

Cross-Sectoral Economic Impact Analysis of Climate Change in New York State

Chapter 9: Water Resources Sector

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Cross-Sectoral Economic Impact Analysis of Climate Change in New York State

Chapter 9: Water Resources Sector

Final Report

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Notice

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Abstract

Climate impacts on water resources affect multiple sectors, including water availability for agricultural irrigation and cooling thermal power plants, impacts on water-based ecosystem services, and others. For this sector, we modeled and quantified the economic impacts associated with water quality due to increased runoff from more frequent and intense precipitation, loss of freshwater available for municipal and industrial uses due to changes in precipitation and saltwater intrusion into aquifers, and increases in storm intensity on urban drainage systems. Other potential impacts are discussed qualitatively but were not able to be modeled for this study, including the impacts of changes in temperature and precipitation leading to increased harmful algal blooms, and sea-level rise leading to saltwater intrusion into public groundwater supplies. Proactive, forward-looking adaptation that incorporates future climate conditions was not modeled for this sector; however, such adaptation measures could reduce the economic impacts in this sector. As with all modeling, this work could not capture every aspect of the water resources sector, and there are data and modeling limitations that are inherent in any analysis like this.

Keywords

climate change, impacts, economics, economic impacts, projections, scenarios, adaptation, socioeconomic, water resources, water quality, water supply, urban drainage, harmful algal blooms (HABs)

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Acronyms and Abbreviations

°C	degrees Celsius
cells/mL	cells per milliliter
CRWU	Creating Resilient Water Utilities
CSL	consumer surplus losses
CyanoHAB	cyanobacterial harmful algal bloom
DEC	New York State Department of Environmental Conservation
DEP	New York City Department of Environmental Protection
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FOIL	Freedom of Information Law
GCM	global climate model
GDP	gross domestic product
GIS	Geographic Information System
HAB	harmful algal blooms
HUC	Hydrologic Unit Codes
M&I	municipal and industrial
MCM	million cubic meters
N ₂	nitrogen
NOAA	National Oceanic and Atmospheric Administration
SSP	Shared Socioeconomic Pathway
USD	U.S. dollars
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WHO	World Health Organization
WQI	water quality index
WTP	willingness to pay

Report Summary

This chapter is part of a report that projects the economic impacts of climate change in New York State across eight sectors through 2100 under multiple climate, socioeconomic, and adaptation scenarios. The research team identified and applied existing literature and models to quantify or qualitatively assess climate-related impact categories, using standardized climate and socioeconomic inputs. The analysis used downscaled Coupled Model Intercomparison Project Phase 6 (CMIP6) climate data and gross domestic product (GDP)/population projections to estimate sector-specific impacts under Shared Socioeconomic Pathway (SSP)2-4.5 and SSP5-8.5 emissions scenarios. While the estimates reflect current best practices and modeling capabilities, limitations such as data availability, missing feedback loops, and gaps in demographic sensitivity likely lead to underestimation of total impacts.

Water Resources Sector Insights

The following is a summary of findings for climate economic impacts in the water resources sector that are detailed in this chapter:

- Willingness to pay for cleaner freshwater and to restore water quality degraded by temperature and other changes ranges from \$312 million to \$403 million annually by late century. These water quality impacts grow over the century.
- Urban drainage impacts, which reflect the costs to upgrade drainage infrastructure in response to changes in extreme precipitation events, account for the largest share of total quantified water resource impacts in all time periods.
- Impacts on municipal and industrial water supply are relatively small compared to other impacts, but the results do indicate that some seasonal effects on municipal water supply (mainly for lower-valued uses, such as lawn watering) may occur more frequently in the future.
- Water quality impacts are largest in the Adirondacks and Great Lakes regions, and urban drainage impacts are projected to be greatest in the New York City and Long Island regions.

1 Introduction

Climate impacts on water resources affect multiple sectors, including water availability for agricultural irrigation and cooling thermal power plants, impacts on water-based ecosystem services, and others.

This chapter focuses on two impacts:

1. Availability of water resources for municipal and industrial (M&I) water supply
2. Effects of changes in temperature and precipitation patterns on water quality

The effects on water quality exceed those on the M&I water supply because changes in the variability of water flows and increases in water temperature, particularly in riverine systems, reduce overall ambient water quality.

The lower estimates for water supply impacts may be surprising in light of recent attention on drought conditions and water restrictions in parts of the Northeastern U.S. Quantified impacts on water supply are relatively small for two reasons:

1. Overall annual and seasonal precipitation is expected to increase in New York State as the climate changes throughout the twenty-first century
2. New York State's extensive artificial and natural water storage systems help mitigate shortages that arise on a weekly to monthly basis

In addition, recent water restrictions in the Northeast have tended to affect lower-valued uses of water, such as for lawn watering, and more expensive implications on high-value indoor municipal water demand and critical industrial and most irrigated agriculture demands have been less affected. Another surprising result is that the urban drainage damages for the 2030s are slightly higher for the lower GHG than the higher GHG scenario. This results because the 50-year storm in the 2030s has a higher total precipitation for many locations under the lower GHG scenario. By the 2050s, though, the higher GHG scenario shows higher damages. Table 9-1 summarizes the sector impacts assessed in this chapter.

Forward-looking (proactive) adaptation measures were not quantified for this sector. The analysis assumes a reactive response scenario, including some market-based changes in water use optimization from low-value uses (e.g., outdoor landscaping) to high-value uses (e.g., drinking water) to adjust to potential shortages (Table 9-2). For this study, the reactive response scenario assumes that response and associated costs increase as impacts and damages increase but practices stay the same and continue to assume the historical climate rather than incorporating future climate change. See Chapter 2, Agriculture Sector, for more information on the adaptation and response scenarios considered in this study.

Table 9-1. Annual Statewide Economic Impacts to Water Resources Categories

Values represent total statewide impacts relative to the baseline by SSP, reported in millions of 2021 USD.

