# A Climate Resilience Research Agenda for the Greater Philadelphia Area

## Findings from 2021 Working Group Discussions
## And
## Updated CMIP6 Projections for the Region

Edited by Nicole Pearl and Franco Montalto

# Preface

The Climate Resilience Research Agenda (CRRA) was developed through a collaboration formed in 2019 between the City of Philadelphia, the Delaware Valley Regional Planning Commission (DVRPC), the Academy of Natural Sciences (ANS) of Drexel University, and Drexel University faculty and staff engaged in the Consortium for Climate Risks in the Urban Northeast (CCRUN).

In that year, Drexel undergraduate students had petitioned the University to take more institutional action on climate change. They organized a Climate Rally attended by students, faculty, and representatives of several NGOs, and obtained over 2000 signatures in support of a student-led proposal to form a Sustainability Office on campus. Though the COVID-19 pandemic soon closed campus, Drexel's leadership responded by declaring 2021 "Climate Year," and committing the university to acceleration of its climate-focused research, civic engagement, and collaboration throughout the city and region.

In recognition of this institutional commitment, Drexel was invited to join the University Climate Change Coalition (UC3), an alliance of more than 20 leading research universities working to build resilience to climate change in their communities. One requirement of UC3 members is that they convene local stakeholders to discuss the climate risks facing the region.

To plan its convening, Drexel took a collaborative, outward-looking approach, reaching out to the partners listed above, each of which was independently engaged in climate initiatives in the Philadelphia region. A Planning Team was formed including:

- Franco Montalto and Korin Tangtrakul, Drexel University/CCRUN
- Hugh Johnson and Jennifer Britton, Drexel University
- Richard Johnson, Alexis Schulman and Roland Wall, ANS
- Saleem Chapman and Matina Granieri, City of Philadelphia Office of Sustainability
- Julia Rockwell, Philadelphia Water Department
- Chris Linn, Robert Graff and Miles Owen, DVRPC
- Ariella Maron, LION Advisors

Together, the Planning Team recruited a much larger team that, through four Working Groups, developed the research needs articulated in this document. The *Climate Resilience Research Agenda* (CRRA) is a ***co-produced preliminary list of research activities that, if undertaken, could help to make the Philadelphia region[1] more resilient to climate change***. Rather than a traditional focus on climate mitigation or climate adaptation, Working Group members deliberated more broadly about how climate action could be integrated into decisions, policies, and strategies that could collectively make the region more resilient to climate change, a field that the Intergovernmental Panel on Climate Change describes as *Climate Resilient Development*.

The research activities listed in this document constitute a ***first step*** **in what must become an ongoing, inclusive public discussion regarding how this region will address the challenges**

[1] *The CRRA Planning Team acknowledges that the entire Philadelphia region is located on Lenapehoking, the traditional land of the Lenni-Lenape tribal nation, most of whom were forcibly removed over the last few centuries. We recognize the Lenni-Lenape as the original people of this land and their continuing relationship with their territory. In our acknowledgement of the continued presence of the Lenape people in their homeland, we affirm the aspiration of the great Lenape Chief Tamanend, that there be harmony between the indigenous people of this land and the descendants of the immigrants to this land, 'as long as the rivers and creeks flow, and the sun, moon, and stars shine.'*

**of climate change.** The intended audience is much more than a group of traditional academic researchers. Rather, the hope is that the needs articulated herein will provide important context for decision-makers and policymakers, practitioners, philanthropic organizations, community-based organizations, and others as they incrementally work to make the region more climate resilient. The Planning Team invites all who read this document to become part of this process.

*A 2/28/20 Climate Rally attended by students, faculty, and NGOs held on the campus of Drexel University*

# CRRA Participants

The following individuals participated in the CRRA process:

- Abby Sullivan, Philadelphia Water Department, currently at City of Philadelphia Office of Sustainability
- Adam Hendricks, Philadelphia Water Department
- Alan Bush, PhD, University of South Florida (based in Philadelphia)
- Alexandra Skula, Philadelphia Department of Public Health
- Allison Lassiter, University of Pennsylvania
- Allison Lau, Philadelphia Water Department, Climate Change Adaptation Program
- Andrew Belfiglio, Fox Chase Cancer Center, Penn Injury Science Center
- Andrew F. Smith, Drexel University
- Ariel A Ben-Amos, Philadelphia Water Department
- Arthur Frank MD, PhD, Drexel University SPH
- Ben Morrow, McCormick Taylor, Inc.
- Bethany Wiggin, University of Pennsylvania
- Bridget Wadzuk, Villanova University
- Brooke Petry, Moms Clean Air Force
- Carlos Claussell Velez, Institute for Sustainable Communities
- Carolyn Kousky, University of Pennsylvania
- Carr Everbach, Swarthmore College
- Charles Ellison, WURD & ecoWURD, 2023 Emerson Collective Fellow
- Charles Haas, Drexel University
- Cheyenne Flores, City of Philadelphia Office of Sustainability
- Christopher Gillespie, Energetics, Inc.
- Christina Rosan, PhD, Temple University
- Dan Bader, Consortium for Climate Risk in the Urban Northeast (CCRUN)
- Daniel Szekeres, Michael Baker International
- Darlene Cavalier, Arizona State Univ and SciStarter
- David Mazzocco, The Sheward Partnership
- Denis Devine, N/A
- Derek Ruhl, PA Public Utility Commission
- Dion Lerman, Pennsylvania Intergrated Pest Management Program/Penn State
- Donald Azuma
- Dorothy (Dottie) Ives Dewey, West Chester University
- Drew Anderson, West Chester University & WFMZ-TV
- Drew Jones, Merck Global Vaccines Organization
- Eliza Alford, Office of City Councilmember at Large Katherine Gilmore Richardson
- Elizabeth Brown, National Audubon Society
- Elizabeth Quinn, Grant Blvd, Drexel University
- Ellen Schultz, Fairmount Water Works
- Ellis Foley, Montgomery County Planning Commission
- Emily Watts, PennDOT
- Emma Giardina, Philadelphia Office of Emergency Management
- Emma Rakestraw, Jacobs
- Erica DePalma, The Water Center at Penn, currently at US Water Alliance
- Eugenia Victoria Ellis, Drexel University
- Franklin Mims, Southwest Leadership Academy Charter School
- Gabrielle Ratliff, Chester County
- Gennifer Rollins, Overbrook Environmental Education Center
- Gregory Scheirer, Dynamic Engineering Consultants, PC
- Hamil Pearsall, Temple University
- Hayden Smith, PHENND Sustainability
- Henry Felsman, Portfolio Associates
- Iulia Barbu, AECOM
- Jack Heide, FEMA Region II
- Jane Clougherty, Dornsife School of Public Health
- Jasmin Velez, Esperanza
- Jean Lynch, PA DCNR
- Jelena Matic, Inch and Meter, PC; also Adjunct Assistant Professor at Temple University
- Jenny Greenberg, Neighborhood Gardens Trust
- Jerry Fagliano, Drexel SPH
- Jessica Caum, Philadelphia Department of Public Health
- Jin Wen, PhD, Drexel University
- John Haak, Philadelphia City Planning Commission
- Jon Lesher, Montgomery County Planning Commission
- Josh Lippert, City of Philadelphia
- Joshua Moses, Haverford College

- Joyce Lee, IndigoJLD Green + Health; Econsult
- Judith Robinson, Susquehanna Clean Up/Pick Up,Inc.
- Julia Rockwell, Philadelphia Water Department
- Julie Ulrich, The Nature Conservancy
- Kaitlin Tucker, Partnership for the Delaware Estuary
- Katera Moore, PhD, University of Pennsylvania, currently at Delaware Department of Natural Resources and Environmental Control (DNREC)
- Katherine Liss, City of Philadelphia
- Katie Bartolotta, Green Building United
- Kermit O, Land/Food/Environmental Organizer
- Kevin Hess, PA Department of Environmental Protection, Coastal Resources Management Program
- Laura Barron, Reinvestment Fund
- Leah Schinasi, Drexel University
- Lindsey Walaski
- Liz Johnson, The Nature Conservancy
- Liza Herzog, LandHealth Institute
- Lyndell (Lindy) Backues, The Dialogue Institute at Temple University
- Lyndon DeSalvo, The Nature Conservancy
- Mari Radford, Federal Emergency Management Agency, Region 3, Mitigation Division
- Maria Dellapina, College of Nursing and Health Professions' AgeWell Collaboratory
- Marina Moses, CNHP/Health Admin Department
- Mark Maimone, CDM Smith
- Matt Slotman, NJ TRANSIT
- Melissa Tier, Princeton University, School of Public & International Affairs
- Micah Shapiro, PEER
- Michael DeVuono, Arcadis U.S., Inc.
- Michael Waring, Drexel University
- Michele Aquino, American University Center for Environmental Policy (School of Public Affairs)
- Michelle Barakat
- Michelle Niedermeier, Pennsylvania Sea Grant College Program (PASG), Penn State University
- Michelle Shuman , City of Philadelphia, Dept. Of Public Property, capital projects division
- Mira Olson, Drexel University
- Molly Hesson, Sage Services, LLC
- Nicole Ochroch, Delaware River Port Authority
- Patrick Gurian, Drexel
- Peleg Kremer, Villanova University
- Peter Barnard, City of Philadelphia Departments of Planning and Development (DPD) and Public Health (DPH)
- Philip Orton, Stevens Institute of Technology
- Radika Bhaskar, Thomas Jefferson University
- Raymond Scheinfeld, City of Philadelphia Division of Aviation
- Rebecca Collins, Temple University
- Richard Whiteford, Independent Environmental Journalist/Climate Reality Project Leader
- Rick Ricciardi, Marathon Engineering and Environmental Services, Inc
- Rob Fleming, THomas jefferson University
- Robert Traver, Villanova University - Civil and Env. Engineering
- Russell Zerbo, Clean Air Council
- Scott Quitel, LandHealth Institute
- Sebastian Malter, CDM Smith
- Simi Hoque, Drexel University, Dept. of Civil, Architectural, and Environmental Engineering
- Sonia Dattaray, Health Union, LLC
- Stefanie Kroll, Academy of Natural Sciences of Drexel University
- Stephanie Chiorean, Philadelphia Water Department
- Steve Krug, Krug Architects, PA Climate Change Advisory Committee
- Straso Jovanovski
- Susannah Anderson, Temple University College of Public Health
- Thomas Daniels, Weitzman School of Design at the University of Pennsylvania
- Thomas Salzer
- Tiffany Ledesma, Philadelphia Water Department, CDM Smith
- Todd Baylson, Solar States
- Tom Bonner, PECO
- Tonyehn Verkitus, Physicians for Social Responsibility Pennsylvania
- Ulysses Sean Vance, Temple University Tyler School of Art and Architecture
- Virginia Smith, Civil and Environmental Engineering/Villanova University
- Walter Tsou, PSR PA
- William Matulewicz, Colliers Engineering & Design, Inc
- Yocasta Lora, AARP Pennsylvan

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# Background

## General Description of the Greater Philadelphia Area

The urban heart of the region, Philadelphia is a large city in the Delaware River valley with a growing population of over 1.5 million residents. It is a racially and ethnically diverse city, with more than 40 percent[2] of the population identifying as Black or African American, 34 percent White, 15 percent Hispanic and 7 percent Asian. Philadelphia, like much of the Delaware River valley, sits on what was once called *Lenapehoking*, the land of the Lenni-Lenape tribal nation. Many Lenape language names are still found throughout region, such as Manayunk, Kingsessing, Wissahickon, Moyamensing and Shackamaxon[3]. Philadelphia is shaped by its vast network of rivers and creeks, including the Delaware and Schuylkill Rivers that bound Center City. It is endowed withs an extensive system of natural lands, including Fairmount Park, the nation's largest landscaped urban park.

Economically, Philadelphia is the poorest big city in the US[4], with nearly a quarter of its population falling below the poverty line. Though the job growth rate is increasing, and the poverty and unemployment rates are declining, there remain great disparities in the city. The poverty rate for non-White Philadelphians is higher than White Philadelphians[3]. The life expectancy rates can vary by up to 20 years in different neighborhoods[5]. These inequities are rooted in legacies of systemic and institutional racism, such as redlining, urban renewal, and discriminatory policing.

