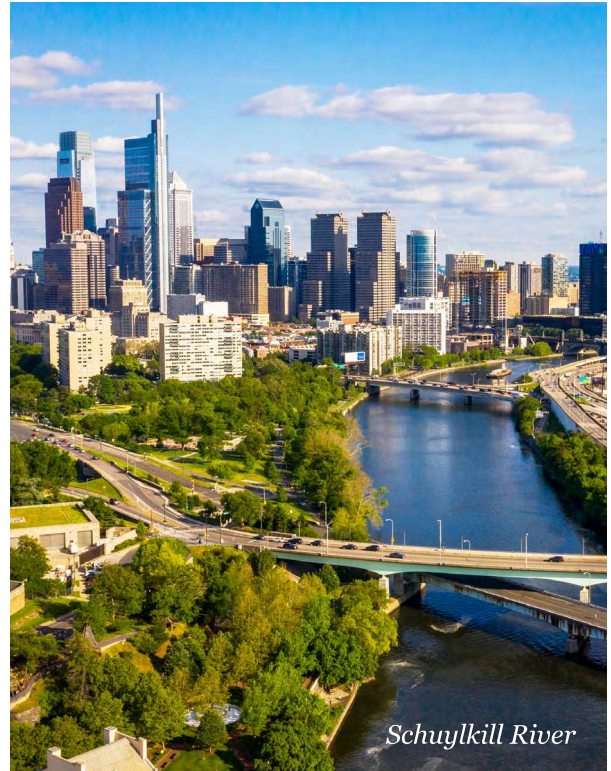
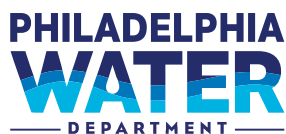


Philadelphia Water Department

CASE STUDY

OCTOBER 2025

In September 2021, torrential rains associated with Hurricane Ida caused severe flooding along the lower Schuylkill River, damaging and threatening **Philadelphia Water Department** (PWD) facilities. For the PWD, this was a “wake-up call” about the utility’s vulnerability to non-tidal riverine flooding. PWD quickly responded by conducting an analysis to assess future flooding risk under climate change, understand the Ida flooding in that context, and inform adaptive management of critical facilities.



LESSONS LEARNED

Updating the flood analyses reinforced the wisdom of adaptive management

There are multiple approaches for climate-informed flood analysis; results will vary with the approach

Handling of uncertainty can be tailored to risk tolerance

Learn more about these lessons on [page 11](#)

SUMMARY

Utility	Philadelphia Water Department
Contact	Climate Change Adaptation Program; pwd.ccap@phila.gov
Consultant	CDM Smith
Project name	Non-tidal riverine flood analysis
Project timeline	Fall 2021 – Spring 2022
Geographic scope	Schuylkill River watershed
Utility business functions affected	Drinking water
Objective	Incorporate ongoing and future climate change effects into flood elevations for the non-tidal reaches of the Schuylkill River to inform planning and design of vulnerable assets
Potential decisions or actions to be informed	Harden or relocate assets vulnerable to flooding
Variables, thresholds, and/or events of interest	Streamflows, elevations, and return intervals of design flood events, e.g., 10-year, 50-year, 100-year, 500-year
Climate data used	CMIP5*with LOCA downscaling, RCP8.5 emissions pathway (32 projections)
Why those data were selected	The only downscaled CMIP dataset that has an associated set of hydrologic projections run with the VIC model for the contiguous U.S., including the Schuylkill watershed
Impact modeling performed	<ul style="list-style-type: none">• VIC hydrologic model to generate future runoff events (modeling was already incorporated in the CMIP5-LOCA hydrology data)• Spreadsheet model to interpolate streamflows, elevations, and return intervals from FEMA Flood Insurance Study (FIS data)
Key attributes of this case study	<ul style="list-style-type: none">• An extreme event created a window of opportunity to produce new risk information and have it accepted by stakeholders• Rapid, lower-cost assessment of future risk leveraged an existing methodology and FEMA datasets• Used a simple regression model to generate site-specific numbers in lieu of a much more complex impact model• Provided one set of numbers to stakeholders to represent the future risk, while explaining the uncertainties

* For definitions of CMIP5 and other climate modeling terminology, see this [glossary](#).

