FEBRUARY 2016

VULNERABILITY & RISK ASSESSMENT

CLIMATE CHANGE ADAPTATION PLAN FOR THE DISTRICT OF COLUMBIA

PREPARED FOR

WE ARE WASHINGTON DC

DEPARTMENT OF ENERGY & ENVIRONMENT

SUSTAINABLE DC

PREPARED BY

AREA

PERKINS +WILL

KLEINFELDER

ACKNOWLEDGMENTS

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DEPARTMENT OF ENERGY & ENVIRONMENT
Tommy Wells, Director
Maribeth DiLorenzo, Deputy Director, Urban Sustainability Administration
Kate Johnson, Climate Program Analyst
Phetmano Phannavong, Environmental Engineer

Produced in collaboration with

PERKINS+WILL
Amy Thompson, Project Manager
Janice Barnes, Principal
Douglas Pierce, Principal
Jon Penndorf, Sustainability Leader

KLEINFELDER
Lisa Dickson, Principal in Charge
Nathalie Beauvais, Project Manager
Indrani Ghosh, Lead Modeler
Nasser Brahim, Vulnerability Assessment
Karin Hagan, GIS Lead

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CONTENTS

LIST OF MAPS AND FIGURES

FIGURES

MAPS

EXECUTIVE SUMMARY

Climate change is redefining risk both locally and globally. Past events are no longer reasonable proxies for current or future conditions. The District of Columbia has taken a proactive stance on climate change and is committed to identifying, prioritizing and addressing climate risks. Sustainable DC, the District's comprehensive sustainability plan adopted in 2013, called on the District to "advance physical adaption and human preparedness to increase the District's resilience to future climate change." In order to achieve that goal, the Department of Energy and Environment (DOEE) launched an effort to develop a citywide climate adaptation and resilience plan for the District. This report is the second step of that multi-phase project. The first phase assessed how climate change is likely to affect the District. This report assesses the vulnerabilities and risks that the District faces due to those climate change effects.

Vulnerability to climate change is expressed as a function of exposure, sensitivity, and adaptive capacity. The risk assessment analyzes the most vulnerable assets identified in the vulnerability assessment and ranks them based on probability of occurrence and consequence of impact.

The vulnerability and risk assessment summarized here is based on climate change projections and scenarios established in the first phase of the project and are summarized in the previously released Climate Projections and Scenario Development Report. Those scenarios include rising temperatures and more frequent and severe heat waves, increased frequency and intensity of heavy precipitation events, rising sea levels, and increased coastal flooding due to storm surge. The scenarios were used to conduct a "stress test" on the District's infrastructure and resources. Based on the climate scenarios developed in the previous report, the project team used GIS mapping and conversations with District government agencies and stakeholders to evaluate the vulnerability of District infrastructure, public facilities, and populations. The findings in this report represent a first order prioritization of at-risk assets and neighborhoods that will inform the final climate adaptation plan as well as related planning efforts. The final climate adaptation plan will provide an integrated analysis of existing climate change data, an assessment of vulnerable assets, and recommend strategies to help the District reduce risk and adapt to a changing climate.

Key Findings

The key findings from the Vulnerability and Risk Assessment are as follows:

- Wards 7 and 8 are home to the largest number of residents with a higher vulnerability to climate change impacts – especially an increase in extreme heat – due to the socioeconomic factors that increase sensitivity to heat, and limit the ability to adapt, including unemployment, age (seniors and young children), and income.
- Ward 7 is also home to the largest number of vulnerable community resources such as schools, medical services and human services, particularly in the floodplain of the Watts Branch tributary.

- Other community resources at risk of flooding, including police, fire, and local and federal emergency operations centers, are concentrated in Downtown DC (around Federal Triangle area) and Southwest DC (south of the Capitol to Buzzard Point). If flooding were to occur in these areas, it could impact multiple facilities that serve critical public safety functions when they would be needed most. Such scenarios could likely occur due to flooding from sea level rise, storm surge and extreme precipitation as a result of climate change.

- Major infrastructure assets, such as electric substations and Metrorail (operated by the Washington Metro Area Transit Authority or WMATA), are at-risk to increased heat and flooding by 2020 or 2050; their failure could have significant regional impact as District businesses, governments, and residents rely on energy supply and public transportation for day-to-day life. Two of the three electric substations identified as at-risk in this report are within or are abutting the 100 year-floodplain and are currently at risk of being flooded. They are all located in the 500-year floodplain, which may be a more appropriate indicator of future flood risk given projected sea level rise and increased frequency of extreme precipitation events.

- Surface flooding from inland precipitation events may pose as much risk as flooding associated with sea level rise and storm surge – especially in the near term.

- Areas of risk to flooding and extreme heat are not evenly distributed throughout the District; but instead are concentrated near particular water bodies (e.g., the Watts Branch tributary to the Anacostia River) or areas with a large number of highly vulnerable residents that will not only be more at risk of exposure to climate impacts, but are also less likely to have the means to adapt or be resilient to flooding or heat stress.

- Under existing conditions, the District is already vulnerable to flooding along the Potomac and Anacostia Rivers as documented by repetitive historic flooding events and the Federal Emergency Management Agency's (FEMA) map of the 100-year floodplain. The combined impact of increased precipitation, sea level rise, and storm surge will require reconsidering the delineation of the current 100-year and 500-year floodplain boundaries to reflect increased flooding risks in the future.

- Taking into account the District's unique geography; as it is bounded by the Potomac River and is bisected by the Anacostia River;bridges provide vital connections within the District and to surrounding areas. Their possible failure, due to flooding impacts, would have significant implications on the functioning of the larger regional transportation network. Key bridges have been potentially identified as at risk in this assessment, such as the 14th Street Bridges[1] that span the Potomac River. It is recommended that a more detailed vulnerability assessment be performed for key bridges spanning the Potomac and Anacostia rivers.

Since many of these risks to regional assets are not limited to the District's jurisdiction, adaptation will require coordination with other states, agencies, and organizations such as regional transportation agencies and energy providers.

Priority Adaption Planning Areas

Planning priority areas have been identified as areas regrouping a concentration of assets most at risk and located in areas also showing highly vulnerable populations.

Map 1, the Priority Planning Areas Map, shows the five (5) identified areas with the most at-risk infrastructure, community resources, and populations with respect to climate change within the boundaries of the District. It represents the results of an assessment and ranking of the comparative risk to infrastructure, public facilities, and community resources based on the likelihood of exposure to climate change impacts and the consequences of a failure or disruption. The scoring system used also considered the cascading impact of one system failing and interdependencies of the infrastructure systems and critical resources. For example, flooding could impact lifeline systems, such as energy and telecommunications, without which some roadway infrastructure (e.g. traffic signals, lighting) may not be able to properly function. The adaptation plan will provide recommendations to reduce risks to the Priority Planning Areas as well as the District as whole. Areas are identified as planning priority areas as they have a higher risk of vulnerability by failure of many systems and would impact populations that are likely to be most impacted by climate change impacts. As informed by the vulnerability and risk assessment key findings, adaption planning should focus on these locations.

PRIORITY PLANNING AREA 1

Includes the neighborhoods of Bloomingdale and LeDroit Park. Because this area has already experienced significant flooding due to the limited capacity of the existing stormwater management systems, the projected increase in frequency and severity of extreme precipitation elevates these neighborhoods to a high-risk level. Ongoing efforts to expand the capacity of the stormwater system capacity in the area, including DC Water's Northeast Boundary Tunnel and interim McMillan Stormwater Storage Project will significantly reduce this risk, but not for the most extreme events.

1. The 14th Street Bridges refers to the group of three highway bridges (Rochambeau, George Mason Memorial, Arlan Williams Memorial), a railroad bridge (Long), and a Metrorail Bridge (Fenwick Metro Transit) that span the Potomac.

PRIORITY PLANNING AREA 2

This area around the Watts Branch, a tributary to the Anacostia River, is currently at risk of flooding, and is projected to be at increased risk as early as 2020. This area has a significant concentration of community resources at-risk, such as medical services and public housing, including the soon-to-redeveloped Kenilworth Courts project, that serve vulnerable populations.

PRIORITY PLANNING AREA 3

This area includes the District's downtown area centered around the Federal Triangle neighborhood. These areas are already at risk of riverine, coastal and interior flooding which will be exacerbated by 2080. These areas have a significant concentration of built infrastructure, including a large concentration of professional businesses, cultural resources including the Smithsonian and National Mall; as well as Metrorail stations and other community resources, such as the John A. Wilson Building (city hall), and other DC agency headquarters. This area's roadway and transit systems also serve a large number of the District's transient population of commuters and tourists. Actions are already being taken to better protect this area from riverine flooding including upgrades to the 17th Street Levee and the greater Potomac levee system. It will however remain at risk to interior flooding, and by 2080 there will be an increased risk from riverine and coastal flooding due to rising sea level.

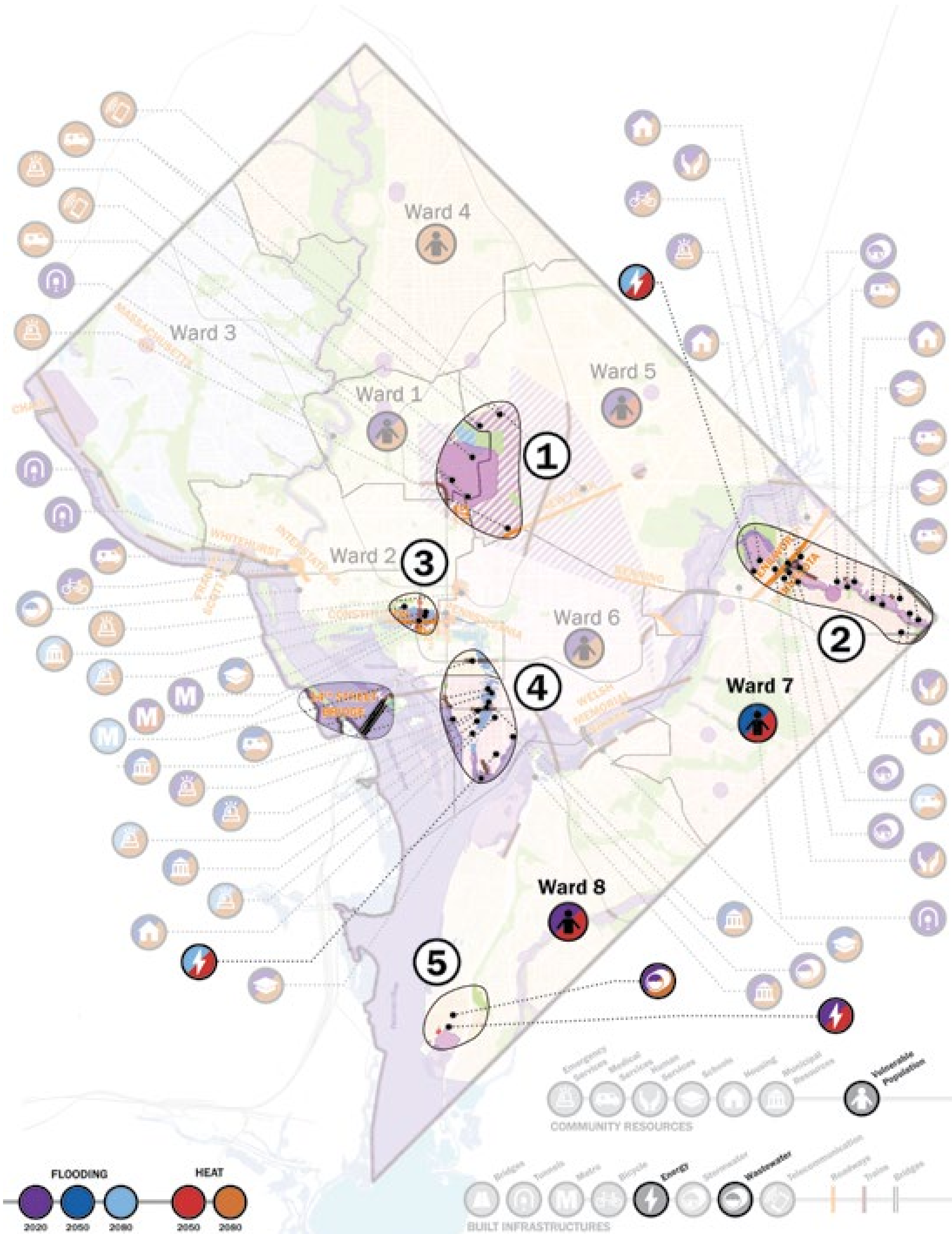
PRIORITY PLANNING AREA 4

This area in Southwest DC extends from south of the Capitol to Buzzards Point and is primarily at risk of riverine and coastal flooding. This area is a mix of residential, commercial, government, and several large development projects and planning initiatives (The Wharf, Buzzard Point, DC United Soccer Stadium, etc.). The area includes a variety of community resource facilities and infrastructure at risk of flooding, including public safety, public housing, human services, transit, energy and wastewater. Several public housing properties are located in Priority Area 4, including the Greenleaf properties that are scheduled to be redeveloped in the near future and James Creek. Metrorail lines that cross through this area include the Green Line and Blue/Orange/Silver Line.