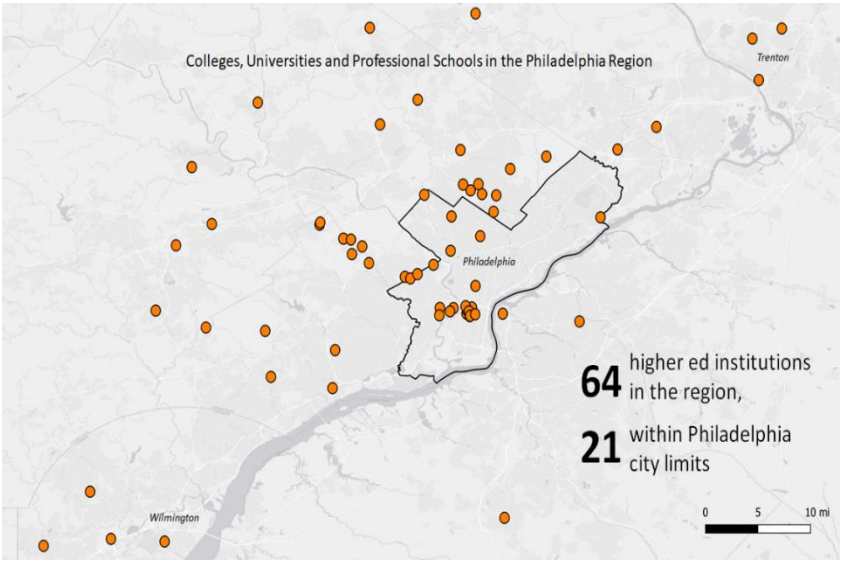


*Figure 1: Colleges, universities, and professional schools map layer from the Integrated Post-Secondary Education System (IPEDS) for the Homeland Infrastructure Foundation-Level Data (HIFLD) database.*

Despite its high rates of poverty and inequity, Philadelphia is also known for its rich history and its many institutions, including dozens of colleges and universities in the city proper and over a hundred in the greater region, and many renowned arts, culture, and science institutions (Figure 1).

[2] Philadelphia Department of Public Health, "Health of the City: Philadelphia's Community Health Assessment 2020". https://www.phila.gov/media/20201230141933/HealthOfTheCity-2020.pdf

[3] Nanticoke Lenni-Lenape Tribal Nation. https://nlltribe.com/

[4] Economy League of Greater Philadelphia, "The Changing Distribution of Poverty in Philadelphia". https://economyleague.org/providing-insight/leadingindicators/2020/12/16/phlpov19

[5] Center on Society and Health, Virginia Commonwealth University, "Mapping Life Expectancy: Philadelphia". https://societyhealth.vcu.edu/work/the-projects/mapsphiladelphia.html

# Climate Change and Philadelphia: Updated Regional CMIP 6 Data

As of this writing, the most up to date climate projections for Philadelphia are presented in Tables 1-4. The Intergovernmental Panel on Climate Change (IPCC) released CMIP 6 data in 2021. Researchers from the Consortium for Climate Risks in the Urban Northeast (CCRUN) downscaled the CMIP6 data to the Philadelphia region in 2022, timed with the publication of this report[6].

Philadelphia is expected to become both *hotter* and *wetter* in the future through increased precipitation, a rising sea level, and increased air temperature. In addition to these changes, extreme weather in the region is projected to continue to increase in frequency and severity, leading to increased riverine and stormwater flooding, among other impacts. Between 2020 to 2022, the region was significantly impacted by tidal flooding events, tropical cyclones (Ida, Henri, Fred, Elsa, Isaias), tornadoes, quick hitting winter storms, tidal flooding events, squalls, and other forms of severe weather.

Increased Precipitation

*Philadelphia is getting wetter* through increased precipitation. Over the past 82 years, annual average precipitation has increased at a rate of 0.82 inches per decade. In the observed record at Philadelphia International Airport, 6 of the 10 wettest years on record have occurred since 1990. While mean annual precipitation levels increased over the past century, year-to-year (and multi-year) variability of precipitation has also become more pronounced. The standard deviation, a measure of variability, increase from 6.1 inches for the 1941 - 1981 period, to 8.3 inches for the 1982 - 2022 period.

Mean annual precipitation is projected to increase 5 to 12 percent by the 2050s and 8 to 16 percent by the 2080s. Of more concern, but harder to predict, the frequency and intensity of precipitation events (such as hurricanes, Nor'easters, cloud bursts, and cyclones) is also increasing, causing more intense pluvial and fluvial flooding. For example, Hurricane Isaias struck Southwest Philadelphia in August 2020, covering large portions of the Eastwick community in upwards of four feet of water in a matter of minutes[7]. In September 2021, remnants of Hurricane Ida caused unprecedented flooding of the Vine Street Expressway due to the swelling of the Schuylkill River[8].

Rising River and Sea Level

*River and sea levels are rising.* Observations indicate that the tidal Delaware River rose at the rate of about 1.2 inches (0.3 meters) per decade over the last century (Figure 2). Sea level is projected to rise in Philadelphia by 7 to 11 inches by the 2030s, 14 to 19 inches by the 2050s, and 24 to 38 inches by the 2080s. The high-end estimate for sea level rise by the 2080s is 45 inches. By 2100, sea levels are projected to rise by as much as 64 inches. Sea level rise alone is increasing the number of days that Philadelphia experiences high tide—or sunny day--flooding (flooding due to tide levels in the absence of a storm). Coupled with storm surges, sea level rise is causing an increased frequency of coastal flooding, which is exacerbated further when accompanied by heavy precipitation events. As the sea level in the Delaware River Estuary

[6] A document summarizing the methods used to generate this data is provided in Appendix 1.

[7] WHYY, "Isaias emergency: Eastwick residents call for city, state aid after 'devastating' flooding". https://whyy.org/articles/isaias-emergency-eastwick-residents-call-for-city-state-aid-after-devastating-flooding/

[8] WHYY, "Why Ida's remnants left the Vine Street Expressway under water". https://whyy.org/articles/hurricane-ida-flooding-vine-street-expressway-infrastructure/

continues to rise, it will also push salty and brackish water upriver causing impacts to ecosystems and water treatment facilities designed to only accommodate fresh water.

*Table 1: CCRUN Precipitation Projections for the Philadelphia Region based on CMIP6. Projections are based on 35 GCMs and 2 SSPs. Shown are the low-estimate (10th percentile), middle range (25th to 75th percentile), and the high-estimate (90th percentile). Baseline data are for the 1981 to 2010 and are from the NOAA National Climatic Data Center (NCDC)*

| Decade | Low Estimate (10th Percentile) | Middle Range (25th to 75th Percentile) | High Estimate (90th Percentile) |
|---|---|---|---|
| 2030s | 0 percent | +2 percent to +8 percent | +10 percent |
| 2040s | +1 percent | +4 percent to +10 percent | +13 percent |
| 2050s | +2 percent | +5 percent to +12 percent | +14 percent |
| 2060s | +2 percent | +5 percent to +13 percent | +17 percent |
| 2070s | +3 percent | +7 percent to +14 percent | +18 percent |
| 2080s | +3 percent | +8 percent to +16 percent | +21 percent |
| 2100 | -2 percent | +6 percent to +22 percent | +30 percent |

*Figure 2: Source National Oceanic and Atmospheric Administration, Tides and Currents*

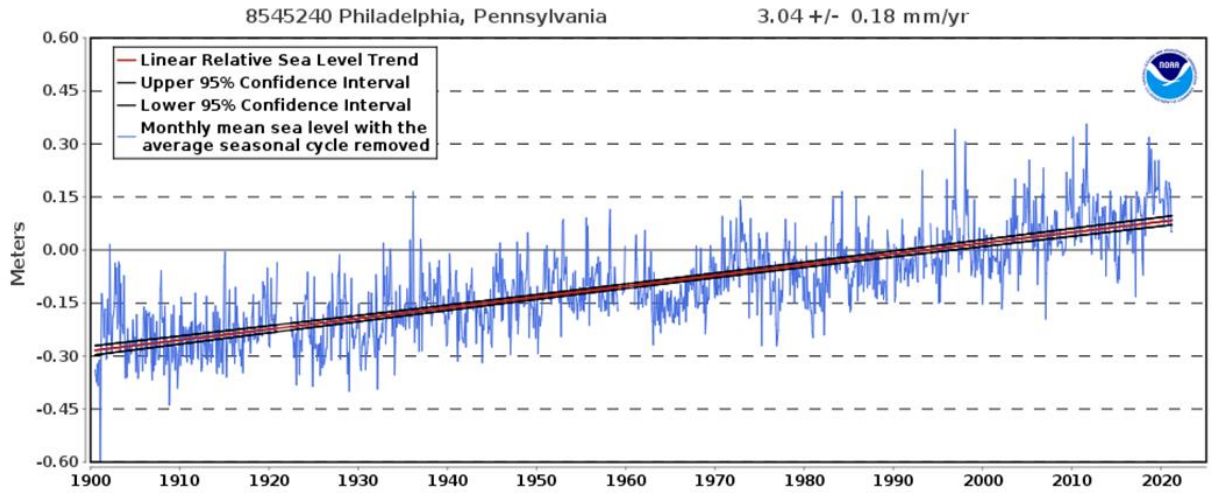

*Table 2: CCRUN Sea Level Rise Projections for the Philadelphia Region based on CMIP6 Projections for future sea level rise are derived from the IPCC's 6th Assessment Report. Projections are relative to the 1995 to 2014 based period. See et Fox-Kemper al., 2021 for a full description of the methods.*

| Decade | 10th Percentile | 25th Percentile | 50th Percentile | 75th Percentile | 90th Percentile |
|---|---|---|---|---|---|
| 2030s | 6 in. | 7 in. | 9 in. | 11 in. | 13 in. |
| 2050s | 12 in. | 14 in. | 16 in. | 19 in. | 23 in. |
| 2080s | 21 in. | 24 in. | 29 in. | 38 in. | 45 in. |
| 2100 | 25 in. | 29 in. | 36 in. | 50 in. | 64 in. |
| 2150 | 38 in. | 47 in. | 58 in. | 88 in. | 177 in. |

Increased Air Temperature

*Philadelphia is also getting hotter.* Over the past 82 years, annual average temperature has increased at a rate of 0.43 °F per decade. In the observed record at Philadelphia International Airport, 8 of the 10 hottest years on record have occurred since 2000.

Looking at extreme events, 7 of the 10 years with the most days at or above 90 degrees in the 83-year record have occurred since 1990. However, it is important to note that the number of events in any given year is highly variable and the long-term trends (1941 to present) for these heat events cannot be distinguished statistically from random variability.

In the near future, mean annual temperatures are projected to increase by 4.1 to 5.8 degrees F by the 2050s and by 5.5 to 9.4 by the 2080s. In addition to mean temperatures increasing, the frequency and intensity of hot days and heat waves is also projected to increase. By the 2050s, the numbers of days with maximum temperatures at or above 95 F (currently experienced on average 6 days per year) is projected to range from 21 to 34 days per year and by the 2080s, 34 to 72 days per year. The frequency of heat waves, defined as three or more consecutive days with maximum temperatures at or above 90 °F, may triple by the end of the century, from 3 events per year in the current climate to 9 events per year in the future.

*Table 3: CCRUN Air Temperature Projections for the Philadelphia Region based on CMIP6. Projections are based on 35GCMs and 2 SSPs. Shown are the low-estimate (10th percentile), middle range (25th to 75th percentile), and the high-estimate (90th percentile). Baseline data are for the 1981 to 2010 base period and are from the NOAA National Climatic Data Center (NCDC).*

| Decade | Low Estimate (10th Percentile) | Middle Range (25th to 75th Percentile) | High Estimate (90th Percentile) |
|---|---|---|---|
| 2030s | +1.9°F | +2.7°F to +3.9°F | +4.7°F |
| 2040s | +2.6°F | +3.3°F to +4.9°F | +5.9°F |
| 2050s | +3.0°F | +4.1°F to +5.8°F | +6.8°F |
| 2060s | +3.6°F | +4.7°F to +6.9°F | +8.5°F |
| 2070s | +4.0°F | +5.3°F to +8.0°F | +9.8°F |
| 2080s | +4.7°F | +5.5°F to +9.4°F | +11.1°F |
| 2100 | +4.9°F | +6.0°F to +10.5°F | +12.9°F |

*Table 4: CCRUN Climate Projections for the Philadelphia Region based on CMIP6. Projections are based on 16GCMs and 2 SSPs. Baseline data are for the 1981 to 2010 base period and are from the NOAA National Climatic Data Center (NCDC). Shown are the low-estimate (10th percentile), middle range (25th to 75th percentile), and high-estimate (90th percentile) 30-year mean values from model-based outcomes. Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty.*

| Extreme Event | Baseline | 2030s | 2050s | 2080s |
|---|---|---|---|---|
| # of days/year with maximum temperature at or above: | | | | |
| 90°F | 27 | 37 (47 to 56) 67 | 43 (56 to 72) 84 | 63 (72 to 102) 117 |
| 95°F | 6 | 11 (17 to 21) 27 | 17 (21 to 34) 51 | 27 (34 to 72) 88 |
| # of heat waves/year | 3 | 5 (6 to 7) 9 | 6 (7 to 9) 9 | 9 (9 to 9) 9 |
| Average length of heat waves (in days) | 5 | 5 (5 to 6) 6 | 5 (6 to 7) 8 | 6 (7 to 10) 12 |
| # of days/year with minimum temperature at or below 32°F | 84 | 45 (57 to 70) 70 | 23 (45 to 63) 63 | 2 (10 to 50) 57 |
| # of days per year with rainfall exceeding | | | | |
| 1 inch | 11 | 10 (11 to 12) 12 | 11 (11 to 13) 13 | 11 (12 to 14) 14 |
| 2 inches | 2 | 2 (2 to 2) 3 | 2 (2 to 3) 3 | 2 (2 to 3) 4 |
| 4 inches | 0.2 | 0.2 (0.2 to 0.2) 0.2 | 0.2 (0.2 to 0.3) 0.3 | 0.2 (0.2 to 0.3) 0.3 |

## What is Climate Resilience, Climate Resilient Development, and the Climate Resilience Research Agenda?

Without action backed by science, impacted community input, and equitable governance, forecasted changes to climate will exacerbate the environmental, economic, social, and health challenges currently facing the Philadelphia region.