Overview of the utility

Philadelphia Water Department (hereafter PWD) serves 1.7 million customers with drinking water (>300 MGD) and over 2 million customers with stormwater and wastewater services. PWD's water supply portfolio is entirely from surface water: about 60% from the mainstem Delaware River and 40% from the Schuylkill River (Figure 1), which is a tributary of the Delaware. PWD has two water treatment plants on the Schuylkill (Belmont and Queen Lane) and one on the mainstem Delaware (Baxter).

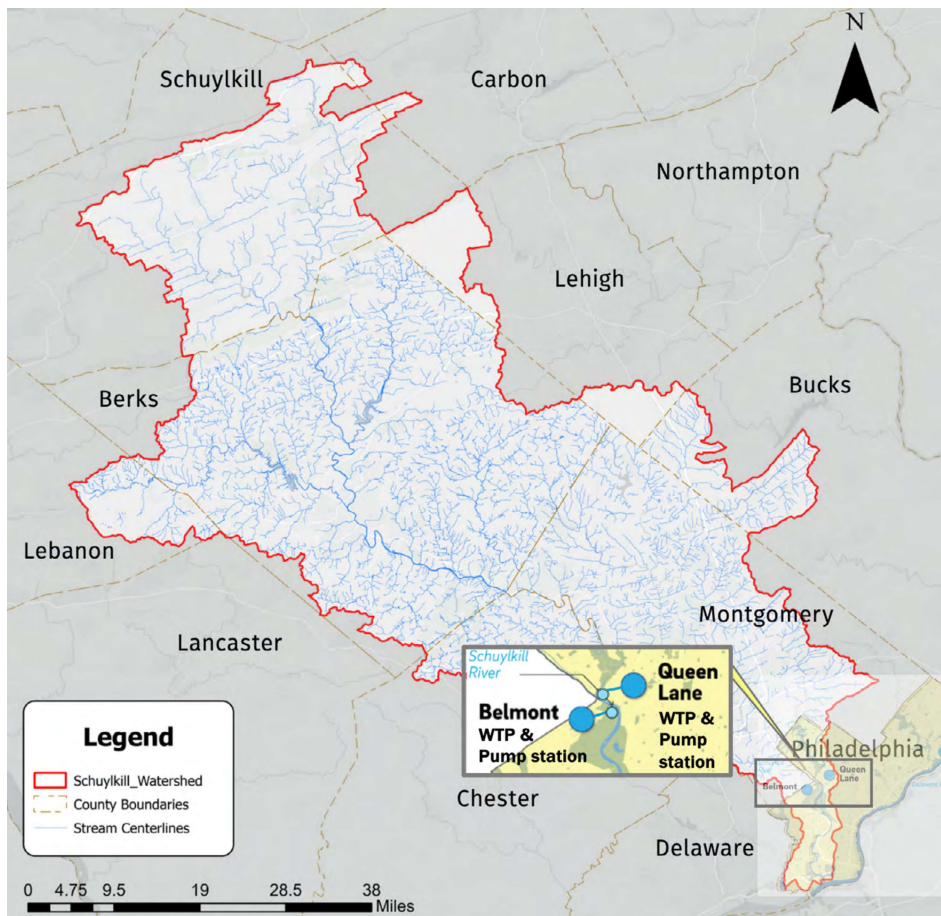


FIGURE 1.

Map of the Schuylkill River watershed, highlighting the City and County of Philadelphia in yellow. The inset shows the location of the Belmont and Queen Lane water treatment plants and their associated pump stations. (Modified from the [East Falls and Manayunk Flood Mitigation Study](#) and a graphic by the Philadelphia Water Department.)

Project background

By 2021, PWD had performed multiple climate change analyses to inform operations and planning, including capital improvement plans (CIP). But the previous work on flooding risk under future climate change focused exclusively on coastal inundation and sea level rise, which pose significant risks to PWD along tidal portions of the Delaware and Schuylkill. Non-tidal riverine flooding on the Schuylkill or other tributaries was not seen as a major source of vulnerability.

On September 1–2, 2021, the former Hurricane Ida—now a “post-tropical” storm, but still carrying abundant tropical moisture—passed over southeastern Pennsylvania, producing several hours of torrential rainfall near and west of the storm track. Within Philadelphia, a total of two to five inches of rain fell. North and east of the city, higher up in the Schuylkill and Delaware watersheds, seven to ten inches fell, leading to major flooding of area creeks and rivers. The Schuylkill at Philadelphia stream gauge recorded a peak stage of 16.35 feet, less than 1 foot below the all-time record.

