GROWING STRONGER:

TOWARD A CLIMATE-READY PHILADELPHIA

Report by the Mayor's Office of Sustainability and ICF International

NOVEMBER 2015

Shifts in weather patterns and increasingly frequent extreme storms are challenging communities around the world, including Philadelphia, and inspiring many cities to begin the important work of understanding how climate change will impact municipal assets and operations. The City of Philadelphia is responsible for a broad swath of activities including protecting public safety; enforcing zoning and building standards; supporting improvements in public health; guiding physical and economic development; constructing and maintaining bridges and streets; collecting trash and recycling from more than half-a-million households; and operating two airports, one of the largest urban park systems in the world, and an integrated water, wastewater, and stormwater utility. To continue providing these services to our 1.5 million residents, nearly 35,000 businesses, and approximately 250,000 workers who commute into the city, the City of Philadelphia needs to understand and prepare for the specific changes in climate coming to our corner of the world.

We recognized our climate adaptation efforts would be most successful with the participation of departments and agencies that will need to adjust to the coming warmer and wetter weather. In 2012, the Mayor's Office of Sustainability (MOS) convened the Climate Adaptation Working Group (CAWG), a group of 10 agencies and departments committed to guiding the city's work to prepare for climate change. Together we commissioned *Useful Climate Information for Philadelphia: Past and Future* to understand what we need to prepare for. The CAWG and MOS then used the report to help city departments understand climate projections and how they can include the information in their decision-making processes.

While we acknowledge that climate change will influence Philadelphia citywide, we decided to focus *Growing Stronger: Toward a Climate-Ready Philadelphia* on beginning to assess vulnerabilities and preparation opportunities for municipal government, and identifying relatively low-barrier and high-impact internal actions we can take while we begin to grapple with larger questions such as how to assess and minimize risks to environmental health, neighborhood investments, and quality of life. We are confident that this first phase of work will help reduce risk, decrease stressors on city infrastructure and services, and guide proactive projects with benefits extending far beyond municipal operations.

Climate adaptation planning will need to be a continuous process, and we are committed to moving the recommendations in this report forward while also expanding the focus beyond government to ensure that Philadelphia continues to be an attractive place to live, work, and play, whatever the weather may bring.

City of Philadelphia Climate Adaptation Working Group

CITY OF PHILADELPHIA LAW DEPARTMENT
MAYOR'S OFFICE OF SUSTAINABILITY
MAYOR'S OFFICE OF TRANSPORTATION AND UTILITIES
OFFICE OF EMERGENCY MANAGEMENT
OFFICE OF THE DIRECTOR OF FINANCE
PHILADELPHIA CITY PLANNING COMMISSION
PHILADELPHIA DEPARTMENT OF PUBLIC HEALTH
PHILADELPHIA INDUSTRIAL DEVELOPMENT CORPORATION
PHILADELPHIA PARKS & RECREATION
PHILADELPHIA WATER

TABLE OF CONTENTS

COVER: PHOTO BY B. KRIST FOR VISIT PHILADELPHIA™

1

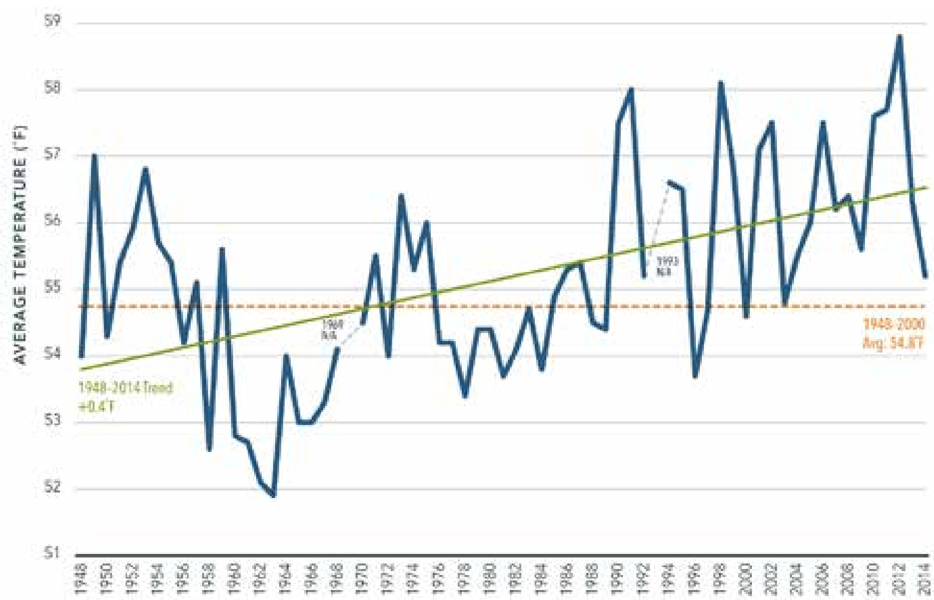
PROJECT BACKGROUND

In 1976, gasoline cost 59 cents per gallon, a first-class postage stamp cost 13 cents, the United States celebrated its bicentennial, and millions of theatergoers nationwide watched Rocky Balboa make his iconic run up the steps of the Philadelphia Museum of Art.

1976 was also the last year in which the Earth's average temperature was below the 20th century mean.[1] Every year since then—38 years and counting—has been warmer than average, and the climate throughout much of the world is very different than it was then.

FIGURE 1

ANNUAL TEMPERATURE TREND FOR PHILADELPHIA, 1948–2014



The horizontal line represents the average temperature in Philadelphia from 1948–2000.[2]

Philadelphia's climate is no exception (see Figure 1). Since 2010, Philadelphia has experienced a variety of extreme weather, including the snowiest winter, the two warmest summers, the wettest day, and the two wettest years on record, as well as two hurricanes and a derecho (a severe windstorm—usually associated with thunderstorms—that produces damage along a relatively straight path). Forty-nine daily high temperature records have been set in Philadelphia since the year 2000, 18 of them since the year 2010.[3] And the sea level around Philadelphia has been rising at a rate of roughly 0.11 inches per year since 1900, equivalent to an increase of nearly one foot in 100 years.[4]

Scientists expect these trends to continue in the future, at an accelerating pace and with increasing severity. The best available climate information suggests that weather in Philadelphia will become warmer and wetter during all seasons in the years and decades ahead, and that the rate of sea level rise will increase, especially toward the end of this century.[4]

Changes in climate matter to Philadelphia. Storms, heat waves, and floods already pose risks to residents and infrastructure, and the city is responsible for responding to these events by plowing the streets, managing stormwater, keeping Philadelphians safe during storms, and leading cleanup efforts when the storms clear. Philadelphia needs to build resilience to accommodate today's extremes while accounting for expected changes in the frequency of these events in the future.

Expected effects of climate change in Philadelphia fall into three broad categories:

1

New Normals

THE CITY'S BUILDINGS AND INFRASTRUCTURE WERE DESIGNED TO WITHSTAND PAST CLIMATE CONDITIONS, NOT THOSE THAT SCIENTISTS EXPECT WILL OCCUR IN THE FUTURE. OVER TIME, PROLONGED EXPOSURE TO HIGHER TEMPERATURES AND CHANGING PRECIPITATION PATTERNS MAY LEAD TO SAFETY HAZARDS, SERVICE OUTAGES, AND HIGHER MAINTENANCE COSTS.

2

Changing Extremes

EXTREME EVENTS SUCH AS HEAT WAVES, INTENSE RAIN OR SNOWSTORMS, AND TROPICAL STORMS AND HURRICANES ARE EXPECTED TO BECOME MORE FREQUENT AND/OR MORE SEVERE AS THE CLIMATE CHANGES.

3

Rising Seas

ALTHOUGH PHILADELPHIA IS 90 MILES INLAND FROM THE MOUTH OF THE DELAWARE BAY, HIGHER SEA LEVELS WILL RAISE WATER LEVELS IN THE DELAWARE AND SCHUYLKILL RIVERS. HIGHER BASELINE RIVER LEVELS WOULD NOT ONLY PERMANENTLY INUNDATE PARTS OF PHILADELPHIA BUT ALSO INCREASE THE DEPTH AND EXTENT OF FLOODING IN AND AROUND THE CITY FROM STORM SURGES.

FIGURE 2

Images (clockwise, from top left) of the Schuylkill River in its current state, an actual photo during Hurricane Irene, a simulation of four feet of sea level rise, which is the expected sea level rise in 2100 under a scenario of moderate greenhouse gas emissions, and a simulation of four feet of sea level rise plus a Category 1 storm, which is the expected sea level rise in 2100 plus the most severe hurricane the region has ever experienced. (The sea level rise and hurricane scenario does not include overland flooding, only coastal water storm surge traveling up the river. Actual flooding will likely be higher due to additional flooding from upriver rainfall.)

Greenworks, Philadelphia's comprehensive sustainability plan, works to measure and reduce greenhouse gas emissions to mitigate the causes of climate change. Between the 2009 release of the *Greenworks* plan and the beginning of the City of Philadelphia's climate adaptation planning process in 2012, extreme weather events increasingly convinced cities that—as the entities responsible for emergency services, stormwater management, and street plowing—municipal governments are the first responders to the results of climate change. As Philadelphia joined the burgeoning community of practice undertaking municipal climate adaptation planning, the Mayor's Office of Sustainability (MOS) along with the Climate Adaptation Working Group (CAWG), a group of 10 agencies and departments committed to guiding the city's work to prepare for climate change, explored models of adaptation in other cities and selected the approach outlined in Figure 3 to understand and prepare for the impacts of a changing climate.

This report is the outcome of a process in which MOS, the CAWG, and a variety of city departments worked with consultant ICF International[5] to examine climate vulnerabilities and adaptation options for Philadelphia's municipal government. With ICF's support, MOS conducted scenario planning workshops, department interviews, vulnerability mapping, and economic analyses to determine how climate change might affect operations. MOS and ICF also developed a set of adaptation options for the city that could reduce vulnerabilities and build resilience to future impacts. By undertaking this work, the city will better understand how to integrate climate considerations in relevant decision making, protect Philadelphia's vulnerable populations, and be better positioned to help residents and businesses with similar resilience-building efforts.

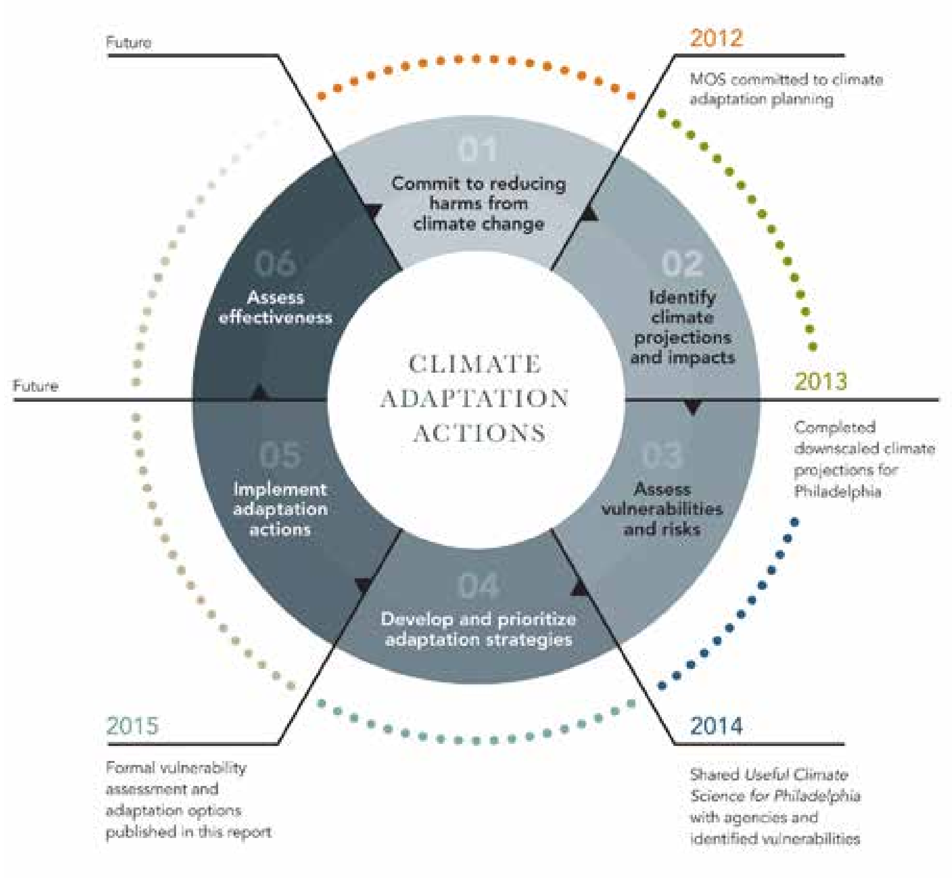
80 BY 50 ANALYSIS

Preparing for future changes in climate is only one critical piece of climate planning, which is incomplete without also working to reduce the causes of climate change. In parallel with this analysis of vulnerabilities and adaptation options, a research team at Drexel University is partnering with MOS to analyze potential pathways for Philadelphia to reduce its greenhouse gas emissions to 80 percent below 2012 levels by 2050. A number of leading cities across the country and internationally are setting aggressive reduction goals, in line with scientific recommendations to avoid dangerous interference with the climate system. The city wants to understand the feasibility of this goal as well as the scenarios that would be required to meet this reduction schedule. This work will help inform the city's next greenhouse gas emissions goal, after the current *Greenworks* goal to reduce emissions by 20 percent from 1990 levels by 2015 expires.

Philadelphia's coordinated approach to addressing the risks of climate change recognizes the need to limit future impacts—by reducing greenhouse gas emissions and thus helping to stabilize the climate—while simultaneously preparing the city and its inhabitants for the unavoidable changes ahead.

FIGURE 3

PROCESS AND TIMELINE FOR DEVELOPING AND IMPLEMENTING CLIMATE ADAPTATION ACTIONS FOR PHILADELPHIA



MOS committed to a climate adaptation process in 2012. *Growing Stronger: Toward a Climate-Ready Philadelphia* is the culmination of adaptation work undertaken by the city to date, and MOS and its partners will continue to identify and implement actions from this report, assess their effectiveness, and consider new climate data to integrate into future adaptation planning processes.

2

IMAGE COURTESY OF FLICKR USER CAMERALUV

SUMMARY

Climate change poses significant risks to Philadelphia, but also creates opportunities for the city to make smart investments that will yield multiple benefits for years to come. By taking advantage of those opportunities, Philadelphia can grow stronger in the face of a changing climate. The adaptation strategies presented in this report, based on scenario planning workshops, department interviews, vulnerability mapping, and economic analyses, can improve the city's resilience to today's weather extremes while ensuring it can handle the changes projected in the years and decades ahead.

The forecast for Philadelphia's future climate can be summed up as "warmer and wetter," but much of that warmth and moisture will be concentrated in the form of heat waves and heavy precipitation events (rain or snow)—posing challenges to infrastructure, city services, businesses, and residents.

Although Philadelphia lies 90 miles from the coast, its tidal rivers make sea level rise, which is likely to reach two feet by 2050 and four feet by 2100, a particularly important risk for the city. By the end of this century, more than 30 city-owned facilities would be highly or moderately vulnerable to flooding from sea level rise alone. Combining sea level rise with storm surge from a hurricane or tropical storm would place hundreds more facilities at risk.

The forecast for Philadelphia's future climate can be summed up as "warmer and wetter," but much of that warmth and moisture will be concentrated in the form of heat waves and heavy precipitation events (rain or snow)—posing challenges to infrastructure, city services, businesses, and residents.

The impacts of climate change in Philadelphia will be costly. Just one severe hurricane could cause more than $2 billion in damages citywide. On top of these additional disaster costs, climate change will increase the everyday cost of doing business. Taking action will help to avoid costs and provide social and economic benefits citywide.

This report identifies vulnerabilities, existing climate resilient strategies, and highly effective, low-barrier adaptation opportunities for 11 departments that manage infrastructure, provide services, or help govern and plan Philadelphia's future growth. The report also outlines opportunities for departments to cooperate and reduce shared vulnerabilities.

Work that the city completed for this report, including downscaled regional climate projections, updated inundation modeling, and planning guidance for flood protection of new facilities, is available publicly and can be used to inform citywide preparations for climate change.

Opportunities outlined in this report are important first steps toward responsibly addressing the City of Philadelphia's vulnerabilities to a warmer and wetter future. Looking forward, the City of Philadelphia will need to continue climate adaptation work at the municipal level, and at the same time, work with residents, businesses, and infrastructure managers to develop a citywide roadmap for adapting to our changing climate.

3

WHY CLIMATE CHANGE MATTERS TO PHILADELPHIA

While air conditioning, central heating, indoor plumbing, and other conveniences have reduced the impacts of climate and weather extremes on daily life and city services, Philadelphia and its residents are far from being "climate proof." Recent weather extremes such as heat waves and hurricanes have exposed vulnerabilities that Philadelphia is likely to confront with increasing frequency in the years ahead as the climate changes. These new weather patterns have the potential to decrease quality of life, disrupt business continuity, reduce the attractiveness of Philadelphia to businesses and residents, and damage built infrastructure and the natural environment—but the changes also provide opportunities to prevent these harms while providing additional benefits to Philadelphians.

See "CLIMATE MATTERS" on pages 23, 29, and 42 for examples of Philadelphia's vulnerabilities to current climate and weather extremes.

Climate Projections for the Philadelphia Region

The first step in adapting to climate change is to understand the nature and extent of anticipated changes. In 2014, the Mayor's Office of Sustainability (MOS) worked with ICF International to analyze and update projected climate changes in the Philadelphia region and release *Useful Climate Information for Philadelphia: Past and Future.*[4]

The projections, which indicate that Philadelphia will experience warmer and wetter conditions in all seasons over the course of this century (see Figure 4), informed the vulnerability assessment and the development of adaptation actions presented in this report, and could be useful to other organizations in the region that undertake their own adaptation planning processes.

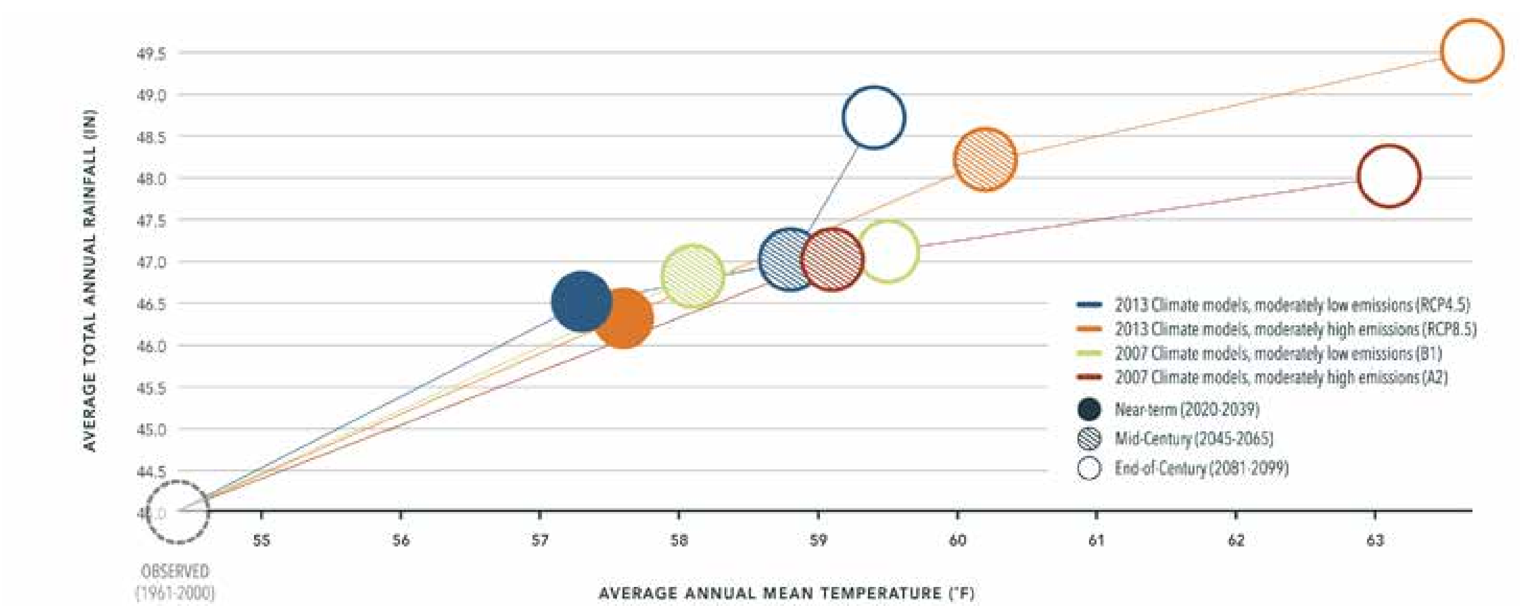
Climate projections suggest that Philadelphia may experience four to 10 times as many days per year above 95°F, and as many as 16 days a year above 100°F by the end of the century, up from the 1950–1999 average of fewer than one. More of these hot days may arrive together as heat waves, increasing the risk of residents experiencing heat-related health problems such as dehydration, heat exhaustion, and heat stroke.

Since 2010, Philadelphia has experienced:

- THE SNOWIEST WINTER ON RECORD.
- THE TWO WARMEST SUMMERS ON RECORD.
- THE WETTEST DAY ON RECORD.
- THE TWO WETTEST YEARS ON RECORD.
- TWO HURRICANES.
- A DERECHO.

FIGURE 4

PROJECTED CHANGES IN AVERAGE ANNUAL TEMPERATURE AND TOTAL ANNUAL PRECIPITATION IN PHILADELPHIA, UNDER FOUR CARBON EMISSIONS SCENARIOS



Scenarios RCP4.5 and B1 assume relatively low emissions, while RCP8.5 and A2 assume moderately high emissions.[4]

TABLE 1

HISTORICAL AND PROJECTED FUTURE TEMPERATURE INDICATORS FOR PHILADELPHIA

	OBSERVED (1950–1999)	PROJECTIONS FOR 2081–2099
Average summer temperature	84.5°F	89–93.7°F
Average number of days above 95°F	3	17–52
Average number of days above 100°F	0	2–16
Hottest 7-day average temperature	92°F	97–102°F

SOURCE: *Useful Climate Information for Philadelphia: Past and Future*

TABLE 2

HISTORICAL AND PROJECTED FUTURE PRECIPITATION INDICATORS FOR PHILADELPHIA

	OBSERVED (1950–1999)	PROJECTIONS FOR 2081–2099
Average annual precipitation (inches)	44.0	47.1–49.5
Winter precipitation (inches)*	9.9	11.2–12.1
Largest 3-day precipitation event-Winter (inches)	2.0	2.3–3.5
Spring precipitation (inches)	11.4	12.2–13.1
Summer precipitation (inches)	12.2	12.5–13.3
Fall precipitation (inches)	10.5	11.0–11.5

* One inch of winter precipitation equates to one inch of rain, two inches of sleet, or 13 inches of snow.

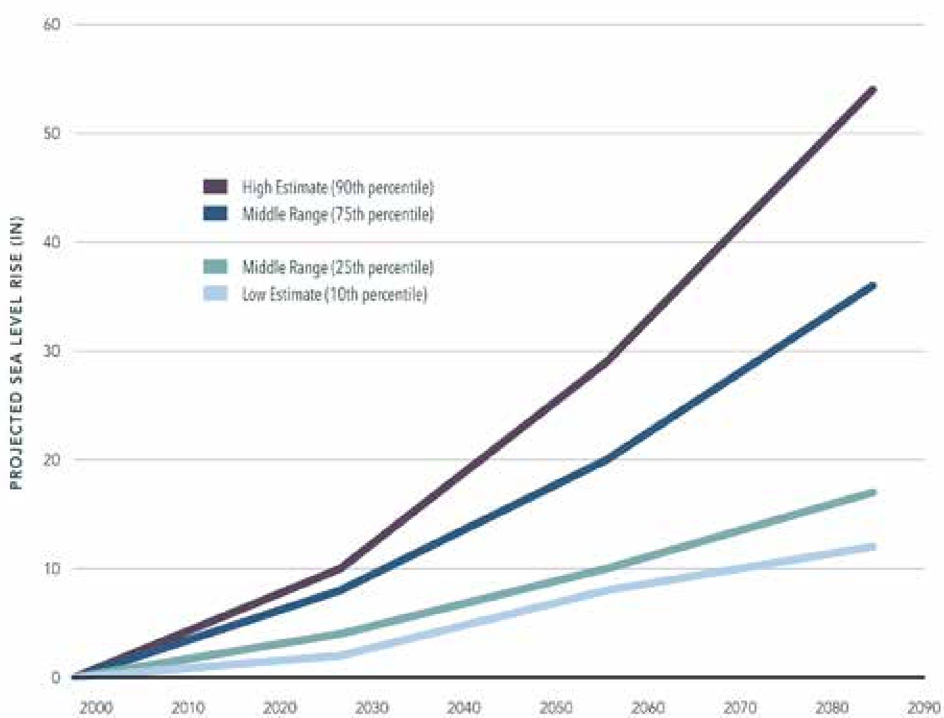
SOURCE: *Useful Climate Information for Philadelphia: Past and Future*

Philadelphia is also projected to experience a greater frequency of heavy and extremely heavy precipitation events, with the largest increase occurring in precipitation that falls during winter months. Heavy precipitation and flooding can be caused by a variety of weather systems, including tropical storms and hurricanes, thunderstorms, and frontal activity. When these heavy precipitation events fall as rain, they often exceed the capacity of the city's storm sewer infrastructure; when they fall as snow, they require many city resources to manage. Some of these projections are already becoming a reality, as Philadelphia has experienced an increase in the intensity and frequency of storm events over the last decade, which has on occasion resulted in significant flooding.