*Climate Action* is the 13th of the United Nation's Sustainable Development Goals (SDGs). Climate Action includes both efforts to reduce the rate of global warming (e.g., Climate Mitigation) and to adjust to the climatic changes that have already taken place (e.g., Climate Adaptation).

*Climate Resilience*[9] refers to the capacity of a social, economic and/or natural system to cope with a climate hazard, trend, or disturbance, allowing them to maintain their essential functions through adaptation, learning, and/or transformation processes.

Introduced in the most recent IPCC report, *Climate Resilient Development* (CRD)[10] refers to a set of decisions, policies, and strategies that make a place more resilient to climate change by simultaneously addressing the goals of mitigation, adaptation, and sustainability. Through CRD, a region, municipality, or community *simultaneously* reduces its exposure and vulnerability to climate hazards, while cutting back its greenhouse gas (GHG) emissions, and advancing its social, environmental, economic, or health-related goals.

In an urbanized region like this one, implementation of CRD is complex because it involves tradeoffs, careful consideration of cascading multi-sector interactions, and unprecedented innovation. In this context, *research* can help to support a transition to CRD by elucidating the unique ways that the region's social, economic, ecological, and health conditions are related to its climate. Specifically, *climate resilience research* can help to:

- Fill knowledge gaps
- Weave together relevant knowledge that is embedded in different sectors
- Identify synergistic decisions, policies, strategies, or actions
- Understand climate hazards and risk
- Identify potential tradeoffs to a specific decision, policy, strategy, or action
- Identify barriers to action
- Broadly create the evidence base for climate action and policy

Developed through several months of collaboration by more than 100 individuals, the *Climate Resilience Research Agenda* (CRRA) is a ***co-produced preliminary list of research activities that, if undertaken, could help to make the Philadelphia region more resilient to climate change***. Rather than a traditional focus on climate mitigation or climate adaptation, the document focuses more broadly on strategies for integrating climate action into decisions, policies, and strategies that could collectively make the region more resilient to climate change. The intended audience is much more than a group of traditional academic researchers. Rather, the hope is that the needs articulated herein will provide important context for decision-makers and policymakers, practitioners, philanthropic organizations, community-based organizations, and others as they incrementally work to make the region more climate resilient. The CRRA is meant to be complimentary to other climate actions being taken throughout the region (Table 5)[11]**.**

[9] IPCC (2022) https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

[10] The term CRD remains under debate within the research community, yet the ambition to link adaptation, mitigation, and sustainability in climate action and practice remains an emerging central policy goal.

[11] See also extensive list of reports and academic papers included in Appendix 1.

*Table 5: Existing Climate Action, Climate Change, Sustainability, and Resilience Plans for the Philadelphia Region*

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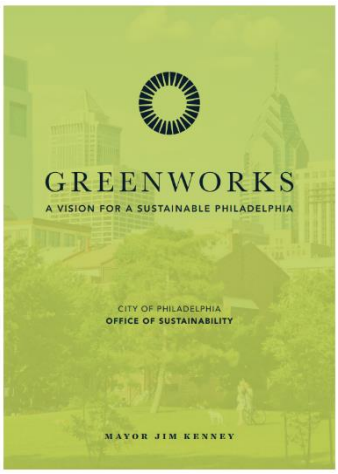
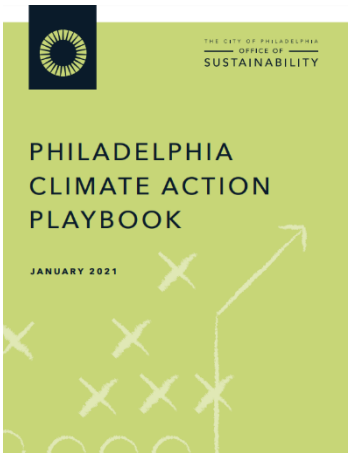
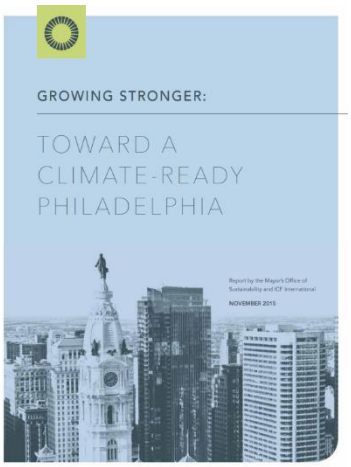
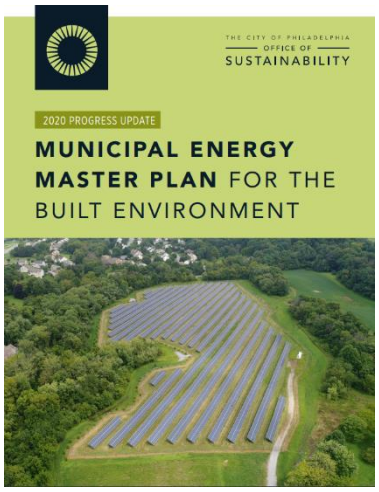
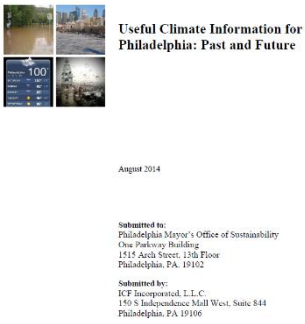
|  |  |  |
| [Greenworks Philadelphia] | [Philadelphia Climate Action Playbook] | [Growing Stronger: Towards a Climate Ready Philadelphia] |
| 2021 (updated) | 2020 | 2015 |
| Philadelphia Office of Sustainability | Philadelphia Office of Sustainability | Philadelphia Office of Sustainability |
|  |  |  |
| [Municipal Energy Master Plan] | [Useful Climate Science Report] | [Beat the Heat Toolkit] |
| 2020 (update) | 2016 | 2019 |
| Philadelphia Office of Sustainability | Philadelphia Office of Sustainability | Philadelphia Office of Sustainability |

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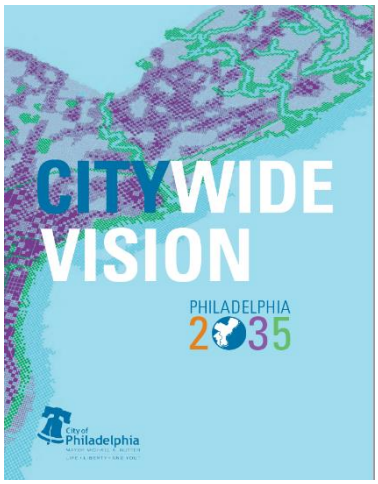
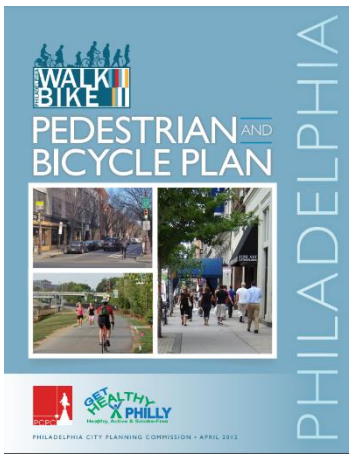
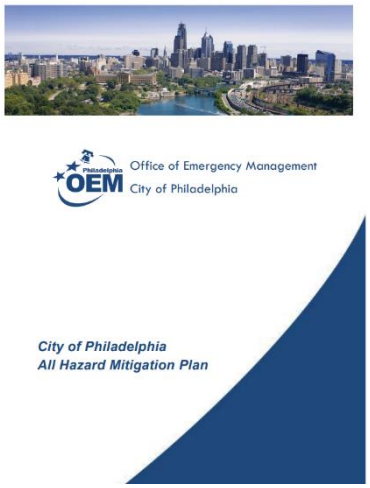
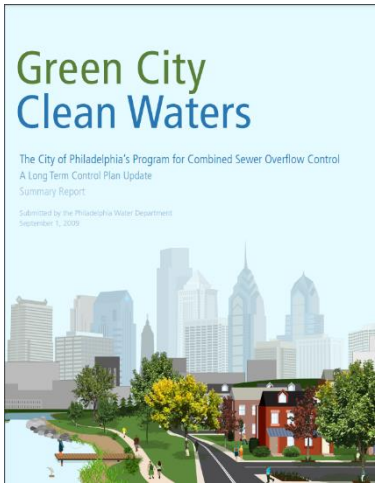
|  |  |  |
| Philadelphia 2035 | Pedestrian and Bicycle Plan | All Hazard Mitigation Plan |
| 2011 | 2012 | 2017 |
| Philadelphia City Planning Commission | Philadelphia City Planning Commission | Office of Emergency Management |
|  |  |  |
| Green City Clean Waters | Green Streets Manual | Complete Street Design Handbook |
| 2009 | 2014 | 2017 |
| Philadelphia Water Department | Philadelphia Streets Department | Philadelphia Streets Department |

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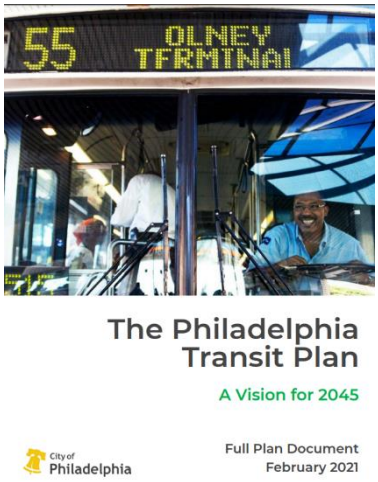
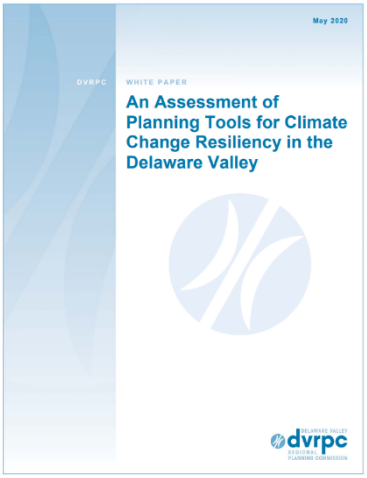
|  |  |  |
| The Philadelphia Transportation Plan, a Vision for 2045 | Connections 2050 | A Resilient Greater Philadelphia |
| 2021 | 2021 | 2020 |
| Office of Transportation and Infrastructure Systems | Delaware Valley Regional Planning Commission | Delaware Valley Regional Planning Commission |

# Methodology: Developing the CRRA

## Planning efforts

Starting in 2019, representatives from the Philadelphia Water Department, Philadelphia Office of Sustainability, the Academy of Natural Sciences (ANS) of Drexel University, the Delaware Valley Regional Planning Commission (DVRPC), and faculty and staff at Drexel University active in the Consortium for Climate Risk in the Urban Northeast (CCRUN) began discussing how to convene stakeholders to plan for the impact of climate change in the Philadelphia region. A Planning Team (PT) was created. Recognizing the need to engage academic researchers, as well as governmental and non-governmental decision makers, and community voices in the process, the PT identified four criteria of research co-production, derived from Norstrom et. al. 2020, to guide the effort. From the beginning, the PT intended the CRRA process to be:

- ***Context-based:*** Research that is context-based is situated in a particular geography, in this case the Philadelphia region, and a set of stakeholders whose needs, interests and beliefs are invested in or affected by the specific stressors of interest.
- ***Pluralistic:*** Research that is pluralistic recognizes the multiple ways of knowing and doing and incorporates multiple kinds of knowledge. Pluralistic research integrates traditional academic methodologies and other methods to address the needs and goals identified by the intended beneficiaries of the research. Climate change requires an "all-in" approach, wherein academic and non-academic researchers, the communities experiencing the impacts of climate change, and practitioners working directly on these issues are equal partners in the research process.
- ***Goal-oriented***: Research that is goal-oriented addresses clearly defined, shared, timely and/or otherwise meaningful goals, with a clear end-product that links knowledge to action. As described below, the CRRA process was conducted in four discreet Working Groups that met three times during the summer of 2021 to ultimately develop the research actions listed in this report.
- ***Interactive:*** Research that is interactive is developed collaboratively through extensive deliberation, and fosters co-learning, as participants share diverse experiences, perspectives, and types of knowledge. The Planning team provided the Working Group Leads with a variety of tools to facilitate collaboration, brainstorming, discussion, prioritization.