The flood caused extensive inundation and damage to property and infrastructure along the Schuylkill, including Interstate 676, a SEPTA rail line, and much of the Manayunk neighborhood. PWD’s Belmont Raw Water Pump Station was damaged, and the Queen Lane Water Treatment Plant was threatened. According to Allison Lau, an engineer with PWD’s Climate Change Adaptation Program (CCAP), the flooding and damage were a “wake-up call” for the utility—but also provided a “window of opportunity” to look at how climate change is impacting non-tidal riverine flooding.

Mark Maimone, Climate Change Discipline Lead with CDM Smith, had collaborated with PWD for many years on many studies and engineering analyses, including on climate change impacts. He and colleagues at CDM Smith had recently completed a project for FEMA (Maimone and Adams 2023) for which they developed decadal climate change factors for river basins across the contiguous U.S.—factors that could be used to adjust design flood elevations (DFEs) to reflect future climate risk. Among those U.S. basins was the greater Delaware-Mid-Atlantic basin (HUC4), but to get a finer-resolution look at PWD’s watersheds, Lau and Maimone decided to deploy the same approach for a new analysis focused on just the Schuylkill River.

Besides rapidly responding to the Ida damage and its implications for the system, the Schuylkill analysis was also well-timed to inform a master planning and capital

The flooding and damage were a “wake-up call”

investment process, the Water Revitalization Plan, which kicked off in 2019. Among the 15 major drinking-water projects identified in the plan, two are related to the Ida flooding on the Schuylkill River: the Belmont Pump Station upgrade and the Queen Lane Water Treatment Plant replacement (to begin in 2026). Other facility improvements could also benefit from more robust information about future non-tidal riverine flood risks.



Project methods and data selection

There were two main parts to the PWD non-tidal riverine flood analysis. The first used the same downscaled climate projections and methods as in the FEMA-funded work to produce decadal delta change factors (DCFs) specific to the Schuylkill River. This part was carried out by Mark Maimone and CDM Smith. The second part applied the decadal change factors to update the design flood elevations and associated flows previously published for the FEMA FIS dataset, then estimated future flows and elevations across a range of flood return intervals, not just the 10-year, 50-year, 100-year, and 500-year events estimated in the FIS. This part was carried out by PWD (Lau and Julia Rockwell, CCAP manager) with guidance from Maimone.

TIME HORIZON AND ASSUMPTIONS ABOUT THE FUTURE

The methodology for the analysis produces decadal change factors for each decade from 2020 through 2090. To calculate the climate change-adjusted design flood elevations and report the results, PWD focused on the 2060s and 2090s. The analysis assumed that existing land-use patterns would be constant through the analysis period, though Maimone and Lau acknowledged that land use (e.g., fraction of impervious surfaces) will in fact change over time.

SELECTING AND PROCESSING CLIMATE MODEL DATA

At the time of CDM Smith's FEMA project, only climate projections from CMIP5 models were available in downscaled form suitable for modeling at the basin (HUC4) scale; downscaled CMIP6 was still a year or two away. Of the numerous options for downscaled CMIP5, the LOCA (Localized Constructed Analogs) downscaled CMIP5 dataset (Pierce et al. 2016) was the only one for which fine-scale hydrology projections had been run with the physics-based VIC hydrologic model, for all basins in the contiguous U.S.¹ CDM Smith also evaluated LOCA against two other

¹ CMIP5 MACA projections have also been run in the VIC model, but the modeled hydrology is available only for selected stream gauges in the Western U.S.



