CLIMATE CENTRAL

NEW YORK AND THE SURGING SEA

A VULNERABILITY ASSESSMENT WITH PROJECTIONS FOR SEA LEVEL RISE AND COASTAL FLOOD RISK

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Climate Central surveys and conducts scientific research on climate change and informs the public of key findings. Our scientists publish and our journalists report on climate science, energy, sea level rise, wildfires, drought, and related topics. Climate Central is not an advocacy organization. We do not lobby, and we do not support any specific legislation, policy or bill. Climate Central is a qualified 501(c)3 tax-exempt organization.

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CONTENTS

CONTENTS

FIGURES AND TABLES

IN MAIN REPORT

IN APPENDICES

EXECUTIVE SUMMARY

Sea levels are rising at an accelerating rate, and the scientific community is confident that global warming is the most important cause. Higher sea levels translate to more and higher coastal floods. Using local sea level projections closely aligned with a likely midcentury range developed by the New York City Panel on Climate Change, this analysis finds a 3-in-4 chance of historically unprecedented coastal flooding in New York City by 2100, assuming sea level rises on the fast end of the spectrum; or a 1-in-10 chance under a slow rise scenario, as might be expected under reduced carbon emissions. We find that sea level rise from warming has already increased the likelihood of extreme flooding at the Battery – flooding high enough to seriously threaten the subway system – by 50%.

120 square miles of land lie less than 6 feet above the high tide line in New York, the height of a statistically extreme flood. This land is home to nearly half a million New Yorkers, 21% of whom live in just three zip codes. $101 billion in property value sits on the same land, as do more than 1,500 miles of road, 1,200 EPA-listed sites, and 100 public schools.

These numbers nearly double when assessed at 9 feet above the high tide line – Sandy's peak flood elevation as measured at the Battery in New York City. In Brooklyn and Manhattan, the most socially vulnerable populations are, respectively, about 30% and 80% more likely than the population as a whole to be flooded at this level.

This updated report is being released as a summary of findings coincident with the upgrade of a New York Surging Seas Risk Finder online tool, accessible at http://sealevel.climatecentral.org/ssrf/new-york . The tool includes:

- interactive local projections of sea level rise and increasing coastal flood risk from 1-10 feet by decade;
- a zooming, zip-searchable map of low-lying areas threatened, plus layers showing social vulnerability, population density and property value;
- detailed assessments of populations, property, infrastructure and contamination sources exposed, for each implicated county, city, town, zip code and more; and
- state- and county-wide heat maps facilitating high-level vulnerability comparisons.

01. INTRODUCTION

IN BRIEF

In March 2012, Climate Central released its first analysis of sea level rise and coastal flood threats in the United States. We published two scientific papers in a peer-reviewed journal; a national report; fact sheets for each coastal state; and an interactive online map called *Surging Seas*. About 800 stories in local to national media covered our findings, and a U.S. Senate committee invited Climate Central to testify about the research in April 2012 – six months before Hurricane Sandy.

This report represents a major update to our 2012 analysis for New York, using the same essential methods as our original work, but incorporating greatly improved and expanded data. The report summarizes major themes and findings taken from a much larger body of results accessible via a new interactive online tool, the New York Surging Seas Risk Finder.

RESEARCH IMPROVEMENTS

Our 2012 analysis used the best available national coverage elevation dataset at the time. This analysis uses far more accurate laser-based (lidar) elevation data. Our 2012 research assessed land, population and housing vulnerable to sea level rise and coastal flooding. This research assesses over 100 additional variables, including socially vulnerable population, populations by racial and ethnic group, property value, roads, rail, airports, power plants, sewage plants, hazardous waste sites, schools, churches, and hospitals. Our 2012 analysis tabulated exposure at state, county, and city levels. This analysis adds zip codes, congressional districts, planning districts, state legislative districts, city districts and more.

For sea level rise projections, this analysis uses updated scenarios for future emissions of carbon pollution, as developed by the global climate research community. We use updated models of the global warming expected from these emissions, and a selection of global sea level rise models, instead of just one. We then factor in local effects, such as sinking land, to develop local sea level rise projections, employing the same methods as in our original peer-reviewed research.

We also carry forward the same methods we previously used to characterize storm surge risk, and integrate it with projected sea levels, to develop projections of overall local flood risk by decade. However, we have updated analysis inputs to include the full available record of hourly water levels at each water level station through the end of 2012. This means decades more data for most stations than the standard 30-year period used in the original analysis, and that Sandy's surge is factored in when developing risk statistics, providing a richer basis for our flood risk projections.

NEW YORK SURGING SEAS RISK FINDER: A NEW ONLINE TOOL

The Surging Seas Risk Finder is searchable by geography, and offers easy navigation and visualization of analysis results from hundreds of thousands of combinations of location, water level, and risk element. The Risk Finder is divided into four components:

- Map: Interactive zooming map of sea level and flood risk zones
- Forecast: Projections of sea level rise and flood risk
- Analysis: Detailed analysis of exposed population, assets and infrastructure by individual location, from zip to state level
- Comparison: Comparisons of exposure across the whole state or selected county

02. A TIMELINE OF GROWING RISKS

Long before sea level rise permanently submerges new land, it will make its presence felt through higher and more frequent coastal floods, because higher seas raise the launch pad for storm surge.

In fact, every coastal flood today is already wider, deeper and more damaging because of the roughly 8 inches (IPCC 2013) of warming-driven global sea level rise that has taken place since 1900. This analysis finds that this rise has already increased the annual chance of extreme coastal floods in New York City by 50%. Looking forward under a fast sea level rise scenario, we compute a 3-in-4 chance of historically unprecedented coastal flooding in New York City by 2100 – or a 1-in-10 chance under a slow rise scenario. Unprecedented floods have a roughly 1-in-2 chance in Montauk by 2060, assuming fast rise; and a 1-in-2 chance in Bridgeport, CT by midcentury, assuming medium rise (Long Island Sound area).

This section explores projected sea level rise and how it aggravates coastal flooding.

SEA LEVEL RISE PROJECTIONS

This analysis projects a main range of local sea level rise from 0.6-1.8 feet by 2050, and 1.9-6.3 feet by 2100, at the Battery in New York City, using sea level in 2012 as the baseline. Projections for Montauk and Bridgeport differ only by an inch from these. The New York City projections align closely with projections recently made by the New York City Panel on Climate Change (2013).

Global Sea Level Rise Projections

The Earth's average temperature has warmed by more than one degree Fahrenheit over the last century, and scientists overwhelmingly agree that most or all of this warming comes from human influence (IPCC 2013). This influence comes mainly through the burning of fossil fuels and resulting accumulation of carbon dioxide in the atmosphere.

Global sea level rise is one of the scientifically best-established consequences of this warming. Warming shrinks glaciers and ice sheets, adding water to the ocean; and also heats up the ocean, expanding it. Over the past two decades, global sea level has risen roughly twice as fast as it did during the 20th century.

Projecting future sea level is a difficult scientific challenge, not least because it will depend upon how much more carbon humans put into the atmosphere. For global sea level rise projections, this analysis relies on scenarios developed by the National Oceanic and Atmospheric Administration (NOAA) and collaborating agencies for the U.S. National Climate Assessment (Parris et al 2012). We focus on the intermediate low, intermediate high, and highest sea level rise scenarios, which point to 1.6 ft, 3.9 ft, or 6.6 ft of sea level rise globally by 2100, from a 1992 starting point. For simplicity, we call these scenarios "slow", "medium" and "fast."

We omit the NOAA lowest scenario in this report. This scenario projects this century's average rate of sea level rise as the same as last century's, lower than the average rate from the last two decades. Such an outcome seems very unlikely given projections for warming this century, and the strong observed relationship between global temperature and sea level change over the last century (Vermeer and Rahmstorf 2009).

The Intergovernmental Panel on Climate Change recently released its Fifth Assessment Report on climate science (IPCC 2013). IPCC's sea level projections range from 0.9-3.2 feet by 2100, but explicitly do not include a potential rapid ice sheet breakdown scenario. NOAA's highest projection is intended to capture such a possibility, and thus the highest plausible sea level rise for the century, as an indicator of maximum risk for planning purposes.

Surging Seas Risk Finder, the interactive web tool accompanying this report, includes projections based on all four NOAA scenarios; IPCC projections; U.S. Army Corps of Engineers guidelines, semi-empirical projections developed by Vermeer and Rahmstorf (2009); and a no-global-warming scenario for comparison. We will add additional global sea level rise projections over time.

Local Sea Level Rise Projections

Local sea level rise can differ from global sea level rise for many reasons. The ocean is not flat, and shifting currents and sea surface temperatures can alter local sea level trends over years or decades. In addition, the land itself is slowly sinking or (more rarely) rising in many coastal areas, augmenting or diminishing local sea level rise.

This analysis employs the same method as Tebaldi et al (2012) to develop projections for each location studied. In essence, we compare global sea level rise to local sea level rise measured at a water level station over a 50-year period. We use the difference to define a local component of sea level rise, and assume that the local component rate will continue unchanged into the future. This is a reasonable assumption at least for the effects of sinking or rising land, effects important enough to account for most or all of the long-term local component in most places (Tebaldi et al 2012). (See Appendix A or Tebaldi et al (2012) for more detail.)

For this report, we developed projections at water level stations at The Battery in New York City; Bridgeport, CT (Long Island Sound area); and Montauk, NY. Projections across these locations were almost identical. We project local sea level rise of 0.6-1.8 feet by 2050, and 1.9-6.3 feet by 2100, at the Battery in New York City, using sea level in 2012 as the baseline. The lower numbers are our "slow" projections and correspond to NOAA's intermediate low projections. The higher numbers are our "fast" projections and correspond to NOAA's highest projections. Our "medium" projections are 1.2 ft for 2050 and 3.9 ft for 2100. For projection plots, see the top row of Figure 1 (for the Battery), or Figures B1-2 (for Montauk and Bridgeport, CT).