To recruit participants, the PT developed a nomination form that was circulated widely throughout the region using email lists associated with Philly CUSP, CCRUN, LinkedIn, as well as DVRPC's Climate Adaptation Forums. Targeted outreach to climate scholars and environmental justice leaders in the region was also conducted. The goal was to attract a wide range of individuals with climate change expertise garnered both through traditional research activities and/or professional or lived experiences.

The form solicited information regarding the nominee's lived and learned experience related to climate resilience, institutional and/or community affiliation, experience participating and/or facilitating group discussions, and optional demographic and accessibility questions, including if compensation was needed for participation. Nominations were evaluated based on their expertise, understanding of local context, diversity in terms of research perspectives, experiences, gender, race and ethnicity.

To encourage diverse participation, economic compensation was provided to individuals representing non-profit organizations or historically marginalized groups through a “Climate Solutions Acceleration” grant from Second Nature[12].

More than 100 participants representing over 60 organizations or entities ultimately participated in the CRRA process. Approximately half of the participants were from academia, with the remainder from governmental, practitioner or non-profit sectors.

## Development of Working Groups

The nominees were organized into four working groups, tentatively given the following thematic foci:

1. Regional Climate Change and Cascading Hazards
2. Health and Environmental Vulnerability
3. Built Environment and Infrastructure System Resilience, and Decarbonization/Electrification of the Energy Sector (originally titled “Planning Low-Carbon Adaptation of the Built Environment”)
4. Regional Climate Governance and Adaptive Management

The working group foci were determined by the planning team according to the range of climate issues faced by the Greater Philadelphia area. Each working group was also assigned two co-leads and approximately 20 members[13]. A level setting meeting for all working groups was conducted on June 17, 2021. Facilitated by the co-leads and supported by the PT members, each working group then met a minimum of three times throughout the summer to develop their research recommendations.

Because the CRRA process was conducted during the COVID-19 pandemic, the working group meetings were conducted virtually using Drexel University’s zoom account.

[12] https://secondnature.org/wp-content/uploads/For-Immediate-Release_Second-Round-Acceleration-Fund-Awardees-Announced-Press-Release_final.pdf
[13] Information regarding the participants and co-leads in each working group is provided in the Appendix

# Findings

Though the initial Working Group descriptions were drafted by the PT, flexibility and adaptability in the process were encouraged. The focus of each working group evolved differently based on the unique insights, experiences, and background of its participants, and the facilitation styles of its co-leads. Each Working Group eventually subdivided its research recommendations into more specific thematic areas.

This section includes a high-level synthesis of each working group's process, followed by its recommended areas for research (numbered sequentially across the working groups). Note that in most cases, the research areas are presented as research questions. However, in other instances, the participants opted instead to present their ideas as statements of need, or descriptions of specific data gathering activities. No attempt to prioritize the individual research activities was made.

At the end of this section, cross-cutting topics of research are also listed.

# Working Group 1: Regional Climate Change and Cascading Hazards (co-led by Kermit O and Daniel Bader)

## High-Level Synthesis of Process

In the first meeting, Working Group 1 brainstormed climate concerns associated with changes in precipitation, temperature, sea level/flooding and storm surges. Next, the participants developed causal linkages between independent and dependent variables (e.g. if this independent event happens then that dependent event will happen). These variables were used to generate an initial set of research questions. During the second meeting, the group developed a broader set of framing questions, while "purging" any of the initial research questions that it saw as better suited to the other working groups, though the focus remained on identified causal impacts. During the third and final meeting, Working Group 1 developed a filtration process through which it integrated climate science into its impact-oriented questions, leading to its final set of recommended research topics.

## WG 1 Research Topics

### 1.1 Water

1.1.1. Investigate the impacts of increased air/ water temperature on pathogen proliferation in summer months, and survival throughout the year in source water and recreational water of the Delaware River Basin.
1.1.2. Investigate how the time elapsed between precipitation events impacts local runoff, flooding and storage capacity in rivers of the Delaware River Basin.
1.1.3. Research the correlation between extreme precipitation events and increased nutrient runoff and/or algae growth in the Delaware River Basin.
1.1.4. Explore how the cascading impacts of increased river water temperature and extreme precipitation events (heavy rainfall from tropical or high-intensity non-tropical storms) impact the effectiveness of water treatment processes (particularly pathogen removal) at drinking water intakes in the Delaware River Basin, now and over the next 50 years.
1.1.5. Investigate how spikes in flow lead to spikes in input concentrations of sediment, nutrients and/or pathogens following individual events.
1.1.6. Explore how the cascading impacts of increased air and river temperature, prolonged drought, and migration of the salt line due to sea level rise will impact drinking water availability and water treatment processes (pathogen removal, disinfection by-product formation) at drinking water intakes in the Delaware River Basin in the next 50 years.

### 1.2 Health Impacts

1.2.1 Explore the relationship between the regional heat island and parallel changes in hardscape/softscape and climate. Specifically, investigate how the frequency and duration of heat waves in Philadelphia County will change over the next 50 years.
1.2.2 Research how changes in vehicle type and use and building HVAC electrification will impact air quality in Philadelphia County over the next 50 years.

### 1.3. Ecosystems and Green Infrastructure

1.3.1. Research how climate change, specifically changes in temperature, drought and flood frequency, water tables, precipitation intensity, and wind will impact the living

components (trees, insects, etc.) of green infrastructure over different geographic scales, within and outside of the flood plain.

1.3.2. Investigate how much green infrastructure can offset the urban contributions to climate change via carbon sequestration.

1.3.3. Explore whether changes to the physical design, imperviousness, and albedo of residential, business, commercial spaces in Philadelphia can improve wellbeing, reduce temperatures, and reduce stormwater runoff as the climate changes.

1.3.4. Identify which kinds of green infrastructure (stormwater, non-stormwater, vegetated and non-vegetated) will be most resilient to the climate changes expected in the Philadelphia region

1.3.5. Explore whether intense precipitation events can mobilize toxins found on contaminated land (including Superfund sites), and/or spread invasive plants and insects

1.3.6. Investigate how temperature increases, water quality degradation, etc. will impact native species migration, as well as how the development of green infrastructure for climate change mitigation can impact biodiversity and connectivity along the urban-rural gradient.

### 1.4. Built Environment

1.4.1. Investigate what geographic areas within the Delaware River Watershed will be impacted by sea level rise, and which housing and buildings will require adaptive retrofits or relocation over the next 50 to 100 years.

1.4.2. Explore how impervious/pervious surface distribution in specific areas of the Delaware River Watershed will impact water flow, velocity, and land and water surface elevations over the course of varied developments and climate change over the next 50 to 100 years.

1.4.3. Explore how projected temperature and humidity increases over the next 50-100 years may affect building materials (e.g., longevity and maintenance requirements) in different communities in the Greater Philadelphia region.

1.4.4. Identify the distribution and vulnerabilities of fuel infrastructure in the Delaware River Watershed, the demand for fuel and electricity during extreme weather events, and requirements for ensuring adequate fuel and energy supplies are available during extreme weather events.

# Working Group 2: Health and Environmental Vulnerability (co-led by Julie Ulrich and Dr. Katera Moore)

## High-Level Synthesis of Process

During the first meeting and in two breakout rooms, Working Group 2 members developed a series of framing questions focusing on human and environmental vulnerability. The questions generated during Meeting #1 were re-organized around key themes: Land (including urban forestry, food systems, access to green space, built environment as it impacts health, housing and transportation), Water (including drinking water, water quality, flooding, aquatic habitat, sea level rise), and Air (including urban heat island, air quality, respiratory issues, air temperature, pests and vector-borne diseases). Knowledge gaps in each of these thematic areas were identified. During meetings #2 and #3, the themes were further refined to: 1) Identifying Vulnerabilities, 2) Assessing Impacts, 3) Identifying Data Needs, and 4) Prioritizing Solutions.

## WG 2 Research Topics

### 2.1 Identifying Vulnerabilities

2.1.1. Improve vulnerability analyses, including through better visualization of cumulative impacts, identification of unmet needs, and by conducting participatory neighborhood-by-neighborhood surveys and mapping the allocation of funding of city services (water/sewer repairs, green infrastructure, flood investigations and mitigation, etc.) to identify health/environment vulnerabilities across the city.

2.1.2. Study how will climate change impact access to resources, such as transportation, green space, medical care, schools, technology, fresh food. Explore whether access to these resources will worsen in already disadvantaged neighborhoods.

2.1.2.1. Investigate how municipal infrastructure can be better planned to address health challenges associated with climate change (equitable transit, access to greenspace, access to technology)

### 2.2. Assessing Impacts

2.2.1. Questions for Environmental Impacts:

2.2.1.1. What are the impacts of climate change (generally) on ecosystem health?

2.2.1.2. What are the best-case conditions and worst-case conditions for urban terrestrial and aquatic ecosystems considering future climate change scenarios?

2.2.1.3. Which terrestrial species might be the most useful indicators for monitoring urban forest health for climate adaptation?

2.2.1.4. What can we learn from urban forest research and climate vulnerabilities assessments conducted in other places to inform forestry management in the Philadelphia region?

2.2.1.5. What habitats are most urgently in need of protection to maintain ecosystem health?

2.2.1.6. What are the greatest threats to aquatic ecosystems in and related to urban areas?

2.2.1.7. How will climate change affect key resources and services provided by aquatic systems (fishing, water quality for recreation, safety and access, etc.)?

2.2.1.8. What restoration strategies have the potential to have the greatest, positive effects in increasing resilience? How much would it cost to implement them?
2.2.1.9. How will changing precipitation patterns and sea level rise impact environmental health?
2.2.1.10. What are the water quality impacts of climate and precipitation changes, and can green infrastructure effectively prevent water quality deterioration?
2.2.1.11. How will regional changes in precipitation impact flow patterns in Delaware River Watershed? How will this amplify and intersect with other issues?
2.2.1.12. Will climate change (specifically droughts and salt migration) threaten the region's drinking water supplies?
2.2.1.13. What types of stormwater management can best improve water quality?
2.2.1.14. Which international best practices in water recycling and agricultural water use are most applicable to the Philadelphia region?
2.2.1.15. What impacts do short duration, high intensity precipitation have on urban forests, specifically with regard to tree species, locations, and soil types?
2.2.1.16. Do permitted effluent loads need to be revised/ reconsidered to preserve stream health under climate change?
2.2.1.17. How will rising temperatures impact environmental health?
2.2.1.18. How will projected changes in temperature impact "native" aquatic and terrestrial flora and fauna?
2.2.1.19. Do warmer climatic conditions exacerbate the threat to native species and increase the ability for non-native and/or invasive species to take hold? What is the relationship between invasive species and vectors? Specifically, do invasive plant species impact tick prevalence in Philadelphia?
2.2.1.20. What are the impacts of worsening heat waves on our urban ecosystems?

2.2.2. Questions for Human Health Impacts:

2.2.2.1. What are best practices for mitigating and adapting to climate related health impacts?
2.2.2.2. How will rising temperatures impact human health?
2.2.2.3. What allergens and diseases can we expect to increase with rising temperatures? And how will this impact health care costs? How will vectors and vector-borne diseases impact human health?
2.2.2.4. What are the mental health impacts of rising temperatures?
2.2.2.5. What is the collective impact of combining greening with other infrastructure investments (i.e., tree planting, energy efficiency, white roofs) to mitigate heat in high priority neighborhoods?
2.2.2.6. How will increases in temperature and vector borne diseases impact outdoor workers and other exposed populations (homeless) and how can results be best communicated to support changes to regulations and policy to better protect them?
2.2.2.7. How does increased vulnerability to flooding impact human health?
2.2.2.8. What are the mental health outcomes of living in a neighborhood that frequently floods?
2.2.2.9. What are best practices for addressing health consequences of recurring flooding and water intrusion?
2.2.2.10. How can we better document increases in mold problems and the populations affected by it?
2.2.2.11. How are communities preparing for and recovering from flood events?

2.2.2.12. How well distributed are support structures and resources, such as the Federal Emergency Management Agency (FEMA) flood claims and neighborhood advocacy?
2.2.2.13. What are the best ways (fact sheets, toolkits, advocacy, etc.) to share information about climate risks, adaptation strategies for homeowners/landlords?
2.2.2.14. How many homes/small businesses do not have back-flow prevention flaps? What is the level of education around this issue?
2.2.2.15. What is the cost/benefit to continuing to permit building in the floodplain?
2.2.2.16. How will degrading air quality impact human health?
2.2.2.17. How will wildfires and desertification (generally happening outside of this region) impact air quality and health in this region?
2.2.2.18. What are the relationships between indoor and outdoor air quality?
2.2.2.19. What will be the air quality improvements resulting from implementation of the Philly Tree Plan?