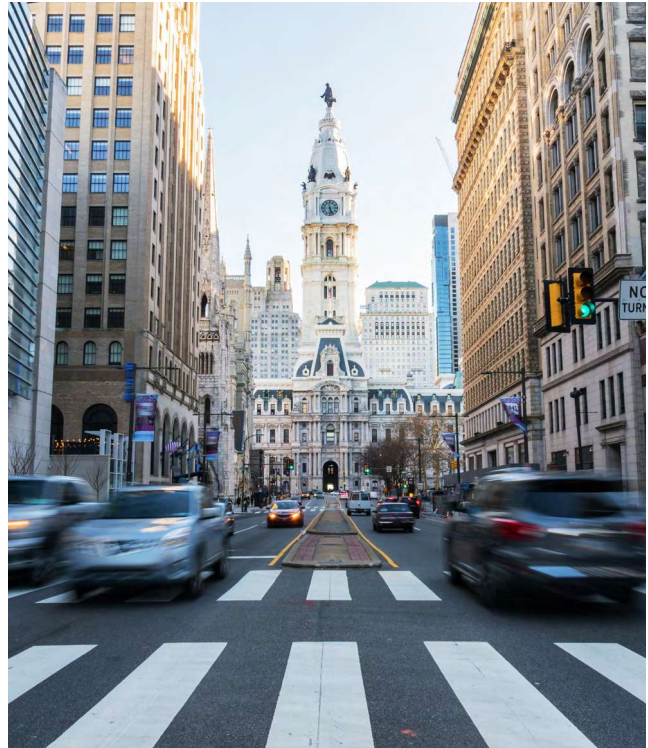
Planning informs PWD's investment in large-scale infrastructure

downscaled CMIP5 datasets, MACA and BCSD, comparing the historical period simulations (1950–2005) from those three datasets with observed precipitation (daily, annual, average) and temperature (daily). They found that the statistics from the LOCA historical simulations best matched Philadelphia's observed climate records.

The “CMIP5-LOCA-VIC” hydrology projections were produced by NCAR for a consortium led by Reclamation and USACE, and made available in 2020 via the GDO-DCHP data portal: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/. The CMIP5-LOCA-VIC dataset includes downscaled projections from 32 climate models run once each under RCP4.5 and RCP8.5, so 64 projections total.

CDM Smith and PWD considered reducing the 32-member model ensemble, either through grouping the models into response quadrants (e.g., hot-dry, cool-wet, etc.) or according to each model's independence from the others, but ultimately they opted to use the entire LOCA ensemble (32 models). This decision was consistent with the Philadelphia Office of Sustainability's use of the entire LOCA ensemble in its city-wide vulnerability assessment.

For the PWD analysis, CDM Smith downloaded only the CMIP5-LOCA-VIC data for those 12-km grid cells covering the Schuylkill River basin, a task facilitated by the “Tributary Area” selection tool in the GDO-DCHP portal. While the nationwide FEMA project used all of the CMIP5-LOCA projections (32 models run once each under RCP4.5 and RCP8.5, or 64 projections), the PWD analysis used only the 32 projections run under RCP8.5. This choice was consistent with PWD’s programmatic climate change guidance², which recommends using RCP8.5 to reflect PWD’s low risk tolerance for interruptions to its critical services.



Philadelphia City Hall

IMPACT MODELING

The PWD analysis leveraged the existing FEMA FIS design flood elevations and flows, bypassing the need to perform new locally specific hydrology and hydraulic modeling (e.g., with HEC-RAS) to simulate flood elevations at different flows. The only new modeling required was a spreadsheet model to interpolate elevations and flows between the four design floods in the FEMA FIS data (10-year, 50-year, 100-year, 500-year). This greatly simplified the workflow and reduced the potential time investment in the project.

One downside of using the FEMA FIS data was that the calculations for design flood elevations for the Schuylkill had been last revised in 2007 using gage data through 2002, as well as hydraulic assumptions, data, and modeling performed by USACE in 1996. Lau acknowledged that these FEMA/USACE data were outdated, but short of PWD building their own hydraulic model of the Schuylkill, their analysis had to rely on the FIS numbers.

Another downside of relying on the FIS numbers was the inability to reliably extrapolate peak flows and elevations for any future design floods that exceeded the

² [PWD Climate-Resilient Planning and Design Guidance \(v 1.1, March 2024\)](#)

FIS 500-year event peak flow and elevation. Because the FIS-published river cross-sections of the Schuylkill only extend to that 500-year level, the contours of the potentially inundated area above that level are unknown (see Figure 3).

OVERVIEW OF THE ANALYTICAL APPROACH

A summary of the data and steps in the Schuylkill flood analysis is shown in Figure 2. Essentially, the approach examines the 32 hydrologic projections to see how the highest-runoff days in the Schuylkill watershed have changed from the 1986–2005 reference period to each of eight future periods (centered on 2020 to 2090). The percentage change, or delta change factor (DCF), is then applied to the FEMA FIS peak flows for the four design floods.