PRIORITY PLANNING AREA 5

This area along the Potomac River is at risk of flooding within 2020, 2050, and 2080 scenarios, which will impact a key electrical sub-station and the Blue Plains Advanced Wastewater Treatment Plant. A planned sea wall at Blue Plains, which is being designed to the current 500-year flood elevation plus three feet to account for sea level rise, will substantially reduce the risk to the plant, but not necessarily the surrounding areas.

PRIORITY PLANNING AREAS MAP



MAP 1: Planning Priority Areas (Source: Kleinfelder, February 2016)

OVERVIEW

In order to assess the impacts of climate change on the District of Columbia, we inventoried key infrastructure and community resources and ranked them based on their vulnerability to climate change and the risk associated with their failure. Assets are determined to be critical or key based on their contribution to the overall functionality of the District as a whole and the consequences if they were to fail.

Examples of critical infrastructure include electrical substations and roadways. Key community resources include facilities that support the well-being of the community, such as affordable housing and human services. The listing below represents the critical infrastructure and key community resources that were included in this analysis. A detailed discussion of each follows.

BUILT INFRASTRUCTURES[2]

Energy

Transportation

Water

Telecommunication

COMMUNITY RESOURCES

Municipal Resources

Emergency Services

Medical Services

Human Services

Schools

Public Housing

In addition to threats to the built environment, we considered the vulnerability of the District's residents, recognizing that some residents will be less able to adapt to the risks of climate change. Social aspects of vulnerability to climate change impacts are more challenging to measure than those in the built environment as they are defined by a complex set of demographic, economic, and health factors. In order to identify the wards with the largest share of vulnerable residents, a vulnerable population index[3] was developed using demographic and socioeconomic indicators of both sensitivity to climate change impacts and ability adapt. Indicators include the following:

2. There are some infrastructure types and community resources that were not included in this study due to a lack of publicly available geospatial data for the resource.
3. Refer to the Attachment titled "Social Vulnerability and Ranking Protocol" for a complete report on the methodology for determining the vulnerable population index.

- Income: poverty is associated with poor nutrition, and less access to medical care. Low-income individuals also have fewer financial resources to cope with and recover from disasters and disruptions such as damage to housing, disruption to work schedules.
- Age: seniors and young children are more sensitive to extreme heat. Seniors may also be less able to cope with flooding and other disasters due to poor health, disabilities or other functional needs, or limited financial resources.

The data used for the index were derived from demographic and place-based indicators as reported in the Sustainable DC Plan (2013). This vulnerability assessment also considers populations within DC, such as the tourist population, commuters or outdoor workers; which are also likely to be impacted by climate change related events, such as flooding and heat waves.

The team did not explicitly assess the vulnerability of natural systems, because those analyses are covered by other studies that have recently been completed or are underway. For example, in the 2015 Wildlife Action Plan, DOEE assessed the vulnerability of the District's wildlife and habitat to climate change and identified priority habitat restoration and protection actions. Furthermore, nature-based strategies to address climate change impacts, such as expanding the current tree canopy, use of green infrastructure to reduce stormwater runoff, and the use of wetlands to mitigate flooding will also be addressed in the forthcoming Climate Change Adaptation Plan Report.

Finally, many of the District's infrastructure and natural systems extend beyond the city's boundaries, or are outside of its direct jurisdiction, so the impacts of climate change on the District at-large are codependent upon regional conditions and actions.

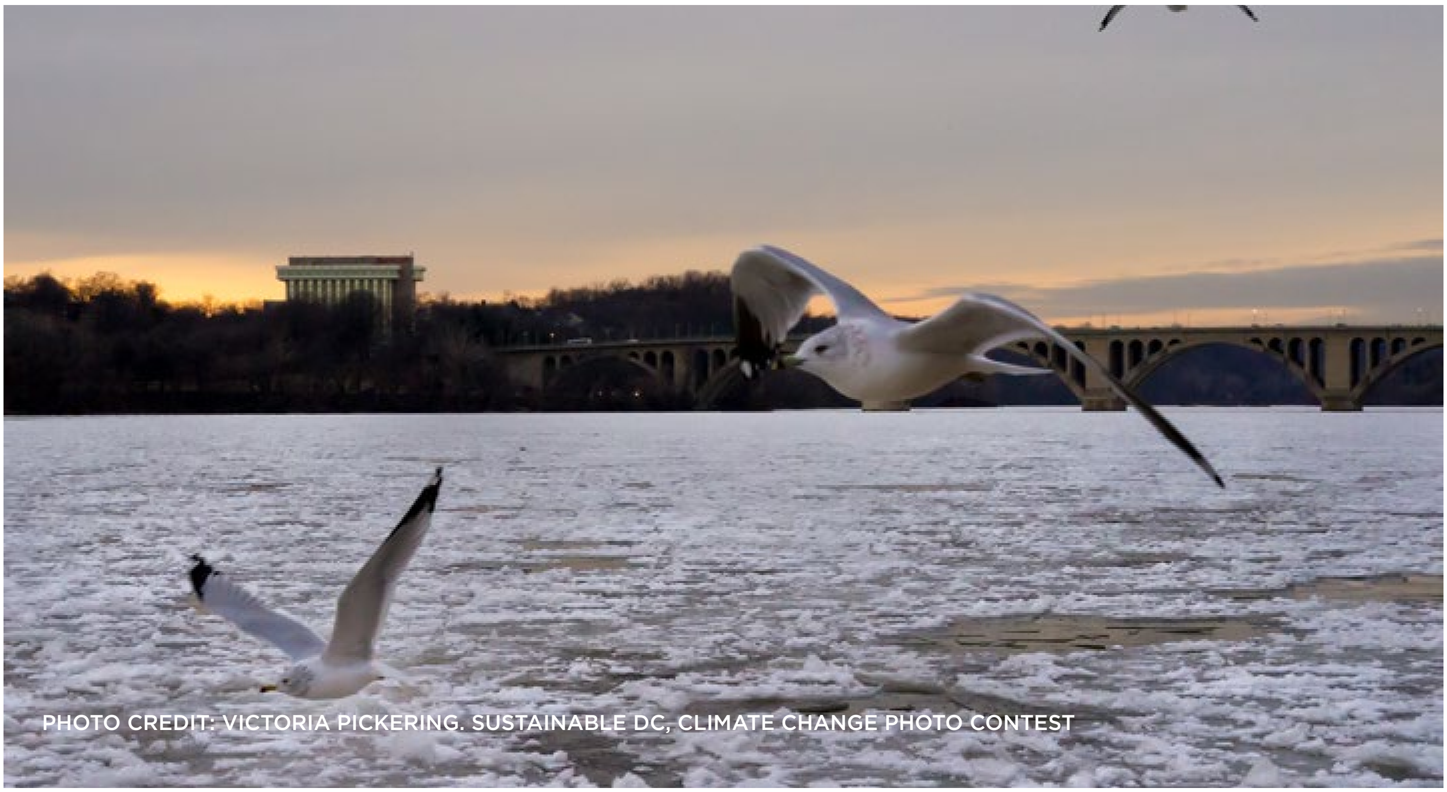


PHOTO CREDIT: VICTORIA PICKERING. SUSTAINABLE DC, CLIMATE CHANGE PHOTO CONTEST

PHOTO CREDIT: KEVIN WOLF. SUSTAINABLE DC, CLIMATE CHANGE PHOTO CONTEST

01

METHODOLOGY

VULNERABILITY ASSESSMENT

Vulnerability to climate change is expressed as a function of exposure, sensitivity, and adaptive capacity.

Exposure refers to the extent to which a system comes into contact with a specific climate change impact. The types and extent of exposure have been determined as part of the Climate Projections and Scenario Development Report which established the basis for conducting the vulnerability and risk assessment. For example, exposure for a specific asset, such as an electric substation, is determined by its location within an area prone to flooding as identified in the 2020, 2050 and 2080 scenarios.

Sensitivity is the degree to which the functionality of a system is affected by a specific climate change impact, whether directly or indirectly. For example, a roadway might be less sensitive to flooding than an electric substation.

Adaptive capacity is the ability or potential of a system to respond successfully to climate change, and includes adjustments both in behavior and in resources and technologies. For example, two emergency facilities in close proximity, one of which is located in a less flood-prone area, would allow for redundancy in service and provide for adaptive capacity. Cost and feasibility are often key factors in determining the adaptive capacity of a system.

For the purpose of this study, **exposure** is used as a proxy for **vulnerability** for critical infrastructures, community resources and populations. However, the sensitivity of an asset in terms of its overall functionality was factored into the scoring and ranking of assets as described in the risk assessment methodology section below.

The vulnerability and risk assessment was performed using existing or as-is conditions for assets, resources and population. Subsequent damages or upgrades to assets, changes in urban development and in the demographics of each ward in the city will yield a different ranking for vulnerability and risk. This assessment has been designed to be revised over time to update the ranking of elements most at risk.

EXPOSURE TO FLOODING

The scenarios used to determine the extent of exposure to climate change impacts are based on data summarized in the previous Climate Projections and Scenario Development Report. The **flood exposure maps** (Map 2, 3 and 4) illustrate projected impacts for flooding in each of the climate projection scenarios. The flooding maps are used as the basis to assess exposure of the District's critical infrastructure and community resources to flooding, and provide a GIS tool to identify areas and assets with increasing risks.

For sea level rise and storm surge, the following scenarios were used:

- 2020: The present 100-year base flood elevation as determined by FEMA is used as a proxy for future coastal storm surge and riverine flooding in 2020. The base flood elevation is the computed elevation to which floodwater is anticipated to rise during the base flood, which in the case of the 100-year flood is an event having a one percent chance of being equaled or exceeded in any given year. In order to account for interior drainage flooding; which is not considered to be part of the floodplain outlined by FEMA; this scenario also considered historic neighborhood flooding as reported by stakeholders, including those areas within 500 feet of a high-risk storm drain[4] and with properties that have suffered repetitive losses as reported by the National Flood Insurance Program (NFIP).
- 2050: The storm surge extent maps for a Category 2 hurricane created by the U.S. Army Corps of Engineers (USACE) for the 2015 North Atlantic Coast Comprehensive Study (NACCS). The Category 2 hurricane map serves as a proxy for the current FEMA 100-year base flood elevation + three feet since these two layers are approximately comparable in extent. The three additional feet accounts for a conservative estimate of projected sea level rise by 2050, as well as based on general scientific consensus that sea level rise is projected to be higher than two feet by mid-century.
- 2080: The current FEMA 500-year base flood elevation. This is approximately equal to the current 100-year flood + four feet. The four additional feet accounts for the projected amount of sea level rise (up to 3.4 feet from 2014 according to the USACE) by 2080.

4. High-risk storm drain according to 2010 DC Multi-Hazard Mitigation Plan.

For precipitation, the following design storms[5] were used.

