

New York State Energy Research and Development Authority

Hydrology, Vulnerability, and Adaptation Implications of Hurricane Irene and Tropical Storm Lee: Case Study of the Mid-Hudson Valley and Greater Catskills Regions

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Hydrology, Vulnerability, and Adaptation Implications of Hurricane Irene and Tropical Storm Lee: Case Study of the Mid-Hudson Valley and Greater Catskills Regions

Final Report

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Keywords

Climate change, Hurricane Irene, Tropical Storm Lee

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Executive Summary

In the summer of 2011, two major storm systems slammed into the eastern United States: Hurricane Irene and Tropical Storm Lee. Making their landfall within days of each other and over much of the same territory, the storms came on the heels of an already wetter-than-normal summer and caused widespread damage. According to the National Oceanic and Atmospheric Administration, Irene cut power to more than 7 million homes and businesses, caused at least 45 deaths, and was responsible for more than \$7.3 billion in damages.¹ Lee spawned 30 tornadoes and is credited with significant flooding, property damage, and loss of life. For some New Jersey, New York, and Vermont communities, these storms seemed to be among the largest and most devastating precipitation and flooding events on record.

But how extreme were these events? What precisely were the flooding patterns? How often can such storms be expected to reappear? And importantly, how can communities be better prepared to mitigate flood damage from future storms?

To help answer these and other questions, NYSERDA funded research teams from the City University of New York and Rutgers University of New Jersey to look closely at these extreme weather events and how they affected the Mid-Hudson Valley and Greater Catskills regions of New York, specifically Orange County and Ulster County.

ES.1 Overview of Research Findings

After gathering information from many government sources and conducting interviews with local stakeholders, researchers determined that pre-storm conditions played a role in the widespread flooding damage. For example, the summer and fall of 2011 were the wettest periods on record for the study region. As a result, the already well-saturated watersheds could not absorb the torrential rains of Irene and Lee's one-two punch, and so the region experienced the greatest 60-day streamflow on record during the months of August and September in 2011. Had the same two storms occurred after a dry, rather than extremely wet, August, and had Lee not hit immediately on the heels of Irene, the amount of flooding would have been much less.

The report also documents how Irene and Lee's devastating impacts varied by region and how the frequency of extreme hydrologic events during late summers and early falls have increased noticeably over the last two decades. This trend is consistent with climate change projections. The project also found that:

¹ National Oceanic and Atmospheric Administration, Extreme Weather 2011, <http://www.noaa.gov/extreme2011/irene.html>.

- The transportation, agricultural, and tourism sectors sustained the worst damage. Existing infrastructure was inadequate. Some of the most noteworthy flood damage occurred as the result of culverts that were not large enough to handle the volume of water from the storms, resulting in road washouts.
- Flooding and river scouring caused most of the damage, while wind or other weather-related damage was minimal.
- Much of the flooding patterns were unprecedented and unforeseen. They took place in areas where locals had not previously seen or ever experienced flooding. Some areas were above historic floodplains, for example, and many properties were flooded for the first time.
- New flood patterns could lead to new uncertainties in real estate markets. Although the storms' effects on housing and real estate values in the region are difficult to disentangle from the general economic downturn of the preceding years, anecdotal evidence suggests that real estate sales prices declined in areas that were flooded and among properties that were flooded for the first time.
- Communities' affordable housing sectors are vulnerable. Much of the limited inventory of affordable housing in the region was built on flood prone locations, and it suffered extensive damage. Some may not be rebuilt. Now significant increases in flood insurance costs may lead to more expensive and fewer units of affordable housing.

ES.2 Adaptation and Information Needs

The project also identified a range of data, information, and resource needs that, if met, could help communities better prepare for future major storms. Findings included:

- Counties need better stream data and hydrology-related information. Local officials were unable to anticipate, plan for, and monitor the floods because they lacked data from stream gauges and an understanding of the regional hydrology. In several instances, stream gauge stations, which provide data for general flood and hydrology modeling that can show watersheds' responses to extreme precipitation events, had recently closed or were about to close.
- Web-based and social media platforms (e.g., Twitter, Facebook) proved to be effective channels for utilities, county emergency services offices, and other responders to communicate local disaster response needs and efforts and disseminate information to the public quickly. Some disaster responders were able to gather significant and useful information from the public through these methods as well.
- New York State provided important information, data, training, and logistical support for short- and medium-term recovery efforts. The State helped locate material resources such as electricity generators and other equipment and provided expertise to assess flood damage and potential rebuilding needs and requirements during the recovery phase.
- By linking their modeling capabilities, New York City and the State could help local communities better understand how watersheds hold and release water and ways debris impacts flow (e.g., how does removal of debris and dredging of waterways enhance water flow through the watershed).
- Past storms can serve to galvanize local officials and communities to implement climate change adaptation strategies. In this case, Irene and Lee gave local officials an opportunity to discuss the consequences of extreme events, the possibility that they might become more frequent in the future, and possible steps to increase resilience to such events, even though many of the communities in the region are economically stressed.

1 Introduction

For this project, researchers from the City University of New York and Rutgers University investigated the hydrological, vulnerability, and adaptation implications of recent climate extremes. In August and September of 2011, Hurricane Irene (Irene; August 26 – 29, 2011) was followed less than two weeks later by Tropical Storm Lee (Lee; September 5 – 8, 2011), both of which precipitated large amounts of rain across overlapping parts of the eastern United States. Based on the damage caused by Irene and Lee, a number of communities, including some in New Jersey, New York State, and Vermont, perceived this episode to be among the historically largest precipitation events, and unprecedented flooding events, on record.

The occurrence of extreme weather and climate events such as these storms have been associated with loss of human life, waterborne disease outbreaks, water quality issues, and high costs for recovery (Easterling et al. 2000; Karl and Easterling 1999; Curriero et al. 2001; Weniger et al. 1983; Towler et al. 2010). Studies of recent events around the world, including tsunamis, flooding, storm damage, and extreme heat or cold weathers, have revealed exponentially increasing costs on the order of billions of dollars (Easterling et al. 2000; Karl and Easterling 1999; Pielke and Landsea 1998; Towler et al. 2010). Recently, the Intergovernmental Panel on Climate Change (IPCC) has emphasized the importance of new approaches to address the management of risks associated with extreme events and disasters as these may be directly affected by climate change and as a necessity to improve climate change adaptation (IPCC 2012).

A number of studies have shed light on trends in extreme events across the globe and regionally. In most studies observed changes in precipitation are occurring concurrently with changing air temperature; for example Burns et al. (2007) studied the Catskill Mountain region in New York and found a 0.6 degree Celsius increase in mean annual temperature associated with a 136-millimeter increase in yearly cumulative precipitation in the past 50-year period. Two recent studies of precipitation and drought over the New York City water supply region demonstrate that the period since the 1970s has been particularly wet when viewed in the context of station observations since the early 20th century (Seager et al. 2012), as well as in the context of longer term hydrological variations based on tree ring reconstructions (Pederson et al. 2013). These studies show that both the drought of the 1960s and the subsequent wet period (which continues until today) were caused by internal atmospheric variability (Seager et al. 2012) and that periods of more extensive drought have occurred in earlier centuries (Pederson et al. 2013).

For the broader region of New York State, no discernible trend in annual precipitation is found in the last century, but intense events are found to be more frequent in recent decades; these precipitation changes occurred simultaneously with increased temperatures (Rosenzweig et al. 2011). Across the northeastern U.S. the trends are similar (NECIA 2006). In any case, the relationship between extreme weather and climate change, as well as how it will directly affect society and sustainable development, remains uncertain. Reducing uncertainty will require (among other aspects) more data on extreme events covering longer periods of record; as well as a better understanding of the physical processes and evidence linking extreme events to climate change (IPCC 2012).

The objective of the research is to discern and assess the “lessons learned” from recent flooding associated with these extreme events for decision-makers and stakeholders in New York State with a focus on the implications and opportunities for future climate change adaptation strategies and response. The work will incorporate a case study approach focused on the Mid-Hudson Valley and Greater Catskills regions of New York, with detailed examination of communities in Orange County, NY, along the Moodna Creek and in Ulster County.

2 Project Design

2.1 Project Team and Funding

The project team, under the leadership of researchers from the City University of New York (CUNY), Institute for Sustainable Cities includes climate and hydrology scientists, a geographer, an environmental planner, and an economic geographer with hazard impact expertise and region-specific knowledge.

2.2 Research Objectives

This research was focused on three main objectives:

- **Review of hydrological data** for select locations within the study area. This product will help set the recent flooding events into historical perspective, and will lay the groundwork for future analyses that will help in defining related adaptation strategies in response to potential 21st century climate changes.
- **Definition of emergent vulnerabilities** that reveal expected and unexpected short-term impacts as well as other impacts that could have longer-term implications than are now being felt in the region (e.g. shifts in local development patterns). This product will help assess to what extent both types of impacts can accelerate or exacerbate existing inequities and economic stresses and shifts already present in the region.
- **Determination of adaptation needs** to enhance the resilience of communities and their adaptive capacity in response to climate change. This product will include identification and assessment of knowledge and information gaps and needs emerging in the stakeholder discussions of long-term response to flooding in the region.

2.3 Research Process

The research includes a variety of data sources and analyses including extreme event analysis of historical hydrological records, hazard event property loss estimates, and economic impacts. Additional data on knowledge and information needs for effective adaptation planning was developed from interviews and surveys with local decision makers and stakeholders.

2.4 Study Area

The study area includes the greater Catskills and mid-Hudson Valley regions (Figure 2-1), with a detailed investigation of the impacts, vulnerability, and adaptation within Orange County and Ulster County, NY.

Figure 2-1. Project Study Area

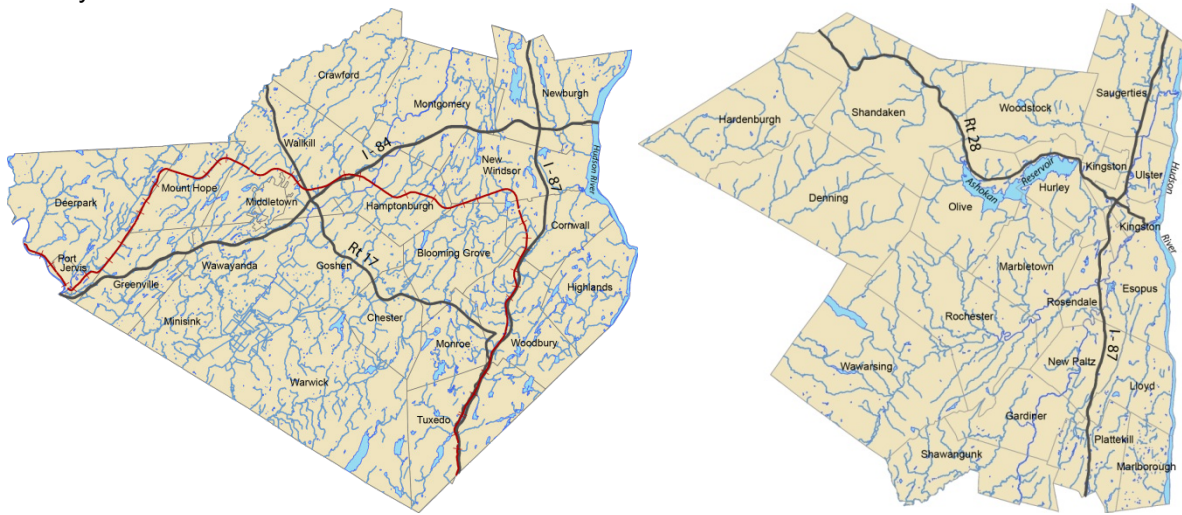
Orange and Ulster Counties, situated in the Greater Catskills and West Hudson Valley area (ClimAID Climate Region 2), are outlined in red.



Orange County (Figure 2-2) is an exurban/suburban county of 839 square miles (2,173 square kilometers) with land use dominated by suburban housing developments, exurban residences, agricultural production, and forest cover. Ulster County (Figure 2-2), to the immediate north of Orange County, is 1,161 square miles (3,007 square kilometers) in size with rugged with mountainous and hilly terrain covered by deciduous and some coniferous forest. As such, village and town settlements are located within the county’s river valleys. Orange County is almost 2.5 times more densely populated than Ulster with population counts of 372,813 and 182,493 respectively (U.S. Census 2011). The median household incomes are \$70,294 in Orange County and \$58,808 in Ulster County; median incomes in both counties are higher than the statewide median household income of \$56,951 (American Community Survey 5-Year Estimates, 2007 – 2011). Several important transportation routes pass through the two counties and the larger region such as the New York State Thruway (I-87), Interstate Highway 84, and Route 17, as well as several rail lines including Metro North’s Port Jervis commuter line.

Figure 2-2. Major waterways, county towns, and villages in Orange and Ulster Counties

(left) Orange County and (right) Ulster County. Metro North's Port Jervis line is highlighted in Orange County in red.



2.5 Data and Methods

A set of methods was used in a case study analysis framework. To conduct the work, a review and analysis of the hydrologic and impact data was undertaken. Data already available or being collected by state and federal response agencies (e.g., FEMA) was used. Interviews with local key decision makers and stakeholders were conducted. The vulnerability and climate needs analysis focused on interviews with stakeholders regarding:

- The specification of emergent vulnerabilities (i.e., identification of key economic and social costs, vulnerable populations, equity implications).
- What the vulnerabilities illustrated about adaptive capacity.
- What the stakeholders needed to facilitate adaptation decision-making (e.g., what kind of data and resources did they need; what do they need to be prepared for the next storm; and how did this affect the long term recovery strategy and transition)?

Other data sources included public meeting transcripts, press articles, and letters to the editor from local newspapers, community e-message boards, blogs, and other sources.

3 Hydrology and Precipitation Analysis

3.1 Introduction

In August and September of 2011, Hurricane Irene (Irene; August 26 – 29, 2011) was followed less than two weeks later by Tropical Storm Lee (Lee; September 5 – 8, 2011), both of which dropped large amounts of rain across various parts of the eastern U.S. Based on the damage caused by Irene and Lee that occurred in close spatial and temporal proximity to each other, a number of communities, including some in New Jersey, New York State, and Vermont, have perceived this episode to be among the historically largest precipitation events, and unprecedented flooding events, on record.

In light of Irene and Lee, and the public perceptions of these events, this report section focuses on two questions:

1. How extreme, in the context of available station records, were Hurricane Irene and Tropical Storm Lee in the Mid-Hudson Valley and Catskill Mountain regions in New York State?
2. Has there been a change in the frequency of extreme events in this region? To achieve these objectives we analyze precipitation and stream gauge records, some of which extend back over a century.

3.2 Study Area and Data

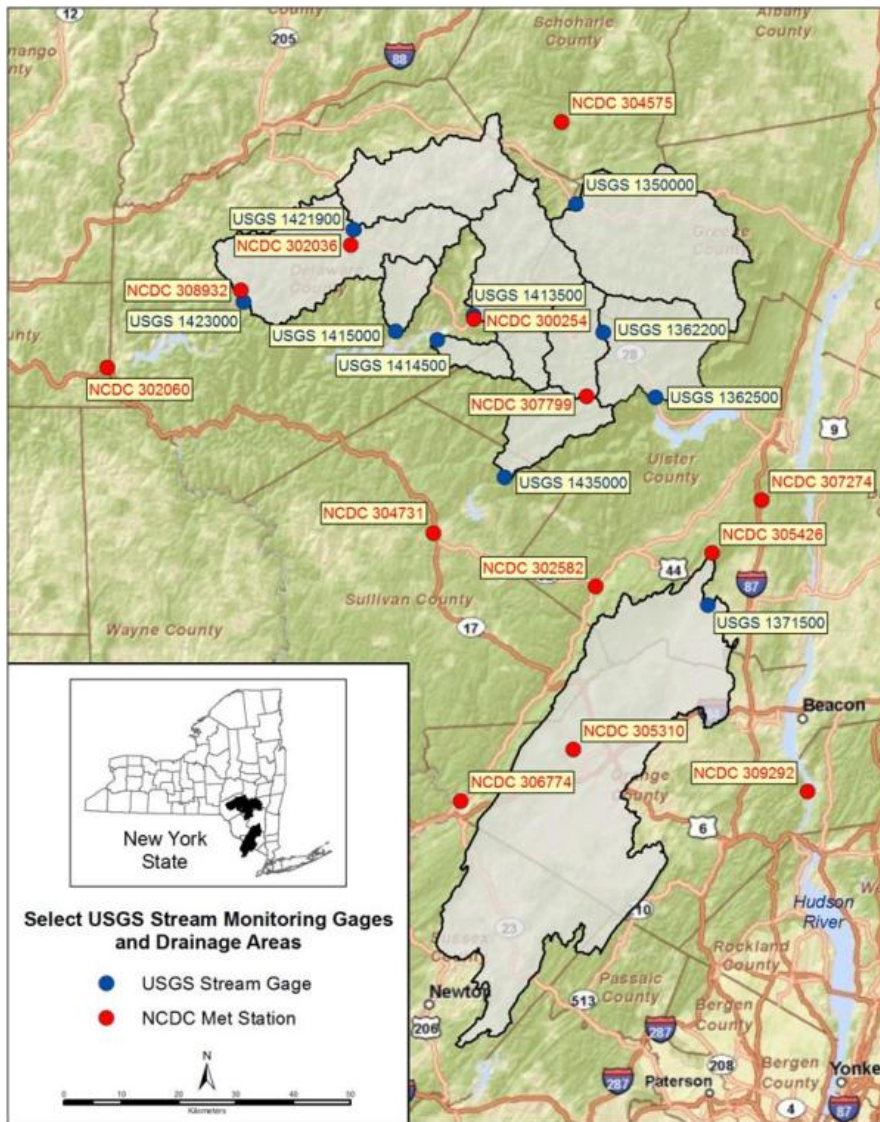
The study area encompasses the Mid-Hudson Valley and Catskill Mountain regions in southern New York State. The Catskill Mountain region is part of the Allegheny Plateau consisting mainly of sedimentary bedrock (Burns et al. 2007), and contains rugged topography through which numerous tributaries drain naturally into the Hudson and Delaware Rivers. The study area, located between 50 miles (80 km) and 155 miles (250 km) north of New York City, extends through Delaware, Greene, Orange, Ulster, Schoharie, and Sullivan counties of New York State. The climate of the region is humid continental with mean daily air temperatures ranging between 23 and 32 °F (-5 and 0 °C) during winter and 59 and 68 °F (15 and 20 °C) during summer. The temperature of the Catskill Mountain region is strongly impacted by elevation which rises to approximately 4,000 feet (1,200 meters) from the Hudson River. Regional hydrology is influenced by snow and snowmelt during winter and early spring particularly at higher elevations (Matonse et al. 2012). Average annual precipitation from the stations included in this study ranges from 40 to 62 inches (1,005 to 1,580 mm). Average daily streamflow for the selected gauges ranges from 55 to 1,100 cubic feet per second (1.6 to 31m³/s).

The analyses included two data sets:

- Historical precipitation records from rain-gauge stations across our region were obtained from both the National Climatic Data Center as well as the Northeast Regional Climate Center. A total of 12 rain-gauge stations with historical precipitation records met criteria for inclusion in this study (Table 3-1): stations must have at least 30 years of continuous data with no significant gaps, and must include data for Irene and Lee in Fall 2011. Three stations have at least 100 years of data. All trace precipitation was set to zero as these have no effect on maximum time series. Table 3-1 also includes 4-day total precipitation during Hurricane Irene (August 26 – 29, 2011) and during Tropical storm Lee (September 5 – 8, 2011). The geographic locations of precipitation gauges are shown in Figure 3-1.

- Historical daily average and annual peak streamflow records are obtained from USGS stream gauge stations. Ten USGS gauges were selected in the Greater Catskill and Mid-Hudson valley watersheds for use in flood frequency analysis (Table 3-2). The selection is based on following two criteria: (1) the gauge is presently active and has 30 or more years of annual maximum streamflow records; (2) the streamflow at the site is natural (not significantly altered by human alteration of the landscape, or diversion or impoundment of water, e.g. dams). No processing was performed to replace missing values. The geographic locations of stream gauges are shown in Figure 3-1.

Figure 3-1. Selected USGS stream gauges and NCDC rain gauges within the study region



One limitation in this analysis is the fact that no stream gauges satisfying all the above criteria are available for the Orange County, one of the focuses of this study. Table 3-1 and Table 3-2 list the name, county, size of Irene and Lee events, and other important site characteristics for each of the streamflow and rain gauges, respectively in Figure 3-1. Both Irene and Lee events have impacted different sites in the study area differently due to the site distance to the storms epicenter and other site characteristics.

Table 3-1. Selected NCDC rain-gauge stations in the study region

Includes the available period of record, the magnitudes of Irene and Lee daily maximum and 4-day total precipitation, and the difference precipitation between Irene and Lee.

NCDC ID Number	Station Name	County	Record Period Available	Irene Max Daily Rain (in)	Lee Max daily rain (in)	Irene 4-day precip (in)	Lee 4-day precip (in)	Difference 4-day Irene minus Lee
300254	Arkville	Delaware	1948-2011	0.19	2.34	n/a	6.48	n/a
302036	Delhi	Delaware	1926-2011	3.05	2.51	4.37	5.23	0.54
302060	Deposit	Delaware	1962-2011	2.07	3.14	3.73	5.63	-1.07
302582	Ellenville	Ulster	1948-2011	2.35	2.64	n/a	7.57	n/a
304575	Lansing Manor	Schoharie	1985-2011	3.5	2.18	7.27	5.45	1.32
304731	Liberty	Sullivan	1950-2011	4.1	2.18	5.43	5.66	1.92
305310	Middletown	Orange	1951-2011	n/a	3.4	n/a	7.91	n/a
305426	Mohonk Lake	Ulster	1896-2011	8.21	2.49	9.28	7.05	5.72
306774	Port Jervis	Orange	1893-2011	4.38	2.37	6.67	4.56	2.01
307274	Rosendale	Ulster	1956-2011	8.52	2.18	8.93	4.15	6.34
307799	Slide Mtn	Ulster	1948-2011	8.62	2.83	11.89	7.28	5.79
308932	Walton 2	Delaware	1956-2011	2.15	3.12	4.73	6.90	-0.97
309292	West Point	Orange	1890-2011	4.39	2.02	8.21	5.73	2.37

Table 3-2. Selected USGS stream gauges in the study region

Includes the drainage area, gauge elevation, average slope, daily median flows for the warm season, and the peak flow during Irene and Lee and the streamflow record period used in this study. N/a means data not available.

USGS ID Number	Gauge Name (County)	County	Record Period Available	Drainage Area (sq mi)	Gauge Elev (ft)	Basin Avg Slope (%)	Daily Median Flow (cfs)	Irene Peak Flow (cfs)	Lee Peak Flow (cfs)
1350000	Schoharie Creek, Prattsville	Greene	1936 - 2011	237	1131.6	21.1	78	120000	12200
1362200	Esopus Creek, Allaben	Ulster	1964 - 2011	63.7	998	32.0	35	39500	4000
1362500	Esopus Creek, Coldbrook	Ulster	1936 - 2011	192	621.5	31.5	370	75800	20500

Table 3–2 continued

USGS ID Number	Gauge Name (County)	County	Record Period Available	Drainage Area (sq. mi)	Gauge Elev (ft)	Basin Avg Slope (%)	Daily Median Flow (cfs)	Irene Peak Flow (cfs)	Lee Peak Flow (cfs)
1371500	Walkill River, Gardiner	Ulster	1936 - 2011	695	185.7	4.6	235	30300	27500
1421900	West Branch Delaware River, Above Delhi	Delaware	1937 - 2011	134	1351.3	17.4	n/a	8860	7060
1423000	West Branch Delaware River, Walton	Delaware	1937 - 2011	332	1190.3	18.4	128	16000	18500
1413500	East Branch Delaware River, Margaretville	Delaware	1937 - 2011	163	1302.4	23.5	71	33,400	10,600
1414500	Mill Brook Near Dunraven	Delaware	1958 - 2011	25.2	1298.5	25.8	14	3,810	1,940
1415000	Tremper Kill Near Andes	Delaware	1951 - 2011	33.2	1285.9	21.6	13	1,730	1,610
1435000	Neversink River Near Claryville	Sullivan	1939 - 2011	66.6	1522.4	23.3	67	21,300	5,600

3.3 Methods

Several statistical analyses were performed on precipitation and streamflow records (details on methods can be found in Matonse and Frei 2013). All analyses are performed for annual, warm season, and cold season separately. Warm season analyses include data from June 1 through October 31, and cold season analyses include data from November 1 through May 31. These seasonal definitions effectively separate events associated with snow (i.e., melt and rain-on-snow events) from those associated with heavy precipitation. For much of nonparametric analysis, our definition of "extreme event" includes all events with magnitudes greater than or equal to the 95th percentile. This definition is applied to each station individually; then, for some parts of the analysis, results from all stations are summarized.