Category	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Water Quality	\$68.0	\$111	\$94.3	\$209	\$312	\$403
Municipal and Industrial Water Supply	\$0.21	\$0.52	\$0.01	\$0.43	\$0.24	\$1.36
Urban Drainage ^a	\$541	\$515	\$560	\$664	\$698	\$858
Harmful Algal Blooms	Increased air and water temperatures and changes in precipitation patterns could create more favorable conditions for HABs, which in turn could increase human exposure to toxins or limit the recreational or drinking water use of affected water bodies.					
Saltwater Intrusion	On Long Island, a rise in sea level could affect the depth to the freshwater–saltwater interface and promote the intrusion of saltwater into public groundwater supply wells.					

^a Impacts are for a 50-year storm scenario. The capital costs reflected in the urban drainage results are annualized over 35 years using a discount rate of 3.6%.

Table 9-2. Summary of Adaptation Response Assumptions for the Water Resources Sector

Note that reactive adaptation response for these impacts does not reflect modeling of the effectiveness and costs of specific strategies but is implicitly reflected in data on historical climate response sensitivity and the resulting physical and economic impacts. The adaptation strategies listed as examples in this table were identified based on other available information available on adaptation strategies employed in the sector.

Category	Reactive Response Assumptions	Proactive Adaptation
Water Quality	Water users' willingness to pay for improved water quality reflects substitution possibilities for alternative, higher quality water bodies.	Not quantitatively estimated
Municipal and Industrial Water Supply	The allocation of freshwater among Municipal and industrial consumers adjusts to changed water availability under climate change, consistent with past patterns of water supply and prices during periods of higher and lower water availability.	Not quantitatively estimated
Urban Drainage	Local governments upgrade the capacity of stormwater drainage systems in response to increasing risks of high precipitation events.	Not quantitatively estimated

1.1 Related Impacts: Connections across Sectors

This section highlights related impacts and connections across other sectors.

- **Agriculture:** Reduced water reliability could affect water availability for irrigation.
- **Buildings:** Inland and coastal flooding of water treatment and distribution facilities can disrupt water treatment processing.

2 Quantitative Damages

2.1 Water Quality

The scope of economic impacts considered in this analysis includes economic impacts resulting from individuals' willingness to pay for cleaner freshwater, due to worsening water quality driven by changes in precipitation, runoff, and atmospheric temperature.

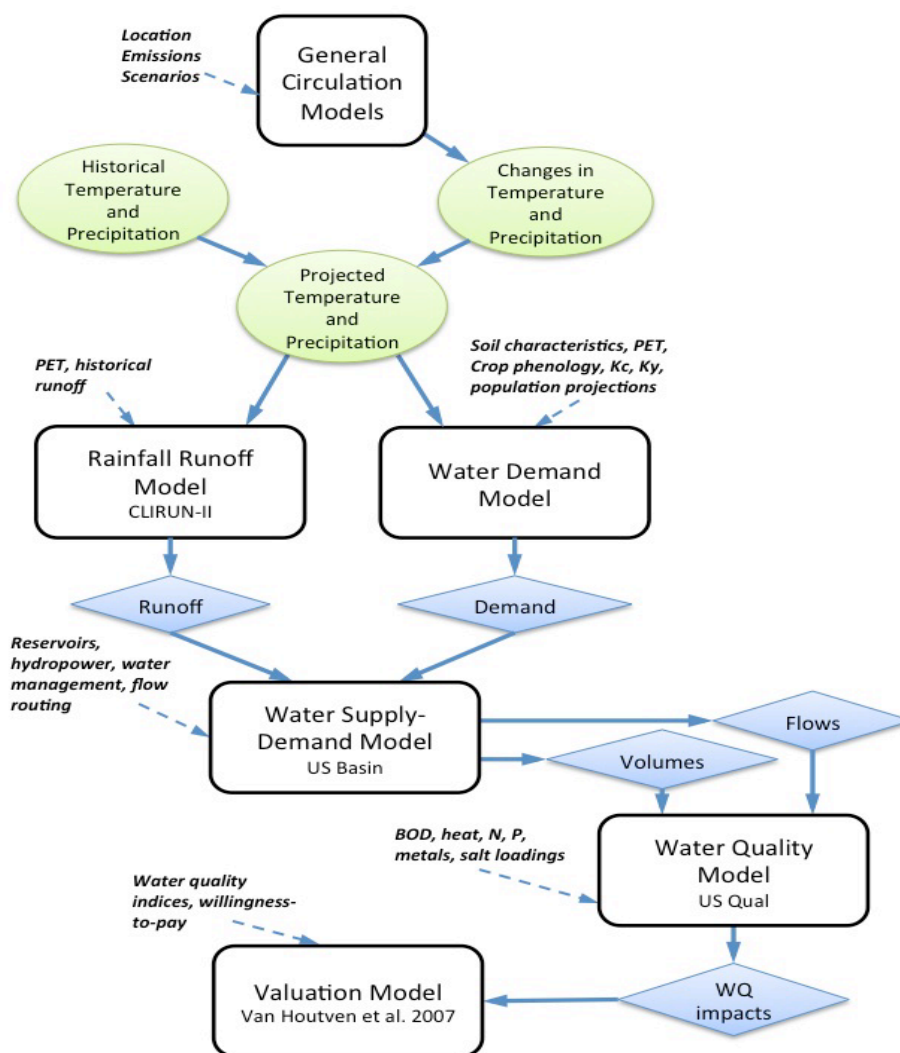
Freshwater ecosystems are a critical component of the connected ecosystems in the state of New York. Rivers, streams, lakes, ponds, and freshwater wetlands provide habitat to a variety of fish, birds, and other species and provide other ecosystem services, such as water supply, wildlife viewing, fishing, climate resilience, and recreational opportunities. Climate change threatens freshwater ecosystems through changes in precipitation, which directly affects runoff from land surfaces into water bodies, and changes in air temperature, which indirectly affects runoff rates through evaporation and evapotranspiration and directly affects water temperature, chemical reaction rates, and competition among phytoplankton species, all of which can lead to changes in water quality.