2020

- Higher scenario: 10.5 inches for the 100-year 24-hour storm
- Lower scenario: 4.6 inches for the 15-year 6-hour storm

2050[6]

- Higher scenario: 10.5 inches for the 100-year 24-hour storm
- Lower scenario: 4.7 inches for the 15-year 6-hour storm

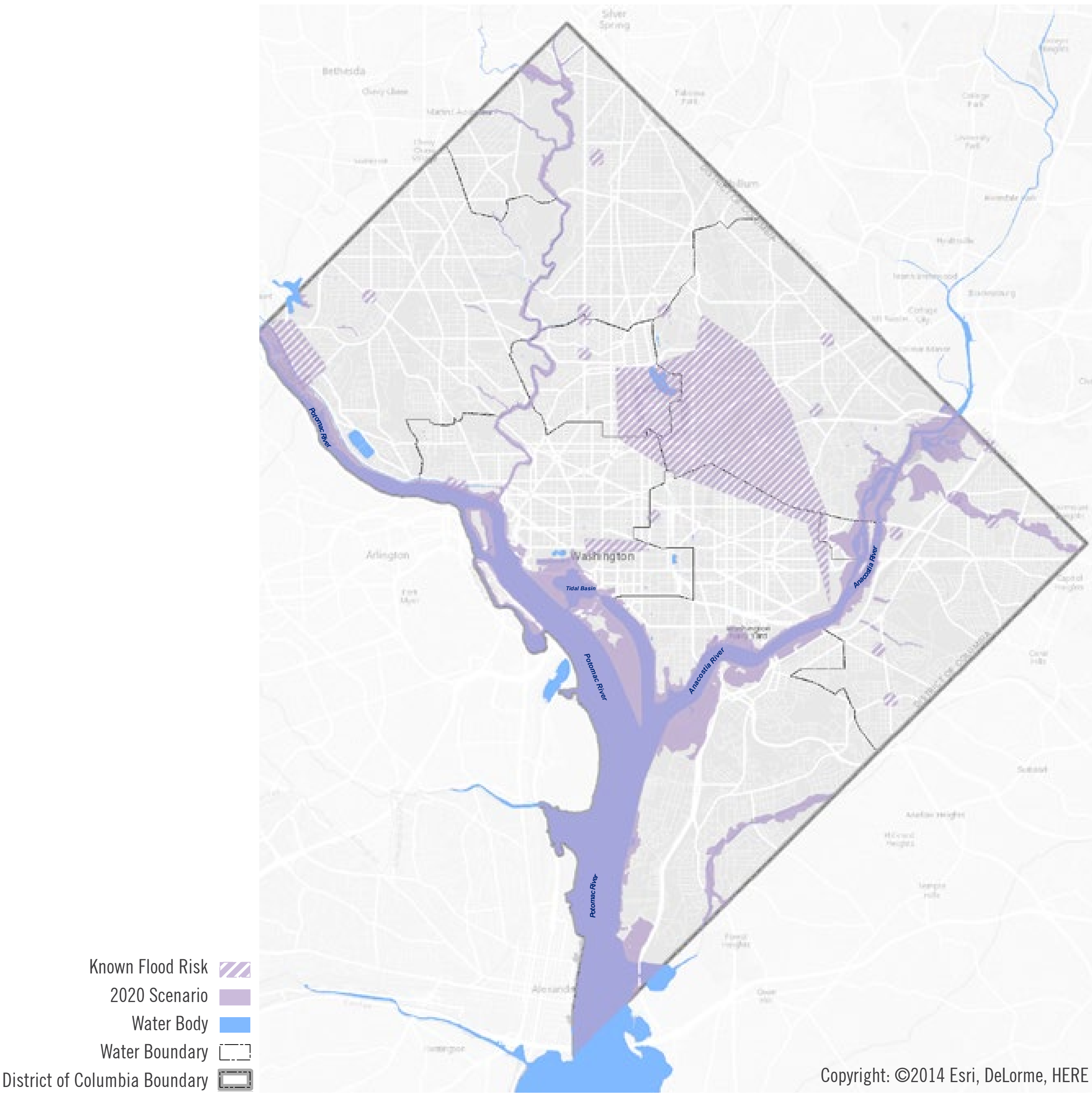
2080

- Higher scenario: 14 inches for the 100-year — 24 hour storm
- Lower scenario: 5 inches for the 15-year — 6 hour storm

While these calculations indicate the depth of rain expected in future storms, they do not provide the extent or depth of flooding that could be associated with each. This requires additional modeling that was beyond the scope of this project. As a proxy, areas within the FEMA floodplain and areas of known flooding risk (refer to maps 2, 3 and 4) have been identified as at-risk areas for increased precipitation in the future. The precipitation scenarios have been considered qualitatively for the purpose of this assessment. The results shown here should be treated as a first-order approximation to identify priority risk areas until additional modeling is completed.

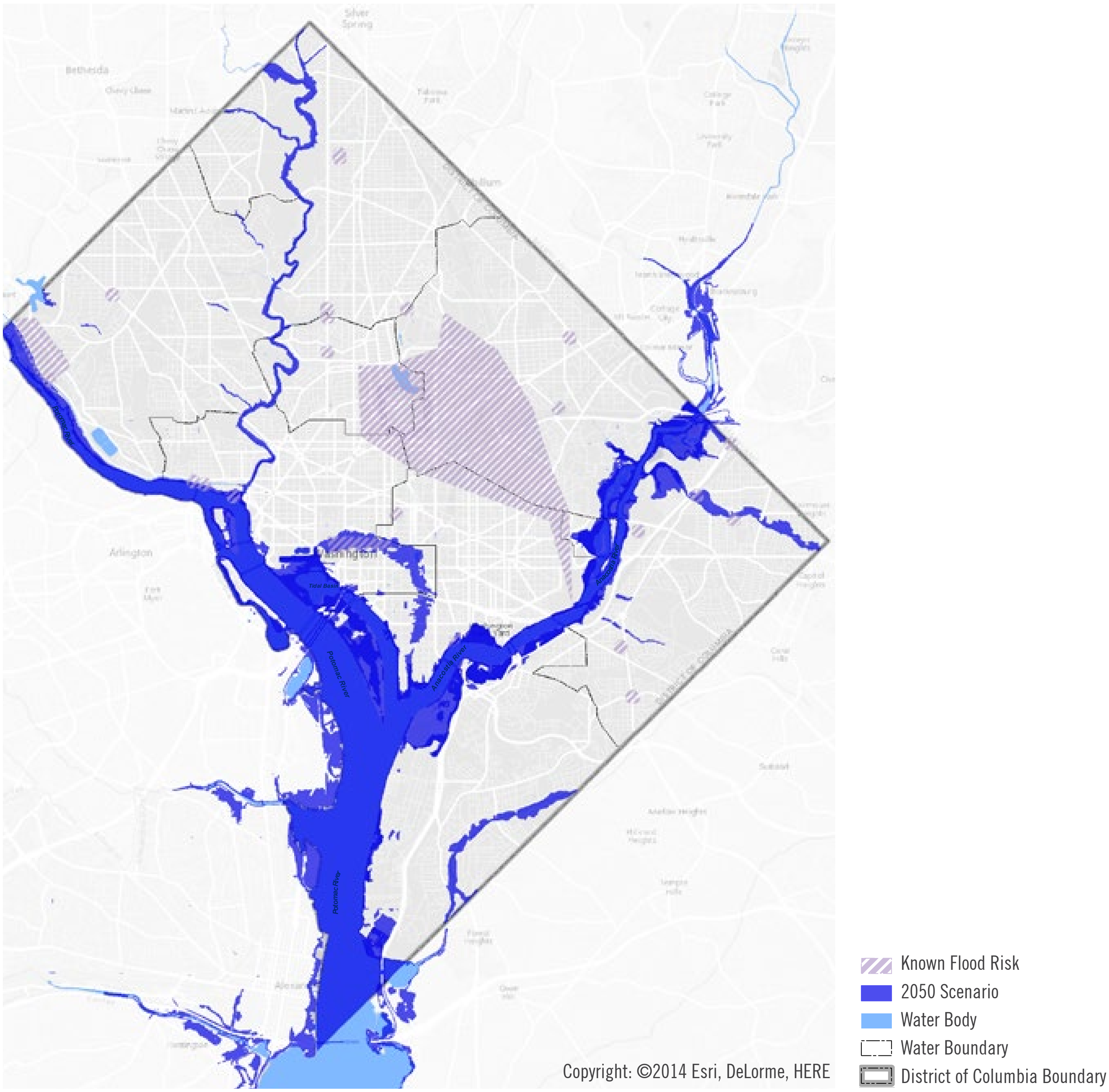
5. Design storms are the precipitation (rain) events that engineers use to design drainage infrastructure, bridges, culverts, etc.
6. According to climate change projections completed for theClimat eprojections and Scenario Development Report, there were no significant changes in the design storm depths (in inches) between the 2020s and 2050s. Hence the precipitation scenarios are similar between these two planning horizons.

2020 SCENARIO FOR FLOODING



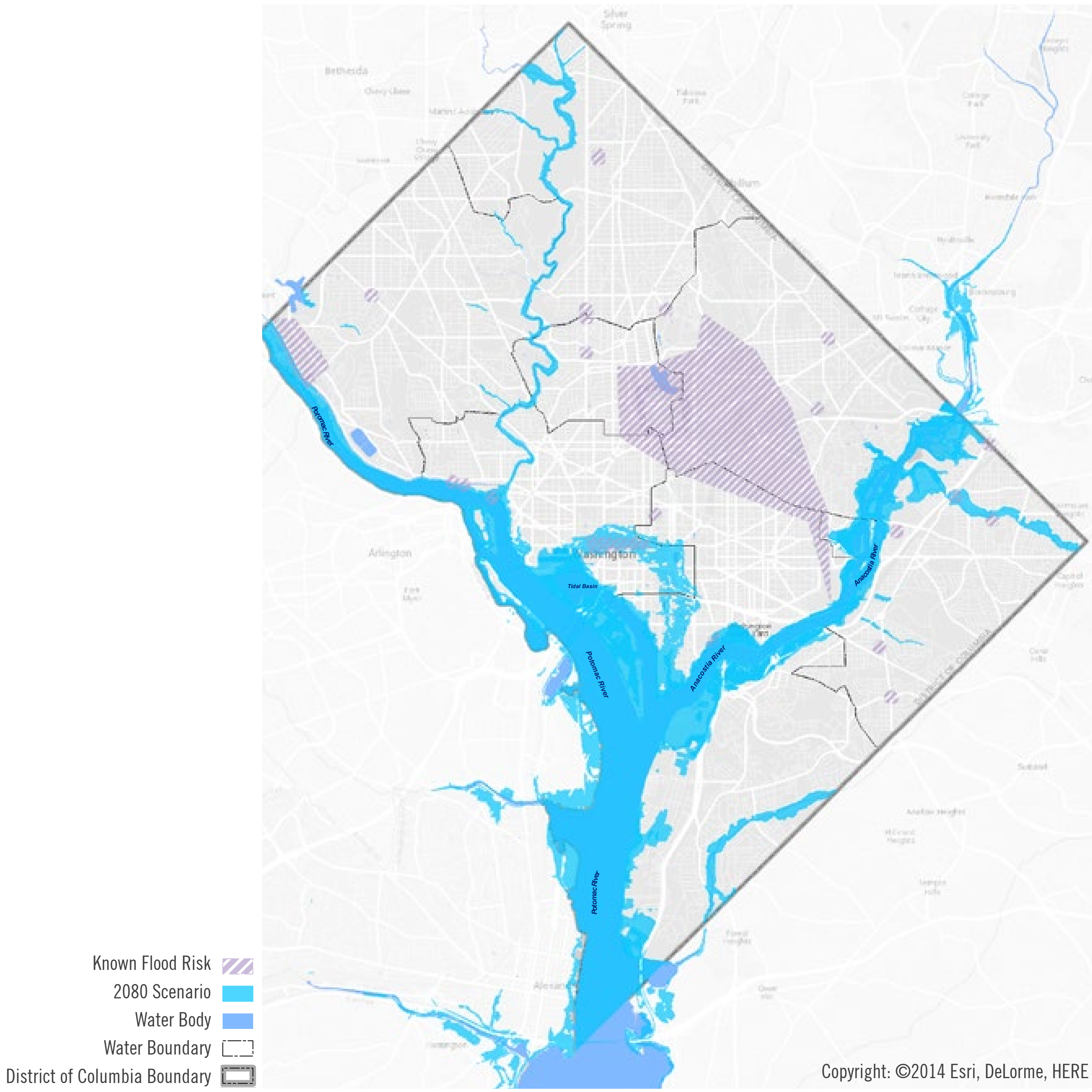
MAP 2: 2020 Scenario for flooding: areas of known flood risk and the current FEMA 100-year floodplain. (Source: FEMA and NACCS maps and historic flooding as identified by stakeholders overlaid on GIS map base, Kleinfelder, 2015)

2050 SCENARIO FOR FLOODING



MAP 3: 2050 Scenario based on NACCS SLOSH hurricane storm surge inundation mapping for present day Category 2 hurricane as a proxy for the current FEMA 100-year base flood elevation + 3 feet of sea level rise (Source: NACCS map and historic flooding as identified by stakeholders overlaid on GIS map base, Kleinfelder, 2015)

2080 SCENARIO FOR FLOODING



MAP 4: 2080 Scenario based on current FEMA 500-year floodplain as a proxy for the current FEMA 100-year base flood elevation + 4 feet of sea level rise. (Source: NACCS map and historic flooding as identified by stakeholders overlaid on GIS map base, Kleinfelder, 2015)

EXPOSURE TO HEAT

Heat waves are defined as an extended period of very high temperatures. For this study, a heat wave was defined as three or more days with a temperature in excess of 95°F. The extended period of heat has significant implications for public health as human physiology is sensitive to long periods of sustained heat exposure, resulting in an increase in heat-related illnesses and deaths. The elderly and very young and those with chronic health conditions such as obesity and diabetes are at greater risk for heat-related illness or death (Basu and Samet, 2002) during extreme or prolonged heat waves as well those with respiratory or circulatory diseases (Anderson and Bell, 2009).