Rising seas (see Figure 5) affect water levels in the Delaware and Schuylkill Rivers bordering Philadelphia. Higher sea levels will increase the depth and extent of flooding in and around the city from storm surges, such as those occurring during hurricanes and other tropical storms. Low-lying areas already experience localized flooding during heavy storm events, and both municipal infrastructure and private development exist along the two rivers.

FIGURE 5

SEA LEVEL RISE PROJECTIONS FOR THE PHILADELPHIA REGION



Developed by scientists at Columbia University as part of the Consortium for Climate Risk in the Urban Northeast, and the Climate and Urban Systems Partnership.[6]

Photo credit: Peter Tobia

Philadelphia's Key Climate Vulnerabilities

Vulnerability to the impacts of climate change is determined by three factors: sensitivity, exposure, and adaptive capacity. The simplest way to explain these concepts is through an example:

> Older adults (those aged 65 years and older) tend to be *sensitive* to extreme heat. During heat waves, the highest number of mortalities occurs among older adults. Older adults are also more susceptible to heat exhaustion, heat stroke, and dehydration during periods of extreme heat. But sensitivity alone does not determine whether older adults are vulnerable: they also have to be exposed. Older adults who remain in an air-conditioned building during a heat wave will not be *exposed* to heat, and thus would not be considered vulnerable. The third component of vulnerability, *adaptive capacity*, refers to an ability to adapt to new conditions. For example, an older person living in an apartment without air conditioning may be both sensitive and exposed to extreme heat, but if she can afford to buy an air conditioner she can avoid future exposure. That means she has strong adaptive capacity, and would not be considered vulnerable compared with a person who could not afford to buy or use an air conditioner.[7]

The vulnerability assessment conducted for this report considered these three factors to evaluate the vulnerability of city departments and city-owned assets to key impacts of climate change. The assessment evaluated exposure of all 2,698 city-owned facilities to flooding, and identified the locations of populations potentially vulnerable to extreme heat (including older adults, young children, low-income populations, and those without nearby access to cooling centers). The assessment also evaluated the flooding vulnerabilities of evacuation routes, vulnerable populations, stormwater outfalls, and assets rated as "critical" by the Philadelphia Office of Emergency Management (OEM). Critical assets include those with high safety, cultural, economic, and environmental value.

Heat Impacts in Philadelphia

Extreme heat is likely to increase risks to the health of vulnerable populations in the city. As noted above, heat events and hot days are projected to increase substantially in Philadelphia by the end of this century. Populations that are potentially vulnerable to extreme heat include the elderly, the very young, people with low socioeconomic status, and people without access to air-conditioned spaces.[11] Nearly 27 percent of Philadelphia's population lives under the poverty level, more than 12 percent of the population is aged 65 years or older, and seven percent is under five years old.[12]

> Extreme heat is responsible for more deaths in Pennsylvania than all other natural disasters combined,[8] killing an average of 50 people per year between 1997 and 2004.[9] A 10-day heat wave that hit Philadelphia in July 1993 resulted in 118 deaths.[10]

Heat can have both direct physiological impacts on health (such as heat stroke) and indirect impacts: for example, hot weather encourages the formation of ground-level ozone, which reduces air quality and poses risks to individuals with respiratory conditions such as asthma.[13] In 2010, nearly a quarter of children in Philadelphia County had asthma, among the highest rates in the nation.[14]

Extreme heat can also affect city services and infrastructure. For example, interviews with city departments indicated that hotter days may require construction activities (including street paving and repairs) to shift to night hours, and pavement may require longer curing times. Extreme heat that persists for multiple days and nighttime temperatures that remain elevated magnify these impacts.

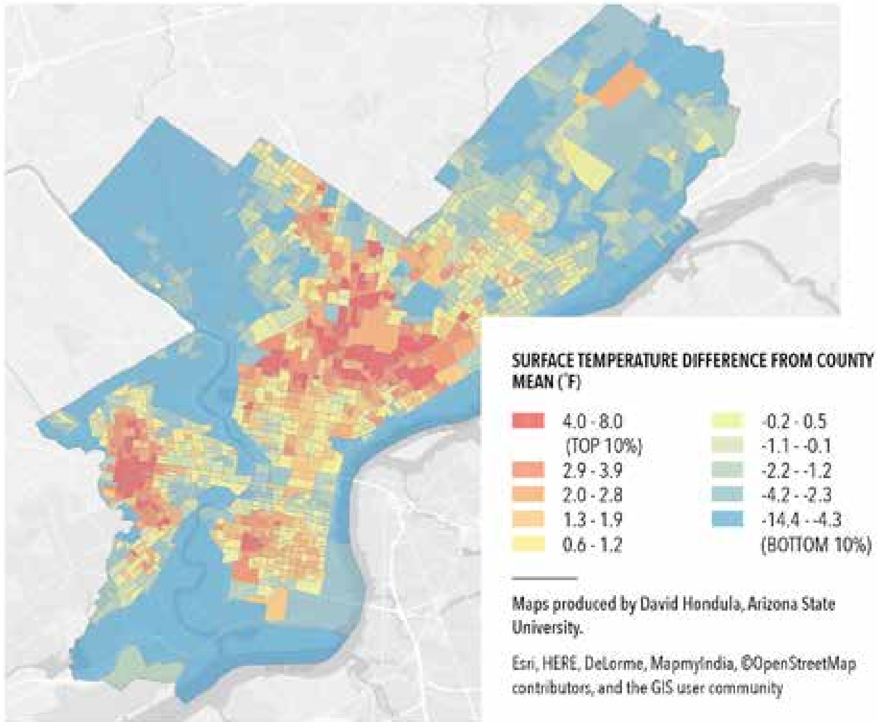
+ FURTHER READING

Information on specific heat-related vulnerabilities in Philadelphia (including risks to public health) is provided in the department-by-department discussion starting on page 21.

The heat island effect exacerbates extreme heat events in most cities, including Philadelphia. Urban areas contain many heat-absorbing surfaces and have less vegetation than their surroundings, causing cities to be warmer than nearby suburban and rural areas. Cities also cool off more slowly at night due to the slow release of heat from urban infrastructure.[15]

FIGURE 6

AVERAGE SURFACE TEMPERATURES BY CENSUS BLOCK, 2013-15



Data are for the seven hottest days on which mostly cloud-free Landsat imagery was available. *Image courtesy of David Hondula, Arizona State University*

Flooding

Rising sea levels are expected to increase the frequency and severity of flooding in Philadelphia. Coastal storms combined with higher sea levels will cause more extensive flooding than the same storms would cause today, although tides, saturation of the ground, ground temperature, and other factors can vary the degree of flooding experienced from two storms with the same amount of rainfall.

Flooding…is the most frequent and costly of all hazards in Pennsylvania.[8]

Flooding presents many risks to Philadelphia, including public health and safety hazards, interruptions in key services, and damage to buildings and infrastructure. Floods can disrupt transportation, hampering emergency services and evacuation efforts. Because fuel pumps and sump pumps require electricity to operate, a power failure during a flood could limit the availability of fuel for generators and vehicles, and allow water levels to rise in buildings and other facilities.

To understand which of the city's assets will be most vulnerable to flooding as the climate changes, the project team analyzed a wide range of scenarios across three different sources of flooding: sea level rise, storm surge (i.e., a rise in water level generated by a storm, over and above normal tides), and riverine flooding, which occurs when heavy rainfall causes water in rivers or creeks to overtop their banks. Six of the resulting scenarios are outlined in the following bullets and referenced in later sections of the report.

Kelly Drive during the April 30 - May 1, 2014 flood. *Photo courtesy Philadelphia Water*

- **SEA LEVEL RISE (SLR):** Two scenarios consider just the impacts of sea level rise: two feet (the local projection for 2050 assuming moderate carbon emissions worldwide) and four feet (the projection for 2100 given the same emissions assumptions).[16]
- **SLR WITH STORM SURGE:** Two scenarios modeled storm surge by pairing the elevated base sea levels described above (two and four feet) with the impacts of a Category 1 storm. Category 1 is the strongest storm to have ever directly hit the Philadelphia region.[17]

+ FURTHER READING

More information on the scenarios used for this analysis can be found on page 6-8 in the Appendix.

- **RIVERINE FLOODING:** Two riverine flooding scenarios use the Federal Emergency Management Agency (FEMA)'s 2007 100- and 500-year floodplain maps, which indicate areas that have a one and 0.2 percent chance of flooding annually, respectively.[18]

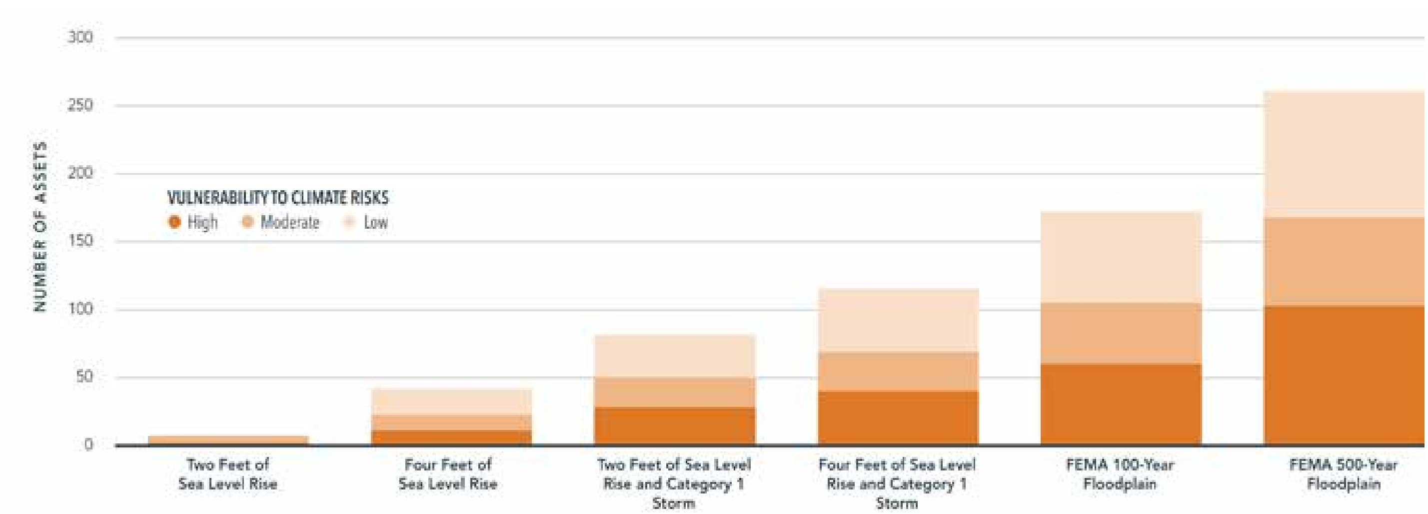
Several maps in the report also show the area that would be inundated under six feet of sea level rise, which is included to show potential flooding risks at the end of this century under a high-carbon-emissions scenario.

Because of Philadelphia's topography and its location next to tidal rivers, many facilities and other properties are vulnerable to sea level rise, even under conservative sea level rise scenarios. For example, the Philadelphia International Airport and at least a dozen other city facilities would be exposed to flooding with two feet of sea level rise, a scenario that is likely to occur by mid-century. Thirteen city-owned historic properties are located within the current (2007) 100-year floodplain (areas with a one percent chance of flooding in any given year).

Figure 7 shows the flooding vulnerability (low, medium, and high) of all city-owned facilities under six scenarios. Under the mid-century sea level rise scenario (SLR2, indicating two feet of sea level rise), only one facility is highly vulnerable to flooding, but under the end-of century sea level rise scenario (SLR4, or four feet of sea level rise), 19 facilities are highly vulnerable and another 12 facilities are moderately vulnerable. Hundreds of additional facilities are highly vulnerable to both riverine flooding and the combination of sea level rise and storm surge.

FIGURE 7

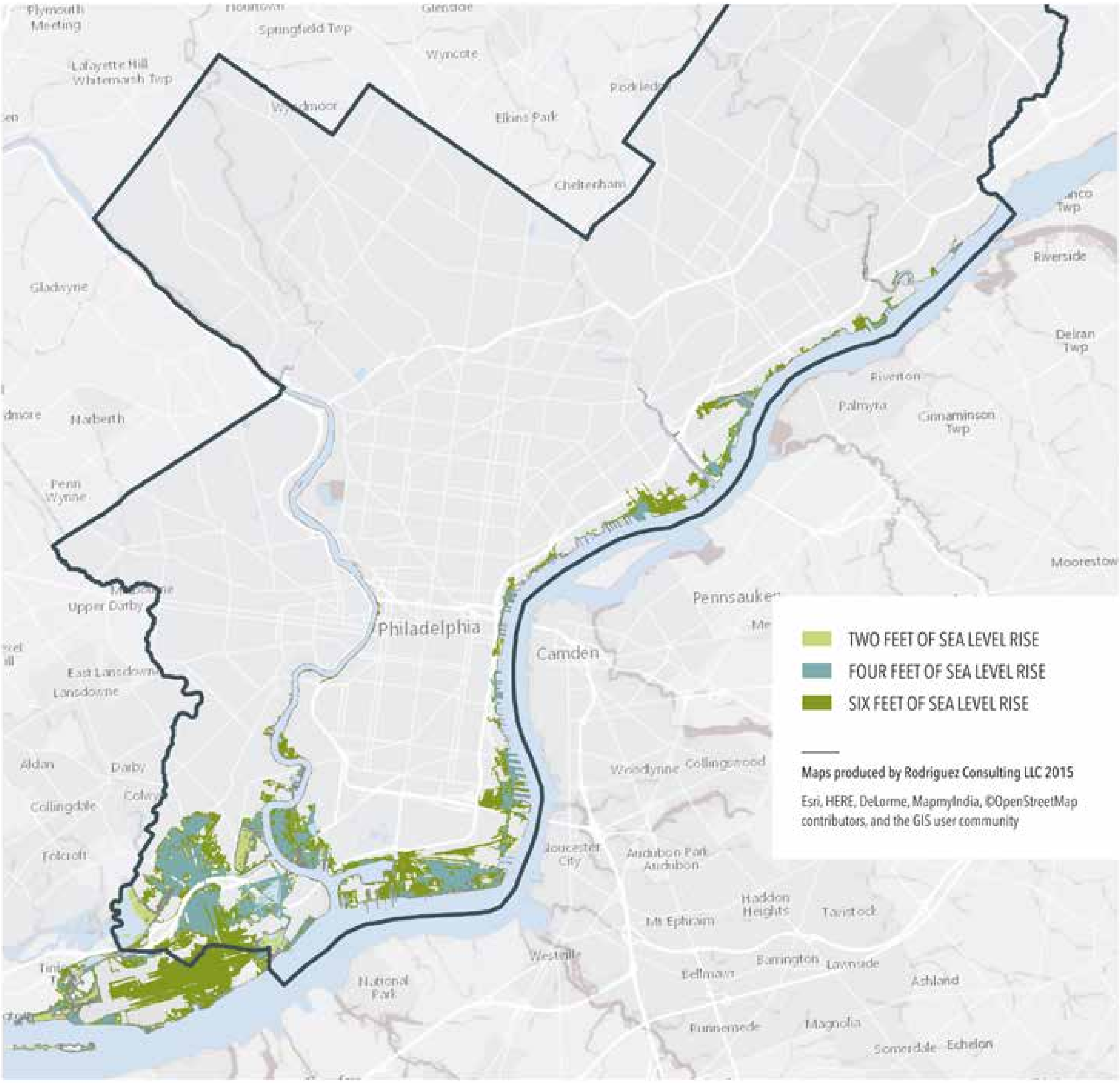
NUMBER OF VULNERABLE CITY-OWNED ASSETS UNDER SIX SCENARIOS, BY VULNERABILITY LEVEL



The high, moderate, and low portions of the bars indicate the number of assets that would have high, moderate, and low vulnerability under each scenario. *Source: Master Facilities Database*

FIGURE 8

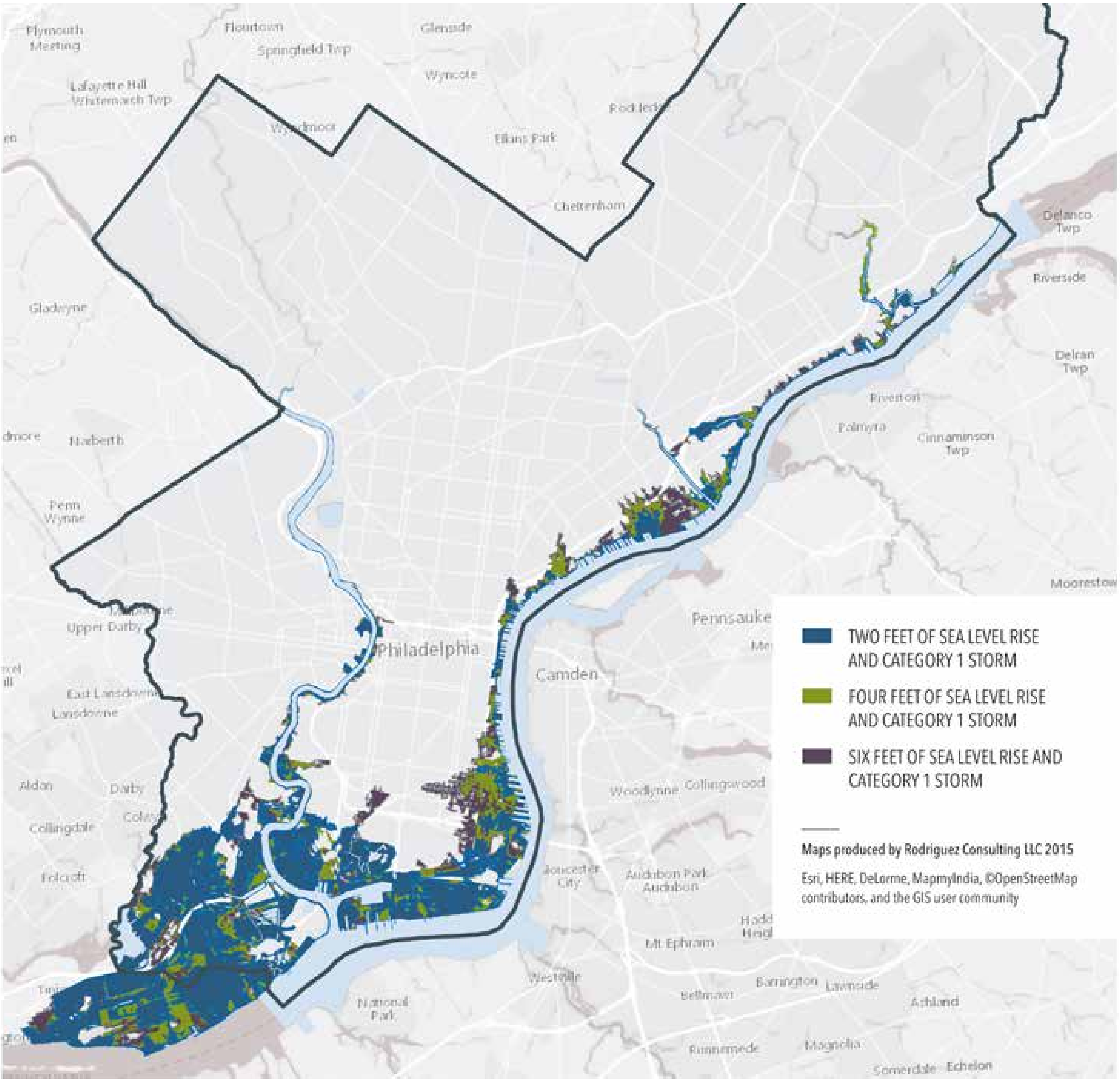
POTENTIAL INUNDATION FROM SEA LEVEL RISE



Areas in Philadelphia at risk of inundation under two feet of sea level rise, which is the expected sea level rise in 2050 under a scenario of moderate greenhouse gas emissions; four feet of sea level rise, which is the expected sea level rise in 2100; and six feet of sea level rise, which is the expected level in 2100 under a high-greenhouse-gas emissions scenario.

FIGURE 9

POTENTIAL INUNDATION FROM SEA LEVEL RISE AND SEVERE STORM

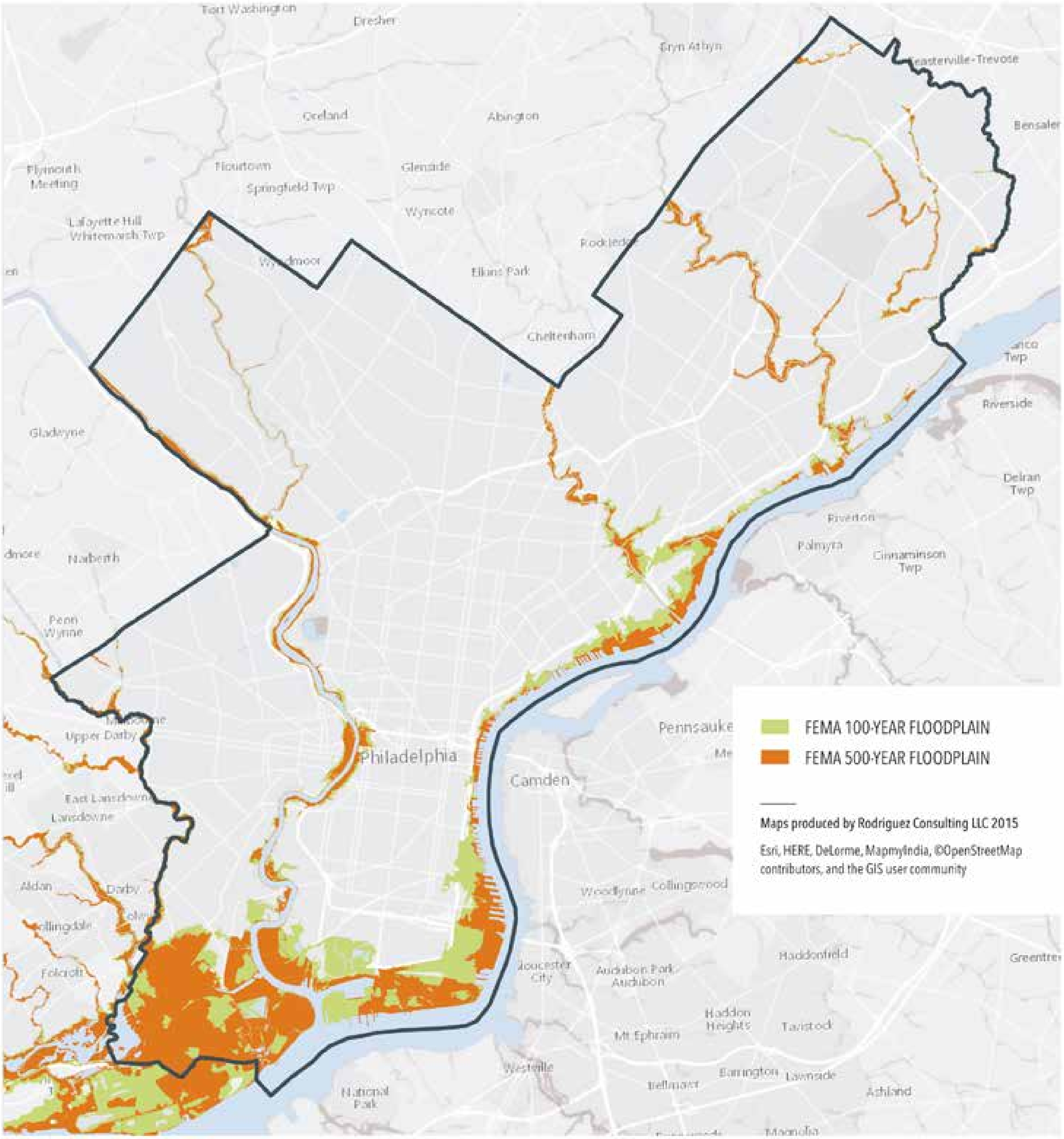


Areas in Philadelphia at risk of inundation by a Category 1 storm on top of two feet of sea level rise, which is the expected sea level rise in 2050 under a scenario of moderate greenhouse gas emissions; four feet of sea level rise, which is the expected sea level rise in 2100; and six feet of sea level rise, which is the expected level in 2100 under a high-greenhouse-gas emissions scenario. A Category 1 storm represents the most severe hurricane the region has ever experienced.