2.2.3. Questions for Overlapping Environmental and Human Health Impacts:

2.2.3.1. What existing water-based challenges to human and environmental health will be exacerbated by climate change?
2.2.3.2. What are the full (social, economic, and environmental) impacts of degraded natural systems, overuse of natural resources, and inaction for climate resiliency?
2.2.3.3. What are the long-term effects of understudied contaminants of emerging concern on human and environmental health?
2.2.3.4. What are the economic outcomes of greening urban spaces, in terms of human health and watershed improvements?
2.2.3.5. What are best practices for managing contaminants that are unearthed by flooding?

## 2.3. Questions for Identifying Data Needs

2.3.1. Are there proxy datasets for longer term studies of impacts to health, infrastructure, built environment? Could a collective data collection framework and data management system would be useful?
2.3.1.1. Collaboration with healthcare providers and/or insurance could provide proxy datasets on human health impacts from extreme weather, environmental vulnerabilities, etc.
2.3.2. What information does the public need to make decisions or seek remediation services for themselves if impacted by environmental events/changes? (e.g., there are structures in place for emergency events, but not for lower-level needs)
2.3.2.1. What data does the city/health department need to address these chronic conditions? What do individuals/citizens need in order to make decisions/seek care?
2.3.2.2. For families with children with asthma, if air quality or heat is bad, do families with health vulnerabilities have tools and information they need?
2.3.3. City scale monitoring of the effectiveness of various adaptation best practices could be expanded (e.g. long term performance of existing green roofs)
2.3.4. Relating data sets, for example: flooding + litter index + demographics, other non-obvious pairs
2.3.4.1. There is a need to coordinate the spatial (e.g. which sites are monitored) and temporal (when are they monitored) post-construction monitoring of best practices. A clearing house such as Open Data Philly could be redesigned to allow users to view/combine/access disparate types of data

2.3.5. Long term monitoring projects would be very useful, for example monitoring tree/vegetation changes/health in response to climate changes along with associated indicator species (i.e. birds, insects).

## 2.4. Prioritizing Solutions

2.4.1. How does this work get prioritized and funded? Develop a rubric as to how we prioritize- rooted in shared understanding around outcomes and measures.

2.4.1.1. Prioritize research projects that could synergize with Infrastructure funding.
2.4.1.2. Identify foundations and funding sources to fund intersectional research.
2.4.1.3. Assess best ways to increase government investment in climate change resilience and equitable distribution of resources.
2.4.1.4. Rank solutions by impact (mitigation and resilience) and feasibility (acceptability and economics)
2.4.1.5. Create a policy roadmap for cities to effectively shift the system toward more environmental equitability.
2.4.1.5.1. What are the policy solutions to equitably distribute funds such as the Regional Greenhouse Gas Initiatives (RGGI) to address health issues?

2.4.2. Building resilient communities

2.4.2.1. What is the scalability of various resilience methods (block vs. neighborhood vs. cities? What is the adaptability of various resilience methods (geographies, communities etc.)?
2.4.2.2. What are strategies to build resilience to more than one vulnerability?

2.4.3. Education & Communication

2.4.3.1. Connect with regional schools on climate change curriculum.
2.4.3.2. Make environmental and climate science curriculum mandatory or a core course in all Philadelphia schools.
2.4.3.3. Create new community initiatives to educate and train young people on climate resilience strategies and also in fields that are designed to respond to climate issues and offer environmental improvement and quality of life solutions in their communities. For example: initiatives to train young people into becoming arborists who can plant and maintain trees to expand tree canopy in their neighborhoods.
2.4.3.4. Educate the political leadership on climate change issues and policy solutions. Connect with local lobbyists to advance a climate education agenda.

2.4.4. Piloting projects as interim solutions

2.4.4.1. Review best practices and/or pilot programs to build resilience and improve health in vulnerable communities.
2.4.4.2. Demonstrate the urgency through mitigation projects, even if the data isn't perfect.
2.4.4.3. Pair surveying with follow up/education, and/or with Civic Science. Follow up is important.
2.4.4.4. Conduct research that implements and monitors practices over time: pairing design/implement with monitoring results/evaluating impact.

# Working Group 3: Built Environment and Infrastructure System Resilience, and Decarbonization/Electrification of the Energy Sector[14] (co-led by Dr. Jin Wen and Steven Krug)

## High-Level Synthesis of Process

During Meeting #1 and in small breakout rooms, Working Group 3 participants developed scenarios, needs and gaps. They initially grouped their ideas broadly into four categories: temperature, water, energy, and natural hazards, discussing both the resilience of infrastructure systems as well as decarbonization of the energy sector and electrification. Next, participants developed more detailed descriptions of the scenarios, needs, gaps, and research activities in each topical area. They also identified cross cutting themes. During Meeting #2, the research activities were compiled into a shared document, which was further elaborated in breakout rooms during Meeting #3. The recommended research activities were finally re-constituted into three overarching categories: 1) Energy Infrastructure Resilience, and 2) Temperature and Water Resilience, and 3) Decarbonization and Electrification of the Energy Sector.

## WG 3 Research Topics

### 3.1. Energy Infrastructure Resilience

#### 3.1.1. Grid Resilience

- 3.1.1.1. Research how to make electrical/power systems resilient to projected flood/storm conditions in our region.
- 3.1.1.2. How will increased temperatures impact electricity systems and how may these impacts shape travel and communications patterns?
- 3.1.1.3. What are best practices for building a climate resilient smart grid that connects and manages the complex mix of new and legacy micro and macro-electrical capacity that will power the future electrified Philadelphia community? Are there transferable models from California and western states (given their predisposition for innovation and climate stressors: prolonged heat waves, droughts, wildfires, grid failures)?
- 3.1.1.4. Mapping scenarios for future energy infrastructure (decentralized, clean, renewable) to understand the hazards/ threats they face.
  - 3.1.1.4.1. Research best practices and expert systems for resilient grid, such as when/where it is best for underground electric utilities, and how to balance the grid in our region.
  - 3.1.1.4.2. If we assume low-carbon future energy sources and end uses, what are the risks, and how to address their resilience? (Ie. wind, solar, geothermal).
- 3.1.1.5. What are best practices for energy storage, with a focus on EV/transit infrastructure.
- 3.1.1.6. Research the effectiveness and potential expansion of the Philadelphia Tune Up Building Energy Performance Program.
- 3.1.1.7. Research latest data on air source heat pumps in our region.
- 3.1.1.8. Can gas distribution lines be repurposed to a climate/weather resilient conduit for fiberoptic broadband cable and smart grid infrastructure? This would recapture value in what looks destined to be another ‘stranded asset’ of the hydrocarbon age.

[14] This Working Group was originally titled “Planning Low-Carbon Adaptation of the Built Environment” but was later changed to better align with the group’s identified themes.

## 3.2. Temperature and Water Resilience

3.2.1. Develop a systematic framework to understand how extreme temperature caused by climate change (intensive heat waves and winter cold snaps) would affect local neighborhoods and pursue localized solutions for extreme temperature impacts. The studies should assess extreme temperatures on human health as well as impacts on built infrastructure (what it can withstand, etc.) Such a study would facilitate the development of easy-to-use tools and frameworks to identify localized remediations and to evaluate these remediations based on their temporal impacts on the local neighborhood.

3.2.2. Research systematically designed financial programs to provide localized remediations for low-income communities to respond to climate change, including managed retreat.

3.2.2.1. Conduct pilot residential programs that evaluate the impact and effectiveness of both technological and financial programs.

3.2.3. Conduct multi-hazard vulnerability assessments:

3.2.3.1. Develop worst scenario cases.

3.2.3.2. Estimate potential impacts on infrastructure, environment (air quality, water quality…), and public health.

3.2.3.3. Identify weakest links within infrastructures and potential coupled impacts (for example, flooding that causes power outage and data tower malfunction)

3.2.3.4. Develop response plans.

3.2.4. Explore Urban Heat Island resilience measures in other cities, including cities on the West Coast and the South experiencing heat waves that may soon be experienced in the Philadelphia region.

3.2.4.1. What heat risk mitigation strategies are most appropriate for Philadelphia's heat stressed neighborhoods?

3.2.4.2. Would it cool a community to strategically locate pocket-parks in a green-desert neighborhood? How do you place them? How many pocket parks for a given area will make a significant difference to the community? Are there other benefits that a 'pocket of green' would bring to a community? What are they? Will these benefits address other neighborhood problems?

3.2.5. What is the capacity of our infrastructure to withstand flooding events?

3.2.5.1. Revised modeling of flooding impacts on critical infrastructure, particularly wastewater treatment.

3.2.5.2. How is funding of city services (water/sewer repairs, green infrastructure, flood investigations and mitigation, etc.) currently allocated across the city and how will climate change impact the needs of neighborhoods?

3.2.6. What best practices from urban flooding and resilient infrastructure adaptation can be applied to the Philadelphia region? There are examples in NYC (Rebuild by Design in response to Hurricane Sandy) and the Netherlands (the Dutch have been learning and adapting to water for its entire history) that could be emulated.

3.2.7. Develop conceptual designs to reinvent water services that are coupled with energy and material recovery, including decentralized solutions at various scales and stepwise implementation for different areas of the city at appropriate scales.

## 3.3. Decarbonization and Electrification of the Energy Sector

3.3.1. Future Energy Mix and Sources

3.3.1.1. Research a comprehensive amalgamation of energy scenarios for the future of the region to understand the land use implications (how much land, and where) of generating enough clean energy to achieve 100% clean electricity by 2035

3.3.1.2. Natural Gas Alternatives: Research pros and cons of biogas and renewable natural gas, including effects of production on regional ecological systems, and effects of combustion on air quality & health. Philadelphia may be well situated for piloting emerging gas alternatives such as blue hydrogen.

3.3.1.3. Hydropower: With the abundance of rivers and creeks in the region, are there potential energy production through existing dams (Art Museum dam, Flat Rock Dam, Wissahickon Dam on Ridge Ave) or energy storage (Water Works Natatorium, unused reservoirs, polders constructed to store and retain stormwater to mitigate severe flood events can be pump-filled during normal times using daylight/wind power for hydropower release overnight) possibilities?

3.3.1.4. Geothermal: Geothermal is expensive and logistically difficult in a densely built urban environment. PGW in their diversification study recommended a feasibility study for networked geothermal systems to explore the technical and geological potential of block-level networked geothermal district systems as well as the utility financial model for such a system. Are there opportunities in the region for geothermal?

3.3.1.5. District Energy and Energy Recovery: District Energy (heating and cooling from a central plant) could be a low-carbon alternative that could be studied in comparison to retiring fossil fuels completely.

3.3.2. Decarbonize and Electrify

3.3.2.1. What are the cost/benefits of neighborhood or block scale electrification, coupled with renewable energy systems resilience, and related social impacts?

3.3.2.2. Electrification at Scale: How can the transition to electrification be deployed at scale, equitably, and addressing the highest impact areas for transformation at the highest priority? What kind of incentives (policies, rebates, top-down, bottom-up, etc.) are most effective at pushing the lever towards electrification city-wide? What communities/companies/ideas may be appropriate models for community transformation at scale?

3.3.2.3. Electric Vehicles (EV): EV penetration in an urban setting (and beyond) is limited by the siting/availability of charging stations and the significant price difference over conventional cars that acts a barrier to all but the wealthy. Identify and study the feasibility of installing charging stations (recommend focusing on Level 3 DC fast charging (20-30 min charge), as opposed to Level 2 (4-6 hours), or Level 1 (overnight). around the city and region. What policies/incentives will expedite regional build-out of EV fast-charging (20-30 min full charge) infrastructure?

3.3.2.4. Potential opportunities for siting include Community Solar/charging stations: Parking lots (commercial, municipal, company, supermarkets, parking garages, schools) and converting parking meters into charging stations.

# Working Group 4: Regional Climate Governance and Adaptive Management (co-led by Dr. Christina Rosan and Charles Ellison)

## High-level Synthesis of Process

During its deliberations, Working Group 4 identified several questions that must be answered to create the change necessary to make Philadelphia more climate resilient. Working Group 4 focused on the need for centering inclusion, action, improved understanding of risks and policy responses, and the various ways that existing governance structures prevent real climate/social/racial justice action. Working Group 4 questioned how to identify and understand the challenges faced by vulnerable communities or populations who tend to be overlooked, ignored, or even silenced. Themes identified included racial justice and inclusion, governance and policy, and knowledge to action, for example through Participatory Action Research (PAR). PAR emphasizes participation and action by community members impacted by the research, and aims to collaborate with and empower the communities of interest[15].

