by NOAA's National Hurricane Center. See municipality appendices Carteret Borough, East Brunswick Township, Edison Township, Highland Park Borough, Milltown Borough, Old Bridge Township, Perth Amboy City, Piscataway Township, Sayreville Borough, South Amboy City, South River Borough, Spotswood Borough and Woodbridge Township for more detailed SLOSH model maps using data from the CFLA.

Figure 4-25
Middlesex County SLOSH Maximum of Maximum (MOM)
Storm Surge Limit, Hurricane Categories 1-4
(Source: FEMA Region IV, Coastal Flood Loss Atlas (CFLA), SLOSH)



Location of the Flood Hazard (Sea Level Rise)

Various studies and data were reviewed to identify the location and future impacts in Middlesex County related to sea level rise. The studies and data included the following

- *The Likelihood of Shore Protection in New Jersey.* Report to the U.S. Environmental Protection Agency. Washington, D.C
- *NOAA Geo Platform, Sea Level Rise Planning Tool.*
- *Resilience – Preparing New Jersey for Climate Change. A Gap Analysis from the New Jersey Climate Adaption Alliance, December 2013*

NOAA, in partnership with FEMA the United States Army Corp of Engineers (USACE) and several other agencies has created a set of map services and related tools to help communities, residents, and other stakeholders consider risks from future sea level rise in planning for reconstruction following Hurricane Sandy in 2012. Even if current storm patterns remain the same in the future, sea level rise will increase the impact of coastal flooding during storms. The map services provided here integrate FEMA's most recent special flood hazard data with four scenarios of sea level rise. These scenarios include

- lowest
- intermediate-low
- intermediate-high
- highest

These scenarios provide estimates of global sea level rise by the year 2050 and 2100 based on the best available science synthesized by a panel of scientists from multiple federal agencies and academic institutions to provide to the U.S. They address different factors known to affect the risk of future sea level rise, including ocean warming and melting of mountain glaciers and ice sheets.[42]

The following maps, Figure 4-26 and Figure 4-27, show the sea level rise scenarios for year 2050 and 2100. This sea level rise data provides best available elevation information for post-Sandy planning and rebuilding, as well as to support federal agency planning, as needed and applicable. These maps are not intended to support regulatory flood hazard zone designation, insurance ratings, or other legal or regulatory constraints. Rather, these maps and services support scenario planning that may help decision makers prepare for and adapt to uncertainties surrounding the future risks posed by sea level rise. They help make transparent the level of risk accepted under different scientific assumptions underlying the expected rate of sea level rise in the 21st century.[43]

[42] NOAA – GeoPlatform. Sea Level Rise Planning Tool – New Jersey and New York
[43] NOAA – GeoPlatform. Sea Level Rise Planning Tool – New Jersey and New York

Figure 4-26
Middlesex County Sea Level Rise Scenario – 2050, Near Raritan River and Bay
(Source: Geo Platform, Sea Level Rise Planning Tool)

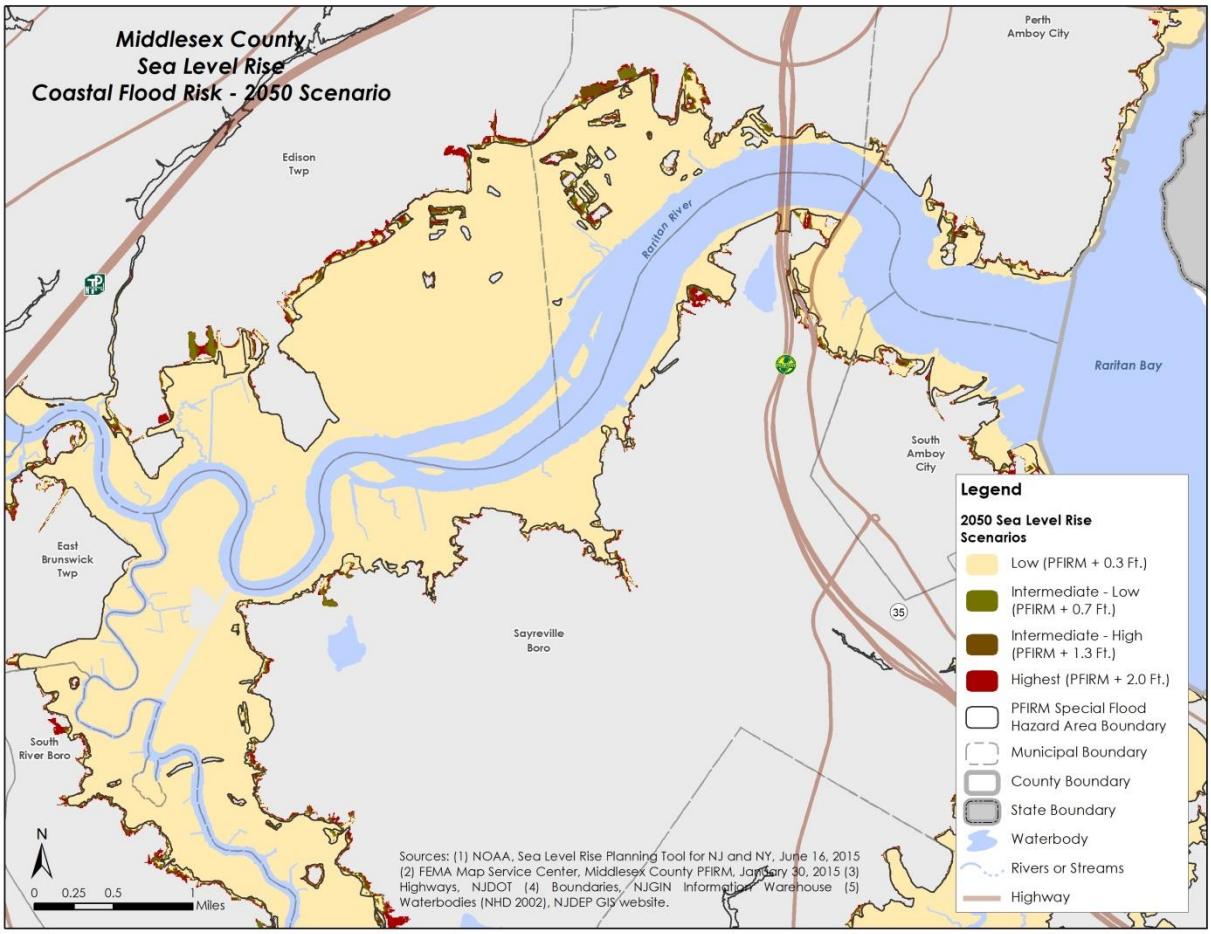
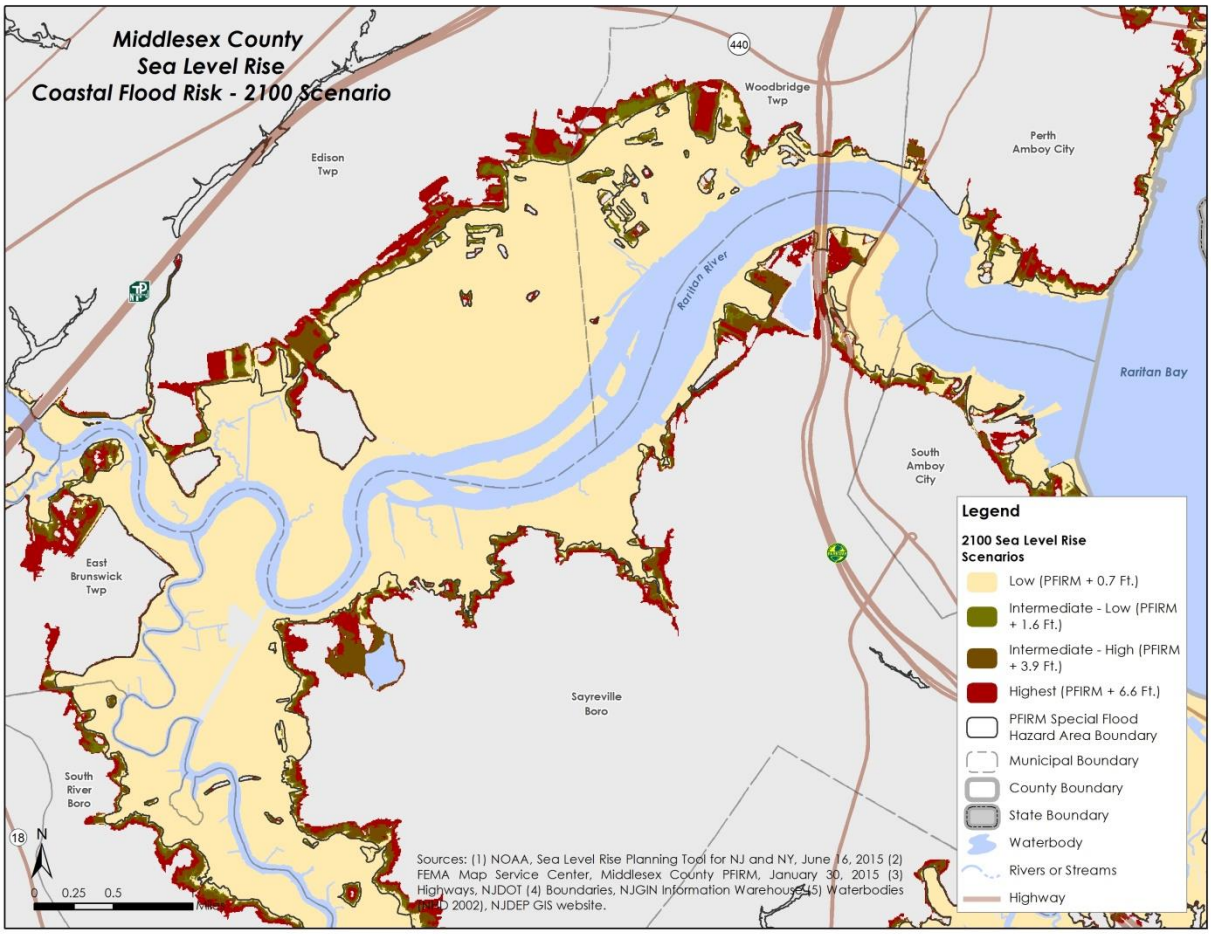


Figure 4-27
Middlesex County Sea Level Rise Scenario – 2100, Near Raritan River and Bay
(Source: Geo Platform, Sea Level Rise Planning Tool)

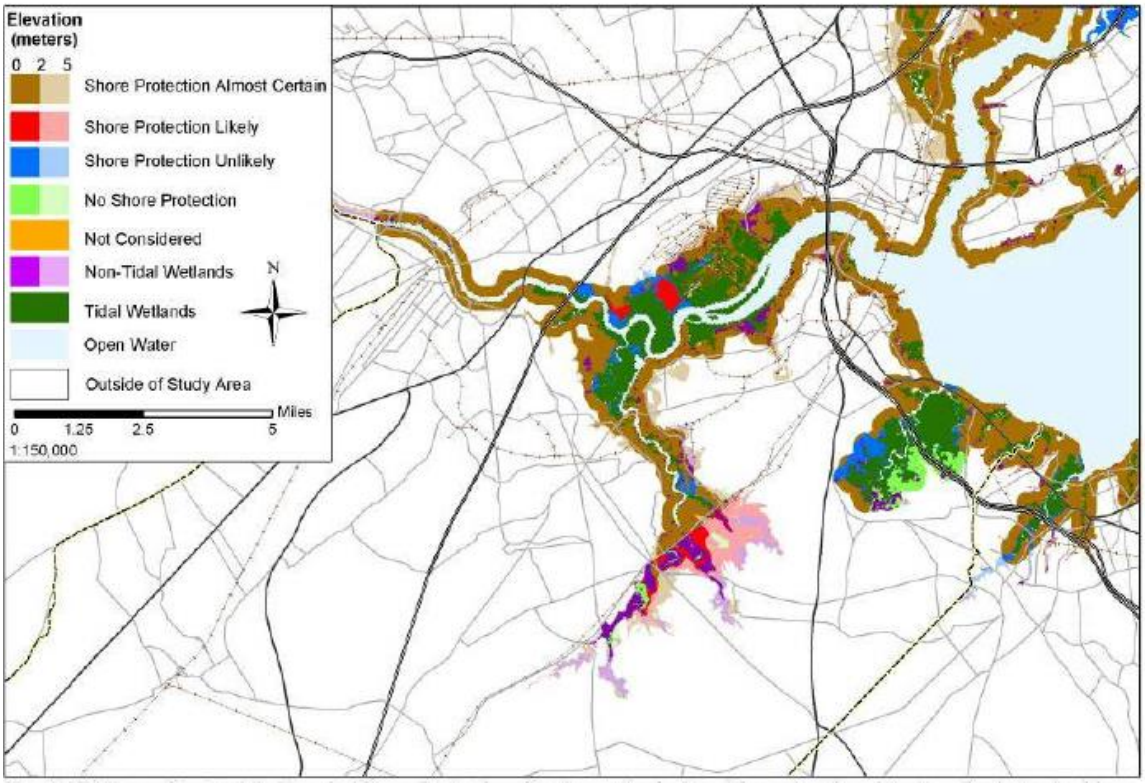


In 2010, a report titled *The Likelihood of Shoreline Protection in New Jersey* was produced for the Environmental Protection Agency (EPA). The report studied the likelihood of shore protection for the coastal zone of New Jersey. The purpose of the study was to identify and develop maps that distinguish the areas likely to be protected as sea levels rise from the areas where shores are expected to retreat naturally. In Middlesex County there are mostly natural shores along the Raritan Bay with substantial dunes. Immediately inland of the beach area there are public roads bike paths and parks with residential development farther inland. The report indicates that these areas are almost certain to be protected, most likely by beach nourishment. Along the Arthur Kill north of Perth Amboy there is a mixture of armored shores and beaches, with dense development inland of the shore.[44] Figure 4-28 is a map of eastern Middlesex County identifying the areas likely to be protected. For each shore protection

[44] Michael Craghan, Jennifer Kassakian, Daniel Hudgens, and James G. Titus. 2010. "New Jersey. G. Titus. 2010.. 2010.us. 2010Hudgens (editors). *The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 1: Mid-Atlantic.* Report to the U.S. Environmental Protection Agency. Washington, D.C

category, the darker shades represent lands that are either less than 6.6 feet above spring high water or within 1,000 feet of the shoreline. The map shows that roughly 85 – 90% of the shore as almost certain to be protected. The remaining areas are about equally divided among the other three categories.

Figure 4-28
Middlesex County, Likelihood of Shore Protection
(Source: The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 1: Mid-Atlantic*)*



Severity of the Flood Hazard

Floods have been and continue to be the most frequent, destructive, and costly natural hazard facing Middlesex County. Flood severity is measured in several ways, including frequency, depth, velocity, duration and contamination, among others. In Middlesex County, characterizing the severity of the flood hazard depends on what part of the county is being considered, but generally speaking the issues relate to how often floods occur. Most recently, the county has been impacted by five significant flood events: in 2005, 2010, 2011, 2012 and 2014.

Because of the nature of floods, discussions of extent (which FEMA considers analogous to *potential severity*) are necessarily location-specific. The jurisdictional appendices to this HMP include narrative and metrics related to flood extent on a local level. In general the flood extent in Middlesex County ranges from a few inches of overland flow and ponding in some areas, to high-velocity flooding of multiple-foot depths in others. The latter type of flooding is found in close proximity to the two major

flood sources in the County, the Raritan and South Rivers. As noted, specifics about flood hazards are discussed in detail in the municipal appendices.

Storm surges inundate coastal floodplains by tidal elevation rise in inland bays and ports, and backwater flooding through coastal river mouths. Severe winds associated with low-pressure systems cause increase in tide levels and water surface elevations. Storm systems also generate large waves that run up and flood coastal areas. The combined effects create storm surges that affect the beach, marsh, and low-lying floodplains. Shallow offshore depths can cause storm driven waves and tides to pile up against the shoreline and inside bays. Table 4-33 highlights the factors that can influence the severity of coastal storms.

Table 4-33
Factors That Influence the Severity of Storm Surge
(Source: NOAA/NCDC)

Factor	Effect
Wind Velocity	The higher the wind velocity the greater the damage.
Storm Surge Height	The higher the storm surge the greater the damage.
Coastal Shape	Concave shoreline sections sustain more damage because the water is driven into a confined area by the advancing storm, thus increasing storm surge height and storm surge flooding.
Storm Center Velocity	Then slower the storm moves, the greater damage. The worst possible situation is a storm that stalls along a coast, through several high tides.
Nature of Coast	Damage is most severe on low-lying island barrier shorelines because they are easily over washed by wave action.
Previous Storm Damage	A coast weakened by even a minor previous storm will be subject to greater damage in a subsequent storm.
Human Activity	With increased development, property damage increases and more floating debris becomes available to knock down other structures.

In addition to the tools developed by NOAA, a study completed in December, 2013 by the New Jersey Climate Adaption Alliance, a network of policymakers, public and private sector practitioners, academics, and nongovernmental and business leaders, indicated that the rates of sea level rise vary globally and sea levels along the New Jersey shore have risen faster than the global average due to land subsidence occurring at the same time water levels are rising. The report titled *Resilience – Preparing New Jersey for Climate Change* indicated a recent study led by Rutgers scientists has projected future rates of sea level rise (Miller et al., 2013). The projections are expressed as a best estimate and a range to account for uncertainties in future rates of global ocean warming and melting rates for the large ice sheets covering Greenland and Antarctica. According to these most recent projections, sea level is projected to rise by 7 to 16 inches by 2030, with a best estimate of 10 inches. In 2050, the range is 13 to 28 inches with a best estimate of 18 inches, and by 2100 the range is 30 to 71 inches with a best estimate of 42 inches. Even if the most conservative of these projections materialize, the implications for coastal flooding will be substantial.[45]

Occurrences of the Flood Hazard

To identify past occurrences of flooding in Middlesex County a query was performed for the NOAA NCDC database. The NCDC database indicates that there have been 60 flood events in Middlesex County in the period from 1996 to May 2015. Of these 60 events, nine of these flood events have resulted in property damage. These events are listed in Table 4-34 below. Note that additional flood events not listed in the NCDC database may have resulted in property and infrastructure damages. Estimated property damages for these floods may not have been listed in the database because either the data was unavailable, or the damages were only minor and therefore not reported to the NCDC.

Table 4-34
Flood Events Resulting in Property Damage, Middlesex County, 1950–June 2015
(Source: NOAA/NCDC, USGS)

Location	Date	Hazard Type	Injuries	Deaths	Property Damage
countywide	10/19/1996	Flash Flood	1	0	$2,700,000
countywide	9/16/1999	Flash Flood (Floyd)	72	0	$28,000,000
Northwest portion of County	8/5/2003	Flash Flood	0	0	$250,000
Southeast portion of County	7/17/2005	Flash Flood	0	0	$10,300,000
South Plainfield	3/13/2010	Flood	0	0	$100,000
countywide	8/28/2011	Flood (Irene)	0	0	$50,000,000
Woodbridge Township	8/9/2012	Flash Flood	0	0	$10,000
Avenel	4/30/2014	Flood	0	0	$500,000
Avenel	5/1/2014	Flood	0	0	$500,000
Grand Total	**----**	**----**	**73**	**0**	**$92,360,000**

[45] Resilience – Preparing for New Jersey Climate Change. A Gap Analysis From the New Jersey Climate Adaption Alliance. December, 2013.

To identify past storm surge events in Middlesex County the NCDC database was queried using the categories Coastal Flooding and Storm Surge/Tidal. The database indicates there have been eight storm surge events and 22 coastal flooding events that have impacted Middlesex County between 1950 and June 2015. All of the events occurred between 1996 and 2015. The database does not provide any indication as to why there are no events listed prior to 1996. The four events resulting in property damage are summarized below in Table 4-35.

Table 4-35
Storm Surge Events Resulting in Property Damage, Middlesex County, 1950 – June 2015
(Source: NOAA/NCDC)

Location	Date	Hazard Type	Injuries	Deaths	Property Damage
Coastal Shoreline Areas	2/12/2006	Coastal Flood	0	0	$50,000
Coastal Shoreline Areas	3/13/2010	Coastal Flood	0	0	$1,000,000
Coastal Shoreline Areas	10/29/2012	Hurricane Sandy	0	0	$500,000,000
Coastal Shoreline Areas	3/7/2013	Coastal Flood	0	0	$10,000
Grand Total	----	----	----	----	**$501,060,000**

In addition to the events listed in the NCDC database, one other flood (or surge) event was identified that resulted in property damage in Middlesex County. A nor'easter in April, 2007 resulted in more than nine inches of rain in parts of New Jersey, causing millions of dollars in damages. The more recent floods that have occurred in Middlesex County are summarized below. Incidents that have been declared a Major Disaster by the President are indicated by the disaster number (DR).

- **10/19/1996 (DR-1088) – Flash Flood.** A strong low pressure system slowly moved off the southern New Jersey coast on October 19, 1996. Heavy rains resulted flash flooding that caused an estimated $2.7 million in damages in Middlesex County. Flooding temporarily closed parts of US 1 and 9, several State routes, and the Garden State Parkway. In Dunellen 20 homes were damaged by the floodwaters.

- **9/16/1999 (DR-1295) –Hurricane Floyd.** This fall hurricane put the entire Eastern Seaboard on flood watch, including every county in New Jersey. Although downgraded from a hurricane by the time it hit New Jersey, the storm lasted approximately 18 hours and caused an estimated $3.5 million in damages to public infrastructure in Middlesex County. In Middlesex, floodwaters from the Raritan River experienced record floods up to 4.5 feet higher than any previous record flood crest resulting in severe flooding.[46] As the Raritan River was rising, the incoming high tide during the early morning of the 17th prevented it from discharging into the bay. The areas of Bound Brook and Manville experienced some of the worst flooding. A total of 500 homes were damaged in Middlesex Borough. Residential damages were estimated at $6 million.

[46] Middlesex County FEMA - Flood Insurance Study (FIS), January 31, 2014

- **05/08/2003 - Severe Storms and Flooding.** Thunderstorms with heavy rains caused flooding in the northwest part of the County. Rainfall totals from the storm were estimated at 2-5 inches and resulted in $250,000 in damages.

- **07/17/2005 - Severe Storms and Flooding.** Flash flooding occurred in the Manalapan Brook Basin in southeastern Middlesex County impacting seven municipalities; East Brunswick, Jamesburg, Monroe, Spotswood, Helmetta, South River and Old Bridge. Collectively the flood damages to these areas totaled $9.7 million. A total of 308 homes, 25 apartments, 20 businesses and one industrial facility were damaged.

- **02/12/2006 - Severe Storms and Flooding.** A major winter storm that impacted the New Jersey shoreline with strong onshore winds that caused coastal flooding and beach erosion. In Middlesex County the area of South Amboy was impacted by coastal flooding.

- **04/15/2007 - Severe Storms and Flooding.** A seven-day Nor'easter deluged New Jersey with over nine inches of rain, causing millions of dollars of damage and killing three residents. In Middlesex County nearly every municipality suffered flood damages or roads closed due to the extensive flooding.
- **03/13/2010 (DR 1897) - Severe Storms and Flooding.** A slow moving storm moving north along the Atlantic coast produced heavy rains from March 12 - 15, 2010. Rainfall amounts were greatest in central and northeastern New Jersey. Event precipitation totals were 5.63 inches in South Brunswick, 5.25 inches in Metuchen and 5.14 inches in Piscataway. Damages were estimated in New Jersey at $30 million dollars as thousands of homes and businesses were damaged. It was the worst flooding in the Raritan Basin since April of 2007.
- **08/28/2011 (DR-4021) – Hurricane Irene.** See detailed description in Section 3.3.8 – Hurricanes and Tropical Storms .
- **10/29/2012 (DR-4021) – Hurricane Sandy.** See detailed description in Section 3.3.8 – Hurricanes and Tropical Storms .
- **04/04/2014 – Flood/Heavy Rains.** A slow moving low pressure system that caused major creek and river flooding along the Raritan River. Event precipitation totals averaged from three to six inches, with the highest amounts in central New Jersey. In Middlesex County very heavy rain caused considerable roadway flooding and also caused some brook flooding within the County. Nearly every major roadway in the County had flooding and many of them were closed. The Lawrence Brook at Weston Mills was above its 18 foot flood stage for roughly 12 hours. The NCDC estimated that in Middlesex County the event caused roughly $500,000 in property damages.

Based on past and recent history, certain parts of Middlesex County clearly have a high probability of flooding repeatedly in the future. Several areas adjacent to the Raritan River and within the Woodbridge River Basin area of the County have flooded several times in the past few years. With a total of 60 past flood events in Middlesex County between 1996 and May 2015, the County experiences a flood event on average roughly three floods per year. However, only ten events have resulted in significant damages. If only considering the ten events that resulted in damage, the County experiences a significant flood event approximately every two years. With one significant event roughly every two years, there is a 50% annual probability of a future (significant) flood events occurring in Middlesex County. Severe flooding in Middlesex County five out of the last ten years suggests that the repeated flooding in specific areas is likely to occur again in the future. Considering the impacts from flooding, the 2016 Middlesex County HMPSC ranked floods as a high risk hazard (See Table 4-1 for a complete list of hazard rankings).

Flood Risk and Vulnerability Assessment (Including Impacts on Life and Property)

The NCDC database indicates that there have been 60 floods in Middlesex County in the period from 1950 to June 2015, with damages of over $92 million from riverine flooding. Figures maintained by NCDC indicate that Middlesex County has experienced no deaths and 73 injuries due to floods. Of those 73 injuries, NCDC reported 72 injuries related to flooding from Hurricane Floyd in 1999. In Middlesex County there have been no deaths or injuries due to storm surge. Approximately $500 million has been reported in property damages related to storm surge. Nearly all of this damage was associated with Hurricane Sandy in 2012.

This subsection uses several approaches to characterize flood risk and vulnerability. First, Table 4-36 lists all the jurisdictions in the County, and provides a series of data related to floodplain (also referred to in the table as SFHA, or Special Flood Hazard Area, i.e. the FEMA-designated 100-year floodplain). The term centroid means the geographic center of a parcel. It is important to recognize that neither the amount or percent of floodplain in a jurisdiction, nor the number or percentage of parcels with centroids in the floodplain directly translate to risk. This is because in many cases (a) even though a community has a large area of floodplain, there are no structures or populations in it, and (b) although the center of a parcel may be in a floodplain, often there are either no structures on a parcel, or structures are in another area of a parcel that is not in the floodplain. Nevertheless, the data do suggest some communities where an above average area or number of parcels in the floodplain may be at increased risk.

Table 4-36
Middlesex County Area, Parcel and Floodplain Data
(Source: FEMA Region II, Coastal Analysis and Mapping, Preliminary FIRM, September 19, 2014)

Jurisdiction	Area (square miles)	Area in SFHA (square miles)	Percent Area in SFHA	# Parcels	Centroid in SFHA	Percent Centroid in SFHA
Township of South Brunswick	41	6.40	15.60%	15,532	528	3.40%
Township of Monroe	42.16	6.31	14.96%	31,925	2,035	6.37%
Township of Old Bridge	38.68	6.20	16.03%	23,198	1,034	4.46%
Borough of Sayreville	17.58	5.16	29.37%	18,180	1,451	7.98%
Township of Edison	30.64	4.74	15.48%	36,891	551	1.49%
Township of Woodbridge	24.01	4.54	18.93%	29,474	1,193	4.05%
Township of Plainsboro	12.11	2.76	22.79%	5,976	80	1.34%
Township of East Brunswick	22.41	1.74	7.76%	19,236	183	0.95%
Borough of Carteret	4.5	1.62	35.92%	5,933	782	13.18%
Township of Piscataway	18.95	1.54	8.13%	14,992	185	1.23%
Township of Cranbury	13.43	1.48	11.05%	1,556	37	2.38%
Borough of South Plainfield	8.32	1.26	15.18%	8,894	406	4.56%
City of New Brunswick	5.75	0.99	17.27%	7,828	111	1.42%
Borough of Middlesex	3.51	0.96	27.35%	5,016	703	14.02%
City of Perth Amboy	5.17	0.93	17.94%	14,074	237	1.68%
Borough of South River	2.92	0.74	25.21%	5,429	723	13.32%
Borough of Spotswood	2.41	0.58	23.96%	3,128	329	10.52%
Township of North Brunswick	12.28	0.55	4.47%	11,681	118	1.01%
Borough of Helmetta	0.87	0.45	52.27%	1,014	152	14.99%
City of South Amboy	1.97	0.44	22.30%	3,100	76	2.45%
Borough of Dunellen	1.06	0.30	27.85%	2,189	508	23.21%
Borough of Highland Park	1.82	0.28	15.32%	4,878	53	1.09%
Borough of Metuchen	2.83	0.13	4.46%	7,823	72	0.92%
Borough of Milltown	1.59	0.12	7.78%	3,316	21	0.63%
Borough of Jamesburg	0.89	0.10	11.14%	2,013	107	5.32%
All Communities	**316.86**	**50.32**	**15.88%**	**283,276**	**11,675**	**4.12%**

NFIP Flood Insurance Claims

One of the most effective ways to characterize flood risk in a community is to study the history of flood insurance claims that have been made through FEMA's National Flood Insurance Program (NFIP). The NFIP is the predominant provider of flood insurance policies nationwide, and has maintained detailed records of claims since the program was established in the late 1970s. Information provided by the NFIP can also be used as an indication of the potential for flooding in Middlesex County, and the amount of damage it has caused in the past. Although the NFIP data set is large and fairly detailed, it should be recognized that it does not provide a complete picture of flood risk in a community because it is based only on insurance claims, so flood damages that were not covered by insurance are not part of the data.

However, there is enough claims data that some inferences about flood can be drawn from reviewing it. The next table (4-37) shows Countywide NFIPs claims information ordered by the total number of claims in the various jurisdictions.

Table 4-37
Middlesex County NFIP claims, all Jurisdictions, ordered by Number of Claims
(Source: FEMA National Flood Insurance Program, February 2015)

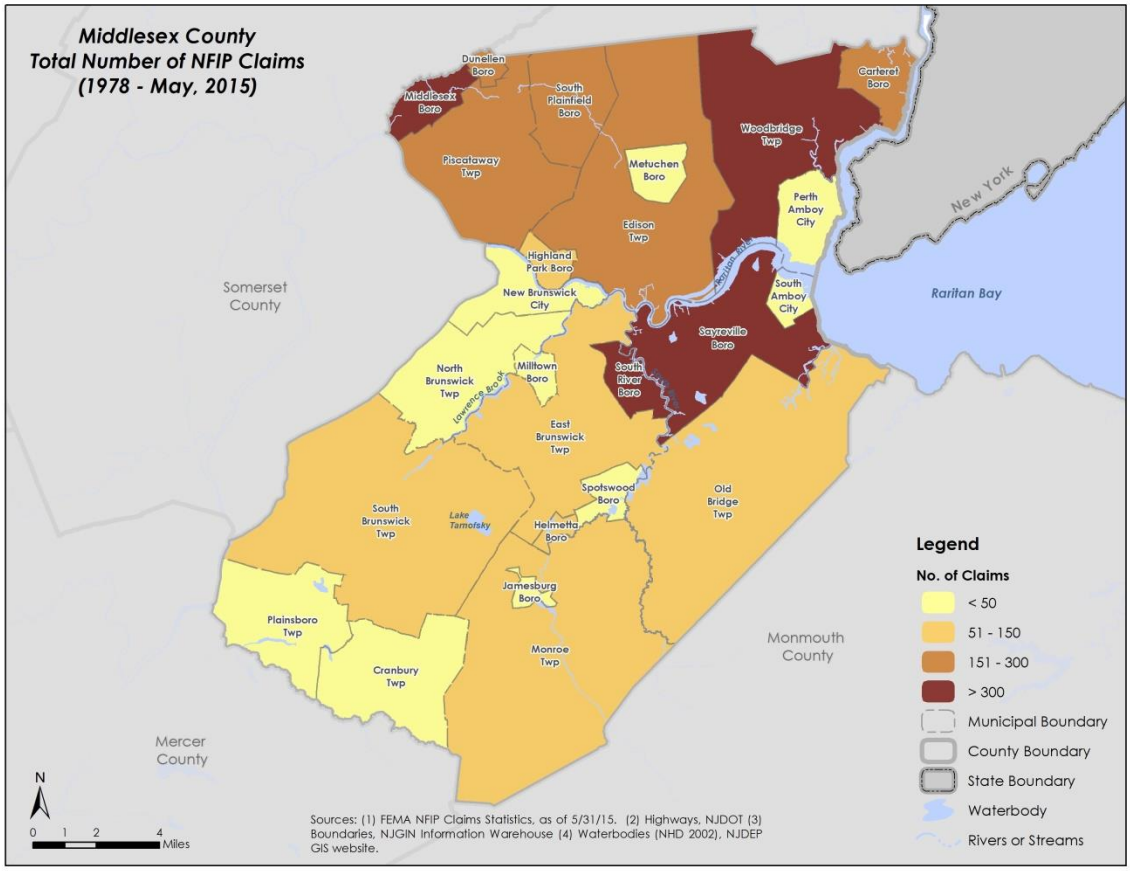
Jurisdiction	Number of Claims	Total Value of Claims	Average Claim	% of County Claim Average
Borough of Middlesex	774	$20,039,465	$25,891	82%
Township of Woodbridge	494	$14,241,347	$28,829	91%
Borough of South River	365	$13,982,513	$38,308	121%
Borough of Sayreville	318	$17,381,933	$54,660	173%
Borough of South Plainfield	242	$4,589,894	$18,967	60%
Borough of Dunellen	224	$2,292,027	$10,232	32%
Township of Piscataway	154	$4,870,148	$31,624	100%
Borough of Carteret	149	$2,942,687	$19,750	63%
Township of Edison	107	$8,393,667	$78,445	249%
Township of Old Bridge	100	$4,654,517	$46,545	148%
Township of East Brunswick	88	$2,076,455	$23,596	75%
Township of Monroe	72	$2,678,160	$37,197	118%
Borough of Helmetta	60	$642,996	$10,717	34%
Borough of Highland Park	45	$382,951	$8,510	27%
City of New Brunswick	40	$1,734,058	$43,351	137%
City of Perth Amboy	37	$3,125,778	$84,480	268%
City of South Amboy	36	$1,898,906	$52,747	167%
Township of South Brunswick	35	$406,718	$11,621	37%
Borough of Spotswood	35	$347,622	$9,932	31%
Borough of Jamesburg	29	$756,064	$26,071	83%
Township of Cranbury	24	$654,757	$27,282	86%
Borough of Milltown	20	$1,427,840	$71,392	226%
Township of North Brunswick	15	$89,603	$5,974	19%
Borough of Metuchen	8	$45,346	$5,668	18%
Town of Plainsboro	7	$72,383	$10,340	33%
All Communities	**3,478**	**$109,727,837**	**$31,549**	**100%**

Note that the jurisdictional appendices include maps of NFIP claims by jurisdiction, which adds an important spatial dimension to the data, i.e. where the claims have occurred and what flood sources are nearby.

The total number of claims by community is a good general measure of risk by jurisdiction. However, the average claim amount and relative size of claims in a jurisdiction to the Countywide average are probably more meaningful measures, depending on how the data will be used. For example, if the data will be used as one basis for identifying areas of high risk (where mitigation efforts could be focused), it may be useful to first look at jurisdictions where average claims amounts are relatively high, to determine if there are specific flood sources or properties that are particularly vulnerable. Average claims amounts in Sayreville, Edison, Perth Amboy and Milltown are well above the County average. This may suggest that flood waters are particularly deep, or that there are other factors such as velocity, debris, or contamination that are increasing the damages. Since the figures in the table are jurisdiction totals and averages, further analysis may be done at the level of individual properties using more detailed NFIP data. Because of confidentiality rules, hazard mitigation plans do not include any information about individual properties or policy holders.