As documented in the previously published Climate Projections and Scenario Development Report, temperatures are projected to continue to increase in the District. Currently, summer daytime maximum temperatures average 87°F and nighttime minimum temperatures average 66°F. In the projected temperature scenarios, summer daytime maximums, the duration of heat waves, and the number of dangerously hot days are all expected to increase. The selected scenarios are:

- 2020: Increase of daytime maximum by 2.5 - 3°F and a possible heat wave of 6 days with a daily maximum heat index value above 95 °F.
- 2050: Increase of daytime maximum by 5 - 7°F and a possible heat wave of 8 - 9.5 days with a daily maximum heat index value above 95 °F.
- 2080: Increase of daytime maximum by 6 - 10°F and a possible heat wave of 9.5 - 12 days with a daily maximum heat index value above 95 °F.

In the absence of heat island maps that show the spatial variability of localized urban heat island impacts, this assessment of heat-related vulnerability has been performed for the District as a whole. A "stress test" was conducted for increased heat for 2050 and 2080 with the assumption that the year 2020 was too close to the present day to reflect a significant change. It was assumed by the research team that the District's critical infrastructure and community resources are designed to adequately meet current high temperatures but might begin to fail under more frequent extreme heat by 2050. It should be noted, however, that some infrastructure assets, such as the Metrorail and regional rail lines, already must reduce service and train speeds during extreme heat events due to concerns about heat-related damage to tracks. (VRE, 2015).

RISK ASSESSMENT

The risk assessment analyzes the most vulnerable assets identified in the vulnerability assessment and ranks them based on probability of occurrence and consequence of impact. It assigns a value to the probability of an event occurring and to the relative impact if it were to occur. For example, a Capital Bikeshare station located near a waterbody may have significant vulnerability to flooding. There may also be a high probability that the flooding would occur. However, the overall impact, such as increased commuting time for bicyclists or decreased recreational biking opportunities, would be less significant to the District as a whole compared to the flooding of an electrical substation, which may leave residents, businesses, and public services without power. Given the same probability of flooding, the electrical substation is identified as a high-risk asset, while the Capital Bikeshare station is not. The areas with the most assets/systems at high-risk are identified as the priority planning areas, and will be a focus for subsequent adaptation planning.

As illustrated in Figure 1, each asset was ranked according to a qualitative assessment based on the extent of area of service loss, the estimated duration of service loss, the cost of damage, and impacts to public safety services, economic activities, public health, the environment, and to vulnerable populations. Scores were assigned for each criteria as 1 (least severe) to 3 (most severe). Area of service loss is scored based on extent of the geographic area that would be impacted during a disruption ranging from a neighborhood, parts of a ward, to one, two or more wards as the most severe. Duration of service loss is scored based on assumptions of the length of time needed to repair or relocate services. Cost of damage is based on preliminary estimates ranging from less than $100,000 to more than $1 million as most severe. Impact to public safety, public health and the environment is based on a qualitative assessment by District agencies of the types of services that would be impacted. The impact to vulnerable populations is informed by the areas impacted and the locations with the largest vulnerable populations as documented in Section 4 of this report.

Score	Area of Service Loss	Duration of Service Loss	Cost of Damage	Impacts to Public Safety Services	Impacts to Economic Activities	Impacts to Public Health / Environment	Impacts to Vulnerable Populations
3 (Most Severe)	Two or more Wards	> 7 days	> $1m	High	High	High	High
2 (Moderate Severe)	Ward	1 - 7 days	$100k - $1m	Moderate	Moderate	Moderate	Moderate
1 (Least Severe)	Neighborhood (not entire Ward)	< 1 day	< $100k	Low	Low	Low	Low

FIGURE 1: Scoring Criteria (Source: Kleinfelder, November, 2015)


PHOTO CREDIT: JOHN SONDERMAN. SUSTAINABLE DC, CLIMATE CHANGE PHOTO CONTEST

02

INFRASTRUCTURE VULNERABILITY & RISK ASSESSMENT

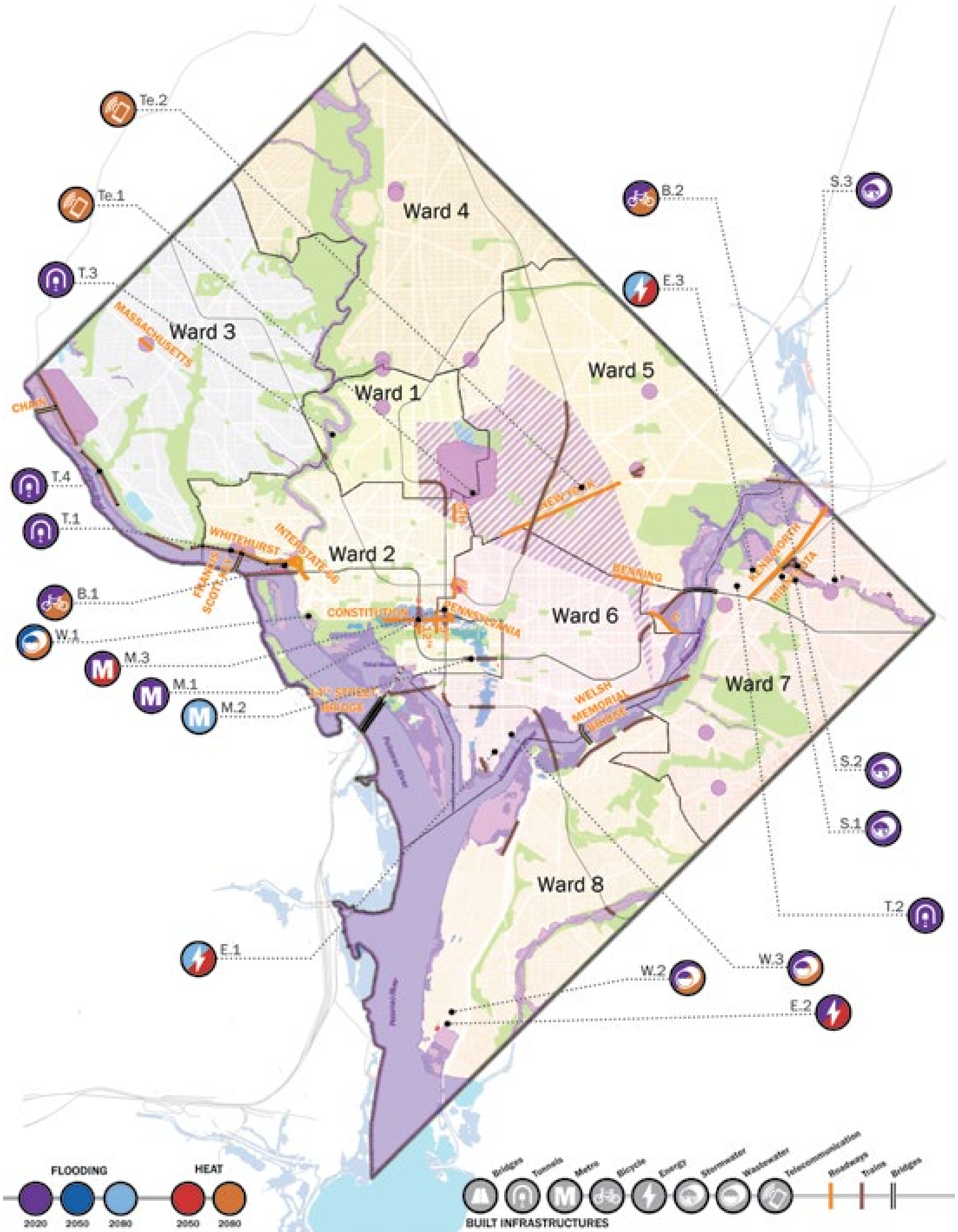
The overall functionality of a city is necessarily tied to its infrastructure; much of which is either out of public view, or simply goes unnoticed until it ceases to function. Until now, infrastructure design guidelines have been based on past weather patterns and events. However, those trends are changing raising the question of whether or not existing infrastructure will be sufficiently resilient in the future. The following section outlines the infrastructure that were analyzed as part of this study.

The Vulnerability and Risk Assessment of the infrastructure systems includes:

- **Energy Infrastructure**: electric substations. Information was not available to assess the natural gas generation/distribution and electrical transmission/distribution systems.
- **Transportation system**: Metrorail lines and stations, regional railroad infrastructure, roadways, and Capital Bikeshare stations. For road infrastructure, we focused on roadways with an Average Annual Daily Trip (AADT) count of greater than 16,000; this included bridges, tunnels and underpasses. It was assumed that impacts to roads would also disrupt bus service and cycling infrastructure.
- **Water infrastructure**: stormwater and combined sewer collection systems including pipes, outfall locations, drainage areas, pumping stations and the treatment plant. The surface water supply source area, drinking water treatment and distribution systems were not addressed since information was not available as part of the GIS database used.
- **Telecommunications**: cellular towers. The locations of AM and FM radio towers and other wireless communications towers were not available.

The results of the vulnerability and risk assessment of built infrastructure are summarized in Figure 2 and Map 5. Figure 2 lists the infrastructure assets that are at highest risk to flooding and extreme heat by 2020, 2050 and 2080. The assets that have been exposed to flooding from historic events are also indicated in the figure. Map 5 presents the location of these high-risk infrastructure assets in relation to the different Wards within the District.

INFRASTRUCTURE MOST AT RISK



MAP 5: Compilation of Infrastructure Most at Risk (Source: Kleinfelder, February 2016)