2.1.1 Methodology

The water quality model used here forms the final component of a suite of models (see Figure 9-1). Climate variables—precipitation and temperature—drive the rainfall-runoff and water-demand models, simulating changes in runoff and agricultural water demands. Population and gross domestic product (GDP) drive nonagricultural water demands from municipal and industrial users. The water management model uses runoff (water supply to the system) and water demand to simulate water allocation to the various users, including hydropower generation, to develop a time series of reservoir volumes and river flows. The water quality model uses these inputs, along with loadings of various constituents, to simulate water temperature, chemical reactions, and the growth of four groups of phytoplankton species and their competition for both nutrients and sunlight.

Figure 9-1. Conceptual Framework for the Water Quality Model System

Source: Boehlert et al. (2015).



The economic impacts of changes in water quality measures are estimated using a valuation of changes in a 10-point water quality index (WQI), which incorporates measures of dissolved oxygen, total nitrogen concentration, total phosphorus concentration, and temperature. The 10-point WQI combines the simplicity of a class-based approach to water quality with its use-specific quality steps (the boatable, fishable, swimmable classes for ambient water quality that are consistent with the U.S. Environmental Protection Agency's (EPA) regulatory classes) while providing a basis for linking in-stream chemical, physical, and biological characteristics to human-based economic value estimates from a total of 18 water quality valuation studies. Changes in WQI are then translated to a willingness to pay (WTP) value using the 10-point values from Van Houtven et al. (2007) to develop a valuation function. We use state-level

data from the U.S. Census Bureau (2020) on persons per household to convert WTP per household to WTP per person, and we use the population projections to estimate municipal and industrial water demands to develop a statewide WTP across scenarios and eras. Appendix B provides additional details on the methodology.

2.1.2 Results

Table 9-3 shows the water quality impacts calculated using WTP by region for all three eras and both Shared Socioeconomic Pathway (SSP)2-4.5 and SSP5-8.5, and Figure 9-2 shows the impacts by county per capita for 2050. Costs rise fairly consistently from the 2030s to the 2080s for the State, with higher costs under SSP5-8.5 than under SSP2-4.5. The Great Lakes region experiences the most adverse water quality impacts in both the 2030s and 2050s. Impacts vary across the other regions, with some benefits in Long Island and New York City, where increased runoff dilutes nutrient contents without significant increases in loadings for both the 2030s and 2050s. On Long Island, higher temperatures in the 2080s increase reaction rates and evaporation, significantly reducing water quality. Most adverse impacts for the region occur near the end of the century. Effects in the Long Island region are larger than for other regions because of the combination of higher temperatures and reduced runoff during summers in particular—in other regions, temperature increases are comparable but runoff decreases much less than on Long Island, or runoff may increase in those other regions as a result of climate change. As shown in Figure 9-3, impacts range from -\$10 per person near the coast to \$50–\$73 per person in the northern parts of the State and in a few counties in the central and western areas.

Table 9-3. Annual Economic Impacts on Water Quality Due to Climate Change by Region

Change from baseline. Economic impacts represent the estimated additional costs due to climate change based on WTP for cleaner freshwater, without adaptation considerations. Results are reported in millions of 2021 USD per year and averaged across global climate models. Negative values represent an economic benefit. Values may not sum due to rounding.

Source: Analysis based on Fant et al. (2017).

Region	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Adirondacks	\$17.91	\$21.18	\$23.23	\$32.52	\$24.87	\$32.30
Catskills	\$11.72	\$13.71	\$16.47	\$21.92	\$16.77	\$20.61
Central/Finger Lakes	\$8.00	\$9.50	\$10.15	\$17.91	\$12.59	\$20.11
Champlain Valley	\$7.88	\$8.64	\$10.48	\$13.77	\$10.09	\$12.71
Great Lakes	\$25.61	\$28.92	\$32.36	\$53.03	\$38.94	\$58.81
Long Island	-\$22.68	-\$12.70	-\$17.76	-\$4.17	\$162.18	\$141.82
Mohawk River Valley	\$7.09	\$8.32	\$9.57	\$12.87	\$5.96	\$8.06
New York City	-\$2.78	-\$1.39	-\$13.38	-\$12.99	-\$3.06	-\$2.01
North Hudson	\$2.42	\$4.40	\$4.74	\$9.72	\$1.11	\$6.26
South Hudson	-\$7.70	\$6.27	-\$7.46	\$25.59	\$5.42	\$55.92
Southern Tier	\$11.46	\$13.24	\$14.10	\$21.11	\$20.54	\$26.84
St. Lawrence Valley	\$9.04	\$11.30	\$11.82	\$17.75	\$16.61	\$21.70
Statewide	\$68.00	\$111.40	\$94.300	\$209.0	\$312.00	\$403.10

Figure 9-2. Annual Impacts of Climate Change on Water Quality in Willingness to Pay per Capita for SSP2-4.5 (left) and SSP5-8.5 (right) by County, 2050s

Source: Analysis based on Fant et al. (2017).