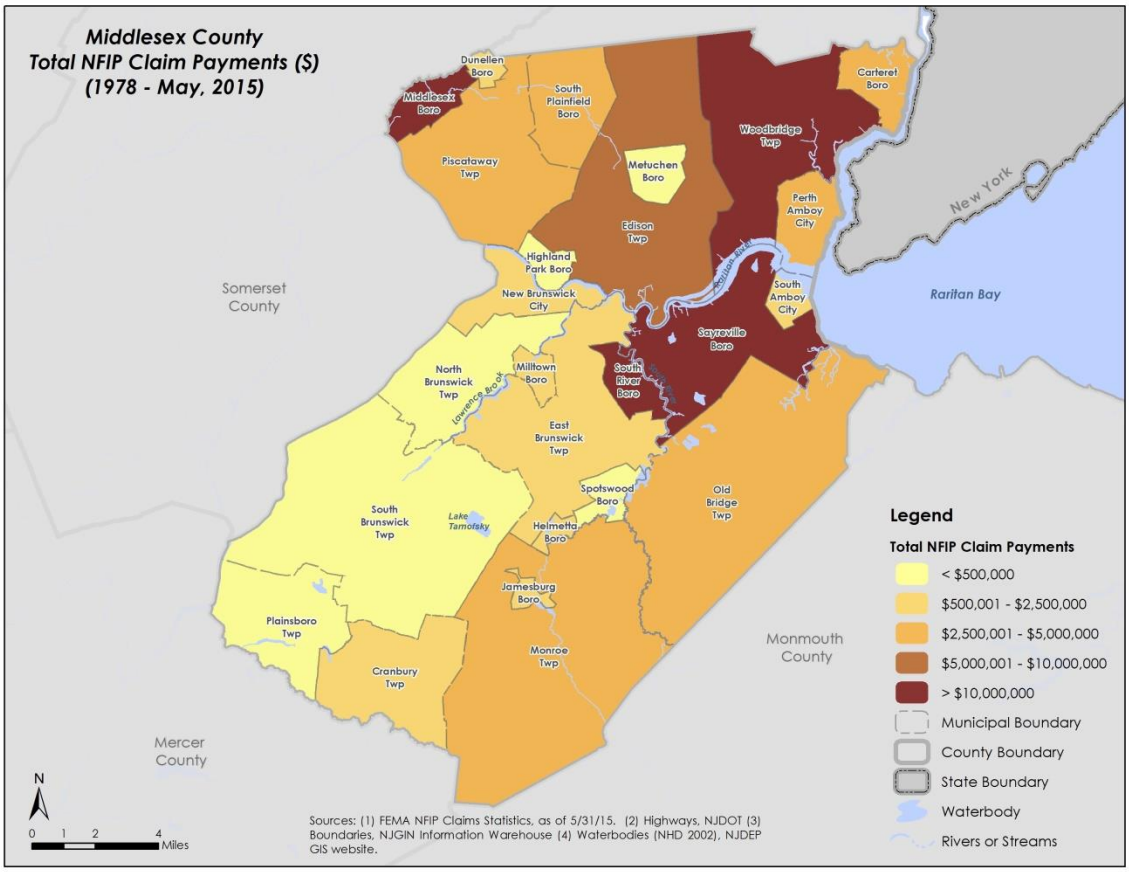
Figure 4-29 show summary-level Countywide NFIP claims data, extending back to the beginning of the program in the late 1970s. The first map summarizes the numbers of NFIP claims for the 25 jurisdictions in Middlesex County .

Figure 4-29
Number of Middlesex County NFIP Claims since 1978, including RL and SRL Claims
(Source: FEMA National Flood Insurance Program, February 2015)



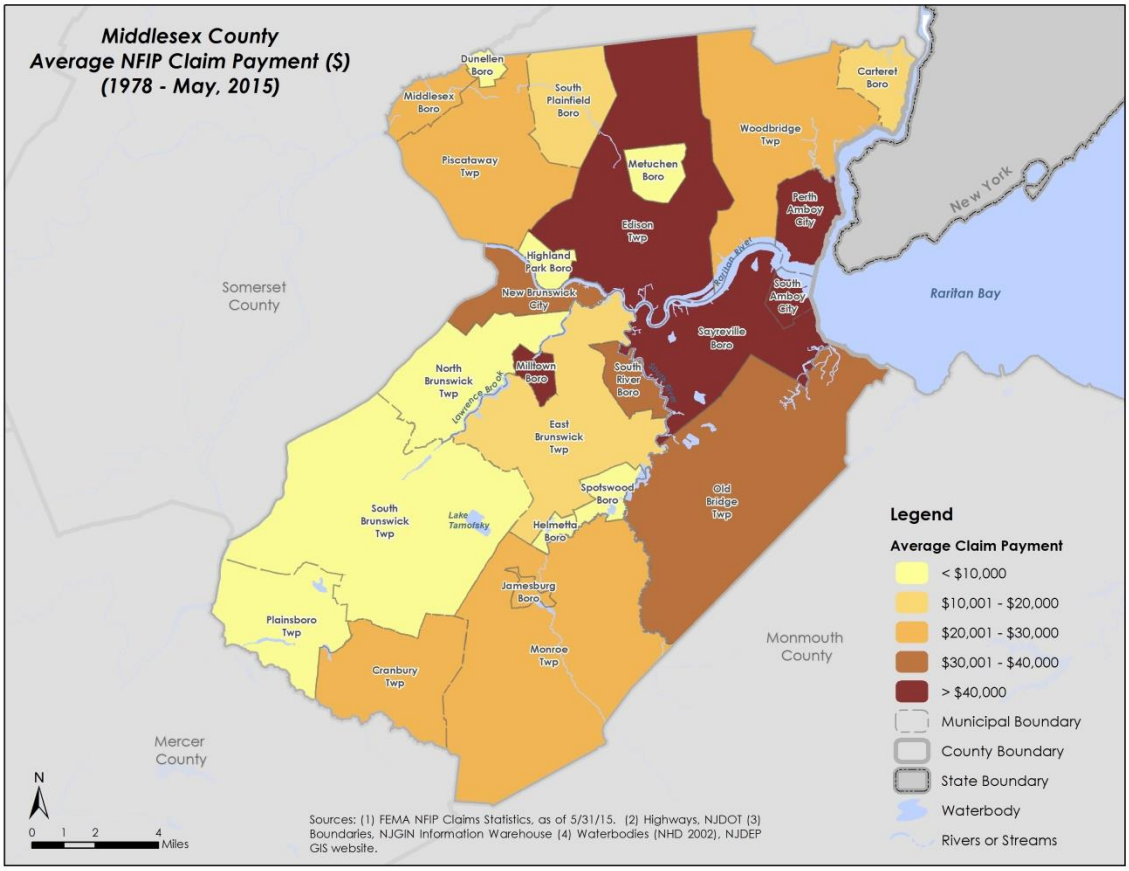
The next figure (4-30) presents Countywide NFIP data, showing the total dollar value of NFIP flood insurance claims paid since 1978, by jurisdiction.

Figure 4-30
Dollar Values of Middlesex County NFIP Claims since 1978, including RL and SRL Claims
(Source: FEMA National Flood Insurance Program, February 2015)



The next figure (4-31) shows the value of average NFIP claims in Middlesex County, extending back to the late 1970s. As discussed elsewhere in this subsection, the average claim value is one method for inferring risk, i.e. where average claims are above the County norm, flood waters are likely deeper, and locations where such floods are occurring may present more long-term risk to the community, although this does not take into account the probabilities of the events that caused the damage. The pattern presented by this data is substantially similar to the other maps above, i.e. the communities with the highest average claims tend to be nearest the Raritan River, Raritan Bay, Arthur Kill, and South River.

Figure 4-31
Average Dollar Values of Middlesex County NFIP Claims since 1978, including RL and SRL Claims
(Source: FEMA National Flood Insurance Program, February 2015)



NFIP Repetitive Loss Properties

The next approach is to examine records of NFIP *Repetitive Loss* (RL) and *Severe Repetitive Loss* (SRL) records in various jurisdictions. RL and SRL are subsets of overall NFIP claims, and were established as part of FEMA's regulatory and programmatic regimes. In July 2012, the United States Congress passed the Biggert-Waters Flood Insurance Reform Act of 2012 (BW-12) which required FEMA and other agencies to make a number of changes to the NFIP. One of the changes implemented by the legislation was to change the definition of RL and SRL properties. A repetitive loss property is now defined as a

structure covered by a contract for flood insurance made available under the NFIP that has incurred flood-related damage on two occasions, in which the cost of the repair, on average, equaled or exceeded 25% of market value of the structure at the time of each such flood event.

Table 4-38 below summarizes the RL and SRL properties in Middlesex County by occupancy class. The table shows the majority of RL and SRL properties are single family residential properties.

Table 4-38
Repetitive Loss Properties by Occupancy Class, Middlesex County

Occupancy Class	Total Number of Repetitive Loss Properties	Total Number of Severe Repetitive Loss Properties
Single Family	332	55
Condo	6	5
2-4 Family	38	7
Other Residential	25	7
Non Residential	28	3
Middlesex County	**429**	**77**

In Middlesex County, as of February 2014, 429 residential and commercial properties were categorized as RL properties. Collectively, claim holders have received payments of just over $49.1 million (the figure includes claim payments for both building and contents damages). Table 4-39 presents this data for the entire County, sorted by total number of claims for RL properties.

Table 4-39
Middlesex County NFIP Repetitive Loss Flood Insurance Claims, all Jurisdictions, ordered by Number of Claims
(Source: FEMA National Flood Insurance Program, February 2015)

Jurisdiction	RL Properties	RL Claims	Total RL Claims	Average RL Claim	% of County Claim Average
Borough of Middlesex	127	427	$11,589,974	$27,143	73%
Borough of South River	50	146	$5,555,225	$38,049	102%
Township of Woodbridge	42	137	$8,110,135	$59,198	159%
Borough of South Plainfield	34	118	$2,157,889	$18,287	49%
Borough of Dunellen	31	98	$1,453,220	$14,829	40%
Township of Piscataway	24	75	$2,354,261	$31,390	84%
Borough of Carteret	29	69	$1,335,518	$19,355	52%
Borough of Sayreville	21	58	$4,638,284	$79,970	215%
Borough of Helmetta	13	40	$407,136	$10,178	27%
Township of East Brunswick	16	38	$1,253,836	$32,996	89%
Township of Edison	7	18	$338,137	$18,785	51%
Borough of Highland Park	5	18	$201,480	$11,193	30%
City of Perth Amboy	3	15	$1,392,402	$92,827	250%

Jurisdiction	RL Properties	RL Claims	Total RL Claims	Average RL Claim	% of County Claim Average
Township of Old Bridge	7	14	$751,473	$53,677	144%
City of New Brunswick	4	13	$874,769	$67,290	181%
Borough of Milltown	5	10	$6,321,993	$632,199	1,701%
Borough of Jamesburg	4	9	$162,533	$18,059	49%
City of South Amboy	2	5	$37,922	$7,584	20%
Township of Cranbury	1	5	$32,850	$6,570	18%
Borough of Spotswood	2	4	$53,729	$13,432	36%
Township of Monroe	1	3	$75,251	$25,084	68%
Township of South Brunswick	1	2	$24,480	$12,240	33%
Grand Total	**429**	**1,322**	**$49,122,494**	**$37,158**	**----**

The RL data set is very useful in identifying areas in the County where there appear to be ongoing flood problems. Information about the average claim amount and how that compares to the County average may also be of use in identifying specific places and flood sources where mitigation may be considered.

NFIP Severe Repetitive Loss Properties

The next category of flood claims considered here is those related to *Severe Repetitive Loss* (SRL) properties. SRL is defined by FEMA/NFIP as: a residential property (a) that has at least four NFIP claim payments (including building and contents) over $5,000 each, and the cumulative amount of such claims payments exceeds $20,000, or; (b) for which at least two separate claims payments (building payments only) have been made with the cumulative amount of the building portion of such claims exceeding the market value of the building. As shown in the next table, Middlesex County presently has 77 such properties. The table provides similar data to the RL tables above.

Table 4-40
Middlesex County NFIP Severe Repetitive Loss Flood Insurance Claims, all jurisdictions, ordered by Number of Claims
(Source: FEMA National Flood Insurance Program, February 2015)

Jurisdiction	SRL Properties	SRL Claims	Total SRL Claims	Average SRL Claim	% of County Claim Average
Borough of Middlesex	29	143	$3,455,315	$24,163	79%
Borough of South Plainfield	9	49	$1,046,677	$21,361	70%
Township of Piscataway	7	34	$1,219,085	$35,855	117%
Borough of Dunellen	7	30	$711,594	$23,720	78%
Borough of South River	6	28	$867,541	$30,984	101%
Township of Woodbridge	8	21	$1,774,914	$84,520	277%
Borough of Helmetta	2	10	$171,316	$17,132	56%
City of Perth Amboy	1	10	$63,509	$6,351	21%
Borough of Highland Park	1	9	$115,777	$12,864	42%
City of New Brunswick	2	9	$721,107	$80,123	262%

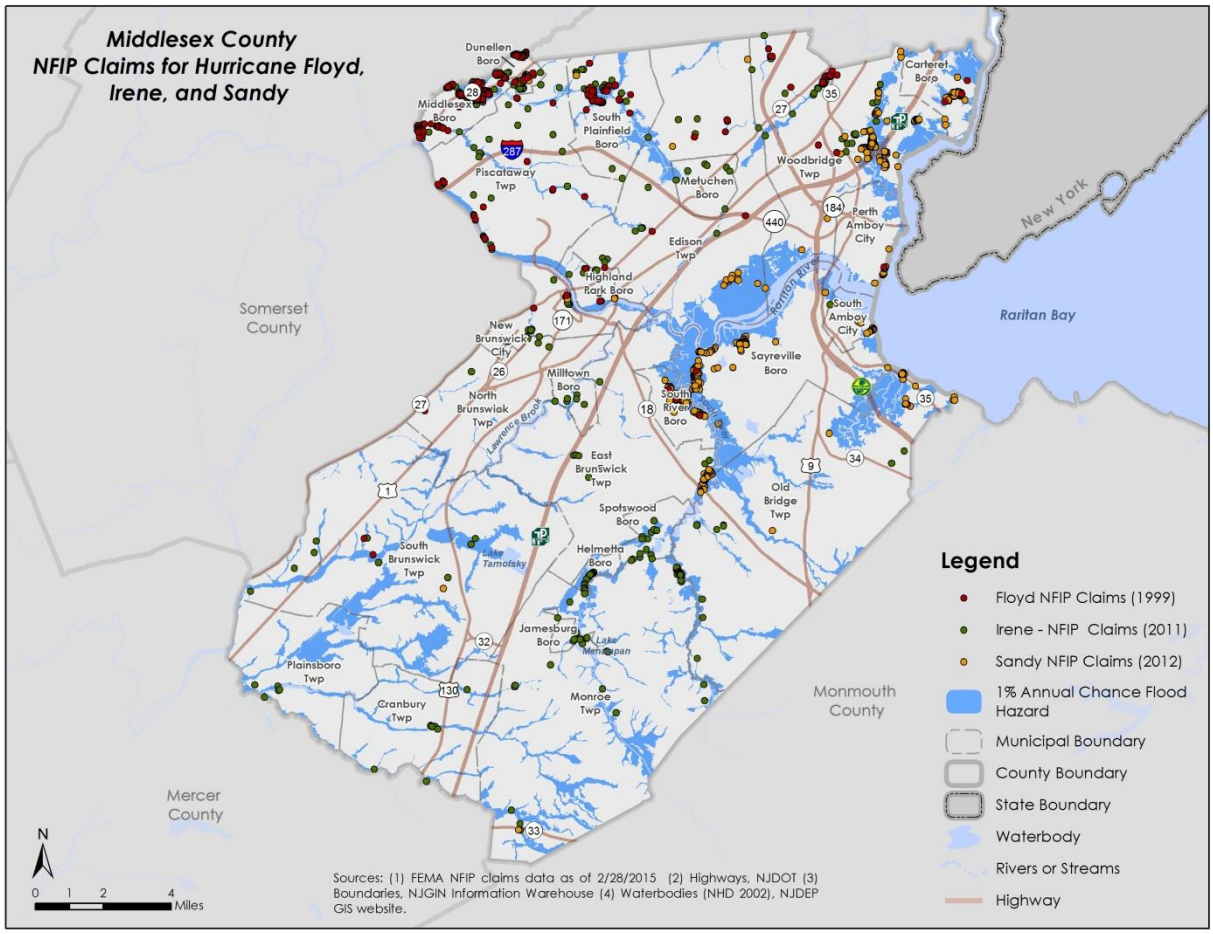
Jurisdiction	SRL Properties	SRL Claims	Total SRL Claims	Average SRL Claim	% of County Claim Average
Borough of Sayreville	2	7	$456,519	$65,217	214%
Township of East Brunswick	1	5	$246,905	$49,381	162%
Township of Edison	1	4	$58,267	$14,567	48%
Township of Old Bridge	1	2	$117,880	$58,940	193%
All Communities	**77**	**361**	**$11,026,404**	**$30,544**	**----**

The Borough of Middlesex clearly dominates the number of SRL insurance claims, but other aspects of the data may be more significant. Some communities with far fewer SRL properties have much higher average claims, both in terms of average claim value, as well as compared to the overall County average. This data may be used to identify and prioritize specific areas or properties that may be good mitigation project candidates.

Hurricanes Floyd, Irene, and Sandy – NFIP Claims

As discussed elsewhere in the present subsection, and in the jurisdictional appendices, several hurricanes and tropical storms caused a large percentage of flood insurance claims in Middlesex County. The NFIP claims for hurricanes Floyd, Irene, and Sandy totaled 1,974 or 57.7% of the 3,419 total historic NFIP claims in Middlesex County. Figure 4-32 identifies the Floyd, Irene, and Sandy NFIP claims. Note that the as a result of the layering many of the Irene NFIP claims are hidden underneath the claims shown for Sandy and Irene.

Figure 4-32
Hurricane Floyd, Irene, and Sandy NFIP Claims in Middlesex County
(Source: FEMA Region III, NFIP Claims Data as of February 28 2015)



Irene and Floyd were primarily rain events, while flooding from Sandy had a very large surge component. Interestingly, there were relatively few claims from Sandy for many areas directly exposed to the Raritan and Arthur Kill, while a few inland areas close to Woodbridge Creek and the South River experienced significant flood damage, presumably related to surge.

Flood (Storm Surge) Risk Assessment

As discussed in the subsections above, various jurisdictions in Middlesex County are exposed to storm surge because of their exposure to Raritan Bay, the Raritan River, South River, and Woodbridge Creek, among others. Much of the flooding from Hurricane Sandy was related to storm surge, as opposed to heavy rain. With the expected increase in sea level over the next century, storm surge will become even more of a factor in estimating risks in communities with exposure to coastal flood sources. The following subsections offer a discussion of these risks in Middlesex County, based on GIS information, and estimates from the FEMA Coastal Flood Loss Atlas (CFLA).

The initial analysis included calculating the land area and estimates of the populations within storm surge Categories 1 - 4 for each of the four counties. This portion of the risk assessment approach matches the vulnerability assessment completed for the State of New Jersey 2014 Hazard Mitigation Plan. There is generally ample warning of impending hurricanes and tropical storms, so injuries and loss of life from surge do not normally present significant risks. However, the data do help in developing an overall understanding of risks in the County, and in various communities. Note that the jurisdictional appendices include additional discussion of surge hazards, as well as community-specific inundation maps by surge category. To estimate the population exposed to the surge inundation areas, the SLOSH zones were overlaid on the 2010 Census block population data in GIS. Since census blocks do not follow the boundaries of the floodplain, the census blocks with their centroid in the SLOSH boundaries were used to calculate the estimated population exposed to the hurricane surge hazard.

Table 4-41 summarizes the 2010 Census population in the category 1 through 4 SLOSH zones for the jurisdictions in Middlesex county that are exposed to storm surge. The table is ordered by the percentage of population in inundation zone Category 1, the Category 2, and so forth. It is interesting to note that while Sayreville dominates the population exposed to a Category 1 event, other communities have significantly greater exposure in less probably events, Categories 2-4. See Municipal Appendices for additional details about the storm surge risk in Middlesex County.

Table 4-41
Middlesex County Population Exposure, by Jurisdiction, SLOSH Inundation Categories 1-4, first ordered by Population exposed in Category 1
(Sources: FEMA Region IV, Coastal Flood Loss Atlas (CFLA) SLOSH – March, 2014, 2010 US Census)

Jurisdiction	Surge Cat. 1	Surge Cat. 2	Surge Cat. 3	Surge Cat. 4
Sayreville Borough	1,443	2,539	3,660	4,492
South River Borough	865	1,541	2,186	2,406
Old Bridge Township	758	1,928	4,586	7,258
Carteret Borough	620	2,952	4,828	5,879
Woodbridge Township	578	3,374	4,824	5,862
South Amboy City	450	532	657	850
Edison Township	245	293	337	381
East Brunswick Township	182	276	474	1,093
Perth Amboy City	180	871	1,943	2,506
Spotswood Borough	84	150	559	1,985
Highland Park Borough	62	106	172	250
New Brunswick City	44	117	204	304
Piscataway Township	21	88	177	344
Monroe Township	7	27	186	2,820
Milltown Borough	0	12	155	289
Middlesex Borough	0	10	35	2,499

Jurisdiction	Surge Cat. 1	Surge Cat. 2	Surge Cat. 3	Surge Cat. 4
North Brunswick Township	0	2	2	3
Helmetta Borough	0	0	0	232
Grand Total	**5,539**	**14,818**	**24,985**	**39,453**

Another measure of exposure and risk is the land area exposed to various storm surge categories. Table 4-42 identifies the area and percent of land area (in square miles) in the region exposed to SLOSH inundation zone Categories 1 through 4. The table is ordered by the percentage of land area in Surge Category 1. The table shows that Old Bridge Township has the highest percentage of land area in two of the four inundation zones (Surge Categories 3 and 4). Knowing the land area within each zone can help determine the overall impact to buildings and other infrastructure in the region a result of storm surge.

Table 4-42
Total Land Area (Square Miles) Located Within SLOSH Inundation Zones 1-4, Ordered by Surge Land Area from Category 1
(Sources: FEMA Region IV, Coastal Flood Loss Atlas (CFLA) SLOSH – March, 2014, 2010 US Census)

Jurisdiction	Surge Cat. 1	Surge Cat. 2	Surge Cat. 3	Surge Cat. 4
Sayreville Borough	4.8	6.1	7.2	7.9
Old Bridge Township	4.2	5.4	7.8	12.9
Edison Township	3.5	4.3	4.7	5.1
Woodbridge Township	3.0	6.5	7.8	8.7
Carteret Borough	1.7	2.8	3.5	4.3
East Brunswick Township	1.4	1.6	2.0	2.6
City of New Brunswick	0.9	1.0	1.2	1.3
South River Borough	0.8	1.1	1.3	1.5
City of Perth Amboy	0.7	1.3	1.7	1.9
Piscataway Township	0.5	0.8	1.1	1.4
City of South Amboy	0.4	0.5	0.5	0.6
Highland Park Borough	0.3	0.3	0.4	0.4
Spotswood Borough	0.3	0.3	0.6	1.8
Monroe Township	0.0	0.1	0.2	1.6
North Brunswick Township	0.0	0.1	0.1	0.1
Milltown Borough	0.0	0.1	0.2	0.3
Middlesex Borough	0.0	0.0	0.1	1.6
Helmetta Borough	0.0	0.0	0.0	0.2
Grand Total	**22.4**	**32.3**	**40.5**	**54.1**

There is no reliable open-source information that allows assignment of specific probabilities to surge categories, so certain assumptions must be made in order to complete a risk assessment (an estimate or calculation of expected future damages from the hazard). The next table shows the assumptions used in

a simple risk calculation for storm surge. These figures are estimates only, and the results of this calculation should be used for planning purposes only, not as an exact indication of possible losses.

Table 4-43
Assumptions for Storm Surge Risk Assessment, Middlesex County

Data Type	Value
Structures per parcel	1
Structure replacement value/s.f.	$150
Contents replacement value/s.f.	$75
Assumed square footage of average structure	2,000

Table 4-44 below shows the results of a risk calculation based on the inputs described above. It should be noted that these figures are *deterministic,* meaning they do not incorporate probabilities. The table after this one incorporates the estimated probabilities noted above.

Table 4-44
Deterministic Surge Scenarios, Middlesex County, ordered by Damages in a Category 1 Event

Jurisdiction	Damages Surge Cat. 1	Damages Surge Cat. 2	Damages Surge Cat. 3	Damages Surge Cat. 4
Sayreville Borough	$188,311,500	$331,339,500	$477,630,000	$586,206,000
South River Borough	$112,882,500	$201,100,500	$285,273,000	$313,983,000
Old Bridge Township	$98,919,000	$251,604,000	$598,473,000	$947,169,000
Carteret Borough	$80,910,000	$385,236,000	$630,054,000	$767,209,500
Woodbridge Township	$75,429,000	$440,307,000	$629,532,000	$764,991,000
South Amboy City	$58,725,000	$69,426,000	$85,738,500	$110,925,000
Edison Township	$31,972,500	$38,236,500	$43,978,500	$49,720,500
East Brunswick Township	$23,751,000	$36,018,000	$61,857,000	$142,636,500
Perth Amboy City	$23,490,000	$113,665,500	$253,561,500	$327,033,000
Spotswood Borough	$10,962,000	$19,575,000	$72,949,500	$259,042,500
Highland Park Borough	$8,091,000	$13,833,000	$22,446,000	$32,625,000
New Brunswick City	$5,742,000	$15,268,500	$26,622,000	$39,672,000
Piscataway Township	$2,740,500	$11,484,000	$23,098,500	$44,892,000
Monroe Township	$913,500	$3,523,500	$24,273,000	$368,010,000
Helmetta Borough	$0	$0	$0	$30,276,000
Middlesex Borough	$0	$1,305,000	$4,567,500	$326,119,500
Milltown Borough	$0	$1,566,000	$20,227,500	$37,714,500
North Brunswick Township	$0	$261,000	$261,000	$391,500
Grand Total	**$722,839,500**	**$1,933,749,000**	**$3,260,542,500**	**$5,148,616,500**

A probabilistic risk estimate is then completed by incorporated using assumptions regarding annual surge probabilities in conjunction with FEMA depth-damage functions and parcel counts, assuming one

structure per parcel.

Table 4-45
Assumptions for Probabilistic Surge Risk Estimate, Middlesex County

Data Type/Surge Category	Category 1	Category 2	Category 3	Category 4
Assumed annual probability	2%	1%	0.5%	0.1%
Assumed flood depth	1	2	3	4

Table 4-46 shows expected annual damages in various surge scenarios, incorporating probabilities. In many cases the damages in Category 3 and Category 4 events are less than in higher-probability events such as Categories 1 and 2. This is because of the effects of probability - Category 4 events are much less likely to occur. It should be understood that although the damages are annualized, there is no presumption that surge will cause similar damage every year. Annualizing damages is a method to characterize and compare risks, and is not intended as an exact measure of future damages.

Table 4-46
Annualized Surge Scenarios, Middlesex County, ordered by Damages in a Category 1 Event

Jurisdiction	Annualized Damages Surge Cat. 1	Annualized Damages Surge Cat. 2	Annualized Damages Surge Cat. 3	Annualized Damages Surge Cat. 4	Annualized Damages, All Cats.
Sayreville Borough	$3,766,230	$6,626,790	$2,388,150	$586,206	$13,367,376
South River Borough	$2,257,650	$4,022,010	$1,426,365	$313,983	$8,020,008
Old Bridge Township	$1,978,380	$5,032,080	$2,992,365	$947,169	$10,949,994
Carteret Borough	$1,618,200	$7,704,720	$3,150,270	$767,210	$13,240,400
Woodbridge Township	$1,508,580	$8,806,140	$3,147,660	$764,991	$14,227,371
South Amboy City	$1,174,500	$1,388,520	$428,693	$110,925	$3,102,638
Edison Township	$639,450	$764,730	$219,893	$49,721	$1,673,793
East Brunswick Township	$475,020	$720,360	$309,285	$142,637	$1,647,302
Perth Amboy City	$469,800	$2,273,310	$1,267,808	$327,033	$4,337,951
Spotswood Borough	$219,240	$391,500	$364,748	$259,043	$1,234,530
Highland Park Borough	$161,820	$276,660	$112,230	$32,625	$583,335
New Brunswick City	$114,840	$305,370	$133,110	$39,672	$592,992
Piscataway Township	$54,810	$229,680	$115,493	$44,892	$444,875
Monroe Township	$18,270	$70,470	$121,365	$368,010	$578,115
Helmetta Borough	$0	$0	$0	$30,276	$30,276
Middlesex Borough	$0	$26,100	$22,838	$326,120	$375,057
Milltown Borough	$0	$31,320	$101,138	$37,715	$170,172
North Brunswick Township	$0	$5,220	$1,305	$392	$6,917
Total	**$14,456,790**	**$38,674,980**	**$16,302,713**	**$5,148,617**	**$74,583,099**

Sea Level Rise

Numerous areas in Middlesex County are presumed subject to the future effects of sea level rise. Those most affected will be ones with direct or near exposure to Raritan Bay, Arthur Kill, and the Raritan River, and other tidal areas. There are also likely to be effects upstream from these areas. Many organizations have produced studies to estimate the potential levels and effects of sea level rise, and most of the projections are presented in ranges, rather than specific expected increases in water surface elevations.

One relatively simple way to explore the potential effects of sea level rise is to use GIS analysis capabilities in conjunction with estimated increases in sea level elevations. Table 4-47 compares the numbers of parcels in each Middlesex County jurisdiction whose centroids would intersect with the 100-year floodplain (Preliminary Flood Insurance Rate Map, Base Flood Elevation) under various sea level rise scenarios. This information should be used only to generally characterize potential flooding and increases in flooding. The first table shows data for the year 2050 SLR, and the second one shows data for the year 2100.

Table 4-47
Parcels with Centroids Intersecting 100-year Floodplain – various Year 2050 Sea Level Rise Scenarios

Municipality	Low (PFIRM +.7 Ft)	Intermediate Low (+1.6 Ft.)	Intermediate High (+3.9 Ft.)	High (+ 6.6 Ft.)
Sayreville Borough	1,584	1,631	1,711	1,810
Carteret Borough	1,086	1,194	1,332	1,530
Woodbridge Township	1,103	1,188	1,297	1,452
Old Bridge Township	1,017	1,040	1,091	1,131
South River Borough	798	844	898	967
Perth Amboy City	225	234	263	308
South Amboy City	164	176	205	241
Edison Township	203	203	208	214
East Brunswick Township	127	128	134	152
Spotswood Borough	41	41	42	44
Monroe Township	0	2	13	25
New Brunswick City	14	14	14	14
Highland Park Borough	7	9	9	12
North Brunswick Township	2	2	2	2
Grand Total	**6371**	**6706**	**7219**	**7902**

Table 4-48
Parcels with Centroids Intersecting 100-year Floodplain – various Year 2100 Sea Level Rise Scenarios

Municipality	Low (PFIRM +.7 Ft)	Intermediate Low (+1.6 Ft.)	Intermediate High (+3.9 Ft.)	High (+ 6.6 Ft.)
Woodbridge Township	1,188	1,362	1,906	2,829
Carteret Borough	1,194	1,406	2,033	2,784
Sayreville Borough	1,631	1,749	2,113	2,583
Old Bridge Township	1,040	1,105	1,402	2,265
South River Borough	844	926	1,131	1,363
Perth Amboy City	234	282	482	842
South Amboy City	176	222	347	448
East Brunswick Township	128	143	223	277
Edison Township	203	211	220	237
Spotswood Borough	41	42	55	96
Monroe Township	2	22	31	52
Highland Park Borough	9	9	17	22
New Brunswick City	14	14	15	18
North Brunswick Township	2	2	2	2
Grand Total	6,706	7,495	9,977	13,818

Differences in topography and the size and distribution of parcels significant affect the results displayed in these tables, and this explains why the order of communities is not the same from one table to the other.

Geologic Hazards

(Includes Landslides, Sinkholes and Subsidence)

Description of Geologic Hazards

A landslide is a natural geologic process involving the movement of earth materials down a slope, including rock, earth, debris, or a combination of these, under the influence of gravity. However, there are a variety of triggers for landslides such as: a heavy rainfall event, earthquakes, or human activity. The rate of landslide movement ranges from rapid to very slow. A landslide can involve large or small volumes of material. Material can move in nearly intact blocks or be greatly deformed and rearranged. The slope may be nearly vertical or fairly gentle.[47] For additional information about landslides see the USGS's Landslide Hazards Program website.

According to the USGS, land subsidence is the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion, owing to the subsurface movement of earth materials. The principal causes are aquifer-system compaction, drainage of organic soils, underground

[47] NJDEP-Landslides in New Jersey, Delano and Wilshusen, 2001.

mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost.[48] For additional information about land subsidence see the USGS's Land Subsidence section of their website.

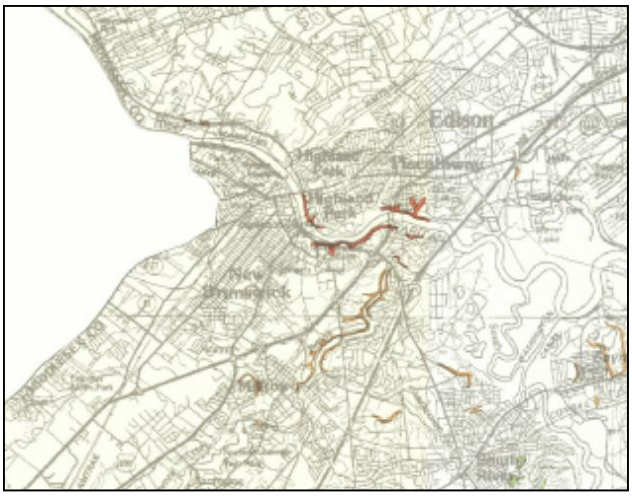
A sinkhole is a natural depression or hole in the surface topography caused by the removal of soil or bedrock by water. Sinkholes are common where the rock below the land surface is limestone, carbonate rock, salt beds, or rocks that can naturally be dissolved by groundwater circulating through them. As the rock dissolves, spaces and caverns develop underground.[49] They can vary in size, form either gradually or suddenly, and are found worldwide. When sinkholes occur in urban areas, it is usually due to water mainhttp://en.wikipedia.org/wiki/Water_main breaks or sewer collapses when old pipes give way. For additional information about sinkholes see the USGS's Sinkholes section of their website.

Location of Geologic Hazards

Landslides are usually associated with mountainous areas but can also occur in areas of generally low relief. In low relief areas, landslides occur due to steepening of slopes: as cut and fill failures (roadway and building excavations), river bluff failures, collapse of mine waste piles, and a wide variety of slope failures associated with quarries and open-pit mines.[50]

In Middlesex County the New Jersey Geological and Water Survey (NJGWS) indicates that the most susceptible landslide areas appear to be concentrated in the areas of New Brunswick, Piscataway, and Highland Park as shown in Figure 4-33 below. The areas shaded orange on the map represent the areas with the highest vulnerability from landslides. There are several other areas within the County that are susceptible to landslides including the southwest border of Cheesequake State Park.

Figure 4-33
Portion of Middlesex County with the Highest vulnerability to Landslides
(Source: NJGWS)



[48] USGS. Ground Information, Land Subsidence.
[49] USGS. Sinkholes.
[50] USGS. Landslide Types and Process. 2004.