The second New York City Panel on Climate Change (2013) has made the most detailed and authoritative study of any scientific body on future sea levels in New York City. The NPCC2 projects 0.9-2.0 feet of sea level rise by the 2050s, as the 25th-75th percentiles of the range of likely rise,

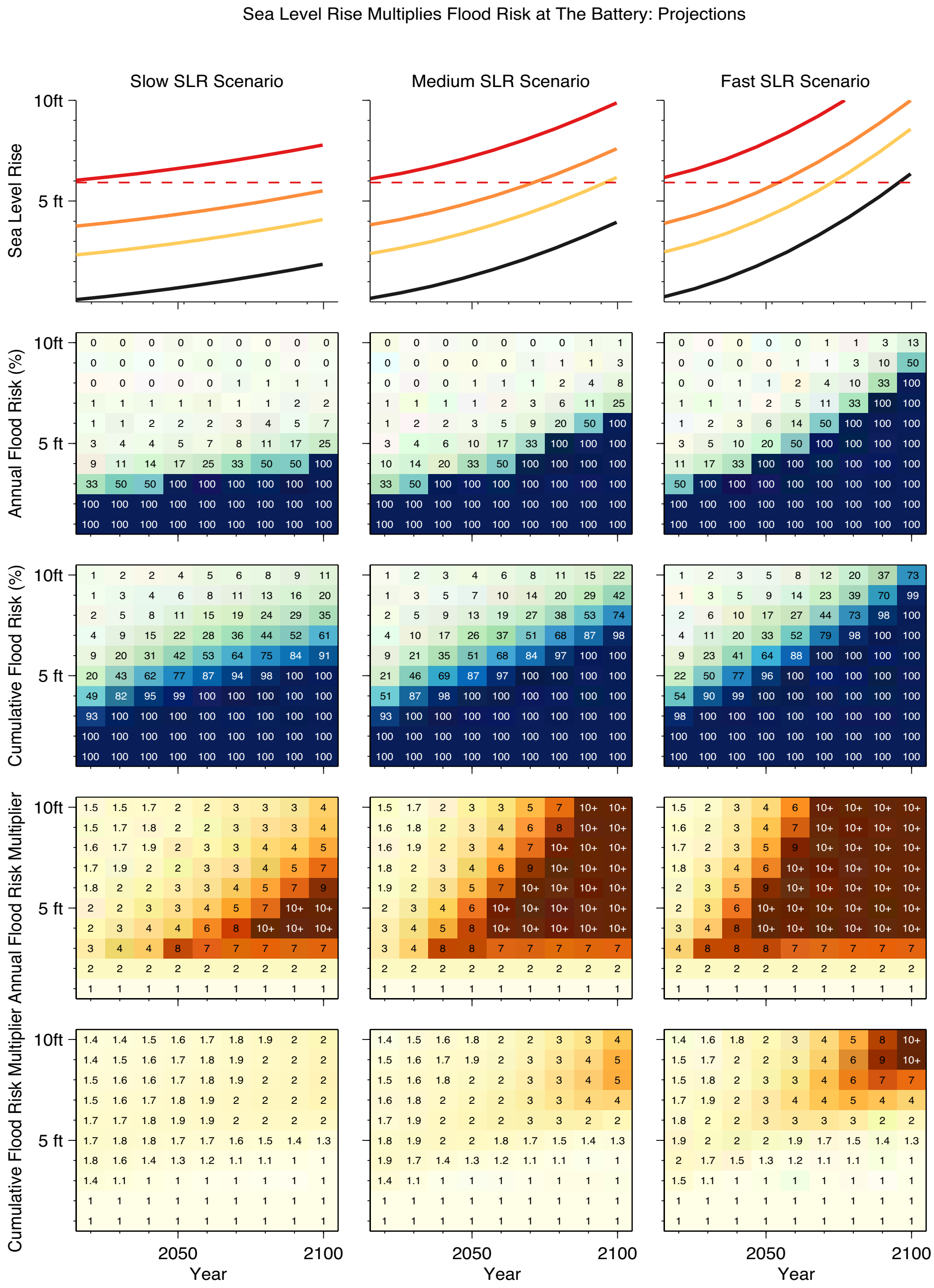


Figure 1. Sea Level Rise Multiplies Flood Risk at The Battery: Projections

The top row shows slow (left hand side) through fast (right hand side) scenario sea level rise projections (black lines), plus the height of 1-year (yellow), 10-year (orange) or 100-year (red) floods. The dashed red line shows the elevation of a 100-year (extreme) flood measured from today's high tide line (MHHW). The next two rows show projections for annual and cumulative percentage risk of floods reaching 1-10 ft MHHW by decade (2020-2100). The final two rows show how the global warming component of sea level rise is projected to multiply these risks, cell-by-cell.

measured against the average sea level from 2000-2005 as a baseline. The range would shift down by about 0.1 ft if measured against a 2012 baseline such as used for this study. The range would shift down again by a similar amount if calibrated to be a projection for the year 2050 instead of averaged over the 2050's. But in short, the slow through fast projections in this analysis (0.6-1.8 ft) match very closely with the 25th-75th percentile projections of the NPCC2 for midcentury. The NPCC2 did not make any projections for later in the century, so midcentury makes the best point for comparison.

The projections given in this analysis should be taken as indicative of long-term trends, and not as precise projections for specific years. Global and local sea level experience natural ups and downs over years and decades that may temporarily obscure the underlying trend, but which will balance out over time.

Table 1. Stations Data and Basic Analysis

	The Battery (NYC)	Montauk	Bridgeport, CT
Start of historic record used for storm surge analysis	1920	1959	1979
Extreme flood level based on statistical analysis of historic record (ft)	5.9	4.2	5.8
Highest observed flood during historic period (ft)	9	5.9	5.7
Year of highest observed flood	2012	1954	2012
Observed local sea level rise during historic record (ft)	1	0.7	0.4
GW multiplier: How much past sea level rise from global warming has already multiplied the annual chances of topping extreme flood level	1.5	3	1.6
Sea level rise projections, 2050 (ft)	0.6 - 1.8	0.7 - 1.8	0.6 - 1.7
Sea level rise projections, 2100 (ft)	1.9 - 6.3	2.0 - 6.4	1.8 - 6.2

Extreme flood level is defined as the water level with a 1% annual chance of being exceeded, commonly referred to as a "100-year" flood. All heights are relative to the Mean Higher High Water (MHHW; the high tide line). All station records run through the end of 2012.

COASTAL FLOODING: HISTORY AND PROJECTIONS

Rising seas raise the launch pad for storm surge, driving coastal floods higher. This study projects future flood risk by superimposing sea level rise projections onto historical patterns of flooding. In other words, we assume that coastal storm statistics remain constant – the same frequency and intensity of coastal storms – while sea levels rise. There is evidence that storm surges have been increasing with global warming (Grinsted et al 2013). If such a trend were to continue, it would mean that our assumption makes our risk estimates lower than they should be.

Historical Analysis to Define Extreme Floods

The first step in this approach is to characterize historical coastal flood risk at each study site – water level stations at the Battery, Montauk, and Bridgeport, CT, in this case. We apply standard methods to estimate the precise relationship between a flood's height and its annual likelihood (the higher the rarer), based on a long historical record of hourly water levels. For example, we estimate that a flood with a 1% annual chance – what we call an "extreme" flood in this study, and commonly referred to as a "100-year" flood – reaches 5.9 feet above the high tide line at the Battery. For reference, this is about one foot higher than any flood since at least the 19th century, except for Sandy. Sandy topped this level by just more than 3 feet. But 5.9 feet is still high enough to threaten the NYC subway system with major flooding (Jacob et al 2011).

02. A TIMELINE OF GROWING RISKS

We apply the same methods as Tebaldi et al (2012) for this analysis (see Appendix A for a briefer summary). However, we update our previous findings by now including water level records through the end of 2012 (thus factoring in Sandy's flood), and back to the earliest year with reliable records at each water level station. Table 1 provides details and findings for each station, including the highest observed flood in the record of each station. This allows us to project future risks of "unprecedented" floods as well as statistically "extreme" ones.

In this report, we give all flood heights and water levels in elevations relative to Mean Higher High Water (MHHW), or what we more simply call today's "high tide line," defined based on tide levels during NOAA's standard 1983-2001 tidal "epoch." Our purpose is to give a good sense of how high floods might reach above normal local high water lines. Different sources use different reference frames, so Appendix C provides tables for converting to and from a variety of them, including Mean Lower Low Water (MLLW) and standard modern map elevation (North American Vertical Datum 1988, or NAVD88). Among the three water level stations analyzed here, the high tide line ranges from 1.0 to 3.5 ft in standard elevation.

Hurricane Sandy has been commonly reported as having produced a more than 14-foot storm surge at the Battery. This reporting misleads in two ways. First, the number reflects the flood's water level, not the surge. Flood level (or storm tide) is the sum of the expected tidal level at a given time, plus the storm surge (the extra water driven by a storm). Sandy's peak storm surge was about 9 feet – and it occurred near high tide.

Second, 14 feet was the flood height relative to MLLW, or the low tide line – about 5 ft lower than the high tide line. Sandy reached a peak of 8.99 ft above MHHW at the Battery.

Coastal Flood Projections

As sea levels rise, they increase the chances of extreme floods by today's standards. For example, an extreme flood reaching 5.9 feet above the present high tide line at the Battery would today require a 1%-annual-chance combination of storm surge and tide. But after 2 ft of sea level rise, a flood reaching the same absolute elevation would only require a 2 ft lesser combination of storm and tide, coming with a roughly 10% annual chance. After 4 ft of sea level rise, storm tides would exceed the same level many times each year. And after 6 ft, no storm would be necessary.
Table 2 shows how different rates of sea level rise affect the annual and cumulative chances for floods that exceed the 5.9-foot extreme flood level at the Battery in the decades ahead. We find a better than 1-in-2 chance for such a subway-system threatening flood to occur by midcentury, given a medium rate of sea level rise. Tables B1-2 give the equivalent flood risk projections for Montauk and Bridgeport, CT.

We conducted the same analysis for water levels from 1-10 ft above the high tide line, computing probabilities for each level by decade. Findings are shown for the Battery in Figure 1, and for the other two stations in Figures B1-2. The results indicate a roughly 3-in-4 chance for a Sandy-beating flood (10 ft) by the end of the century given fast sea level rise, and a 1-in-10 chance given slow sea level rise. The century's likelihood for a Sandy-tying flood (9 ft) ranges from 1-in-5 to near certainty, depending upon scenario. Unprecedented local floods (6 ft) have a roughly 1-in-2 chance in Montauk by 2060, assuming fast rise; and a 1-in-2 chance in Bridgeport, CT by midcentury, assuming medium rise.

While sea level rise projections are quite similar for each of the three water level stations studied, the local flood risk profiles vary more substantially. In general, flood risk by elevation can vary significantly across short distances, depending upon local geography. Thus the escalating flood risks computed for each station may be taken as indicative of increasing risk in its wider area, but should not be interpreted as providing predictions for nearby areas.

Global warming multiplies extreme flood risk

Since sea level rise multiplies extreme coastal flood risk, and global warming contributes to sea level rise, global warming multiplies flood risk. This effect is independent of any potential warming influence on storm frequency or intensity. We assessed the sea level driven global warming multiplier by comparing flood probabilities with and without the global component of sea level rise (leaving out local components that might come from sinking or rising land).

We found that global warming has already multiplied the likelihood of NY-area extreme floods by factors ranging from 1.5 (the Battery) to 3 (Montauk). Multipliers for the annual chances of extreme and higher floods grow throughout the century for all sea level rise scenarios, ultimately exceeding 10X in most cases – see Tables 2 and B1-2, and the bottom two rows of Figures 1 and B1-2.

Multipliers for cumulative flood probabilities behave more complexly, because the cumulative risk for an extreme flood becomes substantial when accumulated across many decades, even in the absence of global sea level rise. This puts a cap on multiplier values: for example, a background 50% cumulative risk cannot have a multiplier any greater than 2X.