Storm Surge/Sea Level Rise Information courtesy of Energy Infrastructure Modeling and Analysis, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy. Original data produced by NOAA with analysis by ICF.

FIGURE 10

POTENTIAL INUNDATION FROM 100- AND 500-YEAR FLOODS



Areas of Philadelphia at risk of inundation under a 100-year flood (a flood with a one percent chance of happening any year) and a 500-year flood (a flood with a 0.2 percent chance of happening any year).

TABLE 3

POTENTIAL COSTS OF FLOODING AND HURRICANE DAMAGES IN PHILADELPHIA

IMPACT CATEGORY	POTENTIAL COSTS
Cost of an additional 100-year flood	$600,000,000
Direct economic loss due to hurricane winds	
Gusts of 73-78 mph (1% chance of occurrence each year)	$20,000,000
Gusts of 81-86 mph (0.5% chance of occurrence each year)	$90,000,000
Gusts of 92-96 mph (.2% chance of occurrence each year)	$300,000,000

The Costs of Climate Change to Philadelphia

Climate change will increase both the risk of expensive extreme events and the regular, recurring costs of doing business, along with equally important but less quantifiable costs to quality of life in Philadelphia. Municipal government, residents, and businesses will share these costs. Proactive planning for climate change can help to reduce many of these costs, both public and private.

Increased Disaster Costs

Climate change is increasing the intensity of extreme storms, and just one severe hurricane could cause more than $2 billion in damages citywide, a cost equivalent to roughly one-half of the city's entire yearly operating budget. Philadelphia will also see more frequent extreme storms with higher winds and more flooding, due in part to sea level rise combined with heavy rains. Depending on severity, each of these storms could cause between $20 million and $900 million in damages citywide, as outlined in Table 3.

Increased Operating Costs

In addition to increasing disaster costs, higher heat and more precipitation will increase the everyday cost of doing business for Philadelphia government, businesses, and residents. A small subset of illustrative examples is outlined below.[19] These examples suggest that a comprehensive tally of increased operating costs from climate change across all sectors would total a significant economic impact in the city. Much of these costs will be borne by city departments in combination with state and federal government; others will fall directly on the private sector.

Yearly costs of climate change to the City of Philadelphia will include a variety of increases ranging from energy and maintenance costs to the increasing costs of continuing to provide services. As examples of these costs, the city expects climate change to:

- Increase annual electricity costs by up to $1 million due to increased demand for air conditioning.
- Create an additional $2 to $4 million in roadway maintenance costs from rutting (permanent pavement indentations from traffic) caused by precipitation, rutting caused by freeze-thaw cycles, and cracking during periods of high temperatures.
- Double or nearly triple the annual cost, currently around $20,000, of running the Heatline, a helpline service the city runs during heat emergencies to advise callers about how to avoid heat stress and refer those in need of help to emergency services.

Citywide, Philadelphia will face a variety of increased costs due to climate change. For example, higher levels of ozone resulting from climate change will increase the incidence and costs associated with a variety of diseases, including asthma, cardiovascular disease, COPD, and other respiratory diseases. Citywide, the higher costs for medical treatment and lost productivity associated with these diseases will approach $20 million by 2050. Regional transit will be affected as well: SEPTA has estimated that without additional resilience investments beyond those implemented to date, its increased operational costs and damages from climate change could rise by almost $2 million per year.

+ FURTHER READING

Additional information on the cost estimates and underlying data sources appears in the Appendix, starting on page 6-11.

4

REDUCING THE RISKS

SCENARIO PLANNING WORKSHOPS

To explore interdependencies and opportunities for cooperation among city departments, MOS held two climate-change-scenario planning workshops—one on extreme heat and one on flooding—in April 2015. These workshops brought together members of key departments, as well as external stakeholders and quasi-city agencies including PECO, the Philadelphia Industrial Development Corporation, and SEPTA. Discussions from the workshops informed development of the vulnerability assessment, cost estimates, and adaptation actions in this report. More information on the workshops is available in the Appendix, starting on page 6-3.

To successfully adapt to the changing climate, the City of Philadelphia will need to make changes at multiple scales. Because many budgeting, asset ownership and management, and programmatic decisions take place at the department or agency level, each has unique vulnerabilities to climate change and individual opportunities to address its issues. At the same time, effective strategies to mitigate risks posed by climate change and weather extremes will require cooperation and coordination among city departments, and also with systems and agencies external to the city, such as electric utilities and the power grid, telecommunications providers and their systems, regional and state transportation and planning agencies, and regional transportation systems.

The city is already taking many steps to reduce vulnerabilities and build its resilience to future impacts, but more opportunities exist to reduce long-term vulnerabilities while addressing near-term goals. After reviewing best practices and consulting with ICF International and the Climate Adaptation Working Group, the Mayor's Office of Sustainability (MOS) selected the following criteria to qualitatively evaluate potential actions that could help the city continue to provide effective services and maintain infrastructure as the climate changes:

- **CAPITAL COSTS:** Up-front capital investment required.
- **RECURRING COSTS:** Costs incurred repeatedly and periodically over the lifetime of an adaptation strategy.
- **FLEXIBILITY:** The ability to make mid-course corrections.
- **CO-BENEFITS:** Additional benefits, such as economic development, preserving or expanding green space, protecting vulnerable and marginalized populations, reducing emissions, and increasing tourism, provided by adaptation activities.
- **OTHER BARRIERS NOT CAPTURED IN OTHER EVALUATION CRITERIA:** Political, legal, or physical barriers to implementation.

Each action or strategy received a ranking of low, medium, or high for each of the five evaluation criteria, and the average of these rankings served as a qualitative score of current feasibility. Each strategy also received an efficacy score, a low, medium, or high ranking of the extent to which a strategy, if successfully implemented, will reduce risk.

This section describes risks identified in the vulnerability assessment that apply to city departments that own or manage assets and run programs, provide services, or make policies that will need to adapt to a changing climate. It also describes specific adaptation actions and strategies for those departments, including opportunities to continue or enhance actions they are already taking to reduce their risks. It outlines strategies that received high feasibility scores and medium-to-high efficacy scores, which departments should consider implementing in the near term.

The departments are organized below according to whether their primary responsibility involves managing physical infrastructure and delivering services, or managing policy, finance, and planning. After a brief description of the department's roles and responsibilities, information for each department is organized into three sections:

1. **RISKS AND VULNERABILITIES:** The department's assets or services vulnerable to flooding and heat.
2. **EXISTING RESILIENCE EFFORTS:** Current adaptive efforts the department should continue or enhance.
3. **EARLY IMPLEMENTATION OPPORTUNITIES:** Highly feasible and highly effective adaptation strategies that the department should consider in the near term and, in some cases, effective adaptation actions identified by departments as priorities.

Both the *Physical Infrastructure & Service Delivery and the Policy, Planning, and Finance* sections conclude with a discussion of interdependencies and opportunities for interdepartmental coordination, which include high-efficacy adaptation actions that require more investment of time, funds, and coordination effort. As departments complete their early implementation strategies and funding opportunities for climate adaptation work arise, the city should consider seeking support for and implementing these longer-term, transformative adaptation actions.

A Guide to the Tables

The descriptions of risks and vulnerabilities for departments with assets vulnerable to flooding include tables similar to the example below. The explanatory balloons and the guide to abbreviations under the table are provided to help readers interpret these tables.

SAMPLE TABLE

NUMBER OF PHILADELPHIA FLEETS ASSETS AND BUILDINGS AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

Number of assets that are in the 100-year or 500-year floodplain (1% and .2% risk of flooding annually, respectively)

Number of assets at risk of being inundated by a Category 1 storm as sea level rises (Category 1 is the strongest storm to ever hit Philadelphia)

Number of assets at risk of being inundated by two and four feet of sea level rise (projections for mid- and end-of-century, respectively)

Overall vulnerability rating for these assets (considers sensitivity, exposure, adaptive capacity)

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Fuel Sites [Total number = 59]	0	2	2	3	4	5
	Garages/Maintenance Building [Total number = 17]	0	1	2	2	2	3

SLR 2 = sea level rise of two feet. SLR 4 = sea level rise of four feet. SLR2 + Cat1 = storm surge from a Category 1 hurricane on top of a two-foot sea level rise. SLR4 + Cat1 = storm surge from a Category 1 hurricane on top of a four-foot sea level rise. 100-yr = a 100-year flood (a flood with a 1% chance of happening any year). 500-yr = a 500-year flood (a flood with a 0.2% chance of happening any year).

CLIMATE MATTERS

On July 27, 2005, temperatures in Philadelphia reached 104°F and SEPTA operators put speed restrictions into effect systemwide. Trains on the Manayunk/Norristown line were unable to proceed through a portion of the track because extreme temperatures caused catenary wire (overhead lines) to sag excessively. To compensate, trains had to alternate operating on an unaffected portion of the track. The extreme heat resulted in 5.8 hours of cumulative delays on the M/N line that day.

In preparation for Hurricane Sandy in October 2012, SEPTA preemptively cancelled all service. This helped prevent significant damage, although Regional Rail lines experienced signal power problems, flooded track, downed trees and catenary wires, and track debris.

SEPTA is a significant contributor to economic value in the region, saving commuter time, reducing crash and travel-related fatalities, improving business efficiency and productivity, reducing pollution, and relieving the stress on parking availability. The savings to the public from SEPTA's operations, in travel time and costs alone, have been estimated at over $2.08 billion annually. [20,21]

Physical Infrastructure & Service Delivery

Climate change is expected to have significant impacts on much of the city's infrastructure, and by extension the departments responsible for managing it. Physical infrastructure includes fixed assets such as roads, bridges, drinking water and wastewater systems, airports, parks, and telecommunications networks. In addition to affecting infrastructure, climate change is expected to affect many of the key services the city delivers, such as sanitation and public health services. Building resilience to climate impacts will help address near-term vulnerabilities as well as those posed by future climate change.

SEPTA participated in a pilot program through the Federal Transit Administration (FTA) to undergo a climate adaptation plan for its Manayunk/Norristown Line, and received $87 million in FTA funding in 2014 to implement actions from that report.

DEPARTMENT OF PUBLIC PROPERTY

The **Department of Public Property** (DPP) has the primary responsibility for the acquisition, care, and maintenance of city property and nearly 4.5 million square feet of city-owned facilities, including City Hall, police facilities, fire facilities, and other buildings. Several of these buildings have historical significance and are more than 100 years old. DPP also manages the design and construction of new city facilities.

RISKS AND VULNERABILITIES

Because DPP manages all of the city's property throughout Philadelphia, the department's vulnerabilities reflect those of the city in general. Flooding risk is the most significant vulnerability of DPP. Several of the city's emergency services buildings could be inundated under certain flooding scenarios, as shown in Table 4. In a major flooding event, these police and fire facilities could be at risk.

DPP also manages many of the city's backup electrical generators, which may be vulnerable to extreme heat—if temperatures exceed the generators' rated tolerances—and in some cases flooding.

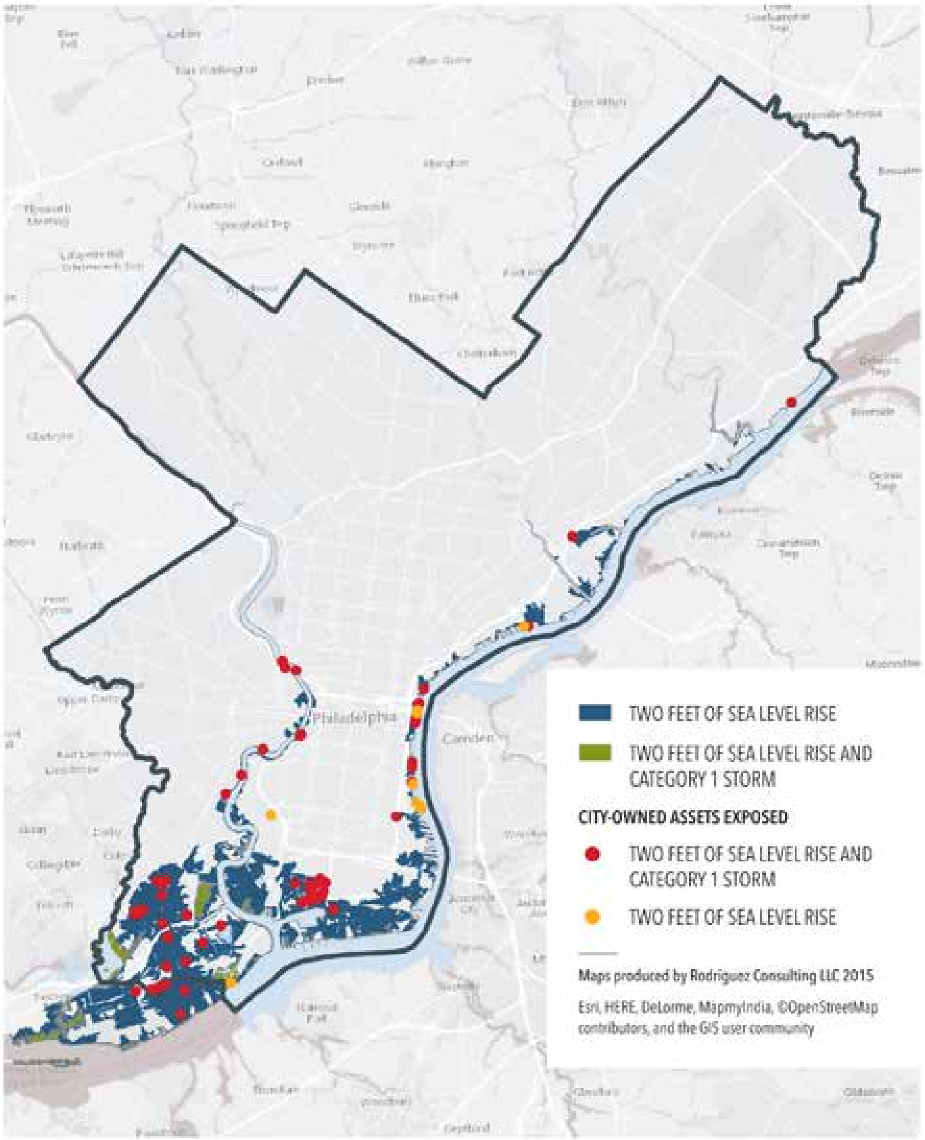
TABLE 4

NUMBER OF DEPARTMENT OF PUBLIC PROPERTY ASSETS AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Fire Stations [Total number = 62]	0	1	2	2	2	4
	Police Stations/ Substations [Total number = 24]	0	0	0	0	1	1
	Fire Stations Marine [Total number = 2]	0	1	1	2	1	2
	Police Operations/Unit [Total number = 17]	0	0	1	1	2	2
Moderately Vulnerable	Public Safety Training Center [Total number = 2]	0	0	0	0	0	1

Note: These facilities cover those that DPP maintains, not necessarily owns/occupies. DPP maintains buildings that are owned/occupied by other departments. For an explanation of each flooding scenario and its significance, see page 22.

FIGURE 11



All assets exposed at two feet of sea level rise will also be exposed at two feet of sea level rise and Category 1 storm.

EXISTING RESILIENCE EFFORTS

- DPP is responsible for ensuring that emergency generators in city-maintained facilities are well maintained and fueled, allowing other city departments to operate and serve the public during emergency situations.
- DPP is in the process of acquiring an asset management database that will be capable of integrating information on climate change vulnerability to inform investment decisions.

EARLY IMPLEMENTATION OPPORTUNITIES

DPP should consider implementing the following strategies, which may be feasible in the near term and would measurably reduce vulnerability to climate change.

- Including climate risks in the DPP preventive maintenance program's return on investment (ROI) calculations. ROI calculations produce a ratio that compares the total cost of a project to the returns that occur throughout the useful life of the structure. Climate change should be integrated into these calculations by considering the potential for increased future maintenance and repair costs due to more frequent and severe weather events. These future costs may justify an up-front investment in adaptation strategies.
- Reviewing equipment specifications to ensure adequacy under future climate conditions. For example, consider updating the specifications for air conditioners, chillers, and generators to ensure continued operation under high heat conditions.
- When possible, site new public infrastructure outside of the sea level rise and storm surge zone.
- Work with the Budget Office and Planning Commission to integrate climate change into capital programming and budgeting, and to determine appropriate freeboard and floodproofing construction requirements.

OFFICE OF FLEET MANAGEMENT

The **Office of Fleet Management** is responsible for the acquisition and maintenance of the City of Philadelphia's vehicles. The agency purchases and maintains vehicles for 43 departments, agencies, and offices. The fleet includes emergency operations and safety vehicles that are responsible for assistance during major weather events. In addition, the office operates 17 repair and maintenance facilities, 59 fuel sites, and 100 underground fuel storage tanks located throughout Philadelphia.

Photo credit: Peter Tobia

RISKS AND VULNERABILITIES

Philadelphia's fleet plays an important role in the city's daily operations and emergency efforts. Fleet garages and fuel sites need to be protected from flooding to ensure that the fleet can be deployed during an emergency event to help protect residents and to deliver fuel to generators. Table 5 summarizes the vulnerability of Fleet assets to flooding under a range of scenarios.

TABLE 5

NUMBER OF PHILADELPHIA FLEET ASSETS AND BUILDINGS AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	**SLR 2**	**SLR 4**	**SLR2 + Cat1**	**SLR4 + Cat 1**	**100-yr**	**500-yr**
Highly Vulnerable	Fuel Sites [Total number = 59]	0	2	2	3	4	5
	Garages/ Maintenance Building [Total number = 17]	0	1	2	2	2	3

Multiple departments, along with Fleet, maintain some of the garage/maintenance buildings. For an explanation of each flooding scenario and its significance, see page 22.

EARLY IMPLEMENTATION OPPORTUNITIES

To increase resilience and ensure the Philadelphia fleet is able to recover rapidly following a major flood or high heat event, Fleet Management should consider the following adaptation strategies:

- Working with departments that operate vehicle fleets to develop a storm protocol that identifies thresholds at which vehicles would be shifted from potentially flooded garages and facilities to locations outside of the storm surge area.
- Investing in backup power generators at additional key fuel pumps to ensure fuel will be accessible during power outages.
- Coordinating with the Streets Department to ensure that only one department's fuel truck is out of service for maintenance or inspection at a time. This will ensure that there is always at least one fuel truck available to refill generators and vehicles during a power outage. Additionally, schedule fuel truck maintenance and recertification to occur outside of peak hurricane season.

PHILADELPHIA DEPARTMENT OF PUBLIC HEALTH

The **Department of Public Health**'s mission is to protect and promote the health of all Philadelphians and to provide a safety net for the most vulnerable. The department is composed of 13 divisions that provide services such as chronic disease prevention, disease control, environmental health, food protection, and other health services. The department operates eight health centers that provide medical care to Philadelphia residents.

RISKS AND VULNERABILITIES

Climate change presents a number of risks to public health in Philadelphia, including impacts related to extreme heat, reductions in air quality, and flooding. Climate change can also broaden the range of certain diseases carried by ticks, mosquitoes, and other organisms.

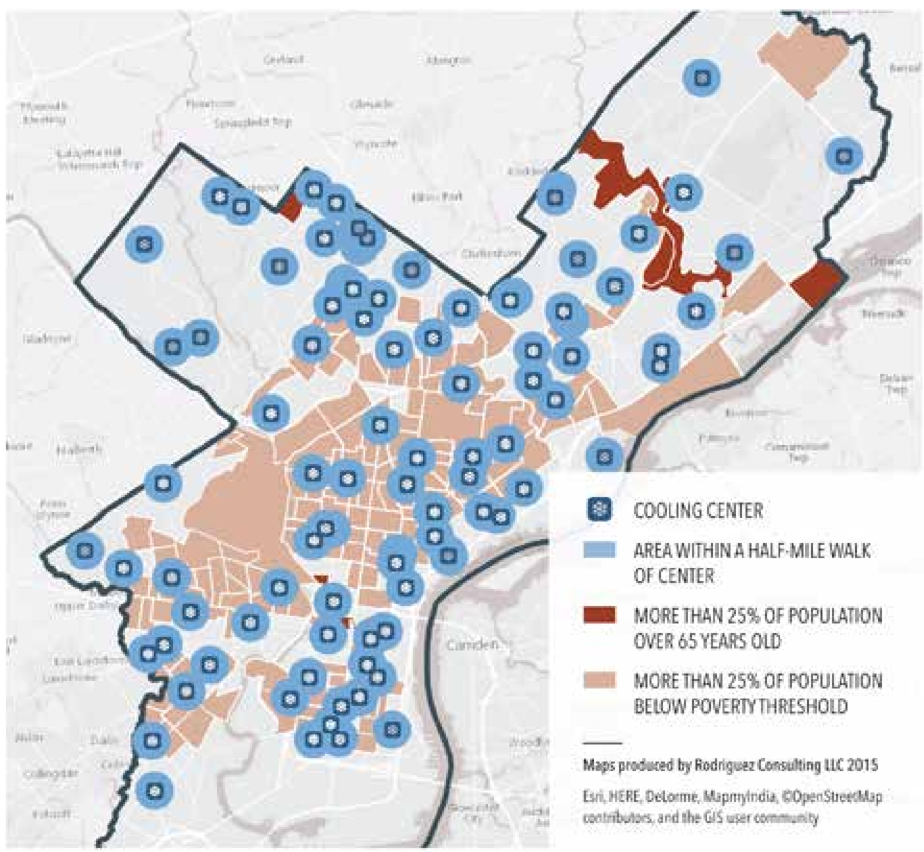
Extreme Heat

Older adults and young children are sensitive to heat for mainly physiological reasons. People living in poverty may also be more sensitive to heat, due mainly to lack of access to air conditioning.

In response to the impacts of previous extreme heat events, Philadelphia has established a heat health warning system and a network of cooling centers throughout the city. The Health Department, in partnership with the Philadelphia Corporation for Aging, also runs a Heatline to provide medical support to vulnerable residents during heat emergencies. To identify areas of potential vulnerability to extreme heat, MOS and its contractors mapped the current locations of sensitive populations and their proximity to cooling centers (existing air-conditioned public spaces that remain open for extended hours during extreme heat events). Figure 12 depicts current conditions rather than projected future vulnerabilities; changes in population demographics over time and the designation of new cooling centers may affect existing vulnerabilities.

FIGURE 12

POPULATIONS IN PHILADELPHIA VULNERABLE TO EXTREME HEAT



The map reveals areas with high populations of older adults and people living below poverty level who are not within easy walking distance of a cooling center, although this in itself is not necessarily an indicator of vulnerability: for example, older adults living in air-conditioned homes would not need access to a cooling center (as long as electricity is available), and the list of cooling centers does not include privately owned but publicly accessible air-conditioned spaces such as movie theaters and malls.

Air Quality

Because the formation of ground-level ozone is heat dependent, ozone levels are expected to rise as temperatures increase. Increases in ozone concentrations exacerbate existing cases of asthma and other respiratory diseases, and may lead to new cases of asthma.[13] In contrast, increases in precipitation can reduce the formation of ozone and remove particulate matter from the air.

Flooding

Following major flooding events, the Health Department is responsible for inspecting food establishments for pests, spoiled food, and stagnant water, which can pose health risks. Increases in flooding frequency could increase the inspection burden on the Health Department, as well as increase the risk for mold and other health issues associated with flooding. The Health Department distributes educational materials to help residents keep safe after a flood, and its Environmental Engineering section offers a call-in help line that provides advice on post-flood cleanup.

The Health Department itself occupies several warehouses, labs, and office buildings, but none of them are vulnerable to flooding.