Severity and Extent of Geologic Hazards

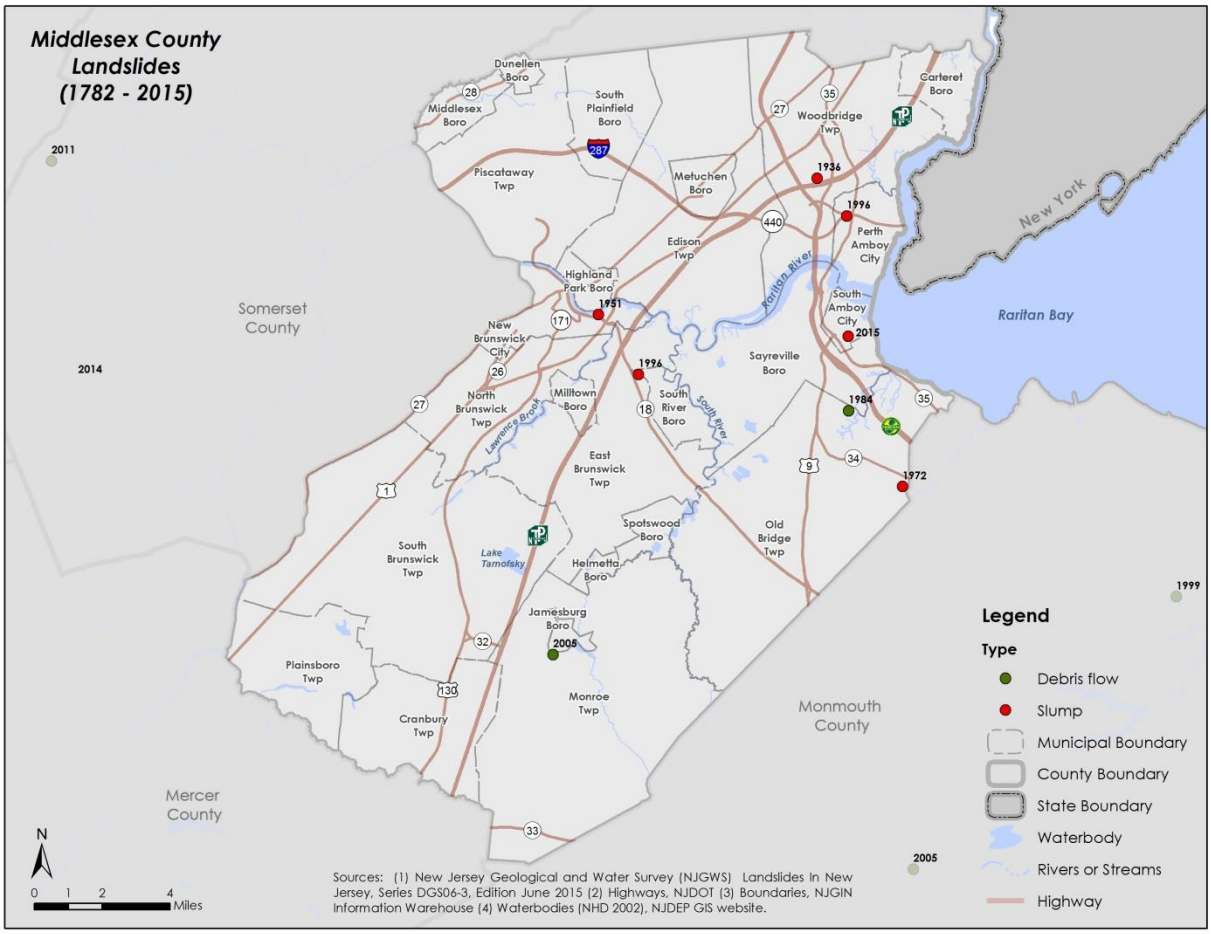
Landslides are considered highly site specific events and are concentrated in areas of steep slopes. The severity of the landslide hazard depends on a combination of slope angle and the geologic material underlying the slope. The severity of land subsidence and sinkholes has no generally established measure, except that it can be described in terms of change in ground elevation relative to sea level. Subsidence is generally permanent, although it can be abated with proper management methods. Sinkholes are generally of short duration, although if not repaired they can become permanent features.

Occurrences of Geologic Hazards

As of July 2015, the NJGWS indicates there have been 278 landslides in New Jersey since 1782.[51] Of this total, eight landslides occurred in Middlesex County between 1936 and 2015. The location of the eight landslides, included six slumps and two debris flows, are shown below in Figure 4-34.

[51] NJGWS. Retrieved from http://www.state.nj.us/dep/njgs/geodata/index.htm#list

Figure 4-34
Landslides in Middlesex County, 1782 - 2015
(Source: NJGWS, Landslides in New Jersey)



The eight landslide events between 1936 and 2015 are summarized below in Table 4-49.

Table 4-49
Middlesex County Landslides, 1936 - 2015
(Source: NJGWS, Landslides in New Jersey)

Municipality	Date	Type	Landslide Cause	Property Damage	Injuries	Fatalities	Description
Monroe Township	7/17/2005	Debris flow	Heavy rain	Yes	0	0	Significant property damage from landslide, a swimming pool was filled in with mud.
Woodbridge Township	Unknown	Slump	Fill material failure	No	0	0	Man made slope, fill material failure.
South River Borough	1/18/1996	Slump	Construction	Yes	0	0	A 40-foot-high slope slid during road construction, undermining Old Bridge Turnpike, between Tices Lane and Edgeboro Road. The road was temporarily closed.
New Brunswick City	Unknown	Slump	Heavy rain	No	0	0	Landslide on Raritan River bluff approximately five acres in size.
Old Bridge Township	1/18/1972	Slump	Heavy rain	yes	0	0	Large slump block slid off from a side yard of a house into a gully after heavy rain. The slump measured 25 by 100 approximately. The house was at risk of falling into the ravine.
Perth Amboy	5/11/1936	Slump	Clay digging	Yes	3	0	A boy and two men buried alive in clay landslide while digging for clay at the Valentine Brothers Clay pit. They were trapped for a half hour but were dug out and survived. Estimated location.
Old Bridge Township	April, 1984 (exact date unknown)	Debris flow	Heavy rain	No	0	0	After heavy rains and high tides, the southern side of a landfill collapsed and slid into wetlands. NJDEP closed the landfill later in 1984.
South Amboy City	3/23/2015	Slump	Water main break	yes	0	0	Erosion from a water main break is believed to have caused a road collapse on Gordon Street. An SUV vehicle had fallen into the ravine. A large section of road and front yard of a house slumped down. Gordon street east of Pine street was closed.
Grand Total	**----**	**----**	**----**	**----**	**3**	**0**	**----**

Landslide probabilities are largely a function of surface geology, but are also influenced by both weather and human activities. Middlesex County has been impacted by eight landslides over the last 79 years. On average, the County experiences a landslide every 10 years. With eight reported landslide in the past, the probability of future landslides having a significant impact on property and life in Middlesex County

is considered low. The County is also generally not subject to sinkholes or land subsidence, and there are no reports of such effects in the planning area. Based on past data, the probability of future sinkholes and subsidence occurring in the County is relatively low.

Geologic Hazards Risk and Vulnerability Assessment (Including Impacts on Life and Property)

As discussed briefly above, there is no significant history of geologic hazards in Middlesex County, and the few events that have occurred have been geographically limited and caused little damage. Risk and vulnerability assessments must be based either on projecting historical damages into the future, or on scientific or engineering evaluations of existing conditions and probabilities of a hazard occurring. Because of the low prevalence of geological hazards in the state, there is no source of such information. As such, it is not possible at this time to develop a valid risk assessment for geological hazards in the County. If the hazard becomes more prevalent in the future, it may be advisable to consider developing such materials for an analysis.

4.3.9 Hazardous Materials

(Includes Fixed Sites, Pipelines, Rail Lines, Other Transportation)

Description of Hazardous Materials

Hazardous materials come in the form of explosives, flammable and combustible substances, poisons, and radioactive materials. These substances are most often released as a result of transportation accidents or because of chemical accidents in plants. Hazardous materials in various forms can cause death, serious injury, long-lasting health effects, and damage to buildings, homes, and other property. Many products containing hazardous chemicals are used and stored in homes routinely. These products are also shipped daily on the nation's highways, railroads, waterways, and pipelines. This section deals those hazardous materials that occur at facilities which are known as fixed site.

Hazardous substances released during transportation refer to uncontrollable releases of hazardous materials during transport, which pose a risk to the health, safety, property, and the environment. Small-scale incidents – those that require a response and implementation of evacuation procedures or other protective actions - are somewhat common along major U.S. highways, but can also occur through other modes of transportation including rail, water transport (shipping and ferries), air, and pipelines. Data collected by the US Department of Transportation (DOT) shows that transportation related hazardous materials incidents are much more likely to occur on highways than through any other mode of transport such as rail transportation.

By definition, a pipeline is used to transport oil, water, sewage, natural gas, etc., over long distances. Pipelines are generally buried underground for safety reasons. Bright yellow warning signs or marker posts usually mark the right-of-way for large pipelines. Smaller buried utility pipelines are not marked and the depth varies from location to location. Pipelines transport all kinds of liquids and gases such as:

gasoline, crude oil, diesel fuel, natural gas, water, sewage, and hazardous materials. A leak or spill from these pipelines could threaten neighborhoods, contaminate water supplies, or pollute environmentally-sensitive land. For additional information about pipelines visit the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Location of Hazardous Materials

Middlesex County is made up of densely populated residential, commercial and heavy industrial land uses and facilities. Consequently, the Middlesex County Hazardous Materials Unit indicates there are over 3,500 facilities that use, produce, or store hazardous materials in the county. This represents 30% of all facilities in the State of New Jersey. These facilities also produce the widest variety of chemicals in the state. Although the scale is usually small, emergencies involving the release of these substances can occur daily at both these fixed sites and on the county's streets and roadways.

There are several sources of information regarding the locations of hazardous materials. There does not appear to be a single comprehensive source that identifies all hazardous materials. There are several open sources of information about hazardous materials. These include the Discharge Prevention Office of Middlesex County, the US Environmental Protection Agency (EPA), the Right-to-Know (RTK) Network (which also acts as a switchboard for access to several other related databases), and local officials responsible for administering the Right to Know Hazardous Substance List (RTKHSL) under the New Jersey Worker and Community Right to Know Act. The paragraphs below describe sources of information about hazardous materials in New Jersey.

The Discharge Prevention Office for Middlesex County maintains required records on the following sites:

Fixed Facilities

- 144 Superfund Amendments and Reauthorization Act (SARA) Facilities
- 18 Toxic Catastrophe Prevention Act (TCPA) Facilities
- 79 Discharge Prevention, Containment and Countermeasure (DPCC) / Spill Prevention, Control and Countermeasure (SPCC) Facilities
- 9 Treatment Storage Disposal (TSD) Facilities
- 78 Licensed for Radioactive Material
- 17 Oil Pollution Act (OPA 90) Facilities
- 727 Known Contaminated Sites (KCS)
- 2,426 Community Right to Know Facilities
- 78 Biological Laboratories

At the Middlesex County level, there are over 1,200 reportable discharges of hazardous substances each year (discharges are a combination of fixed sites and transportation), of which approximately 750 require response actions. Because the risk of hazardous materials incidents is constant, the County of Middlesex has important programs in place.

- P. L. 1991, Chapter 99 declares that it is the policy of the State of New Jersey to provide for the

administration of environmental health services by county departments of health consistent with performance standards promulgated by the New Jersey Department of Environmental Protection (NJDEP) at N.J.A.C. 7:1H-1.1. The environmental health services include monitoring and enforcement of environmental health standards to control air pollution, solid waste, hazardous waste, noise, radiation, and water pollution to protect workers and the public from hazardous substances and toxic catastrophes, and to protect against other environmental threats. The Middlesex County Public Health Department's Environmental Division provides, or makes available, air pollution, solid waste, recycling, noise pollution, water pollution, septic management, GIS and radon education services on a county-wide basis.

- The primary agency for hazardous materials response in the County of Middlesex is the Middlesex County Hazardous Materials Unit. The Hazmat Unit, started in 1979 by six municipalities, is one of New Jersey's first regional emergency services. The Unit was absorbed into the county government in 1981 which has allowed all twenty-five municipalities to have specialty response capabilities without having to duplicate expensive equipment and extensive training required to provide competent service. The Unit is comprised of full-time career employees who are on call twenty-four (24) hours a day, seven days a week. The Unit is an active participant in the New Jersey County Environmental Health Act (CEHA) having signed agreements with the New Jersey Department of Environmental Protection for Hazardous Substance Emergency Response.

Additional sources for information related to hazardous materials are described below.

US Environmental Protection Agency (EPA)

The EPA is host to a variety of databases related to hazardous materials. The Resource Conservation and Recovery Act information (RCRAInfo) is the Environmental Protection Agency's (EPA's) comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. RCRAInfo replaces the data recording and reporting abilities of the Resource Conservation and Recovery Information System (RCRIS) and the Biennial Reporting System (BRS). The RCRAInfo system allows tracking of many types of information about the regulated universe of RCRA hazardous waste handlers. RCRAInfo characterizes facility status, regulated activities, and compliance histories and captures detailed data on the generation of hazardous waste from large quantity generators and on waste management practices from treatment, storage, and disposal facilities. Data can be searched from the following website http://www.epa.gov/fla/facts/rcrainfo/search.html.

Beginning in 1986, as part of the Emergency Planning and Community Right-to-know Act (EPCRA), certain industries as well as federal facilities have been required to report the locations and quantities of chemicals stored on-site to state and local governments in order to help communities prepare to respond to chemical spills and similar emergencies. EPCRA Section 313 requires the EPA and the States to annually collect data on releases and transfers of certain toxic chemicals from industrial facilities, and make the data available to the public as part of the Toxics Release Inventory (TRI). In 1990 Congress

passed the Pollution Prevention Act which required that additional data on waste management and source reduction activities be reported under the TRI program. The TRI database can be searched from the following website http://www2.epa.gov/toxics-release-inventory-tri-program.

In addition to storing hazardous material related data, information from the EPA can also be mapped. The EPA has developed a tool referred to as "EnviroMapper" to map various types of environmental information, including air releases, drinking water, toxic releases, hazardous wastes, water discharge permits, and Superfund sites. The database of maps can be used to select a geographic area within EnviroMapper and view the different facilities that are present within that area. Maps can be created at the national, state, and county levels. Data from the EnviroMapper site can be searched from the following website http://www.epa.gov/emefdata/em4ef.home.

Right to Know Hazardous Substance List (RTKHSL)

The 2010 RTKHSL (the most recent version available as of summer 2015) contains 2,053 hazardous substances. The list and associated descriptive information can be found on the State of New Jersey Department of Health website.

The Right-to-Know Network (RTK)

The Right-to-Know (RTK) network contains data related to hazardous materials that has been compiled from various EPA databases. Several databases from the RTK site include the following

- **Toxic Release Inventory (TRI).** Releases and transfers of toxic chemicals from large facilities. See EPA subsection above for additional details about the TRI database and the "Occurrences" subsection for data related to releases in Middlesex County.
- **Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS).** Information on potential and actual Superfund Sites.
- **Emergency Response Notification System.** Toxic Chemicals and spills reported to the National Response Center. See past Occurrences of Hazardous Materials Release – Transportation for additional details about this database and a list of past transportation accidents in Middlesex County.
- **Facility Registry System.** Names, addresses, and ID numbers of all facilities regulated by the EPA.
- **Resource Conservation and Recovery Act information (RCRAInfo).** Described under EPA section above.

Each of the databases listed can be queried from the following website: http://www.rtknet.org/.

Hazardous Materials – Location (Pipelines, Rails and Other Transportation)

Middlesex County is host to over 3,500 facilities that use, produce, or store hazardous materials. Chemicals are transported along the counties 492 highway miles, 141 railway miles, 155 transmission

pipeline miles and 12 petrochemical docks along the Arthur Kill and Raritan Rivers. This is 30% of all facilities in the State of New Jersey. These facilities also produce the widest variety of chemicals in the State.

The Discharge Prevention Office of Middlesex County maintains required records on the following transportation sites:

- 5 Rail yards and Commodity Movements
- 12 Transmission Pipeline Companies
- 12 Marine Petrochemical Docks

In order to manage the data more efficiently the Unit has implemented two computer database programs, CAMEO (Computer Aided Management of Emergency Operations) and OREIS (Operation Respond Emergency Information System).

Middlesex County is uniquely located in a region that is of critical importance to freight transport in the United Sates. Specifically, in relation to the transport of hazardous materials, the region's high potential for hazardous materials release is due to several key factors:

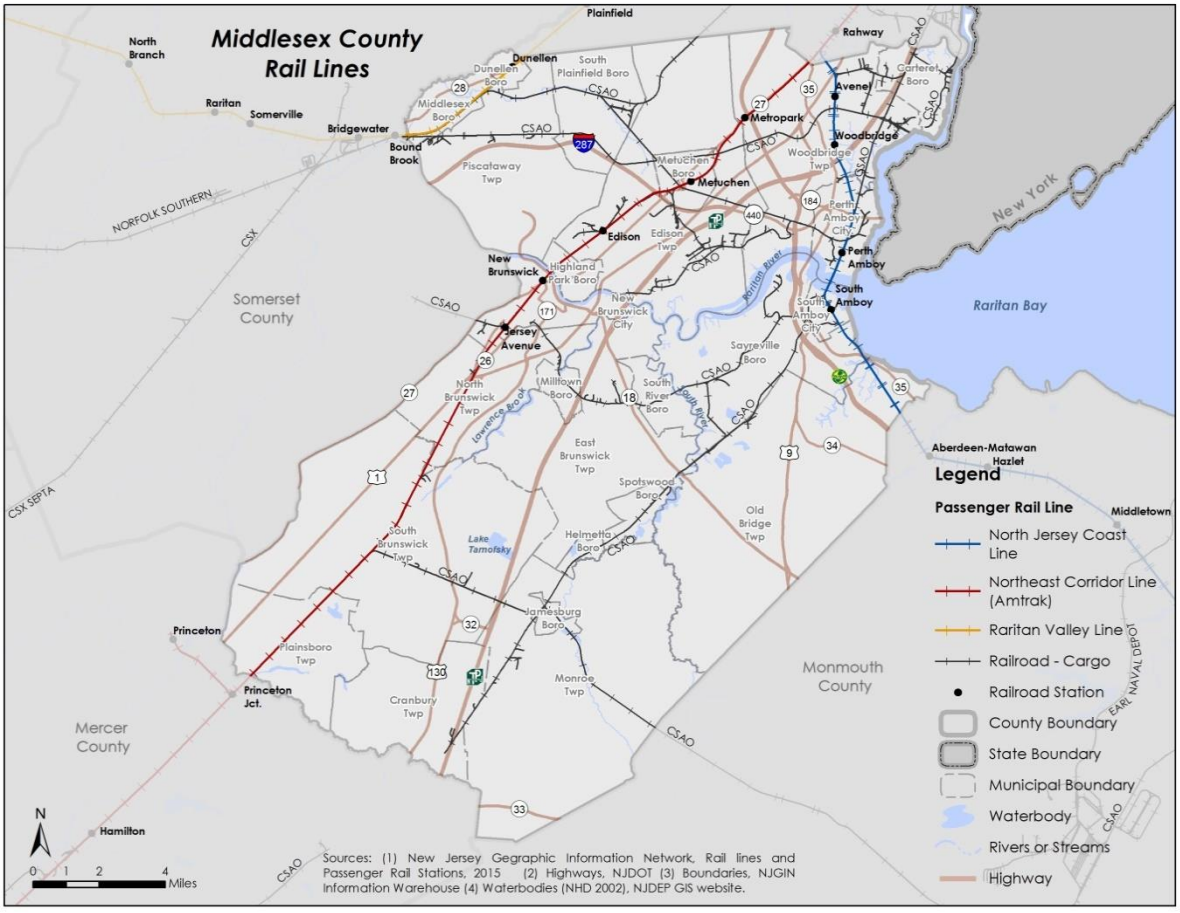
- It collectively houses the major port facilities of Newark international Airport and the marine ports of Newark and Perth Amboy. As such, millions of tons of import/export freight move through the region each year.
- The corridor is an important component of the shortest land path from the Northeastern US to all South- Atlantic States. Thus, an enormous amount of non-local freight traffic is drawn through the area in route to other domestic destinations.
- The region has good accessibility to the metropolitan areas of New York City, Philadelphia, and Pittsburgh, and therefore is a good staging location for warehousing and distribution activity. Moreover, 40% of the US population is accessible within a single day's drive from New Jersey.
- In addition to air and water ports, the region has good rail access and contains several rail intermodal facilities. Moreover, seven major highways merge in the area: Interstates 78, 80, 95, 280, and 287, plus the New Jersey Turnpike (NJTP) and Garden State Parkway (GSP). This region thus serves as one of the most concentrated intermodal "intersections" in the country.
- As a result of the first four points, a large number of warehouse and distribution facilities have clustered in the region (as a state, New Jersey trails only Los Angeles and Chicago in its amount of warehouse square footage).

In Middlesex County there are three main rail lines that travel through the county. The three rail lines include the North Jersey Coast Line, the Northeast Corridor Line, and the Raritan Valley Line. Train movements associated with Bakken crude oil transportation have not been made public in New Jersey. Trains pass through Bergen, Camden, Mercer, Middlesex, Gloucester, Warren, Union and Hunterdon Counties on the freight rail lines.

It is known that trains carrying Bakken oil cross New Jersey each week, entering the state in Bergen County, continuing through Central New Jersey en route to Pennsylvania. Train movements associated

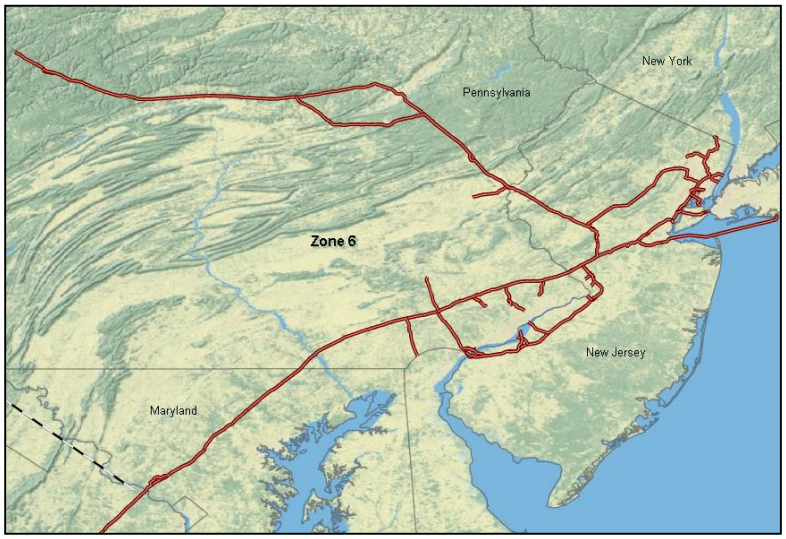
with Bakken crude oil transportation have not been made public in New Jersey. Processing of the crude in New Jersey is known to be underway in Linden at the Phillips 66 facility, in Gloucester County at the PBF Energy facility in Paulsboro, and at a facility in Middlesex County in Perth Amboy (Buckeye Partners LP). These cars pass through the County at unknown times and days and carry an unquantifiable risk associated with them

Figure 4-35
Middlesex County Rail Lines
(Source: New Jersey Geographic Information Network, Rail Lines and Rail Stations, 2015)



One of the main pipelines that travel through part of Middlesex County is the Transco natural gas pipeline. The Transco Pipeline is a 10,200 mile interstate pipeline system, which transports natural gas to markets throughout northeastern and southeastern United States. The northeastern portion of the pipeline is shown in Figure 4-36.

Figure 4-36
Transco Natural Gas Pipeline
(Source: Williams, Transco)



Severity of Hazardous Materials

The severity of a hazardous material release relates primarily to its impact on human safety and welfare and on the threat to the environment.

Threat to Human Safety and Welfare

- Poisoning of water or food sources and/or supply
- Presence of toxic fumes or explosive conditions
- Damage to personal property
- Need for the evacuation of people
- Interference with public or commercial transportation

Threat to the environment

- Injury or loss of animals or plants or habitats that are of economic or ecological importance such as; commercial, recreation or subsistence fisheries (marine plants, crustaceans, shellfish, aquaculture facilities) or livestock; seal haul outs; and marine bird rookeries
- Impact to recreational areas such as public beaches
- Impact to ecological reserves, forests, parks, archaeological and cultural sites

Incident severity is often ranked from 1 to 3 or 4, with a “Level 1” incident considered minor; a Level 2,

moderate; a "Level 3," major; and a "Level 4" severe. Thresholds depend on the sort of incident and hazards. The following table is for releases of hazardous material (using a 1- 4 scale):

Table 4-50
Hazardous Materials
Incident Severity by Category

Category	Severity of Incident	Extent of Incident	Type of Material Involved	Amount of Material Involved	Population Affected	Resources/ Notification
Category 1 (Minor)	A spill, release or potential release of a known hazardous substance.	Limited to initial area of involvement and unlikely that it will spread. For example, a single structure or area of 300 feet or less	Identified hazardous substance that is not radioactive, water reactive or hypergolic. Generally a flammable or combustible liquid but could also include limited amounts of corrosiveness.	A limited amount of a hazardous substance or smaller container. Generally less than 55 gallons.	Evacuation will be limited to the immediate area that can be evacuated in a short period of time for a limited duration (usually does not exceed 4 hours). A limited number of the populace will be affected.	Local resources can handle, includes automatic mutual aid agreements.
Category 2 (Moderate)	A spill, release or potential release of known or unknown hazardous substance. No deaths; injuries can be minor to severe	Release may not be controllable without special resources. Limited to several blocks or buildings.	Unknown hazardous substance or hazardous substance that is toxic, reactive, flammable, radioactive, corrosive, or biological in nature.	An amount limited by the size of the container and the release from it. For example, a small leak from a tanker that is controlled would be a Level II, while a complete failure releasing the entire contents would be a Level III or IV.	Evacuation will be considered to a designated area that local resources can achieve. Extended sheltering is not required.	Local response agencies may need assistance from outside sources. Note 1.

Category	Severity of Incident	Extent of Incident	Type of Material Involved	Amount of Material Involved	Population Affected	Resources/ Notification
Category 3 (Severe)	A spill, release or potential release of a hazardous substance with an associated fire, explosion or toxic/corrosive cloud. Injuries or deaths may have already occurred.	Large area may be impacted possibly disrupting essential community services. Extensive environmental contamination is possible.	Unknown hazardous substance or hazardous substance that is capable of producing a toxic/corrosive gas cloud, is highly reactive or unstable, is a flammable gas or produces significant flammable vapors, is radioactive or chemical/biological pathogen.	Large amounts of hazardous material or limited amount of a very dangerous substance.	Presents an immediate danger to the public and operating personnel. Evacuation will require large numbers of the populace and/or extending over an area that will have a significant impact on the community. It may require activation of shelters for evacuees.	Local response agencies will need assistance from outside sources. Note 1.
Category 4 (Major)	A spill or release of a hazardous substance that has resulted in a serious fire, explosion or environmental contamination over an extended area.	Has an impact over a wide area with the probability that it will spread to a larger area. The impacted area can be smaller in a highly urbanized area with a large population impacted.	A known or unknown hazardous substance that can be highly toxic, very reactive or unstable, flammable or explosive; etiological agents that are extremely pathogenic.	A hazardous substance in a large amount that can affect a large	Evacuation will affect a large area and will have to be done in stages taking several hours or more (evacuation duration could exceed several days). A large number of the populace is affected. Presents immediate danger to the public and operating personnel.	Mutual aid will be needed with a need for a large number of resources. Note 1.

Occurrences of the Hazardous Materials - Fixed Sites

To identify past occurrences for fixed sites in Middlesex County the Toxic Release Inventory (TRI) Explorer database was queried from the US Environmental Protection Agency's (EPA) website. For Middlesex County, the TRI database was queried for the years 2000 through 2006, the most recent year available. The total onsite and off-site disposal or releases is reported in pounds, and includes facilities for all types of industries and chemicals in Middlesex County. The table results show the number of facilities reported in the TRI database for Middlesex County has decreased from a high of 108 in 2001 to

72 in 2006. The quantity of the combined on and off-site disposal and releases has decreased from a high of 9,301,512 pounds in 2001 to 559,172 pounds in 2006.

Additional details about the EPAs Toxic Release Inventory can be found by querying the TRI Explorer database within the EPA's website. To query the database, navigate to the EPA -TRI home page located at http://www.epa.gov/tri and select "Get TRI Data" from the menu on the left side of the page. Then select the link "TRI Explorer", and "Facility" from the reports menu.

The reduction in releases for Middlesex County can also be show graphically by displaying the TRI trend for a list of core chemicals during the period 1987 to 2006. For standard comparison purposes, the core chemical list excludes chemicals that have been added or removed within the reporting period. The core chemical restriction is applied to all RTK bar charts that display yearly trends. Over the past 20 years the pounds released in Middlesex County has dramatically been reduced from the peak in 1989 and 1990. With the exception of 1994, the trend downward has continued in the 1990's and years 2000 - 2006.

Occurrences of the Hazardous Materials -Rails and Other Transportation

To identify past hazardous material transportation incidents for Middlesex County the Emergency Response Notification System (ERNS) database was queried from the Right-to-Know website. The ERNS database is a database of incidents reported to the National Response Center. The National Response Center is operated by the US Coast Guard, and has become the central point of contact used for the reporting of many different kinds of incidents involving hazardous materials. The database includes 12 incident types including vessels (ships), railroads, pipelines, and surface transportation.

Based on previous occurrences (events between 1985 and 2015), the probability of future hazardous substances events in Middlesex County is roughly one event every three years. The overall impact to the planning area from hazardous substances is low considering the frequency and low magnitude of the past occurrences.

One of the largest pipeline events occurred in Edison Township in 1994 when an 80 foot long rupture occurred along a 36 inch diameter natural gas line adjacent to the Durham Woods apartment complex. The rupture caused an explosion resulting in the largest fire in Middlesex history. The explosion destroyed eight apartment buildings and hundreds of vehicles. The 80-foot-long rupture in the pipe occurred on property occupied by an asphalt plant and ripped a crater approximately 100 feet long, 50 feet wide, and 40 feet deep.[52]

[52] New Brunswick Today. Pipeline Tears Through Residential Area in Edison to Supply Fracked Gas to New Woodbridge Power Plant. December 24, 2014.

Figure 4-37
Natural Gas Line Explosion in Edison Township
(Source: New Brunswick Today)

Hazardous Materials Risk and Vulnerability Assessment (Including Impacts on Life and Property)

Hazardous materials incidents (fixed sites) refer to uncontrollable releases of hazardous materials at a facility, which poses a risk to the health, safety, property, and the environment (MSP/EMD). The most well-known example of a large-scale fixed-site hazardous materials incident is that which occurred at the Union Carbide plant in Bhopal, India in 1984. This incident caused 2,500 deaths and injuries to many others. Although incidences of this scale are fairly rare, smaller-scale incidents - those requiring a response and evacuation or other protective measures - are relatively common.

The Office of Hazardous Materials Safety (DOT) tracks hazardous materials incidents by state. New Jersey has had 65 major incidents since 2001, with 10 injuries reported and a damages totaling $5,739,540, an average of $819,934 per year. Based on the intensity of mixed land use in Middlesex County (including heavy industrial and commercial uses), the likelihood for continued Hazardous Material incidents to occur is high within the planning area.

Table4-51 shows the reported hazardous materials incidents nationwide between 1983 and 2005. Within the graphic, the transportation related incidents are shaded green. This data shows that the vast majority of hazardous materials incidents relate to highway born transport. The data also visually demonstrates that the number of hazardous materials incidents have been steadily increasing since the 1980s as the interstate commerce has increased. As Central New Jersey, and Middlesex County, continues to grow and maintain its importance as part of a transportation corridor, the likelihood for transportation related hazardous materials releases will continue to grow.

Table 4-51:
Reported Hazardous Materials Incidents (1983-2005)
(Source: Office of Hazardous Materials Safety)

Although there is a considerable history of hazardous materials incidents in New Jersey, such events are essentially non-probabilistic, meaning that it is impossible to state accurately how many times events will occur in a given time period. There is also no open-source data on the types, amounts or locations of hazardous materials moving via rail and road in New Jersey. For security reasons this information is carefully controlled. As such, it is not possible to produce quantitative risk assessments of the hazard. Specific information may be obtained through federal, state and local transportation agencies, local emergency management organizations and health departments on an as-needed basis.

Hurricanes and Tropical Storms

Description of the Hurricane and Tropical Storm Hazard

Hurricanes, tropical storms, and typhoons, collectively known as tropical cyclones, are among the most devastating naturally occurring hazards in the United States. Hurricanes generate several hazards that can cause extensive damage. High winds, heavy rainfall, tornadoes, and storm surge are all associated hazards. This subsection focuses on the effects from high winds associated with hurricanes.

A hurricane is defined as a low-pressure area of closed circulation winds that originates over tropical waters. A hurricane begins as a tropical depression with wind speeds below 39 mph. As it intensifies, it may develop into a tropical storm, with further development producing a hurricane. A tropical cyclone is a storm system characterized by a large low pressure center and numerous thunderstorms that produce strong winds and flooding rain. The wind speeds from a tropical storm range between 39 and 74 mph. In

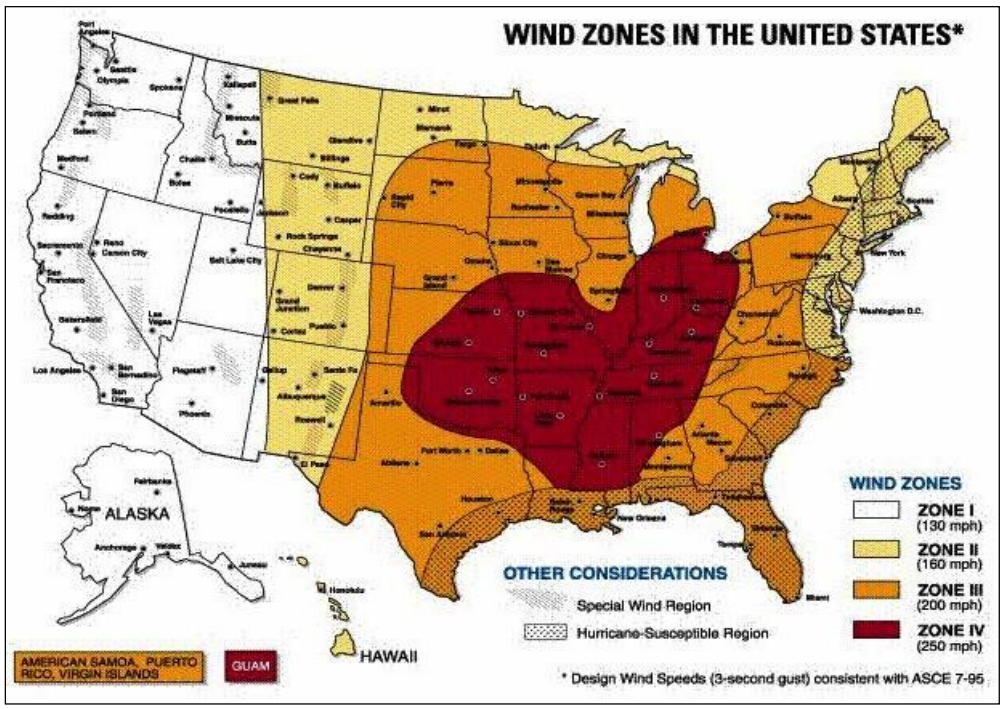
most of the world, a storm is given a name when it reaches tropical storm intensity. For additional information about hurricanes and tropical storms visit the NOAAs National Hurricane Center website at http://www.nhc.noaa.gov/.

Location of the Hurricane and Tropical Storm Hazard

The entire planning area is subject to the wind effects from hurricanes and tropical storms. Hurricane risk in the United States extends along the entire east coast from Maine to Florida, the Gulf Coast (including Florida, Alabama, Louisiana, and Texas), and Hawaii. The northeast United States is at a moderate risk based on historical storm tracks and the number of hurricanes that have made landfall along the Atlantic coastline. The US Wind Zone Map (Figure 4-38) shows how the frequency and strength of extreme windstorms vary across the United States. Developed by the US Army Corps of Engineers (USACE), it is based on the history of 40 years of tornadoes and 100 years of hurricanes. The map shows that New Jersey falls within the hurricane susceptible region (shown as cross-hatching). New Jersey is also within wind Zone II, where wind speeds can reach as high as 160 miles per hour (mph).[53]

[53] FEMA, Wind Zone Map.

Figure 4-38
US Wind Zone Map
(Source: USACE, 7-95 and FEMA 386-2, p.2-20)



Severity and Extent of the Hurricane and Tropical Storm Hazard

The severity of hurricanes and tropical storms is measured primarily by wind velocity, flooding, central pressure, and storm surge. As shown in Table 4-52, the Saffir-Simpson Hurricane Scale is used to classify storms by numbered categories. Hurricanes are classified as Categories 1 through 5 based on central pressure, wind speed, storm surge height, and damage potential.