## WG 4 Research Topics

### 4.1. Racial Justice and Inclusion

#### 4.1.1. Prioritizing Lived Experience in Research, Decision-Making, and Planning

- 4.1.1.1. How do we, from the very beginning, co-create discovery and knowledge with local, marginalized, vulnerable communities – not just as acts of justice, but because the knowledge will be more profound, and it will be owned by local communities from the get-go?
- 4.1.1.2. In addition to physical science and financial considerations, what are the social science and environmental justice perspectives on communities' preferences for adaptation options? What are their perceptions of risks? How do they interact with the city government?
- 4.1.1.3. How is climate change affecting individual's homes, blocks and neighborhoods, according to the people that live there? How do these micro-scale experiences weave into macro-scale challenges?
- 4.1.1.4. How do regional land use changes impact the health, resiliency, and vulnerability of "downstream" communities in the region? (For example, emerging diseases, watershed challenges, air pollution, etc.)
- 4.1.1.5. What is the role of land use regulations (i.e. zoning) to enhance community resilience? How can communities influence these decisions?
- 4.1.1.6. What are best practices for engaging and activating local communities to show up while simultaneously creating the space for their voices to be heard at town hall, council meetings, and planning meetings and speak up about their experiences and needs?
- 4.1.1.7. What are ways that climate resilience advocates, organizations, media, and policymakers use combined "place-based" environmental neighborhood improvement strategies as a way to encourage and build immediate climate resilience in stressed communities?

### 4.2. Governance and Policy

#### 4.2.1. Regional Governance

[15] Additional information on PAR is included in the Appendix

4.2.1.1. Regional climate resilience will require regional climate governance. What are the formal governance structures that will play key roles, at the municipal, regional, state, and federal level? What are the levers of power? How do they work together?

4.2.1.2. What is local government's role in the larger ecosystem of partners? What might a new governance model look like that reflects community priorities and allows for cross-disciplinary, cross-sector collaboration? What governance arrangements support coordination?

4.2.1.3. What are ways that climate resilience advocates, organizations, media and policymakers use combined "place-based" environmental neighborhood improvement strategies as a way to encourage and build immediate climate resilience in distressed communities?

4.2.1.4. Generally, regional governance that is more forward looking (as opposed to retrospective) could create a broader capacity to anticipate and prepare for climate impacts. What are the barriers to getting to a more anticipatory governance model? What role can academics, community, and researchers play in advocating for alternative governance approaches?

4.2.1.5. How do we go from the existing governance structures to be the kind of governance that we need to be resilient? What can we learn from "resilience governance" models elsewhere?

4.2.1.6. How do we connect zoning and Comprehensive Planning done by agencies like the City Planning Commission with the urgency of climate and risk, and promote intersectional climate planning? How can groups like the CRRA support this shift?

4.2.1.7. How can we change the structure and quality of relationships to change how government works in Philadelphia? A social network study could map out how procurement processes work, how decision making happens, and make visible the barriers to action so that they can be resolved.

4.2.1.8. How is Philadelphia's ability to be climate ready dictated by state and federal policies? State regulations can be a barrier to action, for example with solar energy policy. The solar sector has seen tremendous growth nationwide in the last few decades, yet only 2% of eligible rooftops in PA have solar panels.

4.2.1.8.1. What policies would get Philadelphia to an energy grid of 50% solar in a decade, when the state's goal is 0.5%?

4.2.1.8.2. How can Philadelphia put pressure on the state to encourage policies that increase resiliency and equity?

4.2.1.9. How can we better coordinate and share expertise across the many organizations, businesses, and institutions that are all working on a piece of the puzzle but not able to tackle the full spectrum?

4.2.2. Advancing Equitable Regional Resilience through Policy-Making and Planning

4.2.2.1. What is the framework for a Just Transition in the clean energy space, and how do we make it happen in this region?

4.2.2.2. How can we ensure Regional Greenhouse Gas Initiatives (RGGI) proceeds are equitably distributed? How do we determine distribution? Are there criteria to promote equity?

4.2.2.3. How can energy resiliency investments in Philly relieve energy burden challenges (e.g., share of income spent on utilities)?

4.2.2.4. How can energy policy research connect with equity and job issues, and look at opportunities that come from climate investments that meet multiple needs at

once? Can researchers work with city agencies and non-profits to evaluate the effectiveness of policies?

4.2.3. Climate emergency decision making, preparedness and risk

4.2.3.1. What do prepared communities look like?
4.2.3.2. Each impact needs to have a different threshold that needs to be established. That threshold might be different depending on who is doing the action, who it is impacting, what it is impacting. What are the thresholds where our existing governance mechanisms "break," and we can say they are incapable of anticipating and preparing for risks?
4.2.3.3. What risk mitigation practices are most effective, equitable, and realistic for preparing for climate risks?
4.2.3.4. How do we set risk thresholds? What are the decision making factors to implement a project, or to move to plan B?
4.2.3.5. What progress is being made to address vulnerability to flooding and sea level rise at existing superfund and other contaminated sites in the region?
4.2.3.6. How can risk reduction be better quantified and tracked in mitigation projects?
4.2.3.7. What role can faith-based groups play in disaster response and preparedness?

4.2.4. Affording Adaptation vs Climate Impacts

4.2.4.1. How does climate action get paid for?
4.2.4.2. With a strain on municipal budgets and an economic system that favors growth and exploitation over conservation and equity, how can governments afford to take urgent action to address climate impacts?
4.2.4.3. How will climate impacts influence municipal budgets by leading to higher needed expenditures or lowering revenues? Are there financial models or innovations in municipal budgeting that could be pursued?
4.2.4.4. What are the information gaps for municipal government financial managers on how climate change will impact infrastructure and operations, and the cost saving opportunities of acting now?
4.2.4.5. How can climate resilience become a consistent and critical consideration in capital investments?
4.2.4.6. How can municipal governments raise funds for capital projects, aiming to avoid regressive types of fees? How can these approaches be linked to improving affordability?

4.2.5. Responsible Contracting and Purchasing

4.2.5.1. How can procurement processes reflect the transition to a more climate resilient region?
4.2.5.2. Local solar companies in Philadelphia hire locally and are working directly to provide clean energy to mitigate climate change. How can local solar companies be included in incentives and programs to further increase local hiring?

## 4.3. Knowledge to Action

4.3.1. Effective and Inclusive Communication Strategies

4.3.1.1. What are some success stories of using public art for messaging and raising awareness about climate change?
4.3.1.2. Some of the most powerful change agents and communications styles in Philadelphia are surrounded in celebration. How can joy and celebration be paired with effective and receptive communication to create resiliency?

4.3.1.3. How can the people who are living through climate change impacts be considered experts over those who have traditionally had deciding power, in a deliberative effort to message the way that different groups will be impacted by the climate crisis?

4.3.1.4. Civic associations, neighborhood action committees, and other such organizations in Philadelphia, and Environmental Advisory Councils in the region are very effective at reaching their constituents. How can we work with these existing networks to more effectively message climate resilience and political action?

4.3.1.5. Overcoming climate change can be seen as not impacting us as individuals or is “too big”. What are the digestible nuggets, so the public gets it and they feel like they are a part of the solutions? What are the engagement tools to mobilize or activate people?

4.3.2. Education

4.3.2.1. What kind of climate change education, formal and informal, is being offered across the region? How can this be improved? What models exist elsewhere that might be useful?

4.3.2.2. What is the role of educators (informal and formal) to build political will?

4.3.2.3. Where are there opportunities to incorporate and improve eco-literacy and civic literacy? Are eco-literacy and civic literacy more effective as a mandated part of the curriculum, a standalone standard or should it be integrated into other parts of the curriculum? What works and doesn’t work in terms of curriculum design?

4.3.2.4. How can civic/citizen science be incorporated into education and research? For example, overlaying citizen complaint data with Hydrologic & Hydraulic (H&H) models and FEMA flood models?

4.3.2.5. How can climate change education remove barriers that traditionally have considered climate change science as “hard science” and politically untenable for conservatives?

# Cross-Cutting, General, and Complementary Findings

As described above, in some cases the deliberations of the Working Groups yielded research questions and other insights that were deemed valuable but did not fit within the initial or revised scopes of the working groups. These cross-cutting research topics were relayed to the PT and are included in this section.

## 5.1. Cross-Cutting Research Recommendations

5.1.1. What are best practices to translate climate data (e.g. sea level rise) into planning policy? What should the municipal employees and developers do to incorporate climate change considerations when planning/constructing new buildings/infrastructure?

5.1.2. Take a closer look at zoning ordinance potential. Most ordinances include impervious coverage limits. How can zoning ordinances for redevelopment include measures to mitigate human health impacts with regards to climate change?

5.1.3. Comprehensive GIS Philadelphia planning map: immediate short-term planning should go towards identifying what projects to fund, prioritize how to proportionally distribute these funds, and where geographically to make these investments. President Biden's Justice 40 Initiative directs up to 40% of federal infrastructure funding to investments in communities that have historically been neglected. Building a GIS map with the appropriate data layers will facilitate the planning/decision process in an efficient and equitable way. Immediate next steps include identifying what GIS based city data exists, what existing data should be added, and what data does not exist but should be obtained and included.

5.1.4. Create a clearinghouse of all the relevant research that has been done.

5.1.5. Implement long-term monitoring for climate scenarios that can vet model assumptions.

5.1.6. Include behavioral science in modeling assumptions, especially for natural disaster scenarios.

5.1.7. How can we better measure associated benefits of climate adaptation projects beyond just flood/heat objectives? For example, what other associated health, economic, social benefits are provided and how can these be better captured (similar to what is being done to measure GSI impacts but expand to larger climate adaptation projects).

5.1.8. Research opportunities to change people's travel behavior by surface and structured parking incentives/taxes, including changes to the related storm water and other physical conditions.

## 5.2. Real-time climate crisis management of the built environment

5.2.1. Research how data/communications flow during climate crisis management scenarios, and what is needed to make those systems resilient to event disruption.

5.2.2. Research critical systems that require adaptation to be resilient at the regional scale with more extreme weather, using GIS as part of amalgamation of systems. For example, what critical infrastructure (private and public) is in the seal level rise and storm surge zone, etc.

5.2.3. Research building codes regarding occupancy of basement spaces in flood prone areas.

5.2.4. What is the response plan before, during, and after extreme events such as extreme rain fall? Do we need better forecasting for extreme events?

5.2.5. Are there homes with basements that are/will be vulnerable to flooding that weren't before, or with households that do not want to speak out (for example in immigrant communities)?

## 5.3. Concurrent Impacts on Human Health and the Built Environment

5.3.1. What are the long term impacts of hazards, such as mold? Systematical study of the flooded area about their long-term impact on health and exposure and building degradation. How much remediation funding is needed? What are the implications for the city and its residents of not taking immediate action?
5.3.2. Temperature change and flooding have made new long-term hazards to the Northeast (such as mold growing) - need to identify these issues and generate action plans.
5.3.3. What are the co-benefits for public health on urban greening and reducing carbon emissions?

## 5.4. Regional Planning and Land Use

5.4.1. Research how increased precipitation and flooding impact economic productivity of the city. How can we make the transit system more resilient? What's the impact on regional transportation as a whole?
5.4.2. Explore the impact of land use changes (densification and transit-oriented development) that could reduce the energy and water footprint, and reduce generation of GHG.

## 5.5. Missing Subject Matter

5.5.1. How Philadelphia residents approach decision making.
5.5.2. Building the business/economic case for implementing solutions.
5.5.3. Historic sites and public spaces susceptible to flooding.
5.5.4. How to get to low-carbon scenarios (i.e. net zero by 2050)?
5.5.5. A comprehensive list of regulatory barriers in the way.
5.5.6. What Participatory Action Research truly is.

# Reflection and Next Steps

## Post Process Evaluation and Feedback

The CRRA process attracted over 100 participants representing over 60 organizations or entities. At the end of the summer, the PT sent a follow up survey to working group participants and co-leads regarding next steps. The results of this survey are synthesized in this section.

Participants brought great energy and enthusiasm towards working on climate issues. Many had never collaborated with one another before and appreciated the opportunity to network across disciplines. Participants valued both the large and small group discussions, the convening of different groups of people, and the opportunity to learn from each other.

The exchange of information and expertise was highly praised. Many participants expressed an interest in staying involved and offered to dedicate skills and resources to future efforts. However, some reported that the process felt rushed and lacking in direction. Additionally, while the geographic focus of CRRA was supposed to be regional, participants from the city of Philadelphia were over-represented, and some survey respondents felt that the deliberations focused less on the region and more on the "city". Respondents also reported a tension in the working group deliberations between those expressing a need for research and those who were more focused on the need for action: "learning for learning's sake" versus the desire for usable information.