✔ EXISTING RESILIENCE EFFORTS

The Health Department proactively plans for and responds to extreme weather events, including extreme temperatures (both hot and cold), flooding and storms, and other natural events. Some examples of the programs and practices that reduce current and future vulnerabilities to climate change include:

- Maintaining a continuity of operations plan, which directs staff on how to keep the Health Department running after a disaster or extreme weather event to prevent secondary infections and illnesses.
- Activating and managing the Philadelphia Corporation for Aging's Heatline. As needed, the Health Department deploys mobile teams and district environmental health teams in response to Heatline calls.
- Distributing mold abatement information to businesses and residents after flood events.
- Declaring Excessive Heat Warnings in coordination with the National Weather Service.
- Ensuring communication among city agencies during a heat emergency using a notification system with pre-defined heat emergency contacts.
- Preparing and distributing public education materials about hot weather precautions, and maintaining a stockpile of supplies for responding to extreme heat events.
- Educating the public about which items covered by floodwaters are safe to sanitize and which porous household items must be disposed of after a flood event.
- Investigating and controlling disease-carrying insects, such as mosquitoes, that can transmit the West Nile Virus and other diseases typically associated with tropical areas. The Health Department investigates and treats stagnant pools and standing water where mosquitoes can breed, and helps individuals learn how to protect themselves and their homes from mosquitoes.

CLIMATE MATTERS

In 1999, heavy rainfall from Hurricane Floyd led to severe flooding in the Eastwick neighborhood. Homes and businesses were inundated with stormwater contaminated with sewer water. Thorough cleanup after the floodwaters retreated was required to protect public health. The Department of Public Health's Environmental Health Services division conducted outreach about what precautions to take while disinfecting properties and which items needed to be thrown away, such as couches that were soaked with sewer water. The lack of power for two weeks created additional challenges for these critical efforts.

Source: Interview with Environmental Health Services

EARLY IMPLEMENTATION OPPORTUNITIES

Overall, the Health Department is well prepared to continue delivering services during extreme weather, now and into the future, but changes to existing plans and programs could improve the department's preparedness and decrease the influence of climate change on public health in Philadelphia. These changes include:

- The Health Department Commissioner's Office should consider updating the Community Health Assessment—an annual review of population health in Philadelphia, highlighting key public health challenges, assets, and improvements—to include climate change and health tracking metrics. The federal Centers for Disease Control proposes the use of the following indicators:[22]
    - Heat stress emergency department visits.
    - Heat stress hospitalizations.
    - Heat vulnerability maps.
    - Heat-related mortality.
- Regularly mapping locations of vulnerable populations and using the information to:
    - Provide the Office of Emergency Management with information for focused interventions during extreme weather or power outages.
    - Target the location of community outreach to at-risk neighborhoods
- Including information on projected changes in climate and increases in high heat days in health bulletins and outreach materials.

Existing municipal assets like Philadelphia's network of public swimming pools can help residents cope with extreme heat.

PHILADELPHIA INTERNATIONAL AIRPORT

Philadelphia International Airport (PHL) consists of seven terminals and four runways on 2,394 acres. In 2014, the airport accommodated 30.7 million passengers, including 4.5 million international passengers, and handled 419,253 aircraft takeoffs and landings. Twenty-nine airlines offer nearly 550 daily departures. Commercial airlines and a half-dozen cargo carriers move 404,050 tons of cargo and mail annually.

RISKS AND VULNERABILITIES

PHL's operations are highly affected by precipitation, storms, fog, and periods of high wind. The airport also experiences high cooling costs during periods with consecutive days over 90°F. But sea level rise and flooding pose the greatest risk to the airport due to its low elevation and proximity to the Delaware River. Table 6 summarizes the airport's assets that could be inundated under a range of flooding scenarios. Many of the airport terminals and other infrastructure, including tunnels, baggage basements, and substations are at risk of inundation under most of these scenarios.

TABLE 6

NUMBER OF PHILADELPHIA INTERNATIONAL AIRPORT ASSETS AND BUILDINGS AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

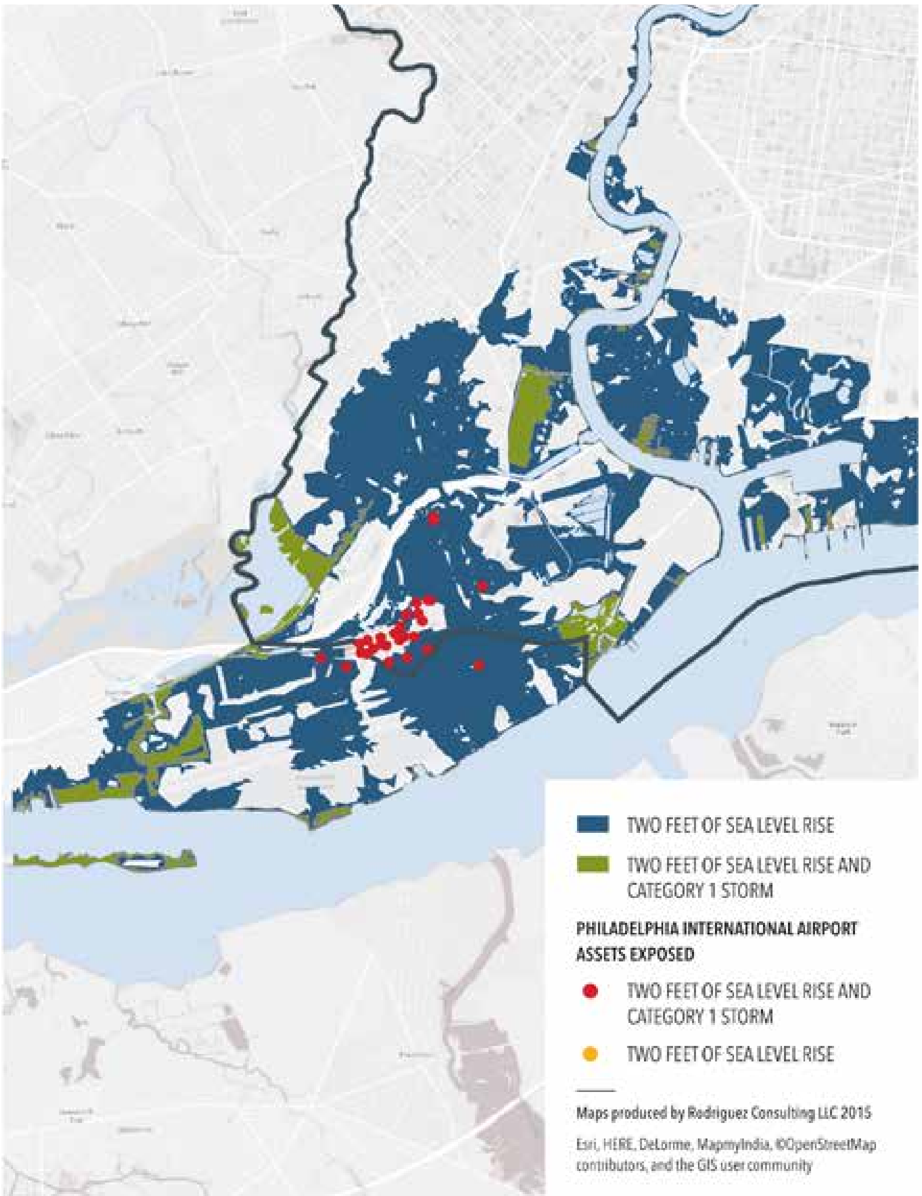
		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Supporting Infrastructure (e.g., tunnels, baggage basements, substations) [Total number = 20]	0	3	5	16	18	20
	Terminals and Hangars [Total number = 12]	0	5	10	11	11	11
	Airport Airfield [Total number = 1]	0	0	1	1	0	0

For an explanation of each flooding scenario and its significance, see page 22.

Photo ©Philadelphia International Airport.

FIGURE 13

EXPOSURE OF PHILADELPHIA INTERNATIONAL AIRPORT'S ASSETS



EARLY RESILIENCE EFFORTS

PHL has already begun to consider and plan for climate change, and has identified the following key strategies to increase the resilience of the airport to sea level rise, increased precipitation, more extreme temperature, and more frequent and intense storms:

- Integrating climate change issues into strategic planning and operational activities.
- Screening existing and planned infrastructure for climate risks.
- Considering longer time horizons for airport planning to ensure the consideration and accommodation of future climate changes. There is currently a discord between the airport's 20-year planning period and both the design life of infrastructure and the escalating impacts of climate change.
- Upgrading electrical substations. In response to past extreme rainfall and flooding events that resulted in power outages and a shutdown of the airport, PHL has invested in upgrades to electrical substations to ensure continued operation. These upgrades will also increase the resilience of the airport to power outages from other climate stressors, such as extreme heat and snowstorms.

EARLY IMPLEMENTATION OPPORTUNITIES

The following strategies have been identified as moderately to highly effective at reducing PHL's vulnerability to climate change, and as feasible for implementation in the near term. These strategies would build upon the steps that PHL has already taken to prepare for climate change.

- Working cooperatively with the Federal Aviation Administration and others to encourage integration of climate change and extreme weather impacts into major infrastructure projects. This coordination will be essential because future construction at the airport that uses federal funding will have to adhere to the revised Federal Flood Risk Management Standard, which requires increased elevations for all new construction projects.
- Continuing coordination with other city, state, and federal agencies active in climate change issues. The Airport Cooperative Research Program (ACRP) is currently developing a climate change planning tool and suite of best practices that may highlight ways to engage with other actors. Anticipated release of the ACRP planning tool is in autumn 2015.
- Implementing a new asset management system. This system, which PHL is already in the process of implementing, should be designed to work with other city asset management systems, and it should integrate data that could be used to inform more resilient decision making. This may include using the system to better track weather-related causes of failure, repair costs, and other metrics.
- Including consideration of future sea level rise, storm surge, and hurricane risks when updating the Airport Flood Emergency Response Plan. PHL should ensure that a protocol for capturing the costs of responding to storm events is included in the plan.
- Revising physical standards to address climate change as a risk in the most recent set of Architectural and Engineering Design Standards. While PHL has recognized climate change as a risk, it has not revised the physical standards to directly address it (see current Volume 2, Section 2.5 of the PHL Design Standards). PHL should consider changing the infrastructure design and materials standards to be more resilient to climate change. These changes may include a higher standard elevation for new construction, required floodproofing standards, mandatory backup power for critical locations, and a checklist for each project to identify vulnerabilities and record actions taken to increase resilience.

PHILADELPHIA PARKS & RECREATION

Philadelphia Parks & Recreation (PPR) connects people to the extensive Fairmount Park System, 204 recreation centers citywide, and a variety of physical and social opportunities. The hundreds of parks and recreation facilities in Philadelphia occupy more than 10,000 acres. The Division of Urban Forestry and Ecosystem Management protects and manages Philadelphia's natural resources. The Division of Planning, Preservation, and Property Management plans, protects, interprets, and manages Philadelphia's public parks and facilities. The Operations Division is tasked with upkeep of the department's public assets including buildings, fields, and parks. The Programs Division oversees several offices, and is responsible for programs and activities.

RISKS AND VULNERABILITIES

Many of the recreational facilities in Philadelphia such as neighborhood parks, baseball fields, pavilions, playgrounds, and tennis courts are prone to flooding. However, the adaptive capacity of recreational facilities is higher than that of other assets, because PPR can often restrict use during flood events.

Historic houses and sites are also under the care of PPR. These have low adaptive capacity and are therefore likely vulnerable when exposed to flooding. Table 7 summarizes PPR's vulnerabilities to flooding under a range of scenarios.

TABLE 7

NUMBER OF PHILADELPHIA PARKS & RECREATION ASSETS AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Historic Houses/Sites [Total number = 79]	0	0	1	6	13	24
	Garages/ Maintenance Buildings [Total number = 46]	0	0	1	1	4	6
	Barns/Stables [Total number = 28]	0	0	0	0	0	3
	Bridges [Total number = 1]	0	0	0	0	1	1
Moderately Vulnerable	Recreation Centers and Buildings [Total number = 426]	0	1	5	9	21	27
	Restrooms [Total number = 26]	0	0	1	1	5	10
	Concessions\Retail\ Cafe [Total number = 10]	0	0	1	2	1	3

Note: This table shows facilities that are maintained by PPR, which includes facilities that are owned by other organizations. This table only includes assets that have a moderate or high vulnerability. Other assets (e.g., baseball fields, fountains, neighborhood parks) have a low vulnerability because they are not likely to be used during a flooding event. For an explanation of each flooding scenario and its significance, see page 22.

Philadelphia Parks and Recreation employees are responsible for cleanup after major storm events.

Storms and high winds can cause damage to trees; no single threshold of wind speed indicates whether a storm will cause damage. Ice storms can also cause significant tree damage, due to the weight added by ice to branches. PPR leads tree removal efforts and maintains cross-department communication following major storm events. PPR's budget can currently accommodate around four big storms per year, depending on severity.

Philadelphia is projected to experience more frequent heavy and very heavy precipitation events in the future, which may increase cleanup costs for PPR. Changes in precipitation patterns can also cause interruptions or delays in the availability of PPR facilities. For example, PPR crews start working as early as February to prepare 150 athletic fields for the summer. Heavy precipitation in late winter and early spring can delay these preparations, pushing maintenance tasks into the busy season.

Warmer temperatures will influence the operation of PPR facilities. Higher temperatures would require higher-capacity cooling facilities for five ice rinks, assuming the rinks continue to operate in the warmer months. Warmer temperatures in the summer may lengthen the swimming season, leading to additional maintenance costs for pool facilities.

Recreation centers around the city are used as cooling centers during heat emergencies. More frequent and severe heat waves will lead to higher cooling costs for these facilities. As temperatures increase, indoor recreation may become more desirable than outdoor activities, driving up the operating costs of recreation centers as they expand or add new equipment to accommodate more users.

Increasing average temperatures will affect forest, lawn, and landscaping vegetation. Currently, PPR budgets for a set number of mowing cycles per year. If the grass growing season is extended due to warming and an increase in precipitation, PPR will need to mow more frequently, leading to higher costs. A warmer climate may also affect the types of trees and plants that are appropriate to plant. On the positive side, if winter temperatures rise, the tree planting season could extend through at least part of the winter.

✔ EXISTING RESILIENCE EFFORTS

PPR currently undertakes a number of actions that will help the department remain resilient to future changes in climate. These include:

- Clearing vegetation and responding to reports of downed trees to prevent debris from blocking drainage systems.
- Clearing drainage inlets along PPR-maintained roadways.
- Moving equipment away from flood-prone areas and closing flood-prone parks when storms are forecast.
- Replenishing building materials and readying equipment for storm damage repair in advance of an event.
- Piloting new forest restoration practices at Haddington Woods, where PPR is working with citizen scientists from the community to identify growing practices suitable for Philadelphia's changing climate.
- Participating in the Energy Office's conservation incentive program, through which departments are eligible to receive a portion of the energy savings that their facilities generate, to reduce energy use and decrease reliance on the power grid.
- Working with the Pennsylvania Historical and Museum Commission and the National Park Service on disaster planning for historic properties in Philadelphia. The disaster planning includes preparing for flooding from sea level rise.

EARLY IMPLEMENTATION OPPORTUNITIES

Several strategies related to vegetation care and maintenance could be implemented relatively easily in the near term and would increase PPR's resilience. These strategies include:

- Building on the pilot project at Haddington Woods, ensuring that any newly planted vegetation can handle increased temperatures and heavy rainfall events; reviewing maintenance schedules to adjust watering, mowing, and other practices, as needed.
- Monitoring the need to increase new tree watering contracts from one to two years to ensure the trees have sufficient time to take root and establish themselves under warmer temperatures.
- Prioritizing maintenance of parks and trails along the rivers to ensure continued access to recreation facilities and natural areas.
- Working to decrease the backlog of more than 2,000 tree maintenance and removal projects to reduce unpruned and dead trees falling on power lines during storm events.
- Investing in HVAC systems at targeted Recreation Centers that could provide public access to cooling during high heat events.

In Haddington Woods, PPR is running a set of experiments in collaboration with community stakeholders to understand forest restoration practices appropriate for the weather Philadelphia will experience in the 21st century.

PHILADELPHIA STREETS DEPARTMENT

The mission of the **Philadelphia Streets Department** (Streets) is to provide clean and safe streets in a cost-effective and efficient manner. The department's Sanitation Division and Transportation Engineering Division deliver a number of city services that are critical to maintaining public health and safety. The department's responsibilities include curbside trash and recycling collection from more than 540,000 households, construction and maintenance of 320 bridges and 2,525 miles of streets and highways, maintenance of all traffic control devices and street lighting, and snow and ice removal from streets and highways.

RISKS AND VULNERABILITIES

Many of Philadelphia's roads are vulnerable to flooding. Table 8 shows the percentage of miles of each road class that would be inundated under a range of flooding scenarios.

Temporary inundation of roadways from flooding can force road closures and disrupt traffic. In addition, floodwaters can create road washouts and standing water can degrade the road base or lead to pavement softening. Philadelphia has many historic streets that are vulnerable to these impacts, and have higher repair costs than non-historic streets.

Beyond roadways, a number of other Streets assets are vulnerable to flooding, as shown in Table 9. Traffic signals throughout the city are also vulnerable to flooding; most signal boxes are located at or belowground, where floods may affect them. The Streets Department's salt sheds, garages and maintenance buildings, and materials yards are not vulnerable to flooding.

Many Streets assets are also vulnerable to heat events. An extreme heat event limits construction activities on the city's roads and bridges; projects take longer and require additional water to cool materials between phases. City employees, including sanitation employees and construction workers, must be monitored for heat-related illnesses. In the past, Streets has sent home employees during multiple-day heat events out of concern for their safety. These delays can be costly and can interrupt services such as trash pickup.

TABLE 8

FLOOD RISK FOR PHILADELPHIA'S ROADWAYS, BY ROAD CLASS

ROAD CLASS		DESCRIPTION NOTES	TOTAL MILES	% OF MILES FLOODED					
				SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
1	**Expressway**	Interstate highways and other limited access roads and primary thoroughfares. Principal routes through the city e.g., I-95, I-76, Roosevelt Expressway	110	13%	19%	29%	32%	30%	43%
2	**Major**	Semi-limited access road; typically multi-lane and usually divided. e.g., Roosevelt Blvd, West River Dr, Cheltenham Ave, Byberry Rd, Broad St	259	4%	9%	11%	12%	18%	21%
3	**Arterial**	Medium-high volume road, feeds traffic to and from limited or semi-limited acces roads. Speed limit about 35 mph. e.g., Market St, 23rd St, Haverford Ave	362	0%	2%	3%	3%	6%	9%
4	**Collector**	Through streets in residential areas. e.g., Morris St, 60th St, Arch St in W. Philly	873	0%	1%	1%	2%	1%	3%
5	**Local**	Non-through streets in residential areas	1,122	1%	2%	3%	4%	4%	6%
6	**Driveway**	Common driveways	2	0%	2%	3%	10%	5%	18%
9	**Low speed ramps**	On- and off-ramps from expressways and major roads	19	4%	7%	16%	19%	28%	37%
10	**High speed ramps**	Interchanges; ramps connecting expressways	41	10%	27%	42%	53%	45%	63%
12	**Non-travelable**	Roads which cannot be driven on. e.g., Wissahickon Dr	42	16%	26%	20%	30%	65%	67%
	TOTAL		**2,831**	**2%**	**4%**	**5%**	**6%**	**7%**	**10%**

Road classes are as provided by the Philadelphia Streets Department. For an explanation of each flooding scenario and its significance, see page 22.

TABLE 9

NUMBER OF STREETS BUILDINGS AND OTHER FACILITIES AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Warehouses [Total number = 4]	0	0	1	4	4	4
Moderately Vulnerable	Multi-Use/ Office Buildings [Total number = 10]	0	0	0	0	0	1
Moderately Vulnerable	Transfer Stations [Total number = 3]	0	0	0	0	0	0

For an explanation of each flooding scenario and its significance, see page 22.

Changes in winter weather also affect Streets assets. For example, winters with heavy snowfall require more plowing, which wears down line striping on streets more quickly and leads to higher re-striping costs. Potholes also represent a significant cost. Extreme temperatures, snow, and freezing rain during recent winters have caused a near-record number of potholes on Philadelphia streets. When snow and ice melt, water seeps under the pavement through cracks. When temperatures dip back below freezing, the water freezes into ice and expands. Freeze-thaw cycles combined with the weight of traffic cause the pavement to collapse, forming a pothole. Crews filled 52,736 potholes in 2014. During the winter of 2014–2015, several trucks were damaged from falling into potholes. The Streets Department also had to deal with a regionwide shortage of road salt during the winter of 2014–2015 due to long periods of low temperatures. Because funding for pothole repairs, which cost an average of $22 per pothole, comes out of the repaving budget, winters with many potholes lead to less money available for repaving.

✔ EXISTING RESILIENCE EFFORTS

The Streets Department engages in several practices that increase resilience to extreme weather events and sea level rise both now and into the future. These include:

- Cleaning Streets Department drainage inlets to ensure they do not cause backups during flood events.
- During extreme weather events, tracking traffic signal outages and regularly providing updates to the Emergency Operations Center.
- Installing concrete pads at bus stops to prevent pavement from rutting on hot days due to the excess pressure exerted when buses brake and accelerate.
- Developing an asset management strategy and database. Asset management will enable the Streets Department to incorporate data about the risks, costs, and impacts of a changing climate into decisions about resource allocation.

EARLY IMPLEMENTATION OPPORTUNITIES

The Streets Department could consider implementing several strategies to increase its preparedness and decrease climate change risk in the long term, including:

- Formalizing coordination with the city's fuel supplier to ensure the Streets mobile fuel truck is full at all times.
- Reviewing standard pavement-mix specifications to ensure the ability of pavement to withstand (and not deform during) future high heat events.
- Ensuring battery backup power sources at street intersections are floodproofed or elevated above the floodplain.
- Implementing a standardized succession planning process and training program to ensure that storm response procedures are not lost with retiring staff.
- Designing bridge expansion joints to withstand longer periods of high heat per industry standards.
- Installing high-reflectivity hardscape when resurfacing roads, multi-use paths, and city parking lots.
- Analyzing vulnerability of Streets-owned bridges and structures to climate change.
- Exploring the use of warm-mix asphalt to extend the paving season.
- Coordinating with Philadelphia Water to install green stormwater infrastructure on streets where feasible.

The Streets Department coordinates with the Office of Emergency Management, Philadelphia Water, and others during flood events.

PHILADELPHIA WATER

The mission of **Philadelphia Water** is to plan for, operate, and maintain both the infrastructure and the organization necessary to purvey high-quality drinking water; to provide an adequate and reliable water supply for all household, commercial, and community needs; and to sustain and enhance the region's watersheds and quality of life by managing wastewater and stormwater effectively. The utility owns and operates an extensive amount of infrastructure to provide integrated stormwater, wastewater, and drinking water services.

To manage stormwater, the department maintains stormwater pipes and inlets to decrease flooding and combined sewer overflows, and to reduce pollution. The department is committed to a balanced "land-water-infrastructure" approach to achieve its watershed management goals, which is evident in the utility's commitment to use green infrastructure on a large scale to manage stormwater runoff throughout the city.

Philadelphia Water operates three drinking water treatment plants that treat an average of more than 230 million gallons of water a day and serve more than 1.5 million people. The drinking water distribution system contains more than 3,000 miles of linear assets. Philadelphia Water also manages the City of Philadelphia's wastewater, a task that includes the upkeep of more than 3,000 miles of sewer pipes carrying waste from homes, businesses, and streets to one of three water pollution control plants (Northeast, Southwest, and Southeast facilities). The wastewater system serves approximately 2.2 million people in the City of Philadelphia and 10 municipalities and authorities located in Montgomery, Delaware, and Bucks counties.

RISKS AND VULNERABILITIES

Philadelphia Water's extensive assets and operations face a range of vulnerabilities to increases in precipitation frequency and intensity, sea level rise, and extreme storm events, as many facilities are located on or next to rivers. Inundation can exacerbate the wear on pipes and damage essential mechanical and electrical equipment. Stormwater infrastructure is at risk of being overwhelmed during heavy precipitation events.

To address these impacts and increase resilience, Philadelphia Water recently created a climate change adaptation program that will expand upon the proposed adaptation strategies in this report and will inform Philadelphia Water planning initiatives, including the Water and Wastewater Master Plans and Philadelphia Water's participation in the Citywide Flood Risk Management Task Force. Philadelphia Water's climate adaptation program consists of a multi-year initiative that will achieve three main objectives: 1) continue to enhance understanding of the climate change-related vulnerabilities that the utility will face in the near- and long term; 2) identify additional adaptation strategies that will increase the long-term resilience of Philadelphia Water; and; 3) develop an integration and implementation framework for critical adaptation strategies. Outlined below are examples of the types of vulnerabilities that the Philadelphia Water drinking water, wastewater, and stormwater systems face due to climate change. Table 10 shows the facility types that are vulnerable to the flooding scenarios considered in this report.