Table 2. Extreme Flood Projections at the Battery (NYC)

Extreme flood level based on statistical analysis of historic record at station: 5.9 ft above MHHW

Annual likelihood of exceeding extreme flood level

	Likelihood			GW Multiplier		
Scenario	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
NoGW	1%	1%	1%	-	-	-
Slow	1%	2%	8%	1.4	2	7
Medium	2%	3%	100%	1.7	3	10+
Fast	2%	7%	100%	2	6	10+

Cumulative likelihood of exceeding extreme flood level

	Likelihood			GW Multiplier		
Scenario	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
NoGW	17%	33%	61%	-	-	-
Slow	21%	45%	93%	1.2	1.4	1.5
Medium	23%	53%	100%	1.3	1.6	1.5
Fast	25%	66%	100%	1.5	2	1.6

03. PEOPLE, PROPERTY AND INFRASTRUCTURE IN HARM'S WAY

120 square miles of land lie less than 6 feet above the high tide line in New York. This land is home to nearly half a million New Yorkers, 18% of whom live in just 3 zip codes; $101 billion in property value; and over 1,500 miles of road, 1,200 EPA-listed sites, and 100 public schools.

These numbers nearly double when assessed at 9 feet MHHW – Sandy's peak flood elevation at the Battery. In Brooklyn and Manhattan, the most socially vulnerable populations are, respectively, about 30% and 80% more likely than the population as a whole to be flooded at this level

LAND

About 186 square miles of land in New York State are less than 9 feet above the high tide line – Sandy's peak level as measured at the Battery. 60% of this area is in Nassau and Suffolk Counties, and 78% for all of Long Island including Brooklyn and Queens as well. 120 square miles are below 6 feet – roughly the same as the extreme flood level estimated in this study – with a similar pattern of geographic concentration.

These totals are based on analysis of high-resolution land and tidal elevation data from NOAA, after screening out areas classified as saltwater wetlands by the U.S. Fish and Wildlife Service (see Appendix A for more detailed methodology).

We further analyzed how much low-lying land might be protected by levees, sea walls, or natural features such as ridges: 6% of the total area at 9 feet, and 9% at 6 feet. We used levee data from FEMA's Midterm Levee Inventory, the most complete levee data publicly available. This analysis assumes levees are always high enough and in good condition; the inventory does not report these data. Much of the levee system is known to be in poor repair; but the inventory does not yet include most levees (American Society for Civil Engineers 2013).

In general, the connectivity of a specific area to the ocean at a given flood or water level can be difficult to assess. Areas that appear connected may not be connected, due to unmapped levees, seawalls or other protections. Areas that appear protected may not be protected, due to faulty levees, or connections via ditches or culverts. Elevation data error may also influence results.

Because of these complications, and because of the relatively small percentage of area that might be protected, this analysis follows Strauss et al (2012) and focuses on the simple metric of how much land falls below different threshold elevations. Further analysis addresses how much population, property and infrastructure sits on that land.

Our approach does not take into account, and also avoids complications from, future erosion as sea levels rise, and the uneven surfaces of floodwaters driven by individual storms, and influenced by details of local geography.

Overall, the maps and analyses here should not be taken as precise predictions or flood emergency guides. Rather, we present them as risk indicators in a world of rising sea levels and increasing floods.

PEOPLE, PROPERTY AND INFRASTRUCTURE

Once maps of land below different threshold elevations are established, it is relatively straightforward to account for the populations, property and infrastructure exposed within these zones. The Surging Seas Risk Finder presents hundreds of thousands of combinations of analysis results by geography, water level, and variable. Here we present some of the major categories and highlights, with a focus on exposure below 6 feet (statistical extreme flood level at the Battery, high enough to threaten NYC's subway system) and below 9 feet MHHW (Sandy's peak at the Battery).

One major feature of exposure to sea level rise and coastal flooding in New York State is its geographic concentration. 481,000 New York residents spread across 300 zip codes live on land below 6 feet; but 21% of them live in just 3 zip codes – for Manhattan Beach, Coney Island, and Far Rockaway. Housing units and EPA-listed sites – sources of potential contamination during floods – are similarly concentrated, both at 6 ft (Table 3) and 9 feet (Table D1). $17 billion in property value on land below 6 ft (17% of the total) is clustered within the top 5 zip codes.

Such concentration suggests that focused efforts might protect a significant portion of both the population and property at risk.

A second major feature of exposure is that a great deal of assets are exposed, of almost every kind. The coasts are the most densely developed parts of the United States. Table 4 provides a summary of 6-ft exposure by county for several high-level variables; Table D2 shows 9-ft exposure.

The dark horizontal striping indicates that high percentages of sewage plants and power plants, in particular, sit on low elevation land in multiple counties. The vertical striping points to Nassau, Queens, Brooklyn, Manhattan, Staten Island and Suffolk counties as most affected. Queens has a small lead among all counties in the percentage of land less than 6 feet above high tide, but Nassau has by far the highest percentage of its housing and population in this zone, as well as road miles and property value (the latter in a tie with Manhattan). Similar patterns pertain at 9 feet, although almost twice the New York State population lives on land below 9 feet as 6 feet (930,000).

All told, 1,529 miles of road in the state are on land below 6 feet (but only 29 miles of federal or state road); 104 public schools; 85 houses of worship; 19 sewage plants; 16 hospitals; 7 power plants; and 1,225 EPA-listed sites, screened to include mostly hazardous waste sites, facilities with significant hazardous materials, and wastewater generators.

This analysis simplifies most facilities as points with a single latitude and longitude. It also evaluates exposure by evaluating the height of the land that structures sit upon. It takes into account neither the full footprint of a facility; nor the potential elevation of structures or equipment above ground; nor the possibility of unsealed basement areas. We regard such analysis

Table 3. Top Zip Codes At Risk, 6 Feet.

New York statewide and top zip code totals for people and property on land less than 6 ft above the high tide line.

Variable	State Total Below 6 ft	Top Three Zip Codes Affected	% of Total < 6ft	Top Five Zip Codes Affected	% of Total < 6 ft	Top Zip Codes (Most to Least Affected)	Total Number of Affected Zip Codes in State
Land (acres)	76,696	5,096	7%	8,174	11%	11758 (Massapequa) 11930 (Amagansett) 11702 (Babylon) 11968 (Southampton) 11706 (Bay Shore)	343
Population	480,807	98,823	21%	139,125	29%	11235 (Manhattan Beach, Brooklyn) 11224 (Coney Island, Brooklyn) 11691 (Far Rockaway, Queens) 11561 (Long Beach) 11236 (Canarsie)	311
Property Value ($ Billions)	101	11.2	11%	17.2	17%	11561 (Long Beach) 11235 (Manhattan Beach, Brooklyn) 11694 (Rockaway Park, Queens) 11758 (Massapequa) 11572 (Oceanside)	357
Housing Units	209,800	44,044	21%	59,089	28%	11235 (Manhattan Beach, Brooklyn) 11224 (Coney Island, Brooklyn) 11561 (Long Beach) 11691 (Far Rockaway, Queens) 11694 (Rockaway Park, Queens)	297
Road Miles	1,529	171	11%	249	16%	11561 (Long Beach) 11758 (Massapequa) 11572 (Oceanside) 11706 (Bay Shore) 11520 (Freeport)	197
EPA-listed sites	1,225	200	16%	277	23%	11224 (Coney Island, Brooklyn) 11520 (Freeport) 11572 (Oceanside) 11231 (Red Hook, Brooklyn) 11096 (Inwood)	173

as useful for assessing the general exposure of different facility types across different geographies, and as useful for screening the possible exposure of individual facilities. However, authoritative assessments for individual facilities are best served by on-the-ground measurement

THE MOST VULNERABLE

Social vulnerability is a broad term that describes the sensitivity of populations to the impacts of environmental risks and hazards, including coastal flooding. Social vulnerability helps explain why some places can experience hazards differently even without differences in exposure. The Social Vulnerability Index is a tool that synthesizes socioeconomic characteristics of populations – characteristics known to influence a community's ability to prepare for, respond to, and recover from hazard events like floods (see e.g. Emrich and Cutter 2011; Finch et al 2010; Cutter et al. 2013).

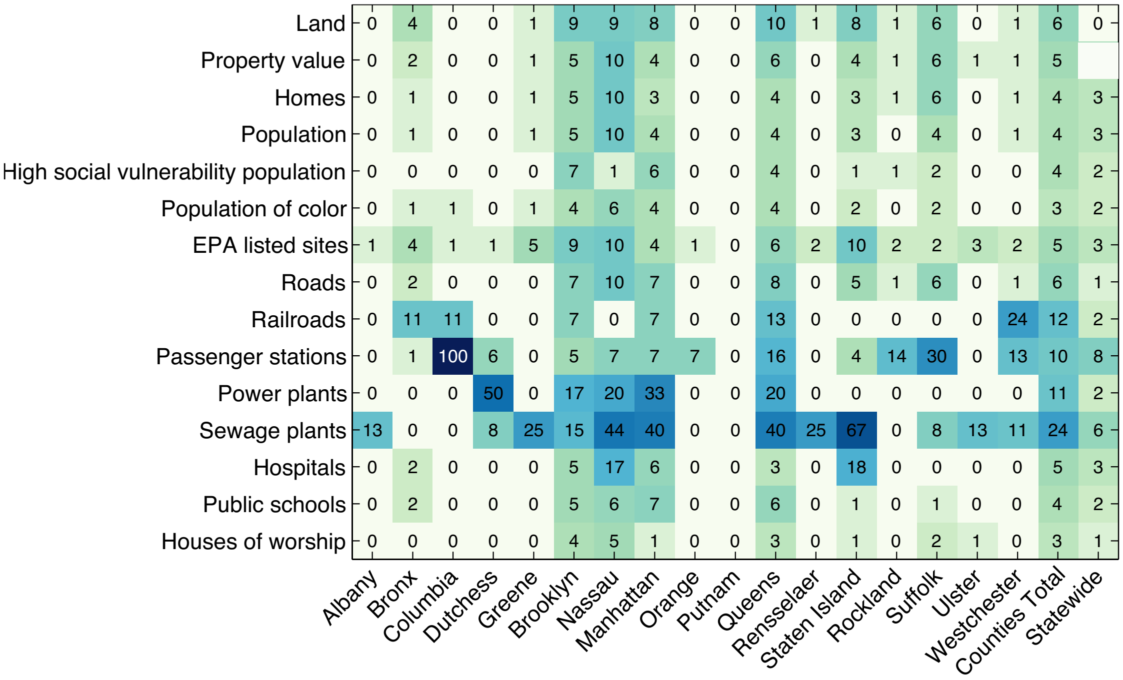
Our analysis found little difference in exposure to Sandy-level or lesser extreme floods when comparing populations with high scores on the Social Vulnerability Index against the population as a whole, in coastal and low-lying areas of New York State. However, about 18% and 14% of the most socially vulnerable live on land below 9 feet in Manhattan and Brooklyn, respectively, versus 10% and 11% of the population at large, showing disproportionate exposure for the vulnerable in these two important boroughs and counties. A similar imbalance exists for populations living on land below 6 feet in these two counties, with the most vulnerable about half again as likely to be exposed than the population at large.