In response to multiple-choice questions on the evaluation:

- 79% or participants were in favor of participating in an annual summit to discuss progress
- 71% were in favor of participating in ongoing meetings to keep refining the research agenda
- 71% were in favor of providing feedback and comments on the draft final deliverable
- 67% were in favor of joining an email networking group (for example a google group) to circulate research opportunities or other relevant opportunities/resources
- 50% were in favor of providing relevant research and expertise to this group on an as needed basis

The most critical feedback received by the PT was an inadequate degree of racial diversity and community perspectives in the CRRA process. Although the PT sought participation from a wide range of constituents, about half of the participants were ultimately from academia, and not the region's front-line communities. Perhaps due to its reliance on communication channels more familiar to academic and practitioner groups, the recruitment strategy was not successful in creating the diversity initially sought by the PT, despite the economic incentives for participation. Future recruitment efforts might emphasize other channels of communication and/or set aside more lead time to better diversify future participation.

Given the PT's initial expressed interest in research co-production, some participants recommended that future phases of the CRRA process pay more attention to best practices for inclusive, action-oriented research including:

- **Participatory Action Research (PAR)** is a framework for engaging in research and organizing for social justice that is rooted in a community's own knowledge, wisdom, and experience. PAR recognizes that those most impacted by systemic injustice are in the

best position to understand and analyze their needs and challenges and to organize for social change.[16]

- **Civic Science** is the practice of public participation and collaboration in the research process. It often entails engaging community members or the public (voluntary or paid) in data collection, and sometimes in the interpretation of the results. This practice can also be called citizen science, but civic science is the preferred term to deter concern about citizenship.
- **Problem-based learning (PBL)** is a method of teaching that is student-centered, where the students are presented with a real-world problem and use reasoning and critical thinking to solve the problem.
- **Applied research** is the practice of solving practical problems, rather than theoretical problems or acquiring knowledge for knowledge's sake.

The working group discussions also put forth several reflections for how to carry the CRRA process forward:

- Given the challenges we know we face, determining what sort of world (or region) we want to see ourselves in 10 years from now. Where do we want to be?
- Can we create a "Collaborative Center for Climate Action" so we know what we're all up to and how we find the bridges and connection points.
- What is the low-hanging fruit strategy (short term and now)? What is the near-term strategy (3-5 years)? And what is long term strategy (10-20 years)?
- Research activities would be prioritized differentiating between short term, near-term, and long term strategies, while engaging policy makers to ensure that this effort translates into actual governance and action.

[16] Definition provided by PARCEO, https://parceo.org/about/par/

# Going Forward

As stated above, the CRRA is a ***co-produced preliminary list of research activities that, if undertaken, could help to make the Philadelphia region more resilient to climate change***. However, it is merely a ***first step*** **in what must become an ongoing, inclusive public discussion regarding how this region will address the challenges of climate change.**

In conclusion, now that a preliminary set of research agenda items have been developed from the participants in this process, additional work needs to synthesize, fine tune, prioritize, and cross reference these research questions with needs of the region's front-line communities, who were under-represented in this preliminary effort, and the goals, visions, and values of local governmental decision makers. Many of the cross-cutting recommendations and those developed by WG#4 point the way forward:

- Ideally, this process would be place based so that it can "co-create discovery and knowledge with local, marginalized, vulnerable communities – not just as acts of justice, but because the knowledge will be more profound, and it will be owned by local communities from the get-go" (11.1.1).
- This process would directly engage "civic associations, neighborhood action committees, and other such organizations in Philadelphia, and Environmental Advisory Councils in the region [that] are very effective at reaching their constituents" (13.1.4)
- It would explore how "climate change affecting individual's homes, blocks and neighborhoods… [and] how these micro-scale experiences weave into macro-scale challenges?" (11.1.13)
- These place-based discussions would also help make future climate resilience research more goal oriented, focused on the "world (or region) we want to see ourselves in 10 years from now" (19.1)

# Appendix 1: CRRA Document Clearinghouse

Participants were encouraged to share documents they deemed relevant to the research agenda, with the intention of creating a shared resource of climate-related knowledge that can easily be added to. We sorted the documents into seven categories, which can be seen below. For each document we included a brief excerpt from its abstract/introduction and its geographical relevance, so that we can easily distinguish which documents are directly related to Philadelphia (or the greater Philadelphia region), ones that would serve as case studies from other places, ones that have broader implications (nation-wide or global), and which documents are purely theoretical (i.e. non-geographic). All of the documents can be found in the Google Drive link below. https://drive.google.com/drive/folders/1NDQoeTPSAv61k3Pk6r4KEf24uqdWrB5i?usp=sharing

## Research Methodologies and Agendas

| **Title (Citation)** | **Description** | **Geographical Relevance** |
|---|---|---|
| The Complexities and Contradictions in Participatory Research with Vulnerable Children and Young People: A Qualitative Systematic Review (Bradbury-Jones et al., 2018) | The review provides a unique, contemporary analysis of participatory research with vulnerable children, illuminating in particular its conceptual complexities and contradictions, particularly regarding power, empowerment and voice. | Non-geographic |
| The Theoretical Standpoint of PAR<br>(Muhammad Anisur Rahman) | The basic ideology of PAR is that a self-conscious people, those who are currently poor and oppressed, will progressively transform their environment by their own praxis. In this process<br>others may play a catalytic and supportive role but will not dominate. | Non-geographic |
| Rooted in Place, Politics, Passion, and Praxis: Decolonization, Popular Education, Community Arts, and Participatory Action Research (Barndt, 2011) | The central ideas driving the VIVA! project can be seen within a circle that acknowledges our colonial history and aims to decolonize our practice as educators, artists, and activists through popular education, community arts, and participatory action research. | Non-geographic |
| The SAGE Handbook of Action Research: Participative Inquiry and Practice<br>(Reason and Bradbury, 2001) | SAGE Research Methods is a research methods tool created to help researchers, faculty and students with their research projects. | Non-geographic |

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| Youth Participatory Action Research (YPAR) 2.0: how technological innovation and digital organizing sparked a food revolution in East Oakland (Akom et al., 2016) | This article argues that technological innovation is transforming the flow of information, the fluidity of social action, and is giving birth to new forms of bottom-up innovation that are capable of expanding and exploding old theories of reproduction and resistance because 'smart mobs', 'street knowledge', and 'social movements' cannot be neutralized by powerful structural forces in the same old ways. | Case study in Oakland, CA |
| An Arts-Based Approach to Participatory Action Research (Spaniol, 2004) | This paper presents a model for collaborative partnerships between art therapists and the people they serve. | Non-geographic |
| Rapid Rural Appraisal and Participatory Rural Appraisal | The purpose of this manual is to familiarize users with RRA and PRA methods, to demonstrate the applicability of these methods to CRS funded projects, and to encourage the rigorous application of the methods in order to obtain the best results. | Non-geographic |
| State of Climate Knowledge 2021 (NYC) (NYC Mayor's Office of Resiliency) | In 2020, the Mayor's Office of Resiliency (MOR) initiated an engagement process, called the Climate Knowledge Exchange, to align research with climate resiliency and adaptation needs. This report, the State of Climate Knowledge 2021, is the first in an annual series that will maintain a public agenda for climate research in NYC. | Research Agenda from New York City |
| Liberatory Methodologies: Participatory Action Research Strategies for Discovering Inclusive Maker Space Practices (Masters et al., 2018) | In this Research Work in Progress paper, we describe the methods chosen for a project exploring best practices of inclusion in maker spaces serving diverse populations. | Non-geographic |
| Climate Change Research Plan for California (CalEPA, 2015) | The Climate Action Team has generated a Climate Change Research Plan for developing a scientific foundation for addressing these climate challenges. The purpose of this Report Brief is to summarize and present highlights from that plan. | Research Agenda from California |

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| The Climate Advocacy Lab's Research Agenda<br>(Climate Advocacy Lab, 2021) | The Climate Advocacy Lab's mission is to help the climate community build grassroots power and win through evidence-based advocacy. Our Research Vision drives the Lab's research, experimentation, and partnerships program, which is constructed to generate knowledge where there are gaps in the community's evidence base, and share that knowledge with the sector so we can be more effective. | Nation-wide |
| Principles for knowledge co-production in sustainability research<br>(Norström et al., 2020) | We propose a set of four general principles that underlie high-quality knowledge co-production for sustainability research. Using these principles, we offer practical guidance on how to engage in meaningful co-productive practices, and how to evaluate their quality and success. | Non-geographic |
| Why am I always being researched?<br>(Chicago Beyond) | In this publication, we offer "how" we can begin to level the playing field and reckon with unintended bias when it comes to research. Chicago Beyond created this guidebook to help shift the power dynamic and the way community organizations, researchers, and funders uncover knowledge together. | Non-geographic |
| Options for Achieving Deep Reductions in Carbon Emissions in Philadelphia by 2050<br>(Prepared by Drexel University for The Philadelphia Mayor's Office of Sustainability) | This report reviews approaches for achieving reductions in greenhouse gas emissions in Philadelphia that are commensurate with the goal of achieving an 80% reduction in emissions by the year 2050. The analysis includes emissions occurring within city limits and emissions due to electricity generated outside the city but consumed within city limits. The analysis does not consider emissions from the manufacture of products outside the city but consumed within the city. Technological options are reviewed in three sectors: energy use in buildings, electricity generation, and transportation. | Philadelphia, PA |

## Water Management

| Title (Citation) | Description | Geographical Relevance |
|---|---|---|
| Cities Alive: Rethinking Green Infrastructure<br>(Armour et al., 2014) | By working with the natural environment as a key driver, Cities Alive presents an economic way of addressing the challenges of population growth and climate change in our cities to deliver significant social and environmental benefits. | Non-geographic |
| Evolving Tides Aggravate Nuisance Flooding Along the U.S. Coastline<br>(Li et al., 2021) | Nuisance flooding (NF) is defined as minor, nondestructive flooding that causes substantial, accumulating socio-economic impacts to coastal communities. While sea-level rise is the main driver for the observed increase in NF events in the United States, we show here that secular changes in tides also contribute. An | Nation-wide |
| Flood Hazard Assessment from Storm Tides, Rain and Sea Level Rise for a Tidal River Estuary<br>(Orton et al., 2020) | Cities and towns along the tidal Hudson River are highly vulnerable to flooding through the combination of storm tides and high streamflows, compounded by sea level rise. Here a three-dimensional hydrodynamic model, validated by comparing peak water levels for 76 historical storms, is applied in a probabilistic flood hazard assessment. | Case study from Hudson River |
| Managing Heavy Rainfall with Green Infrastructure<br>(Fischbach, 2020) | In this project, RAND researchers use simulation modeling to evaluate present and future risks in Negley Run from sewer overflows and flooding given future rainfall uncertainty. The authors then evaluate proposals for a phased series of green stormwater infrastructure (GSI) investments. | Case study from Pittsburgh |
| New York City Panel on Climate Change 2019 Report Chapter 4: Coastal Flooding<br>(Orton et al., 2019) | The objectives of this chapter are to review the latest knowledge on New York City flood risk from storms and tides, and to evaluate how climate change will affect this risk between now and the end of the century. | Case study from New York City |
| The Growing Threat of Urban Flooding: A National Challenge<br>(Galloway et al., 2018) | Center researchers analyzed available data concerning urban flooding, surveyed municipal flood and stormwater managers, and met with professionals whose disciplines intersect with urban flooding at the local, state, and national level. This report presents the results of that study, addressing issues that affect urban flood risk reduction, examining critical challenges, and offering recommendations for action. | Nation-wide |

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| Study Projects a Surge in Coastal Flooding, Starting in 2030s<br>(Zhongming et al., 2021) | In the mid-2030s, every U.S. coast will experience rapidly increasing high-tide floods, when a lunar cycle will amplify rising sea levels caused by climate change. | Global |

## Social Justice and Equity

| **Title (Citation)** | **Description** | **Geographical Relevance** |
|---|---|---|
| A Scoping Literature Review on Indicators and Metrics for Assessing Racial Equity in Disaster Preparation, Response, and Recovery<br>(Finucane et al., 2021) | In this report, researchers describe (1) the results of a literature review and exploratory study on equity, vulnerability, and resilience, (2) the key themes related to conceptual frameworks, (3) indicators and metrics, and (4) knowledge gaps. They also provide recommendations for assessing racial equity in FEMA disaster programs | Nation-wide |
| Community Land = Community Resilience<br>(Georgetown Climate Center, 2021) | Given the magnitude of the challenge and the need to engage residents and the private sector in the development and implementation of solutions, this report explores how mutually beneficial partnerships between cities and community land trusts (CLTs) can be fostered at the state and local levels through the adoption of laws and policies that enable and support CLT work in communities. | Nation-wide |
| Confronting Racism in Environmental Health Sciences: Moving the Science Forward for Eliminating Racial Inequities<br>(Payne-Sturges et al., 2021) | We outline five recommendations the environmental health sciences (EHS) research community can implement to confront racism and move our science forward for eliminating racial inequities in environmental health. | Nation-wide |
| Creating GIS-Based Planning Tools to Promote Equity Through Green Infrastructure<br>(Heckert and Rosan, 2018) | While many planning tools exist to assist in the development of green infrastructure projects, recent critiques have highlighted limitations in their considerations of non-environmental concerns, and several new planning tools have been proposed that use indexes and other need-based approaches to account for a wider range of potential program impacts. | Philadelphia-based |