Daily total precipitation data is used to calculate 4-day, 30-day antecedent, and 60-day events. Four-day events represent individual storms. The 4-day averaging period was chosen because Hurricane Irene and Lee both resulted in precipitation over four days at some stations. An event is defined as any series of consecutive days (including only one day) with precipitation. All events included in this analysis are nonoverlapping. The procedure to calculate the different events is described in Matonse and Frei (2013).

Antecedent conditions were also examined. Ideally, antecedent conditions for warm season events would be determined by observations of soil moisture. However, in the absence of sufficient soil moisture observations, the cumulative 30-day precipitation occurring just prior to an extreme event were used as an indicator of antecedent wetness. These values are calculated by identifying all extreme 4-day precipitation events, and calculating the total precipitation during the 30-days immediately prior to (and not overlapping with) the 4-day event. This process results in a time series of 30-day antecedent precipitation totals for extreme 4-day events. This method allows evaluation of whether hydrologic conditions immediately prior to Irene and Lee were unusual compared to conditions immediately prior to other extreme events (i.e., not in comparison to all 30-day periods on record).

3.4 Overview of Precipitation During Irene and Lee

During Irene, 4-day total precipitation varied spatially over the study area between 8 and 38 centimeters with highest rainfall volumes occurring in the northeastern and southeastern parts of the study area. During Lee (Table 3-1), 4-day total precipitation varied between 12 and 22 cm, with higher values along the eastern and southeastern portions of the region, similar to Irene. However, in contrast to Irene, precipitation during Lee was less variable across the study area. As a result, over the eastern and southeastern portions of the study more precipitation fell during Irene, while over the western portion of the study area more precipitation fell during Lee. The region of greatest difference is found over the northeastern corner of the region, which contain a series of peaks known to locals as the Blackhead Range.

3.5 Summary and Implications of Precipitation and Streamflow Analysis

Hydrological frequency analyses (see Appendix A) indicate that at some sites Irene and Lee were not unprecedented, revealing a discrepancy between public perception of these events and quantitative results. However, when the analysis is performed on a seasonal basis and a more varied set of statistics is considered, it was evident that while storm severity was spatially heterogeneous, each event individually was in fact among the most extreme on record in some portions of the study region. Moreover, there has been a marked increase in the frequency of extreme hydrologic events in this region during the last two decades. This increasing trend is evident during the late summer and early fall (the "warm season"), rather than during the snow melt season. Most precipitation records and all stream gauge records display an increasing warm season trend in the frequency of extreme events since 1985 with an accelerated rate of increase since the mid-1990s. (For more details, see Matonse and Frei [2013].) Such an increase in warm season extreme events, and an accelerated hydrologic cycle, is predicted by climate modelers to be one of the changes associated with anthropogenic climate change in this region. However, whether or not the increasing trend documented here for the last decade is in fact the beginning of a longer-term trend is beyond the scope of this analysis.

4 Impacts and Costs Assessment

Hurricane Irene and Tropical Storm Lee set forth a wide set of impacts. Some impacts were expected (e.g., electric power loss and property damage from flooding), and others were unexpected (e.g., large-scale road and highway infrastructure loss, and flooding in residences and structures that had no previous record of flooding). These resulted in short-term impacts as well as other impacts that could have longer-term implications that are now being felt in the region. Both types of impacts can accelerate or exacerbate existing inequities and economic stresses and shifts already present in the region. This section describes the impacts and costs associated with the storm events drawing upon data collected by state agencies as well as other sources, and interviews with key local and regional stakeholders.

4.1 Data Sources

Dollar value estimates of total damage from storm events are complicated by the fact that numbers are drawn from many different sources including estimates of insured losses, estimates of uninsured losses, estimates of costs to repair or replace damaged infrastructure, and to clear and repair natural areas of tree damage. For the United States as a whole, the National Climatic Data Center estimates that costs from Irene were \$9.8 billion and costs from Tropical Storm Lee were \$1.3 billion. Within New York State, the total storm recovery cleanup cost from both Irene and Lee has been projected to exceed \$1.6 billion (Governor's Press Office 2012).

The study team identified and reviewed data on impacts and costs associated with both Irene and Lee. Costs include both those resulting from the immediate storm response and the aftermath, the property and materials losses from the storm's impact, and the financial requirements of recovery and reconstruction. Information sources for these data included state agencies as well as other sources such as public meeting transcripts, press articles, and letters to the editor from local newspapers, community e-message boards, and blogs. Information was collated and organized by source and sector. Summary statistics relating to range of costs were presented.

Impact and cost assessment data were also collected from in-person interviews with decision makers and stakeholders in the case study regions (see Appendix A.3 for the list of interview participants). The information collected during the interviews included the identification of emergent vulnerabilities (e.g., identification of key economic and social costs, vulnerable populations, and equity implications).

4.2 Direct Impacts

The most significant driver of the damage and disruptions was from flooding as opposed to wind damage. The flooding damage resulted from the height of the flood waters, their intensity, and their persistence or how long the elevated flood waters were present. Riverine flooding resulting from excessive rainfall on pre-saturated soils caused the greatest impacts to Orange and Ulster Counties. The flooding of the Ramapo River in Orange County caused catastrophic washouts on the Metropolitan Transit Authority's Metro-North's Port Jervis line, and on a two-mile section of track between Harriman and Suffern (Figure 4-1; RT&S 2012; MTA Press Office 2012). The damage to this commuter rail line became the single most-costly infrastructure impact from the storm. The Metro-North West-of-Hudson rail line in Orange County cost an estimated \$55 million to replace and repair. These damages caused disruption in rail service for several months and the MTA provided shuttle buses where needed as an interim alternative. Floodwaters in the town of Shandaken in Ulster County washed out 14 bridges with entire roads (Liu 2012). The water treatment system in the Town of New Windsor in Orange County experienced major damage and drinking water was compromised due to a damaged water line in raging Moodna Creek (Office of the Governor of New York 2012).

Figure 4-1. Damage to the Port Jervis line in Orange County

Source: Metropolitan Transit Authority



Economic sectors that were impacted significantly by the storms include tourism and agriculture in both counties. Infrastructure categories that were impacted significantly included transportation (roads, bridges, rail lines, electric and gas utilities) and water and wastewater systems (pipelines and treatment plants). Several small dams were destroyed or damaged, including at least one at a drinking water reservoir. Numerous hotels in the two counties were damaged, which resulted in secondary impacts associated with the loss of hotel rooms. A local museum also suffered flood damage.

Other sectors that experienced significant direct costs include agriculture and tourism. Both Orange and Ulster counties experienced widespread crop losses as a result of flooding. Vegetable crops on the verge of harvest such as tomatoes, lettuce, pumpkins, and wine grapes, were especially hard hit. Crops exposed to river flooding cannot be sold to consumers because of food safety concerns as toxic materials and pathogens could have been released from floodwaters. Within Ulster County, vegetable crop losses were estimated to be in excess of \$5 million, and roughly half of the county's 3,400 acres of vegetable crops experienced damage to agricultural infrastructure including farm roads and drainage ditches (Horrigan 2011). The fall agricultural tourism season in the two counties, which typically begins around Labor Day weekend, was also significantly impacted as a result of flooded fields and damaged roads.

During Irene, many areas in Orange County that typically flood were flooded (with at least one exception being a neighborhood in western Orange County with lower-income homes that did not flood because of lower rainfall amounts in that area). Individuals most adversely affected economically included farmers in the Black Dirt muckland area of Orange County (composed of a large floodplain along the Wallkill River and along the Esopus Creek in Ulster County), private home and business owners in floodplains in both counties, and some property owners in upland areas (i.e., non-floodplain) where smaller headwater streams or roadside ditches flooded. Many municipal properties and properties managed by private and public organizations and entities (e.g., county and state facilities, and civic organizations) were also damaged by flooding. Businesses and other entities whose activities were disrupted by direct flooding also suffered loss in business.

The results of interviews brought out several additional dimensions regarding the storms' key impacts and costs. Specifically, storm damage was widespread in each county with flooding in many (but not all) of the high-risk locations; in many cases, respondents said that there was flooding in places where it had not previously flooded in their memory. Additionally, damage was experienced in the residential, commercial, and municipal sectors in both counties, though higher amounts of infrastructure damage were concentrated at specific locations across the counties (i.e., water and sewage facilities in Orange County). Overall, damage was greater in Ulster County where there were more disruptions of everyday life, especially from destruction to road networks.

In certain locations, physical isolation was another significant impact that resulted from the storm. It was noted that people in remote areas of Ulster County, some of which have no cellphone service, had difficulty with communication. Where power was out and landline/cellphone service was unavailable or disrupted, people had no means of obtaining outside information aside from municipal officials or neighbors. In some cases, damage to bridges or road closures physically cut off access to individual homes and neighborhoods. For people with no working phone, power, or road access, the only source of outside information available was physically delivered in person. Elderly and infirm people were especially vulnerable to the impacts of these disruptions.

It should be noted that several respondents stated that in the Catskill Mountain region in Ulster County, precipitation amounts can vary significantly within a fairly small geographic range, with localized areas receiving much higher amounts than other nearby locations. This highly variable rainfall can result in very site-specific damage and loss of transportation and information infrastructure, furthering the potential for isolation. Even if regional precipitation amounts do not vary significantly, the topography of small mountain valleys in the Ulster County area can lead to significantly worse flooding impacts in some areas and a lower flood risk for other areas.

In addition to physical, economic, and social impacts, several respondents noted their own or others' psychological impacts from the storms and the aftermath. One respondent reported the hospitalization of an immediate family member due to anxiety after their land flooded. This individual now experiences anxiety each time it rains. Similar effects were reported by one professional involved in emergency management and by other interviewees.

4.2.1 Long-Term Impacts

In addition to direct damage costs associated with the Irene and Lee storm events, long-term repercussions have impacted the region. For example, unexpected flooding not only damaged many structures but also may affect local real estate markets by depreciating the value of some properties (e.g., those newly understood to be flood prone and those whose access is now limited by road and infrastructure loss or impairment) while appreciating the values of others (i.e., those accessible and not in flood prone areas). The movement of real estate market value might further stress one location while potentially relieving stress in another.

A significant and challenging issue for local officials and others involved in decisions about responding to flooding and allocating funding for repairs is the risk of reducing local property tax revenues when properties are determined to be more than 50 percent damaged, termed "substantially damaged." Local building and code enforcement officials are typically responsible for assessing damage to homes and making these determinations, yet several respondents noted that these officials have a disincentive to determine that property damage exceeds this 50 percent threshold. If homes are condemned, the home value is reduced and property tax assessments decrease. If a home is condemned and the owner does not rebuild, it becomes a long-term loss of local revenue. In rural communities in Ulster County with a small population, the loss of even a few dozen homes has a significant impact on the property tax base. Respondents reported that as a result, there is a pattern of local officials underestimating property tax

damage. The policy implication is that these decisions allow repairs of structures that would otherwise be condemned. For example, owners might be forced to raise the building to elevate the lowest floor to be 2 feet above the base flood elevation to meet current codes. These kinds of decisions result in the investment of private funding, FEMA grants, and other resources toward rebuilding at locations where future flood damage is very likely. As a result, this issue is relevant for future policymaking and planning regarding sustainable allocation of resources for infrastructure. Such efforts will be extremely challenging because there is a strong feeling among many stakeholders at the local level, including some municipal leaders, that while new buildings should not be built in high-risk locations, existing homes and neighborhoods in these areas should not be abandoned or forced to relocate.

It is important to recognize a distinction between areas and people that were impacted by Irene and Lee in terms of economic losses, social dislocation or physical change, and whether they were able to recover from the impacts. For example, several interviews confirmed that poorer residents were less able to recover from storm impacts because of their economic disadvantage. A trailer park in Ulster County was severely damaged and will not likely be rebuilt. (Information was not available on where the former residents had moved.) Similarly, businesses that were already struggling were less able to respond after the storms. Some reportedly questioned whether to take out loans to rebuild given their already marginal economic condition. In some downtown business districts, even though some businesses were able to reopen within 4-5 days after the storms, signage about detours and closures on nearby main roads reportedly did not clearly alert tourists and created the impression that these areas were still closed, leading to a loss of business. In contrast, two respondents mentioned that the storms created economic opportunity, especially within the building and engineering sectors, including many restoration companies that operate nationally and specialize in work created by local and regional disasters.

4.3 Recovery Costs

Table 4-1 summarizes several sources of recovery aid from federal, state, and nonprofit organizations for Orange County, Ulster County, and other counties across the state. Orange County is considered to be one of the seven hardest hit counties in New York State (along with Broome, Delaware, Greene, Schoharie, Tioga, and Essex counties). Although Ulster County was not as impacted overall, it received nearly as much State recovery aid as Delaware and Essex counties combined.

Table 4-1. Impact costs and aid estimates for Ulster and Orange Counties and New York State

Costs	Area	Costs/Aid*	Notes
Total Recovery Costs	Ulster Orange State	\$30,029,038 \$55,650,079 \$599,158,632	FEMA usually covers 75% of recovery costs, and the remaining 25% is shared by state and localities. NY State will cover 12.5% of expenses.
New York State share of Total Recovery Costs	Ulster Orange State	\$3,753,655 \$6,956,260 \$74,894,829	25% of Total Recovery Costs above. Costs for Hurricane Irene only.
Community Development Block Grants Disaster Relief (CDBG DR) allocated by the U.S. Department of Housing and Urban Development	Ulster Orange State	\$0 \$11,200,000 \$93,213,963	\$71.7M of the statewide funds will be distributed through the NYS Office of Housing and Community Renewal.
Federal Emergency Management Agency Individual Assistance Aid	Ulster Orange State	\$8,774,098 \$18,569,807 \$52,500,598	Individual assistance aid is relief money sent to families, businesses or individuals whose property had been damaged or destroyed.
Metropolitan Transportation Authority Claims	Ulster Orange State	n/a n/a \$65,000,000	The MTA submitted \$27.7M in claims to FEMA with \$21M dedicated to lines West of the Hudson River. FEMA will reimburse \$1,581,244 for Port Jervis line in Orange County.
New York State Agricultural & Community Recovery Fund	Ulster Orange State	\$334,063 \$918,316 \$1,999,306	
U.S. Small Business Administration Loans	Ulster Orange State	\$4,586,000 \$9,481,400 \$128,106,000	124 loans approved in Ulster County; 259 loans approved in Orange County
U.S. Department of Transportation Aid	Ulster Orange State	n/a n/a \$89,751,296	\$67M was allotted for Irene and \$22.5M for Lee.
United Way Aid	Ulster Orange State	\$50,000 \$29,397 \$206,642	The figure for Orange County includes Dutchess county as well.
<p>* All costs and aid accounts for storms Irene and Lee unless noted. See Appendix A.5 for costs and aid source information.</p>			

Total response and recovery costs for Ulster and Orange Counties are 14.2% of the total recovery costs of the state. FEMA usually covers 75% of response and recovery costs, with the state and localities making up the remaining 25%. Federal funding sources also included \$93 million from the U.S. Department of Housing and Urban Development to be distributed through the NYS Office of Housing and Community Renewal, small business loans through the U.S. Small Business Administration, and almost \$90 million from the U.S. Department of Transportation.

In addition to federal funding, New York State employed 17 programs to provide more than \$277 million in direct aid to individuals and businesses in need. These programs included furnace repair, weatherization assistance, appliance rebates, food stamp benefits, business assistance and farm needs, flood recovery grants, and the Hurricane Emergency Loan program, among others (Office of the Governor of New York 2012). The assistance provided to Ulster and Orange Counties (Table 4-2) was only 18.4% of the total state individual and business contributions. In addition the state earmarked an additional \$297 million for transportation to restore bridges and roads statewide.

Table 4-2. New York State Assistance to Ulster and Orange Counties

Reprinted from NYS Responds, Hurricane Irene and Tropical Storm Lee One Year Later, 2012.
<http://www.governor.ny.gov/sites/governor.ny.gov/files/archive/assets/documents/Irene-Lee-One-Year-Report.pdf>

	Ulster	Orange
Individuals and Families	\$2.1m	\$1.8 million
Businesses	\$0.9m	\$0.7 million
Farms	\$0.6m	\$1.9 million
Municipalities	\$7.5m	\$14.0 million
Transportation Costs	\$8.0m	\$8.7 million
Environmental Projects	\$2.7m	\$2.0 million
TOTAL	\$21.8m	\$29.1 million

The New York State Department of Conservation (NYS DEC) shared impact and recovery costs maps collected from a variety of available sources. The maps contained information on stream gauges and dams, water boil notices, sewage treatment overflow, power outages, and roads damaged or impassable, as well as recovery costs and aid distributed at the federal and state levels. These maps are included in Appendix A.1.

4.4 Emergent Vulnerabilities

The research team identified the vulnerabilities that became apparent after recent flooding events through a review of the damages and in-person interviews. Defining emergent vulnerabilities involved analyzing collected human impact information and identifying impacts that were not represented in flood protection plans at the time. Impacts

that have potential long-term development significance and/or exacerbate or lessen existing community or management system stressors, were then drawn from the list for further discussion. An unprecedented localized flood extent is one example of an impact that was cited for further analysis.

According to many respondents, the impacts of Irene and Lee exceeded expectations (based on the weather forecasts). The amount of rain and flooding was particularly surprising to many people, while the wind was not as much of a factor as people expected. The storms exceeded respondents' understanding because people did not previously conceive of flooding as an issue of water volume, but instead an issue of water height. In some locations in the Wallkill floodplain, respondents were surprised how complex the hydrology was; water elevations rose, fell back and rose again, especially in the Black Dirt area of Orange County. In this area, the floodwater has often risen and spilled over its banks, and spread over the floodplain landscape. What was unusual with Irene is how long the water remained. With Lee following soon after, the area was flooded for weeks. Flooding of agricultural areas in Orange County led to unexpected and significant loss of crops for local farm stands.

The amount of stream scouring that took place was also unexpected and in some cases unprecedented. Some of this damage occurred in higher elevation areas that are not floodplains. The hydrology of Orange County involves a series of steps that are relatively flat. The flow between these areas is punctuated by steeper gradients that resulted in more intensive water rushing and scouring during Hurricane Irene. In Ulster County, the hydrology is more rugged with more consistent slopes and relatively narrow river valleys that also led to scouring throughout the county during Irene. While scouring is expected in such areas, the extent was unprecedented.

Although it is clear that the amount of precipitation was the major contributing factor in the flooding from Hurricane Irene, respondents considered other factors as to why the flooding was so intense and widespread. For example, beyond Hurricane Irene's rainfall, interviewees recognized that there was ample rainfall before this storm in 2011 (the extent of which is noted in Section 3 of this report).

However, in Orange County, many responses revealed the respondents' understanding--or misunderstanding--of local hydrology. For example, people thought that vegetative growth and debris along the stream banks slowed the water flow resulted in restricted flow and contributed to flooding. Many respondents also thought that local rivers and their banks had not been maintained and dredged. They believed that over time, sediment from upland erosion had accumulated in stream channels, resulting in a decreased capacity to convey water. As a result, in their view, the flood waters backed up and rose higher than would have been the case. However, dredging and removal of vegetation can actually make erosion and flooding worse (NYSDEC 2013). The best stream-management practices can sometimes seem counterintuitive.

Another factor noted was water release from upstream lakes and ponds. Several respondents felt that organizations responsible for maintaining certain water bodies released water at critical periods during the storm, thereby exacerbating flooding in downstream areas. Some people questioned why water could not be released before storms where flooding is predicted, to free up storage capacity in these impoundments and thereby reduce downstream flooding. Fundamentally, people pointed to hydrologic mismanagement as an additional, critical factor in explaining the flooding. In certain locations, another factor cited by respondents is the presence of a dam that is believed to cause a backup of water into neighborhoods, thereby increasing the height of floodwaters and resulting damage. No established records or reports are available to confirm or reject the assertions that different management of water releases would have resulted in less flooding, or that the particular dams in question had an impact on flooding in those areas.

Respondents expressed the perception that the NYS should maintain rivers. However, the responsibility for floodplain planning and management in NYS is, to a large extent, held by local government through pathways such as home rule land use authority, as well as the federal government through the National Flood Insurance Program. The respondents' perception demonstrates a lack of public understanding of the State's authority over the issue, which perhaps could be alleviated through improved communication.

Several pleasant surprises related to the impacts and community's capacity to respond, both in the immediate response (days) and longer-term (weeks, months), emerged during or after the storm. Most people interviewed said that initial responses (i.e., capacity to connect to expertise, as well as human and capital resources to reduce suffering and support recovery) following Irene were "very good" as a result of hard work by municipal officials and staff, first responders including volunteer fire departments and other emergency service workers, and by neighbors and other volunteers helping each other. Most people felt the logistical and material support in the days and weeks following the storms, including immediate repairs to infrastructure, rescuing people where needed and providing shelter or other support, and other services was as good as it could be considering the situation and proved to be instrumental in preventing the situation from worsening. Respondents said the State of New York provided crucial technical advice, expertise, and information on aid programs and assistance programs. According to one respondent, the large response by local and state officials and stakeholders in the aftermath of Irene assisted communities economically and socially. Local fund raising also took place to help some local entities and businesses. Local farmers in particular were assisted by fund raising and external financial aid, including proceeds from a local Farm Aid benefit event in Warwick (Orange County).

In some situations, the local response capacity was limited by damage to the public service buildings, particularly centers where emergency response activities could be orchestrated. For example, interview respondents talked about cases where the first responders, municipal buildings including town or village halls, or emergency services including fire departments were physically impacted by the storm. In some towns the police department building was in a flood zone, or the road leading to the building is in a flood zone. People did not previously think about this issue when picking sites for these services. In this way, the storms identified weak links in the disaster recovery capacity of the towns.

Other unexpected physical impacts associated with emergent vulnerabilities were observed as well. The unprecedented riverine scouring moved large quantities of sediment and rocks, resulting in minor to dramatic changes in stream channels in some locations. Many trees along streams were undermined and washed away, creating large amounts of woody debris, requiring removal projects in some cases (e.g., under bridges). The amount of debris washed downstream was unexpected, as was the type and extensiveness of scouring. Some farm fields lost all of their topsoil. Multiple respondents were shocked by the length of time Black Dirt was underwater. Individuals expected some flooding, but not the extended period of time it took for floodwaters to recede. Wind was not a major issue, but widespread flooding resulted in real surprises. Utilities expected wind and power outages, but a failure of a gas main (from washout of a stream bank and collapse of an above hillside) was not anticipated and became a costly repair project. Flooding caused the loss of some utility poles—some washed away entirely. Generally, damage facilitated by floodwaters greatly outweighed wind-related damage.