The Social Vulnerability Index compares places based on their relative levels of social vulnerability. For this analysis, vulnerability was assessed at the Census tract level within all New York State counties, using 27 variables from the 2010 Census and the 2006-10 American Community Surveys (see Appendix A for further methodological details). The online Submergence Risk Map that accompanies this report includes a feature visualizing social vulnerability levels in areas that are physically vulnerable to coastal flooding and sea level rise.

The Social Vulnerability Index shows where there is uneven capacity for preparedness and response and where pre and post-event resources might be most effectively used to reduce pre-existing vulnerability and increase resilience post-disaster. The index is also a useful indicator in understanding spatial differences in disaster recovery. It has been used in combination with other disaster data to provide emergency responders with a much clearer understanding of disaster impacts, thus providing decision makers with an objective comparison of damages sustained across the full spectrum of affected communities (see http://webra.cas.sc.edu/hvri/products/SoVIapplications.aspx).

Table 4. County and State Percentages of People, Property and Infrastructure on Land Below 6 Feet.

Figures in the "Counties Total" column give percentages for the listed counties considered collectively. Figures in the "State" column give percentages for the state as a whole (including all state counties). *Statewide percentages for property value are not included due to missing data for high elevation (unlisted) counties.*



	Albany	Bronx	Columbia	Dutchess	Greene	Brooklyn	Nassau	Manhattan	Orange	Putnam	Queens	Rensselaer	Staten Island	Rockland	Suffolk	Ulster	Westchester	Counties Total	Statewide
Land	0	4	0	0	1	9	9	8	0	0	10	1	8	1	6	0	1	6	0
Property value	0	2	0	0	1	5	10	4	0	0	6	0	4	1	6	1	1	5	
Homes	0	1	0	0	1	5	10	3	0	0	4	0	3	1	6	0	1	4	3
Population	0	1	0	0	1	5	10	4	0	0	4	0	3	0	4	0	1	4	3
High social vulnerability population	0	0	0	0	0	7	1	6	0	0	4	0	1	1	2	0	0	4	2
Population of color	0	1	1	0	1	4	6	4	0	0	4	0	2	0	2	0	0	3	2
EPA listed sites	1	4	1	1	5	9	10	4	1	0	6	2	10	2	2	3	2	5	3
Roads	0	2	0	0	0	7	10	7	0	0	8	0	5	1	6	0	1	6	1
Railroads	0	11	11	0	0	7	0	7	0	0	13	0	0	0	0	0	24	12	2
Passenger stations	0	1	100	6	0	5	7	7	7	0	16	0	4	14	30	0	13	10	8
Power plants	0	0	0	50	0	17	20	33	0	0	20	0	0	0	0	0	0	11	2
Sewage plants	13	0	0	8	25	15	44	40	0	0	40	25	67	0	8	13	11	24	6
Hospitals	0	2	0	0	0	5	17	6	0	0	3	0	18	0	0	0	0	5	3
Public schools	0	2	0	0	0	5	6	7	0	0	6	0	1	0	1	0	0	4	2
Houses of worship	0	0	0	0	0	4	5	1	0	0	3	0	1	0	2	1	0	3	1

04. CONCLUSION

Long before rising seas redraw local maps, they will result in more coastal floods reaching higher. They are already having this effect.

The research in this report underscores the high concentration and wide range of populations, property, infrastructure, buildings, and potential contamination sources in low-lying coastal areas. In the densest areas, the most socially vulnerable populations are exposed the most. Patterns vary from place to place.

It will not require another Sandy to cause extensive economic damage and suffering in the future. Knowledge of vulnerabilities can lead to better preparation for the next storm, and the ones after. Higher floods in the future are certain, but how much damage they inflict is not – and will depend on the measures coastal communities take.

05. REFERENCES

American Society of Civil Engineers (2013). "2013 Report Card for America's Infrastructure: Levees." http://www.infrastructurereportcard.org/a/documents/Levees.pdf Accessed October 2013.

Cutter, S. L., C. T. Emrich, D. P. Morath, and C. M. Dunning (2013). "Integrating social vulnerability into federal flood risk management planning", *J. Flood Risk Management* DOI: 10.1111/jfr3.12018.

Emrich, C. T., & Cutter, S. L. (2011). "Social vulnerability to climate-sensitive hazards in the southern United States." *Weather, Climate, and Society*, 3(3), 193-208.

Finch, C., Emrich, C. T., & Cutter, S. L. (2010). "Disaster disparities and differential recovery in New Orleans." *Population and Environment,* 31(4), 179-202.

Grinsted, A., Moore, J. C., & Jevrejeva, S. (2012). "Homogeneous record of Atlantic hurricane surge threat since 1923." *Proceedings of the National Academy of Sciences*, 109(48), 19601-19605.

Intergovernmental Panel on Climate Change Working Group 1 (2013). Summary for Policy Makers.

Jacob, K. et al. (2011). Chapter 9, Transportation, in: Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. "Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report." New York State Energy Research and Development Authority (NYSERDA), Albany, New York.

New York City Panel on Climate Change (2013). "Climate Risk Information 2013: Observations, Climate Change Projections, and Maps." C. Rosenzweig and W. Solecki (Editors), NPCC2. Prepared for use by the City of New York Special Initiative on Rebuilding and Resiliency, New York, New York.

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss (2012). "Global Sea Level Rise Scenarios for the US National Climate Assessment." *NOAA Tech Memo* OAR CPO-1. 37 pp.

Strauss, B. H., Ziemlinski, R., Weiss, J. L., & Overpeck, J. T. (2012). "Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States." *Environmental Research Letters*, 7(1), 014033.

Tebaldi, C., Strauss, B. H., & Zervas, C. E. (2012). "Modelling sea level rise impacts on storm surges along US coasts." *Environmental Research Letters*,7(1), 014032.

Vermeer, M., & Rahmstorf, S. (2009). "Global sea level linked to global temperature." *Proceedings of the National Academy of Sciences*, 106(51), 21527-21532.

APPENDIX A: METHODS

PROJECTING LOCAL SEA LEVEL RISE

To project future sea levels, we followed the same essential methods as Tebaldi et al (2012). In that study, we added "semi-empirical" projections of global sea level rise to separate local sea level change components developed for 55 water level stations around the contiguous U.S. For the New York Surging Seas Risk Finder, we also use global sea level rise projections from the National Climate Assessment (Parris et al 2012), and make these our focal point, with projections limited to three stations in and near New York. We begin here, however, with a description of our overall method using the example of projections built on top of a semi-empirical model, as in Tebaldi et al.

For the global component in our semi-empirical approach, we used projections from Vermeer and Rahmstorf (2009). Their approach, based on the recent historic relationship between global sea level and global average temperature, has successfully hind-casted sea level rise over the last century and millennium with great fidelity. The relation estimated over the past observed records of sea level rise and global warming can be applied to projections of future temperature change produced by climate models. By this approach, therefore, future global sea level rise is not directly derived from the output of climate models, but is projected on the basis of the future temperature projections of these models. As projections based on historical observed relationships generally do, this approach assumes that the dynamics captured by the past relation will remain the same for the projected future period. If the ongoing increase in global temperatures leads ice sheets to unravel in ways not experienced during the model's twentieth century calibration period, then this approach may understate the problem.

Use of Vermeer and Rahmstorf's approach allowed this analysis to take into account a wide range of possible futures, from ones where humanity continues to send great amounts of heat-trapping gasses into the atmosphere, to ones where we sharply reduce these emissions. Through Vermeer and Rahmstorf's method we were also able to incorporate a range of possible relationships between emissions and global temperature increases (by using a range of climate model parameters and thus exploring the dimension of model uncertainty), and a range of possible relationships between temperature and sea level (by considering the uncertainty in the parameters of the empirical model). Our analysis rolled all of these factors together to produce one set of best estimates, and a range of potential outcomes around them.

For the New York Surging Seas Risk Finder, we updated our semi-empirical projections to employ the most recent carbon emissions scenarios ("Representative Concentration Pathways") and warming models being used by the global scientific community (Moss et al 2010).

In addition to future SLR estimates based on the empirical relation fitted between global temperature projections and SLR, we have implemented a range of four scenarios of global sea level rise as described by a NOAA technical input to the upcoming National Climate Assessment (Parris et al 2012). The NOAA approach assumes a relation between time (year) and sea level that is simply linear for the low scenario and quadratic of increasing magnitude for the three higher scenarios (intermediate-low, intermediate-high and high, corresponding to slow, medium and fast in this report).

APPENDIX A: METHODS

Any global sea level rise projection, such as these, can be adapted to help make a local projection.

Changes in local sea level come not only from changes in global sea level, but also from local effects such as the slow rising or sinking of coastal land, driven largely by the ancient retreat of massive ice sheets across North America. To determine local effects, we removed global rise from the total observed local sea level increase over a 50-year period (1959-2008) at each of the 55 nationwide stations we analyzed in our original study. The difference between the total observed local component and global rise during the same period (both of them expressed as linear trends of sea level change per year) is what we call the local component, and, in our projections, we assumed that each local component will continue as a constant rate into the future that offsets or adds on to the global component as an additive term. A detailed analysis using multiyear data from high-precision continuous GPS stations showed that vertical land motion can explain most or all of these local components. The forces behind such motion generally stay constant for thousands of years.

We did not take into account a widely anticipated slowing of the Gulf Stream later this century due to climate change. This slowing may add several inches of rise along the Northeast corridor by 2050 and more by the end of the century. We also did not take into account "gravitational fingerprint" effects, likely smaller than, and partly counteracting, potential Gulf Stream effects this century.

Our projections should not be interpreted as precise predictions for specific years, but rather best estimates that indicate overall trends, because of all of the factors that could lead to a range of outcomes (for example, different emissions futures) and because of natural year-to-year and decade-to-decade variability. For this reason, we present projections at the decade scale only.

PROJECTING COASTAL FLOOD RISK

In Tebaldi et al (2012) and here, to project the probabilities of reaching different high water levels in the future, through combinations of storms, tides and sea level rise, we developed statistics based on patterns of historical extreme water levels, and then superimposed projected sea level rise onto these. For this report, we used local statistics and local sea level projections for each of the 3 New York-area water level stations analyzed.

We used statistical methods specialized for handling extreme values to analyze records of hourly data. We expanded our analysis from the fixed standard 30-year period (1979-2008) used in Tebaldi et al, to use the maximum available high quality data for each water level station through the end of 2012 (utilizing 34-93 year records, depending on the station – see main report Table 1).

We estimate the parameters of a Generalized Pareto Distribution at each station, characterizing the probability density of extreme water levels at that location, and on the basis of those parameters we derive what is called a "return level curve" for each water level station. Our return level curves relate water heights (in MHHW) to their annual probability (given sea level in 2012): for example, heights with a 1% chance of being reached in any given year ("100-year" or "century" or "extreme" floods) are higher than heights with a 10% chance ("decade floods"), and so forth. We filtered out the effects of ongoing historic sea level rise at each station by estimating a linear trend over the length of the record and subtracting it out, in order to calculate baseline return level curves influenced only by tides, storms, and seasonal shifts in water level.