TABLE 10

NUMBER OF PHILADELPHIA WATER ASSETS AT RISK OF FLOODING UNDER A RANGE OF SCENARIOS

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Water Pollution Control Plants [Total number = 3]	0	1	1	1	1	2
	Biosolids Recycling Center [Total number = 1]	0	1	1	1	1	1
	Drinking Water Treatment Plant [Total number = 3]	0	0	0	0	0	0
	Laboratory [Total number = 1]	0	0	0	0	0	0

Only a subset of Philadelphia Water's assets were assessed for vulnerability. For an explanation of each flooding scenario and its significance, see page 22.

Drinking Water Infrastructure

Based on preliminary analyses, several of the department's drinking water and stormwater pumping stations could be vulnerable to flooding under certain scenarios. Philadelphia Water will conduct further vulnerability assessments on this infrastructure. Additional precipitation may also increase stormwater runoff, which can affect source water quality and require changes to the drinking water treatment process. One example of a potential change in source water quality could occur during winter, when salt spread on the roads to improve safety can increase the conductivity of Philadelphia's source water.

The drinking water treatment process may also be affected by changes in temperature. Warmer temperatures in the rivers lead to an increase in algae and the production of taste and odor compounds, which could lead to higher treatment costs. Warmer temperatures also require more energy use throughout the city. Future increases in energy demand may stress the energy grid and potentially lead to temporary losses of power that could affect water operations.

Sea level rise creates a risk of the salt line in the Delaware River moving toward Philadelphia. If the salt line approaches the Baxter Water Treatment Plant intake (Baxter intake) due to sea level rise, there could be major consequences for source water quality and treatment. As stated in the Delaware River Source Water Protection Plan,[23] the salt line is the location where more dense saline water from the Delaware Bay forms an interface with less dense freshwater from the Delaware River. The concentration of sodium and chloride are so high behind the salt front that if the salt line were to reach the Baxter intake, the current intake would have to be closed to prevent contamination of the plant.

Wastewater Infrastructure

Philadelphia Water's water pollution control and storage facilities are vulnerable to flooding from sea level rise, storm surge, and riverine flooding, as shown in Table 10. Intense rainfall events can exceed the capacity of the combined sewer system, which can cause the release of untreated sewage into the waterways as well as basement backups and street flooding. Wastewater operations are dependent on power for both treatment and pumping. Severe storms that cause a loss of power could disrupt operations. An increase in precipitation would increase the frequency of high flows to water pollution control facilities, possibly requiring infrastructure expansion and potentially new operating protocols.

FIGURE 14

PHILADELPHIA'S STORMWATER AND WASTEWATER SYSTEMS

Source: Philadelphia Water

Combined/Sanitary and Storm Sewer Infrastructure

Stormwater infrastructure consists of drains and pipes, green stormwater infrastructure, water pollution control plants, and outfalls. About 60 percent of the city's sewered area, typically the older sections of the city, is served by combined sewers that carry away both wastewater and stormwater (see Figure 14). The other 40 percent of the sewered area is served by separate sewer pipes for sewage and stormwater.[24]

Increases in precipitation intensity and frequency will lead to increases in stormwater runoff and consequent changes to source water quality.

Philadelphia has three different types of outfalls: combined sewer, separate sewer, and treated effluent. Combined sewer outfall overflows occur during storm events when the combined sewer system's capacity is exceeded. Separate outfalls carry stormwater runoff to rivers directly from the separate sewer system drainage network. Treatment outfalls are located at water pollution control plants and send treated effluent into the Delaware River. If sea level rises two feet by 2050, up to 200 outfall structures could be vulnerable to submersion, potentially preventing proper drainage from gravity systems into the tidal zones of the Delaware and Schuylkill Rivers during high tides. Additionally, if sea level rise causes the salt line to reach some outfalls, increased salinity will affect the lifespan and performance of pipes and other infrastructure. Since preliminary modeling by ICF suggests increased intense precipitation and overland riverine flooding have the potential to inundate many outfalls during extreme weather events, Philadelphia Water will need to conduct a more detailed and thorough vulnerability analysis to evaluate the impacts on the system's performance.

EXISTING RESILIENCE EFFORTS

Philadelphia Water has undertaken many initiatives and projects to reduce its vulnerability to flooding events, helping to improve resilience today while working to ensure the utility's continued resilience as climate changes. Strategies outlined below currently help Philadelphia Water increase resilience:

- Providing coordination with the Office of Emergency Management to enhance targeted outreach efforts and ensure that adequate preparedness and response measures are implemented in the most flood-prone portions of the city.
- Increasing understanding of flooding vulnerabilities through extensive modeling and mapping of reported customer complaints. Tracking the location and frequency of customer complaints throughout the city helps to validate flood model results and further informs the existence of potential infrastructure deficiencies. Moving forward, Philadelphia Water will consider approaches to include climate change impacts in flood modeling efforts.
- Promoting green stormwater infrastructure (GSI) as a source control measure to minimize flooding impacts. GSI allows for smaller-scale, decentralized source control projects, providing for an effective and highly adaptive approach to stormwater management. Philadelphia Water will continue to identify high-impact opportunities for GSI projects in the city to reduce stormwater runoff.
- Investigating the adequacy of existing flood management operations, including stormwater pump stations. As an example of existing flood management operations, Philadelphia Water's Mingo Creek Pump Station routinely pumps water from the Eastwick area to the Schuylkill River to avoid flooding. The Eastwick area is particularly vulnerable to flooding since it is below the elevation of the Delaware River at high tide. The existing pumps will continue to serve the city as the sea level rises.
- Continuing the City of Philadelphia's partnerships with federal agencies to analyze and understand the potential need for structural flood interventions.
- Assessing opportunities for projects to manage flood risk.
- Supporting the reduction of health risks to residents during climate-related events. As an example, the utility does not shut off service to customers with outstanding bill payments during heat emergencies.

As noted earlier, Philadelphia Water is in the process of implementing a comprehensive climate change adaptation program that will expand on the proposed adaptation strategies in this report. Philadelphia Water has also embarked on a comprehensive department-wide risk assessment to better understand the magnitude and likelihood of climate-related vulnerabilities at the utility.

EARLY IMPLEMENTATION OPPORTUNITIES

The near-term adaptation strategies outlined here received high feasibility and efficacy rankings:

- Increasing preparedness and response capabilities at the water pollution control plants through the following measures:
  - Prepare for recovery from flooding by stockpiling response materials and storing them outside of flood-prone areas.
  - Maintain turnkey agreements for equipment rental and ensure the contracts provide priority to the water pollution control plants after an event.
  - Pre-position emergency power generation capacity, portable pumps, and debris removal equipment in anticipation of extreme storm or flooding events.

CLIMATE MATTERS

Hurricane Irene in 2011 sent almost one billion gallons of stormwater to Philadelphia Water's water pollution control plants, more than twice the normal volume the plants receive. Prior to the storm, the department proactively prepared by clearing 400 inlets so that stormwater could more easily drain away from the streets. The water pollution control plants maintained performance during the hurricane. This proactive preparation helped reduce the amount of flooding that may have occurred otherwise in the city. After the event, more than 55 Philadelphia Water employees worked over the weekend to answer calls and pump out flooded basements.

Source: Interview with Philadelphia Water; Philadelphia Water blog.

- Ensuring sufficient availability of backup power at all critical sites.
- Prior to major storm events, ensuring that the drainage and collection systems are functioning at maximum capacity. As an example, prior to hurricanes or other large storm events, clear debris and other inlet obstructions that could prevent drainage into the collection system.
- Implementing groundwater instrumentation to better understand short- and long-term changes in the groundwater table.
- Conducting watershed analyses to identify opportunity sites for green stormwater infrastructure or low-impact development techniques that will improve stormwater and flood control system capacity under conditions of heavier precipitation and changes in the groundwater table.
- Analyzing elevation of critical operational infrastructure, including electrical equipment, at drinking water treatment plants, water pollution control plants, and pump stations.
- Adopting design standards for water pollution control plants, pumping stations, and other critical infrastructure that include more robust resilience measures.
- Incorporating climate change adaptation strategies into the long-term Water and Wastewater Master Plans and flood risk management initiatives.
- Completing an asset inventory at water pollution control plants that includes elevations for all critical equipment. This measure will enable Philadelphia Water to accurately assess the vulnerability of assets to flooding from sea level rise and extreme storm events.
- Evaluating flood protection strategies at the Biosolids Recycling Center to ensure continuity of operations.

PHOTO COURTESY OF PHILADELPHIA WATER

Philadelphia Water's Soak It Up Adoption Program provides grants to civic organizations to help maintain the beauty and functionality of green stormwater infrastructure in Philadelphia's neighborhoods.

INTERDEPENDENCIES AND OPPORTUNITIES FOR INTERDEPARTMENTAL COOPERATION

Existing risk mitigation actions underway across the city, augmented by the department-specific adaptation strategies described above, will support enhanced resilience. However, to achieve *transformational* adaptation—i.e., risk mitigation measures sufficient to address projected changes in Philadelphia's climate over the mid- and long term—the city must consider implementation of holistic, citywide strategies. These strategies will require participation, buy-in, and investment from a wide range of internal and external stakeholders.

Interdependencies and opportunities for interdepartmental adaptation efforts to reduce vulnerabilities of the city's physical infrastructure and service delivery are described below. Departments at the two scenario-planning workshops held by the Mayor's Office of Sustainability (MOS) in April 2015 discussed many of these opportunities.

Asset Management

The Office of Innovation and Technology and the Department of Public Property are in the process of procuring an integrated work order and asset management database. Philadelphia Water, the Philadelphia International Airport, the Streets Department, and Philadelphia Parks & Recreation are also developing or upgrading their own asset management and work order systems. The development of these systems provides an opportunity to incorporate climate exposure and sensitivity information into asset management and monitoring, with the goal of tracking information on the costs of future weather events in a format that meets requirements for Federal Emergency Management Agency (FEMA) post-disaster reimbursement. This information can also be used to inform risk-based planning and investment decisions and build the case for proactively addressing climate change vulnerabilities.

Interdepartmental coordination would maximize the usefulness and success of these systems. Philadelphia Water and Philadelphia International Airport are using MAXIMO software for their systems. Parks & Recreation is using Performo by Wizard. If possible, all of the asset management and work order systems should not only integrate climate data, but also "talk" to each other, potentially by using similar data fields and definitions of the scale of assets (e.g., an electrical panel or a building). MOS or another entity could coordinate regular meetings among the system implementers to discuss integration of climate impacts into the databases. These coordination meetings could also serve as working sessions for staff managing the asset management systems, allowing them to develop and discuss ways to ensure that they are keeping the systems up-to-date and using available information to inform decision making.

Extreme Weather Coordination

Information sharing before, during, and after extreme weather events is an important area for interdepartmental coordination.

BEFORE AN EVENT

- Several departments at the scenario planning workshops identified a need for improved sharing of information ahead of extreme weather events, particularly those that do not result in the activation of the Office of Emergency Management (OEM)'s Emergency Operations Center. Functional cross-partner communication channels between the departments exist but are not formal or well documented.
- City departments should continue to build on the momentum of the Citywide Flood Risk Management Task Force. The task force has modeled the kind of coordination of resources and information that could significantly improve responses to extreme weather, while simultaneously informing and strengthening interdepartmental support and commitment for expanded response efforts. A similar coordination approach may effectively address interdepartmental concerns about other types of extreme weather and climate changes.

DURING AN EVENT

The workshops identified a number of potential projects with short implementation timelines and relatively low costs to improve information gathering and sharing during extreme weather events. The city should consider:

- Enhancing communication about access routes during floods.
- Expanding access to real-time tide and rain gauge information.
- Assessing whether citizens could report on local weather-related damages (especially the location of flooding) through the 311 system (including the smartphone application).
- Formalizing coordination of fuel provision among the Fleets fuel truck, the Department of Public Property fuel truck, and external fuel supply contractors.

AFTER AN EVENT

Workshop participants pointed out the need for a system to collect post-event cost data for events that are both above and below the national hazard declaration threshold. Among other benefits, a systematic approach would facilitate cost evaluations for extreme events—and more frequent, less extreme weather-related disruptions—and consideration of possible adaptation investments. Better tracking also facilitates the collection of disaster data for reimbursement following major events. OEM should consider working with the other departments to establish uniform policies and systems to support this tracking effort. The asset management systems discussed above may serve as repositories for this information.

Flood Protection

Floodproofing of individual structures or sites (e.g., constructing flood walls, installing removable flood barriers, or raising mechanical and electrical equipment) may be performed either opportunistically or proactively. *Opportunistic* floodproofing is installed during routine maintenance and upgrades, reducing the incremental cost of installation. *Proactive* floodproofing may be warranted for facilities that have historically experienced significant flooding and are irreplaceable or critical to delivery of services.

To augment department-specific efforts to identify and consider asset-specific flood risks, MOS has prepared a diagram (See Figure 15) as an example of an approach that the city could employ to understand asset-specific flood risks, develop site-specific floodproofing strategies, and inform capital planning decisions. If useful, these kinds of diagrams could be developed and distributed more widely, both as a means to monitor and track vulnerabilities and to support flood mitigation efforts.

FIGURE 15

PHOTO OF BUILDING WITH FUTURE PROJECTED WATER LEVELS ADDED

This former water treatment facility, owned by Philadelphia Water, currently faces a 0.2 percent risk of flooding annually (based on FEMA 2007 flood mapping). The horizontal lines show future water levels under scenarios of two feet, four feet, or six feet of sea level rise plus a Category 1 storm surge.

Work on the guaranteed energy savings project in City Hall and three other downtown office buildings was completed in 2015, and the Energy Office is now monitoring these projects to ensure cost and energy savings are realized. *Photos by MOS*

System-Based Strategies

Systems of interconnected infrastructure require a comprehensive, systematic approach for adapting to sea level rise and future storm surges. Implementing strategies at the systems level requires developing a detailed plan that addresses the funding, phasing, and interdependencies of the strategy. A few examples of potential systemwide adaptation strategies include:

- Increasing stormwater system capacity and functionality in key areas of the city. System capacity improvements could include implementing large-scale green stormwater infrastructure projects, increasing pipe size, installing backflow prevention devices, and installing additional pump stations or upgrading and increasing existing pump station capacity.
- Supporting a regional evaluation of transportation and utility networks that are vulnerable to sea level rise to determine hot spots or weak links that would cause significant disruption to the regional economy and quality of life.
- Integrating flood protection strategies at vulnerable water and water pollution control plants and pump stations. Flood protection strategies include enhanced real-time monitoring and controls, creating flood walls, increasing existing flood wall height, increasing pumping capacity, installing removable flood barriers, and elevating mechanical and electrical equipment.
- Determining low-lying substation vulnerabilities and outlining options for adaptation and mitigation; coordinating with DOE on its vulnerable infrastructure studies.
- Examining the installation of pumps at Philadelphia Water outfalls that discharge from the gravity system into the tidal zones of the Delaware and Schuylkill Rivers.

Energy Efficiency

As described in the Costs of Climate Change section (see page 19), an increase in hot days requiring cooling at municipal facilities could increase the City of Philadelphia's annual electricity bill by up to $1 million. Investing in energy efficiency will help reduce these costs, while also contributing to Philadelphia's goals to mitigate the causes of climate change through reduced greenhouse gas emissions.

As part of the *Greenworks* sustainability plan, Philadelphia has committed to improving the energy efficiency of city-owned facilities. The city recently completed construction of a guaranteed energy savings project in its four largest downtown office buildings and is funding many smaller projects through its Energy Efficiency Fund. Energy efficiency should continue to be prioritized as both a climate mitigation and adaptation measure.

The efficiency of building systems should also be taken into account during the capital planning process. Departments considering repairing, replacing, or adding new cooling capacity in facilities should consider the lifecycle costs of HVAC equipment. Currently, several departments have a requirement that new HVAC equipment must be ENERGY STAR-labeled; expanding this requirement to all departments would better position Philadelphia to mitigate the increase in electricity costs from rising temperatures in the years ahead.

Policy, Planning, and Finance

City departments that work in the areas of policy, planning, and finance will be affected by climate change in many ways, both directly and indirectly. Risks, vulnerabilities, and adaptation opportunities are described below.

OFFICE OF EMERGENCY MANAGEMENT

The **Office of Emergency Management** (OEM) is responsible for ensuring the city's readiness for all types of emergencies. The office works to accomplish this mission through an integrated and collaborative program that educates the public on how to prepare for emergencies, and partners with organizations throughout the city to prepare emergency contingencies, mitigate the impact of emergencies, and enable the city to recover from an emergency as quickly as possible. During an emergency, OEM coordinates with a variety of agencies and organizations including Fire, Police, and other emergency response departments to ensure a timely and efficient response. OEM also prepares after-action reports following events to document activities and explore possibilities for improving future responses.

RISKS AND VULNERABILITIES

Many of Philadelphia's evacuation routes are at risk for flooding during storms, especially as the sea level rises (see Table 11). Flooding of these roads would make it more difficult to access hospitals, schools, and critical infrastructure, as well as to evacuate the city. Flooding of evacuation routes could put vulnerable populations at further risk during a large storm event.

Under a scenario of two feet of sea level rise, which is projected for Philadelphia by 2050 under moderate greenhouse-gas-emissions scenarios, 29.5 miles of the city's nearly 664 evacuation route miles would be permanently inundated. A Category 1 hurricane, the most intense that has ever hit the Philadelphia region, on top of two feet of sea level rise would flood an additional 48.8 miles of evacuation routes. Evacuation routes for private vehicles are the most vulnerable to flooding, followed by routes for pedestrians and all vehicles. Evacuation routes used only by pedestrians and mass transit are generally less exposed to flooding.

TABLE 11

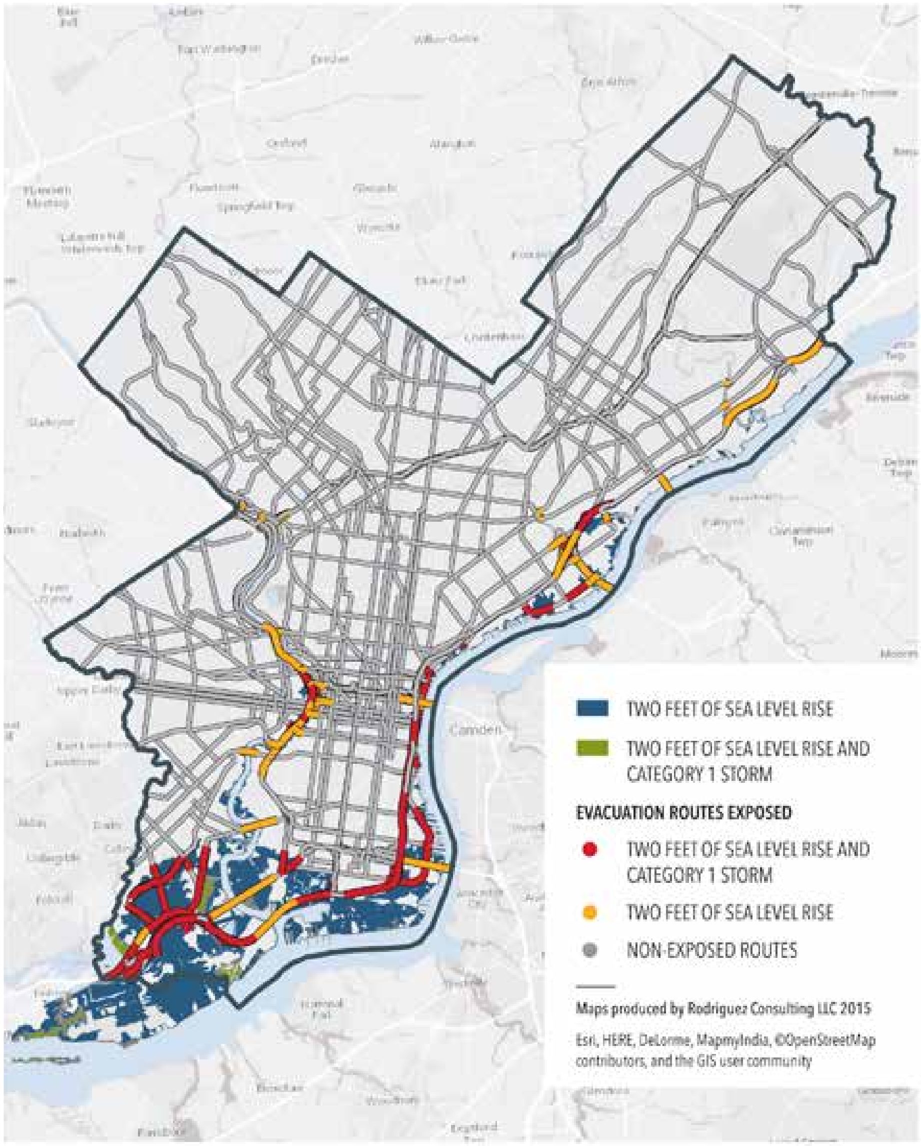
MILES OF EVACUATION ROUTES VULNERABLE TO INUNDATION UNDER A RANGE OF SCENARIOS

		ASSETS POTENTIALLY INUNDATED UNDER FLOODING SCENARIOS					
		SEA LEVEL RISE		SEA LEVEL RISE *with storm surge*		RIVERINE FLOODING	
	TYPE OF ASSET	SLR 2	SLR 4	SLR2 + Cat1	SLR4 + Cat 1	100-yr	500-yr
Highly Vulnerable	Evacuation Routes, in miles [Total number = 663.9]	29.5 (4%)	53.9 (8%)	78.3 (12%)	89.5 (13%)	107.7 (16%)	144.6 (22%)

For an explanation of each flooding scenario and its significance, see page 22.

FIGURE 16

EXPOSURE OF OEM'S DESIGNATED EVACUATION ROUTES



EXISTING RESILIENCE EFFORTS

In the course of fulfilling its core responsibilities, OEM proactively addresses weather and climate change risks on a daily basis. Some of OEM's current key actions that will reduce future vulnerabilities to climate change include:

- Conducting historic property mitigation assessments in cooperation with the State of Pennsylvania to identify strategies for at-risk historic buildings.
- Distributing *Ready Philadelphia* guides and educating the public on general preparedness and business continuity practices.
- Implementing the Ready Notify Campaign to increase subscriptions to the ReadyNotifyPA system.
- Partnering with community groups such as local community organizations, including civic, business, town watch, faith-based, senior, special needs, and tenant associations, to promote emergency preparedness and mitigation efforts.
- Convening seasonal interagency meetings as necessary to review heat responses.
- Routinely updating priority emergency shelter locations for excessive heat.
- Implementing and updating the city's *Excessive Heat Plan* and *Hazard Mitigation Plan*.

EARLY IMPLEMENTATION OPPORTUNITIES

OEM strategies that are feasible to implement in the near term and effective at reducing City of Philadelphia vulnerabilities include:

- Purchasing a redundant alert notification system for extreme weather (e.g., NOAA Radio) to notify facilities managers.
- Actively integrating climate change and climate adaptation strategies in the update of the *Hazard Mitigation Plan*, which began in summer 2015 and will be completed by 2017. Beginning in March 2016, the Federal Emergency Management Agency (FEMA) will require states seeking funds to enhance their preparedness to include assessments of climate change impacts to their communities.[25] In addition, as part of FEMA's integration of climate change into its program, cost-effective hazard mitigation projects that include sea level rise estimates will be eligible for funding. OEM's incorporation of local climate change vulnerabilities in the plan will assist with both local and statewide planning.
- Developing a Hazard Mitigation Steering Committee that identifies climate adaptation strategies as a priority and tracks the implementation of mitigation strategies that increase community resilience, including reporting on the status of projects identified in this report.
- Preparing, adopting, implementing, and updating a comprehensive long-term recovery plan to direct how and where state or federal disaster recovery funds are used to rebuild resilient communities after storm events, including benefit-cost guidance based on the existing FEMA framework for conducting such analyses. The plan should focus on determining when to rebuild assets to a higher standard so they can withstand future events of similar or greater intensity.

OFFICE OF THE DIRECTOR OF FINANCE (BUDGET, RISK MANAGEMENT)

The **Office of the Director of Finance** is responsible for the financial, accounting, and budgeting functions of the city's executive branch. The office includes the Risk Management Division, whose mission is to reduce the financial impact of claims, lawsuits, and employee injuries to the city; to reduce the corresponding frequency and severity of these events through the application of professional risk-management techniques; and to provide a safe environment for employees to work and the public to enjoy. The Office of the Director of Finance also includes the Office of Budget and Program Evaluation, which performs budgetary functions for the city, including preparing and monitoring the annual operating and capital budgets, providing periodic projections of the year-end fund balance for the operating funds, preparing the city's five-year financial and strategic plan (including financial and economic forecasts and assumptions), and other budgetary reports as required.