				FLOODING				HEAT	
		Infrastructure Type	Name	Historic	2020	2050	2080	2050	2080
Energy	E.1	Electrical Substation	Buzzard Point Substation (ELP - 111, ELP - 122, ELP - 119)		Yes	Yes	Yes		
	E.2	Electrical Substation	Blue Plains Substation (ELP - 128, ELP - 129)		Yes	Yes	Yes	Yes	Yes
	E.3	Electrical Substation	Benning Road Substation (ELP - 3, ELP - 103)				Yes		
Roadways (>16,000 AADT)	*by name*	Roadway (>16,000 AADT)	12TH ST Expressway SW	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	Constitution Avenue NW	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	INTERSTATE 66	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	Pennsylvania Avenue NW	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	Whitehurst Freeway NW	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	Benning Road NE	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	C ST NE	Yes	Yes	Yes	Yes		Yes
		Roadway (>16,000 AADT)	Kenilworth Avenue NE	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	Massachusetts Avenue NW	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	Minnesota Avenue NE	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	New York Avenue NE	Yes	Yes	Yes	Yes		
		Roadway (>16,000 AADT)	6TH ST NW	Yes			Yes		
		Roadway (>16,000 AADT)	9TH ST NW	Yes		Yes	Yes		
Tunnels	T.1	Tunnel	Capitol Crescent Trail (570, 571)	Yes	Yes	Yes	Yes		
	T.2	Tunnel	RFK Stadium (436)		Yes	Yes	Yes		
	T.3	Tunnel	Beach Drive at National Zoo (496)		Yes	Yes	Yes		
	T.4	Tunnel	Capitol Crescent Trail (573)		Yes	Yes	Yes		
Bridges	*by name*	Bridge (>16,000 AADT)	Chain Bridge NW	Yes	Yes	Yes	Yes		
		Bridge (>16,000 AADT)	Francis Scott Key Bridge NW	Yes	Yes	Yes	Yes		
		Bridge	Arland D Williams Memorial Bridge (14TH ST)		Yes	Yes	Yes		
		Bridge	Rochambeau Bridge (14TH ST)		Yes	Yes	Yes		Yes
		Bridge	Francis Case Memorial Bridge		Yes	Yes	Yes		
		Bridge	Welsh Memorial Bridge		Yes	Yes	Yes		
		Bridge	Benning Bridge		Yes	Yes	Yes		
Metrorail	M.1	WMATA Metrorail Stations	Federal Triangle	Yes		Yes	Yes		
	M.2	WMATA Metrorail Stations	Federal Center SW				Yes		
	M.3	WMATA Metrorail Stations	Archives-Navy Mem'l	Yes	Yes	Yes	Yes		
		WMATA Metrorail Line	Yellow		Yes	Yes	Yes	Yes*	Yes*
		WMATA Metrorail Line	Blue, Silver		Yes	Yes	Yes		
	NA	WMATA Metrorail Line	Green		Yes	Yes	Yes		
		WMATA Metrorail Line	Orange		Yes	Yes	Yes		
		WMATA Metrorail Line	Red		Yes	Yes	Yes		
Railroad/line (trains)	*NA*	Amtrak Line	Mid-Atlantic	Yes	Yes	Yes	Yes		
		MARC Line	PENN - WASHINGTON	Yes	Yes	Yes	Yes		
		Other CSX Line	Kenilworth area	Yes	Yes	Yes	Yes	Yes	Yes
		Other CSX Line	I-295 right of way	Yes	Yes	Yes	Yes		
Bicycle	B.1	Capital Bikeshare Location	Georgetown Harbor / 30th St NW	Yes	Yes	Yes	Yes		Yes
	B.2	Capital Bikeshare Location	Nannie Helen Burroughs & Minnesota Ave NE	Yes	Yes	Yes	Yes		
Stormwater	S.1	MS4 Stormwater Outfall	Minnesota Ave., SE & Railroad Bridge, SE	Yes	Yes	Yes	Yes		
	S.2	MS4 Stormwater Outfall	Nannie Helen Burroughs Ave & Pedestrian Bridge	Yes	Yes	Yes	Yes		
	S.3	MS4 Stormwater Outfall	49th St., NE & Nannie Helen Burroughs Road, NE	Yes	Yes	Yes	Yes		
Wastewater	W.1	Wastewater Pumping Station	Potomac Pumping Station			Yes	Yes		
	W.2	Treatment Plant	Blue Plains Advanced Wastewater Treatment Plant		Yes	Yes	Yes		Yes
	W.3	Wastewater Pumping Station	Main & O Street Pumping Station		Yes	Yes	Yes		
Telecom.	Te.1	Cellular Radio Transmission Tower	COLUMBIA LODGE 1844 3RD ST, N.W.	Yes	Yes	Yes	Yes		Yes
	Te.2	Cellular Radio Transmission Tower	900 V Street NE	Yes	Yes	Yes	Yes		

* With the understanding that Metrorail Line segments and stations that are underground are not sensitive to heat.

FIGURE 2: Compilation of Infrastructure Most at Risk (Source: Kleinfelder, February 2016)

ENERGY

A reliable and sustainable energy supply is crucial to the safety, livability and economic vitality of the region. In the District, energy infrastructure includes electricity, natural gas and petroleum supply and distribution systems. In addition, there is a growing local supply of renewable energy. For the purpose of this study, only electrical substations were available in GIS format, hence their geographic location was identified and they were ranked according to the projected climate change impacts. Gas and petroleum infrastructure are also vulnerable to climate change stresses, and their distribution could be disrupted by extreme events. However, since spatial information was not available for these infrastructure systems, they were not assessed in this study.

The District is served by one electric distribution utility, Pepco, and imports nearly all of its electricity from outside of its borders. While this study focuses only on facilities within the District, it is important to note that the District's electricity is transported over long-distance transmission lines, and many of which are nearing the end of their useful life. Higher electricity demands, particularly for cooling, will further stress these systems and increase their likelihood of failure.

Electric substations have been assessed to determine if their functionality could be compromised under the study's climate scenarios. Many substations are located within areas that are currently vulnerable to flooding, and are anticipated to be flooded in the future. Three substations located in the 100-year flood plain are subject to existing flood related building codes. However, without a specific assessment of current flood-proofing measures that may have been implemented, we conservatively assume that these are at risk of failing.

Critical energy infrastructure might also be vulnerable to prolonged periods of extreme heat. Substations are designed to run for a limited time using emergency response measures, and prevent customer outages should one component fail. However, running at emergency ratings reduces equipment lifetime, so repeated extreme heat events would affect equipment durability. Additional emergency response measures to reduce the ambient heat of substation equipment and prevent failures, such as misting and other tactics, could be deployed during extreme heat events and would reduce vulnerability.

The three electric substations identified as most at-risk to flooding are the substation in Ward 8 near the Blue Plains Wastewater Treatment Plant and the Anacostia River, the Buzzard Point substation in Ward 6 near the Anacostia River, and the Benning Road substation in Ward 7.

TRANSPORTATION

Transportation infrastructure is fundamental to ensuring the efficient movement of people and goods, as well as enabling critical services and emergency response efforts. Disruptions to transportation systems directly affect citizens and businesses. During extreme events, transportation systems and roadways become critical assets for evacuation and emergency service providers. Public transit is also important to provide access to hospitals, healthcare facilities, and shelters, especially for residents without access to a car. The District Department of Transportation (DDOT) conducted a Climate Change Vulnerability Assessment that identified classes of assets such as bridges and roadways vulnerable to change in temperature, precipitation and sea level rise / storm surge (DDOT, 2013). This report analyzed the same classes of assets to identify those most likely to be impacted by flooding. The economic and operational impacts of failure of the transportation infrastructure has been assessed in a qualitative manner as part of the risk ranking.

Roadways

Map 5 shows the high usage roads, as defined by their AADT counts according to the US Department of Transportation (DOT) that were assessed to be most at-risk. These roads are of particular importance for commuter and freight travel, and are therefore highly consequential if impacted during a major weather event. Many are also designated evacuation routes. Any impacts to the road network along these segments would have cascading impacts on other critical services, such as hospitals, public safety, as well as on commercial and business activities.

This study assesses roadways with AADT above 16,000 vehicles. Many of these key roadways are at high risk of being impacted by flooding due to their proximity to the Potomac and Anacostia Rivers. In addition, sections of important interior urban roadways such as Pennsylvania Avenue and Massachusetts Avenue are at risk of flooding.

Overall, it is assumed that the District's roadway infrastructure is not highly vulnerable to heat. This is primarily due to the low sensitivity of roadways to heat. However, taking into consideration that by 2080 there could be heatwaves lasting from 9.5 - 12 days, current standards might need to be revised to prevent buckling.

Tunnels, Bridges, & Underpasses

As the District is bordered by the Potmac River and bisected by the Anacostia River, bridges are an integral part of all modes of the transportation system.. In addition to being critical routes for vehicular traffic, multiple bridges are critical components of the subway and rail systems and/or support bus routes.

Most bridges along the Potomac and Anacostia Rivers are projected to face increased exposure to flooding impacts. In this report, a few key bridges, such as the 14th Street Bridges[7] and the Francis Case Memorial Bridge, have been identified as most critical as they are part of the most heavily used roadways and/or are part of the Metrorail and railroad network. Tunnels that are part of the transportation network with higher roadway volumes, as measures by AADT counts, that are currently or will be exposed to flooding have also been identified.

7. The 14th Street Bridge refers to the group of three highway bridges (Rochambeau, George Mason Memorial, and Arland Williams Memorial), a railroad bridge (Long), and a Metrorail bridge (Fenwick Metro Transit) that span the Potomac.

TRANSIT

WMATA Metrorail Lines & Stations

The main form of public transportation in the region is the Metrorail operated by WMATA. WMATA's rail and bus lines account for 85 percent of the public transportation in the region. During peak ridership times, many of the Metrorail lines are already at full capacity. WMATA is in the process of upgrading six-car trains to eight-car trains to account for growing system traffic.

As documented by the mapping of historic flooding, Metrorail is already experiencing repetitive flooding in key locations including the Federal Triangle and Archives stations. This flooding is likely to be exacerbated by increased precipitation. Consequently, many assets of the Metrorail system are identified as at-risk as early as 2020. WMATA received funding through the Federal Transit Administration's (FTA) Emergency Relief Program following Hurricane Sandy to mitigate flood risks. The funding will be used to raise vent covers and make other improvements to block stormwater from entering Metrorail tunnels and also to install drainage improvements at 133 sites throughout system (FTA, 2014).

For heat stress, as for roadways, it is assumed that current design standards (e.g., neutral temperature for continuous welded rail) might not be sufficient to prevent buckling as heat stress is likely to increase significantly by 2080. Most of the Metrorail segments and stations in the District are underground and have cooling systems, making them less sensitive and more able to adapt to increasing heat. The aboveground segments that could be more vulnerable to heat impacts are the Yellow Line from L'Enfant Plaza to Pentagon (this segment also crosses the Potomac River via the Yellow Line bridge), the Orange Line from Stadium Armory to Deanwood, and the Red Line from NOMA/Gallaudet University to Brookland CUA. Many of the above ground stations are in Maryland and Virginia, outside of the District's boundaries. However, when there are failures at these stations there are almost always service disruptions to the lines as they travel through the District. This further highlights the need for cooperation among jurisdictions for future adaptation planning.

Railroad

Railroads represent 15 percent of public transportation and comprises the Virginia Railway Express (VRE) and the Maryland Area Regional Commuter (MARC) lines (MWCOG, 2015). AMTRAK is also assessed as part of the regional and national system and a portion of the CSX line is assessed for freight transportation.

Railroad segments are also already experiencing repetitive flooding in key locations, such as the Amtrak Mid-Atlantic line in the District and the CSX line in the Kenilworth area. This flooding is likely to be exacerbated by increased precipitation, sea level rise, and storm surge. Consequently, many assets are identified at risk as early as 2020.

For heat stress, several important railroad lines are aboveground and are therefore more exposed to increased temperatures. It is assumed that current design standards might not be sufficient to prevent buckling as heat stress is likely to increase significantly by 2080.

Bicycling Infrastructure

The District's extensive bicycling infrastructure, including dedicated bike lanes and the Capital Bikeshare system, has grown significantly in recent years. Bicycling can provide valuable alternative transportation options following a disaster. In New York City following Hurricane Sandy, pedestrians and bicyclists represented more than half the river crossings from New Jersey to Manhattan while the subway system was shut down and roads were congested (City of New York, 2013). In response, some 20,000 New Yorkers who usually used other forms of transportation commuted by bike. In the District, Capital Bikeshare stations are powered by solar panels, ensuring that they can provide service even during a power outage. The modularity and ease of installing stations gives Capital Bikeshare a high level of adaptive capacity. For example, temporary Bikeshare stations could be set up in key locations if transit service is disrupted. In light of the growing rate of cycling and its importance in providing mobility in post-disaster situations, Capital Bikeshare locations at risk of flooding have been identified.

WATER

The water infrastructure system is essential to treat and distribute potable water to residents and commercial facilities, provide flood protection, and collect stormwater and wastewater throughout the District. During extreme weather events, water infrastructure and operations can be significantly impacted. This assessment covers many forms of water infrastructure including the wastewater treatment plant, wastewater, and stormwater collection systems.

As reported in the 2015 State of the Region Infrastructure Report, while many of the region's drinking water and wastewater systems have made significant investments in upgrades and expansions, large segments of water and wastewater pipes in the ground are 50 - 80 years old. DC Water averages 400 to 500 water main breaks a year, which are exacerbated by cold weather. Accordingly, DC Water has an extensive, multi-billion dollar capital improvement program to update its aging infrastructure including replacing or repairing water mains and replacing valves and hydrants that will increase its resiliency (DC Water, 2015).

Water Supply, Treatment, and Distribution Infrastructure

The drinking water supply, treatment, and distribution infrastructure in the District is owned and operated by DC Water and the Washington Aqueduct (managed by the US Army Corps of Engineers). DC Water distributes drinking water and collects and treats wastewater. The Washington Aqueduct collects and treats drinking water at two plants - Dalecarlia and McMillan.