Once we establish a curve for the baseline period (that we can think of as today in most cases), it is easy to modify it for a given time in the future, on the basis of the effects of sea level rise alone. For example, if at that future time sea level has risen by one foot, an event reaching 5 feet of elevation will have at that future time the same probability of occurring as a minor event reaching 4 feet has today. Thus, sea level rise will make rare high water events of today more likely in the future.

These considerations allow us to compute the chance that a particular height H will be reached in some future year (say, for example the chance that an event reaching 5 feet will happen in 2030). All that is needed is the amount of sea level rise, say L, between today (the baseline) and that target year, and the return level curve for the baseline: we then take H, subtract L and find, on the curve, the probability associated to the event of size H-L.

Slightly more complex is the computation of the cumulative risk of at least one such event by some future year, i.e., the estimate of the chance that a particular height H will be reached or exceeded by some future year. The way to think of this is as the complement of (i.e., one minus) the probability that such event will never be reached by that year. As an example, let's say the event H is currently a "100-year" event. That means that this year it has 0.01 chances of occurring, and therefore 0.99 chances of not occurring. Next year, if nothing changed, the chance of it not occurring would be the same, therefore the probability of H not occurring this year or next year would be 0.99*0.99=0.98; its complement, that is the chance of H occurring by next year, would be 1-0.98=0.02.

The same calculation applies for any number of years until the target year. We simply multiply the chances of the event H not occurring every year for the entire period, and then take its complement.

Critically, however, sea level rise makes the chance of any event higher –at least on average decade after decade. Therefore we compute changing probabilities over the years, taking into account the effect of sea level rise. To do so, we incorporate local projections of sea level rise decade by decade, not just the total rise projected by the target year.

More specifically, we used the return level curve for each decadal year, e.g. 2040, incorporating sea level rise projected through that year, and applied the same curve for the five preceding and four succeeding years as well. We then used the probability of exceeding H each year between 2011 and the target year to compute the overall odds of exceeding H at least once during the period.

To continue with the example of H as the 100-year event of today one can imagine that for a target year far enough in the future the multiplication will involve values sooner or later (depending on the pace of sea level rise at this station and on the shape of its return level curve) significantly smaller than 0.99, therefore producing a significantly larger value of the complement, by the target year, compared to that computed under the assumption of no sea level rise.

As with our projections of sea level rise, and for similar reasons, we limit our presentation to odds of reaching different flood levels at decade resolution. Any given year, even within a steady long-term trend of sea level rise, may see dips and jumps in the actual value of sea level rise at a given location. Our estimates of sea level rise are appropriate only as long-term average trends, decade after decade.

Note that the same type of calculation performed for a detailed range of values and years in the future allow us to answer a question mirroring the one above. We can search among our results for which size event will become, say, at least x% likely by the next 20 years, rather than starting with a given size event and ask what its likelihood of occurring at least once in the next 20 year will be. Similarly we can ask questions about waiting times, looking for the number of years it will take for a given size event to occur with at least an x% chance.

Our calculations all concern flood levels reaching elevations relative to a stable baseline, the average high tide level during a fixed historic reference period at each station, the so called tidal datum epoch (the current standard epoch is 1983-2001). This way of measuring flood levels is different than pure storm surge, which is calculated as the extra water height above the predicted tidal water level for the very same moment in time. Our focus was not storm surge, but rather how high water actually gets, due to storm surge, plus tide, plus sea level rise.

This analysis assumed that historic storm patterns will not change; in other words, it did not address the possibility that storms might become more or less frequent or severe due to climate change.

This analysis was based on data taken at water level stations. Tides, storm surge, and the resulting statistics vary from place to place, sometimes over short distances, due to factors including land and ocean geometry and storm directions. On the other hand, in our national analysis (Tebaldi et al 2012), results for distantly spaced water level stations within the same region were often similar. Therefore, results from stations may be taken as rough indicators but not precise estimates for their neighborhoods and regions, and the quality and coverage of indication will vary.

ESTIMATING GLOBAL WARMING FLOOD RISK MULTIPLIERS

To estimate how global warming is shifting the odds of high storm surges, through sea level rise, we calculated the odds of extreme events in a hypothetical world with no past or future global sea level rise due to warming, to compare against our original calculations, which included warming. We did this comparison at each water level station in the study. The approach basically translated to subtracting out the roughly 8 inches of historical global sea level rise measured from 1880-2009, and then also assuming no future global sea level rise, for the no-warming scenario at each station (a scenario viewable in the Surging Seas Risk Finder). The no-warming scenarios still included local sea level rise from factors other than warming, such as sinking or lifting land — the full local component of sea level rise.

We made one further adjustment, which was to add back 10% of the historic global sea level rise (10% of 8 inches), in the event that some of the observed historic rise has come from factors other than warming. Research on the sea level budget assigns the great majority of the 8 inches to warming-caused effects: expansion of the ocean as it has warmed, and the melting and calving of glaciers and ice sheets. Small fractions of global sea rise unaccounted for are widely viewed to come at least in part from additional ice loss. We assume 90% of the 8 inches are due to global warming, and thus deduct this amount for our comparison.

For comparison of odds with and without warming, we used standard "100-year" or "century" floods as our reference, meaning water station water levels high enough that they have just a 1% chance of occurring in any given year. We calculated the elevations 100-year floods reach when starting on top of baseline 2012 sea level at each station, using the same data and methods as for our overall water level probability projections. Elevations were relative to average local high tide (MHHW) during a fixed past reference period (the 1983-2001 tidal epoch), as with all elevations in related studies.

In comparing the probabilities of flood levels with and without global warming, we cut ratios off at ten, because higher ratios start to lose a sense of meaning. We also do not compute ratios at all when the chance of flooding is very close to zero without global warming. These situations create very large ratios whose exact values are meaningless: tiny changes in near-zero odds (odds without global warming) would lead to enormous changes in the ratio value.

This analysis did not address the possibility that storms might become more or less frequent or severe due to climate change. We also limited ourselves to looking at the total effects of global warming, and did not aim to separate fractions caused by humans versus natural variations. The strong scientific consensus points to people as causing most, if not all, of the average warming observed over the last century, and to being the dominant cause of future warming.

MAPPING LOW COASTAL AREAS

To develop our maps of at-risk areas, we used high-resolution, high-accuracy laser-based (lidar) elevation data provided by NOAA. These data have a roughly 5 m (16.5 ft) horizontal resolution. In the small fraction of low-lying areas not covered, we used the highest resolution data available from the National Elevation Dataset (NED), a product of the U.S. Geological Survey.

For general discussion of the accuracy of elevation data and what it means for our maps and statistics, see Strauss et al (2012), which used NED data exclusively, as lidar data were not sufficiently available. This discussion concluded that NED quality data are sufficient for the types of analysis conducted here. Nonetheless, the reported vertical accuracy (root mean square error) of lidar data, as used in this analysis, is roughly ten times more accurate than NED.

We began our process by classifying all cells as ocean (ocean, bay, estuary or saltwater wetland) or land (land or freshwater wetland), because ocean or saltwater marsh misclassified as land would lead to overestimates of susceptible total land area. We admitted cells as land according to a conservative consensus of three independent data sets. First, the cells had to be designated as land within the elevation data itself. Second, we included only cells with centers landward of NOAA's Medium Resolution Digital Vector Shoreline. Finally, we eliminated cells with centers inside areas classified in the National Wetlands Inventory (NWI) as estuarine or marine wetland or deepwater. In computing total land area susceptible, we included NWI freshwater wetlands.

Next, we adjusted the elevation of each cell to be in reference to the nearest average high tide line, instead of a standard zero. For example, if a cell's elevation were five feet, but the local high tide reached three feet, then we would compute an elevation of two feet relative to the tide line. Clearly, sea level rise or a storm surge would need to reach only two feet above high tide to threaten this cell with inundation. Sea level and tidal amplitude vary sometimes widely from place to place, and therefore also the average height of high tide. For local high tide elevations, we used values of Mean Higher High Water from VDatum, a NOAA data product and tidal model.

Based on these elevations adjusted relative to MHHW, we identified the set of cells beneath each water level threshold from one to ten feet above local high tide, and drew maps of each area.

Finally, we distinguished areas connected to ocean at a given water level, versus isolated areas, to use in different exposure analyses, and for differential display in our online mapping application. We included levees from the Midterm Levee Inventory in this analysis of connectivity, assuming each levee to be of sufficient height and condition to offer protection at every water level. Additional discussion can be found in the main body of this report (see "Land" in Table of Contents).

ASSESSING SOCIAL VULNERABILITY

The Social Vulnerability Index for 2006-10 marks a change in the formulation of the SoVI® metric from earlier versions (see e.g. Emrich and Cutter 2011). New directions in the theory and practice of vulnerability science emphasize the constraints of family structure, language barriers, vehicle availability, medical disabilities, and healthcare access in the preparation for and response to disasters, thus necessitating the inclusion of such factors in SoVI®. Extensive testing of earlier conceptualizations of SoVI®, in addition to the introduction of the U.S. Census Bureau's five-year American Community Survey (ACS) estimates, warrants changes to the SoVI® recipe, resulting in a more robust metric. These changes, pioneered with the ACS-based SoVI® 2005-09, carry over to SoVI® 2006-10, which combines the best data available from both the 2010 U.S. Decennial Census and five-year estimates from the 2006-2010 ACS.

The table at the top of the following page gives a complete list of the 27 variables used in SOVI® 2006-10 for Census tract level analysis.

APPENDIX A: METHODS

Table A1. Variables Used in Social Vulnerability Analysis

VARIABLE	DESCRIPTION
QASIAN	Percent Asian
QBLACK	Percent Black
QHISP	Percent Hispanic
QNATAM	Percent Native American
QAGEDEP†	Percent of Population Under 5 Years or 65 and Over
QFAM†	Percent of Children Living in Married Couple Families
MEDAGE	Median Age
QSSBEN	Percent of Households Receiving Social Security
QPOVTY	Percent Poverty
QRICH200K	Percent of Households Earning Greater Than $200,000 Annually
PERCAP	Per Capita Income
QESL†	Percent Speaking English as a Second Language with Limited English Proficiency
QFEMALE	Percent Female
QFHH	Percent Female Headed Households
QNRRES	Percent of Population Living in Nursing and Skilled-Nursing Facilities
QED12LES	Percent with Less Than 12th Grade Education
QCVLUN	Percent Civilian Unemployment
PPUNIT	Per Unit
QRENTER	Percent Renters
MDHSEVAL†	Median House Value
MDGRENT†	Median Gross Rent
QMOHO	Percent Mobile Homes
QEXTRCT	Percent Employment in Extractive Industries
QSERV	Percent Employment in Service Industry
QFEMLBR	Percent Female Participation in Labor Force
QNOAUTO†	Percent of Housing Units with No Car
QUNOCCHU	Percent Unoccupied Housing Units

For this analysis, we assessed Social Vulnerability Index scores by Census tract across all New York State counties. We then assigned tracts high, medium, or low social vulnerability scores, based on whether they fell within the top 20%, middle 60%, or bottom 20%, respectively, of vulnerability for the whole set.