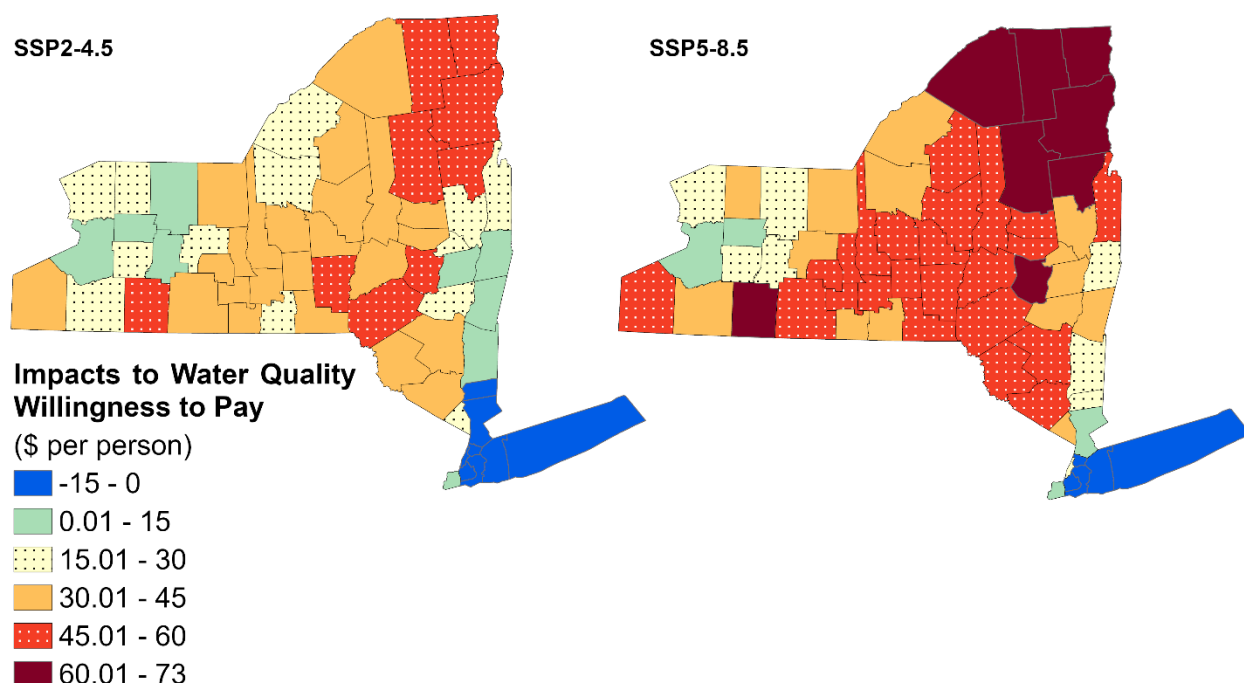
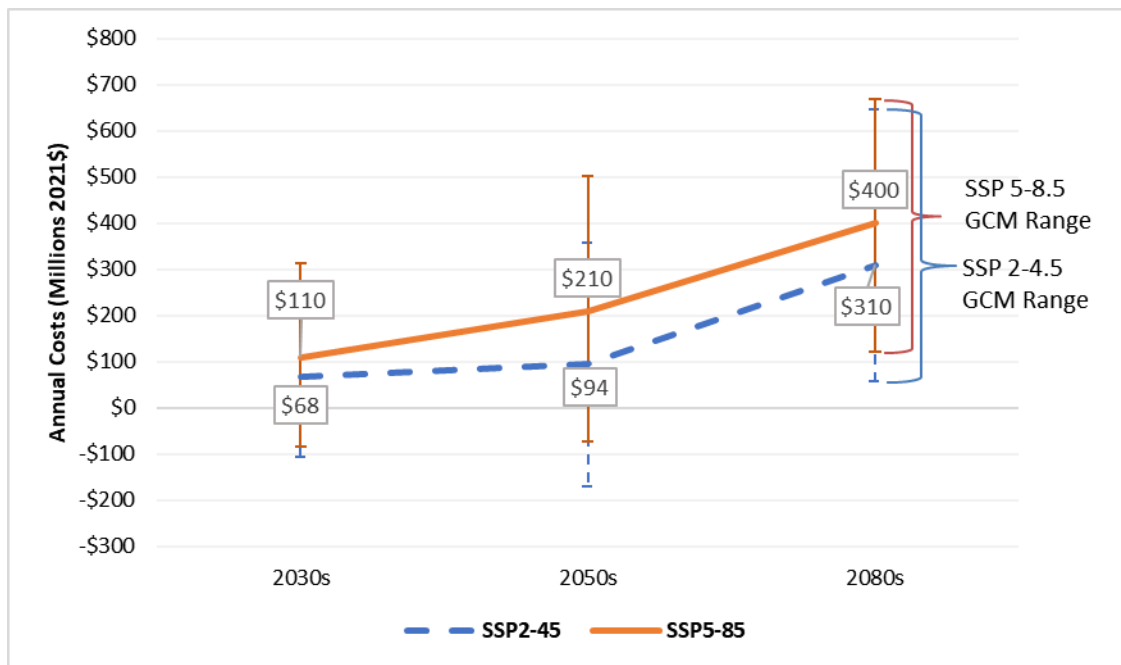


Figure 9-3 shows the impacts by era for both SSPs using the average across global climate models (GCMs), as well as the range across GCMs, indicated by the vertical lines and whiskers. The range across the GCMs is substantial, with one of the six GCMs showing benefits for the State in the 2030s and 2050s. However, most GCMs show costs, with some indicating costs as high as \$200 million to \$300 million per year in the 2030s and \$350 million to \$500 million per year in the 2050s. SSP5-8.5 is consistently higher than SSP2-4.5 for the mean and ranges, and there is an overall increase over time in impacts, reaching \$300 million to \$400 million per year for the mean by the 2080s.

Figure 9-3. Annual Impacts above the Baseline Due to Climate Change by Era, Including the Range across Global Climate Models

Source: Analysis based on Fant et al. (2017).



2.1.3 Limitations

This analysis includes several limitations related to data, modeling assumptions, and scope, which may affect the interpretation and generalizability of the results.

- The water quality model relies on a complex system of models built to assess climate change impacts at a national or regional scale. State-provided data are not used. These analyses are meant to provide a starting point for future, more detailed modeling that could incorporate more New York State-specific information. For example, the modeling does not consider the potential for water pollutant effluent regulation to grow more stringent over time, or for other water quality management practices to grow more effective than current practices (such as improved control of nonpoint source pollution). For more detail on model-specific limitations and caveats, see Boehlert et al. (2015) and Fant et al. (2017) for the water quality model.
- The water quality valuation is based on a WTP survey of both users and nonusers and therefore represents costs from the human perspective. These may not represent the entire burden of costs, particularly any adverse effects to the surrounding ecosystem.
- Decreases in water quality due to climate change will likely have adverse effects on human health and the environment that are not represented in the results of this section. For example, climate change impacts to water quality may affect ecological dynamics of freshwater systems, with cascading effects on ecosystem services and recreational opportunities.