RISKS AND VULNERABILITIES

While the Office of the Director of Finance does not face any vulnerabilities itself, the Risk Management Division is responsible for evaluating and overseeing the legal risks of each of the other departments, including risks associated with aging infrastructure. Together with Finance, Risk Management makes decisions that determine how future climate risks are considered.

EARLY IMPLEMENTATION OPPORTUNITIES

The Office of the Director of Finance is not directly responsible for reducing the city's climate change vulnerabilities. Rather, the role of the Department is to support the implementation of adaptation strategies by other departments.

- The Office of the Director of Finance can support departments by assisting in investigating and pursuing direct and alternative funding mechanisms for adaptation strategies. For example, stormwater infrastructure improvements could be funded through taxes, a fee-based mechanism, assessment districts, or leveraging private sector resources.
- The Office of the Director of Finance can also work with the Planning Commission to integrate climate change considerations into the city's budgeting procedures.
- The Risk Management Division should consider climate change risks along with all other traditionally considered risks.

PHILADELPHIA CITY PLANNING COMMISSION

The mission of the **Philadelphia City Planning Commission** (PCPC) is to guide the orderly growth and development of the City of Philadelphia. The commission addresses issues of community and economic development, public health and environmental sustainability, and multi-modal transportation policy. It also manages the city's Capital Program and annual capital budgeting process.

The Commission's Planning Division is responsible for all aspects, including civic outreach, of preparing and updating *Philadelphia2035*, the city's comprehensive plan. The division develops district, neighborhood, and redevelopment area plans, and conducts planning studies relating to physical development issues. The Development Planning Division reviews site plans for compliance with the zoning code, land subdivision requirements, environmental regulations, and other city and state development controls. The Urban Design Division focuses on the improvement of the city's public realm through physical design and streetscape initiatives. The GIS Division creates, maintains, and develops visual displays of data used for planning studies and analysis undertaken by the Commission. Finally, the Policy and Analysis Division deals with citywide policy issues and planning opportunities in the areas of housing and demographics, transportation, economic development, and planning for healthy communities.

RISKS AND VULNERABILITIES

While PCPC does not face direct risks from climate change or extreme weather events, its planning activities can determine the vulnerability and adaptive capacity of municipal and public assets. Considering current and future flood risks during the planning and approval process for development efforts can help Philadelphia increase its resilience to climate impacts.

EXISTING RESILIENCE EFFORTS

As an inherently forward-looking department, PCPC initiatives should consider future risks to help Philadelphia become less vulnerable to hazards. Examples of existing PCPC efforts to address extreme weather risks include:

- Maintaining enrollment in the National Flood Insurance Program by implementing floodplain management initiatives, reducing flood risk, and allowing residents to receive discounted flood insurance.
- Considering opportunities to reduce the urban heat island effect and implement stormwater management practices during the Civic Design Review process.
- Requiring new facilities located in flood zones to be raised 18 inches above FEMA base flood elevation.

EARLY IMPLEMENTATION OPPORTUNITIES

When considering future land use and infrastructure plans, PCPC should consider implementing several strategies, including:

- Extending the standard planning horizon to match the useful lifetime of the investments and land use changes (at least 30 years in most cases; potentially as long as 100 years for long-lived infrastructure). Extending the standard planning horizon is essential for incorporation of potential future climate change impacts on programs and infrastructure.
- Integrating climate change considerations into the Capital Program and capital budgeting process by requiring project sponsors to self-identify vulnerabilities to climate change (potentially by following the "decision tree" on page 56), and incorporating climate change impacts in the return on investment (ROI) calculations. As the frequency of extreme weather events increases, assumptions used to determine ROI will need to also be adjusted and outcomes of ROI-based investment decisions may change. PCPC should also consider conducting sensitivity tests on the ROI depreciation value to determine if future damages are being too steeply discounted to impact current investment decisions.
- Preserving open space in flood hazard areas and channel migration zones. The Wissahickon Valley Park is an outstanding local example of an appropriately preserved floodplain that helps to protect neighboring communities from flooding.
- Acknowledging and addressing climate change issues, concerns, and impacts in *Philadelphia2035* district plans.
- Incorporating a discussion of climate change resilience into the Civic Design Review process. For example, require the applicant to identify if they are within the 500-year floodplain and, if so, identify what actions they have taken to prepare for flooding.

FIGURE 17

PCPC and MOS are working together to integrate climate science into the District Plan for Philadelphia's River Wards, including Fishtown, East Kensington, Olde Richmond, Port Richmond, Kensington and Bridesburg.

PHILADELPHIA DEPARTMENT OF COMMERCE

The **Philadelphia Department of Commerce** sets and leads policies to help businesses in Philadelphia thrive. The department coordinates activities along neighborhood commercial corridors, programs serving small businesses and entrepreneurs, major real estate development projects, and large-scale business attraction and retention efforts, as well as efforts to increase contracting opportunities for minority- and women-owned businesses. The department is the umbrella organization for all economic development activity in the city and coordinates the work of related agencies, including the Philadelphia Industrial Development Corporation (PIDC) and the Philadelphia Redevelopment Authority (PRA).

RISKS AND VULNERABILITIES

The Commerce Department, PIDC, and PRA are working to redevelop locations along the Schuylkill and Delaware Rivers, where sea level rise and storm surge will increase flooding vulnerability. As these departments make long-term plans, such as the proposed extension of the Broad Street Line to The Navy Yard, they will need to consider future flooding potential.

EARLY IMPLEMENTATION OPPORTUNITIES

Strategies that the Department of Commerce should consider to increase its preparedness and decrease climate change risk in the long term include:

- Requiring all new waterfront development projects to be constructed in a manner that is resilient to future climate changes and sea level rise. To implement this strategy, Commerce should work with the Planning Commission to develop enhanced flood protection building code requirements that take sea level rise into consideration, and should provide potential developers with the best available information about flood vulnerabilities at development sites.
- Adding climate adaptation and business continuity technical assistance to the current services the Department of Commerce provides for small businesses and entrepreneurs.

The new Central Green park will help manage stormwater at the Philadelphia Navy Yard.

INTERDEPENDENCIES AND OPPORTUNITIES FOR INTERDEPARTMENTAL COOPERATION

While planning, policy, and finance departments have fewer direct climate vulnerabilities than those managing infrastructure and services, their participation is critical to achieving transformational adaptation measures. Opportunities for changes in planning, policies, and budgeting to reduce the City of Philadelphia's vulnerability to climate change are described below.

PLANNING EFFORTS

As city departments and partners update or complete planning efforts, they should incorporate findings and recommendations from this report to reduce risks to existing city assets and services, and to ensure that taxpayer investments recognize and respond to emerging climate and extreme weather risks. Consistent cross-agency communication on long-range planning efforts would identify areas for cooperation, create opportunities to leverage funds, and foster an improved understanding of cascading risks (i.e., risks affecting one service or asset that in turn affect services or assets under the management of another department).

PHILADELPHIA CITY PLANNING COMMISSION'S *PHILADELPHIA2035* PLANNING

The Mayor's Office of Sustainability (MOS) is working with the Philadelphia City Planning Commission (PCPC) to incorporate climate adaptation goals into the district plans PCPC is currently developing and other physical development plans involving PCPC. PCPC should incorporate climate vulnerabilities and adaptation options into future district planning and implementation and include discussions of climate change's influence on neighborhoods during the district planning outreach process.

OFFICE OF EMERGENCY MANAGEMENT PLANNING EFFORTS

The Office of Emergency Management (OEM) is responsible for developing Philadelphia's *Hazard Mitigation Plan* (HMP), which contains a risk and vulnerability assessment for the city. The plan is updated every five years, and work has begun on an update that the city will submit to the Federal Emergency Management Agency (FEMA) in 2017. MOS and the Climate Adaptation Working Group are committed to supporting OEM's goal of considering future climate projections and incorporating climate adaptation actions into the HMP. OEM is exploring development of a Hazard Mitigation Steering Committee, which could serve as an all-hazards forum to help guide ongoing implementation activities.

OEM is also in the process of developing a comprehensive recovery plan. As a part of the development process, OEM should consider the strategies from this report.

OEM should consider working with The Navy Yard to develop evacuation routes for the 11,000 employees working on the campus. Because it is technically private development, the area has been excluded from OEM's plans in the past.

PHILADELPHIA WATER LONG-RANGE PLANNING

Philadelphia Water will provide updates on the results of its climate change risk assessment that may help inform the long-term planning and investment strategies of other departments.

COORDINATION WITH KEY CITY PARTNERS' PLANS

The city will need to engage and coordinate with external partners, such as SEPTA, PECO, PJM Interconnection, PennDOT, and other agencies that manage assets and operations that are interdependent with the city's, to ensure coordination across Philadelphia.

For example, the city should continue to support the Delaware River Waterfront Corporation as it seeks funding to establish wetland parks between Washington and Oregon Avenues, as outlined in the Central Delaware Waterfront Master Plan. Similarly, the city should coordinate with SEPTA to ensure that discussions about expanding transit systems consider vulnerabilities to flooding due to climate change.

FUNDING & BUDGETING

- The Office of the Director of Finance and the Mayor's Office of Grants can support departments by assisting in identifying and pursuing external grants and alternative funding mechanisms for adaptation strategies. For example, stormwater infrastructure improvements could be funded through taxes, a fee-based mechanism, assessment districts, or leveraging private sector resources.
- The Office of the Director of Finance should work with the Planning Commission to integrate climate change considerations into budgeting procedures.
- The Risk Management Division should ensure that climate change risks are considered side-by-side with all other risks that are traditionally planned for.

POLICIES TO PREVENT FUTURE VULNERABILITIES

In addition to protecting existing structures and systems, planning future development out of harm's way is also necessary. Some strategies that are feasible for near-term implementation are identified earlier; more aggressive and holistic approaches are suggested below.

LAND USE

- Consider innovative options for voluntary transfers of development rights that could allow property owners to sell existing development rights in high-risk areas in exchange for rights in low-risk areas.
- Implement a program of rolling easements to establish an open space boundary that moves inland as sea level rises along the shoreline. Alternatively, work with parks and habitat preservation partners that may be interested in purchasing properties in these areas. The easement or purchase program should be established soon enough to acquire areas for inland migration of wetlands and to avoid shoreline armoring that would foreclose the option of implementing natural solutions to sea level rise. In 2011, EPA released a report on rolling easements that contains information on the types of easements and strategies available to cities.[26]
- Create a collaboration among appropriate departments such as Public Property, Parks & Recreation, Philadelphia Water, and the Office of Finance to prioritize buyout of properties that are damaged or at high risk of damage from sea level rise or storm events. This may be instituted reactively over time as properties are damaged, or proactively for businesses and residences that fall within the potential flooding areas. For a model program, see the New York Rising Buyout and Acquisition Program that was implemented after Superstorm Sandy.
- Provide a flooding vulnerability assessment of brownfields to the City of Philadelphia Brownfields Working Group, led by the Department of Commerce, and to the U.S. Environmental Protection Agency's Brownfields Program to help support prioritization of remediation based on the timing of exposure to sea level rise, storm events, and elevated groundwater, degree of vulnerability, and extent of the consequences.

BUILDING CODES

- Require high-rise residential housing to have either backup generators or windows that can open for ventilation. High-rises without ventilation can become dangerously hot during power outages.
- Develop and enforce policies for repair and reconstruction to eliminate below-grade habitable space that is damaged by sea level rise, storm surge, or flooding.

PROTECTING ASSETS FROM FLOODING VULNERABILITY

The City of Philadelphia can increase citywide flood resilience by proactively planning for projected sea level rise and storm surge inundation when retrofitting existing facilities and building new facilities, and by providing guidance and information to private developers. A starting point for incorporating future climate and weather risks in engineering design is the draft 2015 Federal Flood Risk Management Standard. It requires that all new federally funded construction be sited and designed in one of three ways:

1) Using best available data and methods that integrate current and future changes in flooding based on science;
2) Building two feet above the current 100-year flood elevation for standard projects, and three feet above the current 100-year flood elevation for future critical assets (e.g., police, fire, other mission-critical structures); or
3) Building above the 500-year flood level.

This standard can be a model for all projects, not just those using federal funding. The City of Philadelphia and other progressive investors that are interested in managing flood risks can use the same approach for non-federal projects located in the FEMA floodplain.

However, some areas of Philadelphia outside the FEMA floodplain are at risk for inundation by sea level rise and storm events. Following the 2015 Federal Flood Risk Management Standard may not sufficiently protect assets in these locations. Additionally, the levels of protection recommended by the 2015 federal standard would protect assets in Philadelphia from sea level rise and storm surge events only through mid-century, while most infrastructure projects are built to last much longer than that.

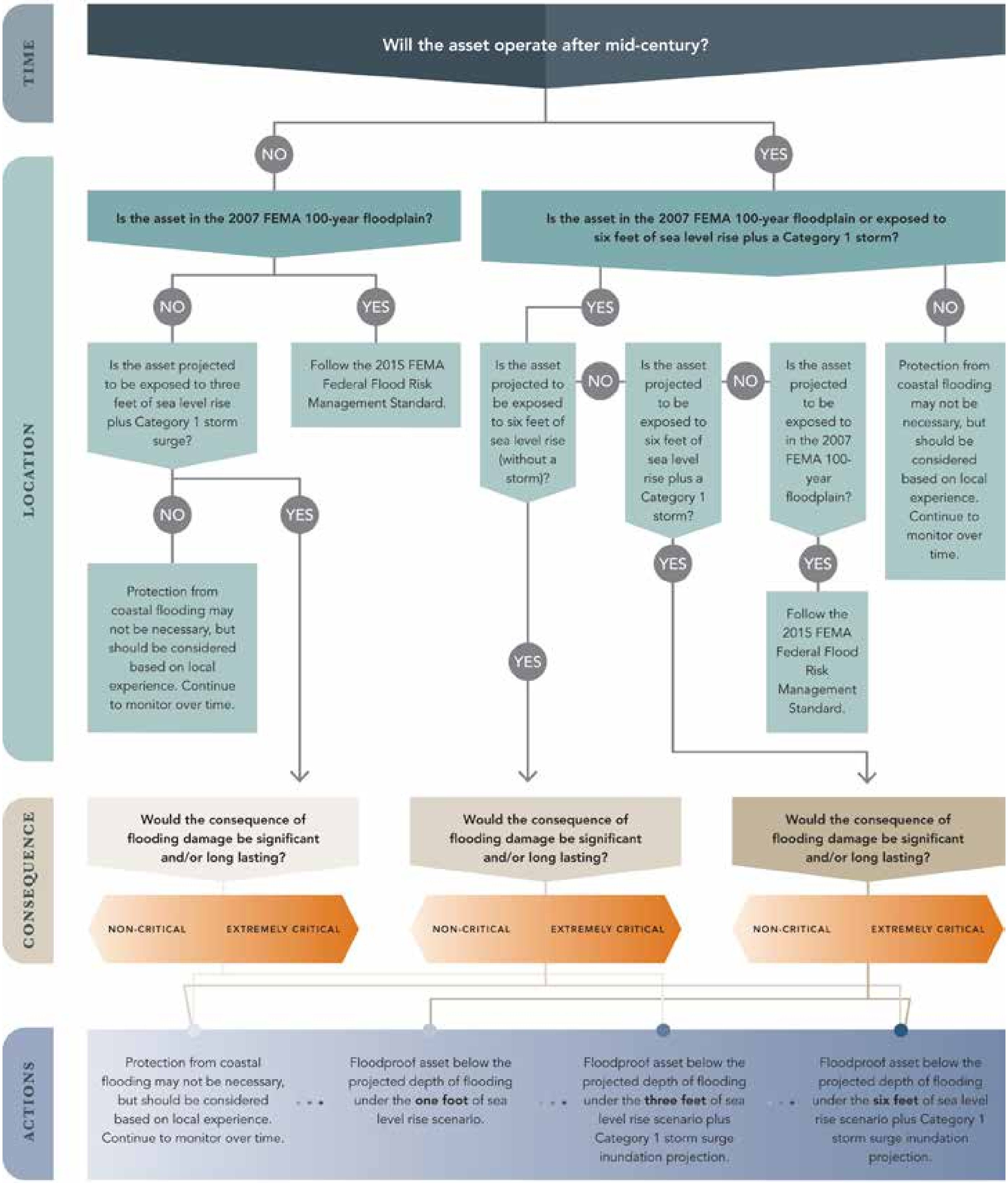
Sea level rise and flooding projections completed for this project give the City of Philadelphia the information necessary to provide local guidance on how to plan for incremental risks from sea level rise. Selecting appropriate flood risk mitigation strategies requires considering three parameters of planned investments: time, location, and consequence.

- **TIME:** Will the project or the asset be in use in 2050? In 2100? Are investment decisions and resource allocations hinging on the project enduring to mid-century or the end of the century?
- **LOCATION**: Is the project or asset located in a FEMA floodplain? Could it be exposed to sea level rise, or storm surge from a Category 1 storm on top of sea level rise?
- **CONSEQUENCE:** What are the consequences of damage to this asset? Is this a case where there is zero tolerance for failure? How easily could this project or asset be replaced or reinstated if it were temporarily out of service or unavailable? Asset managers need to establish their own definitions of criticality and decide where on the spectrum of criticality a particular investment falls.

The following decision tree, when utilized in conjunction with the maps prepared for this study, will help planners walk through these questions and determine how to improve flood resilience of their projects.

FIGURE 18

FLOOD PROTECTION PLANNING GUIDANCE



Match range of flood protection actions to consequence of failure.

- **TIME:** The intended useful lifetime of an asset significantly influences the appropriate flood risk management approach. Short-lived projects are at lower risk from sea level rise than are long-lived ones, and are more likely to be sufficiently protected by following the 2015 Federal Flood Risk Management Standard. Projects expected to endure beyond mid-century should consider planning for a wider range of potential futures.
- **LOCATION:** The extent to which an investment is located in an area projected to be inundated from sea level rise and storm surge, or located in the 2007 FEMA 100-year floodplain should inform flood risk management choices. In South Philadelphia and along the Delaware River, sea level rise and storm surge are projected to inundate an area that is broader than the FEMA floodplain. In other locations, especially along the Schuylkill River and inland on smaller tributaries, the FEMA floodplain covers a larger geographic footprint than sea level rise and storm inundation scenarios. (Maps of these scenarios are included in the Flooding section of this report starting on page 14.) Based on the best projections of sea level rise available in 2015 (see page 6-9 of the Appendix), Philadelphia should be planning for a mid-century sea level rise of between one and three feet and an end-of-century sea level rise of between one and six feet. As sea level rise and storm surge projections develop and improve, the city should update these ranges.
- **CONSEQUENCE:** The level of floodproofing needed for any given structure depends on the criticality and elevation of the structure. If an asset will be short-lived or if the consequences of failure are low, little or no floodproofing may be necessary. In cases where the tolerance for failure of an asset is zero, to mitigate the risk of flooding, asset managers should floodproof below the highest depth of flooding the asset is projected to experience over its lifetime. To do so, planners should use the sea level rise plus Category 1 storm surge depth data developed for this project (as indicated in the decision tree). Many assets will fall in between these two extremes—from short-lived and/or no consequence of failure to extremely high consequence of failure—requiring engineers and planners to balance risk tolerance and consequence with the cost of floodproofing to the indicated levels.

5

LOOKING FORWARD

The existing adaptation measures, early implementation strategies, and interdepartmental opportunities identified in *Growing Stronger: Toward a Climate-Ready Philadelphia* are important first steps toward responsibly addressing the City of Philadelphia's vulnerabilities to a warmer and wetter future. The data analyses and engagement with city staff and external partners completed for this report are already making Philadelphia stronger, but hard work and continued commitment are necessary to continue making progress. The City of Philadelphia will need to continue climate adaptation work at the municipal level, and at the same time work with residents, businesses, and infrastructure managers to develop a citywide roadmap for adapting to our changing climate. As evidenced in this report, planning for climate change poses challenges, but also provides significant opportunities to ensure Philadelphia continues growing stronger.

First Steps to Deepen the City of Philadelphia's Commitment to Climate Planning

Departments across the City of Philadelphia found that participation in climate adaptation planning over the past three years was beneficial, providing them with helpful data, identifying opportunities to share responsibilities and costs, and helping them find potential new funding sources.

Departments recognize that without a single coordinating entity empowered to gather information from a variety of departments, oversee shared actions, and provide resources and staff time for climate adaptation, none of these benefits would have been realized. Assigning responsibility for continued coordination to a department, the Climate Adaptation Working Group, or a new interagency task force will be critical to successful implementation of the strategies in this report.

Near-term priorities to deepen the city's climate preparation should include:

- Continuing to ensure that city employees are trained to use the working data resulting from the analyses completed for this report.
- Integrating climate data and planning efforts with related projects underway, including the update to Philadelphia's *Hazard Mitigation Plan*, the Citywide Flood Risk Management Task Force, and the city's exploration of participating in the National Flood Insurance Program Community Rating System.
- Expanding coordination with external partners currently engaged in the process including SEPTA, PECO, Veolia, PJM, PennDOT, and regional climate scientists, and reaching out to new partners in neighborhoods and the business community.
- Periodically revisiting climate science and updating adaptation plans accordingly.

Investing to Reduce Climate Vulnerabilities

In addition to the process changes identified above that could be implemented relatively quickly, additional investments of effort and resources will be necessary. Specific middle-term priorities the city should consider include:

- Establishing business practices and creating data systems to track information from extreme weather events. Documenting current practices and costs during weather events will allow the city to prioritize projects with the best return on investment and attract federal funding and private investments in upgrades.
- Identifying opportunistic upgrades to increase preparation for climate change. When funding routine maintenance or upgrades to facilities, the city's capital planning process should consider opportunities to make marginal investments that decrease vulnerability to flooding and reliance on the electrical grid, particularly in the city's most critical facilities.
- Acknowledging and working to quantify the benefits, such as improved quality of life, increased attractiveness to business investors, and more equitable distribution of services, that adaptation strategies provide beyond preparing Philadelphia for warmer, wetter weather.

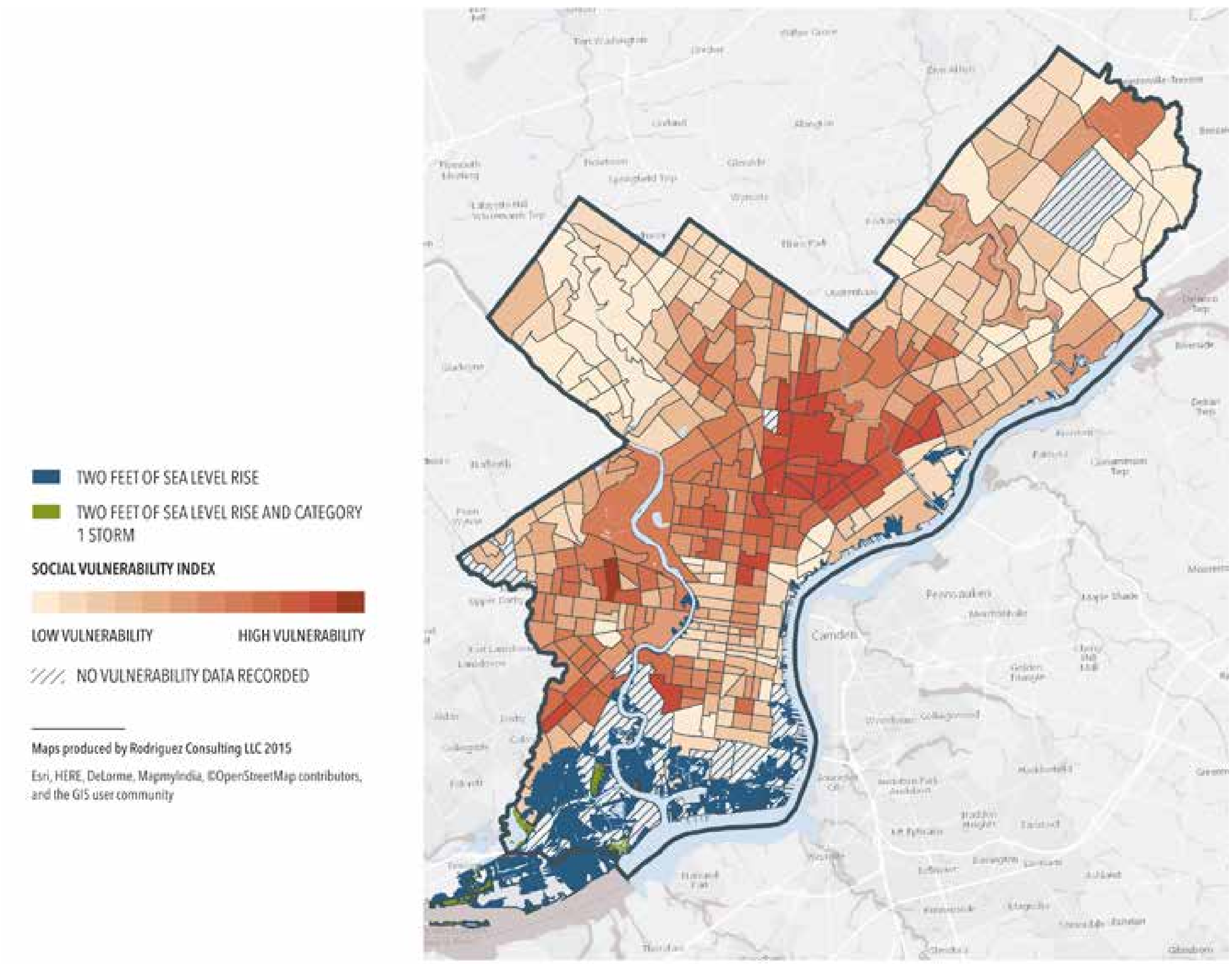
Planning for Climate Change beyond Municipal Government

Work that the city completed for this report, including downscaled regional climate projections, updated inundation modeling, and planning guidance for flood protection of new facilities, is available and can be used to improve citywide preparations for climate change immediately. Gathering this data and completing an initial analysis was a necessary first step toward answering larger, transformative questions such as how to assess and minimize risks to environmental health, neighborhoods, the economy, and quality of life.