More information on the Social Vulnerability Index is available at http://webra.cas.sc.edu/hvri/products/sovi.aspx

APPENDIX A: METHODS

ESTIMATING EXPOSURE OF PEOPLE, PROPERTY, AND INFRASTRUCTURE

To calculate potential risks at each water level within areas such as zip codes, cities or counties, we used boundaries provided by the 2010 U.S. Census to overlay against our maps of land beneath different water level thresholds. We then computed the amount of land below each threshold in each place. For denominators in percentage calculations, we used our own computations of land area for each place, because our definitions of coastline differed slightly in places from that of the Census.

To tabulate population and housing potentially affected, we used block-level data from the 2010 U.S. Census, and assumed development on dry land only (neither freshwater nor saltwater wetland). For each Census block, we divided the population and number of housing units by the number of dry land cells with centers inside the block. We assigned the resulting per-cell density values back to each cell, creating new datasets for population and housing unit density. To estimate the population or housing at risk for a particular water level, we simply added up population and housing densities of land cells affected under the specification. Our analysis considered the elevation of land upon which housing stands, and made no special provision for elevated or multi-story buildings.

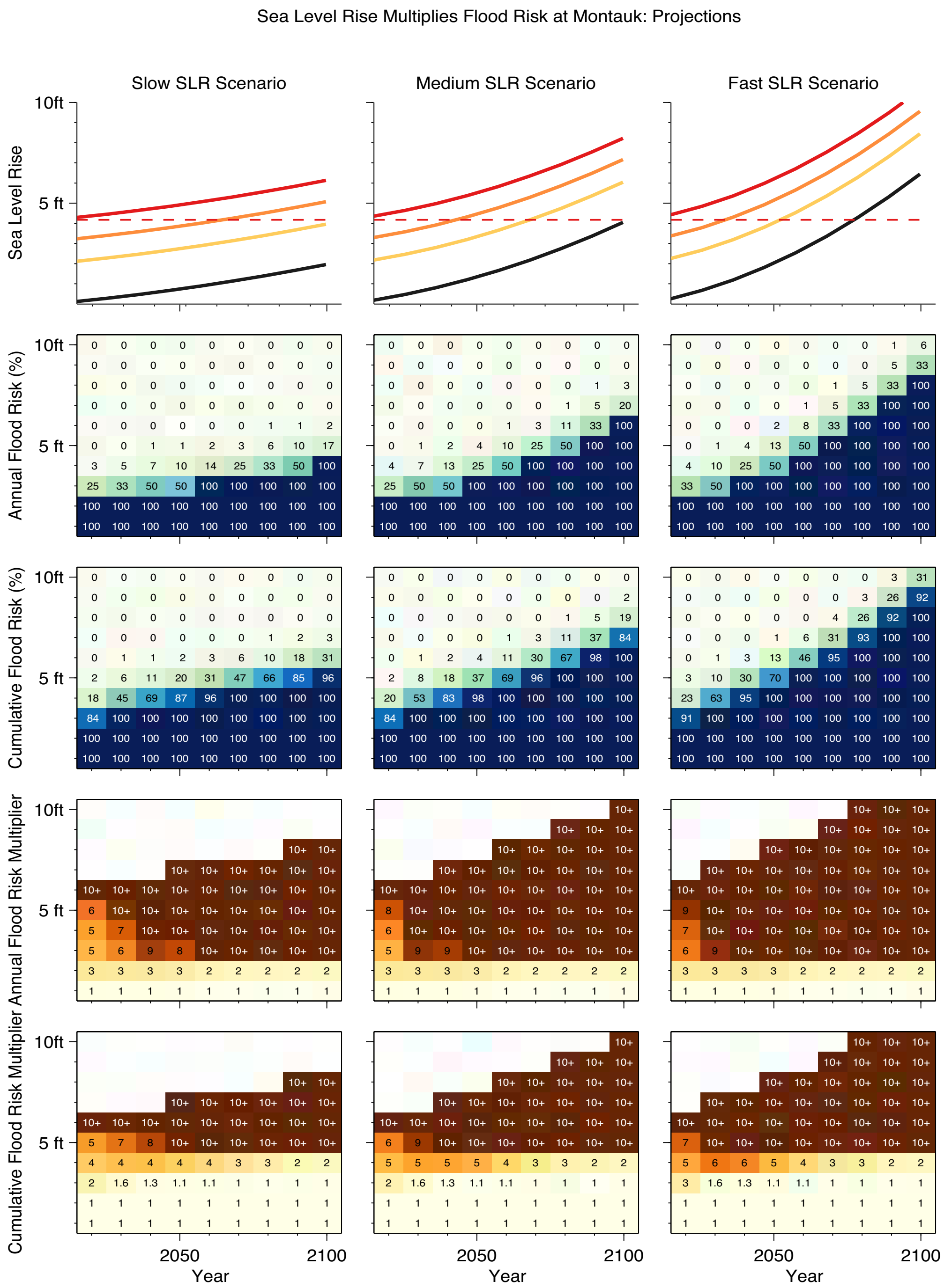
We followed the same essential approach for property value, but using Census block group geometry from the 2000 Census, in order to match with property value data from Neumann et al (2010). The property value is derived mostly from individual parcel assessed values, evaluated in 2008 and 2009, which we adjusted using the Consumer Price Index to 2012 dollars. The data include residential, commercial, industrial, institutional and government property, both taxable and tax-exempt.

For analysis of linear features such as roads and rail, we computed the length of each feature on land below the water level in question, and made totals by feature type (e.g. total roads, federally-owned roads, or mainline rail).

For point features, we simply use latitude/longitude coordinates overlaid onto our MHHW elevation map to evaluate whether a building, site or facility falls below a given water level. This approach does not take into account the actual footprint of a structure, nor the possibility that critical features may be elevated above the ground (or stored in an unsealed basement).

The first step in each type of analysis is to properly filter and de-duplicate records for the feature class or subclass of interest from a source dataset – for example, sewage treatment plants from among all EPA listed sites. Feature data came from latest available versions of the U.S. Census's TIGER lines database (roads), DOT's National Transportation Atlas Database (rail, passenger stations), DOE's Annual Electric Generator Report (power plants), EPA's Facilities Registry Database (EPA listed sites, sewage plants), the Department of Education's National Center of Education Statistics (public schools), and USGS's Geographic Names Information Service (hospitals, houses of worship). The New York Surging Seas Risk Finder "Comparison" and "Analysis" modules give more detail about these data sources and the many additional sources for data analysis presented online only.

APPENDIX B: TABLES AND FIGURES FOR MONTAUK, NY AND BRIDGEPORT, CT WATER LEVEL STATIONS



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3	5	7	10	14	25	33	50	100
25	33	50	50	100	100	100	100	100
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100	100	100	100	100	100	100	100	100

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0	0	0	0	0	0	1	5	20
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100	100	100	100	100	100	100	100	100

0	0	0	0	0	0	0	1	6
0	0	0	0	0	0	0	5	33
0	0	0	0	0	1	5	33	100
0	0	0	0	1	5	33	100	100
0	0	0	2	8	33	100	100	100
0	1	4	13	50	100	100	100	100
4	10	25	50	100	100	100	100	100
33	50	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	2	3
0	1	1	2	3	6	10	18	31
2	6	11	20	31	47	66	85	96
18	45	69	87	96	100	100	100	100
84	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	1	5	19
0	0	0	0	1	3	11	37	84
0	1	2	4	11	30	67	98	100
2	8	18	37	69	96	100	100	100
20	53	83	98	100	100	100	100	100
84	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100

0	0	0	0	0	0	0	3	31
0	0	0	0	0	0	3	26	92
0	0	0	0	0	4	26	92	100
0	0	0	1	6	31	93	100	100
0	1	3	13	46	95	100	100	100
3	10	30	70	100	100	100	100	100
23	63	95	100	100	100	100	100	100
91	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100

							10+	10+
			10+	10+	10+	10+	10+	10+
10+	10+	10+	10+	10+	10+	10+	10+	10+
6	10+	10+	10+	10+	10+	10+	10+	10+
5	7	10+	10+	10+	10+	10+	10+	10+
5	6	9	8	10+	10+	10+	10+	10+
3	3	3	3	2	2	2	2	2
1	1	1	1	1	1	1	1	1

								10+
						10+	10+	10+
				10+	10+	10+	10+	10+
		10+	10+	10+	10+	10+	10+	10+
10+	10+	10+	10+	10+	10+	10+	10+	10+
8	10+	10+	10+	10+	10+	10+	10+	10+
6	10+	10+	10+	10+	10+	10+	10+	10+
5	9	9	10+	10+	10+	10+	10+	10+
3	3	3	3	2	2	2	2	2
1	1	1	1	1	1	1	1	1

						10+	10+	10+
					10+	10+	10+	10+
			10+	10+	10+	10+	10+	10+
	10+	10+	10+	10+	10+	10+	10+	10+
10+	10+	10+	10+	10+	10+	10+	10+	10+
9	10+	10+	10+	10+	10+	10+	10+	10+
7	10+	10+	10+	10+	10+	10+	10+	10+
6	9	10+	10+	10+	10+	10+	10+	10+
3	3	3	3	2	2	2	2	2
1	1	1	1	1	1	1	1	1

							10+	10+
			10+	10+	10+	10+	10+	10+
10+	10+	10+	10+	10+	10+	10+	10+	10+
5	7	8	10+	10+	10+	10+	10+	10+
4	4	4	4	4	3	3	2	2
2	1.6	1.3	1.1	1.1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