- This analysis considers only four water quality parameters and omits other constituents, such as sediment and heavy metals, that may be affected by changes in the climate system.
- The methods underlying the analysis do not consider the effects of climate change-induced extreme events on water quality, such as increased siltation and runoff that might result from a tropical cyclone.
- The analysis considers only a subset of all use and nonuse values linked to water quality changes; therefore, the damages reported here likely underestimate future impacts.

2.2 Municipal and Industrial Water Supply

The scope of economic impacts considered includes consumer surplus loss resulting from increased unmet demand for water due to changes in precipitation patterns and temperatures.

Climate change has the potential to reduce the supply of freshwater resources for M&I uses due to changes in precipitation and because of saltwater intrusion into coastal aquifers. Furthermore, increases in demand due to growth or expansion of water-dependent sectors (e.g., irrigation) can put additional pressure on water resources. This section considers the economic impact of changes in both supply and demand for freshwater resources, but omits the effect of saltwater intrusion, which is partially quantified in the last section of this chapter.

Climate change is projected to affect M&I's water supply due to changing temperatures and precipitation patterns. Water supplied for industrial uses can include a broad range of activities, such as process water for manufacturing processes, industrial cleaning operations, cooling, and food processing. Municipal (sometimes called domestic) uses of water include two broad categories: outdoor uses (primarily for landscaping) and indoor uses (for bathing, cleaning, cooking, drinking, and sanitation). The high value of M&I water also means that when unmet demands do occur, the economic impacts of these shortages can be large.

2.2.1 Methodology

This analysis estimates the welfare loss, or consumer surplus loss, to consumers of water associated with unmet M&I water demands. Consumer surplus can be thought of as a WTP estimate of the value of water to the consumer; a consumer surplus loss therefore represents a "cost" to the consumer based on reduced water availability and the value placed on that water. In other words, if because of climate-induced shortages, water is unavailable for a category, such as municipal outdoor use, the economic loss is measured by consumers' inability to enjoy what the water provides. In the case of municipal outdoor use, this is usually a green and healthy lawn and gardens. Municipal indoor use tends to have the highest

value, and industrial water use is valued between municipal indoor and outdoor water. The ranking of water consumer value by water use class is based on multiple studies of the marginal value of water for these uses, as summarized in Henderson et al. (2015). Consumer surplus is used, rather than price, because often the uses of water provide greater benefit to consumers than what is captured by the price (if the value of water to consumers was less than the price, consumers would not choose to purchase the water).

In summary, this analysis includes modeling of supply and demand for municipally supplied water for indoor and outdoor uses (excluding private groundwater wells), all publicly supplied water for industrial and agricultural uses, and surface water withdrawals for industrial and agricultural uses. Groundwater supply from private wells, for municipal, industrial, or agricultural uses are excluded from the analysis.

Appendix B provides details of the specific methods and data used to estimate these economic impacts.

2.2.2 Results

Total unmet demand throughout the Hydrologic Unit Codes (HUCs) included in the analysis, averaged across GCMs and SSPs, is 8.7 million cubic meters (MCM) per year in the 2050s and 23.2 MCM/yr in the 2080s, 2.3 and 6.7 MCM/yr more than the baseline value, respectively.

The areas with the greatest unmet demand are in the southern portion of the State. In southeastern New York State, the Long Island Sound and Saugatuck subbasins have the largest unmet demand of 22 and 2.7 MCM/yr, respectively, in the 2080s under SSP5-8.5, or 5.9 and 2.3 MCM of additional unmet demand relative to the baseline. However, because the majority of the geographical area for these basins falls outside of New York State, meaning the economic impact of unmet demand for the State portion is not significant. The next two basins with the largest absolute unmet demands are the Upper Delaware and East Branch Delaware subbasins in southeastern New York State, record an average unmet demand of 0.03 and 0.06 MCM/yr, respectively, in the 2050s, and 0.02 and 0.07 MCM/yr per year in the 2080s.¹

¹ Information about subbasins may be found in the USGS Watershed Boundary Dataset at <https://www.usgs.gov/national-hydrography/watershed-boundary-dataset> and https://water.usgs.gov/GIS/wbd_huc8.pdf

The unmet demand throughout the State for the last era is below 1% for all HUC-8s except one, the Saugatuck Basin in southern New York State, near the Connecticut border, which has an unmet demand of around 4% (see Figure 9-4).

When averaged across all GCMs, the corresponding welfare loss to consumers is close to zero dollars for the majority of the state. The largest welfare losses, averaging a total of \$0.98 million per year in the Susquehanna HUC-4, are found in the southern portion of the State as shown in Figure 9-5. Note that while unmet demands are available at the HUC-8 resolution, utility price information is available only at the HUC-4 level, meaning that the estimate for the welfare loss to consumers is done at the coarser HUC-4 resolution. Note that the economic welfare loss estimates are limited to the water users located in New York State, while the physical unmet demand metrics (including the percent unmet demand in Figure 9-4) are for the full geographic scope of the water basins.

Figure 9-4. Percent of Unmet Water Demand in HUC-8 Basins under SSP5-8.5, 2080s

Data is from the average of the SSP5-8.5 GCMs for the 2080s era.