These systems serve all of the District's residents, businesses, institutions, and government agencies. The District's water is sourced entirely from the Potomac River. The Interstate Commission on the Potomac River Basin conducts water demand and resource availability forecasts every five years. Their most recent report included climate change forecasts (2015). The study concluded that an increase in precipitation could positively impact water availability and allow for meeting projected increases in demand in 2040. However, it also reported that uncertainty remains and that despite an overall increase in precipitation, periods of drought could impact the reliability of supply.

In addition to impacts on the availability of supply, the drinking water infrastructure system could be impacted during extreme weather events in the following ways:

- Contamination of the water supply source from polluted stormwater runoff from heavy rainfall events, or from debris resulting from flooding upriver from the District.
- High-heat impacts to the unit operations in the water treatment plant.
- Flooding at entry points in the distribution system, such as the air-release blow-off valves.
- Other impacts to the treatment plant under extreme weather events, such as extended loss of power supply at the plant, equipment inoperability, or inability of plant staff to get to the plant.

Stormwater, Sewer, and Combined Wastewater Collection System

The collection system for DC includes the sanitary sewer, combined sewer, and separate stormwater collection systems. The collection systems include pipes, manholes, catch basins, pump stations, detention/retention structures, and outfall structures. DOEE and DC Water's sewer separation projects and stormwater management efforts are addressing localized flooding problems and water quality issues for existing conditions. However, the District's collection system may be exposed to more extreme and frequent flooding conditions in the future due to the predicted increase in heavy precipitation events, as well as inundation from sea level rise and storm surge.

Few strategic stormwater outfalls have been identified to be at risk for flooding but more information, such as the contributing drainage area to the outfall, invert elevations of the outfalls, stormwater pipe sizes and pipes that are above their design capacity (which were not available for this study) is required to perform a more thorough vulnerability and risk assessment. It is also important to note that the storm sewer system in the District is designed to the convey stormwater for the present 15-year 24 hour storm which corresponds to 5.2 inches (according to NOAA Atlas 14) of rainfall. Based on design storm projections developed as part of the "Climate Projections and Scenario Development" report published by DDOE, the rainfall depth associated with this storm is projected to be 6.8 inches, 7.1 inches and 8 inches, by 2020s, 2050s and 2080s, respectively. Therefore, areas with storm sewers that are either at capacity or are already above capacity are more likely to experience more frequent and intense interior flooding driven by precipitation. In addition to flooding impacts from extreme precipitation events, the stormwater and combined sewer outfalls that discharge to the Potomac and Anacostia rivers and are at low elevations compared to mean sea level, will also be prone to flooding from sea level rise and storm surge "backing up" through the piped infrastructure and potentially flooding low-lying interior areas. It is recommended that the District needs to conduct detailed hydrologic/hydraulic modeling studies to understand the combined impacts of joint flooding from sea level rise and extreme precipitation events in the future.

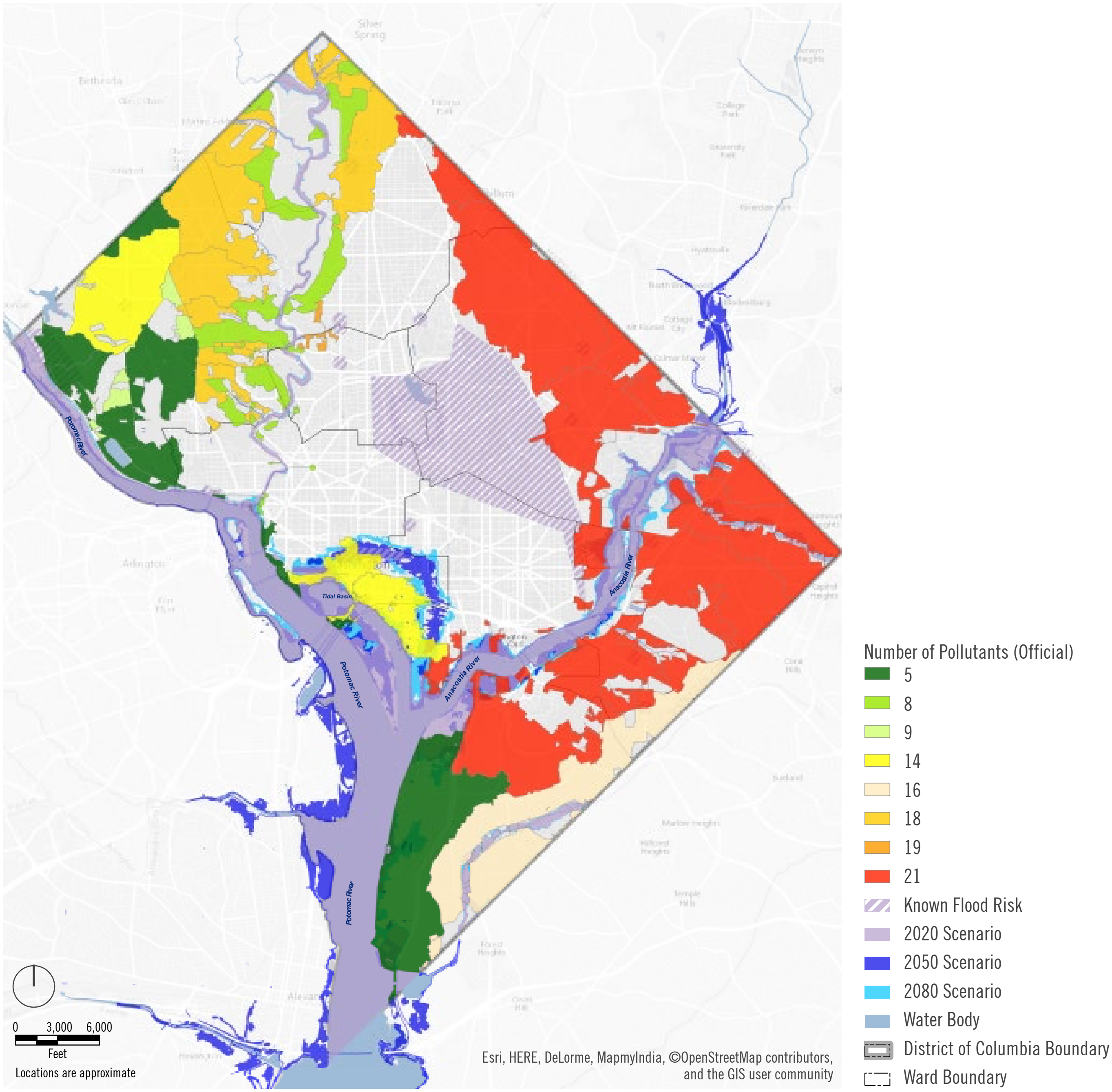
Wastewater collected through the sanitary and combined sewer system is treated at the Blue Plains Advanced Wastewater Treatment Plant, the largest advanced wastewater treatment plant in the world, with a design capacity of 384 million gallons per day covering 150 acres (DC Water). DC Water is already adapting the plant; which is located at one of the lowest points in the District along the Potomac River; to climate change through the construction of a seawall with top elevation of 17.2 feet (DC Datum) protecting against the present 500-year flood elevation of 14.2 feet-(DC Datum) plus three feet to account for sea level rise. (DC Water 2014). In addition to direct flooding impacts, the plant could also be potentially vulnerable to extended power outages.

In addition to flooding, the increased frequency of severe rain events could have a negative impact on water quality due to increased runoff. According to the District's 2014 Integrated Report on Water Quality Assessment[8], of the 36 waterbody segments monitored for the goals of the Clean Water Act that apply to the District, no waterbody monitored fully supported all of its designated uses and hence were considered as impaired. The Water Quality Map (Map 6) shows the number of official pollutants that cause water quality impairment as measured from recent sampling by DOEE. The areas in red, orange, yellow are the most impaired in terms of water quality and pollutant loading. With increased precipitation under climate change scenarios, the volume of stormwater runoff (both overland and from stormwater outfalls) to abutting water bodies are projected to increase. This may cause an increase in pollutant loading and/or increase the number of pollutants in the Potomac and Anacostia Rivers and their tributaries.

For the vulnerability and risk ranking, the number of pollutants reported in water bodies, as well as the runoff co-efficient per Ward were factored. A higher runoff coefficient means more impervious area and a lower coefficient means lower impervious area. The surface water quality in most of Wards 5 and 7, and portions of Wards 6 and 8 is already impaired considering the large number of pollutants reported in these water bodies as shown in Map 6. Since these areas also have a higher runoff coefficient, they are more likely to be vulnerable to water quality impairment due to increased stormwater runoff from more frequent and intense rainfall events as a result of climate change. The higher share of impervious area in these wards implies that urban stormwater runoff could be one of the major sources of water quality impairment. These targeted areas have the potential for implementation of green infrastructure which will have the dual benefit of mitigating stormwater runoff volume and improving water quality from increased infiltration and filtering out pollutants.

8. The District of Columbia Water Quality Assessment 2014 Integrated Report to the US EPA and Congress (http://doee.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/Integrated%20Report%20to%20EPA%20and%20US%20Congress%20regarding%20DC%E2%80%99s%20Water%20Quality%20%E2%80%93%202014_0.pdf)

WATER QUALITY WITH FLOODING SCENARIOS



MAP 6: Water Quality with flooding scenarios 2020, 2050 and 2080 (Source: Kleinfelder and DDOE DC, November 2015)

TELECOMMUNICATION

Telecommunication refers to the electronic transmission of information over distance including voice, data, and images. Telecommunication networks are instrumental for information exchange and serve as crisis communication networks during a disaster. The primary causes for telecommunication infrastructure failure during disasters are:

- Physical destruction of network components that are exposed to hazards such as flooding;
- Disruption of the supporting network infrastructure such as to the electrical distribution system;
- Network congestion.

The telecommunication network as represented by AM/FM radio towers, cellular towers, and TV towers are the rudimentary elements of the District's communication grid, which are still important channels for conveying information publicly. Disruption of these communication networks could limit the public's accessibility to information through television and radio, which may be used by a significant proportion of the population to receive emergency notifications.

Only two telecommunication assets are identified to be at risk of flooding as documented by historic flooding. These are the cellular radio transmission towers located at 1844 3rd Street NW and 900 V Street NE. All remaining assets are outside identified flooding areas for 2050 and 2080. However, it should be noted that the telecommunications system is highly dependent on the energy system. It is also anticipated that the system is resilient to heat and might only be impacted by 2080 when heatwaves gain in intensity and duration as system components may be subject to overheating. Consequently, according to available information, the telecommunication system is considered to be marginally impacted by climate change, but this should be revisited as more information is available.


PHOTO CREDIT: JOHN SONDERMAN. SUSTAINABLE DC, CLIMATE CHANGE PHOTO CONTEST

03

COMMUNITY RESOURCES VULNERABILITY & RISK ASSESSMENT

The following section presents an overview of the vulnerability of the facilities used by the District to provide important social services to people and their communities. Many of these community resources, such as public housing and senior wellness centers, are especially important because of the role they play in providing support to residents that are most vulnerable to climate change impacts.

As outlined in the following section, vulnerable residents include those with less capacity to respond to disasters, or who may be more sensitive to events such as heat waves. For example, seniors, especially those on a fixed income, have fewer financial resources to move should their home be damaged in a flood; or they may be more likely to suffer negative health impacts during a heatwave. Therefore, senior housing, as well as wellness centers that provide services to seniors, are included as critical assets in this assessment. This section focuses on the physical buildings that provide services to vulnerable populations as well as all District residents, and the next section identifies the areas of the District where the largest number of vulnerable residents live.