In general, most respondents answered affirmatively that the climate seemed to be changing and that something anomalous was happening. The respondents had observed several weather and climate shifts. Some noted that the changes were relatively subtle but still noticeable, such as one observation of peak autumn foliage occurring later in the year. Most individuals have observed that precipitation patterns have changed in recent years, with larger more frequent storm events in the moderate size range, i.e., 2-5 inches. However, some people were uncertain about whether longer-term climate change is actually occurring, in some cases claiming that observed changes in weather patterns “could be cyclical.”

The level of understanding of the science of climate change overall was not high. However, in general, there was a sense that local communities need to prepare more and better for these types of events in the future. More than half the people interviewed thought such an impactful and damaging storm can happen again in their lifetime. Only one person thought Irene was a once-in-a-lifetime occurrence. A number of people noted that the predicted return interval for floods is not a good indicator of actual frequency. For example, an individual claimed that they had experienced four 100-year floods in the past 10 years. As for potential long-term changes, people thought changes

in precipitation patterns were likely. It should be noted that the storms did not necessarily change people's perception of the likelihood of changes in climate because many had already accepted that the climate seemed to be changing. Respondents have voiced a need for better hydrologic science, more and improved stream management, and the removal of obstacles perceived to be slowing or blocking river flow. Some people have started integrating thoughts about changes in climate into their decision making process, but only to a moderate extent if at all. Respondents involved with seasonally dependent business and economic activities were most attuned to the possibility of a changing climate.

In summary, several distinct types of emergent vulnerabilities emerging from Irene and Lee can be distinguished from the observed impacts, costs, and responses of the interviewees. Key points are subsequently highlighted with some specific recommendations on how to address them:

- **A new pattern of flood exposure and new uncertainties in real estate markets.** Many properties that had never experienced flooding before were flooded as a result of Irene and/or Lee. Although the effect of these storm events on housing and real estate values in the region is difficult to disentangle from the general economic downturn that has affected values in the region over the past several years, anecdotal evidence suggests that a decline in sales prices occurred in areas that were flooded, including properties that were flooded for the first time.
 - *Recommendation:* There is a need for investigation of impacts of flood exposure on property values and real estate markets in the region.
- **Effects on availability of affordable housing.** Loss of affordable housing in the region as the result of the flooding was a concern. Affordable housing in the region is already limited, and some of this housing (e.g., a trailer park in Ulster County) was washed out by flooding and not expected to be rebuilt. Given the possibility of significant increases in flood insurance costs, the potential for higher cost and reduced availability of affordable housing is another type of emergent vulnerability.
 - *Recommendation:* There is a need for review of affordable housing in the region in light of flood zone maps and flooding impacts.
- **Newly revealed infrastructural weaknesses.** Some of the most noteworthy flood damage occurred as the result of flooding of roadside ditches, where the volume of water present vastly exceeded capacity, leading to road washouts.
 - *Recommendation:* There is a need for review of both the design and maintenance of these ditches and culverts, including their effects on hydrology of watersheds and sediment loads.

5 Adaptation Response and Needs Assessment

Adaptation response and needs assessment were derived from review of primary and secondary data and face-to-face interviews with local and regional stakeholders and decision makers. In-person interviews with decision makers and stakeholders in the case study regions were conducted (see Appendix A.3 for the list of interview participants).

The information collected generally included:

- The identification of emergent vulnerabilities (e.g., identification of key economic and social costs, vulnerable populations, equity implications).
- What these vulnerabilities illustrate about the adaptive capacity of the regions.
- What the stakeholders need in order to facilitate adaptation decision-making (e.g., what kind of data and resources do they need; what do they need to be prepared for the next storm; and how does this affect their long-term recovery strategy and transition?).

The interview questions asked relate to Hurricane Irene and Tropical Storm Lee and their aftermath. The questions focus on professional activities and perspectives on the impact of these two extreme climate events. Table A-3 in Appendix A includes a list of interview questions that were asked of local and state level stakeholders and decision makers.

5.1 Immediate Response

5.1.1 Key Activities

Starting in the days after Hurricane Irene and Tropical Storm Lee and during the course of this research, the study team identified and reviewed data on adaptation and needs assessment associated with the storms' aftermath. Information sources for these data included reports from state and local agencies as well as others such as attending meetings and workshops, public meeting transcripts, press articles and letters to the editor in local newspapers, community e-message boards, and blogs.

In interviews, respondents were asked what key activities (e.g., activities that the respondents deemed to be most significant with respect to time and resources expended and/or illustrative of the majority of the actions that were taken during the immediate response period) were done or are still being done in response to the flooding, and what was driving these activities (e.g., were they required to by law or regulation, new policy, etc.)? In general, the respondents focused on the short-term response that took place especially regarding the emergency response and how to make it better and more effective, particularly with respect to providing additional rapid impact assessment data and enhanced coordination of emergency response resources and services. Respondents did not feel that they have control over long-term responses, regardless of whether they were farmers or local politicians, and as a result did not focus much on those issues.

The interviewees who had responsibilities related to the storm at their jobs had to spend a lot of time documenting what happened, and what the losses were. The immediate response and short term aftermath period where all work was focused on the storm impacts took place over a period of several months. In many cases, all other work had to be put aside during this time, at least in the days and weeks after the storm. Everyone whose job was relevant to response and recovery and assessment was involved in a major way, to the point where the time demands became a problem for many. Some first responders are volunteers, such as fire and ambulance crews. Some first responders, including volunteers and elected and paid staff, had damage to their own homes and had to manage personal and family issues even while responding in their professional or volunteer capacity.

From a planning, regulatory, policy, and educational perspective, these storms have triggered increased attention and discussion about whether and how it is appropriate to actively manage streams using dredging or other steps to alter streamflow. New education and training programs addressing these issues are being implemented for various audiences (NYS DEC 2013). There is significant debate and controversy about these issues, with advocates of environmental protection often lining up against most, if any active stream management steps, and a number of stakeholder groups holding the opposite view. It is well-established that altering streams without a good understanding of stream hydrology can result in more damage and other unintended consequences, including erosion downstream, upstream or at the site of the alteration. This has happened in the past and reportedly some stream projects undertaken after Irene and Lee had to be re-done at additional expense because they were poorly conceived. At the same time, it is clear that some maintenance of stream channels is appropriate. (For example, NYS DEC regulations permit removal of dead trees from streams without a permit, if the work is done without placing machines in the stream and without disturbing the bank of the stream or causing erosion or turbidity problems.) As the basis for an educational and policy approach that responds to all of these issues, among some knowledgeable professionals familiar with relevant technical and policy issues, there may be consensus that a new focus on defining response approaches acceptable to multiple groups is needed.

5.1.2 Most Useful Tools and Resources

Respondents were asked what kind of tools and resources (data and information, human resources, financial resources etc.) were most useful in the immediate aftermath (i.e., days and several weeks), and in the longer term following the flooding. Many respondents talked positively about rapid deployment of human resources and the capacity of responders to effectively mobilize and work together to address to the storm's direct impacts (e.g., disruption of communication, transportation and other infrastructure, evacuation of residents and other stranded individuals, and maintenance of emergency medical services). The respondents felt that local, county, and state personnel worked well together. During the storm and in the day or two following, most local communities had to rely on local personnel before staff and assistance from nonlocal agencies (mostly from the State of New York) could provide assistance and aid.

Quite a few people involved in the first response during and immediately after the storms stated that they had access to a lot of important data and information during the early response period and that helped their capacity to act effectively. Relevant data and information included the locations and types of damage, where people were in need of assistance or evacuation, availability of needed resources, and other data. Face-to-face communication and sector-specific organizing proved to be very powerful. Some interviewees mentioned that they used their cellphones and social media (e.g., Facebook and Twitter) to communicate with others, and in some cases to receive information coming from the public. Emergency service respondents including utility personnel also used social media to gain information regarding problem areas (e.g., areas with power outages) and deploy response crews as needed.

Financial resources of course were useful and always desired—sometimes these resources were delivered, but not always. During the immediacy of the emergency response, financial resources limitations were not considered as action needed to take place and many gave of themselves and their time.

Immediate repairs to public infrastructure were undertaken by municipal, county, and state staff, and in some cases by contractors hired by government entities. The ability to move quickly to contract was important. Some contractors lent equipment to government entities. Adequate construction materials were apparently available, but one respondent noted that if the real estate and construction markets were not as slow as they have been, there could have been more shortages. In the winter months after the storm events, because temperatures were mild, some repair projects were able to continue that would have had to shut down if the weather was colder, and an asphalt plant was able to open earlier than usual in early 2012, thus enabling faster project completion.

5.2 Longer-Term Response

Since Irene and Lee, a number of agencies and organizations have implemented or started developing education, training, research, and other steps to respond to identified needs and support better planning and decision-making. One major set of issues and topics being addressed in new programs is perceptions and beliefs among many stakeholders that streams can be managed simply to provide better drainage by dredging, deepening, widening, straightening, or armoring stream channels and banks. One important source of technical capacity for addressing these issues in the region is agencies involved in stream management and restoration projects in the New York City watershed. The New York City Department of Environmental Protection (NYC DEP) has funded projects there for a number of years as part of the overall watershed management program, working through and with the Catskill Watershed Corporation, soil and water districts and other partners in the city's Catskill and Delaware watersheds. Stakeholders within the New York City watershed region have access to certain significant financial and technical resources that are not available outside these watersheds.

These programs have a strong emphasis on working cooperatively with landowners and on using sophisticated stream analysis tools (such as the Rosgen stream classification system) to design appropriate interventions that minimize undesirable impacts of stream management activities, such as downstream erosion or other damage that often results when dredging, armoring or other work is done without the needed understanding of stream hydrology. Since Irene and Lee, new programs have been implemented, and this base of regional experience and expertise is one key resource for developing and implementing them.

The NYS DEC's Hudson River Estuary Program and partner organizations including Cornell Cooperative Extension are beginning a new education project called "Watershed Resiliency and Flooding Mitigation through Science-Based Stream, Floodplain, and Land Management Outreach and Implementation" for local governments and the general public. This program is designed to provide training in the science of stream and floodplain processes, respond to mistaken beliefs that dredging streams or armoring stream banks can routinely and easily solve flooding risks, and address the tendency to reinvest and rebuild in risky locations or without proper designs. Local highway departments and others involved in public works management, planning, and maintenance are one key audience, as the program will help in making better decisions about how to plan infrastructure and implement repairs to reduce future flood damage.

In Orange County, the Orange County Water Authority (OCWA, an agency with a primary mission to address drinking water needs, but has also supported work on watershed planning and stream monitoring), the Orange County Department of Planning, and the Moodna Creek Watershed Inter-municipal Council (MCWIC) implemented several educational workshops in response to recent floods. Public workshops were held on December 6, 2011, and February 7, 2012, to provide an overview of basic climatology, stream hydrology, state programs and regulations, land use planning, storm water management strategies relevant to flood planning and risk mitigation. On July 9, 2012, a half-day educational Flood Summit was presented by these partner agencies for stakeholders in the Moodna Creek watershed, and a resultant report was produced by Stone Environmental Inc., the consultant that led the workshop. In these workshops, it was evident that the perceptions and beliefs about how streams function and what interventions are appropriate and sustainable (as previously outlined), remain a real challenge.

The MCWIC was formed by adoption of an inter-municipal agreement among 14 local municipalities and the OCWA in October 2010, based on a watershed plan and subsequent municipal outreach process led by the OCWA funded in part by the NYS DEC Hudson River Estuary Program. During the initial outreach process and since the MCWIC's formation, flooding has been the water resources topic that is discussed more than any other. Since Irene and Lee, meetings of the full Council and of its Science and Education committees have included extensive discussion about related issues, including whether and how owners of lakes, reservoirs, and ponds can be enlisted to release water before storms in order to free up storage capacity that might reduce downstream flooding, or to better coordinate releases during storms. There is a strong suspicion among landowners in certain areas that releases

during storms contribute to downstream flooding. For example, in the Wallkill River floodplain in southern Orange County, farmers in the Black Dirt region believe releases from Lake Mohawk in New Jersey exacerbate floods, and also believe that dredging the Wallkill River main channel should be pursued, despite technical advice that challenges this view. The Village of South Blooming Grove is one municipality in the Moodna basin that has been coordinating releases from several dams before storms since flooding in 2007. Twenty-four hours before storms, one private dam owner releases water first, then the Village releases water from a second impoundment they control farther downstream (Merriewold Lake) 12 hours later. The Village believes this practice has reduced damages and avoided some flooding that would have otherwise occurred.

The MCWIC is now beginning research with assistance from Orange County staff to identify legal mechanisms that can enable inter-municipal collaboration for activities to manage streams. Implementing similar approaches will involve addressing scientific and regulatory issues that include designing and permitting the appropriate activities, working with landowners, and finding sources of funding.

In late 2010, the OCWA installed eight stream gauges to monitor the elevation of the water surface at selected locations in the Moodna Creek and Wallkill River watersheds. All but one of these gauges survived Irene and Lee without damage. Since these storms, an engineer also appointed as a municipal representative to the MCWIC, has used the data from FEMA's Flood Insurance Studies to develop rating curves (elevation vs. discharge) for these gauge locations. Starting with the most current computer models produced by FEMA, this research better defines the relationship of the water levels measured by the gauges and the discharge or flow of water in the stream. The flow information developed using OCWA's stream gauge data will help to improve understanding of the hydrology of sub-basins above these gauge locations. One preliminary finding is that one sub-basin in the Moodna Creek watershed, the Otter Kill Creek, may experience less flooding due to the presence of significant wetlands and other areas that capture and hold water during storms, releasing it slowly. The MCWIC is beginning to explore potential funding sources to expand and build on this work.

To address the impacts of flooding on people, a program called Project Hope provides counseling, support and assistance accessing financial and resources for affected people. MCWIC members learned about this program and Project Hope staff made a presentation at a MCWIC meeting on July 30, 2012. MCWIC members assisted Project Hope staff in outreach to inform stakeholders about this resource and follow-up outreach activities reportedly resulted from this activity.

5.3 Needs, Challenges and Opportunities for Improved Adaptive Capacity

5.3.1 Significant Tool and Resource Needs

In addition to asking which tools and resources were most useful (see Section 5.1.2), respondents were also asked what kind of tools and resources (e.g., data and information, human resources, financial resources etc.) were not available, and if they were not initially available in a timely fashion if they eventually arrived or were not available at all. A key tool or resource that was identified by respondents as missing was certain data and information, especially obtaining and managing them in the most useful format. For example, respondents involved in assessing flood damage, whether sites were in mapped floodplains, and addressing related questions relevant to potential FEMA reimbursement for repairs wanted paper maps in the field, but FEMA now relies on digital maps. (These post-storm assessments typically don't start until about 1-2 weeks after a storm because FEMA and State staff often wait a few days to let first responders deal with immediate response and relief efforts.)

Furthermore, many people felt that they did not have enough information about the disaster relief fund and recovery grants available to local governments. For example, FEMA had a cadre of people on reserve to help communities, such as retired state staff that many respondents did not know about. The respondents felt there was value in having information about programs quickly. This feeling was especially true for the local tourism industry which is highly dependent on weekend visitors during late summer and fall season, yet suffered significantly with closed operations and potential customers being discouraged from visiting the area.

Some respondents wanted more digital tools, like hand-held devices for workers in the field, who can then send data back in to command centers as well as using them to access maps and other data. In general, this was the first time they were using Web-based information exchanges during a large-scale emergency, but they lacked the technical tools for use in the field to gather, input, catalog and share the data, because the infrastructure and systems themselves were not quite ready to accomplish these tasks. The NYS Department of Transportation's (DOT) Incident Command System (ICS) worked well, and this system is linked to one used by other State agencies as well. The ICS is a structure for command, control, and coordination used by NYS DOT management and field staff during emergency operations to manage communications and coordinate decision making about resource allocation, prioritizing response at specific locations, and other aspects of emergency response. It is related to the National Incident Management System, a framework for coordination within and between agencies.²

² http://mceer.buffalo.edu/education/Bridge_Speaker_Series/Spring_2011/presentations/Clements_presentation.pdf

Respondents also mentioned a lack of physical materials like cots for shelters, and road barriers, yet questioned the feasibility of making investments in things that might not be used again for many years. At least one suggested that a county or regional approach to stockpiling key items might make sense. Mutual aid agreements do exist among utilities for sharing crews after emergencies, but this event was unusual because Hurricane Irene was predicted to impact a large area along most of the Eastern coastline. This size created restrictions on securing commitments for out-of-state crews before the storms because utilities farther south expected to need them locally. (After the storm passed Florida and Georgia with less damage than expected, utilities there did free up crews to come to New York State.) With respect to human resources, interviewees responded that in almost all cases there were sufficient numbers of emergency first responders (police, fire and ambulance crews) or staff, and contractors needed for repairs of roads and other infrastructure.

A major need identified by at least one respondent (who is involved in providing information about the state's planning and permitting role for streams and floodplains) is better educational tools and resources for local officials and the public, about the basic hydrology of watersheds, streams, and floodplains, and what mitigation strategies are actually feasible. There is a widespread perception that widening and deepening stream channels should enable them to convey more water more quickly. There is a lack of awareness about some fundamental aspects of stream geomorphology, the role of sediment erosion and deposition in shaping stream channels, and how these principles can guide stream management and restoration designs. Some educational work has been implemented to address these issues but more is probably needed (NYS DEC 2013).

A closely related issue is perceptions and attitudes toward wetlands and regulations to protect them. A current topic of significant discussion in Orange County is NYS DEC's proposed, revised wetland maps that would increase the geographic area designated as wetlands subject to state permitting requirements. Some stakeholders in the real estate and business community have mounted a strong campaign against adoption of these new maps, noting that regulating more areas will affect certain property owners and potential development. Several respondents raised this general issue and this campaign specifically and suggested that more education is needed about the value of wetlands for holding floodwaters and thereby reducing flooding downstream because this message is largely lacking in the broader public dialogue. (It is, however, axiomatic within environmental and some land use planning sectors.)

Another example of behavior that indicates a need for more education is people's response to road closures. Several respondents noted a significant problem with people driving around barricades and thereby increasing their risk of injury, which also creates increased risk and workload for first responders. In one case in Orange County, a driver was reportedly charged with reckless endangerment for driving around a barricade with a child in the car. Related situations arise when people do not want to leave their homes even when forecasts or rising floodwaters present significant risks. If people had a better appreciation and understanding of the actual risks these behaviors create for themselves and others, it could counter the tendency to take actions that exacerbate these risks.

One critical distinction that needs to be recognized in educational programs is the difference between the current capacity to design and manage for moderate-sized storms (e.g., 2-4 inches of precipitation), where certain measures may be able to significantly mitigate some risks, and larger events such as Hurricane Irene and Tropical Storm Lee, which demand a more ambitious, comprehensive, and costly response. It is understood that a different intensity of planning and response is needed and appropriate for different sizes of storms. In many locations, it is probably fair to expect that with improved infrastructure, certain retrofits to buildings, and other steps, properties and communities can significantly improve their resilience, reduce future damage, and recover more quickly after storms up to a certain size. For larger storms, however, the best educational message may be that for people in certain geographic areas, evacuating before storms may be essential to reduce risk to life and safety, and that maintaining buildings and some other infrastructure in these areas may not be sustainable over the longer term.

The aforementioned points are related, challenging policy tradeoffs that were mentioned by a number of respondents regarding where and whether resources should be invested to rebuild homes, roads, and other infrastructure, if it is likely to suffer repeated damage in future storms. (None of the subjects interviewed were directly involved in higher-level policy discussions reportedly being held at the State level through the Long Term Recovery Task Force and perhaps other channels.) Specific decisions related to these issues are involved when officials and staff are designing culvert and bridge repairs and replacements, namely, what size storm should they be designed for? This question is further complicated by the fact that precipitation patterns have changed in the past 50-60 years. In the wettest part of Ulster County, in the Shandaken area, for example, the peak 24-hour rainfall during the 100-year storm has reportedly shifted from 8 inches in 1966 to 13 inches in 2003.³ Because climate predictions indicate this trend may continue, design professionals, local officials, and other stakeholders face considerable uncertainty as they attempt to plan infrastructure repairs and upgrades to handle storms of a given size, e.g., 50 or 100-year floods.

5.3.2 Key Areas of Improved Adaptive Capacity

Interviewees were asked which activities they felt would make the most significant improvement in the capacity of the area to respond to another event. Specifically, they were asked what specific things they would recommend. At a general level, respondents stated that rapid cataloging and inventory of the impacts were most important to improve response capacity and as a way to reassure the public that the impacted location will be able to recover. On a more specific level, several respondents said they wanted to know how to better study and manage the regional hydrology, and how to prevent extensive flooding. There was a sentiment that the streams have been allowed to become too natural, and that there should be closer oversight. As a related matter, many respondents echoed a concern expressed by one that “DEC doesn’t let us do this [clear the streams], and they care more about the animals.”

³ Northeast Regional Climate Change Center, <http://www.nrcc.cornell.edu/>

On this note, there is an understanding among some respondents that even while they may be frustrated with NYS DEC's permitting process and restrictions on stream activities, they realize that it is not simple to repair damage in and along streams in a way that does not cause other problems. Some training and education for local officials had been implemented in recent years on stream geomorphology principles, to help provide public works officials and others with a basic understanding of key concepts to guide stream management projects. This activity has been primarily or exclusively in the New York City watershed in the Catskills, but is now being made available to other areas.

One other key area where education is probably needed is on the rationale and regulatory framework for NYS DEC decisions about permitting projects in streams. There is a widespread perception that NYS DEC's primary priorities and goals are for protecting wildlife habitat and perhaps water quality. But NYS DEC's review of proposed projects reportedly includes a strong focus on ensuring that they will not cause flooding or erosion problems for other landowners downstream of the project site. Based on respondents' comments, this concept is not well understood by many local officials and other people who are involved in local and county government and other relevant sectors. Regarding the NYS DEC's permitting standards for stream management and other activities relevant to flooding, one respondent in northwest Ulster County noted that different regional offices of NYS DEC have markedly different approaches. Specifically, the Region 3 office of NYS DEC, which covers Ulster County, is viewed as stricter and less willing to permit some activities compared to the Region 4 office, which covers neighboring Delaware County, and in some cases a single project may be subject to different standards if it includes work in both counties. This respondent suggested that it would make more sense to have a regional approach based on watershed boundaries with one integrated set of standards and approaches applied throughout.

Increased resources for public education to raise awareness about flood risks may be useful to address the tendency to ignore road closure barricades and signs and thereby create additional risk for individuals who drive around them and first responders who may be called upon as a result. The regulatory and other roles of different agencies and levels of government regarding floodplain planning, management, and related issues is another key area where additional education resources for the public, local officials, farmers, and others may be important. These agencies should address the apparent lack of knowledge and misunderstandings about which agencies have relevant jurisdiction and responsibilities at the local, county, state, and federal levels.

More broadly, responses from a number of subjects suggest the need for education and dialogue about appropriate policies for where to invest public resources in re-building and upgrading infrastructure, and about how these issues can be coordinated with land use planning for smart growth and sustainability. Very strong feelings were expressed by several respondents who felt that where homes, farms, and other existing development are in or near floodplains, it is appropriate to re-invest in measures to protect them, even if they are at higher risk in future storms. These respondents also supported codes and restrictions to limit new development in floodplains.

On another policy front, at least one respondent noted the need to re-visit regulatory strategies for protecting wetlands in some areas, for example, where a wetland is located in an existing urban neighborhood that is designated as a priority growth area where development supports many smart growth principles. This respondent suggested that a planning approach is needed to find areas where “mitigation wetlands” (i.e., constructed wetlands designed to replace the hydrologic and other functions of existing, natural wetlands that are protected by State regulations) can be developed to enable planning for desired growth in areas where natural wetlands are obstacles to new development, particularly in existing urbanized areas and other places that are suitable for smart growth based on availability of transportation and other factors. These mitigation wetlands would replace functions of existing wetlands and thereby facilitate permitting those existing wetlands for development.