Table 4-52
Saffir-Simpson Hurricane Scale
(Source: NOAA)

Storm Category	Central Pressure	Sustained Winds	Storm Surge	Potential Damage
1	> 980 mbar	74 - 95 mph	4 – 5 ft	Some
2	965 – 979 mbar	96 - 110 mph	6 – 8 ft	Extensive
3	945 – 964 mbar	111 – 129 mph	9 – 12 ft	Devastating
4	920 – 944 mbar	130 – 156 mph	13 – 18 ft	Catastrophic
5	< 920 mbar	157 or higher mph	> 18 ft	Catastrophic

The winds associated with a hurricane cause many devastating effects. Property damage associated with hurricane force winds increases greatly with the wind strength of the hurricane. A Category 1 storm may cause little or no damage to permanent buildings. Most damage will be to mobile homes, trees, shrubs, and signs. A Category 3 storm will cause some structural damage to homes, down trees, and destroy signs. Winds from a Category 5 storm will be devastating to buildings. There will be complete roof failure on many residences and commercial buildings. In addition to causing wind-blown related structural damage, winds increase the storm surge as they grow stronger.

Occurrences of the Hurricane and Tropical Storm Hazard

Several data sources were researched to identify historical hurricanes and tropical storms that have impacted central New Jersey and Middlesex County. The NCDC database identifies that Middlesex County has been impacted by two tropical storm events and no hurricanes between 1950 and June 2015. The events listed in the database were Tropical Storm (TS) Hanna in 2008 and TS Irene (downgraded from a hurricane) in 2011. In addition to the NCDC database, NOAA's Historic Hurricane Tracks database was also queried to identify past hurricane events with tracks within a 65 mile radius of Middlesex County between 1950 and 2013. The query results identified 12 hurricanes or tropical storms that impacted Middlesex County during this time period. Most of these events were downgraded to a tropical depression or less by the time they reached New Jersey.

Figure 4-39 shows the 12 hurricanes and tropical storms that have impacted northern New Jersey and Middlesex County from 1950 to 2013. The map was developed using NOAA's Historic Hurricane Tracks database with the track of each storm color coded with the hurricanes' intensity (Categories 1 – 5) and tropical storm (green) as it traveled up the coastline. Note that the results of the query did not include Hurricane Sandy in October 2012. At landfall this event was downgraded to extratropical and not categorized as a hurricane or tropical storm. Although not included in the NOAA results, a detailed discussion of this event is included beginning on Page 4-122 as part of describing some of the more significant past hurricanes that have impacted Middlesex County.

Figure 4-39
Hurricanes and Tropical Storms Within a 65 Mile Radius of Middlesex County, 1950 – 2013
(Source: NOAA Coastal Service Center – Historic Hurricane Tracks database)

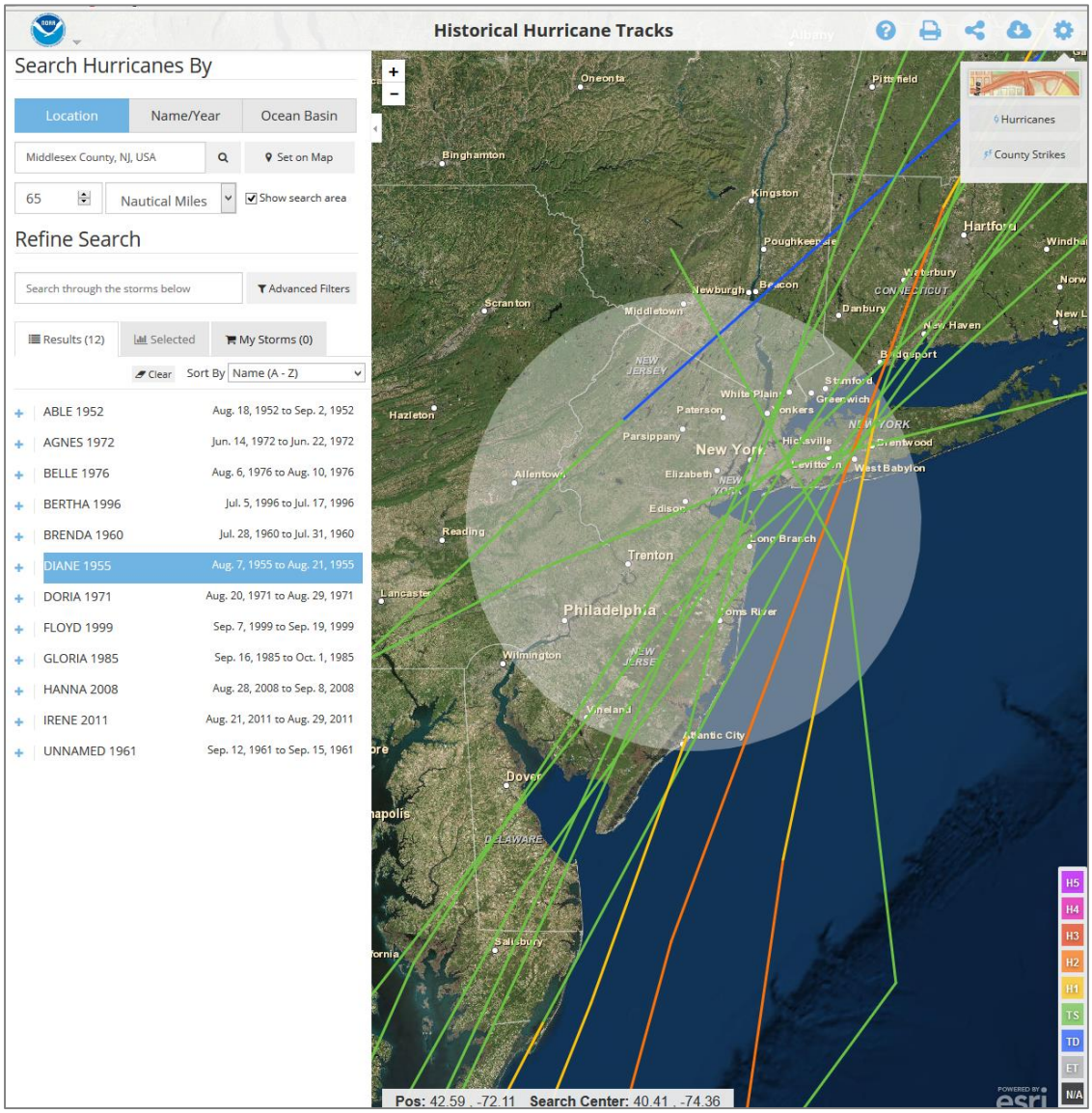


Table 4-53 summarizes the 12 hurricanes and tropical storms included in the above query that have impacted Middlesex County over the last 63 years. As noted above, the results of the query did not include Hurricane Sandy in October 2012. At landfall this event was downgraded to extratropical and is not categorized as a hurricane or tropical storm.

Table 4-53
Hurricanes and Tropical Storms Impacting Middlesex County, 1950 – 2013
(Source: National Hurricane Center – Hurricane and Tropical Storm Tracker)

Event Date	Hurricane/TS	Storm Name	Category (Within 65 Mile Radius)	Maximum Winds at Closest Recorded Point Near Middlesex Co. (knots)
September 1, 1952	Tropical Storm	Able	N/A	30
August 19, 1955	Tropical Storm	Diane	N/A	40
July 28, 1960	Tropical Storm	Brenda	N/A	45
September 12, 1961	Tropical Storm	Unnamed	N/A	35
August 20, 1971	Tropical Storm	Doria	N/A	45
June 14, 1972	Tropical Storm	Agnes	N/A	55
August 6, 1976	Hurricane	Belle	1	60
September 16, 1985	Hurricane	Gloria	2	85
July 5, 1996	Tropical Storm	Bertha	N/A	60
September 7, 1999	Tropical Storm	Floyd	N/A	50
August 28, 2008	Tropical Storm	Hanna	N/A	45
August 21, 2011	Tropical Storm	Irene	1	55

Several of the hurricanes and tropical storms are listed below.

- **September 27, 1985–Hurricane Gloria.** After brushing the outer banks of North Carolina the storm moved northward just off the Atlantic coast until making landfall as a Category 2 Hurricane near western Long Island, New York. Along the coastline of northern New Jersey sustained winds were approximately 80 mph with gusts over 100 mph. Hurricane Gloria caused one of the largest single power outages at the time, including about 230,000 customers in New Jersey.

- **September 18, 2003–Tropical Storm Isabel.** Isabel made landfall as a hurricane near Drum Inlet, North Carolina on the September 18 and weakened as it tracked farther inland. Winds gusted were recorded up to 62 mph in New Jersey. In Middlesex County, high winds downed numerous trees and electrical power lines, which resulted in the closure of major streets and schools. It was one of the worst power outages on record for area utilities. Jersey Central Power and Light (JCPL) reported that 220,000 of its customers lost power while Connectiv Energy reported about 162,000 of its customers lost power.

- **September 16, 1999 (DR-1295) – Hurricane Floyd.** This downgraded fall hurricane put the entire Eastern Seaboard on flood watch, including every county in New Jersey. The storm lasted approximately 18 hours and caused an estimated $3.5 million in damages to public infrastructure in Middlesex County. In Middlesex County, floodwaters from the Raritan River caused severe flooding. As the Raritan River was rising, the incoming high tide during the early morning of the 17th prevented it from discharging into the bay. One of the areas

hardest hit by the flooding was Middlesex Borough where roughly 500 homes were damaged. Residential damages were estimated at $6 million. At the peak of the storm over 650,000 customers in New Jersey were without power.

- **August 31, 2011 (DR-4021) – Hurricane Irene.** Hurricane Irene made landfall along the Outer Banks of North Carolina on August 27, 2011 as a Category 1 hurricane. The storm re-emerged over the Atlantic and made a second landfall as a tropical storm on August 28th in the Little Egg Inlet in southeastern New Jersey. Approximately 1.6 million customers of JCPL and Public Service Enterprise Group (PSEG) lost power in New Jersey. Middlesex County experienced tropical storm force winds as a result of Irene. High winds caused downed trees and widespread power outages (approximately 154,000 customers in Middlesex County) that lasted for up to two weeks in areas that were subsequently impacted by the remnant moisture from Tropical Storm Lee several weeks later in September.[54] (see additional description below).

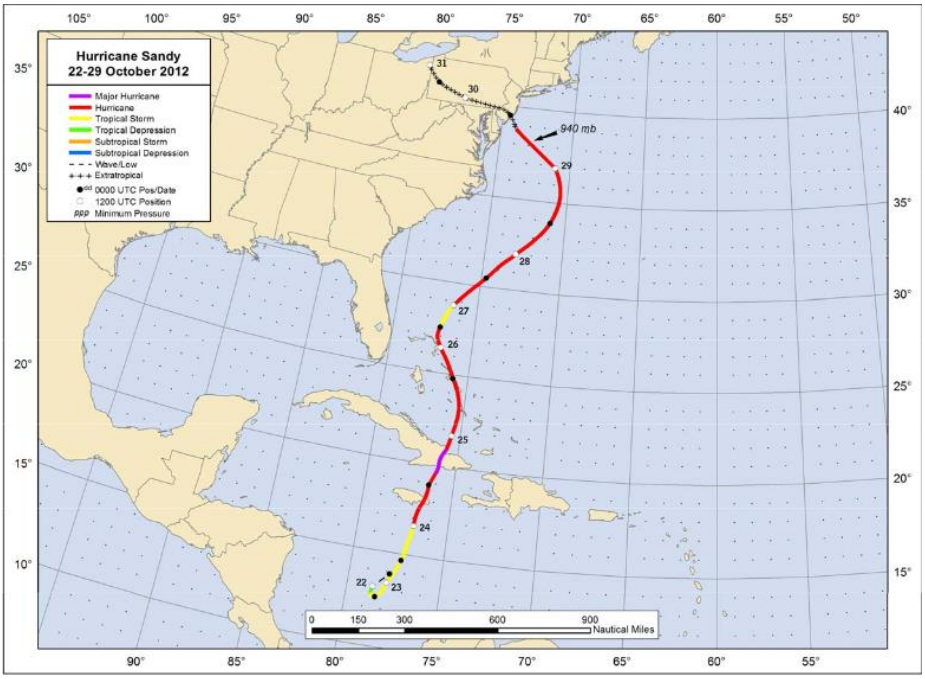
- **October 29, 2012 (DR-4086) - Hurricane Sandy.** Sandy made landfall as a post-tropical cyclone near Brigantine, New Jersey with 80 mph maximum sustained winds on October 29, 2012 (see additional description below).

Hurricane Sandy

In late October of 2012, Middlesex County was impacted by Hurricane Sandy (FEMA DR-4086), a late season hurricane that originated as a tropical wave from the west coast of Africa. Sandy traveled across Cuba and other parts of the Caribbean, before moving northeastward, parallel to the coast of the southeastern United States. Sandy reached a secondary peak intensity of 85 knots while it turned northwestward toward the mid-Atlantic states. Sandy weakened somewhat and then made landfall as a post-tropical cyclone near Brigantine, New Jersey with 70-knot maximum sustained winds on October 29, 2012. Because of its tremendous size, however, Sandy drove a catastrophic storm surge into the New Jersey and New York coastlines. Figure 4-40 shows the storm path between October 22 and October 31, 2012.[55]

[54] NOAA/NCDC Tropical Storms – Middlesex County, New Jersey, Event description.
[55] National Hurricane Center Tropical Cyclone Report, October 22 – 31, 2012. February 12, 2013.

Figure 4-40
Hurricane Sandy Storm Path, October 22 – 29, 2012
(Source: National Hurricane Center, Tropical Cyclone Report)



With the highest storm surge levels on record, Sandy produced widespread damage to coastal and inland communities in New Jersey. Along the Raritan Bay major widespread tidal flooding occurred during the morning and evening high tide cycles on the October 29th, 2012. The highest tide (and surge) along the ocean front and Raritan Bay was with the landfalling high tide cycle on the evening of the 29th. The ocean front and Raritan Bay surge was five to nine feet.

In Middlesex County, the worst reported damage occurred in Woodbridge Township, Sayreville, South River and Old Bridge Townships. Most of this was related to tidal flooding in Raritan Bay and its ripple effects on the inland rivers including the Raritan. Some of the significant impacts to Middlesex County are listed below

- Mandatory evacuations occurred along the Raritan Bay and as far west along the Raritan River as New Brunswick.
- In Perth Amboy, evacuations included Water Street residents. Tidal flooding occurred in both Perth Amboy and Sayreville.
- A 336,000 gallon diesel fuel spill into Raritan Bay occurred in Perth Amboy. Both the Veterans Bridge and Morgan Bridge were closed in Sayreville.
- In Old Bridge, evacuations occurred east of New Jersey State Route 35 and included Cliffwood and Laurence Harbor.
- Homes were damaged by downed trees in Old Bridge and East Brunswick.[56]

[56] NOAA – NCDC, Storm Events Database, Coastal Flooding, Hurricane Sandy

- The flooding and subsequent power loss in Middlesex County resulted in three pumping stations going offline in South Amboy, Edison, and Sayreville.
- An estimated 235,000 Middlesex County households lost power during the event.
- An estimated 87,000 homes and businesses were damaged or destroyed.

South River Borough experienced some of the worst flooding from Hurricane Sandy. Tidal flooding combined with water from the storm surge overflowed the banks of the South River and poured into several neighborhoods along the eastern side of the Borough. During the peak of the storm, floodwaters were estimated at 28 on Reid Street and up to 40 inches on Washington Street. As a result of Sandy, several multi-family apartment buildings were evacuated in South River, dozens of businesses were submerged under several feet of water, and emergency services evacuated residents from single family homes with vehicles, boats, and rescue squad wave-runner watercraft.[57]See the municipality appendices for additional details related to Hurricane Sandy and the impacts to the individual jurisdictions.

After Sandy, the FEMA Modeling Task Force (MOTF), a group of modeling and risk analyst experts from FEMA Regions VIII (Denver) and IV (Atlanta) that was activated by FEMA in support of disaster response operations. The group consists of individuals with experience in multi-hazard loss modeling and impact assessments, including earthquakes, hurricanes, riverine and coastal floods (surges, tsunamis), winter storms and others. The MOTF plays an important role in coordinating hazard and modeling information from a variety of sources to develop consensus for best estimates of impacts before, during, and after events. The MOTF integrates observed information throughout disasters to verify, and enhance impact assessments. The MOTF developed Sandy storm surge inundation areas for both New York and New Jersey. The surge inundation boundary was created from field-verified High Water Marks (HWMs) and Storm Surge Sensor data from the USGS (through February 14, 2013). The MOTF used HWMs and Surge Sensor data to interpolate a water surface elevation, then subtracted from the best available Digital Elevation Model (DEM), to create a depth grid and surge boundary by state.[58]

Figure 4-43 on Page 4-133 identifies the Sandy storm surge inundation area for Middlesex County. The map shows a significant portion of central Middlesex County following the Raritan River was inundated by Sandy. Additional flooding occurred along the South River in Old Bridge and South River Boroughs as well as parts of Woodbridge Township and Sayreville Borough.

As part of the analysis completed by MOTF, the team calculated the population and households exposed to the surge from Sandy. The impacts to Middlesex County are summarized below in Table 4-54.

[57] Borough of South River: Strategic Recovery Planning Report, Post Sandy Planning Assistance Grant Program, March 1, 2014.
[58] FEMA Modeling Task Force (MOTF) Hurricane Sandy Impact Analysis

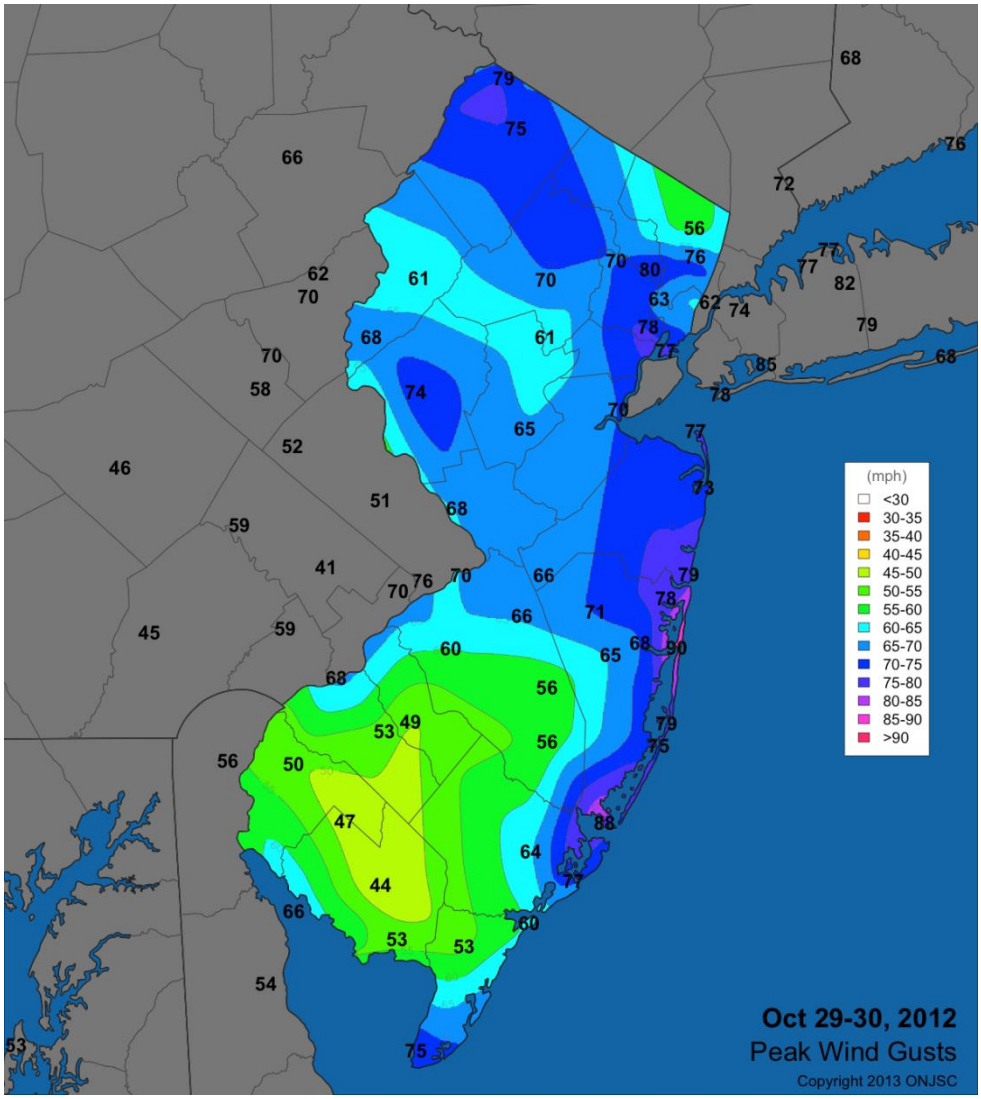
Table 4-54
Middlesex County - Sandy Impacts
(Source: FEMA Modeling Task Force (MOTF) Hurricane Sandy Impact Analysis)

	Population/Households
Population (2010)	809,858
Households (2010)	281,186
Population exposed to Storm Surge	40,678
Households Exposed to Surge	9,036
Total Number of Damaged Structures	3,262
Structures with Major Damage	520
Critical Facilities Exposed to Surge	116

In Middlesex County, high or damaging winds started during the late afternoon and evening hours on August 29th as Sandy was making landfall. Figure 4-41 shows the Sandy peak wind gusts for New Jersey from October 29-30, 2012. The map shows that the peak wind gusts along eastern Middlesex County reached 70-75 mph. The winds decreased to 65-70 mph in the central and western part of the County. The map was produced by the Office of the New Jersey State Climatologist (ONJSC) using reports gathered from a variety of sources including the NWS and the New Jersey Weather and Climate Network stations.

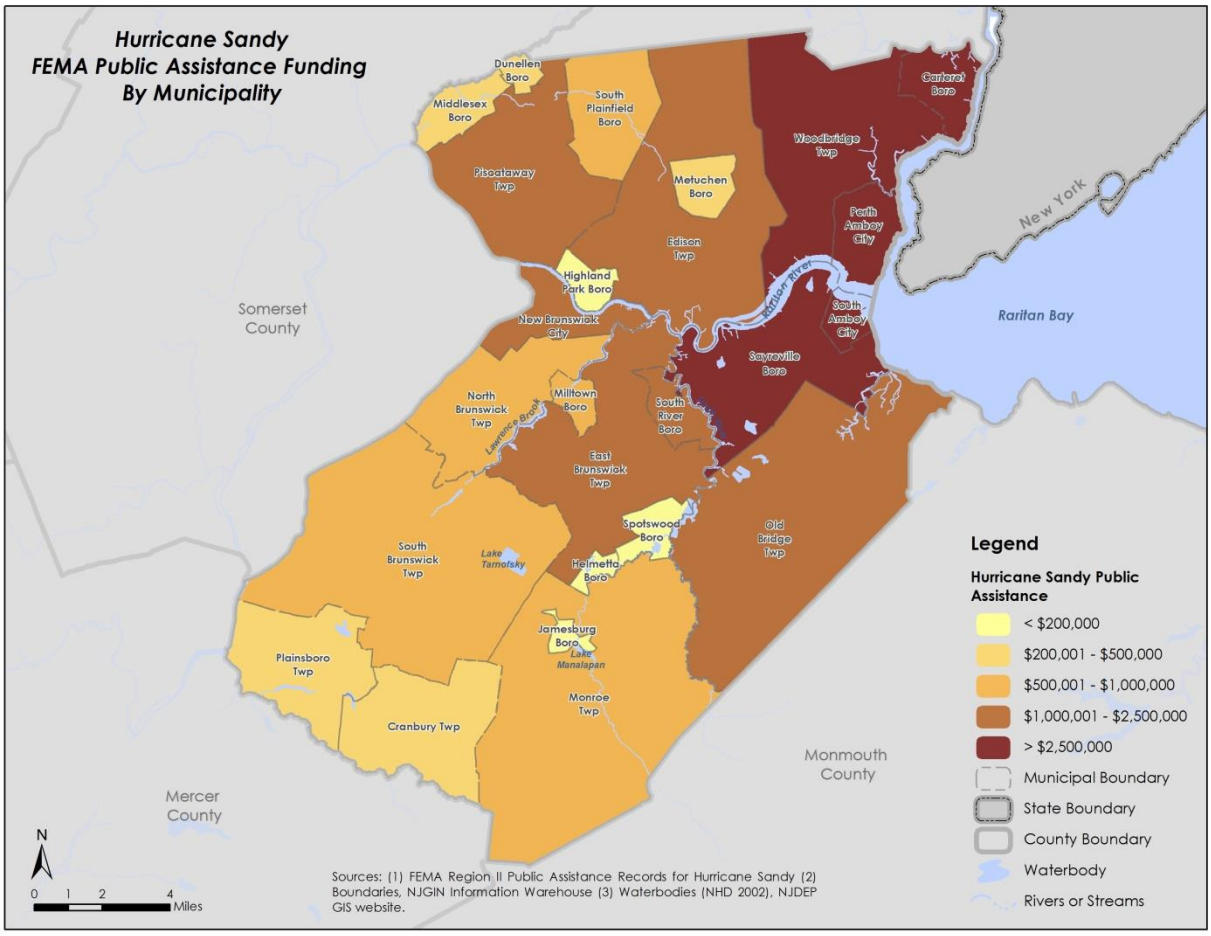
The Department of Energy estimates that as many as 2.6 million customers in New Jersey were without power for as long as two weeks in some jurisdictions. According to a report produced by Rutgers University about the impacts of Hurricane Sandy, the power was out the longest in neighboring Monmouth and Union Counties, losing power for an average period of ten and nine days respectively. In Middlesex County approximately 313,000 customers were without power after Sandy. Power outages were highest in Woodbridge and Edison Townships where roughly 40,000 customers were without power at the peak of the event. See Section 6.3.12 for additional information about power outages after Sandy.

Figure 4-41
Sandy Peak Wind Gusts, October 29-30 2012
(Source: Office of the New Jersey State Climatologist (ONJSC))



After Presidentially-declared disasters such as Sandy, FEMA engineers visit communities to determine the nature and dollar amount of damages, so that federal funds can be provided to repair public facilities. Figure 4-42 identifies the total value of FEMA Public Assistance funds by municipality in Middlesex County after Sandy. The map shows funding was greatest in northeastern Middlesex County, particularly Carteret Borough, Woodbridge Township, Perth Amboy City, South Amboy City, and Sayreville Borough. Public Assistance in all of these municipalities exceeded $2.5 million.

Figure 4-42
FEMA Public Assistance Funding After Sandy (DR-4086) by Municipality
(Source: FEMA Region II, June 2015)



A summary of the Hurricane Sandy Public Assistance funds broken down by FEMA category (Categories A-G) is shown below in Table 4-55. The table shows that FEMA Public Assistance funds in Middlesex County totaled just over $84.8 million. Over half of this was related to emergency work (Categories A and B).

Table 4-55
Project Worksheet Summary for Hurricane Sandy (DR-4086)
by FEMA Public Assistance Program Category, Middlesex County
(Source: FEMA Region II, June 2015)

Disaster #	Cat. A	Cat. B	Cat. C	Cat. E	Cat. F	Cat. G	Total
DR-4086	$16,823,616	$28,461,223	$885,989	$2,248,424	$19,720,722	$16,749,168	$84,889,142

The FEMA Public Assistance categories are generally defined as follows:

- Category A: Emergency work, primarily debris clearance.
- Category B: Emergency protective measures.
- Category C: Permanent repair work, roads and bridges.
- Category D: Permanent repair work, water control facilities.
- Category E: Permanent repair work, public buildings.
- Category F: Permanent repair work, utilities.
- Category G: Permanent repair work, parks and recreation facilities.

The FEMA Public Assistance records for Hurricane Sandy can be further broken down by identifying the applicants that received the highest amount of federal funding. Table 4-56 identifies applicants that received funding greater than $500,000. The table shows that Perth Amboy City was the municipality with highest Public Assistance funding after Sandy. Perth Amboy received slightly more than $9.2 million in FEMA Public Assistance following Sandy.

Table 4-56
Project Worksheet Summary (By Category) for Middlesex Applicants Receiving Greater Than $500,000 in FEMA Public Assistance Funding
(Source: FEMA Region II, June 2015)

Applicant Name	Cat. A	Cat. B	Cat. C	Cat. E	Cat. F	Cat. G	Total
Middlesex County Utilities Authority	$0	$13,874,242	$0	$8,814	$17,856,540	$0	$31,739,596
Middlesex County	$1,867,350	$1,795,682	$31,081	$120,815	$0	$5,665,060	$9,479,988
Perth Amboy City	$191,642	$1,488,307	$17,912	$111,477	$394,983	$7,005,064	$9,209,385
Sayreville Borough	$1,987,881	$2,246,940	$0	$56,779	$483,430	$168,922	$4,943,952
South Amboy City	$229,282	$340,577	$78,491	$83,542	$0	$2,410,150	$3,142,042
Woodbridge Township	$2,312,748	$280,955	$0	$0	$0	$66,118	$2,659,821
Carteret Borough	$360,440	$310,168	$15,626	$454,847	$56,788	$1,354,851	$2,552,719
Piscataway Township	$2,153,281	$63,056	$93,680	$3,478	$0	$2,841	$2,316,336
East Brunswick Township	$1,625,635	$357,101	$183,753	$0	$2,795	$442	$2,169,726
Old Bridge Township	$578,300	$886,730	$381,902	$30,268	$0	$1,475	$1,878,674
New Brunswick City	$416,997	$1,421,555	$11,980	$0	$1,000	$0	$1,851,532
South River Borough	$269,547	$395,566	$0	$330,460	$611,419	$1,000	$1,607,992
Edison Township	$1,001,615	$350,252	$0	$0	$0	$0	$1,351,868
South Brunswick Township	$500,188	$428,157	$34,554	$5,249	$0	$16,110	$984,258
Monroe Township	$489,516	$386,466	$0	$50,080	$0	$0	$926,062
Robert Wood Johnson University Hospital	$6,675	$566,012	$0	$151,140	$0	$0	$723,827
South Plainfield Borough	$551,696	$159,421	$0	$1,402	$0	$1,098	$713,617

Applicant Name	Cat. A	Cat. B	Cat. C	Cat. E	Cat. F	Cat. G	Total
Milltown Borough	$260,008	$114,044	$0	$1,000	$160,956	$0	$536,008
Carteret Housing Authority	$30,328	$3,710	$0	$499,924	$0	$0	$533,961
Old Bridge Municipal Utilities Authority	$93,074	$262,906	$16,892	$0	$152,812	$0	$525,683
North Brunswick Township	$269,558	$248,226	$0	$7,389	$0	$341	$525,514

In addition to reviewing the PA records, National Flood Insurance Program (NFIP) data was also evaluated after Hurricane Sandy to help determine areas in Middlesex County vulnerable to flooding and storm surge. Figure 4-43 identifies the Sandy NFIP claims including those considered repetitive loss and severe repetitive loss properties.

Figure 4-43
Hurricane Sandy Inundation Zone and NFIP Claims in Middlesex County
(Source: FEMA Region III, NFIP Claims Data as of February 28, 2015)

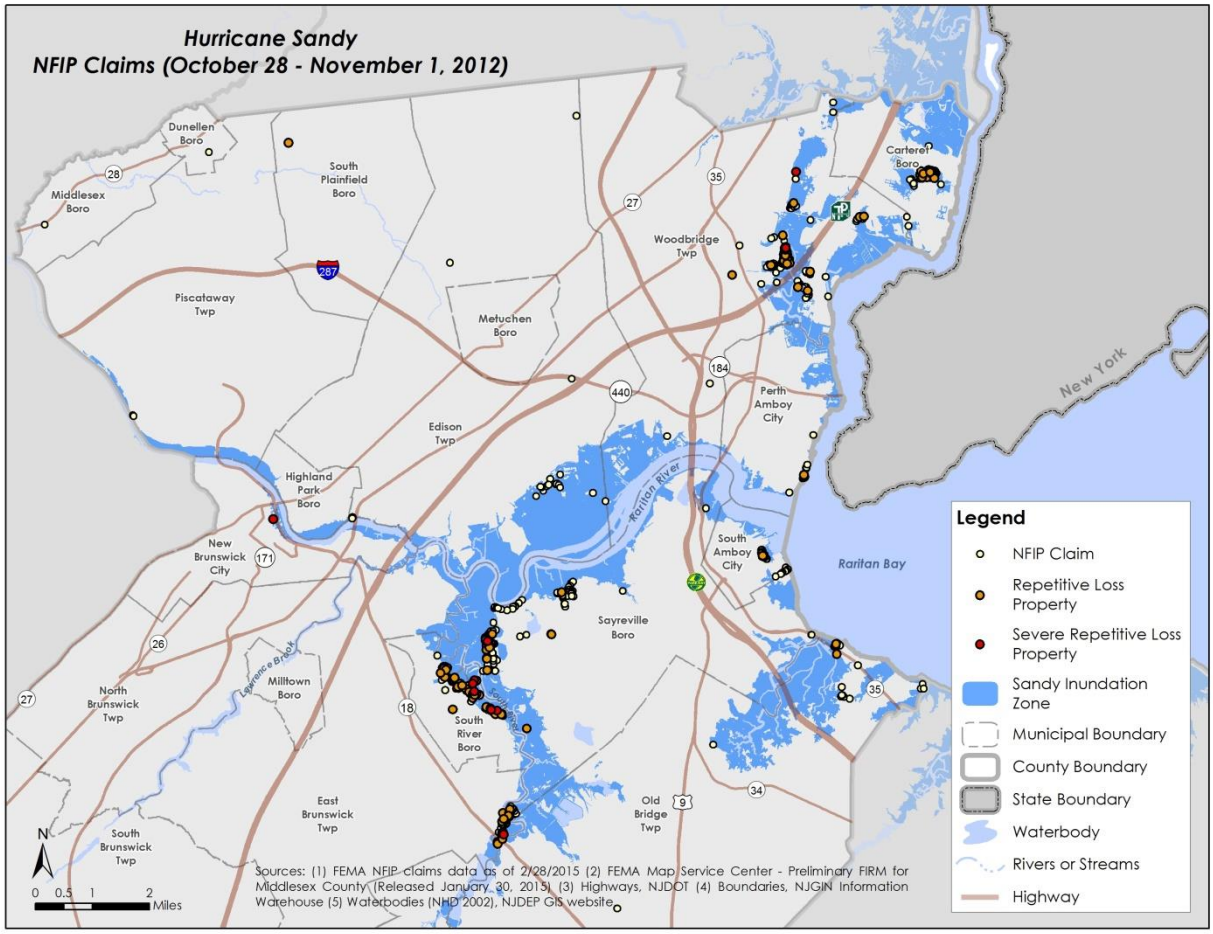


Table 4-57 summarizes the NFIP claims data for the 16 municipalities that filed claims following Sandy. After Sandy a total of 698 properties filed claims for a total of $50.1 million. The highest value of claims paid was located in the areas of Sayreville and South River Boroughs along the South River. In Sayreville a total of 172 properties filed claims for a total of $14.2 million while 142 properties filed claims in South River for a total $10.8 million.

Table 4-57
Hurricane Sandy NFIP Claims in Middlesex County, Ordered by Total Claim Payments
(Source: FEMA Region III, NFIP Claims Data as of February 28, 2015)

Municipality	No. of Properties	Building Payment	Contents Payment	Total Claim Payments
Sayreville, Borough of	172	$12,534,102	$1,754,562	$14,288,664
South River, Borough of	142	$10,290,866	$560,825	$10,851,691
Woodbridge, Township of	165	$6,660,136	$761,601	$7,421,737
Edison, Township of	25	$6,608,704	$150,000	$6,758,704
Old Bridge, Township of	45	$3,168,389	$261,847	$3,430,236
Carteret Borough of	63	$2,059,903	$150,268	$2,210,171
South Amboy, City of	32	$1,676,048	$159,489	$1,835,537
Perth Amboy, City of	13	$1,478,138	$352,416	$1,830,554
East Brunswick, City of	28	$1,072,809	$121,823	$1,194,632
Middlesex, Borough of	5	$211,912	$2,270	$214,182
New Brunswick, City of	1	$93,948	$0	$93,948
South Plainfield, Borough of	2	$46,856	$227	$47,082
Monroe, Township of	1	$10,168	$0	$10,168
Dunellen, Borough of	1	$6,765	$0	$6,765
South Brunswick, Township of	1	$2,568	$0	$2,568
Piscataway, Township of	2	$2,000	$0	$2,000
Grand Total	**698**	**$45,923,312**	**$4,275,329**	**$50,198,640**

Of the 698 NFIP claims filed after Hurricane Sandy, 152 were repetitive loss properties. Table 4-58 summarizes the NFIP RL claims by municipality following Sandy. After Sandy a total of 152 RL properties filed claims for a total of $10,625,439.