To develop this approach for the FEMA project, CDM Smith ran many sensitivity analyses to determine the best number of daily runoff events to pool within the historical and future periods for calculating the DCFs, eventually landing on 20 events. When using fewer than 20 events, the results were too volatile, with abrupt changes in the DCFs from decade to decade that are not physically meaningful.

Note that the step to calculate the DCF for the Schuylkill for each future period involved averaging across the 32 CMIP5-LOCA-VIC projections. This means that there is only one hydrologic future depicted in the final outputs. While the project leads were well aware of the broad range of climate futures (i.e., the magnitude of temperature and precipitation changes) across the 32 projections, the CCAP guidance document recommends reporting only the ensemble average. According to Maimone, this practice is consistent with what PWD stakeholders wanted: “We’ll tell them about all the uncertainty, but they want one number.”



Fairmount Water Works Garden, Philadelphia Art Museum

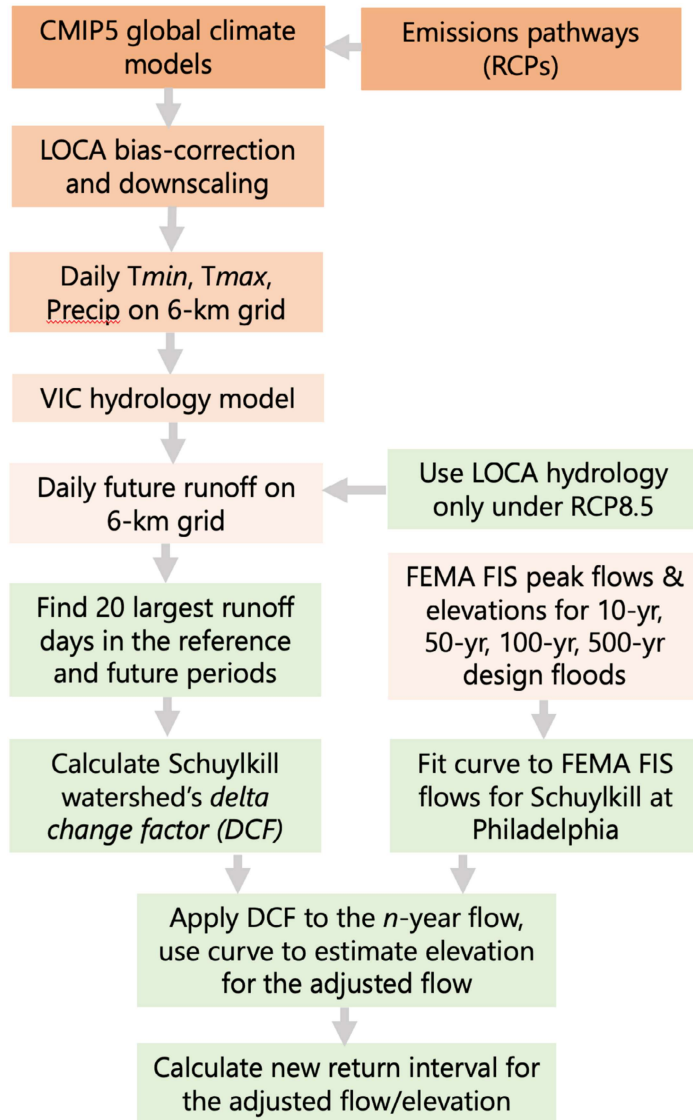


FIGURE 2.

Schematic of the Schuylkill riverine flooding analysis. Orange shading indicates data and processing completed by others prior to the analysis. Green shading denotes the steps performed by CDM Smith and PWD.

DATA HANDLING

The CMIP5 LOCA VIC data—which are large files of several gigabytes for each gridcell—was downloaded, handled, and processed on CDM Smith’s computers. The R codes that CDM Smith used to calculate the Schuylkill flood DCFs from the CMIP5 LOCA VIC data had already been developed for the FEMA project. Once the DCFs were calculated, these data were passed to PWD; the subsequent calculations—using FIS data to derive new flood flows/elevations—were done on a spreadsheet.