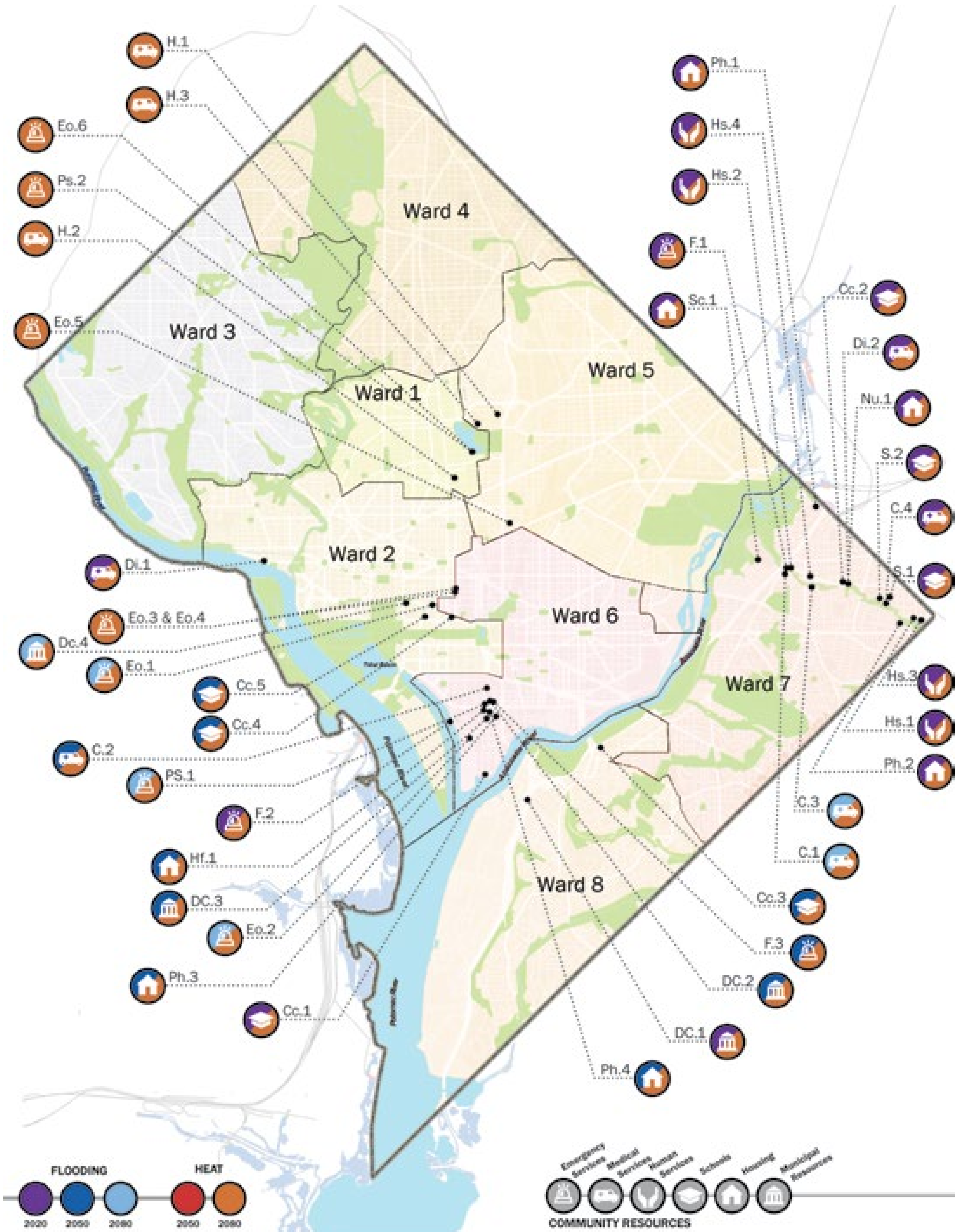
Key community resources addressed in this study include:

- District government agencies
- Emergency services including emergency operations centers, fire, and police stations
- Medical services including hospitals, dialysis clinics, primary care, and interim care centers
- Human services including libraries, recreation centers, and facilities operated by the Department of Youth and Rehabilitation Services
- Schools and child care centers
- Public housing, nursing homes, senior centers, and homeless shelters

Figure 3 and Map 6 present a compilation of key community resources identified to be most at risk based on projected climate change impacts. This first level assessment does not consider the specifics of each facility's building systems or flood-proofing, but rather their location in areas likely to be exposed to flooding. It has been assumed that all buildings have some means to cope with heat up to 2080 when substantial increase in heat wave intensity and duration would test the buildings' systems beyond the conditions they were designed to operate under. Although, it should be noted that buildings could be unusable in the event of a prolonged power failure during a heat wave. A more detailed site-level assessment could provide additional information on adaptive capacity by identifying facilities with backup power, adequate flood proofing, air conditioning, or passive cooling capabilities, etc.

The District Government has Continuity of Operations Plans (COOP plans) for all District agencies to ensure that critical services can be provided following a disaster or disruption. The District also has mutual aid agreements in place with neighboring jurisdictions, which help to minimize disruptions to services. However, a large-scale event with citywide or regional consequences would limit the District's ability to identify alternative service providers and locations. These factors have been accounted for in evaluating the potential consequence of damage to a facility.

COMMUNITY RESOURCES MOST AT RISK



MAP 7: Compilation of Community Resources Most at Risk (Source: Kleinfelder, February 2016)

			DEPARTMENT	ADDRESS	FLOODING Historic	FLOODING 2020	FLOODING 2050	FLOODING 2080	HEAT 2050	HEAT 2080
DC Agencies		DC.1	Motor Vehicles, Department of	2390 South Capitol Street SE		Yes	Yes	Yes		Yes
		DC.2	Motor Vehicles, Department of	95 M Street SW			Yes	Yes		
		DC.3	Employment Services, Department of	201 N Street SW			Yes	Yes		
		DC.4	Executive Office of the Mayor	1350 Pennsylvania Avenue NW				Yes		
Emergency Services	Emergency Operations Centers	EO.1	FBI Strategic Information and Operations Center (SIOC)	935 Pennsylvania Avenue NW				Yes		Yes
		EO.2	Military District of Washington	103 3rd Avenue SW				Yes		
		EO.3	WMATA	600 5th Street NW	Yes					
		EO.4	DC Fire Operations Command Center	500 F Street NW	Yes					
		EO.5	DC DOH	77 P Street NE	Yes					
		EO.6	DCG - MPD - Public Safety Communications	310 McMillan Drive NW	Yes					
	Police Stations	PS.1	First District Polices Station	101 M Street SW			Yes	Yes		Yes
		PS.2	Public Safety Communications Center	310 McMillan Drive NW	Yes					
	Fire Stations	F.1	Engine 27 Station	4201 Minnesota Avenue NE	Yes	Yes	Yes	Yes		Yes
		F.2	Fire Boats 1, 2, and 3	550 Water Street SW		Yes	Yes	Yes		
		F.3	Engine 7 Station	1101 Half Street SW				Yes		
Medical Services	Hospitals	H.1	Veterans Affairs Medical Center	50 Irving Street NW	Yes					Yes
		H.2	Howard University Hospital	2041 Georgia Avenue NW	Yes					
		H.3	Children's National Medical Center	111 Michigan Avenue NW	Yes					
	Dialysis Clinics	Di.1	Da Vita Georgetown	3223 K St NW		Yes	Yes	Yes		Yes
		Di.2	Grant Park Dialysis	5000 Nannie Helen Burroughs Ave SE		Yes	Yes	Yes		
	Primary Care	C.1	Unity - Hunt Place Health Center	4130 Hunt Place NE	Yes			Yes		Yes
		C.2	Unity - Southwest Health Center	850 Delaware Avenue SW			Yes	Yes		
		C.3	Careco 11	4501 Grant Street NE				Yes		
		C.4	RHD	401 56th Street NE		Yes	Yes	Yes		
Human Services	Dept. of Youth Rehab.	HS.1	Extended House (Buddy's Place)	6023 Clay Street NE		Yes	Yes	Yes		Yes
		HS.2	DCG - Fire & EMS Dept. - Minnesota Ave Station	4201 Minnesota Avenue NE	Yes	Yes	Yes	Yes		
		HS.3	DCG - Public Library - Deanwood Kiosk	62nd Street NE and Banks Place NE		Yes	Yes	Yes		
		HS.4	Marshall Heights - Willis Paul Greene Manor	4215 Nannie Helen Burroughs Avenue NE		Yes	Yes	Yes		
Schools	School	S.1	Drew Elementary School	5600 Eads Street NE		Yes	Yes	Yes		Yes
		S.2	H.D. Woodson Senior High School	5600 Eads Street NE		Yes	Yes	Yes		
	Childcare	Cc.1	Coast Guard Headquarters	2100 2nd Street SW		Yes	Yes	Yes		Yes
		Cc.2	Safe And Sound Day Care Center	4922 Nannie Helen Burroughs Avenue NE		Yes	Yes	Yes		
		Cc.3	Ola C. Franks Child Development Center	1310 Ridge Place SE			Yes	Yes		
		Cc.4	Federal Trade Commission Child Care Center	600 Pennsylvania Avenue NW	Yes		Yes	Yes		
		Cc.5	National Office CDC	1111 Constitution Avenue NW	Yes		Yes	Yes		
Housing	Nursing Homes	Nu.1	Deanwood Rehabilitation and Wellness Center	5000 Nannie Helen Burroughs Avenue NE		Yes	Yes	Yes		Yes
	Senior Centers	Sc.1	Marshall Heights - Michaux Senior Center	3700 Hayes Street NE		Yes	Yes	Yes		Yes
	Public Housing	PH.1	Kenilworth Courts	4500 Quarles Street NE	Yes	Yes	Yes	Yes		Yes
		PH.2	Capitol Gateway	201 58th Street NE		Yes	Yes	Yes		
		PH.3	James Creek	1265 Half Street SW			Yes	Yes		
		PH.4	Greenleaf	203 N Street SW			Yes	Yes		
	Homeless Facilities	Hf.1	Southwest Community House Senior Service Center	1200 Delaware Avenue SW			Yes	Yes		Yes

FIGURE 3: Compilation of Community Resources Most at Risk (Source: Kleinfelder, February 2016)

MUNICIPAL RESOURCES

District agencies are critical for the administrative support to the District's residents, commuters and workers, visitors and businesses. Municipal buildings have the capacity to provide operational and logistical support outside of their normal functions during emergencies. These include key municipal buildings, such as the John A. Wilson Building (Wilson Building), specific agency headquarters, and emergency operation centers.

Of the facilities identified as at risk, the Wilson Building is considered at highest risk as the offices located there provide critical administrative and emergency communication services. The Wilson Building has experienced flooding in the past and will continue to be vulnerable in the future to flooding resulting from extreme precipitation, as well as riverine and coastal flooding.

COOP plans have been put in place to ensure essential District agency functions continue during an emergency to protect District residents and visitors. Findings from this study should be coordinated with COOP efforts to ensure that alternate locations for agencies in the case of an emergency, are moved to buildings that are not located in vulnerable areas.

EMERGENCY SERVICES & PUBLIC SAFETY

Emergency services, including fire stations, police stations, and emergency operation centers, are vital for emergency support and recovery during and immediately following a disaster or climate change-related event. Consequently, emergency services should be located in areas protected from flooding. The Engine 27 Station on Minnesota Avenue and the Fire Boats 1, 2, and 3 facilities are among the public safety facilities most at risk. Engine 27 Station is within an area that has historically experienced flooding and is projected to flood in all of the scenarios in this study. Fire Boats 1, 2, and 3 are stored at a pier in the Washington Channel that could experience flooding by 2020. The boats may need to be moved up-river prior to a major flood event in order to be accessible for emergency operations in the aftermath.

MEDICAL SERVICES

Medical services encompass assets and resources associated with public health. These include hospitals, ambulatory services, dialysis, and community-based public health programs. This assessment of medical services focuses on assets located in the District only; it does not consider the facilities belonging to the greater regional network that are outside of District boundaries. There are three hospitals considered at risk of flooding under current conditions including the Veterans Affairs Medical Center, Howard University Hospital and the Children's National Medical Center. It is important to note that the three hospitals identified at risk for historic flooding are all located in proximity to each other; and even if some buildings providing health services are not directly impacted by flooding, flooding of surrounding streets in this area could impede access. The District should further study the implications to continuity of health care and services if an extreme flooding event were to impact all three hospitals. This historic flooding is most likely caused by drainage capacity issues of the stormwater system in these areas, which are likely to be exacerbated by more frequent and intense precipitation events in the future. Of the seven documented dialysis clinics, two are at risk: one in Georgetown and one in Deanwood.

HUMAN SERVICES

Human services refer here to public and privates services and resources dedicated to supporting diverse sections of the population. These include the Department of Human Services (DHS), the Department of Youth Rehabilitation Services (DYRS), and other organizations' intermediate care facilities providing behavioral, mental health, and other forms of support to vulnerable groups. Potential impacts from flooding may have significant consequences for a broad spectrum of communities that require access to these programs. Public libraries, recreation centers, and post offices are also included as they provide gathering places and information services that enable members of the community to receive and ask for help. Most of the human services facilities identified as at highest risk of flooding are located in Ward 7, near the Watts Branch of the Anacostia River.