Table 4-58
Hurricane Sandy NFIP Repetitive Loss Claims in Middlesex County, Ordered by Total Claim Payments
(Source: NOAA/NCDC)

Municipality	Properties	Building Payment	Contents Payment	Total Claim Payments
South River, Borough of	47	$3,321,732	$231,913	$3,553,645
Sayreville, Borough of	21	$2,514,189	$618,874	$3,133,063
Woodbridge, Township of	27	$1,010,470	$57,564	$1,068,034
Carteret, Borough of	27	$856,775	$44,377	$901,153
Perth Amboy, City of	2	$572,379	$238,221	$810,600
East Brunswick, Township of	16	$655,200	$22,978	$678,177
Old Bridge, Township of	7	$281,946	$35,705	$317,651
New Brunswick, City of	1	$93,948	$0	$93,948
Middlesex, Borough of	1	$43,315	$1,270	$44,585
South Amboy, City of	2	$21,020	$0	$21,020
South Plainfield, Borough of	1	$3,563	$0	$3,563
Grand Total	**152**	**$9,374,536**	**$1,250,903**	**$10,625,439**

Hurricane Irene

Hurricane Irene made landfall along the Outer Banks of North Carolina on August 27, 2011 as a Category 1 hurricane. The storm re-emerged over the Atlantic and made a second landfall as a tropical storm on August 28th in the Little Egg Inlet in southeastern New Jersey. Approximately one million people were evacuated from the coast and low lying areas prone to inland flooding throughout the state of New Jersey. A Presidential disaster declaration was declared on August 31, 2011 (FEMA DR-4021) for all 21 counties in New Jersey.

As Irene moved up the coastline, rainfall rates exceeded over one inch per hour at times. The USGS indicated the maximum recorded precipitation in Middlesex County occurred in Edison Township where 8.9 inches of rain fell between August 27-28, 2011. The extremely heavy rainfall combined with already saturated soils form flooding only several weeks prior to Irene quickly flooded roadways causing numerous road closures. Throughout most of New Jersey the flooding from Irene was intensified from heavy rains that occurred throughout most of August leading up to Irene. According to the USGS the total precipitation observed during the 2-week period preceding Hurricane Irene ranged from 300 to 600 percent from southwestern to central New Jersey.[59]

Damage estimates in the State of New Jersey were nearly $1 billion to approximately 200,000 homes and businesses. The widespread flooding resulted in the second highest crest on record for the Raritan Basin (highest was Hurricane Floyd in 1999). Significant flooding occurred in the low lying areas of the

[59] USGS Hurricane Irene and Associated Flooding of August 27-30, 2011, in New Jersey, Scientific Investigations Report, 2013.

County, particularly along parts of the Raritan River. A Presidential disaster declaration was declared on August 31, 2011 (DR-4021) for all 21 counties in New Jersey.

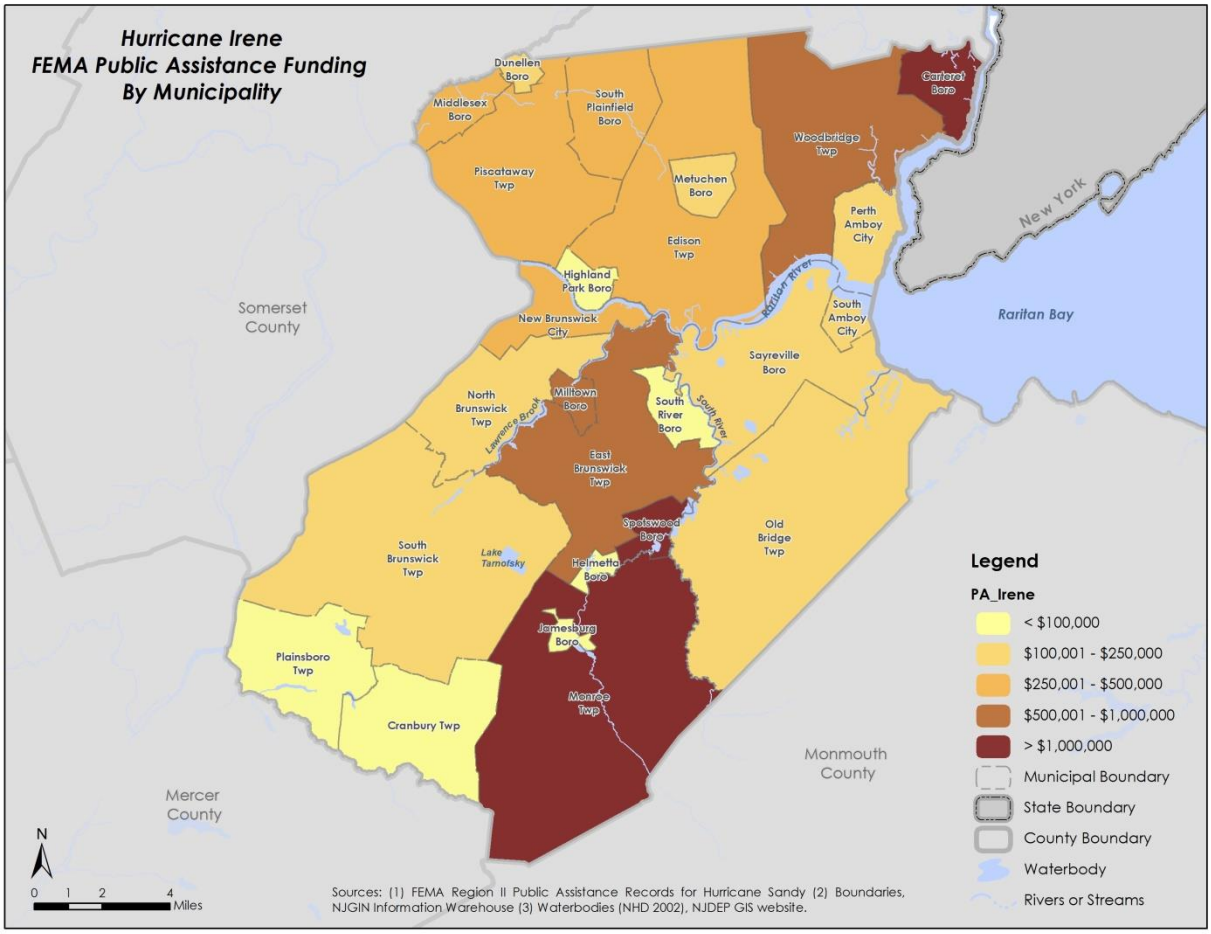
The heavy rains resulted in streams and rivers rising to record or near record stages. In Middlesex County significant flooding occurred along parts of the Raritan River. The USGS reported that stream gages along the Raritan and Rahway recorded peaks greater than the 500-year recurrence interval (or 0.2% annual chance flood). The Middlesex County Flood Insurance Study (FIS) estimated overall damages in the County at $100 million. Figure 4-44 shows flooding along Route 18 in New Brunswick. Figure 4-45 show flooding from the Raritan River near the Rutgers University Boathouse and surrounding area.

Figure 4-44
Flooding from Hurricane Irene along Route 18 in New Brunswick
(Source: The Star-Ledger, NJ.com, August 29, 2011)

Figure 4-45
Flooding from Hurricane Irene along Route 18 in New Brunswick
(Source: The Star-Ledger, NJ.com, August 28, 2011)

In Middlesex County, damages to public infrastructure totaled approximately $13.6 million based on review of FEMA Public Assistance (PA) Project Worksheet (PW) records. Figure 4-46 identifies the total value of FEMA Public Assistance funds by municipality in Middlesex County after Sandy. The map shows funding was greatest in Monroe Township, Carteret Borough, and Spotswood Borough. Total FEMA PA funding in each of these municipalities exceeded $1 million.

Figure 4-46
FEMA Public Assistance Funding After Sandy (DR-4086) by Municipality
(Source: FEMA Region II, June 2015)



A summary of the Hurricane Irene Public Assistance funds broken down by FEMA category (Categories A-G) is shown below in Table 4-59. The table shows that just over $5.4 million or 40% of the funding was related to emergency work (Categories A and B).

Table 4-59
Project Worksheet Summary for Hurricane Irene (DR-4021)
by FEMA Public Assistance Program Category, Middlesex County
(Source: FEMA Region II, June 2015)

Disaster #	Cat. A	Cat. B	Cat. C	Cat. D	Cat. E	Cat. F	Cat. G	Total
DR-4021	$3,061,643	$2,402,651	$682,340	$140,360	$3,172,563	$1,693,609	$2,485,787	$13,638,952

Similar to Hurricane Sandy, the FEMA Public Assistance records for Hurricane Irene can be further broken down by identifying the applicants that received the highest amount of federal funding. Table 4-60 identifies applicants that received funding greater than $250,000. The table shows that Monroe Township was the municipality with highest Public Assistance funding after Sandy. Monroe Township received approximately $1.56 million in FEMA Public Assistance following Sandy.

Table 4-60
Hurricane Irene: Project Worksheet Summary (By Category) for Middlesex Applicants Receiving
Greater Than $500,000 in FEMA Public Assistance Funding
(Source: FEMA Region II, June 2015)

Applicant Name	Cat. A	Cat. B	Cat. C	Cat. D	Cat. E	Cat. F	Cat. G	Total
Middlesex County	$312,608	$198,536	$138,324	$0	$85,353	$0	$1,227,246	$1,962,067
Monroe Township	$173,408	$98,062	$0	$0	$1,231,408	$67,015	$0	$1,569,892
Middlesex County Utilities Authority	$0	$18,831	$233,470	$0	$0	$1,210,371	$0	$1,462,672
Carteret Borough	$68,086	$66,373	$6,129	$27,371	$4,119	$0	$1,042,130	$1,214,207
Spotswood Borough	$35,577	$134,231	$0	$0	$853,961	$0	$0	$1,023,769
Woodbridge Township	$702,355	$48,939	$74,783	$0	$0	$0	$0	$826,078
Milltown Borough	$47,541	$92,688	$0	$0	$256,633	$219,658	$2,500	$619,021
East Brunswick Township	$330,492	$160,094	$98,763	$0	$0	$0	$0	$589,350
Piscataway Township	$163,285	$14,486	$9,591	$0	$67,655	$0	$151,278	$406,294
New Brunswick City	$76,652	$218,551	$0	$98,166	$2,629	$0	$0	$395,997
Edison Township	$94,751	$166,749	$0	$0	$59,437	$0	$0	$320,938
Middlesex Borough	$164,181	$72,297	$0	$14,823	$5,072	$3,109	$37,100	$296,582
Monroe Village	$1,353	$1,337	$0	$0	$292,720	$0	$0	$295,410
South Plainfield Borough	$141,793	$86,064	$0	$0	$32,343	$0	$0	$260,201

In addition to the FEMA Public Assistance records, NFIP claims were also analyzed for Irene. Table 4-61 summarizes the NFIP claims data for all 25 municipalities that filed claims following Irene. After Irene a total of 981 properties filed claims for a total of roughly $28.8 million. The highest value of claims paid was located in Middlesex Borough mainly from properties along Bound Brook and Ambrose Brook, tributaries of the Raritan River. In Middlesex Borough a total of 232 properties filed claims for slightly more than $7.8 million.

Table 4-61
Hurricane Irene NFIP Claims in Middlesex County, Ordered by Total Claim Payments
(Source: FEMA Region III, NFIP Claims Data as of February 28, 2015)

Municipality	No. of Properties	Building Payment	Contents Payment	Total Claim Payments
Middlesex Borough	232	$6,253,560	$1,639,050	$7,892,610
Woodbridge Township	120	$3,251,590	$304,312	$3,555,902
Monroe Township	46	$2,114,986	$325,282	$2,440,268
South Plainfield Borough	84	$1,817,746	$414,624	$2,232,370
Piscataway Township	51	$1,702,520	$80,465	$1,782,985
Sayreville Borough	60	$1,634,815	$73,767	$1,708,582
Milltown Borough	8	$1,362,940	$22,505	$1,385,445
New Brunswick City	20	$996,206	$80,452	$1,076,658
Dunellen Borough	88	$842,314	$59,174	$901,488
Edison Township	23	$788,317	$86,540	$874,857
South River Borough	61	$774,600	$46,556	$821,156
Old Bridge Township	20	$522,810	$139,820	$662,630
East Brunswick Township	28	$585,907	$49,021	$634,929
Jamesburg Borough	14	$583,658	$41,264	$624,922
Cranbury Township	14	$550,369	$65,980	$616,349
Carteret Borough	35	$470,605	$22,048	$492,653
Helmetta Borough	22	$285,038	$9,097	$294,136
South Brunswick Township	11	$238,652	$35,036	$273,688
Perth Amboy City	3	$104,659	$47,727	$152,386
Spotswood Borough	14	$129,392	$5,255	$134,647
Highland Park Borough	9	$86,345	$8,235	$94,580
Plainsboro Township	5	$57,397	$10,371	$67,769
Metuchen Borough	6	$40,981	$1,999	$42,979
North Brunswick Township	4	$32,334	$1,230	$33,565
South Amboy City	3	$15,327	$0	$15,327
Grand Total	**981**	**$25,243,069**	**$3,569,811**	**$28,812,880**

Of the 981 NFIP claims filed after Hurricane Irene, 223 were repetitive loss properties. Table 4-62 summarizes the NFIP RL claims by municipality following Irene. After Irene a total of 223 RL properties filed claims for a total of just over $16.4. The table shows that repetitive loss claims from Irene were highest in Milltown Borough ($6.1 million) and Middlesex Borough ($4.9 million).

Table 4-62
Hurricane Irene NFIP Repetitive Loss Claims in Middlesex County, Ordered by Number of Properties
(Source: NOAA/NCDC)

Municipality	Properties	Building Payment	Contents Payment	Total Claim Payments
Middlesex, Borough of	107	$3,578,198	$1,366,523	$4,944,721
Dunellen, Borough of	29	$424,215	$33,135	$457,350
South Plainfield, Borough of	26	$642,668	$54,188	$696,856
Piscataway, Township of	20	$669,842	$43,186	$713,029
Woodbridge, Township of	11	$2,847,090	$9,889	$2,856,979
Helmetta, Borough of	9	$80,779	$8,693	$89,472
Milltown, Borough of	5	$6,188,278	$0	$6,188,278
New Brunswick, City of	3	$209,779	$2,637	$212,415
Edison, Township of	3	$49,767	$5,114	$54,881
Jamesburg, Borough of	3	$52,352	$944	$53,296
Spotswood, Borough of	2	$35,454	$3,651	$39,105
Highland Park, Borough of	2	$36,268	$0	$36,268
Monroe, Township of	1	$38,860	$13,838	$52,698
Cranbury, Township of	1	$15,070	$0	$15,070
South Brunswick, Township of	1	$11,260	$0	$11,260
Grand Total	**223**	**$14,879,879**	**$1,541,798**	**$16,421,678**

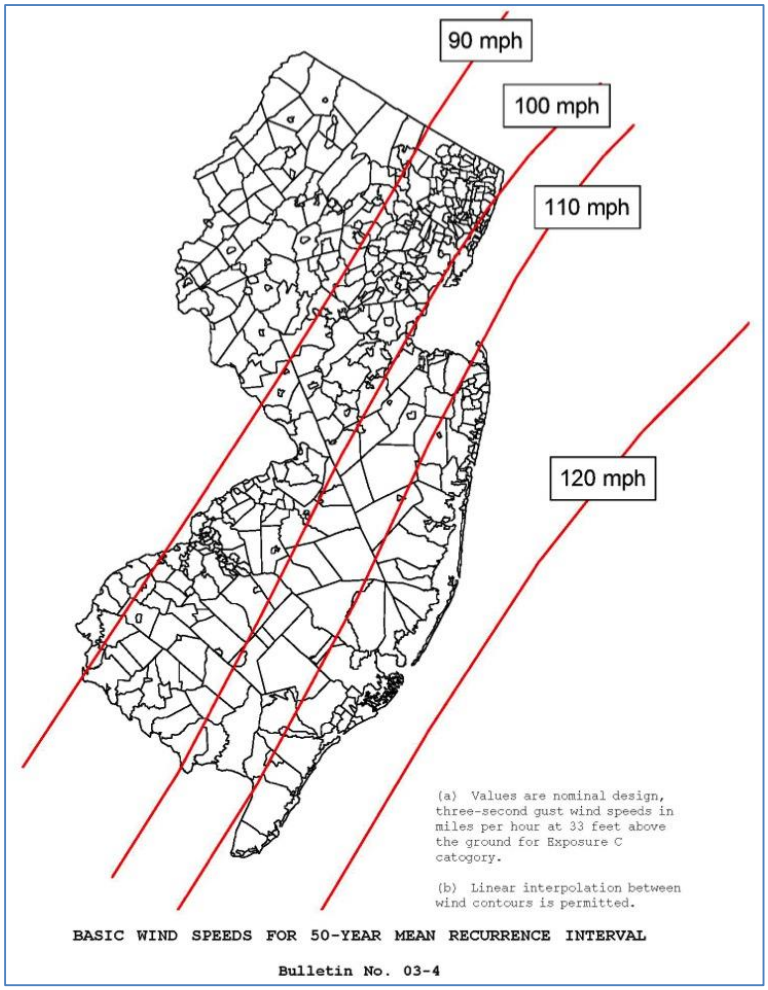
Future Probability of Occurrences

The planning area has been impacted by 12 hurricanes or tropical storms over the last 63 years. On average, Middlesex County experiences the wind effects of a hurricane about every five years. With one event roughly every five years, there is a 19% annual probability of a future flood events occurring in Middlesex County. Recent hurricanes such as Irene (2011) and Sandy (2012) over past few years suggest that future hurricanes or tropical storms are likely to affect Middlesex County again in the future. However, as mentioned, almost all had been downgraded to tropical storm or tropical depression status by the time they reached New Jersey. In the future, Middlesex County can be considered at moderate to high risk from experiencing the high wind effects from hurricanes and tropical storms. Considering the impacts from hurricanes and tropical storms, the 2016 Middlesex County HMPSC ranked the hazard as a high (See Table 4-1 for a complete list of hazard rankings). Hurricane and Tropical Storm Risk and Vulnerability Assessment (Including Impacts on Life and Property)

To protect life and property from wind events, all counties within the State of New Jersey, including the Middlesex County, are required to comply with the design wind loads developed by the International Building Code (IBC) and the International Residential Code (IRC). The building code administered within the incorporated areas of the region requires all new construction to be designed and constructed to a

range between 90 and 110 mph wind loads depending on the location.[60] Figure 4-47 identifies the minimum design wind speeds for New Jersey as of 2010 (American Society of Civil Engineers (ASCE 7-5). The region is divided into three different wind speed zones. The majority of the County falls within the 100 mph minimum design wind speed. The far eastern part of the County (south of the Raritan River) is within the 110 mph range.

Figure 4-47
New Jersey Wind Zone Map From the International Building Code
(Source: ASCE Minimum Design Loads for Buildings and Other structures (ASCE 7-5), New Jersey Department of Community Affairs, Bulletin 3-4, December 2013)



HAZUS – Hurricane Wind Risk Assessment

This subsection describes the risk assessment for the high wind–straight-line wind hazard (non-tornado). As discussed previously, this hazard category includes high winds related to hurricanes, tropical storms, nor'easters, and thunderstorms. The risk calculations are completed using both the data and methodology of FEMA HAZUS-MH 2.1 (SP2, Fall 2014). The model has been substantially improved in

[60] Department of Community Affairs-Division of Codes and Standards: Bulletin No. 3-4-Wind Speed Map.

last several years, and gives estimates for both the hazard profiles and for the risk calculations on a census-tract basis.

Middlesex County comprises 313.58 square miles and 177 census tracts. There are over 265,000 households in the County, which has a total population of 750,162 (2002 Census Bureau data, used by HAZUS 2.1). There are an estimated 234,852 buildings in the County, with a total replacement value (including contents) of $119,948,782,000. Approximately 91 % of all the buildings and 59% of the total building exposure are associated with residential housing. Note that Tables 4-21 and 4-22 in the Earthquake hazard section of this mitigation plan provide building counts and total County exposure, both of which are incorporated into the software and used in the risk calculations. For reasons of brevity the tables are not repeated in the present section.

HAZUS calculated the total annualized hurricane wind risk in Middlesex County at $14.71 million. Table 4-63 presents the annualized losses in Middlesex County, broken down by the seven occupancy classes and by the municipality. The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses (or Capital Stock Losses) are the estimated costs to repair or replace the damage caused to the building and its contents. Table 4-64 these losses are contained within three subcategories: Building, Contents, and Inventory loses. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the hurricane. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the damages sustained by the hurricane wind. In Table 4-64, these losses are defined in four sub-categories: relocation cost, business income loss, rental loss, and lost wages. The total annualized losses were $14.71 million; of which less than 10 % were related to business ($1.46 million). The projected losses over the 50-year and 100-year horizons were $202.99 million and $209.87 million, respectively. Projected losses were calculated using conversion factors of 13.801, and 14.269, which are based on FEMA discount rate of 7%. Each of the Middlesex County municipality annexes contains a more detailed version of Table 4-64, further broken down by the occupancy class.

The total annualized damages, broken down by the census tract are depicted in the HAZUS-MH output. The map shows that census tracts in southwest Middlesex County and southern Edison Township have the highest annual losses. Because populations and buildings are major components of wind risk estimates, census tracts with high populations and numerous buildings will have more risk than those with less development.

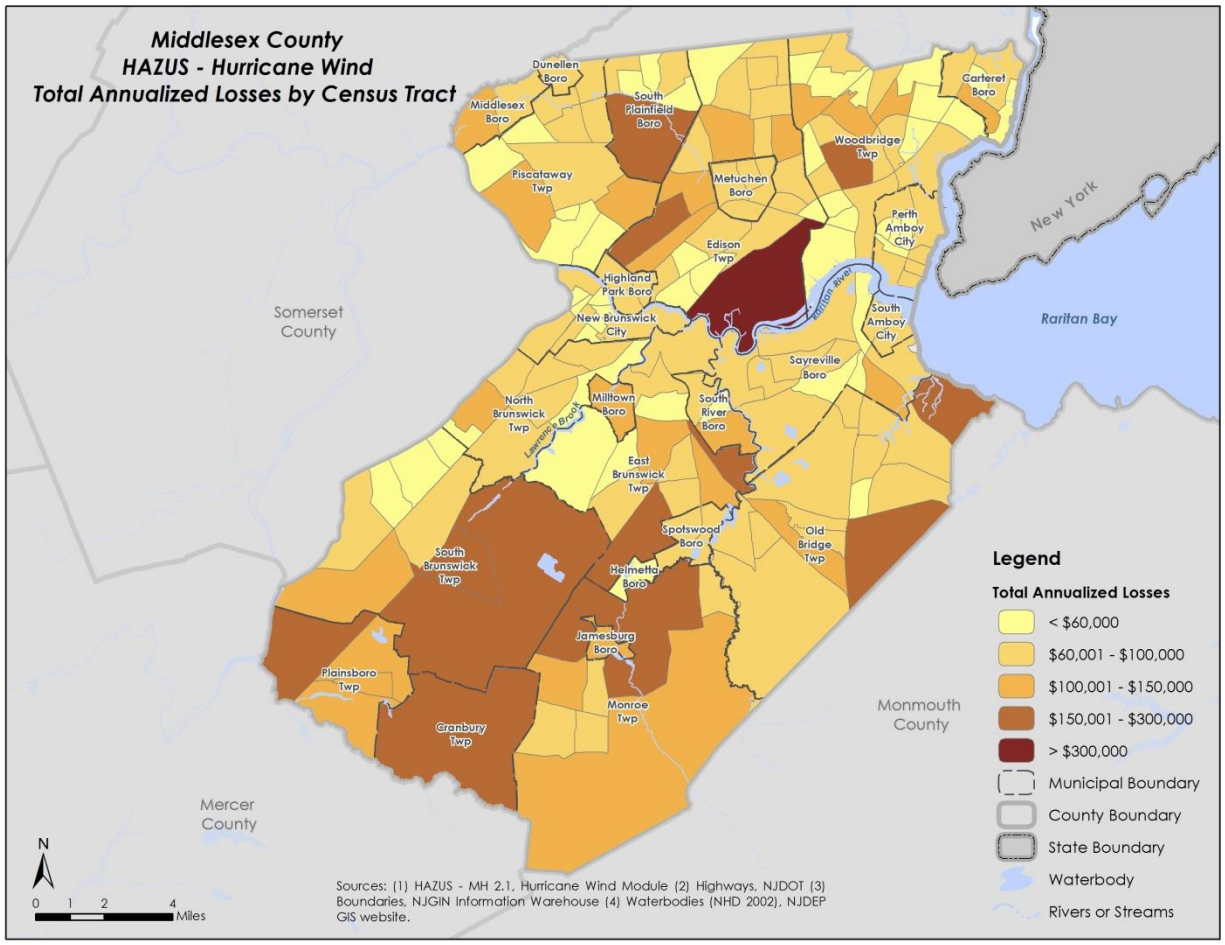
Table 4-63:
Middlesex County Annualized, 50-year and 100-year Straight-Line Wind Risks by Jurisdiction and Occupancy Class
(Source: HAZUS- MH 2.1 Hurricane Wind Module, August 2015)

Municipality Name	Residential	Commercial	Industrial	Agricultural	Religious	Government	Education	Annualized Loss
Carteret Borough	$268,516	$70,963	$20,725	$417	$3,186	$885	$2,922	$367,614
Cranbury Township	$113,630	$38,067	$35,502	$1,002	$990	$760	$413	$190,365
Dunellen Borough	$83,648	$10,678	$1,215	$54	$989	$321	$308	$97,213
East Brunswick Township	$905,534	$140,211	$29,917	$1,855	$7,450	$4,765	$7,431	$1,097,162
Edison Township	$1,407,226	$642,369	$79,691	$2,724	$8,368	$39,479	$14,417	$2,194,274
Helmetta Borough	$34,312	$927	$112	$109	$190	$13	$55	$35,718
Highland Park Borough	$201,893	$26,020	$1,498	$169	$2,436	$362	$2,083	$234,461
Jamesburg Borough	$101,690	$10,014	$1,863	$365	$1,181	$865	$1,406	$117,384
Metuchen Borough	$240,367	$36,043	$11,177	$324	$5,179	$752	$2,374	$296,216
Middlesex Borough	$157,261	$18,109	$13,613	$428	$1,845	$470	$1,039	$192,765
Milltown Borough	$123,641	$13,716	$3,111	$115	$1,366	$421	$440	$142,810
Monroe Township	$695,686	$50,508	$10,714	$4,446	$2,894	$2,835	$1,374	$768,457
New Brunswick	$422,151	$86,285	$37,447	$254	$8,222	$6,013	$9,629	$570,001
North Brunswick Township	$466,580	$60,427	$24,644	$783	$3,861	$369	$4,537	$561,201
Old Bridge Township	$1,310,554	$81,169	$19,319	$1,661	$7,089	$1,800	$6,834	$1,428,425
Perth Amboy	$553,498	$91,194	$30,800	$483	$8,676	$2,930	$3,062	$690,643
Piscataway Township	$639,196	$84,121	$31,692	$6,800	$5,845	$1,817	$13,445	$782,917
Plainsboro Township	$405,846	$53,013	$33,321	$263	$2,056	$2,797	$1,319	$498,614
Sayreville Borough	$724,739	$77,817	$30,120	$556	$2,453	$1,858	$2,697	$840,239
South Amboy	$140,912	$13,454	$2,340	$80	$1,928	$1,145	$1,272	$161,132
South Brunswick Township	$555,756	$131,116	$50,123	$1,342	$4,345	$2,275	$2,069	$747,027
South Plainfield Borough	$317,479	$74,065	$83,709	$880	$1,707	$601	$7,076	$485,516
South River Borough	$214,306	$21,959	$7,013	$321	$2,698	$1,108	$759	$248,165
Spotswood Borough	$157,869	$10,862	$1,067	$578	$698	$90	$779	$171,942
Woodbridge Township	$1,435,788	$265,332	$62,980	$1,719	$8,434	$5,388	$8,140	$1,787,780
Totals	**$11,678,078**	**$2,108,439**	**$623,713**	**$27,728**	**$94,087**	**$80,116**	**$95,882**	**$14,708,043**

Table 4-64
Middlesex County Annualized Losses by Occupancy Class and Overall Risk for 50-year and 100-year Horizons, in 1000s
(Source: HAZUS- MH 2.1 Hurricane Wind Module, August, 2015)

Occupancy Class	Total SF	Building Damages	Contents Damages	Inventory Loss	Relocation Cost	Business Income Loss	Rental Loss	Lost Wages	Total Annualized Loss	50-year Risk	100-year Risk
Residential	360,517,522	$8,439,723	$2,416,258	$0	$528,198	$1,135	$290,090	$2,674	$11,678,078	$161,169,148	$166,634,489
Commercial	127,778,959	$1,111,242	$495,875	$13,768	$179,197	$106,303	$100,871	$101,184	$2,108,439	$29,098,573	$30,085,322
Industrial	41,673,986	$323,442	$232,263	$32,738	$21,580	$3,781	$3,775	$6,133	$623,713	$8,607,861	$8,899,759
Agricultural	2,115,958	$15,919	$8,047	$980	$2,470	$153	$99	$61	$27,728	$382,671	$395,647
Religious	5,566,060	$53,816	$19,422	$0	$7,513	$3,781	$664	$8,890	$94,087	$1,298,495	$1,342,528
Government	4,929,922	$33,183	$15,722	$0	$7,586	$402	$2,279	$20,945	$80,116	$1,105,686	$1,143,180
Education	7,036,673	$52,753	$24,673	$0	$9,809	$2,426	$512	$5,709	$95,882	$1,323,261	$1,368,134
Totals	**549,619,081**	**$10,030,077**	**$3,212,260**	**$47,486**	**$756,352**	**$117,981**	**$398,291**	**$145,597**	**$14,708,043**	**$202,985,696**	**$209,869,060**

Figure 4-48
Estimated Hurricane Wind Risk to Middlesex County, Total Annualized Losses Per Census Tract
(Source: HAZUS- MH 2.1 Hurricane Wind Module, August 2015)



4.3.11 Nor'easters

Description of the Nor'easter Hazard

Nor'easters are cyclonic storms that typically track up the east coast of the U.S., (most common in winter) and often are first felt as a northeast wind. These winter weather events are known for producing heavy snow, rain, and tremendous waves that crash onto Atlantic beaches. This wave action and storm surge can often result in beach erosion and sometimes even structural damage. Wind gusts associated with these storms can exceed hurricane force in intensity. A nor'easter gets its name from the continuously strong northeasterly winds blowing in from the ocean ahead of the storm and over the

coastal areas.[61] For additional information about nor'easters visit NOAAs Know the Dangers of Nor'easters website at http://www.noaa.gov/features/03_protecting/noreasters.html.

Location of the Nor'easter Hazard

The entire planning area is subject to the wind effects from nor'easters. These storms usually develop between Georgia and New Jersey within 100 miles of the coastline, and generally move in a north or northeastward direction. The shoreline areas of the Raritan Bay and Raritan River along with other low lying areas are at greatest risk from nor'easters.

Severity and Extent of the Nor'easter Hazard

The severity of a nor'easter is measured primarily by a combination of wind velocity, flooding, beach erosion, and snowfall totals. The effects from high winds can be exacerbated by long durations of continuously strong northeasterly winds and the presence of windborne debris. Nor'easters typically become more intense as they move up the Atlantic coastline, often reaching their greatest intensity offshore of New England.

Occurrences of the Nor'easter Hazard

The NWS, NOAA, and the NCDC do not specifically track nor'easter events. However, the events listed for Middlesex County within the Coastal Flooding category of the NCDC database along with other open data sources indicates there have been numerous nor'easters in the past that have impacted the planning area with high winds. Several of the more significant nor'easter events are highlighted below.

- **October 28, 1991 (Perfect Storm).** The 1991 Halloween Nor'easter, also known as the Perfect Storm, caused strong waves of up to 30 feet (nine meters) in height. High tides along the shore were only surpassed by the 1944 hurricane, while significant bay flooding occurred. Strong waves and persistent intense winds cause extreme beach erosion. In all, damage estimates totaled $90 million. The event resulted in no deaths within the State of New Jersey.

- **December 18, 1992 (DR-0973).** A powerful nor'easter resulting in wind gusts of 90 mph along parts of the New Jersey coastline and up to 60 mph farther inland. Hundreds of homes along the coast were destroyed or damaged. In New Jersey the storm produced strong winds and record high tides. In Middlesex County the highest tide was in Perth Amboy (10.4 feet) along the Raritan River, which broke the record set in 1960. In many locations the storm produced the highest tides since the Ash Wednesday Storm of 1962. A Federal Disaster Declaration was declared for 12 counties in New Jersey, including Middlesex County.

- **March 16, 1993 (Storm of the Century).** One of the most intense nor'easters to ever affect the United States. The "Storm of the Century" label was given to the event due to the record low pressure, wind speeds, temperature, and snowfall. Fallen trees from high winds left 3

[61] NOAA,NWS – Nor'easter definition

million customers without electrical power.[62] Wind gusts of over 70 mph were reported at New York City's LaGuardia airport.

- **October 18, 1996.** A 5-day nor'easter that lasted from October 18– 23. Record rainfall, flooding, and high winds effected parts of New Jersey from Morris County to Camden County to Hunterdon County.

- **February 12, 2006.** A Nor'easter that impacted the New Jersey shoreline with strong onshore winds that caused coastal flooding and beach erosion.

- **April 15, 2007 (DR-1694).** An intense Nor'easter that brought heavy rain and flooding to New Jersey between April 15th and 16th, 2007. In Middlesex County nearly every municipality experienced flood damages with the worst flooding along the Raritan River Basin. The NCDC indicated that at the time it was considered the worst flooding in the Raritan Basin since Hurricane Floyd in 1999. The nor'easter also brought strong to high winds as well as some snow to the state on the 16th. Peak wind gusts averaged between 40 and 60 mph. The combination of the heavy rain, even some snow and the winds helped knock down numerous trees and power lines. The strong winds caused about 120,000 homes and businesses in the state to lose power. Statewide damage was estimated at $180 million dollars. The NCDC reported 129 homes in in Middlesex County were severely damaged by flooding. A Federal Disaster Declaration was declared for 12 counties in New Jersey, including Middlesex County.
- **November 12-13, 2009.** A powerful Nor'easter also known as "Nor'Ida" (after Hurricane Ida) produced wind gusts to nearly 60 mph, widespread moderate tidal flooding, heavy rain and severe beach erosion along the New Jersey coast from November 12th through the 14th. Initial damage estimates were placed at $180 million. By several measures this was one of the worst Nor'easters to affect New Jersey since 1991.
- **November 7, 2012.** A strong Nor'easter that occurred only several weeks after Hurricane Sandy, caused high winds along the coast, heavy snow in east central New Jersey and ten foot waves along the ocean front and minor tidal flooding along the ocean front. The event caused setbacks with restoration efforts near and along coastal areas caused by Hurricane Sandy, particularly in Monmouth and Ocean Counties. It also forced some coastal area evacuations again.

Nor'easter Risk and Vulnerability Assessment (Including Impacts on Life and Property)

The impacts of Nor'easters are substantially the same as hurricanes and tropical storms, although Nor'easters occur more frequently than the other two hazards. As with hurricanes and tropical storms, Nor'easters can be subdivided into two distinct hazards: wind and rain. The effects of

[62] NOAA/NCDC database

nor'easters can be exacerbated by the fact that they often occur in winter, so snow and ice are also in the range of hazards related them. Generally, Nor'easter wind speeds are less than hurricanes and tropical storms, although this is not always the case, as shown by the historical descriptions above. Most of the vulnerability to this hazard is in coastal areas, where there is more direct exposure to wind, waves and other effects. The entire planning area is vulnerable to power losses related to this hazard, particularly when high winds are accompanied by snow and ice.