Outcomes and next steps

RESULTS OF THE ANALYSIS

Severe flooding will become more frequent

PWD’s non-tidal riverine flood analysis depicts a future with significant increases in design flood peak flows and elevations on the Schuylkill River; peak flows would increase by 32% in 2060 and by 60% in 2090 under RCP8.5, compared to the 1986–2005 reference period (Figure 3). Conversely, the peak flows and elevations associated with the current FIS design floods would occur at shorter intervals, on average. For example, the FIS 500-year event becomes a 100-year event in the hydroclimatology of 2060 and only a 40-year event in 2090. Similarly, the level of the 2021 Ida flooding is estimated as a 65-year event in the (outdated) FIS data, but that level is a 30-year event under current conditions (2020) and would be rated as a 6-year event in 2090.

At the Belmont RWPS: Flows and Associated River Elevations for RCP8.5									
		Return interval							
Decade (year)	DCF	10-year		50-year		100-year		500-year	
		Flow (cfs)	Elev. (ft.) NAVD88	Flow (cfs)	Elev. (ft.) NAVD88	Flow (cfs)	Elev. (ft.) NAVD88	Flow (cfs)	Elev. (ft.) NAVD88
	RCP8.5								
2020	24%	91,969	23.1	136,711	28.9	159,082	32.3	212,523	42.2
2030	28%	94,408	23.4	140,336	29.4	163,300	33.0	218,159	43.4
2040	29%	95,169	23.5	141,467	29.6	164,616	33.2	219,917	43.8
2050	25%	92,250	23.1	137,128	28.9	159,567	32.4	213,172	42.3
2060	32%	97,731	23.8	145,275	30.1	169,047	33.9	225,837	45.1
2070	41%	103,998	24.5	154,592	31.6	179,889	35.8	240,321	48.5
2080	53%	113,308	25.7	168,431	33.8	195,992	38.8	261,833	54.0
2090	60%	118,106	26.3	175,563	35.1	204,291	40.5	272,920	57.0

FIGURE 3.

Delta Change Factors (DCFs) by decade, and the associated peak flow and elevation of the Schuylkill at the Belmont Raw Water Pump Station at each design flood return interval. The orange shading indicates results with more inherent uncertainty since the elevations are extrapolated beyond the envelope of the underlying FEMA FIS data, i.e., the current 500-year event. (Philadelphia Water Department)

Facility operators see the increasing risk

The details of how this increasing risk would impact specific elevations and infrastructure on the Schuylkill made a strong impression on the PWD facility operators who saw the project team’s first presentation of the results, according to Lau and Maimone. With memories of the Ida flooding still fresh, the operators were alarmed by the vulnerabilities that the PWD facilities would face in a rapidly warming future. Interestingly, presenting the risk in terms of flood return intervals (e.g., Ida as a 6-year event in 2090) appeared to resonate more with the operators as a metric of vulnerability than the increases in flood elevations.

USE AS DECISION SUPPORT

Informing infrastructure design hardening for resilience

Based on the results of the analysis, PWD investigated an alternative location for the Belmont Pump Station, at a higher elevation and upstream of the existing facility, though there has not yet been a decision or action. As the Water Revitalization Plan moves forward, the results of the analysis will inform implementation of at least two projects: the retrofit/move of the Belmont Pump Station and the replacement of the Queen Lane WTP based on the Raw Water System Intake. There are three alternatives for improving the Belmont Pump Station. These include rehabilitating the existing facility, constructing a new pump station at the current location, or building a pump station at a new, higher elevation site.

Supporting community resilience planning beyond utility assets

In response to the Ida flooding, the East Falls and Manayunk neighborhood development corporations carried out their own flood mitigation study, which was released in July 2024. The “Future Flooding” section of that study, carried out by AKRF, Inc., used the approach from PWD’s analysis, including Delta Change Factors (DCFs) for the Schuylkill River provided by PWD, to project how many additional properties in the neighborhoods would be inundated in 10-year and 100-year design flood events in 2050 and 2090, compared to the current FEMA FIS elevations.



Lessons learned

UPDATING THE FLOOD ANALYSES REINFORCED THE WISDOM OF ADAPTIVE MANAGEMENT

Lau says that understanding the potential changes in flood frequencies has been very important and impactful for PWD. The detailed findings helped inform what

alternative sites would be feasible and whether it would be possible to retrofit the Belmont Pump Station at its current location to the design flood elevation. The findings of the analysis also reinforced the wisdom of adaptive management, in which adjustments to plans and operations are made systematically and iteratively as conditions change and new information becomes available.