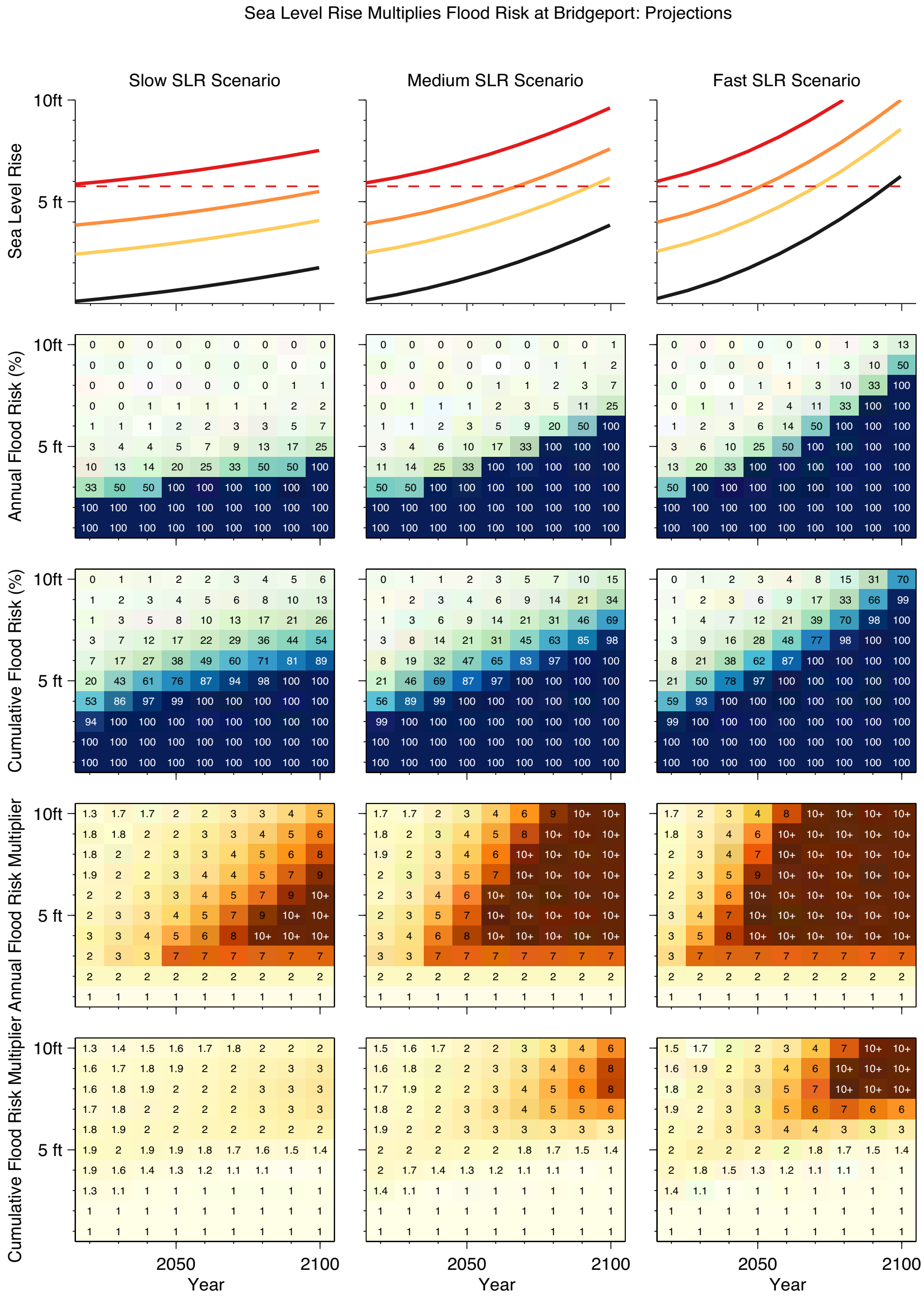
								10+
						10+	10+	10+
				10+	10+	10+	10+	10+
		10+	10+	10+	10+	10+	10+	10+
10+	10+	10+	10+	10+	10+	10+	10+	10+
6	9	10+	10+	10+	10+	10+	10+	10+
5	5	5	5	4	3	3	2	2
2	1.6	1.3	1.1	1.1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

						10+	10+	10+
					10+	10+	10+	10+
			10+	10+	10+	10+	10+	10+
	10+	10+	10+	10+	10+	10+	10+	10+
10+	10+	10+	10+	10+	10+	10+	10+	10+
7	10+	10+	10+	10+	10+	10+	10+	10+
5	6	6	5	4	3	3	2	2
3	1.6	1.3	1.1	1.1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

Figure B1. Sea Level Rise Multiplies Flood Risk at Montauk, NY

The top row shows slow (left hand side) through fast (right hand side) scenario sea level rise projections (black lines), plus the height of 1-year (yellow), 10-year (orange) or 100-year (red) floods. The dashed red line shows the elevation of a 100-year (extreme) flood measured from today's high tide line (MHHW). The next two rows show projections for annual and cumulative percentage risk of floods reaching 1-10 ft MHHW by decade (2020-2100). The final two rows show how the global warming component of sea level rise is projected to multiply these risks, cell-by-cell.

APPENDIX B: TABLES AND FIGURES FOR MONTAUK, NY AND BRIDGEPORT, CT WATER LEVEL STATIONS



10ft	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	1	1
	0	0	1	1	1	1	1	2	2
	1	1	1	2	2	3	3	5	7
5 ft	3	4	4	5	7	9	13	17	25
	10	13	14	20	25	33	50	50	100
	33	50	50	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100

10ft	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	1	1	2
	0	0	0	0	1	1	2	3	7
	0	1	1	1	2	3	5	11	25
	1	1	2	3	5	9	20	50	100
5 ft	3	4	6	10	17	33	100	100	100
	11	14	25	33	100	100	100	100	100
	50	50	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100

10ft	0	0	0	0	0	0	1	3	13
	0	0	0	0	1	1	3	10	50
	0	0	0	1	1	3	10	33	100
	0	1	1	2	4	11	33	100	100
	1	2	3	6	14	50	100	100	100
5 ft	3	6	10	25	50	100	100	100	100
	13	20	33	100	100	100	100	100	100
	50	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100

10ft	0	1	1	2	2	3	4	5	6
	1	2	3	4	5	6	8	10	13
	1	3	5	8	10	13	17	21	26
	3	7	12	17	22	29	36	44	54
	7	17	27	38	49	60	71	81	89
5 ft	20	43	61	76	87	94	98	100	100
	53	86	97	99	100	100	100	100	100
	94	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100

10ft	0	1	1	2	3	5	7	10	15
	1	2	3	4	6	9	14	21	34
	1	3	6	9	14	21	31	46	69
	3	8	14	21	31	45	63	85	98
	8	19	32	47	65	83	97	100	100
5 ft	21	46	69	87	97	100	100	100	100
	56	89	99	100	100	100	100	100	100
	99	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100

10ft	0	1	2	3	4	8	15	31	70
	1	2	3	6	9	17	33	66	99
	1	4	7	12	21	39	70	98	100
	3	9	16	28	48	77	98	100	100
	8	21	38	62	87	100	100	100	100
5 ft	21	50	78	97	100	100	100	100	100
	59	93	100	100	100	100	100	100	100
	99	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100

10ft	1.3	1.7	1.7	2	2	3	3	4	5
	1.8	1.8	2	2	3	3	4	5	6
	1.8	2	2	3	3	4	5	6	8
	1.9	2	2	3	4	4	5	7	9
	2	2	3	3	4	5	7	9	10+
5 ft	2	3	3	4	5	7	9	10+	10+
	3	3	4	5	6	8	10+	10+	10+
	2	3	3	7	7	7	7	7	7
	2	2	2	2	2	2	2	2	2
	1	1	1	1	1	1	1	1	1

10ft	1.7	1.7	2	3	4	6	9	10+	10+
	1.8	2	3	4	5	8	10+	10+	10+
	1.9	2	3	4	6	10+	10+	10+	10+
	2	3	3	5	7	10+	10+	10+	10+
	2	3	4	6	10+	10+	10+	10+	10+
5 ft	2	3	5	7	10+	10+	10+	10+	10+
	3	4	6	8	10+	10+	10+	10+	10+
	3	3	7	7	7	7	7	7	7
	2	2	2	2	2	2	2	2	2
	1	1	1	1	1	1	1	1	1

10ft	1.7	2	3	4	8	10+	10+	10+	10+
	1.8	3	4	6	10+	10+	10+	10+	10+
	2	3	4	7	10+	10+	10+	10+	10+
	2	3	5	9	10+	10+	10+	10+	10+
	2	3	6	10+	10+	10+	10+	10+	10+
5 ft	3	4	7	10+	10+	10+	10+	10+	10+
	3	5	8	10+	10+	10+	10+	10+	10+
	3	7	7	7	7	7	7	7	7
	2	2	2	2	2	2	2	2	2
	1	1	1	1	1	1	1	1	1

10ft	1.3	1.4	1.5	1.6	1.7	1.8	2	2	2
	1.6	1.7	1.8	1.9	2	2	2	3	3
	1.6	1.8	1.9	2	2	2	3	3	3
	1.7	1.8	2	2	2	2	3	3	3
	1.8	1.9	2	2	2	2	2	2	2
5 ft	1.9	2	1.9	1.9	1.8	1.7	1.6	1.5	1.4
	1.9	1.6	1.4	1.3	1.2	1.1	1.1	1	1
	1.3	1.1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1

10ft	1.5	1.6	1.7	2	2	3	3	4	6
	1.6	1.8	2	2	3	3	4	6	8
	1.7	1.9	2	2	3	4	5	6	8
	1.8	2	2	3	3	4	5	5	6
	1.9	2	2	3	3	3	3	3	3
5 ft	2	2	2	2	2	1.8	1.7	1.5	1.4
	2	1.7	1.4	1.3	1.2	1.1	1.1	1	1
	1.4	1.1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1

10ft	1.5	1.7	2	2	3	4	7	10+	10+
	1.6	1.9	2	3	4	6	10+	10+	10+
	1.8	2	3	3	5	7	10+	10+	10+
	1.9	2	3	3	5	6	7	6	6
	2	2	3	3	4	4	3	3	3
5 ft	2	2	2	2	2	1.8	1.7	1.5	1.4
	2	1.8	1.5	1.3	1.2	1.1	1.1	1	1
	1.4	1.1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1

Figure B2. Sea Level Rise Multiplies Flood Risk at Bridgeport, CT

The top row shows slow (left hand side) through fast (right hand side) scenario sea level rise projections (black lines), plus the height of 1-year (yellow), 10-year (orange) or 100-year (red) floods. The dashed red line shows the elevation of a 100-year (extreme) flood measured from today's high tide line (MHHW). The next two rows show projections for annual and cumulative percentage risk of floods reaching 1-10 ft MHHW by decade (2020-2100). The final two rows show how the global warming component of sea level rise is projected to multiply these risks, cell-by-cell.

APPENDIX B: TABLES AND FIGURES FOR MONTAUK, NY AND BRIDGEPORT, CT WATER LEVEL STATIONS

Table B1. Extreme Flood Projections at Montauk, NY

Extreme flood level based on statistical analysis of historic record at station: 4.2 ft above MHHW

Annual likelihood of exceeding extreme flood level

	Likelihood			GW Multiplier		
Scenario	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
NoGW	1%	1%	2%	-	-	-
Slow	3%	7%	50%	3	5	10+
Medium	5%	20%	100%	4	10+	10+
Fast	7%	50%	100%	6	10+	10+

Cumulative likelihood of exceeding extreme flood level

	Likelihood			GW Multiplier		
Scenario	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
NoGW	19%	38%	72%	-	-	-
Slow	34%	75%	100%	1.8	2	1.4
Medium	40%	94%	100%	2	3	1.4
Fast	50%	100%	100%	3	3	1.4

APPENDIX B: TABLES AND FIGURES FOR MONTAUK, NY AND BRIDGEPORT, CT WATER LEVEL STATIONS

Table B2. Extreme Flood Projections at Bridgeport, CT

Extreme flood level based on statistical analysis of historic record at station: 5.8 ft above MHHW

Annual likelihood of exceeding extreme flood level

	Likelihood			GW Multiplier		
Scenario	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
NoGW	1%	1%	1%	-	-	-
Slow	2%	2%	9%	1.5	2	9
Medium	2%	4%	100%	1.9	4	10+
Fast	2%	8%	100%	2	8	10+

Cumulative likelihood of exceeding extreme flood level

	Likelihood			GW Multiplier		
Scenario	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
NoGW	17%	32%	59%	-	-	-
Slow	21%	46%	95%	1.3	1.4	1.6
Medium	23%	56%	100%	1.4	1.8	1.7
Fast	26%	72%	100%	1.6	2	1.7

APPENDIX C: ELEVATION AND TIDAL DATUM CONVERSION TABLES

Table C1: Flood Elevation Conversion Tables

For this analysis, we use elevation relative to Mean Higher High Water (MHHW) as the standard of comparison for all flood heights. Some other sources use different frames of reference for elevation. To compare across sources, use the conversion tables below. Note that there are different conversions at different water level stations because of different tidal regimes.