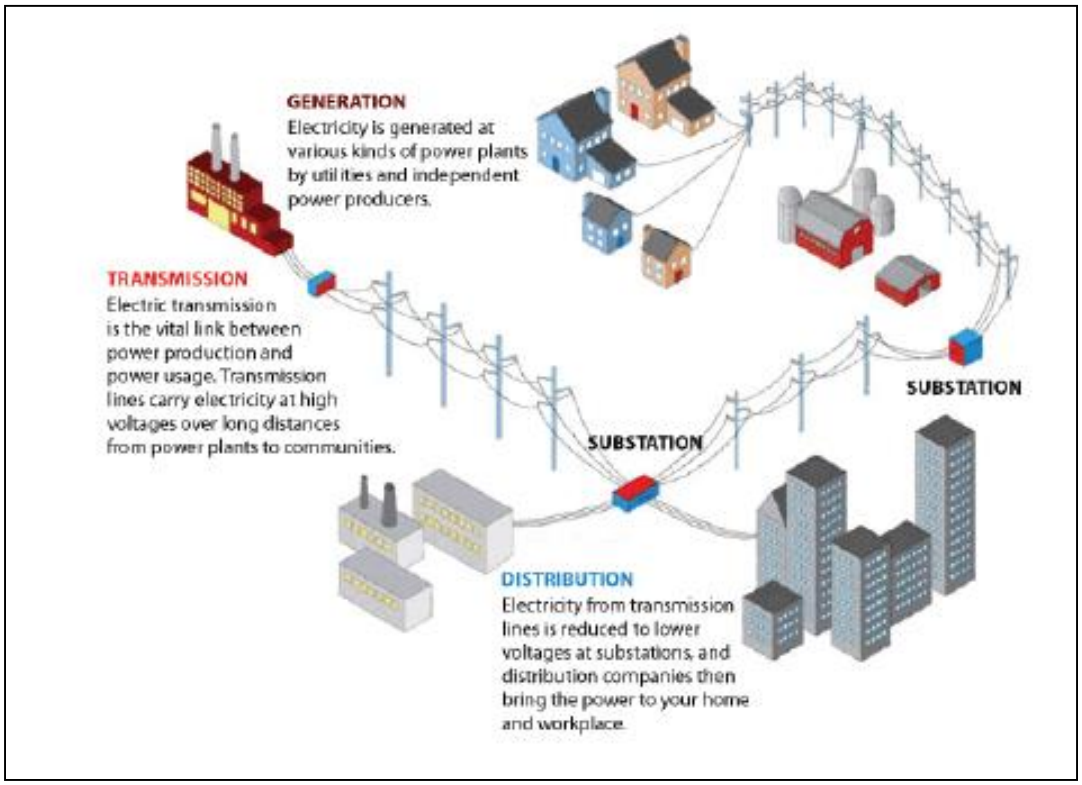
There is not presently sufficient and reliable damage information directly related to Nor'easters to produce a quantitative risk assessment for the hazard.

4.3.12 Power Outages

Description of the Power Outage Hazard

The U.S. electricity system can be generally divided into four general components: power generation, high-voltage transmission, local distribution, and the end-use customers (Figure 4-49). An intricate power management system connects all four components together. Damage to power generators (power plants, primarily), high-voltage transmission lines and local power lines, can each threaten overall power supply to customers, as can an overall shortage of fuel for electricity generation. Most major power outages and disturbances (those which threaten power to tens of thousands of customers) are ones that disrupt high-voltage transmission.

Figure 4-49
U.S. Electric Grid System
(Source: Blackout: Extreme Weather, Climate Change and Power Outages)



Power failure is defined as any interruption or loss of electrical service caused by disruption of power transmission caused by accident, sabotage, natural hazards, or equipment failure (also referred to as a loss of power or power outage). A significant power failure is defined as any incident of a long duration, which would require the involvement of the local and/or State emergency management organizations to coordinate provision of food, water, heating, cooling, and shelter.

Location of the Power Outage Hazard

The entire planning area is equally subject to the impacts from power outages. In Middlesex County, with the exception of the Borough of South River and Borough of Milltown, the County's power systems are overseen by the State of New Jersey Board of Public Utilities (BPU). Under New Jersey law, consumers can shop for electric suppliers through a variety of third-party vendors. While the *supply* portion of energy is open to competition, the majority of the *delivery* of electricity in Middlesex County is limited geographically to Jersey Central Power and Light (JCP&L) and Public Service Electric and Gas (PSE&G). The Boroughs of South River and Milltown have their own electric utilities and not overseen by the BPU.

Figure 4-50
New Jersey Electrical Utilities Territory Map
(Source: New Jersey's Clean Energy Program)

These service providers are responsible for maintaining power throughout their respective regions. Figure 4-50 shows the locations of electric service delivery providers for New Jersey. The map shows that Middlesex County is roughly divided in half, with JCP&L provided electrical service to the eastern half of the County (shaded light blue) and PSE&G providing power to the western half (shaded orange).

Power failures in Middlesex County are typically localized and are usually the result of a natural hazard events involving high winds (hurricanes, tornadoes, severe thunderstorms), floods, extreme heat and ice storms.

Severity and Extent of the Power Outage Hazard

The severity of power outages are typically measured by the duration of the outage and the number and types of customers impacted. Power failures can range from minor loss of communication systems at a facility to catastrophic loss of critical services such as water and electricity.

Due to the varied nature of power outage causes ranging from vehicle accidents to severe weather, utility interruptions can happen at any time. Power disruption can lead to significant consequences, including service disruption, disruption to infrastructure operations, and loss of heat or cooling that can

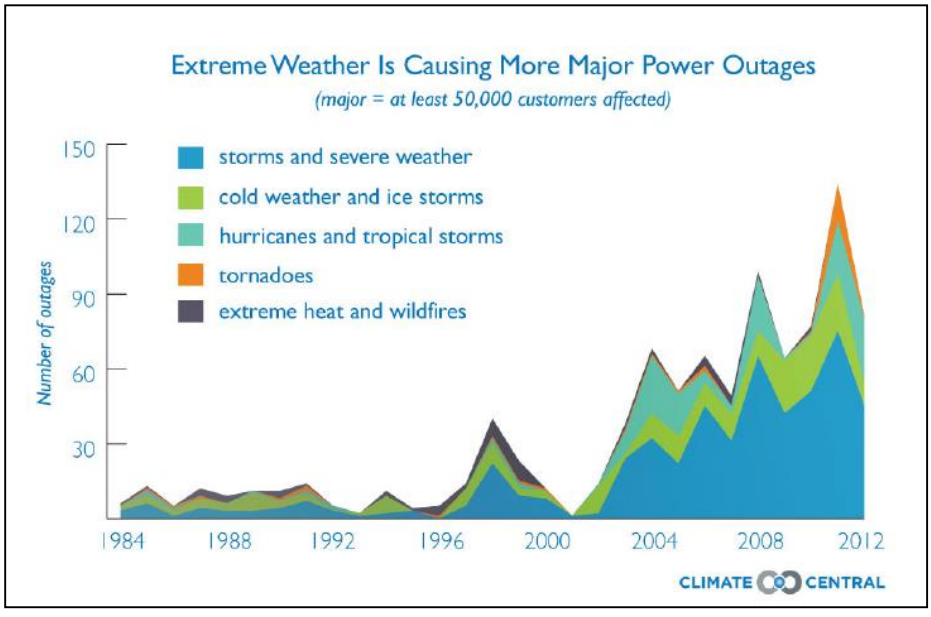
cause further disturbance or injury.

Impact of Climate Change on Future Power Outages

A report produced by Climate Central in 2014 titled *Blackout: Extreme Weather, Climate Change and Power Outages* indicates that climate change will increase the risk of more violent weather and more frequent damage to our electrical system, affecting hundreds of millions of people. According to the report, cclimate change is causing an increase in many types of extreme weather. Heat waves are warmer, hurricanes intensities are increasing, thunderstorm wind and heavy rain events produce higher wind speeds and rainfall totals, and winter storms have increased in both frequency and intensity. To date, these kinds of severe weather are among the leading causes of large-scale power outages. [63]

Figure 4-51 identifies the number of power outages in the United States by hazard type between 1984 and 2012. The graphic shows that number of power outages (with at least 50,000 customers affected) has increased significantly since year 2000. The table also shows that severe weather (shaded blue) causes the greatest number of outages in the U.S. when compared to other categories.

Figure 4-51
Number of Power Outages in the U.S. by Natural Hazard Type
(Source: Blackout: Extreme Weather, Climate Change and Power Outages)



Occurrences of the Power Outage Hazard

Several sources were reviewed to identify past power outage events in Middlesex County. The data included power outage statistics from PSE&G and JCP&L, Rutgers Report titled *Overview of New Jersey Power Outages: Risk to the New Jersey Grid*, and the State of New Jersey 2014 Hazard

[63] Climate Central. Blackout: Extreme Weather, Climate Change and Power Outages, 2014

Mitigation Plan Update. According to the Rutgers report there have been 143 power outages with greater than 1,000 customers without power for an extended period of time in New Jersey between 1985 and 2013. These events are summarized below by category. Although not specific to Middlesex County the table provides an indication as to the type of events causing power outages in New Jersey. The table shows that hurricanes and Tropical Storms have affected the greatest number of customers (5,768,500) during this time period, followed by High Wind/Rain (4,430,900). These two hazards are followed by Winter Weather/Nor'easters which affected a total of 2,018,200 customers between 1985 and 2013.

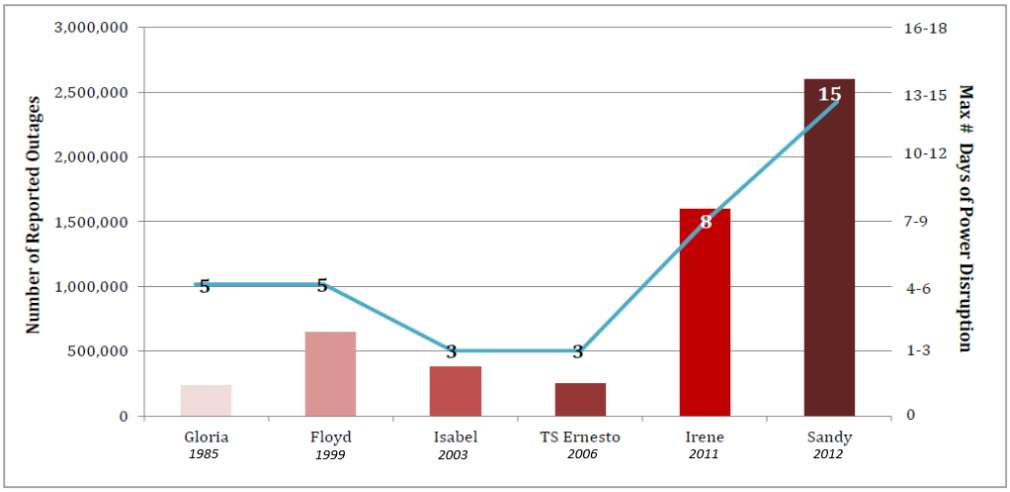
Figure 4-65
Summary of Power Outages in New Jersey by Natural Hazard Type, 1985 - 2013
(Source: Blackout: Extreme Weather, Climate Change and Power Outages)

Hazard Type	No. of Total Events	No. of Cumulative Affected Customers (Meters)	Percent of Reported Events
Hurricane/Tropical Storm	9	5,768,500	6.3%
High Wind/Rain	96	4,430,900	67.1
Winter Weather/Nor'easters	22	2,018,200	15.4
Lightning	9	175,800	6.3
Tornado	2	121,000	1.4
Ice Storm	5	95,500	3.5

The Rutgers report identified six of the nine hurricanes and tropical storms between 1985 and 2013 resulted in large scale power outages with over 100,000 outages. These six major storms accounted for an estimated total of 5,717,800 reported outages over the course of 1985 - 2013, averaging to 952,966 outages per storm.[64] The number of reported outages and days of power disruption for the six events are summarized in the Figure 4-52 below. The table shows that of the six events Hurricane Sandy in October, 2012 resulted in the most power outages in New Jersey. Most of these events impacted Middlesex County, particularly Hurricanes Floyd, Irene and Sandy.

[64] Rutgers University. Center of Energy, Economic and Environmental Policy. Weather Related Power Outages in New Jersey, February 27, 2014

Figure 4-52
Major Hurricanes and Tropical Storms in New Jersey, 1985 – 2013
Storm Outages and Duration of Outages
(Source: Rutgers University, Center of Energy, Economic and Environmental Policy, February, 2014)



Most recently, the two greatest events that resulted in power outages in Middlesex County were Hurricane Irene in 2011 and Hurricane Sandy in 2012. After Hurricane Irene a total of 154,268 customers (120,045 PSE&G customers and 34,223 JCP&L customers) were without power in Middlesex County. Table 4-66 summarizes the power outages by municipality for both utility providers in Middlesex County. The table shows outages from Hurricane Irene were highest in Edison and Woodbridge Townships.

Table 4-66
Hurricane Irene (August, 2011): Power Outages in Middlesex County by Municipality and Customers Affected
(Source: JCP&L, PSE&G)

Municipality	Customers Affected (JCP&L)	Customers Affected (PSE&G)	Total
Carteret Borough	0	2,677	2,677
Cranbury Township	186	311	497
Dunellen Borough	0	2,489	2,489
East Brunswick Township	3,761	6,396	10,157
Edison Township	0	19,799	19,799
Helmetta Borough	732	0	732
Highland Park Borough	0	1,936	1,936
Jamesburg Borough	1,558	0	1,558
Metuchen Borough	0	7,982	7,982
Middlesex Borough	0	3,848	3,848
Milltown Borough	0	3	3
Monroe Township	8,509	0	8,509

Municipality	Customers Affected (JCP&L)	Customers Affected (PSE&G)	Total
New Brunswick City	0	2,934	2,934
North Brunswick Township	0	5,643	5,643
Old Bridge Township	9,585	0	9,585
Perth Amboy City	0	3,158	3,158
Piscataway Township	0	6,367	6,367
Plainsboro Township	0	6,318	6,318
Sayreville Borough	4,301	0	4,301
South Amboy City	1,792	0	1,792
South Brunswick Township	51	14,992	15,043
South Plainfield Borough	0	7,701	7,701
Spotswood Borough	3,748	0	3,748
Woodbridge Township	0	27,491	27,491
Grand Total	**34,223**	**120,045**	**154,268**

In Middlesex County a total of 313,763 customers (234,873 PSE&G customers and 78,890 JCP&L customers) were without power after Sandy. Although not included in Table 4-67 below, an additional 6,300 customers in the Boroughs of Milltown and South River lost power after Sandy. As mentioned earlier, these two Boroughs are not part of the BPU and have their own electrical service provider. Similar to Irene, power outages from Sandy were highest in Woodbridge and Edison Townships where roughly 40,000 customers were without power at the peak of the event.

Table 4-67
Hurricane Sandy (October, 2012): Power Outages in Middlesex County by Municipality and Customers Affected
(Source: JCP&L, PSE&G)

Municipality	Customers Affected (JCP&L)	Customers Affected (PSE&G)	Total
Carteret Borough	221	9,195	9,416
Cranbury Township	0	1,407	1,407
Dunellen Borough	0	2,467	2,467
East Brunswick Township	4,676	14,831	19,507
Edison Township	0	42,361	42,361
Helmetta Borough	995	0	995
Highland Park Borough	0	6,840	6,840
Jamesburg Borough	2,876	0	2,876
Metuchen Borough	0	6,493	6,493
Middlesex Borough	0	6,264	6,264
Milltown Borough	0	10	10
Monroe Township	18,853	14	18,867

Municipality	Customers Affected (JCP&L)	Customers Affected (PSE&G)	Total
New Brunswick City	0	17,125	17,125
North Brunswick Township	0	16,985	16,985
Old Bridge Township	24,626	0	24,626
Perth Amboy City	0	19,078	19,078
Piscataway Township	0	19,067	19,067
Plainsboro Township	0	6,599	6,599
Sayreville Borough	17,756	0	17,756
South Amboy City	4,964	0	4,964
South Brunswick Township	94	16,049	16,143
South Plainfield Borough	0	9,981	9,981
Spotswood Borough	3,829	0	3,829
Woodbridge Township	0	40,107	40,107
Grand Total	**78,890**	**234,873**	**313,763**

Power Outages Risk and Vulnerability Assessment (Including Impacts on Life and Property)

The loss of utilities (including electric service, potable water service and sewage treatment) is one of the most significant kinds of risk created by natural hazards. This is particularly true of power outages because they occur fairly often, and during major events affect large numbers of people. In its *Benefit-Cost Analysis Re-Engineering (BCAR), Development of Standard Economic Values* publication (2011), FEMA provided per-capita values for loss of electric service. The 2011 value was $106.27 per person per day of lost power. Using this information and data provided by the two power providers in Middlesex County (PSE&G and Jersey Central Power & Light) regarding the numbers of customers who lost power during Tropical Storm Irene and Hurricane Sandy, it is possible to generate rough estimates of future power loss damages (risks), although the utilities did not provide any information regarding the duration of the power outages, so this must be estimated. Because the FEMA power loss valuation is provided on the basis of days lost, the issue of duration is critical to the outcome, so the figures in the table below should be considered only a general estimate. There is also considerable disagreement about the return frequencies of Irene and Sandy, and these are also key factors in the risk estimate. Estimated return frequencies for Sandy vary from less than 100 years to more than 700, so for a risk assessment that is based in part on Sandy and Irene damages, it is necessary to assign frequencies to both events based on a review of open-source studies. For the purpose of this assessment, Irene is assigned a return frequency of 50 years, and Sandy 100 years. Increasing the frequency (for example, making Irene a 20 –year event) would increase estimated risks, and decreasing it would have the opposite effect.

Table 4-68
Middlesex County Power Outages in Tropical Storm Irene and Hurricane Sandy, by Municipality and Customers Affected.
(Source: PSE&G and Central Jersey Power and Light)

Jurisdiction	Irene Customer Outages	Sandy Customer Outages
Carteret Borough	2,677	9,416
Cranbury Township	497	1,407
Dunellen Borough	2,489	2,467
East Brunswick Township	10,157	19,507
Edison Township	19,799	42,361
Helmetta Borough	732	995
Highland Park Borough	1,936	6,840
Jamesburg Borough	1,558	2,876
Metuchen Borough	7,982	6,493
Middlesex Borough	3,848	6,264
Milltown Borough	3	10
Monroe Township	8,509	18,867
New Brunswick City	2,934	17,125
North Brunswick Township	5,643	16,985
Old Bridge Township	9,585	24,626
Perth Amboy City	3,158	19,078
Piscataway Township	6,367	19,067
Plainsboro Township	6,318	6,599
Sayreville Borough	4,301	17,756
South Amboy City	1,792	4,964
South Brunswick Township	15,043	16,143
South Plainfield Borough	7,701	9,981
Spotswood Borough	3,748	3,829
Woodbridge Township	27,491	40,107
Total	**154,268**	**313,763**

The term “customers affected” refers to the number of power connections, not individuals, so for the purpose of this exercise it is assumed that each customer hookup has a related population of 2.5 individuals. It is further assumed that the average duration of power loss was two days, given that power was likely restored to some customers within hours, and others took much longer.

Table 4-69
Middlesex County Power Outages in Tropical Storm Irene and Hurricane Sandy, by Municipality and Population Affected
(source: PSE&G and Central Jersey Power and Light)

Jurisdiction	Irene Population Outage	Sandy Population Outage
Carteret Borough	6,693	23,540
Cranbury Township	1,243	3,518
Dunellen Borough	6,223	6,168
East Brunswick Township	25,393	48,768
Edison Township	49,498	105,903
Helmetta Borough	1,830	2,488
Highland Park Borough	4,840	17,100
Jamesburg Borough	3,895	7,190
Metuchen Borough	19,955	16,233
Middlesex Borough	9,620	15,660
Milltown Borough	8	25
Monroe Township	21,273	47,168
New Brunswick City	7,335	42,813
North Brunswick Township	14,108	42,463
Old Bridge Township	23,963	61,565
Perth Amboy City	7,895	47,695
Piscataway Township	15,918	47,668
Plainsboro Township	15,795	16,498
Sayreville Borough	10,753	44,390
South Amboy City	4,480	12,410
South Brunswick Township	37,608	40,358
South Plainfield Borough	19,253	24,953
Spotswood Borough	9,370	9,573
Woodbridge Township	68,728	100,268
Total	**385,670**	**784,408**

Adjusting the FEMA BCAR value for lost power per person to a 2015 value (using the CPI inflation calculator) yields a daily value of $112.74. This value is used to calculate power loss damages in Irene and Sandy, based on the assumed two days of outage. The figures are shown below in Table 4-70.

Table 4-70
Estimated Losses from Power Outages in Tropical Storm Irene and Hurricane Sandy, by Municipality
(source: PSE&G and Central Jersey Power and Light; FEMA BCAR Development of Standard Economic Values)

Jurisdiction	Irene Power Outage Value	Sandy Power Outage Value
Carteret Borough	$1,509,025	$5,307,799
Cranbury Township	$280,159	$793,126
Dunellen Borough	$1,403,049	$1,390,648
East Brunswick Township	$5,725,501	$10,996,096
Edison Township	$11,160,696	$23,878,896
Helmetta Borough	$412,628	$560,882
Highland Park Borough	$1,091,323	$3,855,708
Jamesburg Borough	$878,245	$1,621,201
Metuchen Borough	$4,499,453	$3,660,104
Middlesex Borough	$2,169,118	$3,531,017
Milltown Borough	$1,691	$5,637
Monroe Township	$4,796,523	$10,635,328
New Brunswick City	$1,653,896	$9,653,363
North Brunswick Township	$3,180,959	$9,574,445
Old Bridge Township	$5,403,065	$13,881,676
Perth Amboy City	$1,780,165	$10,754,269
Piscataway Township	$3,589,078	$10,748,068
Plainsboro Township	$3,561,457	$3,719,856
Sayreville Borough	$2,424,474	$10,009,057
South Amboy City	$1,010,150	$2,798,207
South Brunswick Township	$8,479,739	$9,099,809
South Plainfield Borough	$4,341,054	$5,626,290
Spotswood Borough	$2,112,748	$2,158,407
Woodbridge Township	$15,496,677	$22,608,316
Total	**$86,960,872**	**$176,868,203**

It is then possible to estimate the expected future losses (risk) based on annualizing losses from one of these events. In this case the estimates are based on annualizing expected losses from events similar to Hurricane Sandy, which was assigned a return probability of 100 years in this exercise. As such, 1% of the Sandy damages are expected annually. Once this figure is developed, a present value coefficient is used to estimate total losses over a 100-year planning horizon, using the current FEMA discount rate of 7%. The results of this calculation are displayed in Table 4-71 below.

Table 4-71
Estimated Losses from Power Outages in Tropical Storm Irene and Hurricane Sandy, by Municipality, over a 100-year Planning Horizon

Jurisdiction	Annual Outage Value	100-year Outage Value
Carteret Borough	$53,078	$757,423
Cranbury Township	$7,931	$113,179
Dunellen Borough	$13,906	$198,445
East Brunswick Township	$109,961	$1,569,143
Edison Township	$238,789	$3,407,518
Helmetta Borough	$5,609	$80,038
Highland Park Borough	$38,557	$550,210
Jamesburg Borough	$16,212	$231,345
Metuchen Borough	$36,601	$522,297
Middlesex Borough	$35,310	$503,876
Milltown Borough	$56	$804
Monroe Township	$106,353	$1,517,661
New Brunswick City	$96,534	$1,377,535
North Brunswick Township	$95,744	$1,366,273
Old Bridge Township	$138,817	$1,980,915
Perth Amboy City	$107,543	$1,534,634
Piscataway Township	$107,481	$1,533,749
Plainsboro Township	$37,199	$530,823
Sayreville Borough	$100,091	$1,428,292
South Amboy City	$27,982	$399,304
South Brunswick Township	$90,998	$1,298,543
South Plainfield Borough	$56,263	$802,872
Spotswood Borough	$21,584	$308,005
Woodbridge Township	$226,083	$3,226,207
Total	**$1,768,682**	**$25,239,093**

Severe Weather

(Includes High Winds, hail and tornadoes)

Description of the Severe Weather Hazard

The Severe Weather hazard consists of hail and tornadoes which are produced as a result of severe thunderstorms. Hail is a form of precipitation comprised of spherical lumps of ice. Known as hailstones, these ice balls typically range from 5 mm–50 mm in diameter on average, with much larger hailstones forming in severe thunderstorms. The size of hailstones is a direct function of the severity and size of the storm.

A tornado is a rapidly rotating vortex or funnel of air extending ground ward from a cumulonimbus cloud. Most of the time, vortices remain suspended in the atmosphere. When the lower tip of a vortex touches earth, the tornado becomes a force of destruction. Approximately 1,000 tornadoes are spawned by severe thunderstorms each year. Thunderstorms are local storms produced by cumulonimbus clouds, and always accompanied by lightning and thunder. For additional information about tornadoes, hail and severe weather visit NOAAs National Severe Storms Laboratory (NSSL) website at http://www.nssl.noaa.gov/education/svrwx101/tornadoes/.

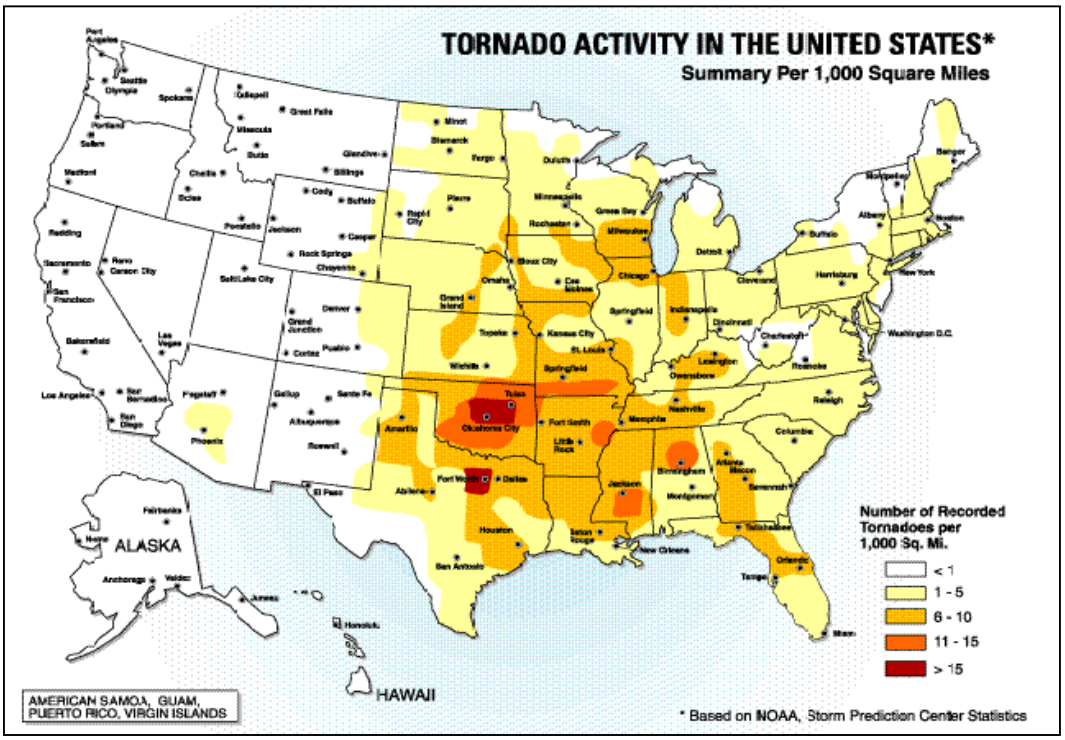
Location of the Severe Weather Hazard

Hailstorms affect areas within Middlesex County equally and uniformly, although the probability is relatively low compared to other parts of the U.S. There are at least a few occurrences of hail almost every year in the planning area, although for the most part they are minor. Hailstorms occur more frequently during the late spring and early summer, when the jet stream migrates northward across the Great Plains. This period has extreme temperature changes from the ground surface upward into the jet stream, which produces the strong updraft winds needed for hail formation. The land area affected by individual hail events is not much smaller than that of a parent thunderstorm, an average of 15 miles in diameter around the center of a storm.

The likelihood of tornadoes is uniform throughout Middlesex County. From 1991 - 2010, Texas experienced the highest average annual number of tornadoes with 155, followed by Nebraska (96), Florida (66), and Oklahoma (62).[65] During this time period New Jersey averaged two tornado events per year. Figure 4-53 shows tornado activity in the United States. The map indicates that NOAA has recorded 1 - 5 tornadoes per 1,000 square miles across the northern half of New Jersey, including Middlesex County.

[65] NOAA/NCDC US Tornado Climatology, Historical Records and Trends

Figure 4-53
Tornado Activity in the United States
(Source: FEMA http://www.fema.gov/hazards/tornadoes/**)**



Severity and Extent of the Severe Weather Hazard

The severity of hailstorms is measured by duration, size of the hail itself, and geographic extent. All of these factors are directly related to the weather phenomena that create the hail that occurs as part of thunderstorms. The NWS and the Tornado and Storm Research Organization (TORRO) have tables measuring the intensity of hail. Table 4-72 below combines the two intensity scales.

Table 4-72
Hail Intensity Scales
(Source: NWS, TORRO – Tornado and Storm Research Organization)

Size Code	Intensity Category	Typical Hail Diameter (inches)	Approximate Size	Typical Damage Impacts
HO	Hard Hail	Up to 0.33	Pea	No Damage
H1	Potentially Damaging	0.33 - 0.66	Marble or Mothball	Slight damage to plants, crops
H2	Potentially Damaging	0.60 -0.80	Dime or Grape	Significant damage to fruit, crops, vegetation
H3	Severe	0.80 – 1.20	Nickel to Quarter	Severe damage to fruit and crops, damage to glass and plastic structures, paint and wood scored
H4	Severe	1.2 – 1.6	Half Dollar to Ping Pong Ball	Widespread glass damage, vehicle bodywork damage
H5	Destructive	1.6 – 2.0	Silver Dollar to Golf Ball	Wholesale destruction of glass, damage to tiled roofs, significant risk of injuries
H6	Destructive	2.0 – 2.4	Lime or Egg	Aircraft bodywork dented, brick walls pitted
H7	Very Destructive	2.4 – 3.0	Tennis Ball	Severe roof damage, risk of serious injuries
H8	Very Destructive	3.0 – 3.5	Baseball to Orange	Severe damage to aircraft body
H9	Super Destructive	3.5 – 4.0	Grapefruit	Extensive structure damage. Risk of severe or even fatal injuries to persons caught in open
H10	Super Destructive	4+	Softball and up	Extensive structure damage. Risk of severe or event fatal injuries to persons caught in open

The planning area has a relatively low potential for significant hail events, based on previous records. Although the severity or extent of hailstorms is potentially as much as H-10 (super Destructive) in the table above, events in the middle of the range are much more likely. Extreme hail events are usually localized, but the entire planning area can be considered about at equal risk. There is fairly high potential every year for smaller events lower on the scale above, with damage to exposed automobiles, trees and plants being the main kinds of effects.

Tornado damage severity is measured by the Fujita Tornado Scale (F-Scale), named after Dr. T. Theodore Fujita who first introduced the scale in 1971. The Fujita Scale assigns numerical values based on wind speed and categorizes tornadoes from 0 to 5. The scale is based on damage caused by a tornado related to the fastest quarter-mile wind speed at the height of a damaged structure. The letter “F” precedes the numerical value. Tornadoes are related to larger vortex formations, and therefore often form in convective cells such as thunderstorms or in the right forward quadrant of a hurricane, far from the hurricane eye.

In February of 2007 the F-Scale was replaced with a more accurate Enhanced Fujita Scale (Enhanced F-scale). The modifications made to the F-scale were limited to ensure that the new Enhanced F-scale could continue to support the original tornado database found within the NDCD. The Enhanced F-scale is a set of wind estimates (not measurements) based on observed damages after a tornado. Its uses three-second gusts estimated at the point of damage based on a judgment of eight levels of damage to 28 indicators that include various commercial and residential building types, transmission towers, poles, and trees.

Similar to the original scale, the new Enhanced F-scale includes five classes ranging from EF0 to EF5.[66] The wind speeds from the Fujita Scale were used as basis for development of the Enhanced F-scale. The following Table displays the wind speed ranges for the original Fujita Scale, the derived wind speeds (Enhanced F-scale), and the new Enhanced F-scale currently in use since February of 2007. Table 4-73 compares the Fujita Scale to the new Enhanced F-Scale.

Table 4-73
Wind Speed Comparison of the Fujita Scale and Enhanced Fujita Scale
(Source: NOAA, NWS)

Fujita Scale			Derived EF Scale		Operational EF Scale	
F Number	Fastest 1/4-mile (mph)	3 Second Gust (mph)	EF Number	3 Second Gust (mph)	**EF Number**	**3 Second Gust (mph)**
0	40-72	45-78	0	65-85	**0**	**65-85**
1	73-112	79-117	1	86-109	**1**	**86-110**
2	113-157	118-161	2	110-137	**2**	**111-135**
3	158-207	162-209	3	138-167	**3**	**136-165**
4	208-260	210-261	4	168-199	**4**	**166-200**
5	261-318	262-317	5	200-234	**5**	**Over 200**

New Jersey currently ranks thirty-seventh for frequency of tornadoes when compared to other states. The severity of the tornadoes identified in the NCDC database for Middlesex County ranged from F0 to an F3.

Occurrences (and Future Probability) of the Severe Weather Hazard

The NCDC indicates there have been 123 significant thunderstorm wind events from straight-line high winds from thunderstorms (separate from tornado winds) between 1950 and June 2015. Of this total, nine events in Middlesex County have exceeded 69 mph (60 knots) since 1950. The information in the NCDC database, reflect a significant part of the costs of recovery from strong winds. However, there are also additional costs associated with interrupted business, lost wages, lost tax base, etc. that are very difficult to quantify, but are nevertheless important metrics for determining the severity of the risk. These nine events with wind speeds in excess of 60 knots are summarized in Table 4-74. The NCDC

[66] NOAA - Enhanced F-scale

began tracking specific locations in 1993. The specific locations are unknown for thunderstorm wind events prior to 1993.

Table 4-74
Thunderstorm High Wind Events With Winds Exceeding 69 mph
in Middlesex County, 1950 – June 2015
(Source: NOAA/NCDC)

Location	Date	Maximum Windspeed (knots)	Injuries	Deaths	Property Damage
unknown	7/3/1960	68	0	0	$0
Countywide	9/7/1998	60	1	0	$1,860,000
South Plainfield	5/18/2000	65	0	0	$1,000,000
Plainsboro	9/4/2001	65	0	0	$0
Countywide	9/23/2003	65	0	0	$0
Dayton	6/29/2008	61	0	0	$100,000
Port Reading	7/27/2008	56	0	0	$0
Edison Township	7/29/2009	61	0	0	$0
Perth Amboy City	9/16/2010	70	1	0	$50,000
Grand Total	**----**	**----**	**2**	**0**	**$3,010,000**

With a total of 123 past thunderstorm events in Middlesex County between 1950 and June 2015, the County experiences on average roughly two severe thunderstorms per year. Since 1950, nine of the 123 events in the County had winds that exceeded 69 mph (60 knots). Based on these historical statistics, Middlesex County experiences a severe thunderstorm with winds in excess of 69 mph approximately once every 14 years. With one event every 14 years, there is a 7% annual probability of a future severe thunderstorm event occurring in the County with winds greater than 69 mph.

The National Climatic Data Center (NCDC) reported 33 hail events in Middlesex County from the period 1950 through June 2015. A summary of the events by hailstone diameter is shown in Table 4-75. The table shows that hailstone sizes from the 33 events ranged in diameter from 0.75 inches to 1.75 inches.

Table 4-75
Hail Events Summary By Magnitude, Middlesex County, 1950 – June 2015
(Source: NOAA/NCDC)

Magnitude (Hailstone Diameter)	No. of Events
0.75	12
0.88	8
1	8
1.75	5
Grand Total	**33**

Table 4-76 summarizes nine of the 13 Middlesex County hail events between 1950 and June 2015 with hailstones of 1.0 diameter or larger. The remaining four with unknown locations were excluded from the table.