As planning for climate change expands beyond municipal assets and services, identifying both geographic areas and concentrations of population that are particularly vulnerable to increased heat and precipitation should help focus adaptation planning efforts and investments. Data gathered during the completion of this report, including Figure 19, a map of where the Centers for Disease Control's social vulnerability index suggests sensitive populations may be exposed to flooding by 2050, can provide a helpful first screening of where to focus additional work.

FIGURE 19

SENSITIVE POPULATIONS EXPOSED TO FLOODING BY 2050



Source: Centers for Disease Control's Social Vulnerability Index

Current climate projections and the resulting vulnerabilities in Philadelphia suggest that asset-by-asset adaptation strategies will be the most effective protections against increased heat and precipitation. However, as the city continues to monitor updates to climate science, if certain areas of Philadelphia become more vulnerable, the city should consider potential projects to protect larger areas. One example of an area-wide adaptation investment is an engineered shoreline protection measure such as a berm, levee, or sea wall, which would physically stop water from entering a portion of the city, protecting multiple structures close together.

As the city begins to tackle the early implementation opportunities identified in this report, the lessons from our first three years of adaptation planning will help Philadelphia begin additional, complementary efforts at the neighborhood level and with partners who manage the critical systems such as the power grid, transportation infrastructure, and food supply, on which government, residents, and businesses all rely. Through this process, we can work together to ensure our city grows stronger even as the climate changes.

6 Appendix


Useful Climate Information for Philadelphia: Past and Future

August 2014

Submitted to:
Philadelphia Mayor's Office of Sustainability
One Parkway Building
1515 Arch Street, 13th Floor
Philadelphia, PA 19102

Submitted by:
ICF Incorporated, L.L.C.
150 S Independence Mall West, Suite 844
Philadelphia, PA 19106

Assessing Vulnerability

The assessment of Philadelphia's vulnerabilities to the impacts of climate change was built on the foundation of previous analyses to project future trends in climate and related effects (e.g., sea level rise) in the Philadelphia region.

Climate Science Information

With guidance from Philadelphia's Climate Adaptation Working Group, ICF International used a combination of current and new science to give past, current, and future projections for temperature, precipitation, drought, and sea level rise, downscaled[27] specifically for Philadelphia. These projections were compiled in a document entitled *Useful Climate Information for Philadelphia: Past and Future.*[4] To engage regional academics and researchers, the Mayor's Office of Sustainability (MOS) convened a group of 12 climate change scientists and experts from the region. The meeting, held in May 2014, focused on a draft version of the climate science document. Attendees were given the opportunity to comment on the methods and results. Specific recommendations from the participants regarding draft results and gaps in available information were evaluated, and are reflected in the final science document. The document was published online in August 2014 for the public to review and use as the current understanding of climate science in Philadelphia.

Projections for future temperature and precipitation in the report were developed using the U.S. Department of Transportation's CMIP Climate Data Processing Tool,[28] and were supplemented with other climate projections (e.g., for drought and sea level rise) from best available sources.

City Department Information

Information for the vulnerability assessment on city departments, their assets, and specific areas of concern was obtained through direct contact with departments, through two scenario-planning workshops (see below), from department websites, from asset management systems, and other sources.

DATA

MOS actively engaged departments in early 2015 to identify and collect information needed to understand and evaluate department-specific and citywide vulnerabilities. MOS worked with ICF to ensure that the analysis contained in this report would include a comprehensive picture of vulnerable assets as well as an understanding of critical services provided to residents. To achieve this comprehensive picture, qualitative information was solicited to support improved understanding of how vulnerabilities not associated with infrastructure (e.g., constraints on staff resources or fuel) may contribute to overall vulnerability.

EXCESSIVE HEAT WORKSHOP

MOS held a workshop on April 20, 2015 to discuss interdepartmental vulnerabilities related to extreme heat events in Philadelphia. MOS worked with ICF to create maps that outlined current exposures of vulnerable populations in the city. In general, heat events affect the city's population more than they do its physical assets, but the city needs to ensure that power and other services are maintained in order to keep the population safe.

The workshop explored responses to four different heat event scenarios based on historical events, described below:

Scenario I: Hot temperatures throughout the summer

During the summer of 2005, hot days averaged 91.4°F, with average warm nights of 72.2°F. Philadelphians experienced 13 days above 100°F (the normal average number of days per year over 100°F is zero) and 30 days above 95°F (the normal average number of days per year over 95°F is three).

Scenario II: Multi-day heat event

During these events, daytime temperatures surpassed 95°F, with nighttime temperatures dropping only to 70°F or warmer for several days in a row. These events were divided into events with power (Scenario IIA) and events without power (Scenario IIB).

Scenario IIA: Events without power outages

- July 6–14, 1993: 118 heat-related deaths in Philadelphia. This event led to the development of a more effective heat warning system.
- July 4–7, 2012: City employees were released during the event. Health officials expressed concern about black-roofed, brick rowhouse neighborhoods where hot nights led to cumulative heat storage within the houses.
- July 15–20, 2013: The city's Heatline experienced its highest-ever number of calls over a six-day period.

Scenario IIB: Events with power outages

- July 13–17, 1995: On July 15, PECO energy transformers overheated and the circuit overloads led to 30,000 customers losing power. (Note that PECO has since taken precautions to prevent such overloads in the future.) This heat wave was followed by three additional weeks of hot weather. From July 13–August 14, an estimated 72 people died from exposure to excessive heat.
- June 7–10, 2008: Power outages throughout the city exacerbated heat impacts and led to suspension of rail service. Twenty-six deaths were attributed to high temperatures and humidity, and the event was the most expensive Heatline activation event recorded from 2005 to 2013.

FLOODING WORKSHOP

MOS held a workshop on April 24, 2015 that focused on issues experienced across departments during a variety of previous flooding events. The purpose of the flooding workshop was to discuss responses before, during, and after the events, to identify opportunities to improve interdepartmental coordination, and to identify vulnerabilities.

Scenario I: Tropical storms and hurricanes

- *Tropical Storm Allison* (June 15–17, 2001): This storm caused widespread flooding, and President Bush issued a major disaster declaration for the state (covering damage to private property). Flooding at an apartment complex in Upper Moreland caused an explosion and fire due to damage to a gas line from floodwaters. Floodwaters required home evacuations in low-lying areas; hardest hit were Bucks and Montgomery Counties. At least seven people were killed (due to the fire and explosion); damages within Pennsylvania totaled $215 million (2001 dollars). SEPTA cancelled service for the R2 Warminster, R5 Lansdale/Doylestown, and R3 West Trenton trains; the storm washed out rail lines. About 700,000 customers in the region including Philadelphia County lost power.
- *Hurricane Irene* (August 27–28, 2011): Philadelphia experienced widespread power outages and major inland flooding. Damage costs included: $49,000 of damage to city vehicles (flooding), $124,000 of damage to streets (railings, debris collection, sanitation, roof repairs), and $330,000 of damage to parks (trail repair, debris collection). SEPTA cancelled all service on August 28. Impacts to SEPTA included downed catenaries throughout the system, downed trees potentially blocking rail routes, service disruptions from flooding and loss of signal power on the Manayunk/Norristown line, 59 train cancellations and 2.5 hours of delays for trains that did operate for the Manayunk/Norristown line. PECO reported that 139,000 area residents lost power due to downed power lines.

Scenario II: Heavy rain

Heavy rain event (April 30–May 1, 2014): This event caused extensive flooding through the early afternoon, and a flash flood warning was in effect. SEPTA cancelled service on the night of April 30 and the morning of May 1 due to high river levels and partially submerged tracks. Major roads were closed due to flooding, including sections of MLK Drive, Kelly Drive, and Lincoln Drive.

Vulnerability Assessment Methodology

The sections below describe how the vulnerability assessment was conducted.

EXPOSURE DATA

This section presents quantitative projections of climate variables, including heating degree-days, cooling degree-days, temperature metrics, and precipitation metrics, that were used in the vulnerability assessment. It also presents a qualitative analysis based on a targeted literature review, which shows the suggested direction of change for snow, heavy winds, and drought. For more detail describing the climate models, scenarios, and methodology, see the *Useful Climate Information for Philadelphia: Past and Future* report.

Temperature Metrics

The findings from the CMIP processing tool, as presented in Table B.2.1 in *Useful Climate Information for Philadelphia: Past and Future*, were used to inform the projections of select temperature metrics useful to the vulnerability assessment. Projections of each metric for each scenario and future time period were developed using a two-step approach: (1) calculating the difference between the projected and baseline climate model ensemble; and (2) summing the projected difference with the observed baseline.

By mid-century, Philadelphia is projected to experience a notable increase in the frequency, intensity, and duration of hot days and reduction in days below freezing. The number of hot days continues to increase by the end of the century. For the end-of-century projections, there is a large range in the number of hot days projected across scenarios, with more than a doubling in hot days from the lower scenarios to higher scenarios.

Precipitation Metrics

The findings presented in Table B.2.1 in *Useful Climate Information for Philadelphia: Past and Future* were used to provide projected changes for a handful of precipitation metrics for use in the vulnerability assessment. The precipitation projections were developed using the same methodology as that for the temperature projections.

By mid-century, the number of heavy precipitation events is projected to increase along with increases in seasonal precipitation. The greatest increase in seasonal precipitation is projected for the winter months. It is not clear whether this precipitation will continue to fall as snow or shift to an increase in rainfall (see qualitative analysis on snow in the following section).

The end-of-century precipitation projections that informed the vulnerability assessment suggest an increase in seasonal precipitation amounts particularly for winter and spring, but do not suggest a notable overall change from mid-century projections for the other precipitation metrics.

Qualitative Analysis

In addition to temperature and precipitation, additional climate-related variables were considered qualitatively for this assessment, including snow, high wind, and drought. The analysis for each variable draws from available literature and from the *Useful Climate Information for Philadelphia: Past and Future* report. As noted in the discussion below, robustly quantifying the projected change in these variables is an area of active research.

The findings suggest the following trends:

VARIABLE	FUTURE CHANGE
Snow	Increase in winter precipitation events but a shift from snow to rainfall
High Wind	Increase in the frequency and intensity of storms that may create high wind conditions (though a lot of uncertainty)
Drought	Greater potential of short-term drought during summer months

Snow

The literature is consistent with ICF's findings from the U.S. Department of Transportation's CMIP Climate Data Processing Tool: winter precipitation for Philadelphia is projected to increase in mid-century and end-of-century. However, this increase does not necessarily equate to more snow. There may be an increase in winter precipitation, and more of this precipitation will occur as rain.[29,30] In theory, this could be create problems during cold winter months if the ground continues to be frozen, leading to runoff and ponding conditions.

High Wind

A number of atmospheric phenomena can create high wind conditions, including tropical cyclones (e.g., hurricanes, tropical storms), thunderstorms, and frontal activity (e.g., cold fronts and warm fronts). Projecting how storm events responsible for heavy winds may change is complicated by the need to understand how changes in climate may affect shifts in the jet stream, which can affect storm tracks, wind shear, and vertical temperature gradients.

- **TROPICAL CYCLONES:** The general scientific consensus suggests tropical storms may decline in number globally in the decades ahead, but there may be an increase in the number of Category 3, 4, and 5 storms. There is some suggestion that the greatest increase in major hurricanes could occur over the western Atlantic basin in response to warmer sea surface temperatures and reductions in vertical wind shear.[31]
- **THUNDERSTORMS:** A recent study considered how climate change may affect two ingredients necessary for severe thunderstorm activity: convective available potential energy (CAPE) and wind shear. There is some evidence that severe thunderstorms may increase for the United States in response to increases in CAPE, but tornadoes and hail may be reduced under projected decreased wind shear conditions.[32] Overall, this is an active area of research, and findings should be treated with caution.[30]
- **FRONTAL ACTIVITY:** Since 1950, winter storms have tended toward an increase in intensity and frequency, with a poleward shift in the storm track.[30] A recent study suggests that the jet stream will have more frequent "wavy" patterns as the Arctic warms at a faster rate than the United States (and other mid-latitude locations), causing a higher frequency of extreme weather events such as cold snowy weather in the eastern United States.[33]

Keeping in mind the challenges and uncertainties underlying these findings, the overall conclusion is that Philadelphia may experience more frequent and potentially more severe storms accompanied by high winds in the decades ahead.

Drought

The scientific community uses a variety of definitions to explain what is meant by the word "drought." For example, drought can be defined as dry weather patterns that persist in a given area or as a period of low water supply in response to prolonged periods of dry weather.[34] For purposes of this analysis, short-term drought is considered to last one to three months and medium-term drought is considered to last three to six months.

Philadelphia is affected both by droughts within the city boundaries and by droughts affecting the Pocono and Catskill Mountains. These mountains represent the headwaters of the Delaware River watershed. Philadelphia Water's water intake along the lower Delaware River provides drinking water to nearly one million people, including 60 percent of Philadelphia's residents. Droughts in the mountains may affect the quality of water at the lower Delaware River, increasing its salinity. Philadelphia Water has been exploring climate change risks, including salt line[35] movement and water quality changes that that may occur in the Delaware River as a result of the combined impact of potential droughts and projected sea level rise.

Past and Present Conditions. Eastern Pennsylvania is affected by short-term droughts about once every two years, but is rarely affected by medium-term drought.[36] The longest drought on record occurred from 1962 to 1965, during an extended period of low precipitation.[36] This drought was so significant that Philadelphia Water uses this period as a benchmark for preventing the intrusion of salinity in the water supply system.

Future Conditions. Drought projections for the state of Pennsylvania are inconclusive:

- One study suggests that droughts may increase in frequency in late spring and early fall as a result of decreases in snow cover, increases in extended dry periods, little or only slight changes in summer rainfall, and greater evapotranspiration (the combination of evaporation and plant transpiration).[36]
- Another study suggests little or no change in short-term drought frequency in the southeast portion of the state, but an increase in short-term drought in the Pocono Mountains.[37]
- Finally, the United States Global Change Research Program[38] suggests under a high emission scenario that short-term droughts could occur every summer in the Catskills Mountains, potentially affecting water quality in the Delaware River.

Soil moisture can be an indicator of potential drought conditions. Using the U.S. Geological Survey's National Climate Change Viewer under a higher emissions scenario, Philadelphia County is projected to experience a notable reduction in soil moisture from May through November, with the reductions increasing with future time.[39] The projections do not suggest change in soil moisture compared with current conditions from December through April. It is not clear how these reductions will translate to short-term drought conditions.

Focusing on the month of August, soil moisture has decreased since 1950 and is projected to continue to decrease. By mid-century, August soil moisture is projected to decrease by about one inch (a roughly 30 percent decrease). By end-of-century, soil moisture could decrease between about 0.8 and 1.5 inches.

Vulnerability to Heat

Philadelphia's primary vulnerability to extreme heat is the risk to human health. Heat affects infrastructure as well—for example, extreme heat can cause pavement buckling, materials degradation, and decreased efficiency of electrical equipment—but human health impacts are likely to be more severe.

Extreme heat is most likely to have adverse health impacts on already vulnerable populations, including children, the elderly, the sick, and the poor. For example, extreme heat can lead to increased formation of ground-level ozone, which in turn can exacerbate asthma. Factors (several of which are interrelated) that can indicate vulnerability to extreme heat include:

- **AGE:** Children and the elderly are the most physiologically vulnerable to heat-related illness.
- **INCOME:** People living in poverty are less likely to be able to afford in-home air conditioning, and may have more difficulty getting to cooling shelters during a heat wave.
- **ACCESS TO AIR CONDITIONING:** People without in-home air conditioning are more vulnerable to heat-related illness.
- **ACCESS TO TRANSPORTATION:** People who are reliant on public transportation may be less likely to access cooling shelters unless they are within short walking distance.
- **HOUSING TYPE:** People without air conditioning who live on the upper floors of flat-roofed apartments, in ground-level floors in high crime neighborhoods, or in apartments with windows that do not open may be less able to cool their homes and thus more susceptible to heat-related illness.

MOS and ICF undertook a mapping exercise to identify places and populations in the city that may be most vulnerable to extreme heat events. Using available data and the aforementioned heat vulnerability indicators, the city mapped locations that are not within easy access to a cooling center and have high concentrations of young, elderly, or poor populations.

MOS and ICF identified locations that are:

- More than ¼ mile, ½ mile, or one mile from a cooling center; *and*
- Have greater than 10, 15, 20, 25, 33, or 50 percent of the population above 65, less than age five, or below the poverty line.

Data on cooling center locations were obtained from the Office of Emergency Management; population data came from the U.S. Census Bureau.

The city can review the vulnerable locations under all permutations of the thresholds (e.g., ¼ mile from a cooling center and 10 percent vulnerable populations vs. ½ mile from a cooling center and 25 percent vulnerable populations) to identify "hot spots" where heat-related vulnerabilities exist, and to target for adaptation strategies. One of these permutations is presented in Figure 12.

Vulnerability to Flooding

SCENARIOS

For this report, ICF assessed the exposure and subsequent vulnerabilities of infrastructure in Philadelphia to the flooding scenarios shown in Table 12.

TABLE 12

FLOODING SCENARIOS USED IN THE VULNERABILITY ASSESSMENT

FLOODING TYPE	SCENARIOS SELECTED	SCENARIOS SELECTED
Sea Level Rise (SLR)	2050: SLR 2 ft 2100: SLR 4 ft	National Oceanic and Atmospheric Administration Digital Coast
Tropical Cyclone/Storm Surge	2 ft SLR + Category 1 4 ft SLR + Category 1	U.S. Department of Energy Modeling[17]
Riverine Flooding	FEMA 500-yr flood zone	Federal Emergency Management Agency (2007)

The sea level rise scenarios were chosen based on a synthesis of sea level rise projections from the U.S. Department of Energy (DOE)[17] and the Climate & Urban Systems Partnership (CUSP).[40] Table 13 shows the DOE and CUSP projections for Philadelphia for mid-century and end-of-century. The project team took a conservative approach and selected the more conservative projections for the moderate-high scenario from each set of projections (see the highlighted box in Table 13).

TABLE 13

SEA LEVEL RISE PROJECTIONS FOR PHILADELPHIA

SOURCE	TIMELINE	SCENARIO			
		Low (10th%)	Mid (25th%)	Mid (75th%)	High (90th%)
CUSP	MID-CENTURY	< 1 ft (7-8”)	< 1 ft (10”)	2 ft (20”)	3 ft (30”)
	END-OF-CENTURY	1 ft (12”)	1-2 ft (18”)	3 ft (36”)	4-5 ft (55”)
		NCA Low	NCA Intermed-Low	NCA Intermed-High	NCA High
DOE	MID-CENTURY	< 1 ft	1 ft (2069)	1 ft (2045), 2 ft (2067)	<2 ft (2051)
	END-OF-CENTURY	< 1 ft	2 ft (2109)	4 ft (2100)	6 ft (2095)

Storm surge scenarios were then selected to represent the types of tropical storms that are most likely to affect the Philadelphia area, combined with the selected sea level rise projections.

The only data available to evaluate exposure to riverine flooding were the 2007 FEMA 100- and 500-year floodplains. These floodplains are based on historical precipitation extremes, and do not incorporate potential changes in the frequency or severity of heavy precipitation associated with climate change.

ASSETS

The flooding vulnerability analysis covered all 2,698 city-owned facilities. In addition, the analysis covered the exposure of officially designated evacuation routes, stormwater outfalls, roadways, severe weather shelters, hazardous waste sites, hospitals, and homeless shelters.

METHODOLOGY FOR ASSESSING THE FLOODING VULNERABILITY

Vulnerability to flooding of all city-owned facilities was evaluated by determining whether the facility is exposed to flooding under each scenario, and determining the likely sensitivity[41] and adaptive capacity[42] of each facility based on its type.

For all 87 types of city-owned facilities (fire stations, fuel pumps, maintenance buildings, piers, sheds, libraries, baseball fields, etc.), the ICF team determined a preliminary rating of the sensitivity and adaptive capacity of that asset type to flooding as Low, Moderate, or High (see examples in Table 15). These ratings were based on expert judgment and information gleaned during workshops and department interviews.

Vulnerability ratings for each asset type were then defined based on the sensitivity and adaptive capacity ratings. For example, an asset with low sensitivity and high adaptive capacity has low vulnerability (see Table 14). Each of the 2,698 facilities was then assigned a vulnerability rating of Not Exposed, Low, Moderate, or High, based on whether it was exposed and its facility type.

TABLE 14

VULNERABILITY RATINGS ASSIGNED BASED ON SENSITIVITY AND ADAPTIVE CAPACITY

SENSITIVITY		ADAPTIVE CAPACITY		VULNERABILITY
Low	+	High	=	Low
Low	+	Moderate	=	Low
Low	+	Low	=	Moderate
Moderate	+	High	=	Low
Moderate	+	Moderate	=	Moderate
Moderate	+	Low	=	High
High	+	High	=	Moderate
High	+	Moderate	=	High
High	+	Low	=	High

TABLE 15

EXAMPLE FLOODING SENSITIVITY AND ADAPTIVE CAPACITY RATINGS FOR CITY-OWNED FACILITIES

FACILITY TYPE	SENSITIVITY RATING	SENSITIVITY RATIONALE	ADAPTIVE CAPACITY RATING	ADAPTIVE CAPACITY RATIONALE	VULNERABILITY RATING (IF EXPOSED)
FIRE STATION	High	Floodwaters could damage equipment or prevent firefighters from responding to fires.	Low	Fire stations provide a critical service to the city, and cannot be out of service because of flooding.	**High**
PARKING LOT	High	Floodwaters can render parking lots unusable or damage vehicles parked there.	High	With sufficient warning, vehicle owners can move their vehicles from flood-prone parking lots. When floodwaters recede, the parking lot is usable.	**Moderate**
BASEBALL FIELD	Moderate	Floodwaters can render a baseball field temporarily unusable.	High	Baseball fields are unlikely to be in use during an event that might render it flooded.	**Low**

Evaluating Costs

This section describes the methodology for evaluating the costs of climate change to Philadelphia.

Projecting Costs of Inaction

The costs that Philadelphia will experience as a result of climate change were estimated in very rough terms, using several sources of data. As described below, estimates were developed combining data generated by the climate projections and the vulnerability assessment with published studies of climate effects, or with historical data on the effects of extreme weather events in Philadelphia in the past (since they provide evidence of the types of costs that may be borne in the future). Additional estimates were developed using published studies for larger geographic areas that estimated the costs of climate change.

The diverse costs of inaction can be categorized into the following components:

- The direct costs of actions that are taken reactively by the city to respond to extreme weather and other impacts of climate change.
- The cost of actions that households and business take in response to changes in climate.
- Residual damages or lost services (often referred to as indirect costs).
- Health effects.
- Other social damages and declines in quality of life.

Information is available to project or estimate costs for only a small subset of the possible costs of inaction. Many assumptions were made in order to generate these costs, and rules of thumb were in some cases developed using data for other geographic regions and a variety of studies using different climate scenarios. Hence, the cost estimates should not be viewed as definitive estimates, but rather indicative of the order of magnitude of potential costs.

HEATLINE OPERATIONS

The city activates a heat hotline, or Heatline, on days when the Health Commissioner for Philadelphia calls a heat emergency for the city. Between 2001 and 2013, the Heatline operated an average of nine days per year. Due to climate change, the number of days when the Heatline operates is projected to increase to between 13 and 23 days in 2050 and to as many as 52 days in 2100. Using conservative assumptions about the increase in the annual number of activation days, the incremental costs (relative to the current climate) of operating the Heatline, including staffing and emergency response, were estimated.