5.3.3 Key Barriers or Limitations

Respondents were asked to express their thoughts on any limitations or significant barriers to developing or making the most critical tools and/or resources available and what they perceive as limitations or barriers to their availability, if any. Respondents said an important barrier to action was the lack of information on local and regional hydrology. It was felt that this knowledge could have been used to better manage flood waters and lessen the likelihood of upstream discharges by property owners and other water managers who were trying to limit their own flooding but inadvertently caused greater flooding downstream. Respondents, wanted to know more about the upstream water managers and know who they were and how to better understand their water management decisions and how to better coordinate with them. Particularly in Orange County, how and why do flood waters rise and fall was an issue of specific concern, and acknowledged limitation. Respondents also talked about information tools including hand-held tools, maps, and ways to send data into a central location or website as a barrier to availability of additional resources. Physical barriers, specifically not being able to get to a certain place for a while and resulting delays in damage assessment, was defined as an issue as well.

Local stakeholders want the State, counties, or other authorities to do more to coordinate and oversee these releases, including lowering water levels before storms to provide more storage during storms. Certain dam owners and government officials, however, have responded to these suggestions by noting that most dams are not designed to allow controlled water releases, the total storage volume that is available in existing impoundments is probably not sufficient to significantly reduce flooding in many watersheds, and that by intentionally releasing water at any time, a dam owner could be subject to liability for damage if such a release is not based on adequate planning and knowledge of downstream hydrological conditions, land use, and so on. One dam owner stated that they would not do such releases unless the State specifically authorized and managed this activity to reduce the dam owner’s liability.

Individuals also cited a demand for State level initiative and leadership, especially in the realm of stream management. Many interviewees mentioned that locals perceived State regulations as a significant barrier to action especially on issues such as stream dredging. Local property owners considered the regulations as an undue burden

because they felt that they could not directly and immediately address what they unscientifically considered to be an impediment to flood control (the shallowness of local stream and their inability to hold significant amounts of flood waters). It was understood that some local people actually went out and did stream dredging and debris removal from streams themselves without having permits.

To address these issues, it seems appropriate that work could take place to enhance community understanding of how natural stream structure can improve flood protection and scientific evidence that dredging can exacerbate flooding problems.

5.4 Changes in Adaptive Capacity

5.4.1 Changes in Understanding of Medium and Long Term Management

Many respondents were really surprised about the intensity of the flooding, which changed how they thought about flooding. They considered the storm to be a “wake-up call” event and that it provided an opportunity to promote heightened awareness of storm impact. Most respondents focused on their own position and work demands rather than the whole region. Only a few respondents were aware of the sustainability efforts currently ongoing in the Mid-Hudson Valley region and they did not significantly connect it to their professional work.

5.4.2 Changes Implemented Through Budget Priority and Funding

Respondents were asked to reflect on how these extreme weather events changed their agency or community’s funding and budget priorities with respect to future event response and planning. They were also asked if there have been decisions to reallocate funding as a result of the flood. Interviewees felt the events signaled the start of something different, and were thinking about their implications profoundly. Respondents were thinking about change for the long term, but not changing anything in the short term. Right now, local governments do not have flexibility or resources to put into flood control due to budget cutbacks in the past several years. Overall, there was not much immediate change or reallocation. Individuals felt that changes will unfold on a higher government level, particularly through the work of the NYS Long Term Recovery Task Force.

5.4.3 Changes Not Yet Implemented

Interviewees were asked if there were any steps that they thought needed to be implemented locally in the immediate region, that have not been implemented as of yet. They were also asked why they felt such actions have not been taken. In general, responses to this question involved referring back to responses to previous questions where substantive answers that addressed the same basic question were given, without much new material provided by respondents.

6 Conclusions and Recommendations

Several sets of conclusions and recommendations are derived from the report results. They are presented for each section including hydrology and precipitation analysis, impacts costs and vulnerabilities, and adaptation response and needs assessment.

6.1 Conclusions

6.1.1 Hydrology and Precipitation Analysis

During fall 2011, Hurricane Irene and Tropical Storm Lee precipitated 3 to 15 inches (8 cm to 38 cm) and 5 to 9 inches (12 cm to 22 cm), respectively, during 4-day periods over the Hudson Valley and Catskill regions of southern New York State. Precipitation and streamflow data were analyzed to evaluate the relative magnitude of these two storms, to determine how unique this series of events was when considered in historical context, and to detect possible changes in the frequency of extreme hydrological events during the period of historical records available. The main conclusions are:

- Hurricane Irene and Tropical Storm Lee were both devastating; however, their impacts were quite different and varied spatially across the study region. The maximum precipitation rates for the entire region were higher for Irene than for Lee. Irene resulted in more intense precipitation in the eastern portion of the study region, while Lee was associated with more intense precipitation in the western portion.
- By examining streamflow as well as precipitation records, seasonal as well as annual mean values, and antecedent as well as subsequent conditions, hydrologic conditions during summer 2011 were found to be historically unprecedented in this region.
- The large amount of precipitation during August 2011, prior to Hurricane Irene; the proximity in time and space of the two events; and additional precipitation subsequent to Tropical Storm Lee resulted in the greatest 60-day streamflow on record during the months of August and September 2011. Had the same two storms occurred after a dry, rather than extremely wet, August, and had Lee not hit immediately on the heels of Irene, the magnitude of devastation would have been significantly diminished.
- Extreme precipitation events in the region have become more frequent during the past two decades. The frequency of extreme warm period precipitation and streamflow events during the first decade of the twenty first century has risen to levels 40-70% higher than at any earlier time on record.

6.1.2 Impacts, Costs, and Vulnerabilities

The impacts and costs were widespread in the region across a broad range of sectors although the majority of the direct impacts and costs were in the agriculture, transportation, and tourism sectors. The vast majority of the impacts and costs resulted from flooding as opposed to wind damage or any other storm related losses. The flooding impacts were geographically concentrated within each county. In some cases, traditionally vulnerable areas (i.e., locations that typically flooded during high precipitation events) were not impacted by the flooding, while areas that had not previously flooded were affected. The main conclusions are:

- Emergent (i.e., new or previously not recognized) vulnerabilities and new patterns of flood exposure were present. Some locations flooded that had not been flooded in recent memory. As a specific example, significant flooding and sediment transport was observed in roadside ditch areas throughout the two counties. More roadside ditches than previously recorded were washed out compromising many nearby road and rail beds often resulting in their structural failure.
- The largest single impact and costs was transportation related and resulted from the need to rebuild a section of the Metro North rail line washed out south of Woodbury as a result of Hurricane Irene. The rebuilding cost was approximately \$21 million.
- The timing of the Hurricane Irene and Tropical Storm Lee had significant impact on the agricultural sector of the region because harvest was imminent. The storms also disrupted the lucrative late summer and early fall agri-tourism (e.g., pick-your-own and farm stand purchases) in the region because of less produce to sell or fewer patrons. Topsoil was also washed away by floodwaters on some farms.
- The storms' impacts exceeded the expectations of most respondents. The amount of stream scouring that took place was also unexpected and in some cases unprecedented. The storms exceeded respondents' understanding because people did not previously conceive of flooding as an issue of water volume, instead focusing on the more typical flood concern of water height.
- The pattern of flooding resulting from Irene and Lee raised questions about the function and structure of the hydrology of the region. Although floodplain inundation did occur, local residents and other stakeholders also observed significant flooding of upland roadside ditches and as well associated with the fluctuating height of flood waters (i.e., first a rise then a fall followed by a second rise again).
- Some local stakeholders and decision makers are very concerned about planning, coordination, and management of water levels in lakes and reservoirs before and during predicted storms. They also believe that releases of water during storms by dam owners focused on protecting their own property, and may have exacerbated downstream flooding.
- The pattern of storm damage loss and impact and associated emergent vulnerabilities will likely affect the local real estate market, specifically in terms of the market value for homes. Flood damaged houses might lose value relative to undamaged houses. Property values could rise in those locations not flooded during the storms as they will be more sought out in comparison to those already known to be at risk and those identified as at risk of flooding during Irene. Low- to moderate-income housing in Ulster County was negatively affected by the storm (e.g., a trailer park was flooded during Irene and will likely not be re-established).

6.1.3 Adaptation Response and Needs Assessment

Hurricane Irene and Tropical Storm Lee impacted many communities, including those of Orange and Ulster Counties, and have altered the understanding of local flooding risk and how it is related to development patterns within the study area. These factors have impacts on the emergency response, needs assessment, and adaptive capacity of the local communities. Critical for future work is the development and implementation of new adaptation strategies and tools for local stakeholders. The main conclusions are:

- Several opportunities for enhanced emergency response were defined. These opportunities included providing additional information on the availability of local and state level resources include material resources such as paper maps, hand-held data gathering devices (e.g., GPS), and information on financial resources such as State level funds and grants for impacted communities.

- Flooding took place in locations that had not previously flooded, or not flooded in the memory of the respondents. Damage was observed in elevation areas outside of the traditional floodplains in the area. The predicted return interval for floods was felt to be not a good indicator of actual frequency. These issues clearly call for more analysis of measured climate trends, future projections, and how to evaluate risks for areas that are not in mapped flood plains. Some new education and training initiatives are underway or planned and more research is needed to identify specific gaps in these programs and opportunities to fill them with additional educational resources.
- Respondents felt that critical information needs are not being met in the counties. Understanding the floods and their timing and extent was limited by the lack of available stream gauges data.
- New Web-based and spatial data collection technologies (e.g., Twitter and Facebook) were employed during the disaster response and recovery phase during and after the flooding to facilitate disaster needs and assessment efforts. Respondents found these tools very useful for augmenting their ability to receive information such as damaged infrastructure reports, and also for disseminating information including updates on when power outages would be repaired. Some integration on a largely haphazard basis took place during the immediate recovery and aftermath of Hurricane Irene.
- Many communities in the region are already under conditions of financial and economic stress, and the impacts of flooding have fostered initial discussion of whether future development should take a different path and trajectory. Conversely, the storm was also seen by some communities as an opportunity to enhance the resilience of communities and their adaptive capacity in response to climate change.
- Responding to these storms, different stakeholder groups have undertaken new activities to mitigate future flooding by addressing stream management, including removing dead and living trees, dredging, stabilizing streambanks, and other steps, some of which may be counter-productive to preparing for future events. In some cases, these activities have been implemented and in others they are under discussion. A major need is better educational tools and resources for local officials and the public about the basic hydrology of watersheds, streams, and floodplains and what mitigation strategies are actually feasible and how some may actually be detrimental to future flood management.
- Several respondents saw an opportunity to link together New York City and New York State modeling capabilities for use by local communities in and downstream from the New York City reservoir watershed areas. New York City Department of Environmental Protection (NYC DEP) has extensive modeling programs and data for this area, but these data and tools are not currently used to provide information for local or county governments on issues relevant to hydrology and flooding.

6.2 Recommendations

Several general recommendations can be derived from the report results and conclusions. In most cases, the recommendations connect with two or three sections of the results and conclusions. The recommendations include the following:

- Reactivating and maintaining functionality of a number of stream gauges that provide historical records and extensive spatial coverage across the study area to address the data and information needs of stakeholders and decision makers regarding short- and longer-term response to the storm.
- Assessing existing hydrologic data sources to fill gaps where critical data collection is not taking place. It is important to review whether the existing monitoring stations are in the locations that are most vulnerable, and where not present in vulnerable locations how they could be strategically extended to those sites.

- Investigating how to adapt and extend current hydrological models to examine flood conditions in the region. Current NYC DEP watershed modeling efforts could be adapted for other watershed areas in the state to provide results to other stakeholders in the region, generally, and to stakeholders immediately downstream of the watershed, specifically.
- Providing basic watershed science and management education and assessment tools for local community stakeholders and decision makers. Focus should be on integrated watershed management, natural and human impacts on water flow, and emergent vulnerabilities and system level stresses.
- Reviewing potential opportunities for the use of data and information generated, distributed, received via social media applications such as Facebook, Twitter, and blog posts and technologies such as GPS that could enhance the understanding and assessment of emergency response and recovery needs and resources during future storms.
- Reviewing the impact of flooding events on the availability and cost of housing for lower and moderate income residents given the potential loss of low-income housing units and shift in house valuation resulting from flooding (e.g., houses flooded by Irene will lose value relative to houses that did not).
- Reviewing of design standards and maintenance of roadside ditches could be done to mitigate emergent vulnerability associated with higher magnitude extreme hydrologic events and resulting roadside ditch flooding. This could address the issue of whether current design standards including the size of culverts is correct given the potential for more frequent future intense flooding.
- Coordinating data needs and data gathering to provide better access for on-the-ground activities. This effort could sort, organize, and connect existing data gathering and distribution activities, and make this information available for local and county stakeholders. An assessment can be done on how best to organize and manage the information to provide added value to climate change adaptation decision makers and stakeholders. This activity could include brief recommendations and an outline for future development of guidance materials for, and potential effective means of distribution to, local municipalities and counties regarding planning for large storm and flooding events in the future.
- Increasing effort to ensure that New York State recovery efforts and studies are better communicated to local county and municipal stakeholders. Overall, better communication and connection among local, state, and federal entities would increase local adaptation capacity.
- Conducting training related to pre- and post-event stream mitigation techniques that address the fundamental aspects of stream geomorphology and how the role of sediment erosion and deposition in shaping stream channels can guide stream management and restoration designs.

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Appendix A

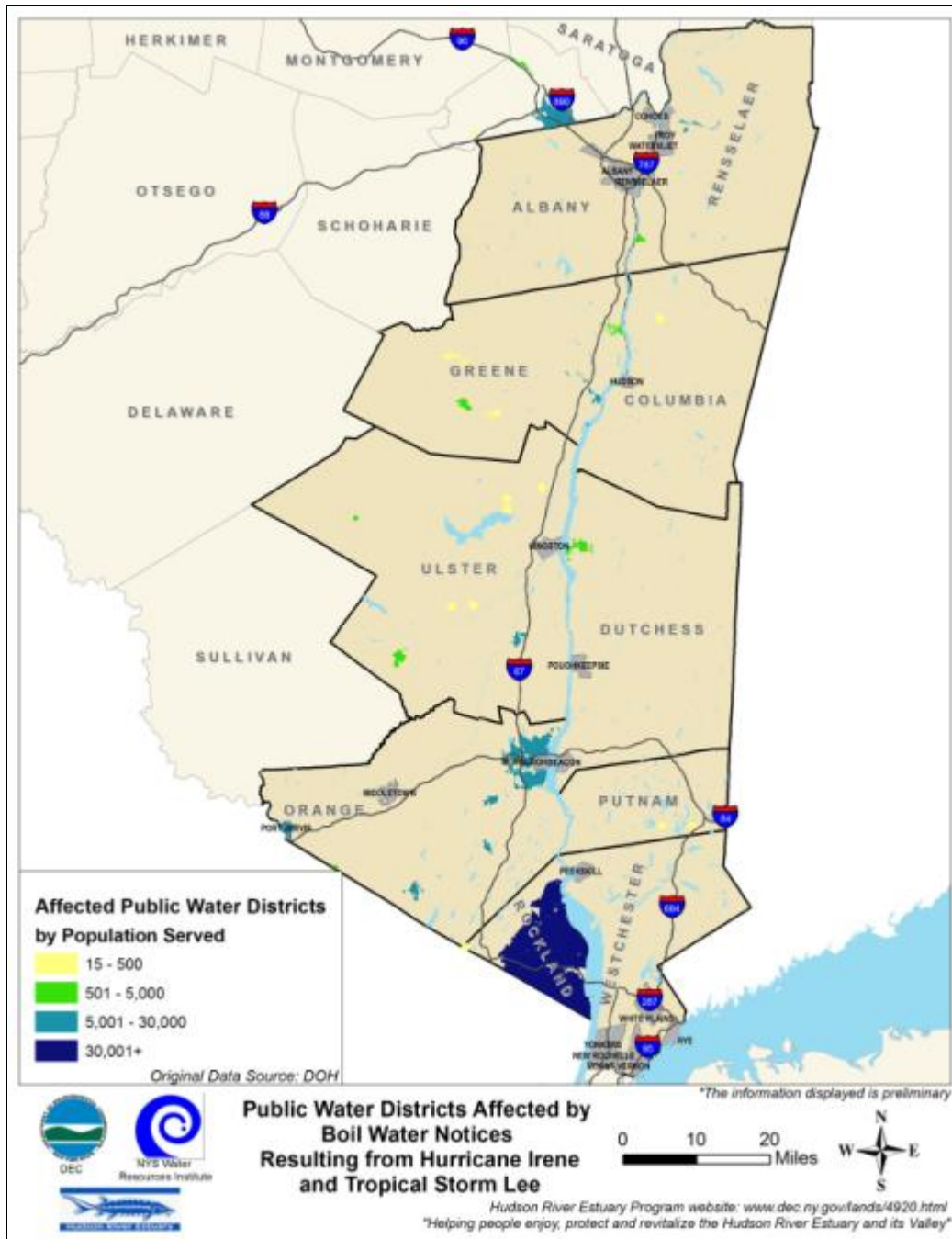
A.1 Impact and Hydrology Maps

Figures A-1 through A-13 were developed by the New York State Department of Environmental Conservation (NYS DEC) to show storm impacts, recovery costs, and hydrology for Hurricane Irene and Tropical Storm Lee. The maps cover part of the Hudson Valley only and are not comprehensive of all affected areas.

A.1.1 Impact Data - NYS DEC Hydrology and Related Infrastructure

Figure A-1. Hudson Valley Public Water Districts Affected by Irene and Lee

Source: NYS DEC



A.1.2 Impact Maps

Figure A-2. USGS Stream Gauges in the Hudson Valley that Exceeded Previous Flood Record during Irene

Source: NYS DEC

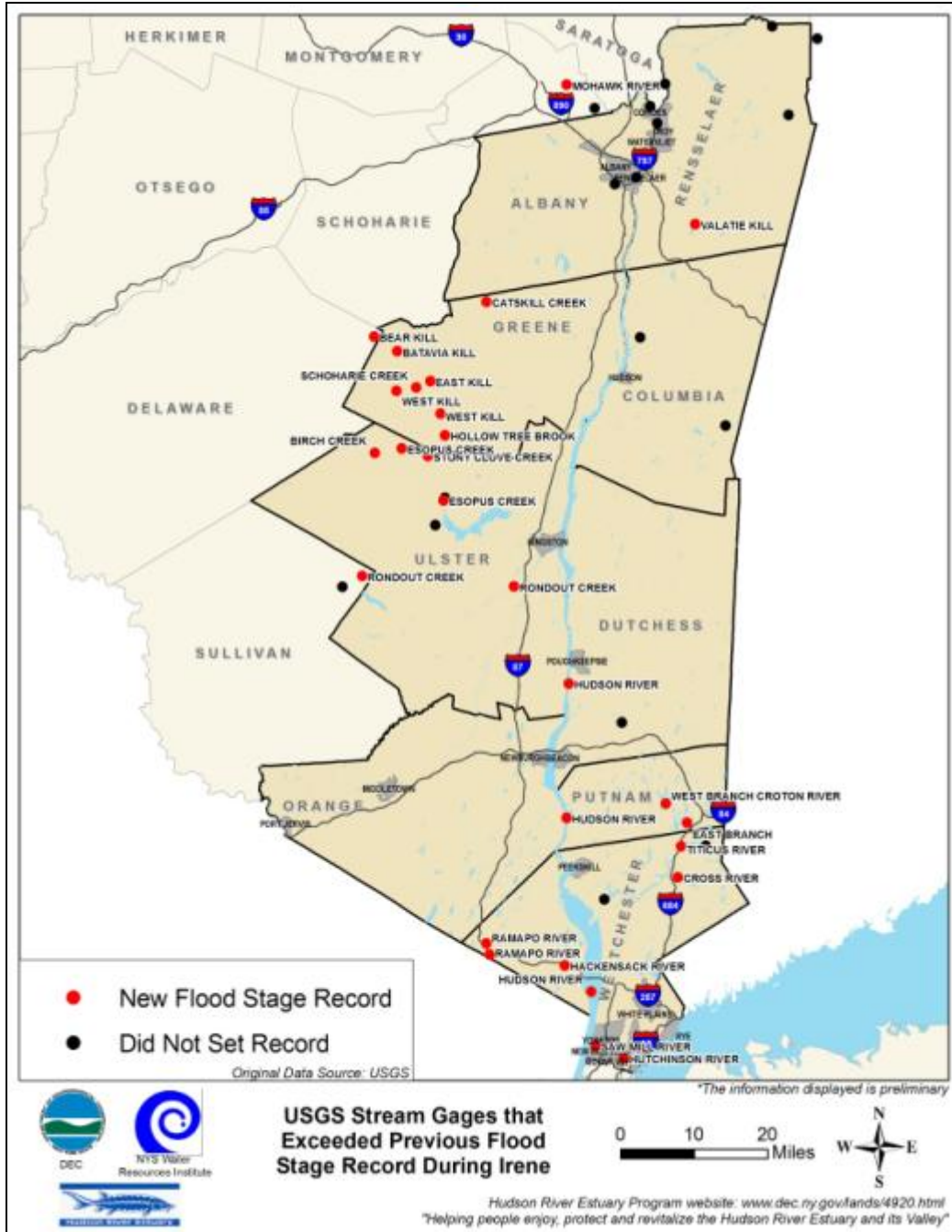


Figure A-3. Wastewater & Sewage Treatment Facilities in the Hudson Valley that Experienced Overflow, Bypass, or Inundation during Irene