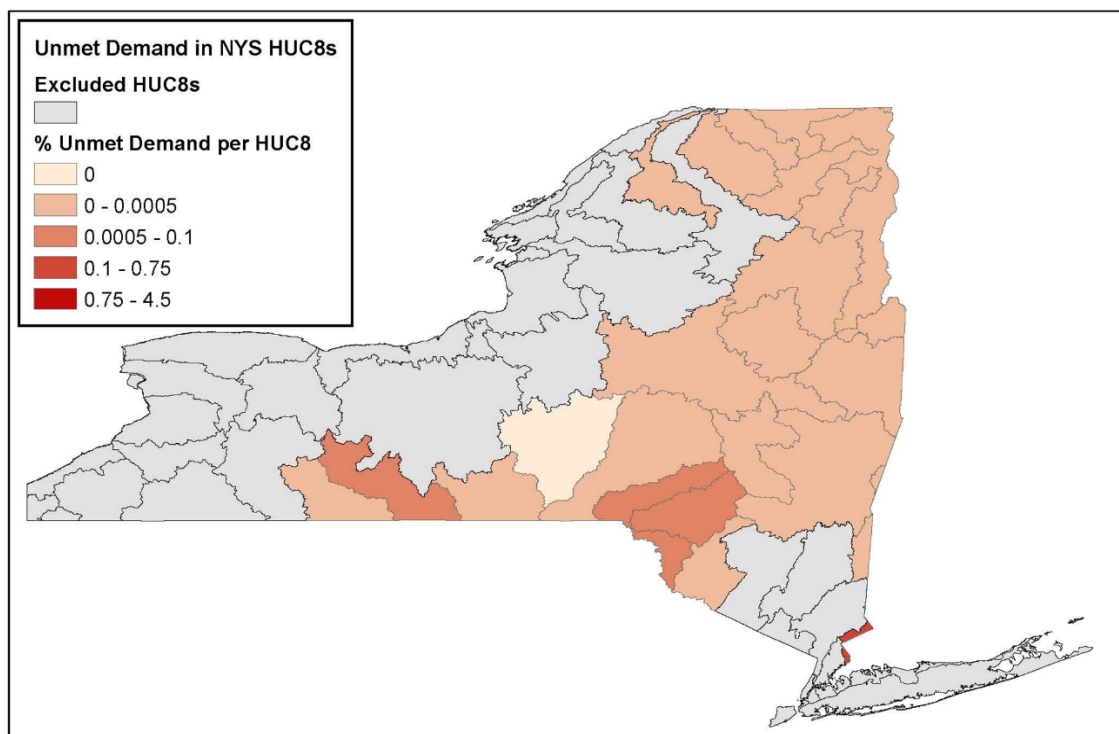
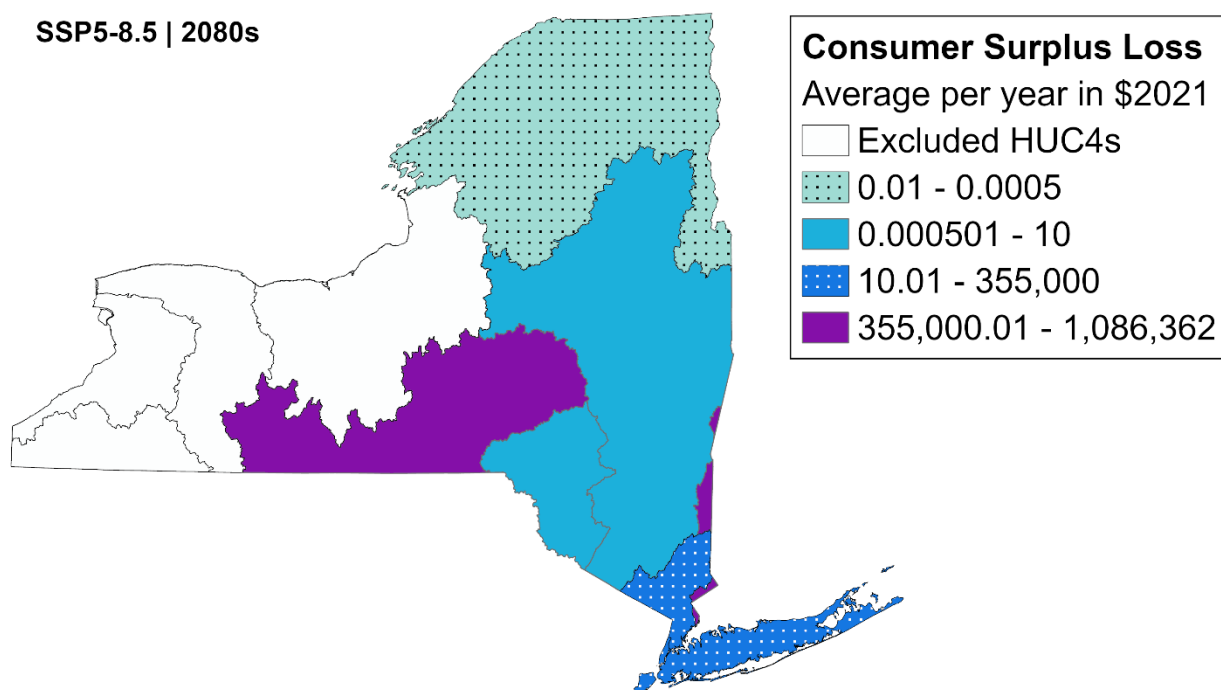


Figure 9-5. Annual Consumer Surplus Loss in HUC-4 Basins under SSP5-8.5, 2080s

Data is from the average of the SSP5-8.5 GCMs for the 2080s era.



Averaging across all the GCMs and SSPs, the total welfare loss due to unmet demand estimated per year for the State in the 2050s is \$219,600 and by the 2080s is \$798,600 (see Table 9-4). During the 2050s, SSP5-8.5 shows \$0.4 million more in welfare losses per year than SSP2-4.5 for the State, and the difference in costs across the two SSPs increases to \$1.1 million for the 2080s. Figure 9-6 shows the cost impacts by era for both SSPs using the average across GCMs, as well as the range across GCMs, indicated by the vertical lines and whiskers. The decrease in economic impacts from the 2030s to the 2050s is the result of overall Higher projected rainfall estimates in a few basins mainly in the Hudson River Valley, which increase water supply in that area and reduce economic impacts from the 2030s to the 2050s. However, that trend reverses by the 2080s.