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| From Struggle Space to an Inclusive and Climate-Ready Philadelphia: Policy Proposals for a more Equitable Green Future<br>(Rosan et al., 2021) | Unless Philadelphia centers climate planning and development policies around equity and resident-identified needs, the city risks replicating and exacerbating historic racial injustices. The city needs to work collaboratively with communities to identify and innovatively plan for climate investments that offer tangible opportunities to transition to a sustainable, green, equitable, and carbon-neutral city that improves the lives of Black and Brown residents. | Philadelphia-based |
| Improving the Post-Flood Financial Resilience of Lower-Income Households through Insurance<br>(Wiley and Kousky, 2021) | This brief presents six policy options for local governments to harness the benefits of insurance to help achieve this goal. The policy options are aimed at improving the financial resilience of homeowners. | Nation-wide |
| Neighborhood-Level Interventions to Improve Childhood Opportunity and Lift Children Out of Poverty<br>(Sandel et al., 2016) | Neighborhood-level efforts to alleviate poverty for all children require alignment of cross-sector efforts, community engagement, and multifactorial approaches that consider the role of people as well as place. We highlight several accessible tools and strategies that health practitioners can engage to improve regional and local systems that influence child opportunity. | Nation-wide |
| Networked Community Land Trusts: Analysis of Existing Models and Needs Assessment for the Greater Boston Community Land Trust Network<br>(Baldwin, 2016) | Through case studies of community land trusts (CLT) networks nationwide and a needs assessment of Greater Boston network partners, this thesis makes recommendations for achieving a best organizational structure moving forward. It addresses use of the “central-server” structure, how it has fared in comparison to other interorganizational network structures, and how it can be adapted to the Greater Boston context. Finally, this thesis identifies opportunities for a technical assistance program with the city of Boston. | Case study from Boston |

## Public Health

| Title (Citation) | Description | Geographical Relevance |
|---|---|---|
| Climate Change and Air Pollution: Effects on Respiratory Allergy (D'amato et al., 2016) | Studies on the effects of climate change on respiratory allergy are still lacking and current knowledge is provided by epidemiological and experimental studies on the relationship between allergic respiratory diseases, asthma and environmental factors, such as meteorological variables, airborne allergens, and air pollution. | Global |
| Climate Change and Vector-Borne Diseases in the Philadelphia Region (Horowitz, 2021) | This report will examine the prevalence of the vectors and reservoirs (both current and potential) and the threat posed by diseases they carry, specifically in the Philadelphia region. | Philadelphia-based |
| Environmental health equity: moving toward a solution-oriented research agenda (Zota and Shamasunder, 2021) | The current global COVID-19 disease pandemic exemplifies how structural inequities can amplify disease burdens in vulnerable groups. Collectively sustained effort in this arena, and deepening this body of knowledge can move us toward health equity and help secure environmental and health justice. | Nation-wide |

## Heat

| Title (Citation) | Description | Geographical Relevance |
|---|---|---|
| Assessing Vulnerability to Heat: A Geospatial Analysis for the City of Philadelphia (Barron et al., 2018) | This paper investigates vulnerability to heat in the Philadelphia, Pennsylvania and identifies where street trees can be planted as a public intervention. We used geospatial information systems (GIS) software to map a validated Heat Vulnerability Index to identify vulnerability at the block level. | Philadelphia-based |
| Associations Between Historical Redlining and Present-Day Heat Vulnerability Housing and Land Cover Characteristics in Philadelphia, PA (Schinasi et al., 2022) | Historical, institutional racism within the housing market may have impacted present-day disparities in heat vulnerability. We quantified associations between historically redlined areas with present-day property and housing characteristics that may enhance heat vulnerability in Philadelphia, PA. | Philadelphia-based |

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|---|---|---|
| Municipal Management of Extreme Heat (DVRPC, 2021) | Prepared and adopted by the Delaware Valley Regional Planning Commission (DVRPC), the long-range plan provides a sustainable land use and transportation vision for the region's growth and development through the year 2045. | Greater Philadelphia region |

## Energy and Resilience

| Title (Citation) | Description | Geographical Relevance |
|---|---|---|
| Methane Reduction Program (PGW, 2021) | Philadelphia Gas Works is strongly committed to achieving an 80 percent reduction in methane emissions from its natural gas distribution system by 2050. The main pathway to this goal is PGW's accelerated main and service replacement program. | Philadelphia-based |
| NYSERDA Environmental Research Program Plan; Research Area 2: Climate Change Adaptation (NYSERDA, 2021) | This report serves as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives. | Case study from New York City |
| Options for Achieving Deep Reductions in Carbon Emissions in Philadelphia by 2050 (Foti et al., 2015) | This report reviews approaches for achieving reductions in greenhouse gas emissions in Philadelphia that are commensurate with the goal of achieving an 80% reduction in emissions by the year 2050. | Philadelphia-based |

## General Urban Resilience

| Title (Citation) | Description | Geographical Relevance |
|---|---|---|
| An Assessment of Planning Tools for Climate Change Resiliency in the Delaware Valley (DVRPC, 2021) | DVRPC is preparing this assessment so that our planning partners can avoid the confusion of assessing and learning about hundreds of potentially superfluous tools and resources and quickly identify and prioritize those tools that will best meet their climate change planning and data needs. | Greater Philadelphia region |

| | | |
|---|---|---|
| Applying Resilience Thinking: Seven principles for building resilience in social-ecological systems<br>Building Community Resilience with Nature-Based Solutions<br>(Biggs et al., 2015) | This present a set of seven principles that are considered crucial for building resilience in social-ecological systems and discuss how these principles can be practically applied. | Non-geographic |
| Climate Resilience Design Guidelines<br>(The Port Authority of NY & NJ, 2018) | The purpose of the Climate Resilience Design Guidelines (CRG) is to maximize the long-term safety, service, and resilience of the Port Authority's assets, now and in the future, as climate conditions change. | Case study from New York and New Jersey |
| Defining urban resilience: a review<br>(Meerow et al., 2016) | This paper proposes a new definition of urban resilience. This definition takes explicit positions on these tensions, but remains inclusive and flexible enough to enable uptake by, and collaboration among, varying disciplines. | Non-geographical |
| From fail safe to safe-to-fail: Sustainability and resilience in the new urban world<br>(Ahern, 2011) | This essay discusses the theory of resilience as it applies to urban conditions, and offers a suite of strategies intended to build urban resilience capacity: multifunctionality, redundancy and modularization, (bio and social) diversity, multi-scale networks and connectivity, and adaptive planning and design. | Non-geographical |
| Nature Based Solutions Handbook<br>(Kabisch et al., 2017) | This book series Theory and Practice of Urban Sustainability Transitions is intended to explore the different dynamics, challenges, and breakthroughs in accelerating sustainability transitions in urban areas across the globe. | Global |
| Nature-Based Solutions to Climate Change Adaptation in Urban Area<br>(Somarakis et al., 2019) | This Handbook has been developed in the framework of the ThinkNature project. Its main objective is to gather and promote state-of-the-art knowledge regarding Nature-Based Solutions (NBS), comprising a comprehensive guide to all relevant actors. | Global |
| Planned Relocation: Pluralistic and integrated science and governance<br>(Moss et al., 2021) | We discuss how science, governance, and their interactions need to evolve to make planned relocation a strategic option that leaves people, communities, and the environment better off. | Global |

| | | |
|---|---|---|
| Vulnerability Assessment and Adaptation Framework (Federal Highway Association, 2017) | The Federal Highway Administration's (FHWA's) Vulnerability Assessment and Adaptation Framework (the Framework), third edition, is a manual to help transportation agencies and their partners assess the vulnerability of transportation infrastructure and systems to extreme weather and climate effects. | Nation-wide |

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# Appendix 2: Climate Downscaling Methodology

Temperature and precipitation projections were developed using downscaled outputs from general circulation models (GCMs) used in the Intergovernmental Panel on Climate Change Sixth Assessment Report, in conjunction with two shared socioeconomic pathways (SSPs; SSP2-4.5 and SSP5-8.5) (Riahi 2017). Projections are presented as averages across 30-year future year time periods, known as timeslices, and are expressed relative to the baseline period, 1981 to 2010. The timeslices are centered around a given decade. For example, the 2050s timeslice refers to the period from 2040 to 2069

Projections for mean annual temperature and mean annual precipitation were computed using 35 GCMs. As a result of using the 35 GCMs and two SSPs, the combination produces a 70-member matrix of outputs. The results are presented across this range of outcomes at selected points in the distribution: the 10th, 25th, 75th, and 90th percentiles.

The results for future time periods are compared to the model results for the baseline period (1981 to 2010). Mean temperature change projections are calculated via the delta method. The delta method is a type of bias-correction whereby the difference between each model's future simulation and that model's baseline simulation is used, rather than 'raw' outputs from the models. The delta method is a long-established technique for developing local climate change projections (Gleick 1986; Arnell 1996; Wilby et al., 2004; Horton et al., 2011). Mean precipitation change is similarly based on the ratio of a given model's future precipitation to that model's baseline precipitation (expressed as a percentage change).

For projections of extreme events, daily data from weather stations and GCMs is utilized. A total of 16 models had daily data available for both SSPs. Projections of daily temperature (maximum and minimum) and precipitation were computed using a method known as quantile mapping. Quantile mapping adjusts a model value by mapping percentiles of the model's distribution onto percentiles of the observations (Cannon et al., 2015; Thrasher et al., 2012; Zhao et al., 2017).rThe synthetic time series were then used to calculate the projections of extreme temperatures and precipitation. These projections are provided for climate hazards that generally are relevant to stakeholders (e.g., hot days, days with intense precipitation).

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# Appendix 3: Description of Working Group Co-Leads

**Working Group 1:** Regional Climate Change and Cascading Hazards, was co-led by Daniel Bader and Kermit O. **Daniel Bader** is the program manager for Consortium for Climate Risk in the Urban Northeast (CCRUN), a NOAA RISA Project. He has extensive experience with preparing and communicating climate science information to policy makers, specifically in states across the Northeast. The data he has worked with is the foundation for climate resiliency planning efforts in New York City (through the New York City Panel on Climate Change), New York State and across the National Aeronautics and Space Administration (NASA). **Kermit O** is a fourth-generation Philadelphian, a former teacher turned school abolitionist and community organizer, working at the intersection of land, food and climate. His research and direct experience as a teacher coalesced into a critical understanding that schooling actively reproduces various forms of enclosure: the physical, digital and sociopolitical infrastructures placed between people and their fundamental needs — exploiting our labor, polluting our environments, disrupting ecosystems, driving desperate migrations and fueling the climate crisis. Kermit sees abolition as the work of breaching these enclosures, and to that end he continues to explore alternative formations such as participatory action research, to engage people in the collective construction of knowledge, and shared struggle toward ideals of social and environmental regeneration, community self-determination, and ultimately, liberation.

**Working Group 2:** Health and Environmental Vulnerability, was co-led by Dr. Katera Moore and Julie Ulrich. **Dr. Moore** is an environmental justice practitioner and researcher with expertise and practical experience with food systems, health disparities, and flooding vulnerability in Philadelphia. She previously served as the director of the Agatston Urban Nutrition Initiative at UPenn and currently teaches in the Environmental Studies department at Unity College. **Julie Ulrich** has an interdisciplinary background with expertise in natural science, social science, design and planning, and public health. She has over ten years of climate experience in both environmental and social vulnerability and is currently the director of urban conservation at the Nature Conservancy.

**Working Group 3:** Low Carbon Adaptation of the Built Environment, was co-led by Dr. Jin Wen and Steve Krug. **Dr. Wen** has extensive research experiences in smart building technologies, building-grid integration, urban scale building energy simulation, and occupant behavior. She is a professor in Drexel University's Civil, Architectural and Environmental Engineering department. **Steve Krug**'s expertise is in energy-efficient buildings and planning in Pennsylvania and the mid-Atlantic region. He is principal of Krug Architects and has led a number of large firms the past 4 decades. He serves on several committees, including as chairperson of the PA Climate Change Advisory Committee, appointed by the Governor.

**Working Group 4**: Regional Climate Governance and Adaptive Management, was co-led by Dr. Christina Rosan and Charles Ellison. **Dr. Rosan** is an associate professor of Environmental Studies, Geography and Urban Studies at Temple University. Her expertise spans from urban and regional planning, politics and governance to green infrastructure and urban agriculture with a particular interest in social justice and action-based research. **Charles Ellison** is the Executive Producer, Host and Managing Editor of WURD & ecoWURD.com. As a communications strategist with specializations in crisis response, advocacy and public affairs, he has extensive expertise in environmental justice/"eco-justice" issues intersecting with multiple policy issues.