Source: NYS DEC

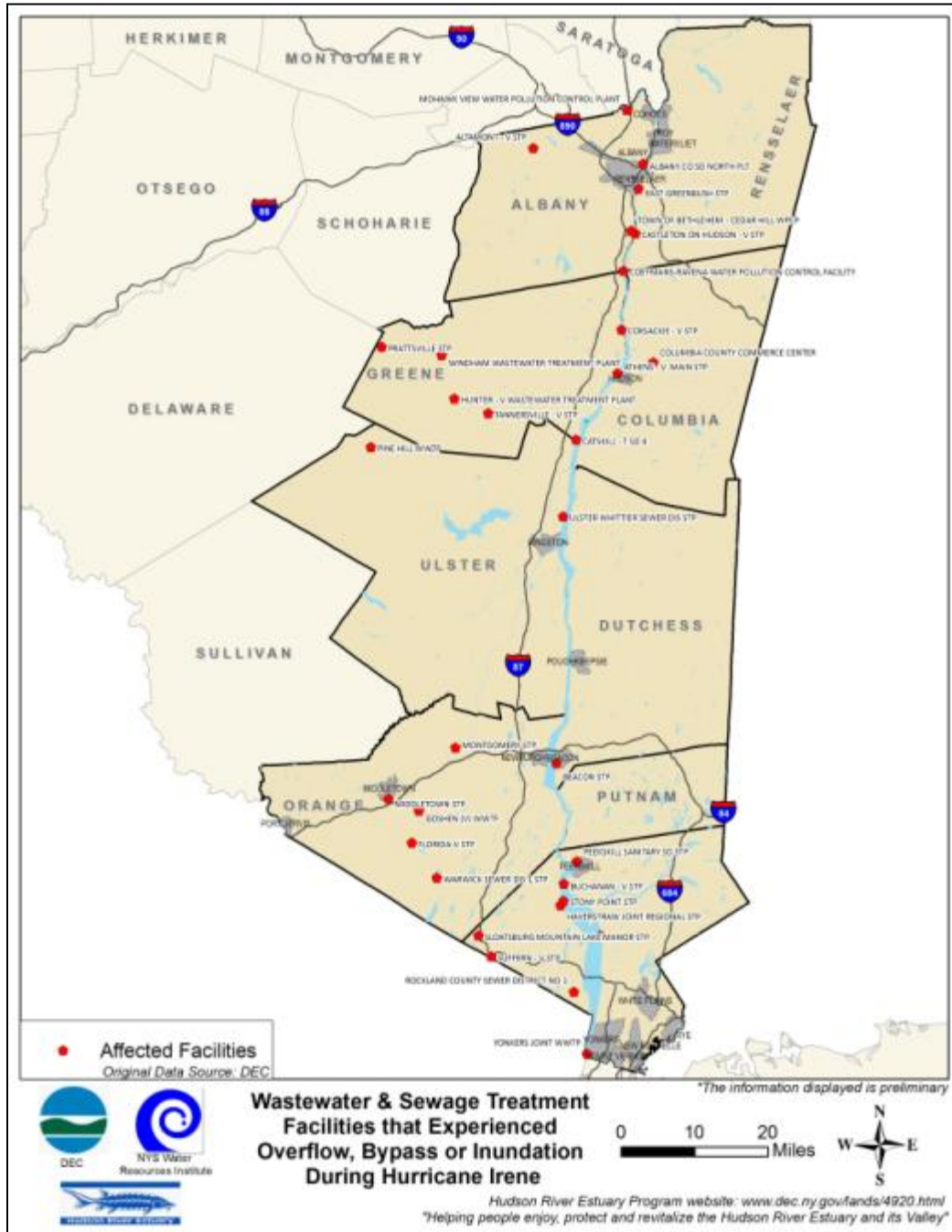
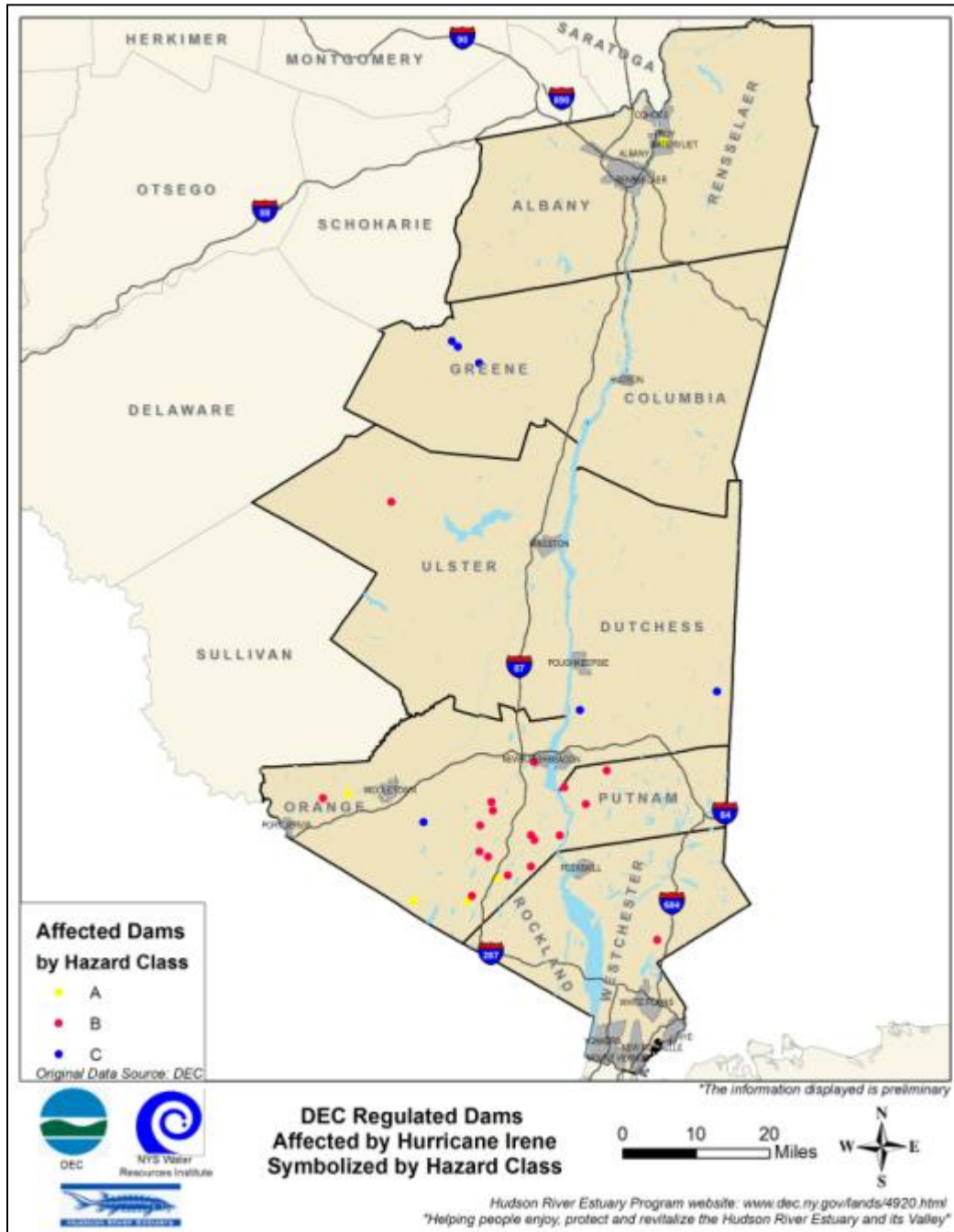


Figure A-4. NYS DEC-Regulated Dams in the Hudson Valley Affected by Hurricane Irene

The term affected indicates a range of recorded damage – everything from minor seepage, minor erosion around wingwalls, overtopping, sinkholes, and eroded spillways, all the way to total failure of the structure. Hazard Class equates to the level of potential impact resulting from dam failure – Class A is low and Class C is high.

Source: NYS DEC



A.1.3 Impact Data – NYS DEC Economic and Related Infrastructure Impact Maps

Figure A-5. Total Agricultural & Community Recovery Fund (ACRF) Aid to the Hudson Valley

Source: NYS DEC

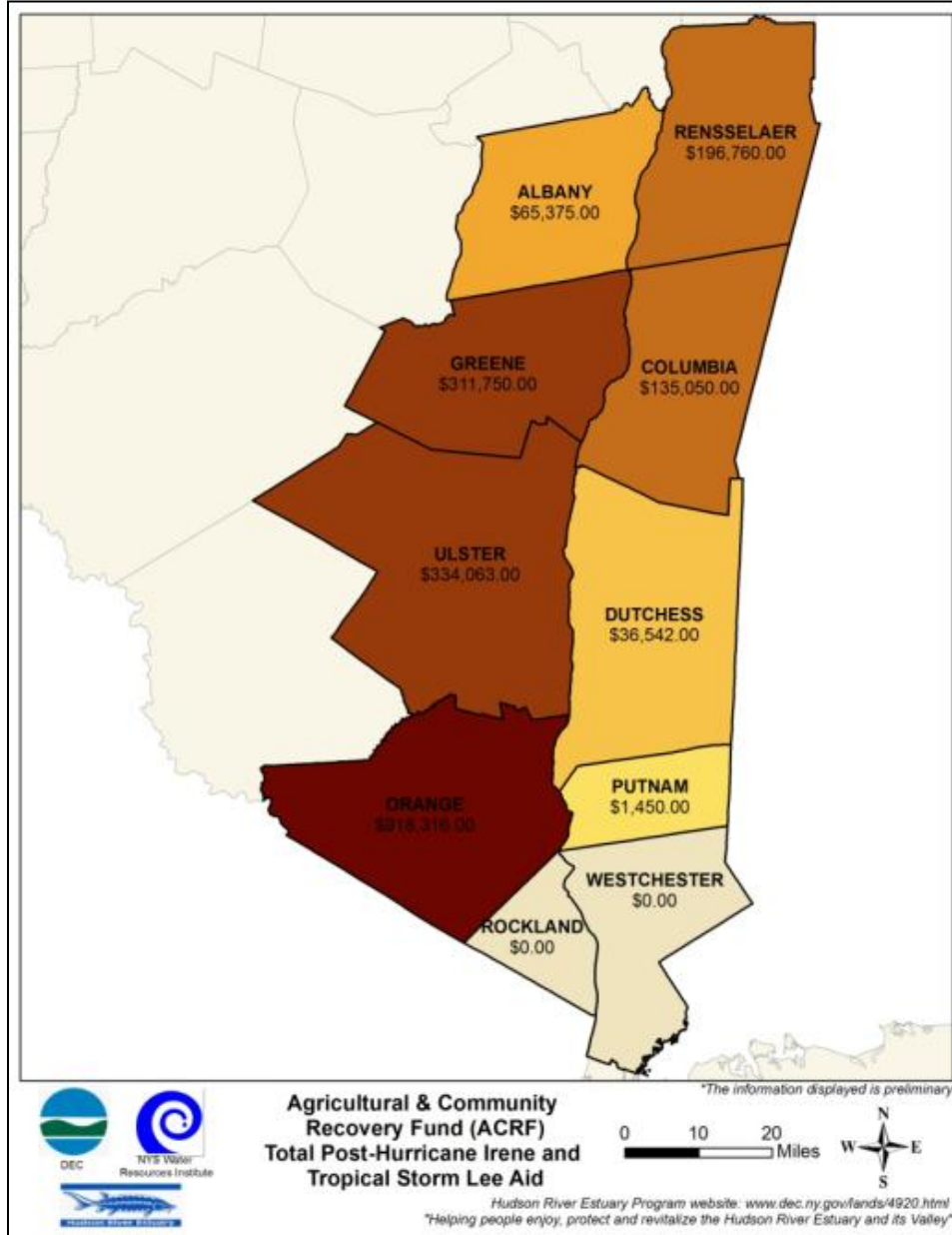


Figure A-6. Agricultural & Community Recovery Fund (ACRF) Aid per Acre in the Hudson Valley

Source: NYS DEC

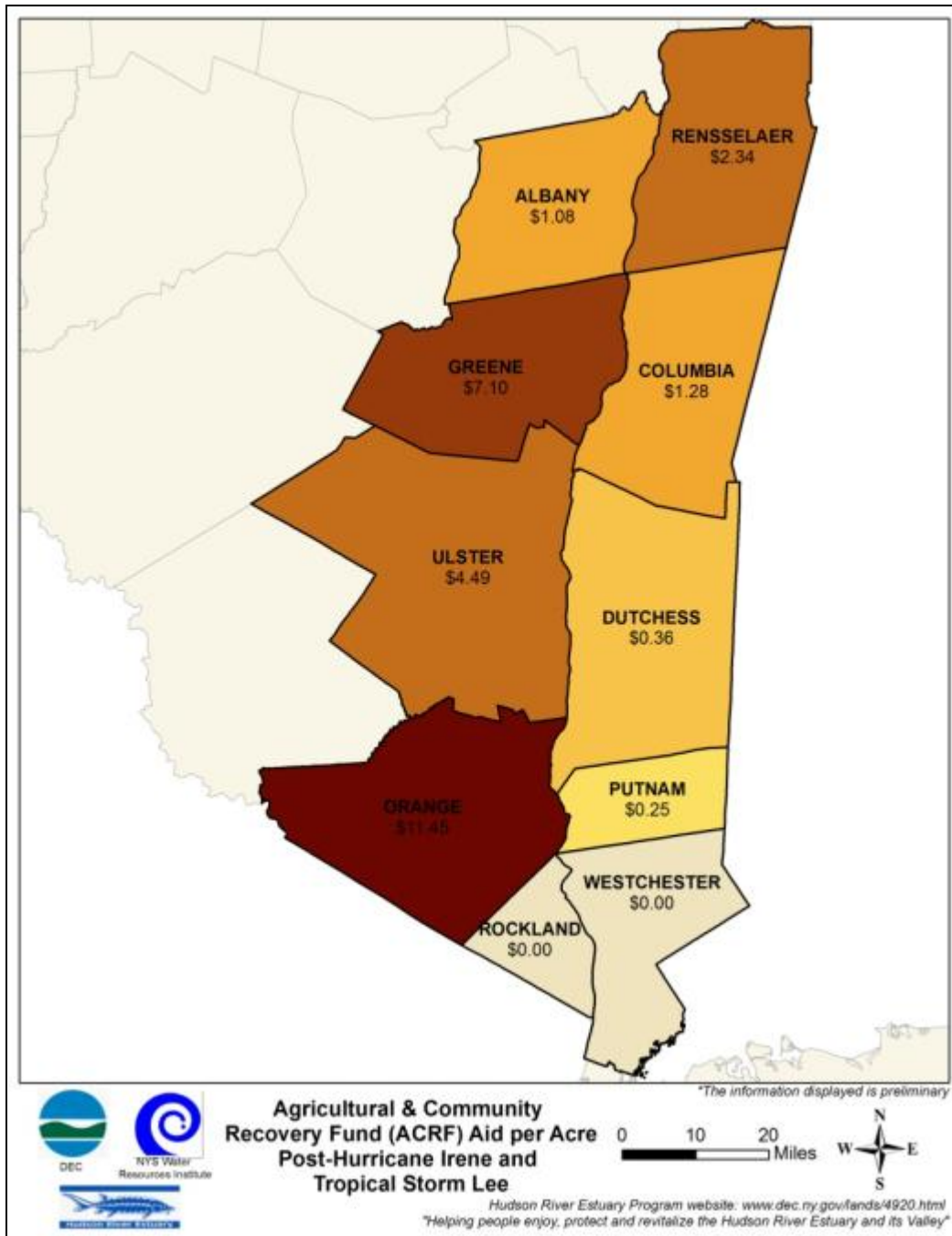


Figure A-7. FEMA Individual Assistance Aid Awarded to Individuals in the Hudson Valley for Hurricane Irene Recovery

Source: NYS DEC

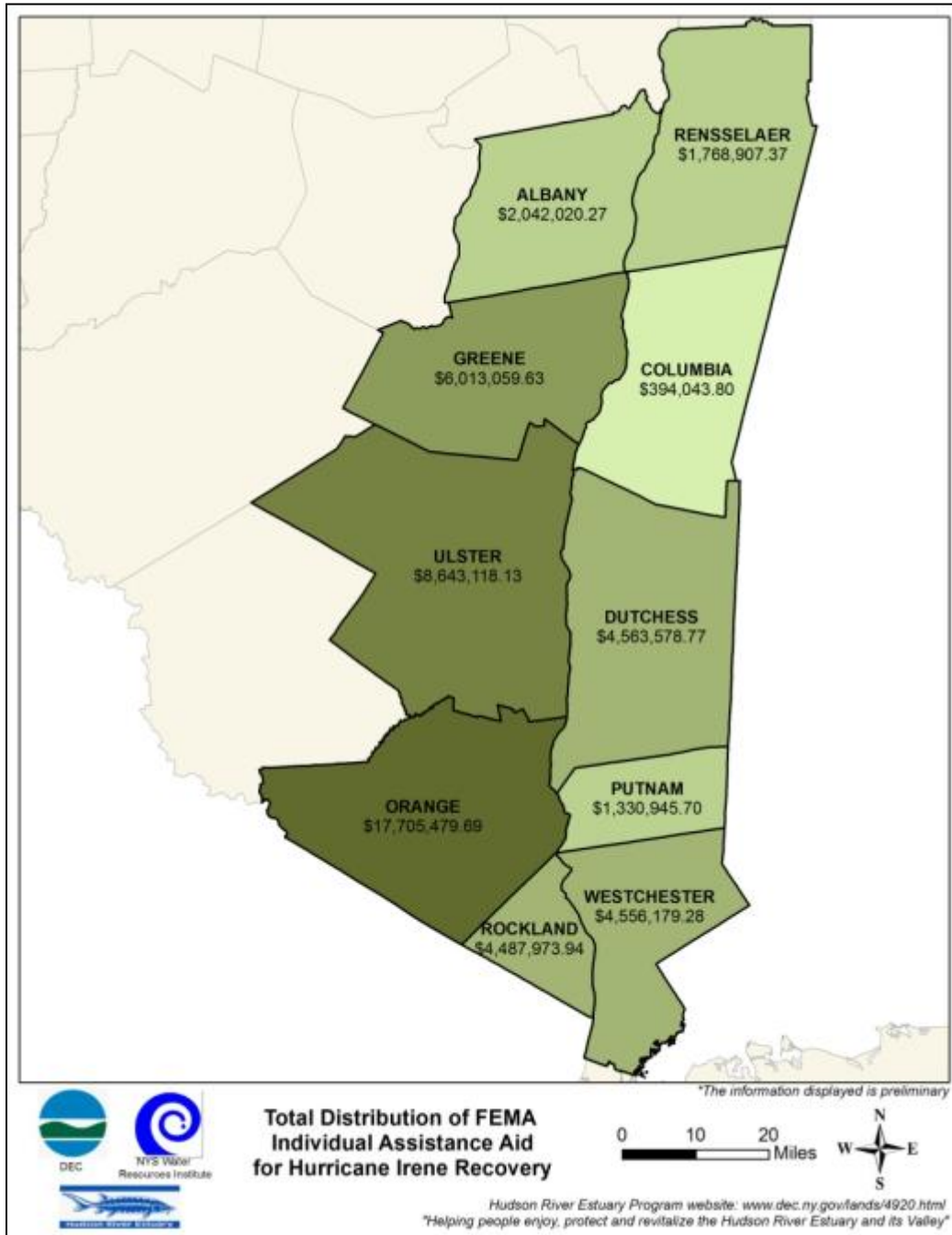


Figure A-8. FEMA Individual Assistance Aid Awarded to Individuals in the Hudson Valley for Tropical Storm Lee Recovery

Source: NYS DEC

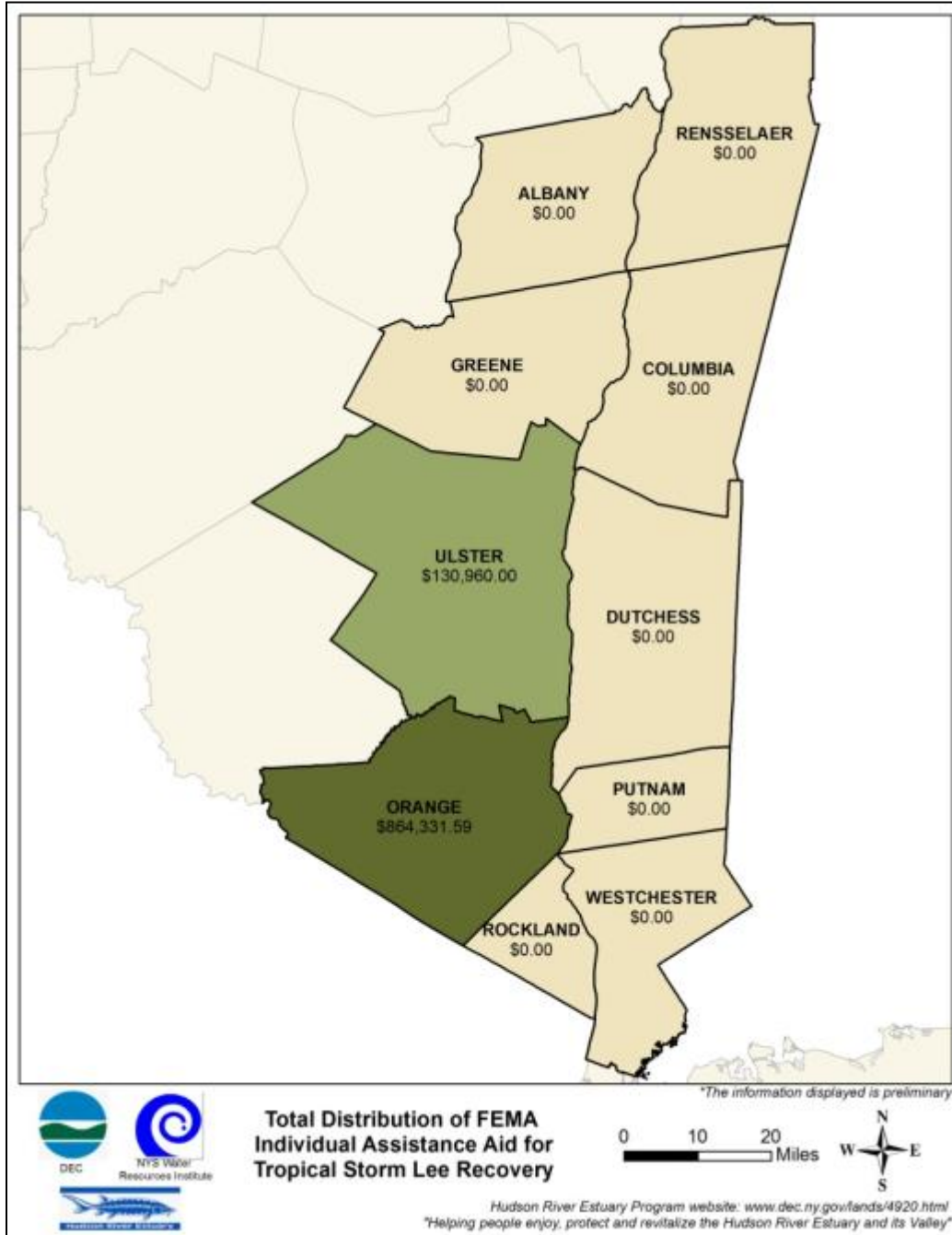


Figure A-9. Percentage of Customers in the Hudson Valley without Power after Irene

Source: NYS DEC

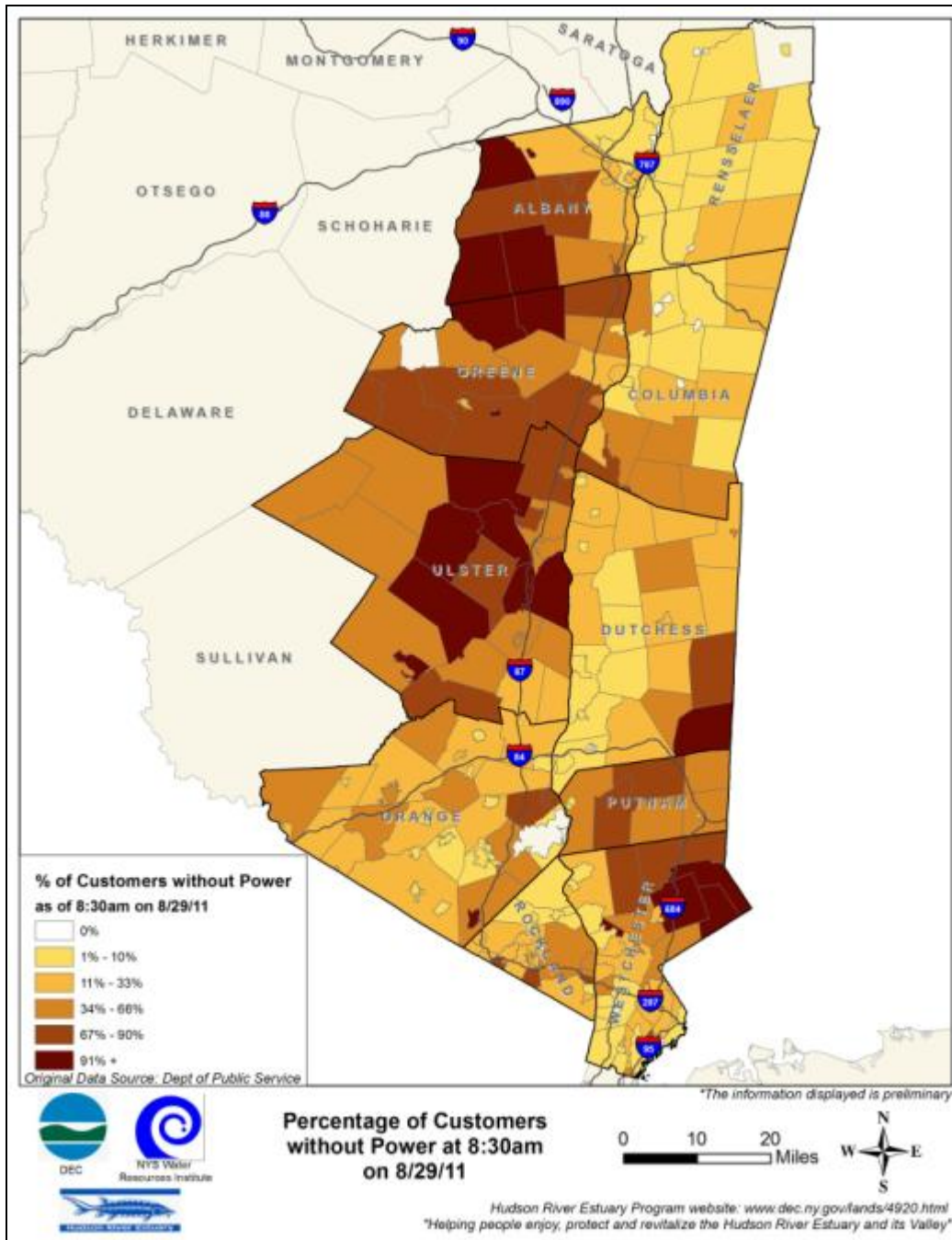


Figure A-10. Damage to Bridges and Culverts in the Hudson Valley during Irene and Lee