Table 9-4. Annual Economic Impacts Associated with Climate Change by Region

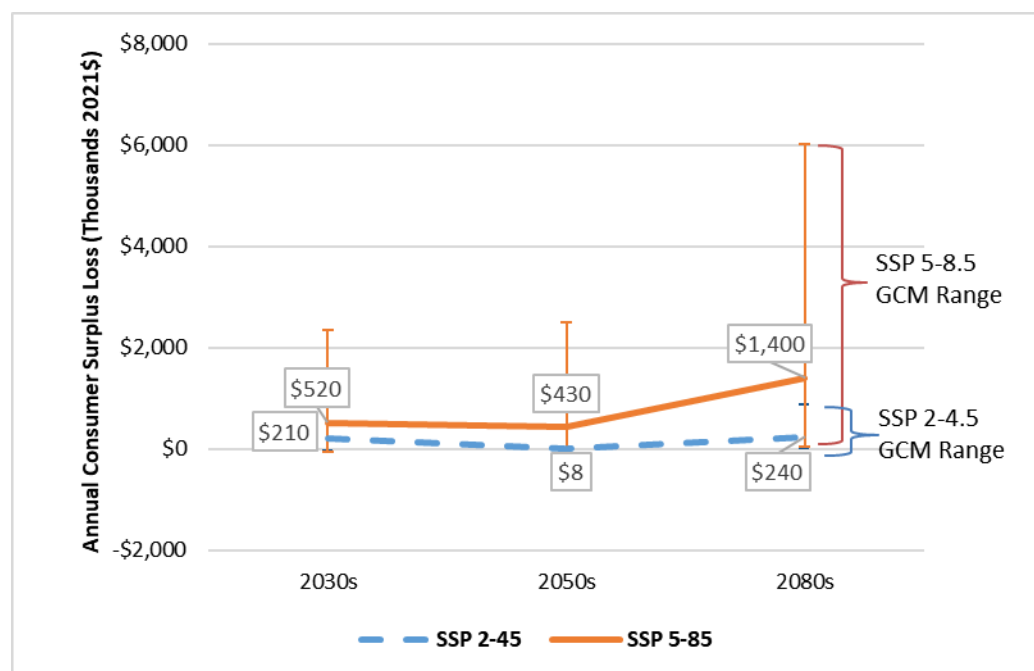
Change from baseline. Economic impacts are defined as the economic value, measured as consumer surplus loss. Results are reported in thousands of 2021 USD per year and averaged across GCMs.

Values may not sum due to rounding.

Region	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Adirondacks	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Catskills	\$2.09	\$32.0	\$0.36	\$20.1	\$0.79	\$45.6
Central/Finger Lakes	\$7.77	\$74.8	\$1.32	\$74.7	\$2.94	\$170
Champlain Valley	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Great Lakes	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Long Island	\$0.00	\$0.00	\$0.00	\$0.00	\$1.39	\$14.5
Mohawk River Valley	\$8.38	\$80.6	\$1.43	\$80.5	\$3.17	\$183
New York City	\$0.00	\$0.00	\$0.00	\$0.00	\$0.35	\$3.63
North Hudson	\$23.8	\$10.2	\$0.00	\$0.05	\$30.4	\$49.4
South Hudson	\$145	\$62.6	\$0.00	\$0.33	\$187	\$321
Southern Tier	\$26.6	\$257	\$4.54	\$256	\$10.1	\$583
St. Lawrence Valley	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Statewide	\$214	\$517	\$7.65	\$432	\$236	\$1,361

Figure 9-6. Consumer Surplus Loss above the Baseline per Year Due to Climate Change

Consumer surplus loss above the baseline per year (in thousands of 2021 USD) due to climate change.



2.2.3 Limitations

- Water demand for certain HUC-8s next to the Great Lakes or with more than 50% area in large metropolitan statistical areas could not be calculated—these areas account for a large portion of the overall State water demand. In addition, U.S. Geological Survey (USGS) water withdrawal, used for baseline water demands, reports withdrawals at the point of withdrawal instead of the point of consumption, so these areas in particular may have spatial misallocations of demands and growth in demands (e.g., based on population changes). The implications of this limitation are unclear, but existing information suggests that potential climate-induced shortages for the New York City and Great Lakes–adjacent urban areas from changing precipitation patterns could be substantially mitigated by the artificial and natural reservoir and water storage systems used to supply these areas. Nonetheless, risks to drinking water quality (as opposed to water quantity) remain a high priority for these systems, as documented in the New York City “2023 Water Demand Management Plan” (DEP 2023) and “New York’s Great Lakes Action Agenda” (DEC 2023).
- While unmet demands are available at the HUC-8 resolution, utility price information is only available at the HUC-4 level, meaning that the estimate for the welfare loss to consumers is done at the coarser HUC-4 resolution. The implication of this limitation is unknown, but likely to be small, because there are not large variations in price across the HUC-4 basins, and it is not expected that there would be large variations at the HUC-8 level if more detailed HUC-8 data were available.

2.2.4 Potential for Adaptation to Reduce Impacts

State- and local-level adaptation action has the potential to reduce impacts of water shortages attributable to climate change. For example, programs to encourage reductions in lawn watering can be effective to reduce municipal outdoor water use. Educational campaigns targeted toward households with high summer water usage have proven to be effective in some regions of the country—these campaigns could be deployed more widely, and reductions in landscape water use would free up significant water capacity for more critical uses. The EPA offers a number of resiliency strategies through their Creating Resilient Water Utilities (CRWU) program. Water source protection, including reducing nutrient loading in drinking water source watersheds is important to protect against cyanobacteria blooms. Implementing intermunicipal and regional water purchase agreements and emergency connections could reduce vulnerability to localized water shortages. In addition, there may be an opportunity to install sufficient groundwater wells to satisfy surface water shortages. Considering the projected gradual increases in precipitation under climate change, these additional wells may remain sustainable, aside from the effects of saltwater intrusion.

2.3 Urban Drainage

Scope of economic impacts considered: total annual costs, costs per square mile, and costs per capita of adapting drainage infrastructure to accommodate increased frequency of heavy rain events.