The city provided data on the costs of operating the Heatline and the number of days it was in operation for years between 2001 and 2013. These data were supplemented by data on the cost of an hour of a nurse's time and the cost of an ambulance visit, obtained online, to produce an average cost per day of operation of about $2,220 (in 2010 dollars).

The number of days of operation for 2050 and 2100 were simulated assuming that the Heatline would operate each day the temperature rose above 95°F; this was chosen as a proxy for the Health Commissioner calling a heat emergency, and is probably conservative. The observed historical average of nine days was subtracted from the projected number of days to determine the incremental number of days and the incremental costs (the lower bound estimate). A more aggressive estimate was constructed by estimating the incremental number of days over baseline in the climate scenarios (three days).

POLLUTION AND ASTHMA

Higher levels of ozone resulting from climate change will increase the incidence and costs associated with a variety of diseases, including asthma, cardiovascular disease, COPD, and other respiratory diseases. The American Lung Association estimates that about 152,000 adults and children have asthma in a given year in Philadelphia. The total direct and indirect costs of asthma are estimated to be about $2,600 per person. Together, these figures suggest that the current costs of asthma for Philadelphia exceed $400 million annually. These are costs associated specifically with asthma, and not with other health conditions that the individuals may have.

One study of the relationship between asthma and climate change[43] finds that, by 2050, the number of summer days exceeding the eight-hour regulatory limit for ozone will grow by 68 percent on average across 50 cities studied, including Philadelphia. This is similar to the results of Kahrl and Roland-Holst,[44] which project the number of days with conditions conducive to ozone formation to increase by 25-80 percent by 2100. Note that some studies have found much higher levels of ozone associated with climate change. For example, *Climate Change Impacts and Solutions for Pennsylvania*[45] discusses the effects of climate change at the state level for Pennsylvania: "In the Philadelphia metropolitan area, the number of days failing to meet the federal ozone standard is expected to at least quadruple under the higher-emissions scenario."

Bell, Goldberg et al.[43] estimates that higher levels of ozone will increase the rate of hospitalization by 2.1 percent, on average across 50 cities studied, in the year 2050. It is assumed that this increased rate of hospitalization is associated with an equivalent increase in the direct and indirect costs of asthma. Increased levels of ozone are also likely to be associated with increases in hospitalization for respiratory disease and COPD in older adults. It was assumed that collectively these costs are equal in magnitude to the asthma incremental costs.

These costs do not include any morbidity or mortality associated with heat stress, increases in levels of fine particulate matter, or other health effects associated with climate change. Note that Bell, Goldberg et al.[43] estimated that elevated ozone levels correspond to approximately a 0.11 to 0.27 percent increase in daily total mortality due to asthma, and additional mortality due to cardiovascular and respiratory disease.

SEPTA

SEPTA has estimated the savings in operational and other costs/damages that could be obtained if actions to make SEPTA systems more climate resilient are undertaken. These costs can be viewed as costs of inaction: they are costs that will occur if adaptation measures are not undertaken. The costs reported here are associated with six specific improvements that could be made to the system, including stabilization of slopes, monitoring, modernization of systems, and other changes. The types of damages that could be avoided by undertaking these measures include operational savings (e.g., repair and maintenance), reduced damage to railcars and other property from flooding, and reduced delays and closings, as well as avoided health effects. Costs are reported both in present value terms (discounted at seven percent for the lifetime of the project) and annually, i.e., for each year of the project, over the duration of the project. Project lifetimes range from 14 to 100 years. Not all costs would be incurred in every year.

ELECTRICITY CONSUMPTION BY CITY DEPARTMENT

The exposure analysis estimated monthly heating degree days (HDD) and cooling degree days (CDD) from 1994 to 2011, and then calculated future projections based on a 65°F day.[4] According to the climate scenarios developed for this vulnerability assessment, average annual CDDs will increase significantly by 2050 (between 46 and 71 percent), and by between 58 and 122 percent by 2100.

Jaglom et al.,[46] a study of the impacts of climate change on the power sector, provides data on the relationship among electricity consumption, CDD, and HDD. Using unpublished data from that study (provided by the authors), these relationships were calculated and applied to the projections for Philadelphia. The data were used to estimate the proportion of electricity consumption used for heating and cooling combined (temperature-sensitive consumption), which was assumed to be the same as the proportion across all users, and the split between heating and cooling consumption (which was assumed to be the same as for commercial users). Next, data were used to derive a linear relationship for the percent change in electricity consumed for cooling for each percent change in average annual cooling degree-days, and the percent change in electricity consumed for heating for each percent change in average annual heating degree-days. The linear relationship was applied to the climate scenarios developed for this study, and combined with data on total electricity consumption by the city, averaged over selected years.

By the year 2050, expenditures on heating and cooling combined could rise by between 75 and 120 percent of expenditures on heating and cooling in recent years, and even more by 2100—in some scenarios rising by more than 200 percent, or triple today's levels. The study does not estimate the declines in heating costs using natural gas or other heating sources. Note that the study from which the relationship between degree-days and electricity consumption was derived uses different climate scenarios than were used in Philadelphia's vulnerability assessment.

ROADWAYS

Paved roads are subject to a number of climatic impacts. A recent study[47] investigated the cost of adapting paved roads to three specific effects: rutting of paved roads from precipitation, rutting of paved roads caused by freeze-thaw cycles, and cracking of paved roads during periods of high temperatures. The study provided estimates of the total discounted and undiscounted costs (divided between paved and unpaved roads) of responding to climatic effects for several years (2025, 2050, and 2075). The study also provides undiscounted costs for all roads together. The discounted costs allowed the costs to be scaled and the split between paved and unpaved roads determined.

The study also provided the total number of lane-miles in paved roads, nationally, which can be used to estimate per-lane-mile costs for 2025, 2050, and 2075. The number of lane-miles for Philadelphia was estimated by making assumptions about the number of lanes in each category of road (total miles for each road type were provided by the City of Philadelphia). Total costs are the product of per-mile costs and total lane-miles estimated for Philadelphia.

OTHER IMPACTS

The City of Philadelphia has also projected some costs of climate change, as part of its May 2012 Natural Hazard Mitigation Plan. The city prepared estimates of direct economic losses due to a 100-year flood event using HAZUS and data supplied by Philadelphia. Data on the costs and other impacts of past extreme events were also investigated for the Natural Hazard Mitigation Plan.

Identifying Strategies To Reduce Vulnerability

Methodology for Developing Adaptation Strategies

After the completion of the vulnerability assessment, ICF used a four-step approach to develop adaptation strategies for the City of Philadelphia:

1. Compile existing department practices that help prepare them for a changing climate and recommend modifications (based on steps 2-4) to increase their effectiveness.
2. Review and consolidate adaptation recommendations that emerged during the two scenario planning workshops (on heat events and flooding) and interviews with departments. These sources provided insight on each department's top priorities and generally included strategies that would help to reduce risks now as well as into the future.
3. Review and gather relevant adaptation strategies from other cities and other relevant resources. Other studies and efforts provided access to information from a wide range of technical experts and ideas.
4. Use ICF professional experience to develop strategies to specifically address identified vulnerabilities. ICF staff reviewed identified vulnerabilities that had not yet been addressed through the first two adaptation strategy collection efforts. For these vulnerabilities, ICF drew upon internal technical experts to develop appropriate adaptation strategies.

The documents from other cities and research groups included:

- Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use (Georgetown Climate Center)
- Adapting to Rising Tides (San Francisco Bay Area, CA)
- Adapting to Urban Heat: A Tool Kit for Local Governments (Georgetown Climate Center)
- Baltimore Disaster Preparedness and Planning Project
- City and County of Denver Climate Adaptation Plan
- City of Benicia Climate Change Vulnerability and Adaptation Plan
- Climate Change Preparation Strategy: Preparing for Local Impacts in Portland and Multomah County
- Climate Change Vulnerability Assessment and Adaptation Plan (City of Portsmouth, NH)
- Climate Ready Boston: Municipal Vulnerability to Climate Change
- King County Strategic Climate Action Plan (Oregon)
- NYC Wastewater Resiliency Plan
- One New York: The Plan for a Strong and Just City
- plaNYC: A Stronger, More Resilient New York
- Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts
- Ready for Tomorrow: The City of Salem Climate Change Vulnerability Assessment & Adaptation Plan
- Safeguarding California: Reducing Climate Risk (An update to the 2009 California Climate Adaptation Strategy)
- Sea Level Rise Adaptation Strategy for San Diego Bay

Methodology for Classifying Adaptation Strategies

The strategies were sorted and classified in a number of ways in order to assist departments in selecting strategies to advance. The classification fields include:

- Lead City Department.
- Supporting Department(s).
- Climate Change Hazard (e.g., flooding, heat).
- Type of Impact (e.g., human health/mortality, general flood impacts).
- Source.
- Type of Strategy (defined below).
- Active Timeframe (defined below).

The types of strategies gathered and developed for Philadelphia were classified in the following manner:

- **PLANNING:** Strategies related to planning emergency response efforts and long-term planning efforts.
- **OPERATIONS:** Strategies that recommend changes to city department standard operations before, during, and after extreme weather events.
- **POLICY:** Strategies that recommend a change to city policies or the development of new policies.
- **OUTREACH:** Strategies that recommend additional or modified outreach to the public.
- **INFRASTRUCTURE:** Strategies that recommend physical construction in order to protect assets from climate change hazards.
- **INFORMATION SYSTEMS:** Strategies that recommend additional information-gathering technology or protocols in order to better respond to changing climatic conditions, inform the development of additional adaptation strategies, or build a case for additional investment.
- **MONITORING:** Strategies that recommend monitoring conditions to inform when to implement additional adaptation strategies.

The "active timeframe" criterion refers to the timeframe during which an adaptation strategy would be implemented. Throughout the United States, most resilience strategies have been implemented in response to a disaster rather than proactively implemented before a disaster occurs. Figure 20 demonstrates the time periods during which adaptation strategies can be implemented.

FIGURE 20

DIAGRAM OF THE PREPAREDNESS, DISASTER, AND RECOVERY PROCESS

In its matrix of adaptation strategies, ICF broadly grouped strategies into the following time periods:

- **PRE-EVENT:** Policy, structural changes, and pre-event coordination that need to be implemented before an event in order to be effective.
- **DURING:** Operational response strategies.
- **POST-EVENT:** Repair, rebuilding, and data tracking strategies.

Methodology for Evaluating and Selecting Adaptation Strategies

After reviewing best practices and consulting with ICF and the Climate Adaptation Working Group, MOS selected the following criteria to qualitatively evaluate potential actions that the city can take to help it continue to provide effective services and maintain infrastructure as the climate changes:

CAPITAL COSTS

Implementation of adaptation strategies will require up-front capital investment; the relative impact of capital costs on a department's ability to implement a strategy may depend on the total budget of the department (i.e., $50,000 to one department may mean something different than $50,000 to another department).

- **HIGH:** Moderate-to-large construction projections.
- **MEDIUM:** May include policy revisions and plan updates or minor construction.
- **LOW:** Free or staff time only. Generally less than $10,000 to implement.

RECURRING COSTS

Costs incurred periodically over the lifetime of the strategy. Like capital costs, the relative amount will depend on the total budget of the department.

- **HIGH:** Significant operations and maintenance (O&M) cost increases due to complex mechanical systems or high infrastructure upkeep costs.
- **MEDIUM:** Moderate increases in O&M costs or strong behavior change programs (e.g., outreach, education).
- **LOW:** No-to-very-low ongoing costs to the city due to minor O&M changes or light behavior change programs.

FLEXIBILITY

Refers to the city's ability to make course corrections if a particular strategy is adopted. Such corrections are an essential part of adaptive management.

- **HIGH:** Can easily make corrections to the strategy after adoption. For example, a change in a software program, or a strategy that requires coordination between departments.
- **MEDIUM:** Can make corrections, but it takes time to get everyone up to speed on the new policy measure, etc. For example, a procedure for collecting data or a physical structure that is designed to adjust to changes in the environment (e.g., a flood gate).
- **LOW:** Cannot easily make corrections to the strategy. This may include capital spending (e.g., purchase of new equipment), changing of laws, changing land use, etc.

CO-BENEFITS

Refers to other benefits that would result from implementation of the strategy. In some cases, these co-benefits can offset much of the cost of the adaptation. Examples of co-benefits include economic development (or preserving an important economic hub), preserving or expanding green space and recreational areas, protecting peoples of concern, reducing emissions, increasing tourism.

- **HIGH:** Several significant co-benefits exist that would either offset the cost (i.e., long-term cost savings) and/or would further justify the implementation of this action.
- **MEDIUM:** Some co-benefits exist.
- **LOW:** Few if any co-benefits would exist to implementing this strategy. May include negative externalities.

OTHER BARRIERS NOT CAPTURED IN OTHER EVALUATION CRITERIA

Refers to hurdles or blockades that may make it more difficult to implement the strategy. These barriers may be political, legal, or physical in nature.

- **HIGH:** Several barriers exist, such as legal, policy, political barriers that would make it difficult to implement this strategy.
- **MEDIUM:** Many barriers may exist, but they are barriers that can be broken down with effort from department leaders.
- **LOW:** Few barriers exist, and any that do can be overcome with little time, effort, and money.

COMPOSITE FEASIBILITY SCORE

The above criteria were averaged, with weighting applied equally, to obtain an overall feasibility score. Feasibility refers to the ease with which a particular strategy could be implemented by a department under today's conditions.

- **HIGH:** A high feasibility for implementation. Feasibility may be high because the strategy is already a part of a department's plan, is relatively inexpensive, or has extensive co-benefits.
- **MEDIUM:** The strategy is practical to implement, but outside factors may hinder implementation (e.g., it requires complex coordination or modeling).
- **LOW:** A low feasibility for implementation means the strategy is unlikely to be implemented due to outside circumstances such as political barriers.

Separately from the other measures, MOS evaluated the efficacy of each strategy. Efficacy refers to the extent to which the strategy, if successfully implemented, would reduce the climate change risk.

- **HIGH:** There is little doubt that the strategy will directly reduce the risk of extreme weather to a department or the public.
- **MEDIUM:** The strategy may only reduce the risk in some extreme weather circumstances but not all.
- **LOW:** On its own, the action will more than likely not reduce the risk of extreme weather, or it will only reduce risk by a small amount. These strategies are more beneficial when implemented as part of a suite of strategies.

The evaluation criteria were then used to provide a recommended implementation time period. The implementation periods were defined as follows:

- **NEAR TERM:** Strategies with high feasibility and medium-to-high efficacy. These strategies can colloquially be referred to as the "low-hanging fruit" strategies; they are strategies that departments can and should look to implement in the near term.
- **MEDIUM TERM:** Strategies with medium feasibility and medium-to-high efficacy.
- **LONG TERM:** Strategies with low feasibility but medium-to-high efficacy. Due to the low feasibility, it may be necessary to begin planning for these strategies far in advance of actual implementation.
- **UNLOCKING STRATEGY:** These strategies have low efficacy. A low efficacy score simply means that, on its own, the strategy will not reduce risk; however, low-efficacy strategies can frequently serve as "unlocking strategies" that help city departments increase coordination and/or justify further investment in resilience.

The results of this evaluation process were used to inform the selection of adaptation strategies for inclusion in the body of this report. The individual departments made final selection of the adaptation strategies based on their priorities and current capabilities. It is only through continued conversation with the department staff, elected officials, and the public that some of these actions can be recommended for implementation.

7 Endnotes

[1] NOAA National Climatic Data Center. 2015. *State of the Climate: Global Analysis for Annual 2014*. Retrieved May 27, 2015 from http://www.ncdc.noaa.gov/sotc/global/201413.

[2] NOAA. 2015. *Climate at a Glance*. National Centers for Environmental Information. Retrieved July 28, 2015 from http://www.ncdc.noaa.gov/cag/time-series/us.

[3] Pennsylvania State Climatologist. 2015. *Daily Temperature Means and Extremes*. Retrieved June 8, 2015 from http://www.climate.psu.edu/data/city_information/index.php?city=phl&page=mae&type=big7.

[4] ICF International. 2014. *Useful Climate Information for Philadelphia: Past and Future*. Philadelphia, PA: ICF International. http://www.phila.gov/green/pdfs/UsefulClimateScience.pdf.

[5] ICF International, founded in 1969 as the Inner City Fund, has supported federal, state, and local agencies (as well as commercial and international clients) on climate, clean energy, and risk issues for more than 30 years.

[6] Horton, R., C. Little, V. Gornitz, D. Bader, and M. Oppenheimer. 2015. New York City Panel on Climate Change 2015 Report: Sea level rise and coastal storms. *Annals of the New York Academy of Sciences* 1336:36-44.

[7] Gamble, J.L., B.J. Hurley, P.A. Schultz, W.S. Jaglom, N. Krishnan, and M. Harris. 2013. Climate change and older Americans: state of the science. *Environ Health Perspect* 121 (1):15-22.

[8] City of Philadelphia. 2012. *Natural Hazard Mitigation Plan*. Philadelphia, PA: Office of Emergency Management.

[9] Lawrence County. 2015. *Lawrence County 2010 Hazard Mitigation Plan*. Retrieved July 13, 2015 from http://co.lawrence.pa.us/wp-content/uploads/2014/09/Lawrence-County-2010-Hazard-Mitigation-Plan.pdf.

[10] Centers for Disease Control and Prevention. 2013. Heat-related deaths after an extreme heat event--four states, 2012, and United States, 1999-2009. *Morbidity and Mortality Weekly Report* 62 (22):433-436.

[11] Hondula, D.M., R.E. Davis, M.J. Leisten, M.V. Saha, L.M. Veazey, and C.R. Wegner. 2012. Fine-scale spatial variability of heat-related mortality in Philadelphia County, USA, from 1983-2008: A case-series analysis. *Environ Health* 11:16.

[12] U.S. Census. 2015. *State and County QuickFacts: Philadelphia County*. Retrieved June 26, 2015 from http://quickfacts.census.gov/qfd/states/42/42101.html.

[13] U.S. Environmental Protection Agency. 2013. *America's Children and the Environment: Third Edition*. Washington, DC: U.S. EPA, Office of Policy, Office of Children's Health Protection. http://epa.gov/ace/pdfs/Environments-Contaminants-Climate-Change.pdf.

[14] Public Health Management Corporation. 2015. *CHDB Report: The State of Our Children's Health*. Retrieved June 22, 2015 from http://www.phmc.org/site/publications/directions-archive/directions-spring-2011/587-chdb-report-the-state-of-our-childrens-health.

[15] U.S. Environmental Protection Agency. 2008. Urban Heat Island Basics. In *Reducing Heat Islands: Compendium of Strategies*: U.S. EPA, Office of Air and Radiation, Climate Protection Partnership Division.

[16] NOAA. 2015. *Digital Coast*. Retrieved July 24, 2015 from http://coast.noaa.gov/digitalcoast/.

[17] Storm Surge/Sea Level Rise Information courtesy of Energy Infrastructure Modeling and Analysis, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy. Original data produced by NOAA with analysis by ICF.

[18] FEMA. 2015. *Flood Map Service Center*. Retrieved July 24, 2015 from https://msc.fema.gov/portal.

[19] The estimates of the future costs of inaction required many assumptions, including generalizing from historical data on specific events and adapting data generated for different geographic regions and different climate scenarios to conditions in Philadelphia.

[20] Economy League of Greater Philadelphia. 2013. *Understanding SEPTA's Statewide Economic Value*. Philadelphia, PA. http://www.septa.org/sustain/pdf/Understanding_SEPTAs_Statewide_Economic_Value_0.pdf.

[21] Federal Transit Administration. 2013. *A Vulnerability and Risk Assessment of SEPTA's Regional Rail*. http://www.fta.dot.gov/documents/FTA_Report_No._0071.pdf.

[22] Centers for Disease Control and Prevention. 2015. *Indicators Available on the Tracking Network*. Retrieved July 20, 2015 from http://ephtracking.cdc.gov/showClimateChangeIndicators.action.

[23] Philadelphia Water. 2007. *The Delaware River Watershed Source Water Protection Plan*. http://www.phillywatersheds.org/doc/Delaware_SWPP_2007.pdf.

[24] Philadelphia Water. 2015. *Watershed Issues: FAQ*. Retrieved July 21, 2015 from http://www.phillywatersheds.org/watershed_issues/stormwater_management/faq#q2.

[25] FEMA. 2015. *State Mitigation Plan Review Guide, Effective March 2016*. FP 302-094-2.

[26] U.S. Environmental Protection Agency. 2011. Rolling Easements. Washington, DC: U.S. EPA Climate Ready Estuaries Program. http://www2.epa.gov/sites/production/files/documents/rollingeasementsprimer.pdf.

[27] Downscaling refers to the process of generating regionally relevant projections from global climate models. Climate models divide the world into a grid. While the size of each grid cell has declined since the early 1990s, it is still too large (about 30 to 60 miles on each side) to capture important local variations in topography and other factors that influence climate. Downscaling allows projections to be made at finer scales relevant to a city such as Philadelphia.

[28] The U.S. DOT CMIP Climate Data Processing Tool was used to provide post-processing of statistically downscaled climate data based on information provided by downscaled CMIP3 and CMIP5 climate and hydrology projections using the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3) and phase 5 (CMIP5) multi-model datasets.

[29] Rawlins, M.A., R.S. Bradley, and H.F. Diaz. 2012. Assessment of regional climate model simulation estimates over the northeast United States. *Journal of Geophysical Research* 117:D23112.

[30] U.S. Global Change Research Program. 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Edited by J. M. Melillo, T. C. Richmond and G. W. Yohe.

[31] Ingram, K., K. Dow, L. Carter, J, Anderson, ed. 2013. *Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability.* Washington, DC: Island Press.

[32] Brooks, H.E. 2013. Severe thunderstorms and climate change. *Atmospheric Research* 123:129-138.

[33] Francis, J., and S. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. *Environmental Research Letters* 10.

[34] NOAA. *Definition of Drought*. National Oceanic and Atmospheric Administration. Retrieved from http://www.ncdc.noaa.gov/monitoring-references/dyk/drought-definition.

[35] The chloride standard for drinking water 250 parts per million (ppm) or milligrams per liter is sometimes referred to as the salt line.

[36] *Pennsylvania Climate Impact Assessment*. 2009. Pennsylvania Climate Impact Assessment: Environment and Natural Resource Institute and The Pennsylvania State University.

[37] Northeast Climate Impacts Assessment. 2008. Climate Change and Solutions, Impacts and Solutions for the Keystone State. Cambridge, MA: Union of Concerned Scientists.

[38] U.S. Global Change Research Program. 2009. *Global Climate Change Impacts in the United States*. Edited by J. M. M. Thomas R. Karl, and Thomas C. Peterson: Cambridge University Press.

[39] U.S. Geological Survey. 2015. *National Climate Change Viewer*. Retrieved July 22, 2015 from http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp.

[40] Climate & Urban Systems Partnership. 2013. *Philadelphia Climate Projections*. http://www.cuspproject.org/uploads/files/485063842785882816-philadelphia-cmip5.pdf.

[41] Sensitivity is defined as the degree to which a system is affected, either adversely or beneficially, by climate variability or change.

[42] Adaptive capacity is defined as the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

[43] Bell, M.L., R. Goldberg, C. Hogrefe, P.L. Kinney, K. Knowlton, B. Lynn, J. Rosenthal, C. Rosenzweig, and J.A. Patz. 2007. Climate change, ambient ozone, and health in 50 US cities. *Climatic Change* 82 (61-76).

[44] Kahrl, F., and D. Roland-Holst. 2008. *California Climate Risk and Response*.

[45] Union of Concerned Scientists. 2015. *Climate Change Impacts and Solutions for Pennsylvania*. Retrieved July 14, 2015 from http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/Exec-Summary_Climate-Change-in-Pennsylvania.pdf.

[46] Jaglom, W.S., J.R. McFarland, M.F. Colley, C.B. Mack, B. Venkatesh, R.L. Miller, J. Haydel, P.A. Schultz, B. Perkins, J.H. Casola, et al. 2014. Assessment of projected temperature impacts from climate change on the U.S. electric power sector using the Integrated Planning Model®. *Energy Policy* 73:524–539.

[47] Chinowsky, P., J. Price, and J. Neumann. 2013. Assessment of climate change adaptation costs for the U.S. road network. *Global Environmental Change* 23 (4):764–773.

THE CITY OF PHILADELPHIA

MAYOR'S OFFICE OF SUSTAINABILITY

GREENWORKS

PHILADELPHIA

www.phila.gov/green