Source: NYS DEC

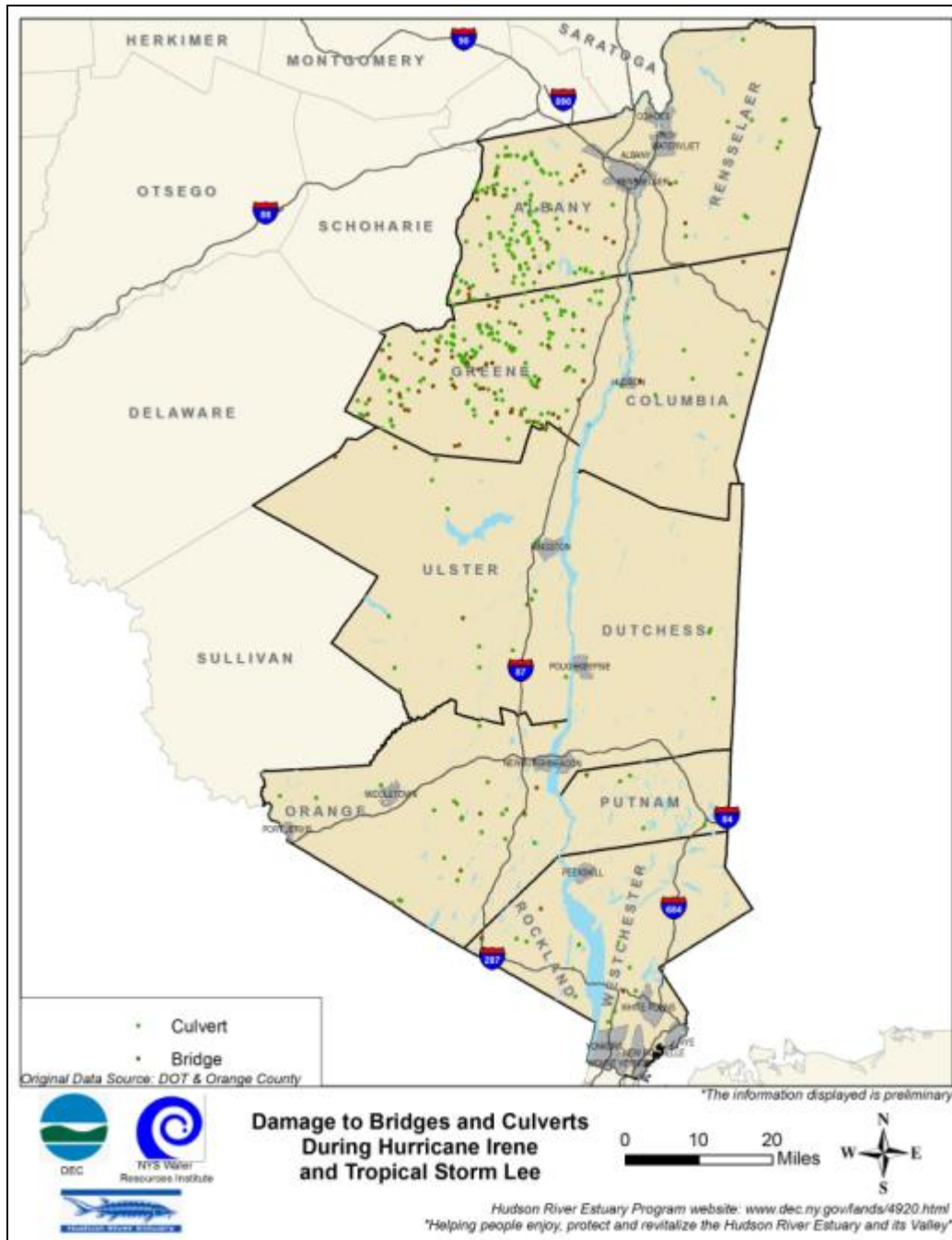
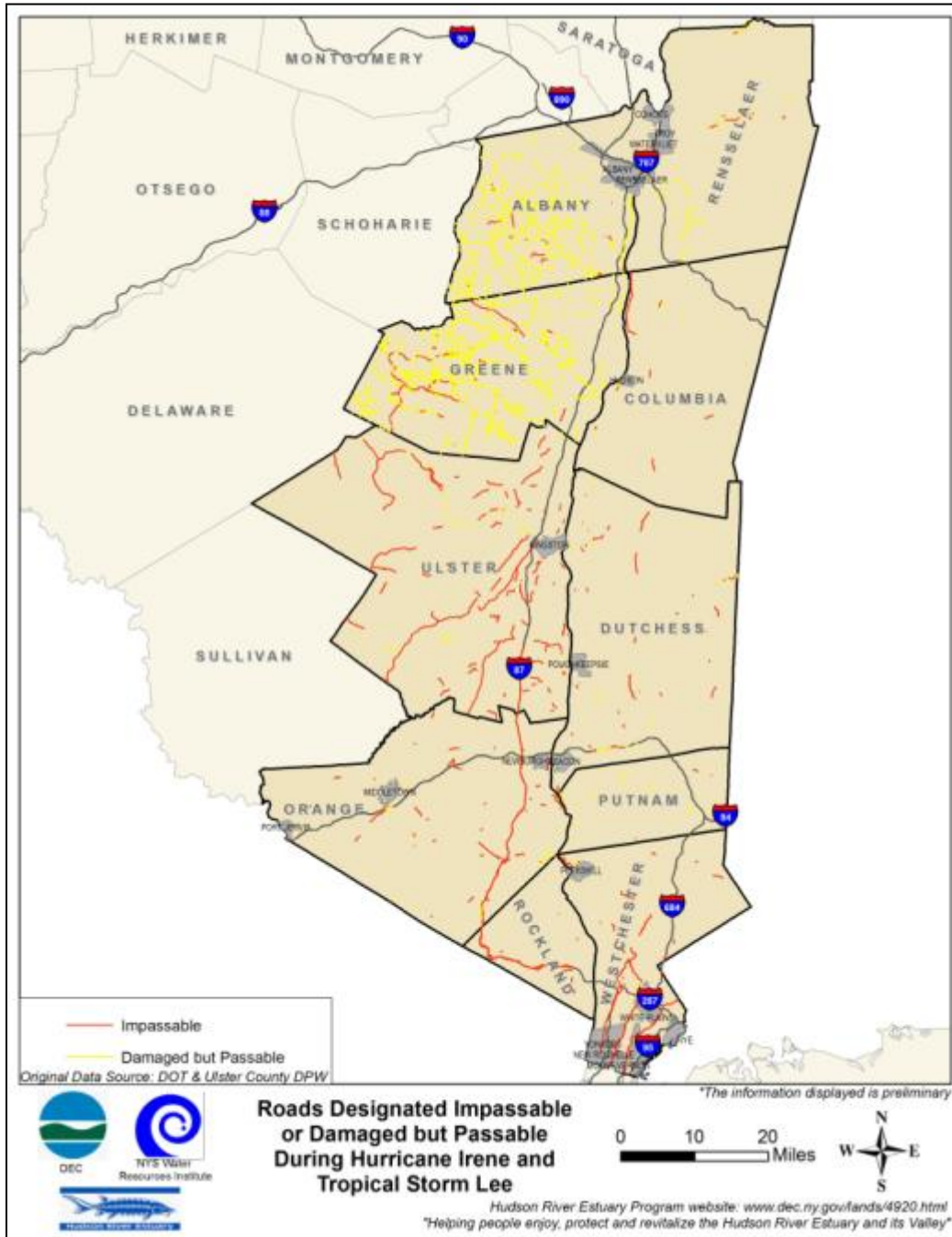


Figure A-11. Roads Designated Impassable or Damaged but Passable in the Hudson Valley during Irene and Lee

Source: NYS DEC



A.1.4 Storm Hydrology

Figure A-12. Total Precipitation Accumulation in the Hudson Valley during Hurricane Irene in the Hudson Valley

Source: NYS DEC

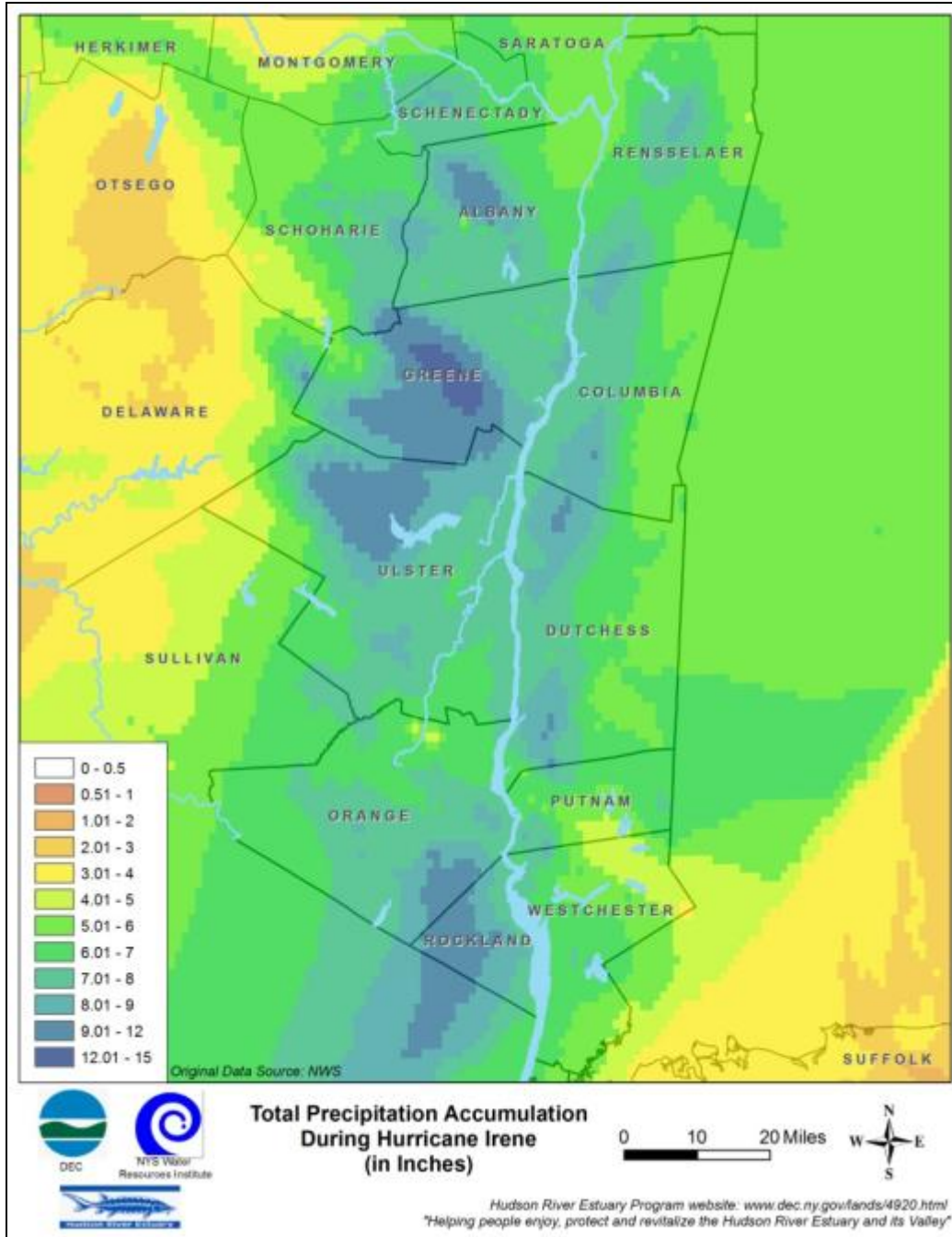
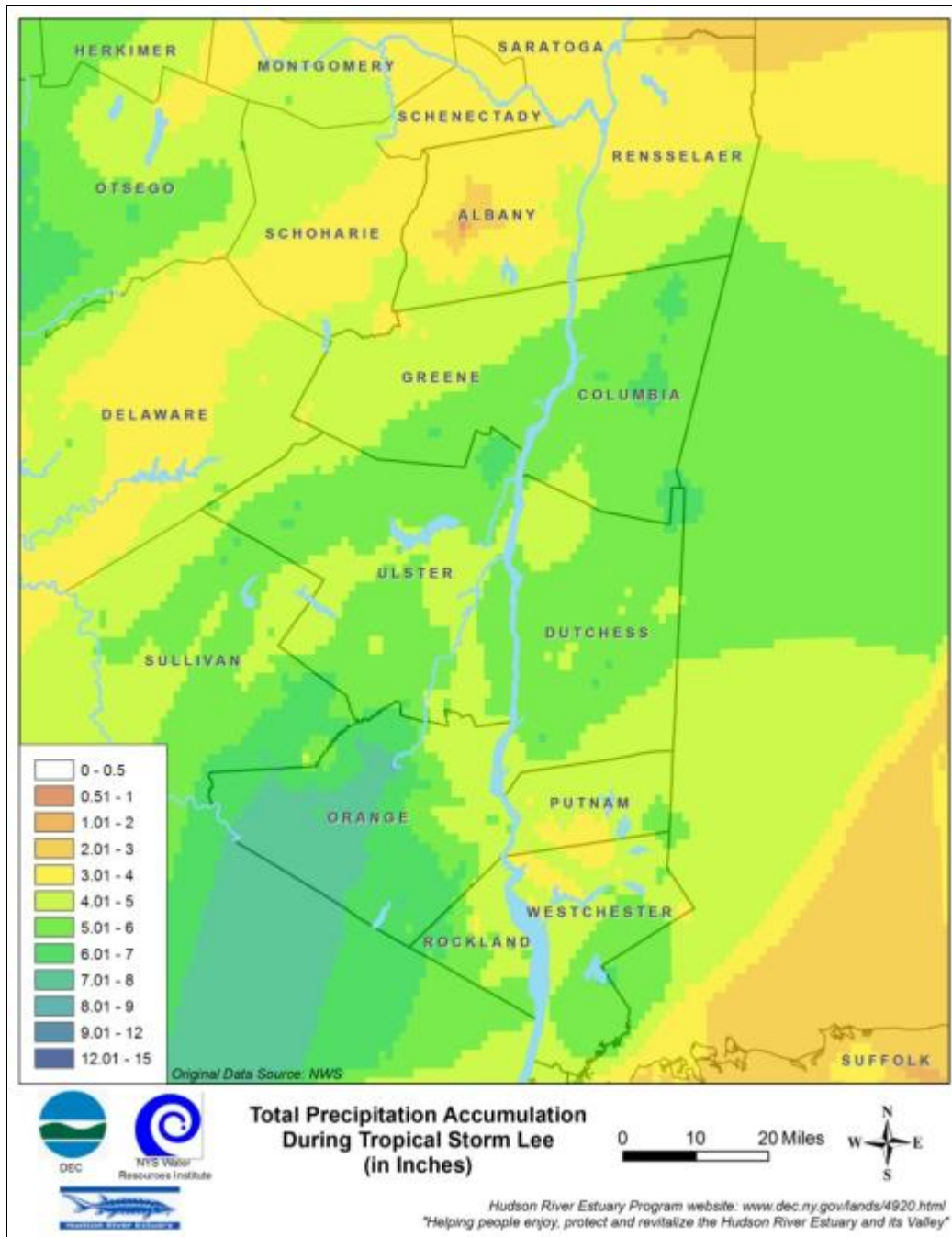


Figure A-13. Total Precipitation Accumulation in the Hudson Valley during Tropical Storm Lee

Source: NYS DEC



A.2 Hydrological Frequency Analysis: Irene and Lee in Context of Long-Term Historical Events

A.2.1 Precipitation frequency analysis

Precipitation return periods for Hurricane Irene calculated using AMS (annual return period) are greater than twenty years at only three stations, which have return periods of 88, 407, and 472 years (Table A-1). All annual return periods for Tropical Storm Lee are under ten years.

The same analysis applied to warm season events is also presented in Table A-1. Precipitation return periods using only warm season values indicate that at six stations Irene had warm-season return periods greater than annual return periods. Four stations for which Irene warm season return periods were equal to, or lower than the annual return periods are located in the western portion of the study area. In contrast, annual precipitation return periods during Lee were all under ten years. Thus, with regards to the maximum daily precipitation during the warm season, Hurricane Irene was an extremely unusual event in the eastern portion of the study area, while Lee was of a more common magnitude and spatially less variable throughout the region. Also shown on Table A-1 is the return period using data from warm season months only.

Table A-1. Hurricane Irene and Tropical Storm Lee estimated annual and warm season precipitation return periods

A similar record period (instead of full available period in Table 3.1) was used for all precipitation stations so that that the results for the frequency analysis are comparable.

Station ID Number	Station Name (County)	Record Period for Frequency Analysis	Irene Annual Return Period (yrs)	Irene Warm Period Return (yrs)	Lee Annual Return Period (yrs)	Lee Warm Period Return (yrs)
300254	Arkville (Delaware)	1952 - 2011	n/a	n/a	2	4
302036	Delhi (Delaware)	1952 - 2011	7	7	4	5
302060	Deposit (Delaware)	1962 - 2011	2	2	7	7
302582	Ellenville (Ulster)	1952 - 2011	n/a	n/a	2	3
304731	Liberty (Sullivan)	1952 - 2011	16	20	2	2
305310	Middletown (Orange)	1952 - 2011	n/a	n/a	7	8
305426	Mohonk Lake (Ulster)	1952 - 2011	407	387	<2	2
306774	Port Jervis (Orange)	1952 - 2011	9	11	2	2
307274	Rosendale (Ulster)	1958 - 2011	472	449	<2	2
307799	Slide Mtn (Ulster)	1952 - 2011	88	169	<2	2
308932	Walton 2 (Delaware)	1956 - 2011	2	2	6	6
309292	West Point (Orange)	1952 - 2011	7	9	<2	2

A.2.4 Streamflow frequency analysis

Both Irene and Lee were more unusual streamflow than precipitation events (Table A-2). For Irene, annual streamflow return periods were greater than 20 years at eight of 10 stations, and greater than 100 years at five of 10 stations. Streamflow return periods for Lee were less extreme than for Irene, with only one station greater than 20 years. When considering warm season events only, return periods for Irene increase in comparison to annual results at almost all stations, with about half of the stations showing an increase greater than 100%. For Lee, warm season results increase in comparison to annual results at nine of 10 stations. Except for one station, 60-day average streamflow during fall 2011 was the first-, second-, or third-highest on record (Table A-2).

Table A-2. Hurricane Irene and Tropical Storm Lee estimated annual and warm streamflow return period

Also included is the rank of the 2011 60-day mean streamflow

USGS ID Number	Gauge Name (County)	Drainage Area (sq. km)	Record Period for Frequency analysis	Irene Annual Return Period (yrs)	Irene Warm Season Return (yrs)	Lee Annual Return Period (yrs)	Lee Warm Season Return (years)	Rank of 2011 60-day mean stream flow
1350000	Schoharie Creek at Prattsville (Greene)	613.829645	1936 - 2011	> 1000	n/a	4	9	3
1362200	Esopus Creek at Allaben (Ulster)	164.982904	1964 - 2011	981	1406	2	5	1
1362500	Esopus Creek at Coldbrook (Ulster)	497.279712	1936 - 2011	77	172	4	12	1
1371500	Walkkill River at Gardiner (Ulster)	1800.04896	1936 - 2011	116	249	64	127	1
1413500	East Branch Delaware River at Margaretville (Delaware)	347.059799	1937 - 2011	385	324	6	6	1
1414500	Mill Brook Near Dunraven (Delaware)	859.879502	1937 - 2011	22	n/a	4	11	4
1415000	Tremper Kill Near Andes (Delaware)	422.169756	1937 - 2011	3	13	3	9	n/a
1421900	West Branch Delaware River Upstream from Delhi (Delaware)	65.2679622	1958 - 2011	31	96	11	28	n/a
1423000	West Branch Delaware River at Walton (Delaware)	85.9879502	1951 - 2011	7	29	12	26	1
1435000	Neversink River Near Claryville (Sullivan)	172.4939	1939 - 2011	109	49	< 2	5	2

A.2.5 Has the frequency of extreme events changed during the period of record?

Finally, variations in the frequency of extreme events during the periods of record for stations in this region were examined. For each precipitation and streamflow gauge station, the magnitude of the 95th percentile event (4-day total precipitation or daily streamflow) was calculated using all events from the entire period of record, and then make a yearly count of how many such events occur, resulting in an annual time series.

An example of such an analysis for one station (Ellenville in Orange County) is shown in Figure A-14. Figures A-14a and A-14b show scatter plots of 4-day precipitation for each season (with one cross for each event); 95th percentile values are indicated by the horizontal line. Warm season extreme (95th percentile) precipitation events are larger than cold season extreme events at this station (and, in fact, at all stations). The resulting time series of the number of extreme events per season (Figures A-14c and A-14d for cold and warm season, respectively) indicate significant interannual variations. Superimposed on the annual time series is the smoothed (11-year centered mean), which we use to represent decadal scale fluctuations in the frequency of extreme events. The maximum smoothed value (or values, if two or more years had the same maximum value) is indicated with a circle. For this station, one can see that the number of extreme events per smoothed 11-year period during the cold season peaked near 1980, while the number of extreme events during the warm season has reached the historical highest values on record during the most recent decade.

To provide a time series that represents regional scale variations in the frequency of extreme events, results from individual stations are combined for precipitation (Figure A-15) and streamflow (Figure A-16). These figures were produced by calculating the mean, for each year, of the number of extreme events at all available stations. The dry 1960s are apparent in the annual records as well as in the records from each individual season. However, the wet 2000s are only apparent during the warm season (Figure A-15). A dramatic increase in extreme precipitation frequency since the 1980s is apparent during the warm season (and in the annual mean records) but not during the cold season. The mean number of extreme precipitation events per year has increased from approximately 0.6 during the early 1980s to approximately 1.8 during the most recent decade. Also shown is the time series of number of stations per year included in the regional mean (Figure A-15d).

The regional mean frequency of extreme streamflow events was relatively high during the 1970s and low during the 1960s in both the cold and warm seasons (Figure A-16). During the warm season only (Figure A-16a) the occurrence of extreme streamflow has increased dramatically since the mid-1990s, and has reached historical highest values in the most recent decade. The regional mean frequency of extreme events has increased from approximately six per year in the mid-1990s to approximately sixteen per year during the most recent decade. This recent increase in warm (but not cold) season streamflow is related to the increased frequency of extreme precipitation events, and also to an increase in the frequency of extreme 30-day antecedent totals prior to extreme precipitation events (not shown here).