Examples: If the water level is 10 feet above the MHHW at the Battery, then it is 15.05 feet above the MLLW

If the water level is at a standard elevation of 8 feet (NAVD88) at the Battery, then it is also 7.72 ft above MHHW (7.72 = 10 - 2.28)

The Battery, New York, NY

Datum	Description	To convert elevations from MHHW	To convert elevations to MHHW
MHHW	Mean Higher High Water	-	-
MHW	Mean High Water	MHHW + 0.32 ft	MHW - 0.32 ft
NAVD88	North American Vertical Datum, 1988	MHHW + 2.28 ft	NAVD88 - 2.28 ft
MLLW	Mean Lower Low Water	MHHW + 5.05 ft	MLLW - 5.05 ft

Bridgeport, CT

Datum	Description	To convert elevations from MHHW	To convert elevations to MHHW
MHHW	Mean Higher High Water	-	-
MHW	Mean High Water	MHHW + 0.33 ft	MHW - 0.33 ft
NAVD88	North American Vertical Datum, 1988	MHHW + 3.48 ft	NAVD88 - 3.48 ft
MLLW	Mean Lower Low Water	MHHW + 7.32 ft	MLLW - 7.32 ft

Table C1: Flood Elevation Conversion Tables (continued)

Montauk, NY

Datum	Description	To convert elevations from MHHW	To convert elevations to MHHW
MHHW	Mean Higher High Water	-	-
MHW	Mean High Water	MHHW + 0.29 ft	MHW - 0.29 ft
NAVD88	North American Vertical Datum, 1988	MHHW + 0.96 ft	NAVD88 - 0.96 ft
MLLW	Mean Lower Low Water	MHHW + 2.53 ft	MLLW - 2.53 ft

APPENDIX D: TABLES OF EXPOSURE AT 9 FEET MEAN HIGH HIGHER WATER

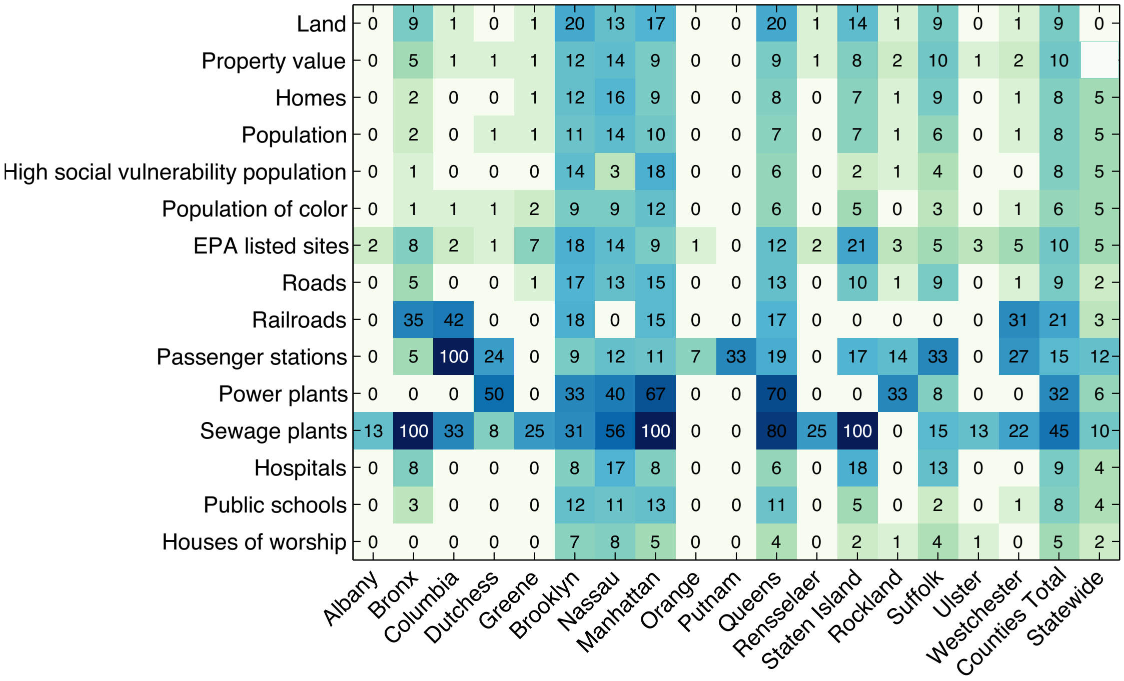
Table D1. Top Zip Codes At Risk, 9 Feet.

New York statewide and top zip code totals for people and property on land less than 9 ft above the high tide line.

Variable	State Total Below 6 ft	Top Three Zip Codes Affected	% of Total < 9ft	Top Five Zip Codes Affected	% of Total < 9 ft	Top Zip Codes (Most to Least Affected)	Total Number of Affected Zip Codes in State
Land (acres)	118,737	8,342	7%	12,878	11%	11430 (JKF Int. Airport, Queens) 11758 (Massapequa) 11968 (Southampton) 11937 (East Hampton) 11930 (Amagansett)	356
Population	930,270	164,130	18%	234,094	25%	11235 (Manhattan Beach, Brooklyn) 11224 (Coney Island, Brooklyn) 11236 (Cararsie, Brooklyn) 11561 (Long Beach) 11691 (Far Rockaway, Queens)	336
Property Value ($ Billions)	176	17.9	10%	26.9	15%	11235 (Manhattan Beach, Brooklyn) 11561 (Long Beach) 10004 (Battery Park City) 11694 (Rockaway Park) 11234 (Mill Basin, Brooklyn)	374
Housing Units	404,952	73,240	18%	101,502	25%	11235 (Manhattan Beach, Brooklyn) 11224 (Coney Island, Brooklyn) 11561 (Long Beach) 11236 (Canarsie, Brooklyn) 11691 (Far Rockaway, Queens)	322
Road Miles	2,448	208	8%	318	13%	11561 (Long Beach) 11758 (Massapequa) 11572 (Oceanside) 11235 (Manhattan Beach, Brooklyn) 11706 (Bay Shore)	230
EPA-listed sites	2,323	243	10%	376	16%	11101 (Long Island City, Queens) 11520 (Freeport) 11224 (Coney Island, Brooklyn) 11231 (Red Hook, Brooklyn) 11222 (Greenpoint, Brooklyn)	217

Table D2. County and State Percentages of People, Property and Infrastructure on Land Below 9 Feet.

Figures in the "Counties Total" column give percentages for the listed counties considered collectively. Figures in the "State" column give percentages for the state as a whole (including all state counties). *Statewide percentages for property value are not included due to missing data for high elevation (unlisted) counties.*



	Albany	Bronx	Columbia	Dutchess	Greene	Brooklyn	Nassau	Manhattan	Orange	Putnam	Queens	Rensselaer	Staten Island	Rockland	Suffolk	Ulster	Westchester	Counties Total	Statewide
Land	0	9	1	0	1	20	13	17	0	0	20	1	14	1	9	0	1	9	0
Property value	0	5	1	1	1	12	14	9	0	0	9	1	8	2	10	1	2	10	
Homes	0	2	0	0	1	12	16	9	0	0	8	0	7	1	9	0	1	8	5
Population	0	2	0	1	1	11	14	10	0	0	7	0	7	1	6	0	1	8	5
High social vulnerability population	0	1	0	0	0	14	3	18	0	0	6	0	2	1	4	0	0	8	5
Population of color	0	1	1	1	2	9	9	12	0	0	6	0	5	0	3	0	1	6	5
EPA listed sites	2	8	2	1	7	18	14	9	1	0	12	2	21	3	5	3	5	10	5
Roads	0	5	0	0	1	17	13	15	0	0	13	0	10	1	9	0	1	9	2
Railroads	0	35	42	0	0	18	0	15	0	0	17	0	0	0	0	0	31	21	3
Passenger stations	0	5	100	24	0	9	12	11	7	33	19	0	17	14	33	0	27	15	12
Power plants	0	0	0	50	0	33	40	67	0	0	70	0	0	33	8	0	0	32	6
Sewage plants	13	100	33	8	25	31	56	100	0	0	80	25	100	0	15	13	22	45	10
Hospitals	0	8	0	0	0	8	17	8	0	0	6	0	18	0	13	0	0	9	4
Public schools	0	3	0	0	0	12	11	13	0	0	11	0	5	0	2	0	1	8	4
Houses of worship	0	0	0	0	0	7	8	5	0	0	4	0	2	1	4	1	0	5	2

APPENDIX E: GLOSSARY AND ABBREVIATIONS

EPA – U.S. Environmental Protection Agency

Extreme flood – As used in this report, a coastal flood height with a 1% or lower annual chance, assuming the sea level for 2012.

High tide line – see MHHW

IPCC – Intergovernmental Panel on Climate Change

Lidar – Light detection and ranging technology. A method of measuring distance that relies on firing laser beams and analyzing their returned, reflected light.

MHHW – Mean Higher High Water: a local frame of reference for elevation based on the elevation of the higher of the two high tides each day averaged across a reference period. The reference period used is the current tidal epoch, 1983-2001. This report uses "high tide line" as the equivalent of the height of MHHW.

MLLW – Mean Lower Low Water. See MHHW; MLLW is instead a frame of reference based on the elevation of the lower of the two low tides each day.

NCA – National Climate Assessment

NOAA – National Oceanic and Atmospheric Administration

NPCC2 – New York City Panel on Climate Change

Sea level rise, slow – In this report, the NCA intermediate low global sea level rise scenario

Sea level rise, medium – In this report, the NCA intermediate high global sea level rise scenario

Sea level rise, fast – In this report, the NCA fast global sea level rise scenario

SLR – Sea level rise

Social vulnerability - A broad term that describes the sensitivity of populations to the impacts of environmental risks and hazards, including coastal flooding; related to a community's ability to prepare for, respond to, and recover from hazard events.

Storm tide – the height of tidal stage plus storm surge

Tidal epoch – Period over which tidal levels are defined. See definition for MHHW.

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