SCHOOLS

This assessment included K-12 schools and childcare facilities, including special education facilities that serve students with special needs. Schools and childcare facilities are valuable community assets, and their closure can be disruptive and costly for families. Most of the schools and childcare facilities identified as at risk of flooding under current conditions or by 2020-2050 are located in the floodplain of the Anacostia River and the Watts Branch impacting Wards 6, 7 and 8.

PUBLIC & SENIOR HOUSING, SHELTERS

Public housing, managed by the District of Columbia Housing Authority (DCHA), provides critical affordable housing for low-income families and individuals. Residents of public housing have fewer resources to evacuate or relocate if their housing is damaged, and there is little redundancy in the availability of affordable units to house households that may be displaced. The public housing locations most at risk are Kenilworth Courts in Ward 7 (290 units), Capitol Gateway in Ward 7 (29 units), James Creek in Ward 6 (239 units), and the Greenleaf complex in Ward 6 (493 units). Combined, these developments provide 1051 housing units. Greenleaf also includes a senior center and the Southwest Family Enhancement Career Center which provides job training and family support services.

Senior centers and nursing homes were also assessed. Due to age, mobility, and other health-related concerns, the elderly are more sensitive and therefore more vulnerable to climate change-related impacts, such as flooding and heatwaves. Disruptions to power supply could also create high risks for senior housing that lack backup power, or have insufficient power to provide heating and cooling. The Deanwood Rehabilitation and Wellness Center in Ward 7 is considered the most at-risk senior housing facility.

Homeless shelters have also been assessed as they support highly vulnerable populations. The Southwest Community House Senior Service Center, which is co-located with the Greenleaf Senior housing noted above, is at risk of flooding in the 2050 scenario. While the District has emergency shelter capacity for homeless individuals and families, a disruption such as flooding or power outage to even one facility could have significant consequences for the entire District.

PHOTO CREDIT: MISTY BROWN. SUSTAINABLE DC, CLIMATE CHANGE PHOTO CONTEST

04

VULNERABLE POPULATIONS

POPULATION AT RISK

The vulnerability of the social environment is assessed in two parts – vulnerable population, and community resources that are deemed critical to the support of vulnerable populations. The latter includes a broad variety of community based organizations and facilities that were considered in Section 3 of this report. Equity is an integral consideration for climate change and vulnerable populations are at increased risk. They are disproportionately affected in post-disaster response and recovery and more susceptible to negative health impacts associated with a changing climate (Melillo et al. 2014). Communities that prepare for the impacts of climate change can become more resilient as they rebuild and a first step is to identify populations and neighborhoods most at risk with the metropolitan area. Hurricane Katrina and its resulting desperation, desolation, and dislocation also brought into stark relief the intersection of natural disasters, human social systems, and the built environment. (Shannon et al. 2012) The storm and subsequent flooding dramatically and tragically exposed longstanding patterns of inequality that left some populations more vulnerable than others to the consequences of disaster. It is acknowledged that anticipated outcomes of the on-going recovery efforts in New Orleans and surrounding areas will be uneven across different social units, and many will never recover.

Heat has been the largest single weather-related cause of death in the US since NOAA began reporting data for heat in 1988. In addition, heat impacts on health are the most well understood, measurable, and yet preventable impacts of climate change. For many, simply being older, obese or diabetic are risk factors for heat-related morbidity and mortality (Basu and Samet, 2002). It is also recognized that those with respiratory or circulatory disease face greater physiological challenges during extreme or prolonged heatwaves (Anderson and Bell, 2009). A large number of studies have characterized health responses during and following severe heat waves such as the European heat wave of 2003 (Vandentorren et al., 2004) and the 1995 heat wave in Chicago.

VULNERABLE POPULATIONS

The social vulnerability assessment has been performed to identify where the most vulnerable populations live in the District. Social vulnerabilities are often more challenging to categorize and rank than those in the built environment since they are defined by a complex set of demographic, economic, and health factors that impact an individual's sensitivity to climate change and adaptive capacity. **Sensitivity** to climate change is based on social and biophysical aspects that might predispose individuals to being more sensitive to climate impacts such as heatwaves and flooding. **Adaptive capacity** refers to an individuals ability to adapt and respond to the stresses caused by climate change. Social indicators of sensitivity and adaptive capacity were derived from the demographic and place-based indicators as reported in the Sustainable DC Plan.[9 10]

Unemployment, educational attainment (those without a high school diploma), and poverty prevalence were used as proxies for populations with less access to medical care or ameliorating living conditions, such as access to air conditioning, and with less financial resources to cope with disruptions. These indicators affect both sensitivity and adaptive capacity. Rates of obesity and adult asthma and age were used as a proxy for those less physiologically able to cope with flooding and heat, and who therefore are more sensitive. The methodology used for identifying the most vulnerable populations is further described in Appendix 1.

Sensitivity	Adaptive Capacity
Unemployment	Unemployment
Educational attainment (without HS diploma)	Educational attainment (without HS diploma)
Poverty prevalence	Poverty prevalence
Obesity	
Adult asthma	
Senior	

FIGURE 4: Sensitivity and Adaptive Capacity Indicators[11]

9. "Senior", as reported in U.S. Census data (2014) for population of 65 years and above, has been added the indicators from Sustainable DC as a key indicator of sensitivity to heat.
10. Metrics and methodology Attachment titled Social Vulnerability and Ranking Protocol for a complete report on the methodology for determining the vulnerable population index. are reported in Attachment titled Social Vulnerability and Ranking Protocol.
11. The Indicators are Census based Social Indicators per Wardas reported in Sustainable DC.

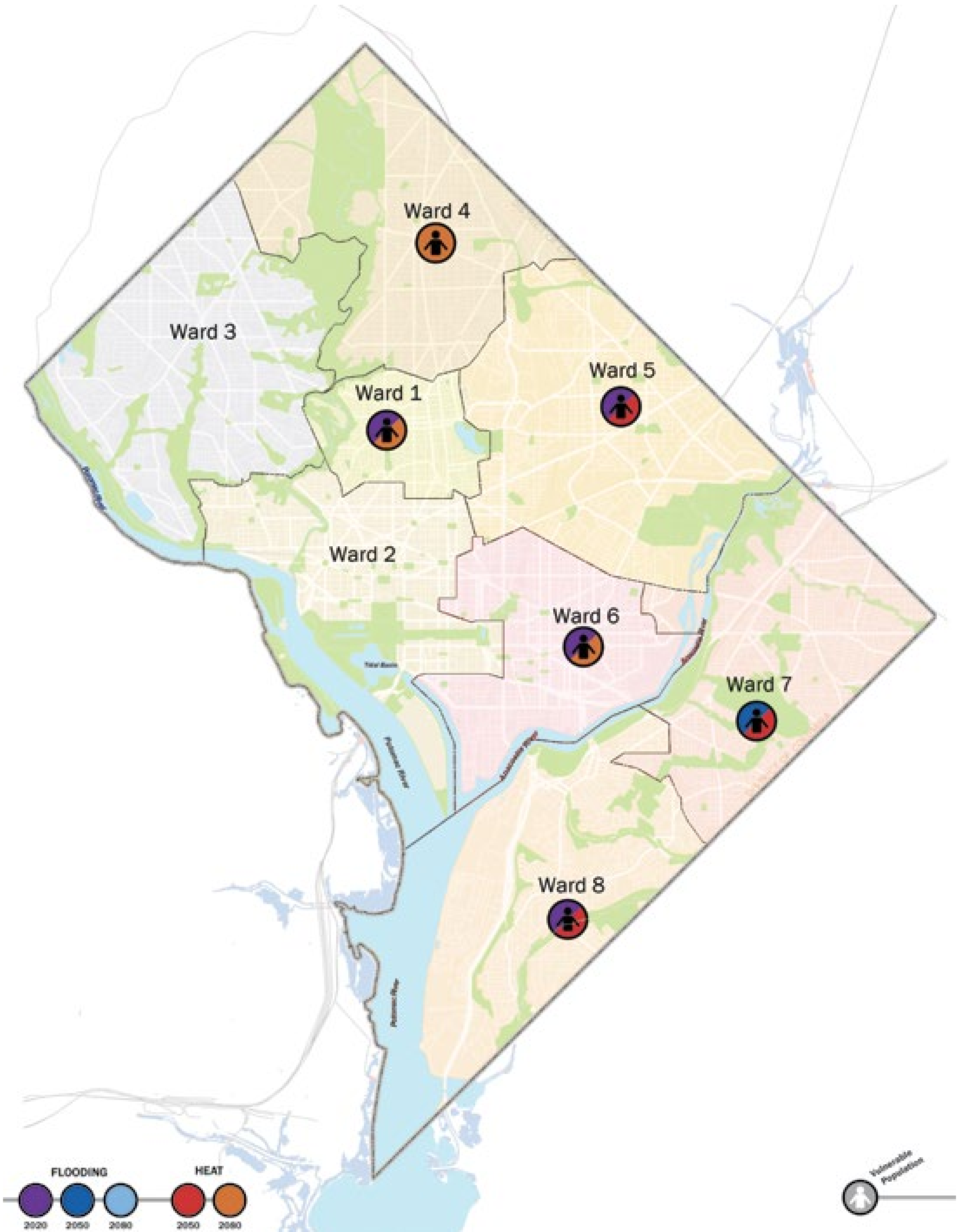
The purpose of this assessment is to provide a first step in identifying areas with the greatest number of residents vulnerable to the impacts of climate change. There are other factors that more comprehensively define vulnerable populations such as adults and children who have mobility limitations or developmental disorders, non-English or limited-English speakers, and immigrant communities. Subsequent analyses should include these factors.

Map 8 illustrates the wards with the largest number of vulnerable residents, and which climate impacts (heat or flooding) will likely impact each. The shades of blue represent if the ward is likely to be impacted by flooding as reported in the climate change scenarios for 2020 (purple), 2050 (dark blue) or 2080 (light blue). Vulnerable populations likely to be most impacted by heat, as informed by social and biophysiological indicators, are illustrated by shades of orange and red for 2050 and 2080.

Mapping the vulnerability rankings of the wards illustrates that social vulnerability is not evenly distributed across the city. Populations at risk (as defined by a high sensitivity and low adaptive capacity) are located in Wards 1, 5 and 6, with the largest populations in Wards 7 and 8. The easternmost Wards, 5, 6, 7, and 8, are home to the largest number of vulnerable populations, and are also vulnerable to flooding. Ward 4 also has large numbers of residents vulnerable to heat.

The difference in population per Ward was not considered. At the time data was compiled for the Sustainable DC Plan, Ward 7 had the lowest population (65,777), and Ward 6 had the highest (83,821). Density per Ward could be an additional indicator of possible stress to flood and heat exposures by increasing the number of people effected by a particular event or disruption like a power outage and in need of emergency services.

VULNERABLE POPULATIONS PER WARD



MAP 8: Vulnerable Populations per Ward (Source: Kleinfelder, February 2016)


PHOTO CREDIT: ALEXANDRA HAY. SUSTAINABLE DC, CLIMATE CHANGE PHOTO CONTEST

05

NEXT STEPS

In the Climate projections and Scenario Development report, we reviewed the science to determine how climate change is likely to impact the District. In this report we assess the vulnerability of the District's infrastructure, community resources, and populations to those impacts and prioritized them based on the risks.

It is important to emphasize that the climate scenarios used for this report present a combination of possible flood and extreme heat events, which can be considered as "probable futures" that serve as guidance for future adaptation planning. These projections are meant to be reviewed and updated as the science of climate change evolves with new tools and is informed by revised observed trends.

Following the Vulnerability Assessment the team will create an Adaptation Plan to help implement some of the changes that will need to occur in the District in order to respond to the climate change projections and identified vulnerabilities in Tasks 1 & 2 Reports.

An important next step will be to combine resources and to refine the message from the District as a whole. Key actions include:

- Develop the governance structure and partnerships with lead agencies, stakeholders who have parallel efforts ongoing.
- Establish schedule for completion of remaining assessments noted herein while establishing metrics + evaluation approaches.
- Identify funding sources and lead agencies for remaining assessments.
- Begin discussions regarding public/public-private financing and detailed implementation strategies.

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