This analysis is important for improving our understanding of the baseline regional hydrology and its variability, and to better address the challenges imposed by climate change adaptation and better serve stakeholders and community needs. Maintenance of stream and weather monitoring stations are important for extending existing historical records to evaluate climatic variations in this region.

Figure A-14. Example of nonparametric analysis for the Ellenville precipitation record

(a) and (b) show the magnitudes of every 4-day precipitation event on record during cold and warm seasons, respectively. Also shown is the 95th percentile value and the top 5 historical extreme events (blue circles). (c) and (d) show the number of extreme (i.e., ≥ 95 th percentile) events per year, as well as a smooth line (i.e. 11-year centered mean) and a blue circle indicating the year(s) with the highest smoothed value. Figure adapted from Matonse and Frei (2013).

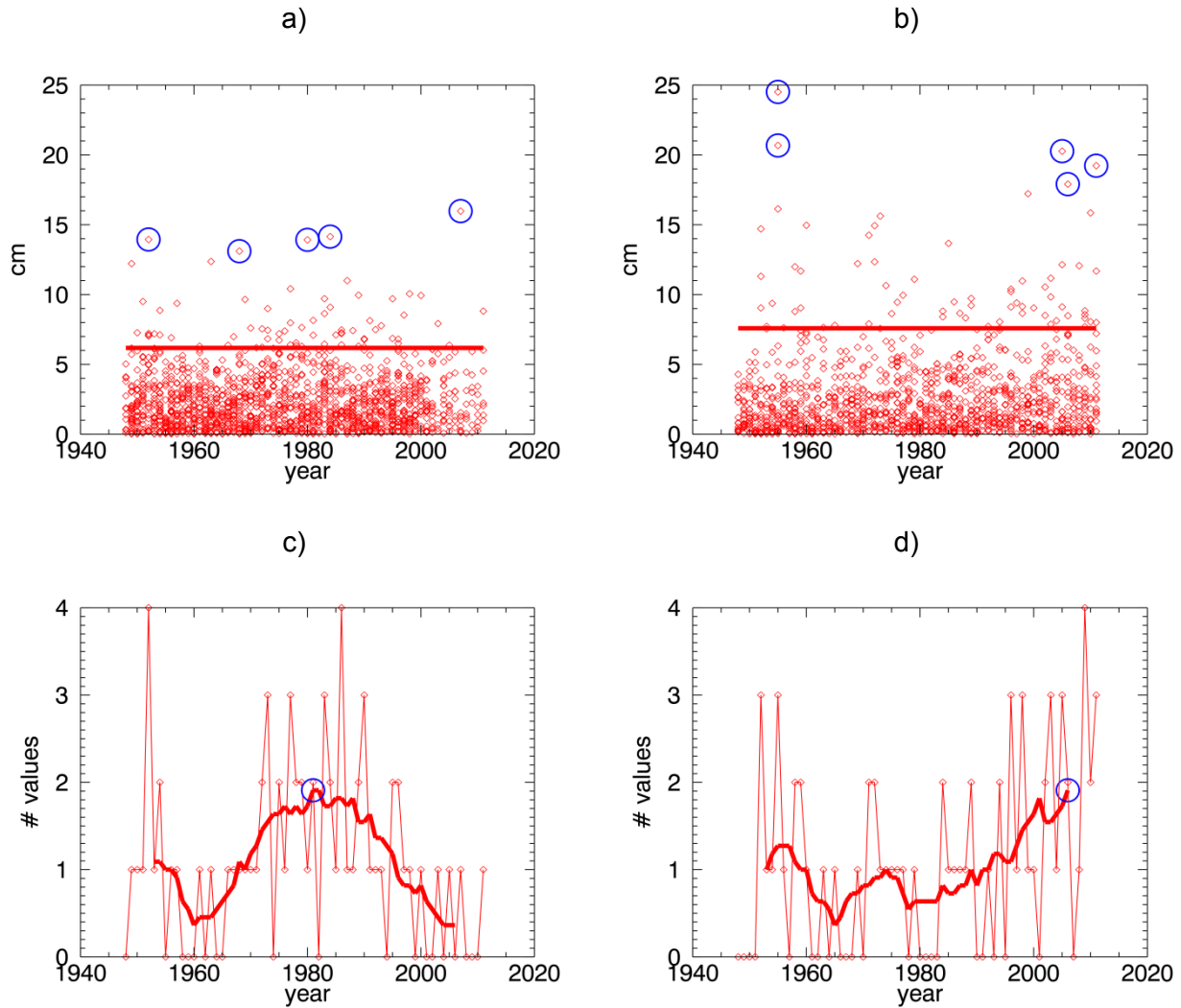


Figure A-15. Regional mean number of 95th percentile 4-day precipitation values per year

For each year, the number of 95%tile values per year, averaged over all stations available, is shown (solid line) along with the 11-year running mean (bold line) and a blue circle indicating the year with the highest smoothed value. Panel a) includes warm season values only; b) includes cold season values only; c) includes values from all months; d) shows the number of stations available for each year of calculations. Figure adapted from Matonse and Frei (2013)

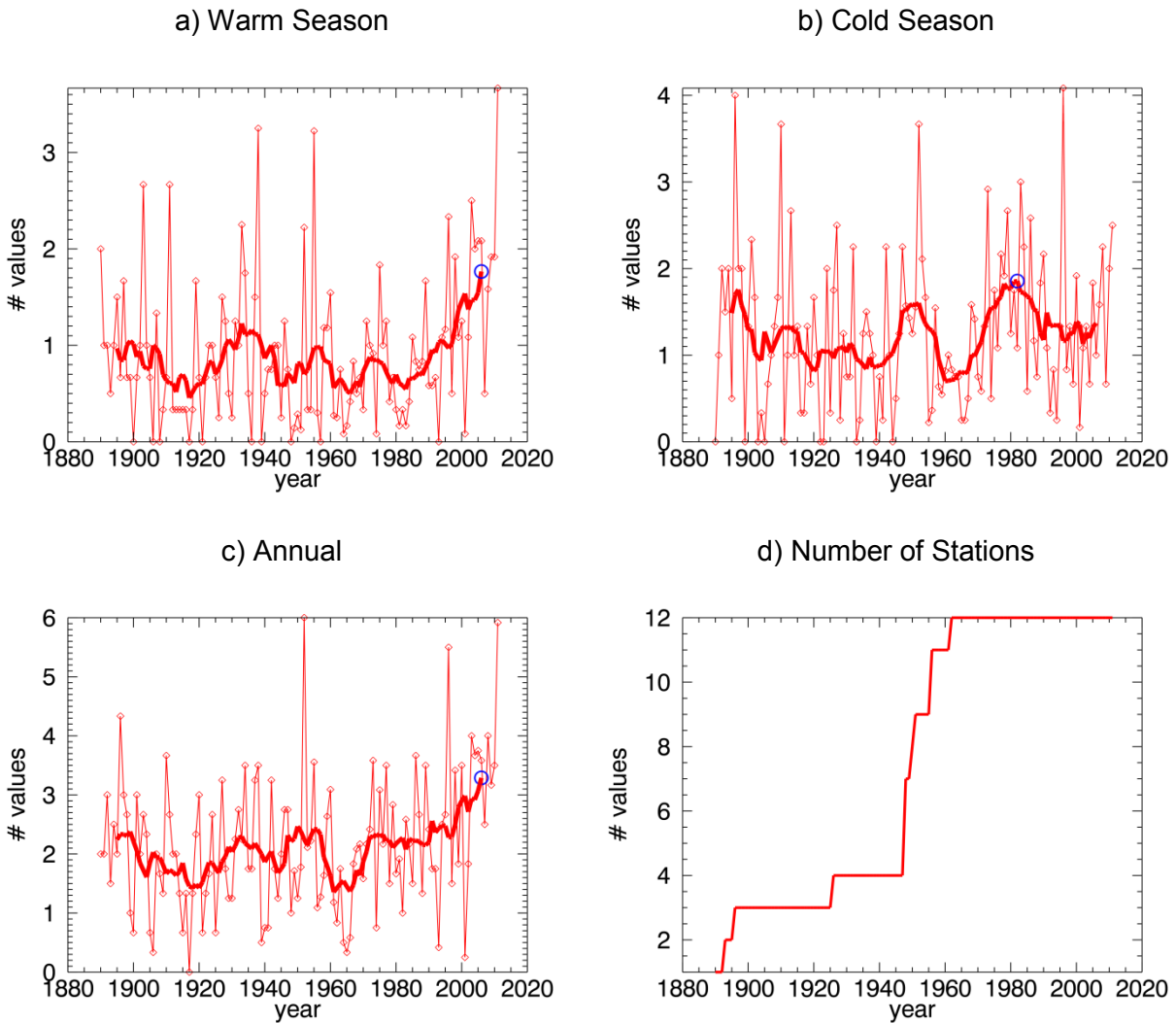
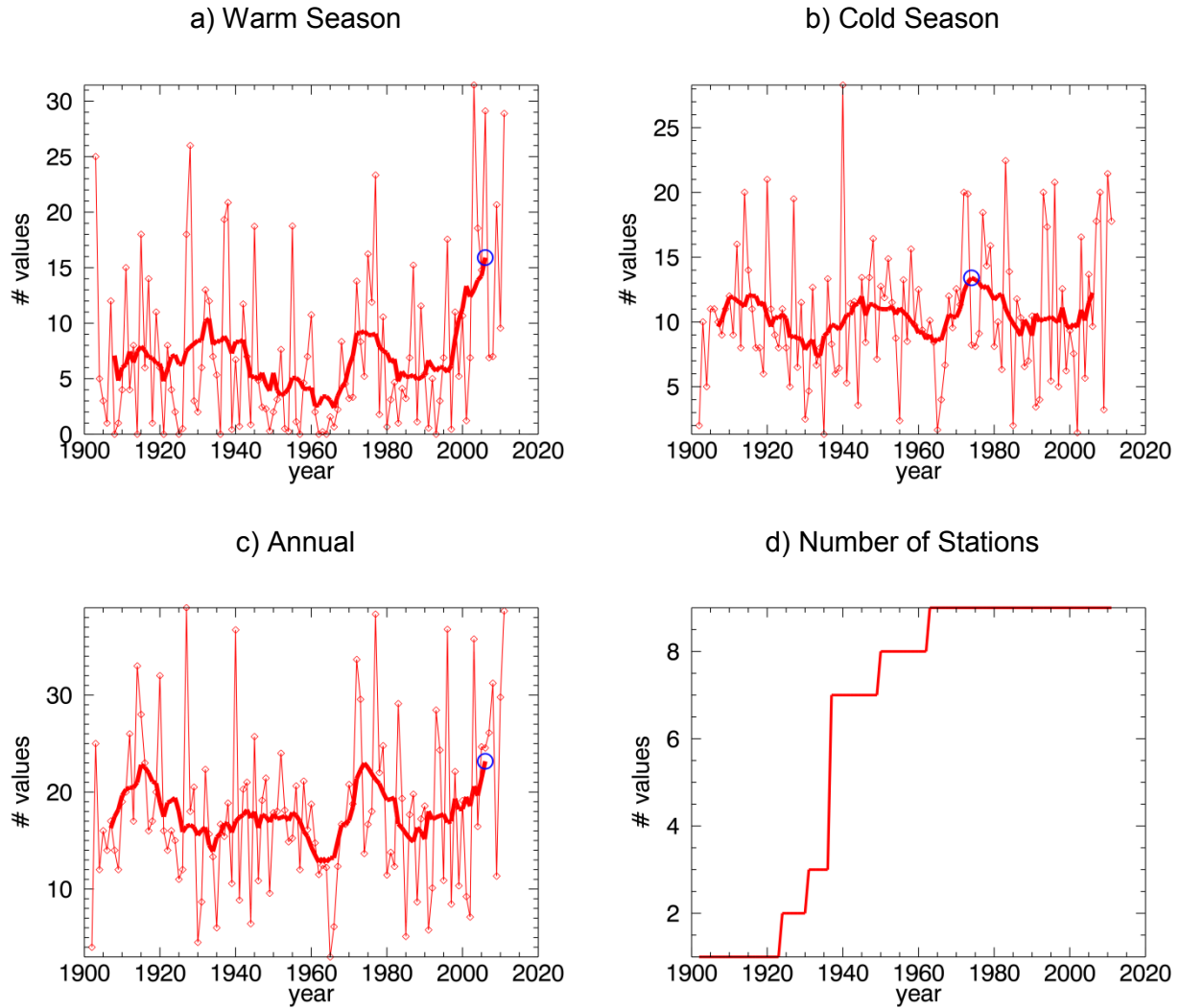


Figure A-16. Regional mean number of 95th percentile daily streamflow values per year

For each year, the number of 95%tile values per year, averaged over all stations available, is shown (solid line) along with the 11-year running mean (bold line) and a circle indicating the year with the highest smoothed value. Panel a) includes warm season values only; b) includes cold season values only; c) includes values from all months; d) shows the number of stations available for each year of calculations. Figure adapted from Matonse and Frei (2013)



A.3 Interview Participants and Questions

- Ashokan Watershed Stream Management Program, USDA-NRCS
- Black Dirt farmer
- Builders Association of the Hudson Valley
- Central Hudson Gas & Electric
- NYS Department of Environmental Conservation, Hudson River National Estuarine Research Reserve
- NYS Department of Transportation
- Orange County Cornell Cooperative Extension
- Orange County Department of Planning
- Orange County legislator
- Orange County Municipal Planning Federation
- Orange County Soil & Water Conservation District
- Palisades Interstate Park Commission
- Town of Goshen
- Town of Shandaken
- Town of Ulster
- Town of Warwick
- Ulster County Department of Environment
- Ulster County Planning Department
- Village of Woodbury

Table A-3. Interview Questions for Local and State Level Stakeholders and Decision Makers

Questions about Flooding Impacts
1. What do you consider the key impacts and costs (economic, social, or physical) as a result of H. Irene and T.S. Lee (either within your community or area of professional responsibility as appropriate)? What do you consider to be the key immediate impacts and possible longer term impacts?
2. Which groups or types of individuals within the impacted region (or community, as appropriate) do you think were most affected (economically, socially, physically) by the flooding? Why do you feel these groups were most adversely affected?
3. In what ways did the two events (Irene and Lee) exceed your expectations (understanding) of the flooding potential in the region (community, as appropriate)?
4. Besides the fact that there was a lot of rain associated with the storms why do you think the local flooding became so intense and widespread?
5. Were there any unexpected surprises related to the impacts and capacity to respond - both in the immediate response and longer-term (i.e., days and weeks following) that emerged during or after the storm? For example, did things occur that you never expected would become an issue (i.e. they were never thought of as an issue in this part of the New York State)?
Questions about the Response to the Flooding Impacts
6. What are key activities that were done or are still being done in response to the flooding that took place? Why are these activities taking place (e.g. required to by law or regulation, new policy, etc.)? What activities (if any) were you involved with in a major way (i.e., committed significant time or resources)?
7. If you were (are) involved in responding to the storm and flooding events in a professional capacity, what kind of things (data and information, human resources, financial resources etc.) were most useful for you?
8. If you were (are) involved in responding to the storm and flooding events in a professional capacity, what kind of things (e.g., data and information, human resources, financial resources etc.) did you need but were not available? What were the most critical items that were not available in a timely fashion (i.e. came too late to be really useful) or were not available at all?
9. Do you feel that there are any limitations in achieving success with respect to these new initiatives (e.g. what new data and information is needed, is there a clear policy mandate and are the resources available)?
10. Which of the new activities do you feel will make the most significant improvement in the capacity of the region (community as appropriate) to respond to another event. In what ways, do you feel that these activities will make the region (community as appropriate) better prepared? How so?
11. How have these recent events changed your agency's (community's as appropriate) funding or budget priorities with respect to extreme climate event response and planning? For example, have there been decisions to re-allocate funding as a result of the flood? In your professional opinion, are there any steps that you think need to be taken but have not been taken as of yet? Why have they not been taken?
12. How has Hurricane Irene changed your own professional thinking about local flooding, either within this region specifically or New York State generally? Why do you feel your thinking has changed? What factors do you feel most influenced your thinking?

A.4 Detailed Summary of Interview Responses

A.4.1 Storm Flood Impact and Costs

What do you consider the key impacts and costs (e.g., residential, commercial, municipal, etc.) as a result of H. Irene and T.S. Lee (either within your community or area of professional responsibility as appropriate)? What do you consider to be the key immediate impacts and possible longer-term impacts?

Several general statements regarding key impacts and costs were made by the interviewees. The storm damage was widespread in each county with many, but not all, of the high-risk locations flooded. Some areas with no previous record of flooding were flooded. Damage was experienced in the residential, commercial, and municipal sectors in both counties. Higher infrastructure damage amounts were concentrated in specific locations across the counties (water and sewage facilities in Orange County for example). Overall, damage was greater in Ulster County where there were more disruptions to everyday life, particularly from decimated networks of roads. The single largest impact resulted from the costs associated with the loss and repair of the Metro-North West-of-Hudson commuter rail line in Orange County, which cost an estimated \$55 million. The most significant driver of the damage and disruptions was from flooding as opposed to wind damage. The flooding damage resulted from the height of the flood waters, their intensity as well as their persistence – how long the elevated flood waters were present.

In many cases, respondents said that there was flooding in places where it had not previously flooded in recent time. With respect to specific economic sectors, agriculture and tourism stood out as the two sectors that were most impacted. The impacts on these sectors occurred partially as a result of the time of the year. The storm hit just before Labor Day weekend, a major holiday weekend and at the beginning of the fall tourist season. In the agricultural sector, many crops that were about to be harvested were lost to inundations. This was reported for crops such as tomatoes, lettuce, pumpkins, and wine grapes among others.

A significant and challenging issue for local officials and others involved in decisions about responding to flooding and allocating funding for repairs is the risk of reducing local property tax revenues when properties are determined to be more than 50% damaged, termed “substantially damaged.” Local building and code enforcement officials are typically responsible for assessing damage to homes and making these determinations, yet several respondents noted that these officials have a dis-incentive to determine that property damage exceeds this 50% threshold. If homes are condemned, the home value is reduced and property tax assessments go down. If the home is condemned and the owner does not rebuild, this becomes a long-term loss of local revenue. In rural communities in Ulster County with small populations, the loss of even a few dozen homes has a significant impact to the property tax base. Respondents reported that as a result, there’s a pattern of local officials underestimating property tax damage. A related issue is that local officials often know owners personally, especially in smaller towns, and this is another factor that tends to lead to underestimating damage due to potential financial impacts to these owners.

A.4.2 Significant Impacts

Which groups or types of individuals within the region do you think were most impacted by the flooding (for example, economically, socially, or physically)? Why do you feel these groups were most adversely affected?

Economic sectors that were impacted significantly by the storms include tourism and agriculture in both counties. Infrastructure categories that were impacted significantly include transportation – roads, bridges, rail lines, electric and gas utilities, and water and wastewater systems, including pipelines and treatment plants. Several small dams were destroyed or damaged, including at least one at a drinking water reservoir. Numerous hotels in the two counties were damaged which resulted in secondary impacts associated with the loss of hotel rooms. A local museum also suffered flood damage.

A series of short term and immediate impacts as well as longer term impacts were discussed by the respondents. With this storm, many areas in Orange County that typically flood were flooded, with one exception being a neighborhood in western Orange County with lower income homes. This area typically floods but did not flood following Irene, due to lower rainfall amounts across western Orange County. Groups affected the most economically included farmers in the Black Dirt muckland area of Orange county, (a large floodplain along the Wallkill River), property owners in flood plains in both counties, including homes, businesses, municipalities and other organizations, some property owners in upland (i.e., non-floodplain) areas that flooded where smaller headwater streams or roadside ditches flooded, farmers in floodplains along the Wallkill and Esopus Creeks in Ulster County, and businesses and other entities whose activity was disrupted through direct flooding or loss of business. On farms, crops exposed to floodwaters could not be sold since the release of toxic materials and pathogens via floodwaters can spoil crops.

It is important to recognize a distinction between whether areas and people were impacted by the storm in terms of economic losses, social dislocation or physical change, and how well they were able to recover from the impacts. For example, several interviews confirmed that poorer residents were less able to recover from the storm's impact. A trailer park in Ulster County was severely damaged and likely will not be rebuilt. Similarly, businesses that were struggling prior to the storms were less able to respond after the storms. Some reportedly questioned whether to take out loans to rebuild, given their already marginal economic condition. In some downtown business districts, even while some businesses were able to reopen within 4-5 days after the storms, signage about detours and closures on nearby main roads reportedly did not clearly alert tourists and created the impression that downtown areas were still closed, leading to a loss of business. Two respondents also mentioned that the storms created economic opportunity especially within the building and engineering sectors, including restoration companies which specialize in work in the wake of disasters, some of which are national franchises.

In certain locations, physical isolation was another significant impact that resulted from storms Irene and Lee. It was noted that people in very rural areas of Ulster County, some of which have no cell service, had difficulty with communication. Where power was out, and land line/cellphone service was down or disrupted following the storm, some people had no outside information sources aside from municipal officials or neighbors. In some cases, damage to bridges or road closures physically cut off individual homes or neighborhoods from access to outside areas. Under these circumstances, individuals could only receive outside information from people traveling into storm-ravaged areas on foot. Elderly and infirm people were especially vulnerable to the repercussions of Irene and Lee.

Several respondents noted that in the Catskill Mountain region in Ulster County, precipitation amounts can vary significantly over small geographic areas, with localized areas receiving much higher amounts than other proximal areas. Even if precipitation amounts do not vary significantly, the topography of small mountain valleys in this area can lead to significantly worse flooding in some areas and little to no flood related impacts in others.

In addition to physical, economic and social impacts, several respondents noted their own or others' psychological impacts from the storms and the aftermath. At least one individual reported an immediate family member had to go to the hospital for several days due to anxiety after the flooding of their land. This individual now experiences anxiety during each rainfall event. Similar effects were reported by at least one professional involved in emergency management and by others interviewed.

A.4.3 Impacts and Expectations

Did the impacts exceed your expectation with respect flooding extent and consequences? If so, in what ways did the two events (Irene and Lee) exceed your expectations (understanding) of the flooding potential in the region?

According to many respondents, the storm's impacts exceeded expectations. The amount of rain and flooding was particularly surprising to many people. Winds proved to have a lesser impact. The storms exceeded respondents' understanding, because people did not conceive of flooding as an issue of volume, but more or less an issue of water height. In some locations in the Wallkill floodplain, respondents were surprised by how convoluted the hydrology was where water elevations rose, fell back and rose again especially in the Black Dirt area of Orange County. In this area, the water rises and spills over the bank, and spreads over the landscape. What was unusual with Irene is how long the floodwaters took to recede. With Lee following soon after, the area became flooded for weeks. Flooding of agricultural areas in Orange County lead to unexpected loss of crops and produce for local farm stands.

The amount of stream scouring that took place also was unexpected and in some case unprecedented. Some of this damage occurred in higher elevation areas that are not floodplains. The hydrology of the Orange County involves a series of steps that are relatively flat. The flow between these areas is punctuated by steeper gradients that resulted during Hurricane Irene in more intensive water rushing and scouring. In Ulster County, the hydrology is more rugged with more consistent slopes and relatively narrow river valleys that during Irene, lead to scouring throughout.

A.4.4 Non-rain Factors for Flooding

There was a large amount of rain associated with both storms. Do you think any other factors contributed to the intensity and breadth of the flooding?

While it is clear that the amount of precipitation was the major contributing factor in the flooding from Hurricane Irene, respondents considered other factors as to why the flooding was so intense and widespread. Beyond Hurricane Irene rainfall, interviewees recognized that there were ample rainfall events before this storm last year (the extent of which is noted in the hydrology section in the early part of this report). In Orange County, there were many responses that focused on the respondents' understanding of local hydrology. People thought that vegetative growth and debris along the stream banks slowed the water flow and as a result restricted flow and contributed to flooding.