THERE ARE MULTIPLE APPROACHES FOR CLIMATE-INFORMED FLOOD ANALYSIS; RESULTS WILL VARY WITH THE APPROACH

While using downscaled hydrology projections to calculate DCFs showed significant increases in the design flood peak flows and elevations for the Schuylkill under RCP8.5—as it has for most basins across the U.S.—the change factors turned out to be smaller than what one would obtain using a simpler method based on Clausius-Clapeyron (C-C) scaling. C-C scaling says that changes in extreme rainfall will follow the increase in the atmosphere’s capacity to hold water vapor as temperatures warm: +7% per degree C of warming.³

A joint study by CDM Smith and PWD staff (Maimone et al. 2023) conducted after the Schuylkill analysis laid out two potential approaches for handling C-C scaling to project future changes in future extreme precipitation events, and compared them to the VIC model runoff approach. Using a C-C approach for a future PWD flood analysis for the Schuylkill would require a hydrology and hydraulic model of the watershed to translate from extreme precipitation events to flood elevations and peak flows.

Having worked with these different approaches to evaluating future change in extreme precipitation and flooding, Maimone says one should put a lot of thought into the choice of approach: “The results can be very, very different depending on what method you choose.” He also noted that if one derives future change factors (DCFs) from projected precipitation, the percent changes will be much smaller than those derived from projected runoff (as in the PWD project). Thus one should not apply precipitation-derived change factors directly to historical runoff or peak flows, such as FIS data.

CDM Smith is currently evaluating the CMIP6 LOCA2 downscaled temperature and precipitation projections, which became available in 2023. If the projected changes point to substantial differences in storms and flooding compared to CMIP5 LOCA, that would prompt PWD to redo the non-tidal riverine flood analysis with the CMIP6-based dataset.

HANDLING OF UNCERTAINTY CAN BE TAILORED TO RISK TOLERANCE

The discussion above underscores that there can be no certain answer to the

³ C-C scaling of extreme precipitation is broadly supported by observational evidence, although precipitation extremes in warm-season convective events (i.e., thunderstorms) can show “super-C-C” scaling, increasing by roughly 15% per degree C of warming.

question “How will non-tidal riverine flood risk for PWD change in the future?” There is significant uncertainty in the climate inputs (e.g., CMIP5 model projections) and also sensitivity of the outputs to the various methodological decisions and assumptions. While it is important to understand the sources of uncertainty, it is also appropriate to deliberately constrain uncertainty to reflect the risk tolerance of the system being analyzed.

As noted earlier, PWD’s decision to model and report flood risk only under RCP8.5, and not RCP4.5, was made because of the low risk tolerance associated with the critical infrastructure and services at issue. That inherently conservative approach had the effect of tilting the analysis toward the higher end of the broad range of plausible future flooding outcomes, regardless of the other specifics of the methodology. (Focusing on the ensemble mean under RCP8.5 simplified the presentation of future risk while deemphasizing extreme-high-end outcomes.) If the findings under RCP8.5 had pointed the utility toward an action that appeared excessively costly relative to the values at risk, there was flexibility under PWD’s Climate Resilience Planning and Design Guidance to use a lower estimate of future climate change instead (e.g., the RCP4.5 ensemble mean).

Further reading

OTHER INFORMATION ABOUT THE PROJECT

- Rockwell, J. ‘Keeping Pace with Evolving Climate Science: Planning for Climate Change at the Philadelphia Water Department.’ Presentation to SE PA-AWWA Spring Conference, April 2024 (slides 30-39).

RESEARCH OUTPUTS ABOUT THE METHODOLOGY/DATASET(S)

- Maimone and Adams (2023). A practical method for estimating climate-related changes to riverine flood elevation and frequency.
- Maimone et al. (2023). Three methods of characterizing climate-induced changes in extreme rainfall: a comparison study.

OTHER RELEVANT LITERATURE/WEBPAGES

- PWD Climate-Resilient Planning and Design Guidance (v 1.1, March 2024)
- East Falls and Manayunk Flood Mitigation Study (July 2024)

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This case study was developed by Jeff Lukas (Lukas Climate Research and Consulting and AGCI) and Julie Vano (AGCI) based on conversations with staff from the Philadelphia Water Department. Additional guidance and input came from WUCA project managers Keely Brooks (Southern Nevada Water Authority) and Nolie Templeton (Central Arizona Project), and from WUCA’s Climate Modeling Work Group.

We thank all who provided their insights!