Table 4-76
Hail Events, Middlesex County, 1950 – June 2015
(Source: NOAA/NCDC)

Location	Date	Magnitude (inches)	Injuries	Deaths	Property Damage	Crop Damage
Cranbury	6/12/1996	1	0	0	$0	$0
Carteret	6/20/1998	1.75	0	0	$0	$0
Middlesex Borough	3/21/2003	1.75	0	0	$10,000	$0
Milltown	7/22/2003	1.75	0	0	$0	$0
South Plainfield	5/12/2004	1	0	0	$0	$0
Monmouth Jct.	5/24/2004	1	0	0	$0	$0
North Brunswick	5/24/2004	1	0	0	$0	$0
Woodbridge	7/27/2008	1.75	0	0	$0	$0
South Plainfield	7/29/2009	1	0	0	$0	$0
Grand Total	**----**		**0**	**0**	**$10,000**	**$0**

With a total of 33 previous hail events in Middlesex County between 1950 and June 2015, the County experiences a hail event on average about once every two years. With one event every two years, there is roughly a 50% annual probability of a future hail event occurring in Middlesex County. Based on historical records from the NCDC database, the future probability of hail events in Middlesex County is relatively high.

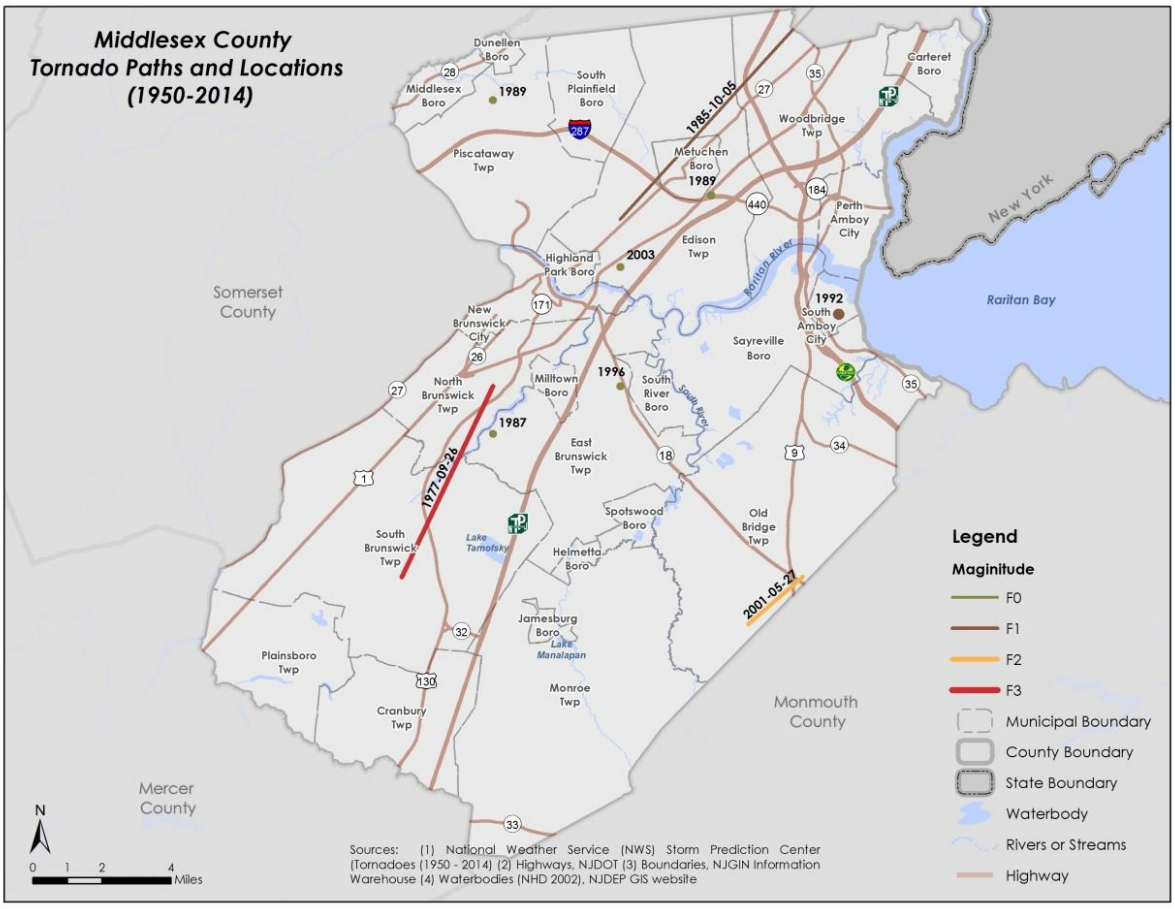
The NCDC reports that ten tornadoes have occurred in Middlesex County between 1950 and June 2015. The ten events are summarized below in Table 4-77. The table shows the most severe tornado (F3) occurred on September 26, 1977. However, an F1 tornado on October 5th, 1985 caused eight injuries, the most reported for a single tornado event in Middlesex County. The tornado touched down in southwestern Edison Township and was on the ground for approximately 12 miles with the path extending into Union County (See Figure 4-62). The NCDC data only included property damage for three of the ten tornadoes. Of the three events that had reported property damages, the tornado causing the greatest damage was an F2 tornado that occurred on May 27, 2001. This event caused an estimated $1,000,000 in damages.

Table 4-77
Tornado Events, Middlesex County, 1985 – June 2015
(Source: NOAA/NCDC, NWS - Storm Prediction Center)

Location	Date	Magnitude (Fujita Scale)	Injuries	Deaths	Property Damage
North Brunswick Township, South Brunswick Township	09/26/1977	F3	0	0	$5,000 – 50,000
Edison Township, Metuchen Borough, Woodbridge Township	10/5/1985	F1	8	0	unknown
North Brunswick Township	7/14/1987	F0	0	0	unknown
Edison Township	8/29/1989	F0	1	0	unknown
Piscataway Township	11/16/1989	F0	0	0	unknown
South Amboy City	7/31/1992	F1	0	0	unknown
Countywide	06/09/1993	F0	0	0	unknown
East Brunswick	9/8/1996	F0	0	0	$10,000
Old Bridge Township	05/27/2001	F2	0	0	$1,000,000
Highland Park	10/27/2003	F0	0	0	unknown
Grand Total	**----**	**----**	**9**	**0**	**----**

Figure 4-54 identifies tornado locations in Middlesex County between 1950 and June 2015. The tornado data is from the NWS's Storm Prediction Center, and appears to only include some of the past events. Highlighted on the map are the three tornado paths for events that occurred in 1977, 1985, and 2001.

Figure 4-54
Middlesex County Tornadoes, 1950-2014
(Source: NOAA/NCDC, NWS - Storm Prediction Center)



With a total of ten past tornado events in Middlesex County between 1977 and June 2015, the County experiences a tornado event on average roughly every four years. With one event roughly every four years, there is a 26% annual empirical probability of a future tornado events occurring in Middlesex County. Based on previous occurrences, the probability of future tornado events in Middlesex County is one event every four years. The overall impact to the planning area from tornadoes is moderate considering the frequency and magnitude of the past occurrences.

Severe Weather Risk and Vulnerability Assessment (Including Impacts on Life and Property)

High Winds

As discussed elsewhere, high straight-line winds are most often the result of hurricanes or severe thunderstorms. Modern building codes are designed to ensure the survivability of structures to wind speeds up to the equivalent of a Category I or II hurricane, although this does not mean that older buildings will meet this standard, because many were likely designed before codes were implemented, or when standards were lower. Hurricanes, tropical storms and nor'easters can achieve wind speeds that damage structures and infrastructure, in particular by downing trees and power lines. Hurricanes, tropical storms and power losses are discussed in other subsections of this hazard mitigation plan. Physical damage and personal injury risks from thunderstorm winds exist in this area of the country, but are negligible. As shown in Table 4-74 on Page 4-164, according to NCDC records, there have been nine thunderstorms with winds exceeding 60 knots, and damages of $3,010,000 since 1960, a period of 55 years. As such, annualized damages are $54,727 per year Countywide. The NCDC also reported two injuries in this period. Assuming these were minor injuries (FEMA BCAR value $13,267), the annualized value is $482. Total annualized damages Countywide are then $55,208, which yields a 100-year expected risk of $787,832.

Hail

There are no known instances of injuries or death from hail events in Middlesex County. The NCDC database indicates only one event in 2003 caused $10,000 in property damage. Presumably there are additional damages, but most of these are likely addressed by citizens or insurance companies, and therefore there is no readily accessible record of damages. Damages that do occur are presumably orders of magnitude less than other hazards such as floods or hurricane winds.

All of Middlesex County is subject to occasional hail. With rare exceptions there are no significant or long-term damages fairly often and has the potential to affect nearly anyone in the jurisdiction. The County-wide potential impact of the hail hazard is very small, however, as evidenced by historical records, which show little or no specific damage from hail. This is typical of such relatively minor hazards. In the case of hail, most losses are expected to be damage to vehicles. In such cases, automobile owners often make insurance claims, but such data sets are proprietary and not available for use in this plan. There are no significant vulnerabilities to structures from the hail hazard, and no expected recurrent losses, except occasional and relatively light damage to vehicles.

As noted elsewhere, hail damages are fairly rare, and are nearly always addressed through private insurance or private payment when they do occur. As such, there are no reliable open-source records on which to base a quantitative risk assessment. Given the lack of a detailed historic record, future expected hail risks are likely negligible.

Tornados

The NCDC database reports there have been no deaths and nine injuries from tornadoes in Middlesex

County. The tornadoes caused an estimated $10,000 in property damage. The low property damage is indication that tornadoes have had a relatively minor impact on the planning area.

People living in manufactured or mobile homes are most exposed to damage from tornadoes. Even if anchored, mobile homes do not withstand high wind speeds as well as permanent, site-built structures. Older residential structures are also more vulnerable to damages from a tornado.

The FEMA BCA software includes default historical data about the numbers of tornadoes to impact Middlesex County since 1950, and where they fell on the Fujita scale. Table 4-78 provides this information. The 33.34 events over 64 years translate to an annualized figure of 0.52 tornadoes per year. This figure does not account for differences in where the annual tornado count would fall on the Fujita scale, but the large majority of events are either Class 0 or Class 1.

Table 4-78
Tornadoes in Middlesex County 1950-2012, per FEMA BCA Software, version 5.1

Fujita Scale	Historical Number
0	7.41
1	19.13
2	5.00
3	1.24
4	0.56
5	**0.00**
Total	**33.34**

Compared to other natural hazards, tornadoes typically have a very small area of impact, although the data in the NCDC table above, there have been nine injuries from tornadoes since 1977. The same database reports $10,000 in damages in the same period. Annualizing these damages yields $3,142 injury risk (assuming all injuries are minor, and using the FEMA minor injury value of $13,267) and $263 in damage risk, a total of $3,405. Projecting this risk over a 100-year planning horizon yields $48,509 (the projection includes discounting to present value). As with straight-line wind and hail, the risks to Middlesex County from tornadoes are minimal.

4.3.14 Wildfire

Description of the Wildfire Hazard

Wildfires are uncontrolled fires often occurring in wildland areas, which can consume houses or agricultural resources if not contained. Wildfires/urban interface is defined as the area where structures and other human development blend with undeveloped wild land. Common causes include lightning, human carelessness, and arson. Wildfires are fueled by naturally occurring or non-native species of trees, brush, and grasses. Topography, fuel, and weather are the three principal factors that impact

wildfire hazards and behavior. The areas of highest risk to life and property are the Wildland Urban Interface (WUI). The United States Forest Service (USFS) defines the WUI as the area where houses meet or intermingle with undeveloped wildland vegetation. This makes the WUI a focal area for human-environment conflicts such as wildland fires, habitat fragmentation, invasive species, and biodiversity decline. For additional information about wildfires visit the State of New Jersey Forest Fire Service website.

Location of the Wildfire Hazard

The potential for wildfires exists over the entire planning area, although the probability is relatively low because of the predominately urban nature of the planning area, as well as the fire detection and suppression capabilities that exist in the county. Nevertheless, open-source data can provide some insight into relative wildfire risks within the County. There are two data sets that are useful in this regard. The first of these comprises the *Wildland Urban Interface* statistics, which respectively indicate (a) populations and housing units with some peripheral exposure to wildlands that have the potential for wildfire, and (b) the *intermix,* areas where housing units and populations are closely integrated with potential wildfire areas (wildlands).

The second data set is the *wildfire fuel hazard* statistics for the county. Figure 4-55 below identifies the wildfire fuel hazard risk for Middlesex County. Fuel hazard refers to the risks associated with the amount of biomass that will burn under a given set of conditions. Moisture content and fuel size are the primary determinants of availability. Arrangement and compactness of fuel may also determine availability.[67] The map was developed based on GIS data obtained from the New Jersey Forest Fire Service (NJFFS) a division of the New Jersey Department of Environmental Protection (NJDEP) website. The NJFFS developed the Wildfire Fuel Hazard data based upon NJDEP's 2002 Land Use/Land Cover (LU/LC) datasets and NJDEP's 2002 10-meter Digital Elevation Grid datasets (considering both land use and slope to determine rankings).

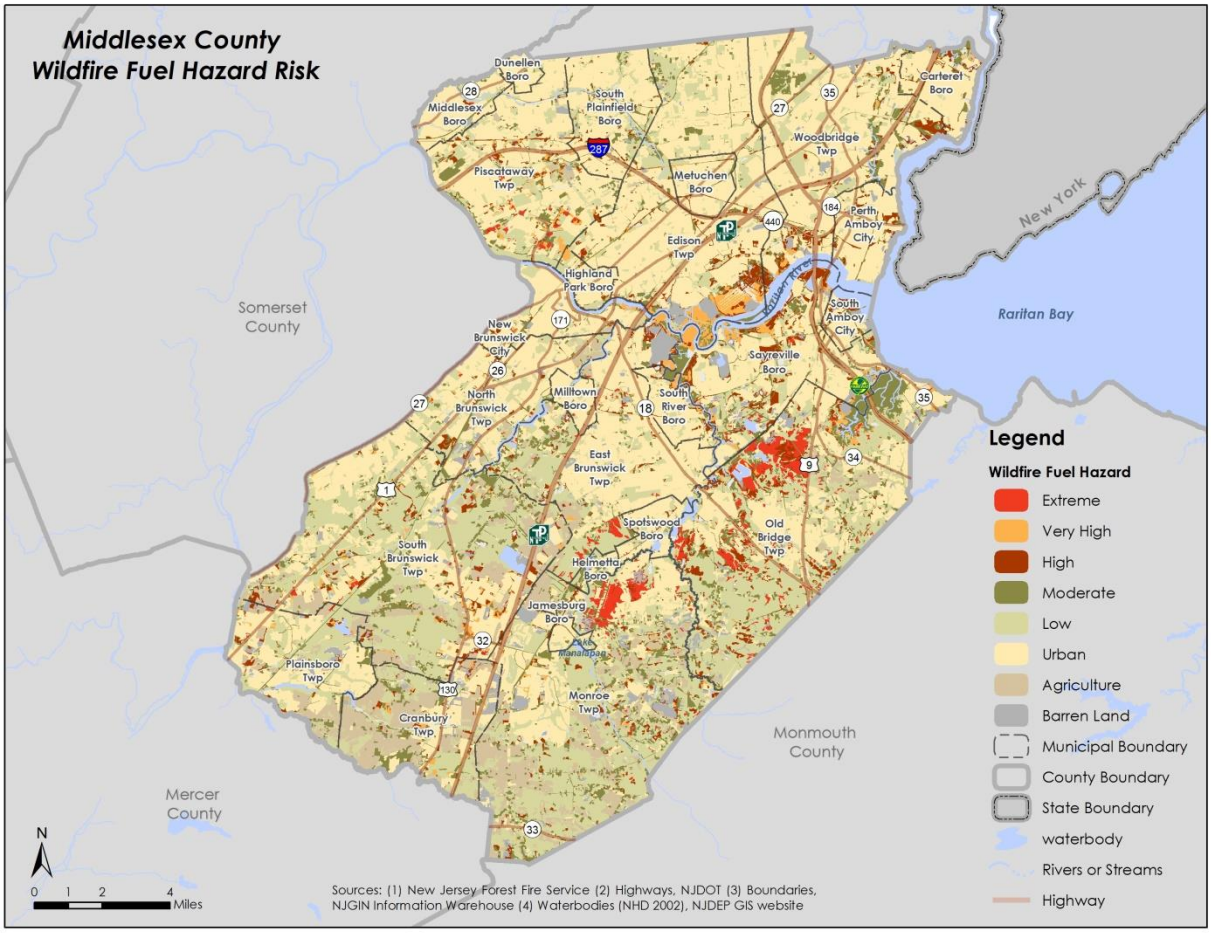
The wildfire fuel hazard data was released for the State of New Jersey in May, 2009. The Wildfire Fuel Hazard Data includes five fuel related categories and several other non-fuel related categories such as urban and agricultural lands. The five fuel hazard categories include

[67] National Park Service. Fire and Fuel Management: Definitions, ambiguous terminology and references.

- Extreme
- Very High
- High
- Moderate
- Low

The map (and following table) shows that the majority of the county is located in the urban category (shaded light yellow) with minimal fuel hazard risk from wildfires. The high risk areas of Middlesex County are colored red (extreme) and orange (very high risk). There are some small high and very high risk areas predominately in southern and eastern Edison Township, Sayreville Borough, Old Bridge Township, and Monroe Township.

Figure 4-55
Middlesex County Wildfire Fuel Hazard Risk
(Source: NJDEP (GIS), New Jersey Forest Fire Service)



Note: This map was developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state-authorized.

Table 4-79 below identifies the number of acres and square miles per wildfire fuel hazard risk category in Middlesex County. The "Low" fuel hazard risk category has the highest number of square miles, with a total of 85.09 square miles within the County. Although not included in the table below, the majority of the County is urban (as reflected on the map above) with a total of 133.01 square miles, indicating a low to moderate risk from the wildfire hazard. However there are some small high risk areas as reflected by the 4.67 square miles within the extreme category and 5.58 acres within the very high category.

Table 4-79
Middlesex County Wildfire Fuel Hazard Risk, Number of Acres and Square Miles
(Source: NJDEP (GIS), New Jersey Forest Fire Service)

Fire Description	Total Acres	Square Miles
Extreme	2,994	4.67
Very High	3,572	5.58
High	7,660	11.96
Moderate	16,458	25.71
Low	54,463	85.09
Total	**85,147**	**133.01**

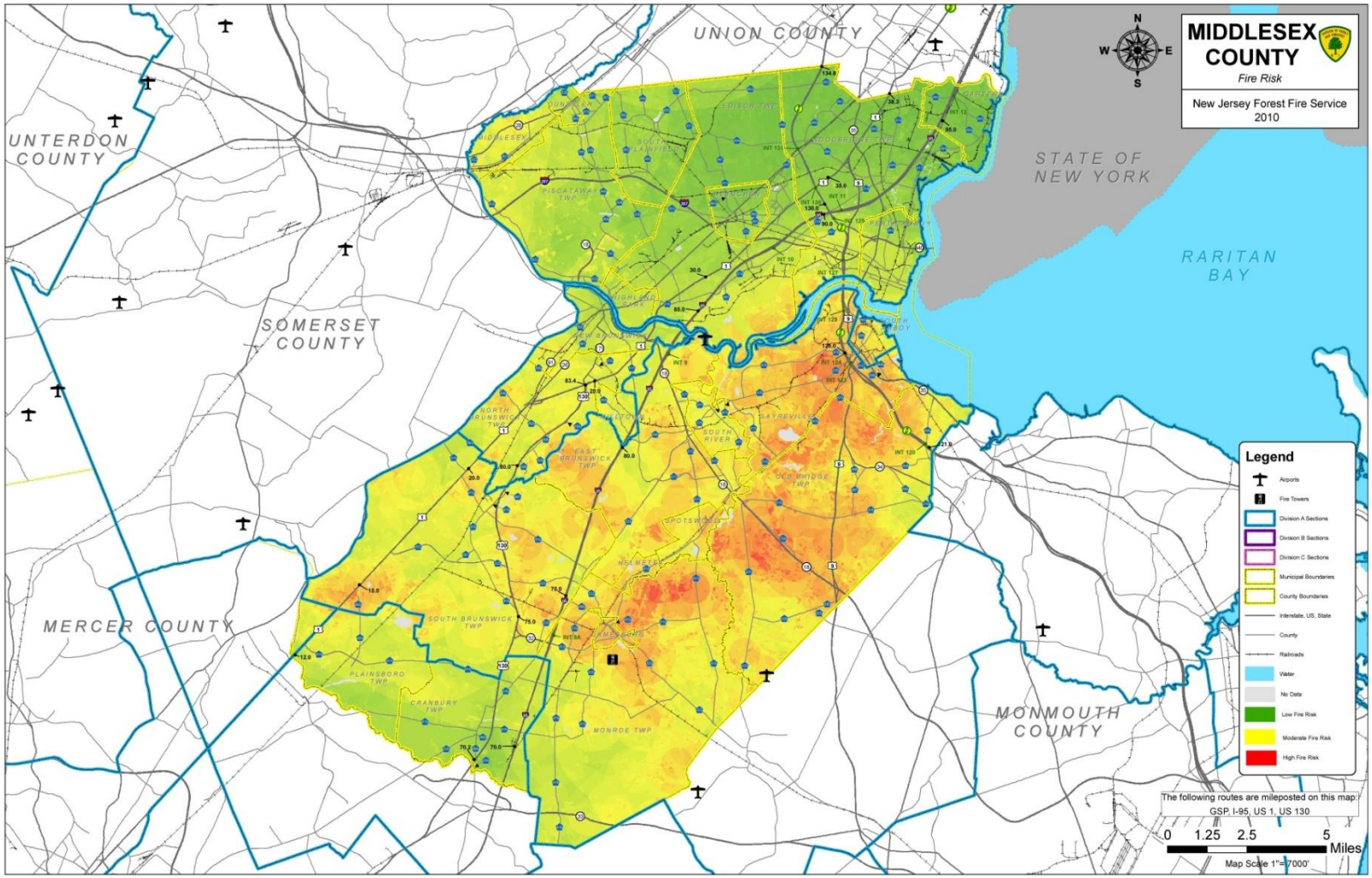
The Wildfire Fuel Hazard Data can be further broken down by municipality. Table 4-80 shows the number of square miles of fuel hazard category for each municipality in Middlesex County. The table shows that Old Bridge Township has the highest total square miles of extreme fuel hazard.

Table 4-80
Middlesex County Wildfire Fuel Hazard Risk by Municipality, Square Miles
(Source: NJDEP (GIS), New Jersey Forest Fire Service)

Municipality	Extreme Square Miles	Very High Square Miles	High Square Miles	Moderate Square Miles	Low Square Miles
Old Bridge Township	2.401	0.427	2.191	4.139	15.555
Monroe Township	1.141	0.299	1.165	4.068	17.176
East Brunswick Township	0.420	0.341	0.580	1.416	5.722
Piscataway Township	0.286	0.589	0.545	1.435	4.207
South Brunswick Township	0.151	0.669	1.244	3.338	16.522
Sayreville Borough	0.131	0.898	1.665	2.048	2.532
North Brunswick Township	0.043	0.071	0.237	0.701	2.807
Plainsboro Township	0.034	0.082	0.336	0.797	3.407
Edison Township	0.030	1.239	1.179	1.799	5.066
Middlesex Borough	0.010	0.000	0.057	0.181	0.564
Spotswood Borough	0.007	0.000	0.037	0.115	0.492
Milltown Borough	0.006	0.015	0.013	0.078	0.111
Cranbury Township	0.005	0.251	0.299	1.261	3.380
New Brunswick City	0.005	0.133	0.109	0.289	0.665
South Plainfield Borough	0.003	0.064	0.168	0.646	1.362
Helmetta Borough	0.000	0.000	0.014	0.184	0.297
Jamesburg Borough	0.000	0.000	0.015	0.040	0.168
Carteret Borough	0.000	0.080	0.298	0.408	0.190
Dunellen Borough	0.000	0.000	0.000	0.030	0.098
Highland Park Borough	0.000	0.086	0.042	0.063	0.364
Metuchen Borough	0.000	0.042	0.057	0.132	0.355
Perth Amboy City	0.000	0.002	0.304	0.190	0.291
South Amboy City	0.000	0.001	0.203	0.119	0.115
South River Borough	0.000	0.118	0.157	0.106	0.345
Woodbridge Township	0.000	0.171	1.053	2.116	3.244
Total	**4.673**	**5.581**	**11.968**	**25.699**	**85.035**

The NJFFS has also produced wildfire risk maps in 2010 for New Jersey. Figure 4-64 below identifies the wildfire risk for Middlesex County. The map shows the wildfire risk is highest near the eastern and southeastern portion of the County. The greatest risk is located in Sayreville Borough, Old Bridge Township, Jamesburg Borough, and Monroe Township.

Figure 4-56
Middlesex County Wildfire Risk
(Source: New Jersey Forest Fire Service, 2010)



Severity of the Wildfire Hazard

The frequency and severity of wildfires is dependent on weather and on human activity. In the planning area, severity has historically been very low, and duration a matter of hours to a day. The risk is increased and compounded by increasing development within the WUI. Within this zone of natural landscape, buildings become additional fuel for fires when fires do occur. Most wildland fires are man-caused and occur in the interface of developed lands and forest and range lands. In particular, the dry conditions, high temperatures, and low humidity that characterize drought periods set the stage for wildfires.

The Colorado State Forest Service has developed a fire intensity scale (FIS) that quantifies potential fire intensity based on high to extreme weather conditions, fuels, and topography. The FIS was developed to measure wildfire intensity by magnitude. The FIS consists of six classes and ranges in magnitude from one to six and similar to the Richter scale of earthquake magnitude, each unit increase in FIS is a meaningful ten-fold increase in fireline intensity. The minimum class, Class 1, represents very low wildfire intensities and the maximum class, Class 6, represents extreme wildfire intensities. [68] A detailed description of the FIS classes is provided in the following table.

[68] Colorado State Forest Service. Colorado Wildfire Risk Assessment Project. Final Report. February 21, 2013.

Table 4-81
Wildfire Intensity Scale
(Source: Colorado State Forest Service, Wildfire Risk Assessment, 2013)

Fire Intensity Class	Description of Fire Behavior and Potential Effects	General Preparedness Recommendations
1	Very small, discontinuous flames, usually less than 1 foot in length; very slow spread rate; no spotting. Fires suppressible by lay-firefighters without specialized tools. Very little potential for harm or damage. Fires of this intensity occur on the flanks and rear of large fires, and near the beginning and end of burning periods. These fires are relatively rare due to their slow spread rate and easy control.	**Basic preparedness measures will better protect your home and property.**
2	Small flames, usually less than two feet long; small amount of very short range spotting possible. Fires easily suppressed by trained hand crews with protective equipment and firefighting tools. Little potential for harm or damage. This intensity class can occur at the head of a fire in a mild fire environment or on the flanks and rear of fires in more severe fire environments. This intensity class is very common, especially on fires not being actively suppressed.	**Increasing potential to cause harm or damage to life and property.** Increased preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property.
3	Flames up to 8 feet in length; short-range spotting is possible. Hand crews will find these fires difficult to suppress without support from aircraft or engines, but dozers and plows are generally effective. Increasing potential to cause harm or damage. This intensity class occurs at the head and flanks of fires in moderate fire environments, or near the rear of fires in heavy fuel. This intensity class is common.	**Increasing potential to cause harm or damage to life and property.** Increased preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property.
4	Large flames, up to 30 feet in length; short-range spotting common; medium-range spotting possible. Direct attack by hand crews and equipment is generally ineffective, indirect attack may be effective. Moderate potential for harm or damage. This intensity class is generally observed at the head of fires in moderate fire environments or near the head and flank of fires in moderate to severe fire environments. This intensity class is relatively common.	**Significant potential for harm or damage to life and property.** Extensive preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property.

Fire Intensity Class	Description of Fire Behavior and Potential Effects	General Preparedness Recommendations
5	Very large flames up to 150 feet in length; copious short-range spotting, frequent long-range spotting; strong fire-induced winds. Indirect attack marginally effective at the head. Great potential for harm or damage. This intensity class is usually observed near the head of fires in severe fire environments. Despite the high spread rate, this intensity class is relative infrequent due to the rarity of the fire environment and spread direction.	**Significant potential for harm or damage to life and property.** Similar to the previous category, extensive preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property.
6	Extraordinary flame size, greater than 150 feet in length; copious spotting; very strong fire-induced winds. Conditions supporting this behavior are rare and short-lived. All suppression efforts are ineffective. Great potential for harm or damage. This intensity class is usually observed near the head of fires in severe fire environments. Despite the high spread rate, this intensity class is relative infrequent due to the rarity of the fire environment and spread direction.	**Great potential for harm or damage to life and property.** Extensive preparedness measures may be needed to better protect your home and property.

Occurrences of the Wildfire Hazard

The NJFFS indicates there are approximately 1,500 wildfires that destroy 7,000 acres of forest land in New Jersey each year. A variety of sources were reviewed to identify past wildfire events in New Jersey including the NJFFS, the NCDC, and other open sources of data. The NCDC database indicates there have been 17 wildfires in Middlesex County between 2000 and June 2015. The 17 events resulted in an estimated $5,000 in property damage and no injuries or deaths. There have most likely been other small similar wildfire events, but due to the size did not meet the threshold to be reported as part of the data collected by the NDCD. The events from the NCDC are listed below in Table 4-82.

Table 4-82
Middlesex County Wildfire events, 2000 – June 2015
(Source: NOAA/NCDC)

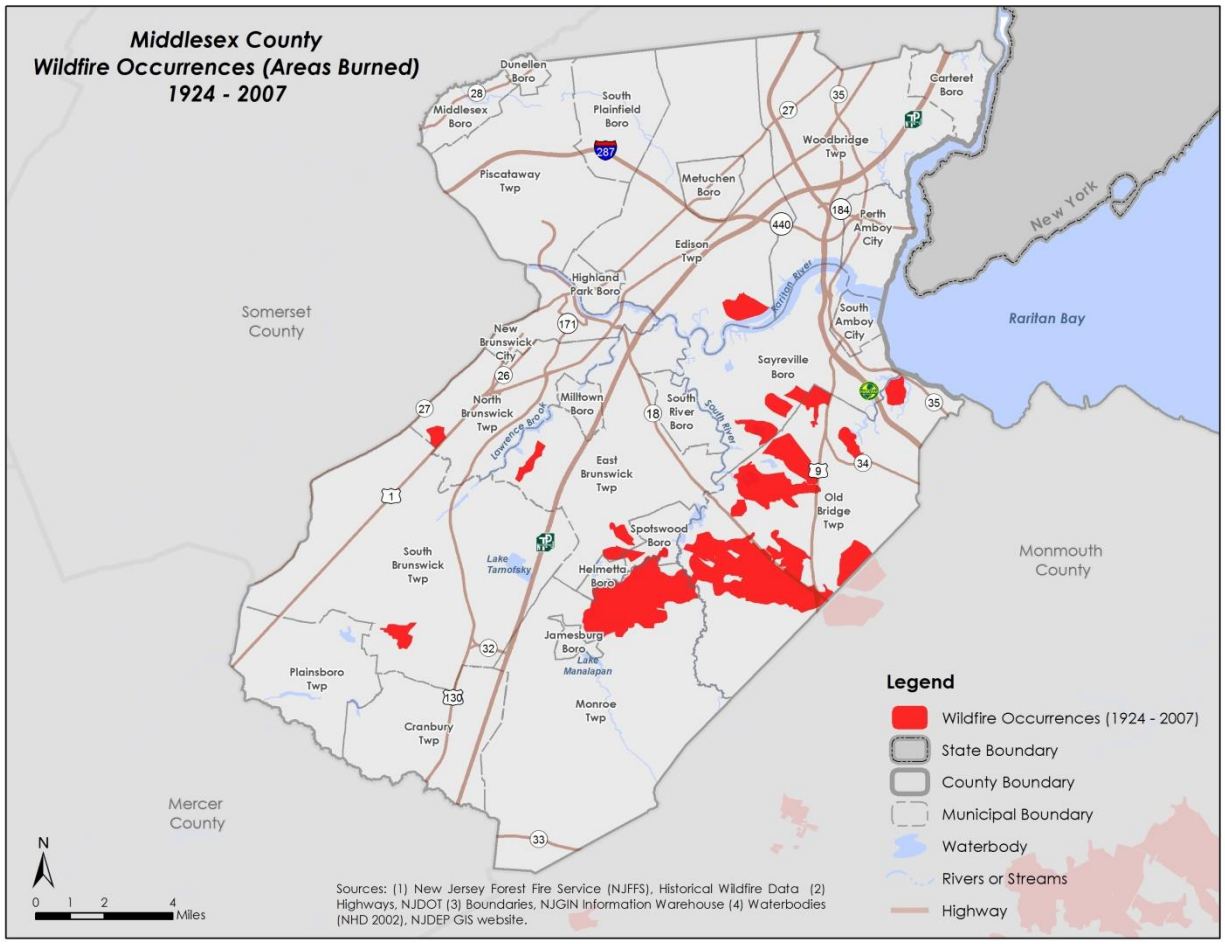
Date	Location	Description	Acres Burned	Property Damage	Source
4/29/2000	Sayreville Borough	A small salt marsh fire burned an unknown number of acres.	0	$0	Newspaper
4/30/2000	Old Bridge Township / Sayreville Borough	Two small salt marsh fires burned approximately 30 acres.	30	$0	Newspaper
4/27/2001	Old Bridge Township	A brush fire burned about 80 acres in the Joseph Court area of Old Bridge Township	80	$0	Park/Forest Service
4/28/2001	Old Bridge Township	The wildfire forced the evacuation of 25 homes in Old Bridge Township, closed some roadways and forced the closure and the evacuation of campers within Cheesequake State Park.	151	$0	Park/Forest Service
4/29/2001	Old Bridge Township	A wildfire occurred near the London Terrace Apartments adjacent to Cheesequake State Park.	9	$0	Newspaper
4/30/2001	Piscataway Township	Three separate wildfires occurred along a two mile stretch of railroad tracks.	unknown	$0	Newspaper
3/15/2005	Edison Township	A brushfire with 30 to 40-foot-high flames burned across 75 to 100 acres in Raritan Center within Edison Township.	100	$0	Newspaper
3/23/2008	Old Bridge Township	Several fires occurred in Old Bridge on March 23rd, 2008. The largest fire burned 27 acres at the former Global Landfill.	27	$0	Newspaper
3/24/2008	Woodbridge Township	A fire started in Woodbridge Township the afternoon of March 24, 2008 and burned about 80 acres.	80	$0	Newspaper
4/28/2009	Woodbridge Township	A large brush fire occurred in the area of Olympic Drive near the railroad tracks.	unknown	$0	Trained Spotter
2/19/2011	South Brunswick Township	A total of 10 wildfires were reported in New Jersey. The largest of the 10 wildfire started in a mulch pile near the Reliable Wood Products on Broadway Road in South Brunswick Township.	N/A	$0	Newspaper

Date	Location	Description	Acres Burned	Property Damage	Source
3/26/2012	Edison Township / Sayreville Borough	Several wildfires reported throughout New Jersey on this date. Largest was in the Raritan Center area (Sweetwater Lane) of Edison Township. Four separate small brush fires occurred in Sayreville.	30	$5,000	Newspaper
4/9/2012	Monroe Township	Small brush fire occurred along Disbrow Road.	unknown	$0	Newspaper
4/10/2012	Monroe Township / Sayreville Borough	A pair of small wildfires occurred in Sayreville. Another fire occurred near the Woodland Elementary School in Monroe Township.	unknown	$0	Newspaper
4/18/2013	Old Bridge Township	A brushfire occurred in Cheesequake State Park in Old Bridge Township. The fire caused the closure of the southbound lane of the Garden State Parkway near Mile Marker number 122 for about an hour and a half.	5	$0	Newspaper
11/24/2013	Old Bridge Township	A large brushfire occurred in Cheesequake State Park, burning about 230 acres.	230	$0	Newspaper
4/10/2014	Edison Township / Woodbridge Township	A major brushfire occurred on the Edison and Woodbridge municipal line near Olympic Drive near Raritan Center.	194	$0	Law Enforcement
Total	**----**	**----**	**936**	**$5,000**	

Review of additional data sources identified one of the largest wildfire events occurred in Monroe Township on April 18, 1985. The wildfire burned a total of 700 acres between Manalapan Brook and Old Forge Road, Outcalt, Inwood Estates and the Lower Road to Matchaponix.[69] The wildfire was considered one of the largest firefighting efforts in the history of Monroe Township. Figure 4-57 below shows areas burned from past wildfire occurrences in Middlesex County between 1924 and 2007 as reported by the NJFFS.