Many respondents thought that the local rivers and their banks had not been maintained and dredged. They believed that over time, sediment from upland erosion had accumulated in stream channels, resulting in a decreased capacity to move water. As a result, in their view the flood water backed up and rose higher than expected. Another factor noted was water release from upstream lakes and ponds. Several respondents felt that organizations responsible for maintaining certain water bodies released water at critical periods during the storm, thereby exacerbating flooding in downstream areas. Some people questioned why water could not be released before storms, when flooding is predicted, to free up storage capacity in these impoundments and thereby help to reduce downstream flooding. Fundamentally, people pointed to hydrologic mismanagement as a critical additional factor as to why flooding occurred. Many respondents indicated that they felt that the rivers need to be dredged, stream banks need to be cleared, and management of water releases before and during storms needs to be better regulated or coordinated. In certain locations, another factor cited by respondents is the presence of a dam that is believed to cause a backup of water into neighborhoods, thereby increasing the height of flood waters and resulting damage. Respondents expressed perception that the NYS should maintain rivers. At the same time, NYS DEC stated that they did not have regulatory authority for this type of maintenance. A lack of understanding of the NYS' authority over the issue was evident. One state staff person noted that the responsibility for floodplain planning and management is, to a large extent, held by local government, through home rule land use authority and perhaps other pathways, and the federal government through the National Flood Insurance Program.

A related issue regarding the risks and impacts of the flooding is people's response to road closures. Several respondents noted a significant problem with people driving around barricades and thereby increasing the risk that they would be injured, which also creates increased risk and workload for first responders. In one case in Orange County, a driver was reportedly charged with reckless endangerment for driving around a barricade with a child in the car. Related situations arise when people do not want to leave their homes even when forecasts or rising floodwaters present significant risks.

A.4.5 Surprises – Impacts and Capacity to Respond:

Were there any unexpected surprises? For example, did things occur that you never expected would become an issue (i.e. they were never thought of as an issue in this part of the New York State)?

Several surprises related to the impacts and community's capacity to respond, both in the immediate response (days) and longer-term (weeks, months), emerged during or after the storm. Most respondents said that initial responses following Irene were "very good" as a result of hard work by municipal officials and staff, first responders including volunteer fire departments and other emergency service workers, and by neighbors and other volunteers helping each other. Most people felt the response was as good as it could be considering the situation and proved to be instrumental in preventing the situation following Irene from worsening. Respondents said the State of New York provided crucial immediate and long-term advice and support. According to one respondent, the large response in the aftermath of Irene proved to assist communities economically and socially. Local fund-raising also took place to help some local entities and businesses. Local farmers in particular were assisted by fund-raising and external financial aid.

Unexpected physical impacts associated with emergent vulnerabilities were observed as well. The unprecedented riverine scouring moved large quantities of sediment and rocks, resulting in minor to dramatic changes in stream channels in some locations. Many trees along streams were undermined and washed away, creating large amounts of woody debris, requiring removal projects in some cases (i.e., under bridges). The amount of debris washed downstream was unexpected as was the type and extensiveness of scouring. Some farm fields lost all of their topsoil. Multiple respondents were shocked by the length of time Black Dirt was underwater. Individuals expected some flooding, but not the extended period of time it took for floodwaters to recede. Wind was not a major issue, but widespread flooding resulted in real surprises. Utilities expected wind and power outages, but a failure of a gas main (from washout of a stream bank and collapse of an above hillside) was not anticipated and became a costly repair project. Flooding caused the loss of some utility poles (some washed away entirely). Generally, damage facilitated by floodwaters greatly outweighed wind related damage.

A.4.6 Climate Change – Present and Future

Do you feel that the climate in the region is changing? What types of physical or environmental changes do you expect under predicted changes in climate and climate variability? If any, what types of physical impacts do you expect as a result of these changes in the near term (next 1-2 years)? What about in the long term (next ten years and beyond)?

The level of understanding of the science of climate change overall was not high. In general, there was a sense that local communities need to prepare more and better for these types of events in the future. More than half of the respondents thought such an impactful and damaging storm can happen again in their lifetime. Only one person thought Irene was a once-in-a-lifetime occurrence. A number of people noted that the predicted return interval for floods is not a good indicator of actual frequency. For example, an individual claimed that they had experienced four 100-year floods in the last 10 years. As for potential long-term changes, people thought changes in precipitation patterns were likely. It should be noted that the storms did not necessarily change people's perception of the likelihood of changes in climate because many had already accepted that the climate seemed to be changing.

Respondents have voiced a need for better hydrologic science, more and improved stream management, and the removal of obstacles perceived to be slowing or blocking river flow. Some people have started integrating thoughts about changes in climate into their decision making process, but only to a moderate extent if at all. Respondents involved with seasonally dependent business and economic activities were most attuned to the possibility of a changing climate.

A.4.7 Key Activities

From your perspectives what key activities were done or are still being done in response to the flooding? Why are these key activities taking place (e.g. required to by law or regulation, new policy, etc.)? Were you involved in any of these activities in a major way (i.e., committed significant time or resources)?

Respondents were asked what key activities were done or are still being done in response to the flooding, and what was driving these activities (e.g., were they required to by law or regulation, new policy, etc.)? In general, the respondents focused on the short-term response that took place especially regarding the emergency response and how to make it better and more effective. Respondents did not feel like they have control over long-term response, whether they were farmers or local politicians, and as a result did not focus much on those issues. Many activities were sector or industry specific, for example working with local farmers.

The interviewees who had responsibilities related to the storm at their jobs had to spend a lot of time documenting what happened, and what the losses were. The immediate response and short term aftermath period where all work was focused on the storm impacts took place over a period of several months. In many cases, all other work had to be put aside during this time, at least in the days and weeks after Irene. Everyone whose job was relevant to response and recovery and assessment was involved in a major way, to the point where the time demands became a problem for many. Some first responders were volunteers, such as fire and ambulance crews. Some first responders, including volunteers and elected and paid staff, had damage to their own homes and had to manage personal and family issues even while responding in their professional or volunteer demands.

In several interviews, people talked about cases where the first responders, town hall, or emergency services were physically impacted by the storm. For example, in some towns the police department building was in a flood zone, or the road leading to the building in a flood zone (people did not think about this before). Evidently, the storm identified weak links in the disaster recovery capacity of towns impacted by the storms.

A.4.8 Most Useful Tools and Resources

*If you were (are) involved in responding to the storm and flooding events in a professional capacity, what kind of tools and resources (data and information, human resources, financial resources etc.) **were most** useful for you in the immediate aftermath, and in the longer term following the flooding?*

Respondents were asked what kind of tools and resources (data and information, human resources, financial resources etc.) were most useful in the immediate aftermath and in the longer term following the flooding. In response, many respondents talked positively about human resources and their capacity to effectively mobilize and work together to respond to the storms' impacts. Different local, county, and state personnel worked together well. During the storm and in the day or two following most local communities had to rely on local personnel before staff and assistance from non-local agencies could provide assistance and aid.

Quite a few people stated that they had access to a lot of important data and information that helped in the response including the locations and types of damage, where people were in need of assistance or evacuation, availability of needed resources among other data. Face-to-face communication and sector-specific organizing proved to be very powerful. Some interviewees mentioned that they were using their phone line and social media (Facebook, etc.) to communicate with people, and in some cases to receive information coming from the public. Emergency service respondents also used social media. Both utility and emergency respondents were able to identify problem areas through information that was coming in to them. During the immediacy of the emergency response financial resource limitations were not considered a priority.

Immediate repairs to public infrastructure were undertaken by municipal, county and state staff, and in some cases by contractors hired by government entities. The ability to move quickly to contract was important. Some contractors lent equipment to government entities. Adequate construction materials were available, but one respondent noted that if the real estate and construction markets were not as slow as they had been, there could have been more shortages. In the winter months, because temperatures were mild, some repair projects were able to continue through the winter months (i.e., an asphalt plant was able to open earlier than usual in early 2012 enabling faster project completion).

A.4.9 Most Important Tools or Resources Not Available

*If you were (are) involved in responding to the storm and flooding events in a professional capacity, what kind of tools and resources (e.g., data and information, human resources, financial resources etc.) did you need that **were not available**? Were they not available in a timely fashion, (i.e., came too late to be really useful), or not available at all?*

Respondents were asked what kind of tools and resources (e.g., data and information, human resources, financial resources etc.) were not available, and if they were not initially available in a timely fashion, did they eventually arrive or did they not available at all? A key tool or resource that was identified as missing during critical moments by respondents was data and information availability and accessibility. For example, respondents involved in assessing flood damage and addressing related questions relevant to potential FEMA reimbursement for repairs wanted paper maps in the field, but FEMA now relies on digital maps. Some respondents wanted more digital tools, such as hand-held devices for workers in the field, which would have allowed respondents to send data back to command centers and allow instant access to maps and other data. In general, this was the first time responders were using Web-based information exchanges during a large scale emergency, but individuals in the field lacked the technical tools for gathering, inputting, cataloging and sharing data. The NYS DOT's Incident Command System worked well, and this system is linked to one used by other state agencies as well. (This ICS is a "systematic tool for command, control and coordination" used by NYS DOT management and field staff during emergency operations to manage communications and coordinate decision-making about resource allocation, prioritizing response at specific locations, and other aspects of emergency response. It is related to the National Incident Management System, a framework for coordination within and between agencies (Clements 2011).

Respondents also mentioned a lack of physical materials such as cots for shelters and road barriers, yet questioned the feasibility of making investments in purchases that might not be used for many years. At least one individual suggested that a county or regional approach to stockpiling key items might be logical. There are mutual aid agreements among utilities for sharing crews after emergencies, but this event was unusual because Irene was predicted to impact a large area along much of the East coast. This created restrictions on securing commitments for out of state crews before the storms. Utilities from southern portions of the US expected to need their crews available locally (after Irene passed Florida and Georgia with less damage than expected, utilities did free up crews to head to New York). However, at the local level people in hard hit areas did not hear too much about people in critical positions such as emergency first responders (police, fire and ambulance crews) or staff or contractors needed for repairs to roads and other infrastructure being in short supply. An important question for respondents was whether the State of New York would provide compensation for local government expenditures related to the storms. Information on disaster relief fund and recovery grants to local governments was not made readily available. For example, FEMA had a cadre of people on reserve to help communities (e.g., retired state staff) that many respondents did not know about. The respondents felt there was value in having information about programs made quickly available. The need for rapid information was acutely present within specific sectors such as the local tourism industry.

A major need identified by at least one respondent (who was involved in providing information about the state's planning and permitting role for streams and floodplains) is better educational tools and resources for local officials and the public, on the basic hydrology of watersheds, streams and floodplains and what mitigation strategies are actually feasible. There is a widespread perception that widening and deepening stream channels should enable them to move more water more quickly. There is a lack of awareness about some fundamental aspects of stream geomorphology, the role of sediment erosion and deposition in shaping stream channels, and how these principles can guide stream management and restoration designs. Some educational work has been implemented to address these issues but more is probably needed. A closely related issue is perceptions and attitudes toward wetlands and regulations to protect them. A current topic of significant discussion in Orange County is the NYS DEC's proposed, revised wetland maps that would increase the geographic area designated as wetlands subject to state permitting requirements. Some stakeholders in the real estate and business community have mounted a strong campaign against adoption of these new maps, noting that regulating more areas will affect certain property owners and potential development. Several respondents raised this general issue and this campaign specifically and suggested that more education is needed about the value of wetlands for holding floodwaters and thereby reducing flooding downstream because this message is largely lacking in the broader public dialogue (it is, however, axiomatic within environmental and some land use planning sectors).

One critical distinction that needs to be recognized in educational programs is the difference between the current ability to design and prepare for moderate-sized storms (e.g., 2-4 inches of precipitation). Certain measures may be able to significantly mitigate some risks (and larger events), but even the most ambitious and costly available measures may not be able to make much difference in some parts of the landscape.

There are related, challenging policy tradeoffs that were mentioned by a number of respondents regarding where and whether resources should be invested to rebuild homes, roads, and other infrastructure, if infrastructure is likely to be damaged severely again in future storms. It should be noted that none of the subjects interviewed were directly involved in higher-level policy discussions reportedly being held at the state level through the Long Term Recovery Task Force and perhaps other channels. Specific decisions related to these issues are involved when officials and staff are designing culvert and bridge repairs and replacements, namely, what size storm should they be designed for? This question is further complicated by the fact that precipitation patterns have changed in the last 50-60 years. In the wettest part of Ulster County, in the Shandaken area, for example, the peak 24-hour rainfall during the 100-year storm has reportedly shifted from 8 inches in 1966 to 13 inches in 2003. Since climate predictions indicate this upward trend in precipitation may continue, design professionals, local officials and other stakeholders face considerable uncertainty as they attempt to plan infrastructure repairs and upgrades to handle storms of a given size (e.g., 50 or 100-year floods).

A.4.10 Opportunities to Improve Response Capacity

Which items do you feel will make the most significant improvement in the capacity of the area to respond to another event? Why do feel they will make the region better prepared? If you were to do one thing, what would you recommend doing?

Interviewees were asked which activities they felt would make the most significant improvement in the capacity of the area to respond to another event. Specifically, they were asked what specific things would they recommend. At a general level, respondents stated that rapid cataloging and inventory of the impacts were most important to improve response capacity and as a way to reassure the public that the impacted location(s) will be able to recover. On a more specific level, several respondents said they wanted to know how to better study and manage the regional hydrology, and how to prevent extensive flooding. There was a sentiment that we have allowed the streams to become too natural, and that there should be closer oversight. As a related matter, many expressed a concern that “DEC doesn’t let us do this [clear the streams], and they care more about the animals.” On this note, there is an understanding among some respondents that even while they may be frustrated with NYS DEC’s permitting process and restrictions on stream activities, they realize that it is not simple to repair damage in and along streams in a way

that does not cause other problems. Some training and education for local officials had been implemented in recent years on stream geomorphology principles, to help provide public works officials and others with a basic understanding of key concepts to guide stream management projects. This activity has been primarily or exclusively in the New York City watershed in the Catskills, but is now planned to be made available to other areas. One other key area where education is probably needed is on the rationale and regulatory framework for NYS DEC decisions about permitting projects in streams. There is a widespread perception that NYS DEC's primary priorities and goals are for protecting wildlife habitat and perhaps water quality. But NYS DEC's review of proposed projects reportedly includes a strong focus on ensuring that they will not cause a flooding or erosion problem for other landowners downstream of the project site, and based on respondents' comments, this is not well understood by many local officials and other people who are involved in local and county government and other relevant sectors.

Increased resources for public education to raise awareness about flood risks may be useful to address the tendency to ignore road closure barricades and signs and thereby create additional risk for individuals who drive around them and first responders who may be called upon as a result. The regulatory and other roles of different agencies and levels of government regarding floodplain planning, management and related issues is another key area where additional education resources for the public, local officials, farmers and others may be important, to address the apparent lack of knowledge and misunderstandings about which agencies have relevant jurisdiction and responsibilities at the local, county, state, and federal levels.

More broadly, responses from a number of subjects suggest the need for education and dialogue about appropriate policies for where to invest public resources in re-building and upgrading infrastructure, and about how these issues can be coordinated with land use planning for smart growth and sustainability. Strong feelings were expressed by several respondents who felt that where homes, farms and other existing development are in or near floodplains, it is appropriate to re-invest in measures to protect them, even if they are at higher risk of being damaged by future storms. However, these individuals also support building codes and restrictions to limit new development on floodplains.

On another policy front, at least one respondent noted the need to re-visit regulatory strategies for protecting wetlands in some areas. For example, where a wetland is located in an existing urban neighborhood that is designated as a priority growth area, smart growth should be encouraged. This respondent suggested that a planning approach is needed to find areas where mitigation wetlands can be developed in coordination with smart growth planning, yet noted that some NYS DEC officials seemed reluctant to discuss a revised approach to their regulatory program.

A.4.11 Limitations or Barriers to Most Critical Tools or Resources

Do you feel that there are any limitations or significant barriers to developing or making the most critical tools and/or resources available (for example, if new data and information is needed, there is no clear policy mandate and resources available to make them happen)? What are the limitations or barriers?

Respondents were asked to express their thoughts on any limitations or significant barriers to developing or making the most critical tools and/or resources available and what they perceive as limitations or barriers to their availability, if any. Respondents said that they wanted better information about the local and regional hydrology. Also, they wanted to know more about the upstream water managers and know who they were and how to better understand their water management decisions and how to better coordinate with them. Particularly in Orange County, individuals want to know how and why floodwaters rise and fall. Respondents also talked about information tools including hand held tools, maps, and ways to send data into a central location or website as a barrier to availability of additional resources. Physical barriers, specifically not being able to get to a certain place for a while and resulting delays in damage assessment, was defined as an issue as well.

Individuals also cited a demand for state level initiative and leadership, especially in the realm of stream management. Many interviewees mentioned that state regulations are a significant barrier to action especially on issues such as stream dredging. It was understood that some local people actually went out and did stream dredging and debris removal from streams themselves without having permits.

A.4.12 Hurricane Irene and New Priority Setting

How have these recent events changed your agency's (community's) funding or budget priorities with respect to extreme climate event response and planning? For example, have there been decisions to re-allocate funding as a result of the flood?

Respondents were asked to reflect on how these extreme weather events changed their agency's or community's funding or budget priorities with respect to future event response and planning, and, if there been decisions to re-allocate funding as a result of flooding brought on by Irene? Interviewees felt the events (including Lee) signaled the start of something different, and were thinking about their implications profoundly. Respondents were thinking about change in the long term, but not changing anything in the short term. Right now, local governments do not have flexibility or resources to put into flood control due to budget cutbacks in the last several years. Overall, there was not much immediate change or reallocation. Individuals felt that changes will unfold on a higher government level particularly through the work of the NYS Long Term Recovery Task Force.

A.4.13 Local Steps Still to be Taken

In your professional opinion, are there any steps that you think need to be taken locally within the immediate region that have not been taken as of yet? Why do you feel they have not been taken?

Interviewees were asked if there were any steps that you think need to be taken locally within the immediate region that have not been taken as of yet? Why do you feel they have not been taken? In general, responses to this question involved referring back to responses to previous questions where substantive answers that addressed the same basic question were given, without much new material provided by respondents.

A.4.14 Changes in Professional Approach to Flooding

How has Hurricane Irene and Tropical Storm Lee changed your own professional thinking about local flooding, either within this region specifically or New York State generally? Why do you feel your thinking has changed? What factors do you feel most influenced your thinking?

Many respondents were really surprised about the intensity of the flooding, which changed how they thought about flooding. They considered the storm to be a “wake-up call” event and that it provided an opportunity to promote heightened awareness of storm impact. Most respondents focused on their own position and work demands rather than the whole region.

A.4.15 Impacts and Climate Change and Sustainability Planning

Have the storms and their impacts changed your professional thinking about long term sustainability planning and climate change response planning. If so, how?

Only a few respondents were aware of the sustainability efforts currently ongoing in the Mid-Hudson Valley region and they did not significant connect it to their professional work.

A.5 Source Information for Impact Costs and Aid Estimates

Table A-4. Source Information for Table 4.1. Impact Costs and Aid Estimates for Ulster and Orange Counties and New York State

<p>Total Recovery Costs:</p> <p>Governor's Press Office, April 18, 2012. Governor Cuomo Announces New York State to Cover Local Share of Hurricane Irene and Tropical Storm Lee Response and Recovery Costs for Hudson Valley Counties. http://www.governor.ny.gov/press/041812stormresponse</p> <p>Governor's Press Office, April 11, 2012. Governor Cuomo Announces New York State to Cover Local Share of Hurricane Irene and Tropical Storm Lee Response and Recovery Costs. http://www.governor.ny.gov/press/04112012-tropical-storm-lee</p>
<p>New York State share of Total Recovery Costs:</p> <p>New York State Office of Community Renewal, July 3, 2012. State of New York Action Plan for Community Development Block Grant Program Disaster Recovery. http://www.nyshcr.org/Publications/ActionPlan12/CDBGDRActionPlan2012.pdf</p> <p>Governor's Press Office, April 18, 2012. Governor Cuomo Announces New York State to Cover Local Share of Hurricane Irene and Tropical Storm Lee Response and Recovery Costs for Hudson Valley Counties. http://www.governor.ny.gov/press/041812stormresponse</p> <p>Governor's Press Office, April 11, 2012. Governor Cuomo Announces New York State to Cover Local Share of Hurricane Irene and Tropical Storm Lee Response and Recovery Costs. http://www.governor.ny.gov/press/04112012-tropical-storm-lee</p>
<p>Community Development Block Grants Disaster Relief (CDBG DR) allocated by the U.S. Department of Housing and Urban Development:</p> <p>HUD Press Release No. 12-011, January 20, 2012. HUD Provides \$400M to Help Communities in Eight States to Recover from 2011 Disasters. http://portal.hud.gov/hudportal/HUD?src=/press/press_releases_media_advisories/2012/HUDNo.12-011</p> <p>Governor Press Office, January 20, 2012. Governor Cuomo Announces New York State to Received \$93M in Federal Grants for Disaster Relief. http://www.governor.ny.gov/press/01202012fedgrant</p>
<p>Federal Emergency Management Agency Individual Assistance Aid:</p> <p>Andrew Meyer, Personal Communication, NYS Department of Environmental Conservation. January 24, 2012.</p>
<p>Metropolitan Transportation Authority Claims:</p> <p>RT&S, October 1, 2012. FEMA will reimburse MTA for storm damage along Port Jervis line. http://www.rtands.com/index.php/passenger/commuter-regional/fema-will-reimburse-mta-for-storm-damage-along-port-jarvis-line.html?channel=280#.UGryVhilJNA</p> <p>MTA Press Office, August 27, 2012. Metro-North's Port Jervis Line Strengthened. http://www.mta.info/mta/news/releases/?en=120827-MNR1</p> <p>Castillo A., August 27, 2012. MTA Files \$65M in Irene Claims. Long Island Newsday. http://www.newsday.com/long-island/transportation/lirr/mta-files-65m-in-irene-claims-1.3931464</p>
<p>New York State Agricultural & Community Recovery Fund:</p> <p>Andrew Meyer, Personal Communication, NYS Department of Environmental Conservation. October 25, 2011.</p>
<p>Small Business Association Loans:</p> <p>Walsh, J. January 13, 2012. SBA's Loans for Local Storm Damage Total \$14,5M. The Times Herald Record Online. http://www.recordonline.com/apps/pbcs.dll/article?AID=/20120113/NEWS/201130380</p> <p>Parr P. and Kuhr S. January 26, 2012. Hurricane Irene and Tropical Storm Lee Response and Recovery Operations. Http://www.nysema.org/2012Diasaster_Briefing%20PPT_01_26_12.pdf</p>

Table A-4 continued

U.S. Department of Transportation Aid:

Office of Senator Charles E. Schumer, January 4, 2012. Schumer, Gillibrand Announce New York Set to Receive Nearly \$90M in Emergency Funding for Highway Flood Damage from Hurricane Irene and Tropical Storm Lee. <http://www.schumer.senate.gov/record.cfm?id=335526&>

United Way Aid:

United Way of Ulster County, December 16, 2011. United Way of Ulster County Receives \$50,000 from NYS Hurricane Irene Recovery Fund.

<http://archive.constantcontact.com/fs092/1102115599904/archive/1108966829247.html>

Shaheen, M. Hurricane Irene Recovery Fund, United Way of New York State, Final Report. August 2012.

http://www.uwnys.org/images/Final_HIRF_report.doc

Figure A-17. Looking north on Walkkill River on Route 6 bridge



Figure A-18. Black Dirt agricultural area, Orange County



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Final Report
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