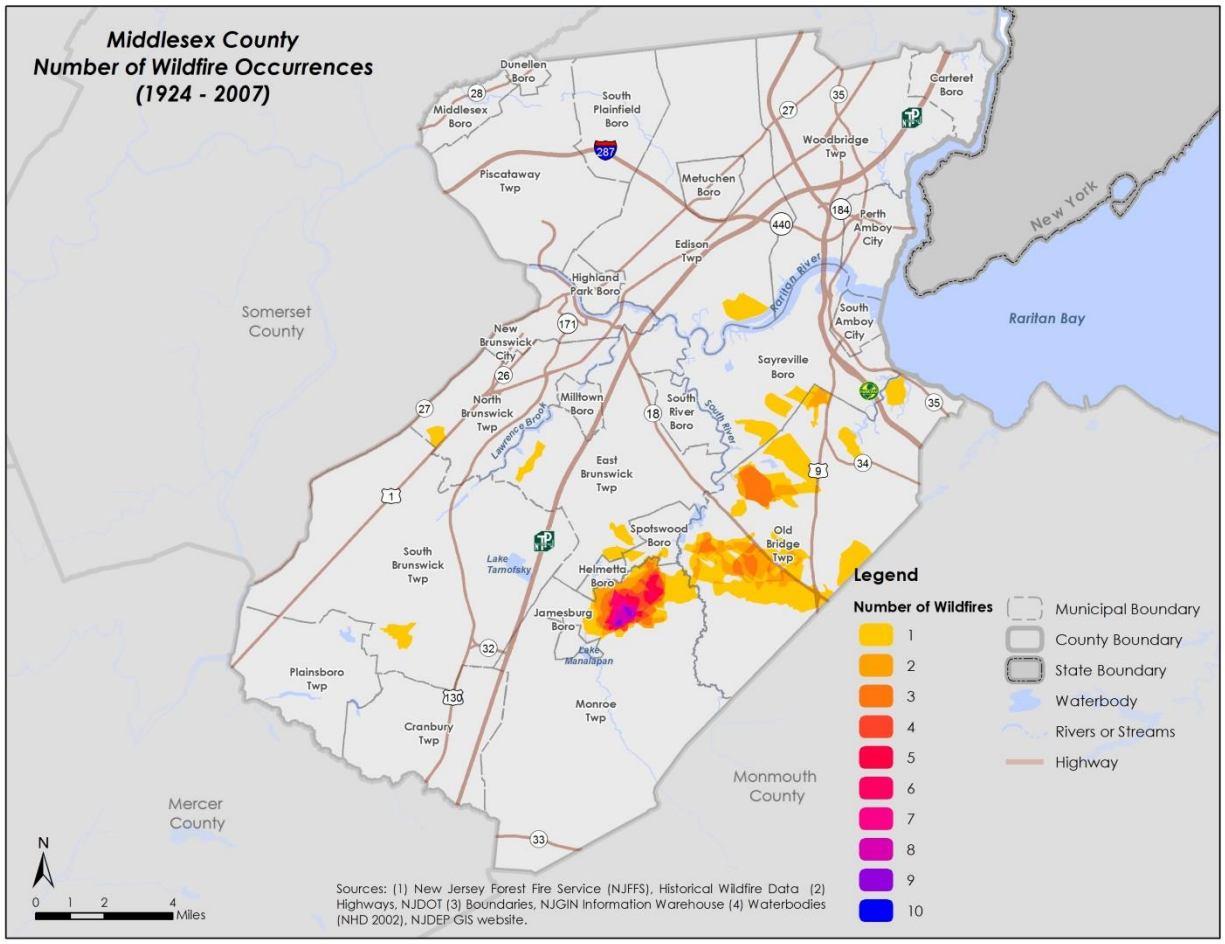
[69] Sentinel. The Day Monroe Burned. Pine Barrens fire scorched hundreds of acres one memorable day in April, 1985.

Figure 4-57
Middlesex County Wildfire History, Areas Burned Between 1924 - 2007
(Source: New Jersey Forest Fire Service)



The NJFFS historical wildfire data from 1924 – 2007 was also used to determine the number of wildfires by geographic area within the County. Figure 4-58 shows the highest number of wildfires in Middlesex County has occurred in northeastern Monroe Township. In this area of Monroe Township (east of Jamesburg Borough) there have been as many as 8-10 past wildfire events.

Figure 4-58
Middlesex County Wildfire History, Number of Wildfires 1924 - 2007
(Source: New Jersey Forest Fire Service)



With a total of 17 past wildfire events in Middlesex County between 1950 and June 2015, the County experiences a wildfire event on average roughly once every year. With one event roughly every year, there is a 100% annual probability of a future wildfire event occurring in Middlesex County. The past wildfire data indicates that the probability of future wildfires occurring in the county is fairly high, however with only $5,000 in property damages the impacts on property and life in the planning area will most likely be moderate to low. Considering there are some areas of moderate wildfire risk, the 2016 Middlesex County HMPSC ranked wildfire as a medium risk hazard (See Table 4-1 for a complete list of hazard rankings). As a medium risk hazard, the HMPSC determined that wildfire would be included as part of the more detailed risk assessment.

Wildfire Risk and Vulnerability Assessment (Including Impacts on Life and Property)

As noted, there are several areas in the County that are considered vulnerable to wildfires. Most of these more vulnerable areas are at very low risk because of the nature of the landscape, weather, and the effectiveness of detection and suppression capabilities. Potential impacts are very limited and generally not life-threatening. Some structures in the County are vulnerable to fires, but there is no practical way to determine relative risk because this depends on factors such as fuel availability, structure type and proximity to fire-prone areas.

There are no records of deaths or injuries and no recorded loss of property from wildfires in the planning area. Although there have been no reported injuries or property damage from wildfires the areas of highest risk to life and property in Middlesex County can be identified by examining the Wildland Urban Interface (WUI). The United States Forest Service (USFS) defines WUI as the area where houses meet or intermingle with undeveloped wildland vegetation. This makes the WUI a focal area for human-environment conflicts such as wildland fires, habitat fragmentation, invasive species, and biodiversity decline. The WUI is where wildfire poses the biggest risk to human lives and structures. Using GIS, the USFS integrated U.S. Census and USGS National Land Cover Data, to map the risk areas related to the WUI.

The Middlesex County risk assessment included analyzing data from the New Jersey Forest Fire Service (NJFFS) and the United States Forest Service (USFS). Figure 4-59 identifies the WUI areas for Middlesex County. As mentioned the WUI is the area where houses meet or intermingle with undeveloped wildland vegetation. The map includes areas of WUI Interface and WUI Intermix. The two areas are defined below.

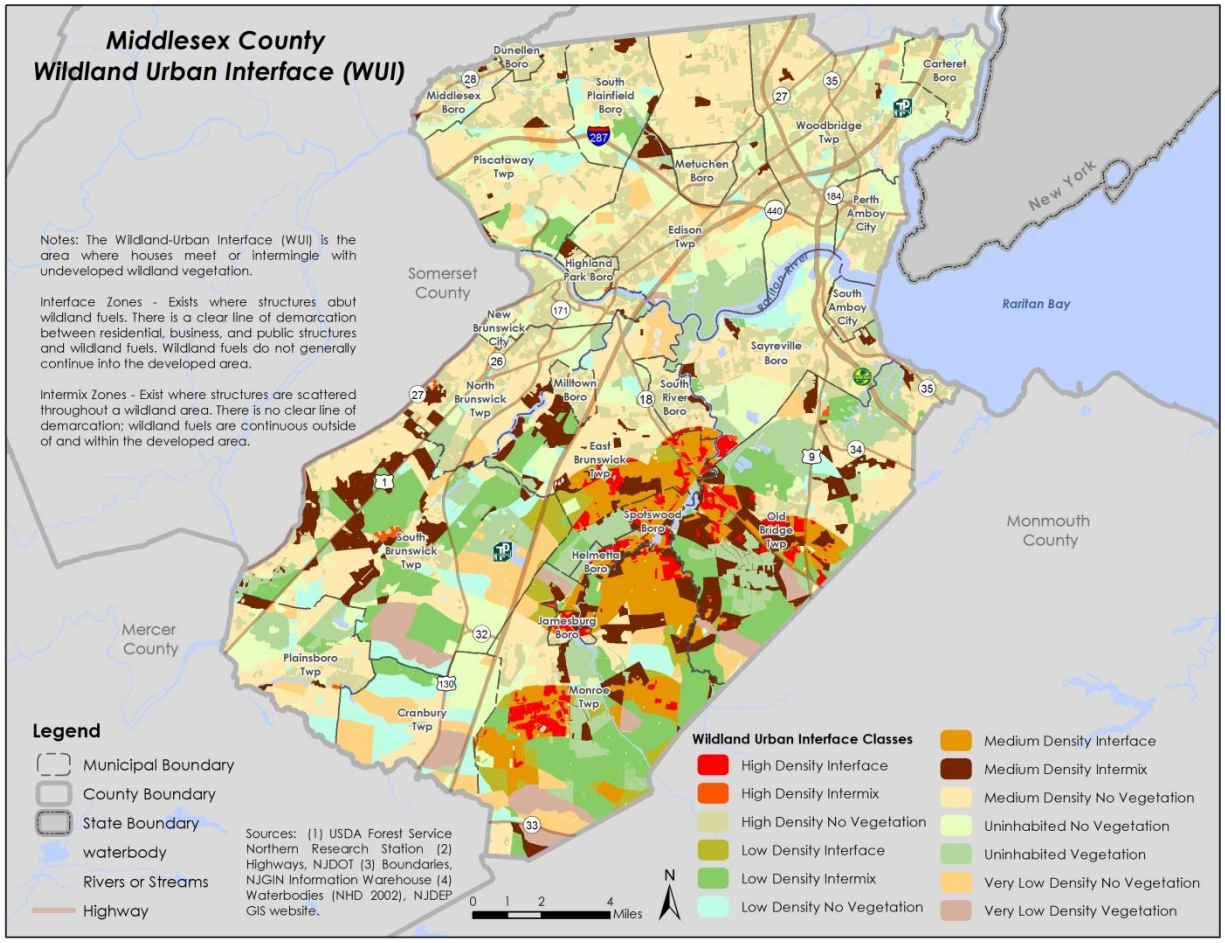
Interface Zones - Exists where structures abut wildland fuels. There is a clear line of demarcation between residential, business, and public structures and wildland fuels. Wildland fuels do not generally continue into the developed area.

Intermix Zones - Exist where structures are scattered throughout a wildland area. There is no clear line of demarcation; wildland fuels are continuous outside of and within the developed area.[70]

The data from the USFS includes 13 different WUI classes ranging from uninhabited with no vegetation (low risk) to high density interface (high risk). The map shows the highest risk areas are the high density interface/intermix (shades of red and orange) and the medium density interface/intermix (shades of brown). The map shows there are areas of high density interface/intermix in the southern half of the County, particularly parts of Sayreville Borough, Spotswood Borough, Helmetta Borough, Old Bridge Township, Jamesburg Borough, South River Borough, East Brunswick Township, and Monroe Township. For these municipalities, see individual jurisdictional appendices for additional maps and analysis related to the wildfire hazard.

[70] National Wildlife Coordinating Group. Wildand Urban Interface Wildfire Mitigation Desk Reference, August, 2014

Figure 4-59
Middlesex County Wildland Urban Interface (WUI)
(Sources: USDA Forest Service Northern Research, NJDEP (GIS))



Note: This map was developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state-authorized.

Table 4-83 summarizes this information by jurisdiction. It should be understood that this information is not an independent measure of vulnerability or risk, but in combination with other data (such as the wildfire fuel hazard discussed later) does offer some insight into the areas in County that may be at increased risk from wildfires.

Table 4-83: Middlesex County High- and Medium-Density Interface and Intermix Statistics by Jurisdiction, Ordered by High Density Interface (Population)
(Source: NJDEP (GIS), New Jersey Forest Fire Service)

Municipality	High Density Interface		High Density Intermix		Medium Density Interface		Medium Density Intermix	
	Population (2010)	Housing Units (2010)	Population	Housing Units	Population	Housing Units	Population	Housing Units
Old Bridge Township	12,623	4,755	422	195	8,960	2,748	10,516	3,679
Monroe Township	10,544	6,076	139	88	15,057	5,404	3,777	1,194
East Brunswick Township	9,833	4,108	6	2	12,706	4,259	3,347	1,141
Spotswood Borough	4,246	1,843	0	0	5,134	1,804	1,323	492
Sayreville Borough	3,941	1,634	244	98	17	6	280	113
Jamesburg Borough	3,329	1,305	0	0	740	264	605	239
Helmetta Borough	1,373	602	2	2	521	205	474	173
South River Borough	779	258	19	5	1,049	310	367	164
Cranbury Township	0	0	224	71	56	15	202	73
Dunellen Borough	0	0	0	0	0	0	323	119
Edison Township	0	0	528	212	0	0	1,320	434
Highland Park Borough	0	0	358	152	0	0	497	281
Metuchen Borough	0	0	0	0	0	0	541	182
Middlesex Borough	0	0	0	0	0	0	650	239
Milltown Borough	0	0	38	19	0	0	655	218
New Brunswick City	0	0	0	0	0	0	66	30
Piscataway Township	0	0	0	0	0	0	838	421
Plainsboro Township	0	0	224	71	0	0	986	387
South Amboy City	0	0	0	0	0	0	128	48
South Brunswick Township	0	0	1,657	667	0	0	7,403	2,998
South Plainfield Borough	0	0	0	0	0	0	633	291
Woodbridge Township	0	0	0	0	0	0	343	132
North Brunswick Township	0	0	952	511	0	0	2,016	803
Grand Total	**46,668**	**20,579**	**4,813**	**2,093**	**44,240**	**15,015**	**37,290**	**13,851**

Most significant wildfires in this part of the country take only a matter of days to suppress and are very unlikely to pose any significant risk to structures or infrastructure. In part this is because most of Middlesex County is highly populated (meaning that wildfires are quickly detected and reported), and like most developed areas on the east coast, the County and its jurisdictions have well-organized and well-equipped firefighting organizations. Also, antecedent conditions such as drought and buildup of fuel loads are not nearly as significant in this area of the country as in others (particularly the western and southwestern parts of the U.S.). As such, potential future losses from wildfires may be considered quite low in Middlesex County. To further explore this, the subsection below projects wildfire risks based on some simple assumptions about high and low values. Table 4-84 briefly summarizes these assumptions and the estimated risks, both annually and over a 100-year planning horizon. It should be understood that these figures are assumptions, developed to give a general sense of risks. There is no documented history of residential structure fires caused by wildfires in Middlesex County, so those risks are included here only as an illustration of risks under severe conditions. The various intermix and interface data and maps above provide insight into what specific areas of the county appear to be at higher risk from wildfire, although in many cases these areas are not necessarily prone to wildfires – the areas are defined by the proximity of potential fuels to the built environment, not by the probability of fires occurring.

Table 4-84
Assumptions used in Wildfire Risk Estimate, Countywide

Data	Value
Acres burned annually	62 (see above)
Events annually	1.2 (see above)
Cost of firefighting/event	$1,000 (estimated; overtime only; ordinary costs are sunk)
Cost of firefighting/year	$1,200
Potential residential fire	0.1% annually (estimated for planning)
Number of structures	3 (estimated for planning)
Replacement value/structure	$300,000 (includes contents)
Total value at risk	$900,000
Assumed annual risk	$900 (0.1% of exposed value)
Injuries/loss of life	Assumed zero
Total annual risk	$2,100
Risk in 100-year planning horizon	$29,967 (Countywide)

This assessment illustrates that even with upper-bound assumptions regarding overtime costs and structures burned, wildfire risk in Middlesex County should be considered relatively minor.

4.3.15 Winter Storm

(Includes Snow, Blizzards, and Ice Storms)

Description of the Winter Storm Hazard

Winter storms bring various forms of precipitation that occur only at cold temperatures, such as snow, sleet, or a rainstorm where ground temperatures are cold enough to allow icy conditions. Heavy snowfall and extreme cold can immobilize an entire region. Even areas that normally experience mild winters can be hit with a major snowstorm. Generally, the winter storm season in the region runs from December to March. Winter storms can result in flooding, storm surge, closed highways, blocked roads, downed power lines, and hypothermia.

These cold weather storms can also take the form of freezing rain or a wintry mix. Although snow is the weather phenomenon most commonly associated with winter, ice storms can cause significant disruption to business and create treacherous driving conditions. The freezing rain that coats all objects in a sheath of ice can cause power outages, structural damage, and damaging tree falls. Ice storms occur when rain droplets fall through freezing air and but do not freeze until they touch objects such as trees, roads, or structures. A clear icy sheath, known as a glaze, forms around branches, structures, and wires and has been known to bring down high-tension utility, radio, and television transmission towers. For additional information about severe winter weather, visit the National Weather Service (NWS) Winter Storm Safety website at http://www.nws.noaa.gov/os/winter/.

Location of the Winter Storm Hazard

The potential for winter storms is uniform for the entire planning area. Besides temperature, their occurrence depends on the regional distribution of pressure systems, as well as local weather conditions. All people and assets are considered to have the same degree of exposure. The distribution of ice storms often coincides with the general distribution of snow. A locality's distance to the passing storm center is often the crucial factor in determining the temperature and type of precipitation during a winter storm.

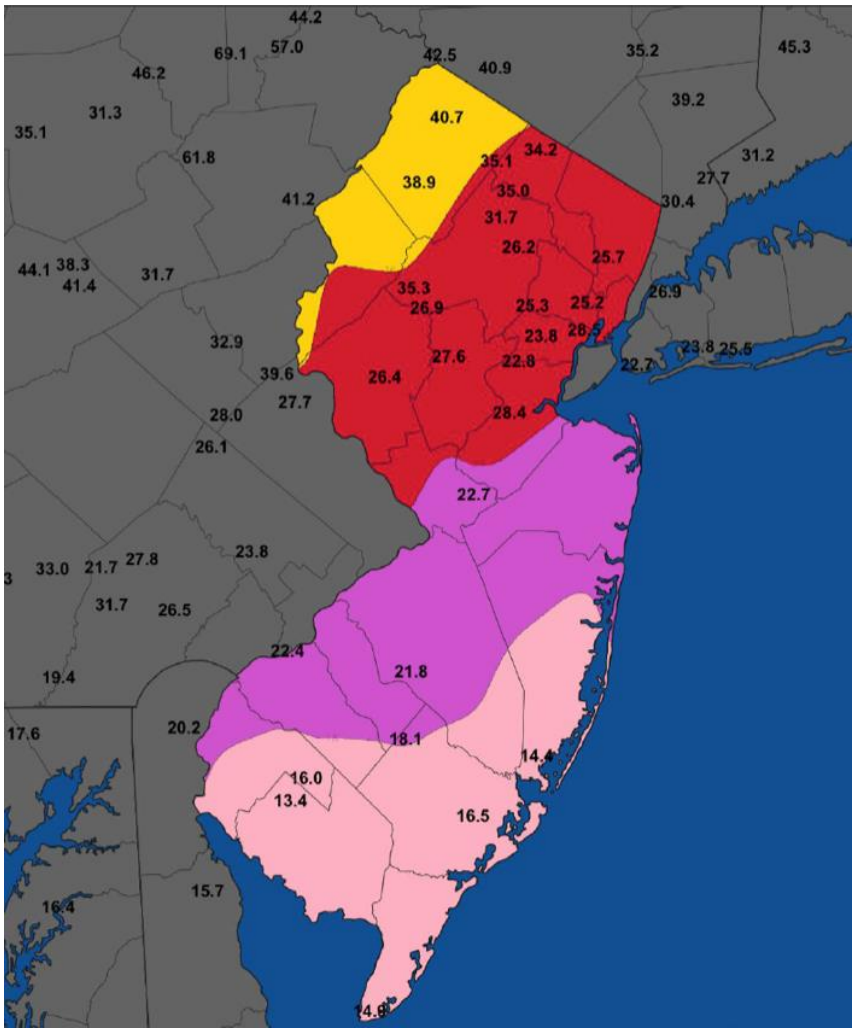
Generally, the winter storm season in Middlesex runs from December to March. Seasonal snowfall in New Jersey varies from an average of about 13" in Cumberland County to as much as 40" in parts of Sussex County. There is, however, significant variation from year to year. February is the month when maximum accumulations on the ground are usually reached. Figure 4-60 shows that the average seasonal snowfall in Middlesex County between 1981 and 2010 has average between 22 and 28 inches.

Severity of Winter Storm Hazard

The severity of winter storms can range significantly from a dusting of snow to a blizzard. From a review of the State of New Jersey 2014 Hazard Mitigation Plan Update, the magnitude or severity of a severe winter storm depends on several factors including a region's climatological susceptibility to snowstorms,

snowfall amounts, snowfall rates, wind speeds, temperatures, visibility, storm duration, topography, time of occurrence during the day (e.g., weekday versus weekend), and time of the season.[71]

Figure 4-60
Average Seasonal Snowfall in New Jersey, 1981 - 2010
(Source: Office of the New Jersey State Climatologist)



The extent of the winter storm hazard is based on a classification system developed by NOAA's National Climatic Data Center (NCDC) for winter storms impacting the eastern two-thirds of the United States. The ranking system, referred to as the Regional Snowfall Index (RSI) includes five categories that range from Notable to Extreme. The RSI is based on the spatial extent of the storm, the amount of snowfall, and the interaction of the extent and snowfall totals with population. Table X identifies the five ranking categories and RSI Values.

[71] State of New Jersey 2014 Hazard Mitigation Plan, Section 5.11 Severe Winter Weather

Table 4-85
Regional Snowfall Index (RSI)
(Source: NOAA, NCDC 2011)

Category	Description	RSI Value
1	Notable	1-3
2	Significant	3-6
3	Major	6-10
4	Crippling	10-18
5	Extreme	18+

The most severe type of winter storm is the blizzard. Low temperatures, strong winds, and heavy blowing snow characterize these storms. In the region there have been five snowstorms categorized as blizzards since 1978. The NCDC database query results include winter storm events between 1996 and June, 2014. In mid-March 1993, the eastern U.S. experienced one of the most intense winter storms on record. The event, known as the "Storm of the Century," caused blizzard conditions throughout most of New Jersey, dumping as much three feet of snow in some parts of the state.

The severity of the ice storm hazard is dependent on a variety of factors including the surface temperature, duration of the event, and thickness of the ice.

Occurrences of the Winter Weather Hazard

In Middlesex County the NCDC database includes six different categories related to winter weather. These categories and the number of events are summarized in Table 4-86 below. The table shows there have been a total of 151 events between 1996 and June 2015. Although the query results begin in 1950 the first reported event is in 1996. It is unclear why the database does not include any events prior to 1996, but the frequency prior to this date is assumed to be similar to what has been reported in the NCDC database.

Table 4-86
Middlesex County Winter Storm Events by Category, 1996 – June, 2015
(Source: NOAA, NCDC)

Event Type	No. of Events	Injuries	Deaths	Property Damage
Heavy Snow	27	8	1	$3,000,000
Ice Storm	1	0	0	$0
Sleet	5	0	0	$0
Winter Storm	26	0	1	$0
Blizzard	1	0	0	$4,400,000
Winter Weather	91	5	0	$0
Grand Total	**151**	**13**	**2**	**$7,400,000**

Some of the larger winter storm events between 1978 and 2015 are summarized below in Table 4-86.

Table 4-86
Summary of Notable Winter Storm Events impacting Middlesex County
(Source: NOAA, National Weather Service)

Date(s)	Storm Type	Description
February 7, 1978	Blizzard	This blizzard caused an estimated $24 million in damage Statewide, primarily to dunes, beaches, and public facilities along the beachfront.
March 13, 1993	Blizzard	Event known as the "Storm of the Century" affected as many as 26 States from Florida to Maine, the Gulf Coast, and the Ohio Valley. One of the most intense nor'easters to ever effect the United States. The "storm of the Century" label was given to the event due to the record low pressure, wind speeds, temperature and snowfall. All 21 counties in New Jersey were included in the Presidentially Declared Disaster. In Middlesex County snowfall totals ranged from 12-14 inches.
January 7, 1996	Blizzard	A State of Emergency was declared for the blizzard that hit the State. Road conditions were dangerous due to the high winds and drifts. Both government and contract snow plowing operations were running at a maximum. Local roads were impassable. This blizzard also brought on coastal flooding with the high tides of Sunday evening and Monday morning, and there were reports of damage to dunes and beaches from the heavy wave activity. More than 400 National Guard personnel were activated for transport assistance, primarily for medic missions. In Middlesex County snowfall totals ranged from 19-32 inches.
February 16, 2003	Snow Storm	The combination of the very cold temperatures and the approach of a strong storm system caused widespread snow to break out, starting before sunrise on Sunday, February 16th. Snow continued during the day Sunday, heavy at times, and continued into Sunday night. Precipitation continued on Monday, before finally coming to an end on Tuesday. Total snowfall in the county ranged from 12 to 24 inches. The President's Day snowstorm tied or set records in all 21 New Jersey counties, and all municipalities were involved in states of emergency. New Jersey requested and was granted a Snow Emergency Declaration.

Date(s)	Storm Type	Description
December 26, 2010 (DR-1954)	Blizzard	A rapidly intensifying low pressure system tracked from off the Southeast US coast on Christmas Day and then past the Mid Atlantic Coast on Sunday December 26th. Bands of heavy snow plus embedded thunderstorms and very strong winds affecting the region Sunday afternoon through Sunday night. The powerful blizzard brought a widespread area of 20 to 30 inches of snow across Northeast New Jersey, including Middlesex County. The heavy snow was accompanied by area wide winds of 25 to 40 mph and gusts in excess of 60 mph Sunday afternoon into Sunday night, resulting in near whiteout conditions with blowing and drifting snow and making all forms of travel extremely difficult to nearly impossible Snowfall totals in Middlesex County were highest in Edison Township with 25 inches followed by 20 inches in New Brunswick. In South Brunswick about fifty vehicles were abandoned due to blowing and drifting snow. A Major Disaster Declaration was declared on February 4, 2011, including Middlesex County. Additional details about the event can be found from the National Weather Service – New York Office http://www.erh.noaa.gov/okx/SOO/case_studies/12262010.html
October 29, 2011 (DR-4048)	Snow Storm	A historic and unprecedented early-season winter storm impacted the area on Saturday, October 29, with more than one foot of heavy wet snow falling on interior portions of northeast New Jersey. This is the first time a winter storm of this magnitude has ever occurred in October. The heaviest snow fell across interior northeast New Jersey, with up to 18 inches of snowfall across higher elevations. Thousands of people across northeast New Jersey lost power during this event as heavy snow accumulated on trees that still had partial to full foliage during mid-autumn. This caused extensive felling of trees and limbs across the region and damage to power lines. In Middlesex County a significant number of trees came down due to the heavy wet snow. A Major Disaster Declaration was declared on November, 30, 2011, including Middlesex County.
January 18, 2015	Ice Storm	Freezing rain on January 18th cause hundreds of accidents across central and northern New Jersey on the morning into the mid afternoon of the 18th. In Middlesex County, both South and East Brunswick reported dozens of traffic accidents. The NCDC reported five injuries in Middlesex County from the event.

With a total of 151 past winter storm events in Middlesex County between 1996 and June, 2015, the County experiences roughly seven winter storm events on average per year. With seven events per year, there is a 100% annual probability of a future winter storm events occurring in Middlesex County. Of the 151 events, 27 were considered heavy snow events. The County experiences a heavy snow event on average about one to two times per winter season. Based on past history, the probability of winter weather events occurring in the future is relatively high, based on previous data.

Winter Storm Risk and Vulnerability Assessment (Including Impacts on Life and Property)

All residents of Middlesex County are subject to the effects of winter weather. As noted elsewhere, these effects include direct impacts on specific structures, injuries or deaths from hypothermia (discussed in the Extremely Low Temperatures subsection, above), traffic accidents and (perhaps most significantly) power interruptions resulting from ice-laden trees falling on power lines. This hazard was

prioritized by the HMPSC as high, mostly because the hazard occurs regularly and affects nearly everyone in the County. Potential impacts are widespread, though generally not life-threatening. Structures are generally not vulnerable to the effects of winter weather, except in the rare cases where roofs collapse under extreme snow loads. Although there is some potential for this in Middlesex County, the risk is small. Because such losses are general borne by either property owners or insurance companies, it is generally not possible to obtain any information about winter weather-related damage to structures, expect publicly owned-ones.

Winter storms occur frequently enough in Middlesex County to be a threat to people and property. The NCDC reports there have been 13 injuries and two deaths due to snow and ice conditions. Approximately $7.4 million has been reported in property damages related to winter storms between 1996 and 2005. More recently FEMA Public Assistance in Middlesex County for the two events that received Presidential Disaster Declarations (DR-1954 in 2010 and DR-4048 in 2011) totaled approximately $5.9 million for costs related to overtime and snow removal.

Table 4-87
Winter Storm Events Resulting in Property Damage, Middlesex County, 1996 – June 2015
(Source: NOAA/NCDC)

Date	Event Type	Deaths	Injuries	Property Damage
1/7/1996	Blizzard	0	0	$4,400,000
2/16/2003	Heavy Snow	1	8	$1,000,000
1/22/2005	Heavy Snow	0	0	$2,000,000
Grand Total	**----**	**1**	**8**	**$7,400,000**

The NCDC database indicates there have been no deaths, injuries or property damage from previous ice storms in Middlesex County. However, ice storms clearly have caused both infrastructure and property damage such as downed electrical power lines (discussed in another subsection) and trees falling on houses. There is a wide range of risks (i.e. future costs) related to the winter storm hazard. Such risks include those discussed earlier in this subsection, as well as damaged infrastructure (particularly electrical), failed roofs, snow removal, transit and traffic disruptions and the significant economic impacts on businesses and workers. There is very little reliable information to allow exact valuation of such losses.

Aside from infrastructure and residential damage (primarily to roofs), perhaps the most significant risks created by winter storms are injuries and deaths related to traffic accidents. The Federal Highway Administration compiles and interprets data related to traffic accidents that are related to winter weather effects such as snow, sleet, icy pavement, and snow/slushy pavement (see http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm). One approach to estimating potential losses (risks) in Middlesex County is to use the national-level statistics and proportion them to the population of the County, then assign values to injuries and lost lives in accordance with procedures FEMA uses for benefit-cost analysis. This allows quantitative projections of losses over various time periods. Figure 4-60 shows the numbers of injuries and deaths nationally in 2011-2012.

Figure 4-61
FHWA Statistics on Injuries and Deaths from Winter Weather-related Traffic Accidents, 2011-2012
(source: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm)

Table: Weather-Related Crash Statistics (Annual Averages)

Road Weather Conditions	Weather-Related Crash Statistics		
	10-year Average (2002-2012)	10-year Percentages	
Wet Pavement	959,760 crashes	17% of vehicle crashes	74% of weather-related crashes
	384,032 persons injured	16% of crash injuries	80% of weather-related injuries
	4,789 persons killed	13% of crash fatalities	77% of weather-related fatalities
Rain	595,900 crashes	11% of vehicle crashes	46% of weather-related crashes
	245,446 persons injured	10% of crash injuries	52% of weather-related injuries
	2.876 persons killed	8% of crash fatalities	46% of weather-related fatalities
Snow/Sleet	211,188 crashes	4% of vehicle crashes	17% of weather-related crashes
	58,011 persons injured	3% of crash injuries	13% of weather-related injuries
	769 persons killed	2% of crash fatalities	13% of weather-related fatalities
Icy Pavement	154,580 crashes	3% of vehicle crashes	12% of weather-related crashes
	45,133 persons injured	2% of crash injuries	10% of weather-related injuries
	580 persons killed	2% of crash fatalities	10% of weather-related fatalities
Snow/Slushy Pavement	175,233 crashes	3% of vehicle crashes	14% of weather-related crashes
	43,503 persons injured	2% of crash injuries	10% of weather-related injuries
	572 persons killed	2% of crash fatalities	10% of weather-related fatalities
Fog	31,385 crashes	1% of vehicle crashes	3% of weather-related crashes
	11,812 persons injured	1% of crash injuries	3% of weather-related injuries
	511 persons killed	2% of crash fatalities	9% of weather-related fatalities
Weather-Related *	**1,311,970 crashes**	**23% of vehicle crashes**	
	480,338 persons injured	**20% of crash injuries**	
	6,253 persons killed	**17% of crash fatalities**	

FEMA values for minor and major injuries, and deaths are: minor injuries $13,267; major injuries $1,483,750 and death $6,412,265. These figures reflect values in the FEMA “BCAR” guidance, inflated from the date of publication to 2014.

Table 4-88 provides estimate annual and long-term risks from traffic-related winter weather effects. The figures in the “100-year” injuries and deaths are the risk values over a 100-year planning horizon (based on the annual expected losses), discounted using the OMB standard 7% rate.

Table 4-88
Estimated Risks from Traffic Accidents in Middlesex County related to Winter Weather

Jurisdiction	% US Pop.	Annual Injuries	100-year Injuries	Annual Deaths	100-year Deaths	100-year Total
Carteret	0.0072%	$7,931,408	$861,797	$113,181,187	$12,297,837	$125,479,024
Cranbury	0.0012%	$1,339,145	$145,506	$19,109,606	$2,076,377	$21,185,983
Dunellen	0.0023%	$2,509,205	$272,641	$35,806,358	$3,890,583	$39,696,940
East Brunswick	0.0150%	$16,496,106	$1,792,404	$235,399,430	$25,577,606	$260,977,036
Edison	0.0316%	$34,708,415	$3,771,284	$495,289,080	$53,816,226	$549,105,306
Helmetta	0.0007%	$756,199	$82,166	$10,790,957	$1,172,504	$11,963,462
Highland Park	0.0044%	$4,854,533	$527,475	$69,274,180	$7,527,069	$76,801,248
Jamesburg	0.0019%	$2,053,680	$223,145	$29,306,020	$3,184,281	$32,490,301
Metuchen	0.0043%	$4,712,875	$512,083	$67,252,733	$7,307,426	$74,560,159
Middlesex	0.0043%	$4,734,055	$514,384	$67,554,959	$7,340,265	$74,895,224
Milltown	0.0022%	$2,393,241	$260,040	$34,151,546	$3,710,777	$37,862,323
Monroe	0.0124%	$13,586,580	$1,476,266	$193,880,503	$21,066,318	$214,946,821
New Brunswick	0.0175%	$19,158,773	$2,081,719	$273,395,688	$29,706,135	$303,101,823
North Brunswick	0.0129%	$14,145,570	$1,537,004	$201,857,290	$21,933,045	$223,790,335
Old Bridge	0.0207%	$22,698,117	$2,466,291	$323,902,124	$35,193,972	$359,096,096
Perth Amboy	0.0161%	$17,642,556	$1,916,973	$251,759,274	$27,355,204	$279,114,478
Piscataway	0.0177%	$19,458,405	$2,114,276	$277,671,444	$30,170,722	$307,842,166
Plainsboro	0.0073%	$7,985,223	$867,644	$113,949,139	$12,381,280	$126,330,418
Sayreville	0.0135%	$14,826,774	$1,611,021	$211,578,070	$22,989,268	$234,567,337
South Amboy	0.0027%	$2,996,672	$325,607	$42,762,512	$4,646,412	$47,408,924
South Brunswick	0.0137%	$15,074,327	$1,637,919	$215,110,646	$23,373,104	$238,483,750
South Plainfield	0.0074%	$8,119,242	$882,206	$115,861,586	$12,589,079	$128,450,665
South River	0.0051%	$5,557,957	$603,906	$79,312,049	$8,617,745	$87,929,794
Spotswood	0.0026%	$2,866,820	$311,498	$40,909,519	$4,445,073	$45,354,592
Woodbridge	0.0315%	$34,575,785	$3,756,873	$493,396,451	$53,610,580	$547,007,032
Total	**0.26%**	**$281,181,664**	**$30,552,129**	**$4,012,462,351**	**$435,978,886**	**$4,448,441,237**