Climate change is expected to increase the frequency and severity of storms. This intensification of rainstorm events has the potential to overwhelm existing urban drainage systems across New York State, leading to urban flooding. Most urban drainage systems currently in place were designed to accommodate the drainage of extreme precipitation based on historical precipitation records. However, climate change is expected to significantly change the frequency and intensity of future extreme precipitation. To adapt to more intense rainfall events and prevent more extensive urban flooding, communities across New York State will need to invest in more robust urban drainage infrastructure capable of managing higher stormwater volumes.

Modeling the impacts of flooding when urban drainage capacity is exceeded presents significant challenges. For example, the Federal Emergency Management Agency (FEMA), which establishes flood risk zones for both inland riverine and coastal flooding for the purposes of administering and rate-setting for the National Flood Insurance Program, does not estimate flood risk zones (i.e., Special Flood Hazard Areas) associated with the failure of stormwater drainage, primarily because there are insufficient data to

do so. At least one organization has begun to fill this gap. The First Street Foundation has estimated the combined flood risk from coastal, riverine, and drainage sources across the contiguous U.S., but it does not yet publicly report flood risk from each of these three sources.² As a result, this analysis focuses on the costs of adapting drainage infrastructure to accommodate the increased frequency of heavy precipitation events.

2.3.1 Methodology

This analysis estimates the effect of climate change on urban drainage management costs for the 50 largest cities in New York State (Appendix B lists the cities). Specifically, this analysis estimates the cost of expanding the capacity of urban drainage systems in New York State to prevent an increase in urban flooding events, effectively holding the level of service for individual urban drainage systems constant at baseline levels. These estimates represent the costs of adapting urban drainage systems in New York State to a changing climate, using EPA unit-cost values for retention, detention, and infiltration basins (Price et al. 2016) to manage the additional water volume projected.

Unlike many of the other sectors examined in this report, this analysis does not estimate urban drainage impacts under a reactive response scenario. While the urban flooding impacts of such a scenario would be significant, such impacts would be highly site specific, and their analysis would require significant detail for each location examined (e.g., identification of where flooding would be most likely in each city and the property that would be damaged by flooding in each of these locations). In the absence of such detail, this analysis focuses on the costs of adapting urban drainage systems to avoid such impacts, without optimizing between adaptation investments and residual damages.

Because the analysis focuses on the 50 largest cities in New York State rather than all cities across the State, it provides an underestimate of climate change costs for the State's urban drainage systems. The assessment of adaptation costs for New York State's urban drainage systems presented here applies the methodology from Price et al. (2016). Appendix B details the methods applied.

² See for example, <https://firststreet.org/research-library/the-precipitation-problem>

2.3.2 Results

Figure 9-7 presents the annualized costs of climate change for urban drainage systems across the 50 largest cities in New York State based on each of the frequency-duration storm events, under both SSP2-4.5 and SSP5-8.5. Overall, annualized costs across the 50 cities range from approximately \$300 million and \$850 million, depending on the era, SSP, and reference storm event. Costs grow over the study period for all three frequency-duration events, although costs are nearly the same for each given frequency-duration event in the 2030s and 2050s under SSP2-4.5 before increasing in the 2080s. Across all three eras and under both SSP2-4.5 and SSP5-8.5, costs increase between the 10-year and 25-year storms and between the 25-year and 50-year storms as expected.

Table 9-5 through 9-7 present the annualized adaptation costs of climate change to improve urban drainage infrastructure by region for each return period. These costs reflect the distribution of costs only for the 50 cities addressed in this analysis across these regions. Costs for other relatively smaller cities in each region were not estimated.

Across all frequency-duration events, SSPs, and eras, projected costs are highest for Long Island, followed by the South Hudson region. Costs for other regions are significantly lower than those for these two areas. Costs reflect three factors: the existing drainage capacity of the system, the degree of impervious surfaces, and the change in precipitation from baseline conditions. Costs for the Long Island and South Hudson regions reflect the largest changes in precipitation from baseline conditions, even though other locations (e.g., New York City) may have higher levels of imperviousness.

Figure 9-7. Annualized Climate Change Adaptation Costs for New York State Urban Drainage Systems for SSP2-4.5 (top) and SSP5-8.5 (bottom)

Results are reported in millions of 2021 USD per year.



Table 9-5. Annual Adaptation Costs for Urban Drainage Infrastructure Due to Climate Change by Region (10-Year Storm)

Shows the annual adaptation costs for urban drainage infrastructure due to climate change (millions of 2021 USD) by region over a 10-year storm return period.

Region ^a	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Central/Finger Lakes	\$1.32	\$0.88	\$1.41	\$2.52	\$3.63	\$5.25
Great Lakes	\$5.97	\$6.04	\$7.40	\$12.17	\$15.34	\$25.56
Long Island	\$212.87	\$202.45	\$218.32	\$270.40	\$286.24	\$368.47
Mohawk River Valley	\$1.81	\$1.46	\$1.60	\$2.22	\$2.32	\$3.04
New York City	\$3.61	\$3.31	\$3.77	\$5.14	\$5.67	\$7.85
North Hudson	\$8.68	\$6.67	\$7.58	\$12.35	\$12.69	\$18.39
South Hudson	\$75.87	\$72.94	\$76.74	\$87.80	\$92.05	\$109.69
Southern Tier	\$7.72	\$7.42	\$7.87	\$8.93	\$9.40	\$10.58
Statewide	\$317.85	\$301.16	\$324.70	\$401.53	\$427.34	\$548.83

^a No cities were modeled in the Adirondacks, Catskills, Champlain Valley, and St. Lawrence Valley regions.

Table 9-6. Annual Adaptation Costs for Urban Drainage Infrastructure Due to Climate Change by Region (25-Year Storm)

Shows the annual adaptation costs for urban drainage infrastructure due to climate change (millions of 2021 USD) by region over a 25-year storm return period.

Region ^a	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Central/Finger Lakes	\$2.96	\$2.32	\$3.26	\$4.58	\$5.93	\$8.06
Great Lakes	\$12.14	\$11.53	\$14.27	\$23.18	\$26.37	\$40.67
Long Island	\$298.44	\$285.33	\$307.63	\$369.37	\$388.92	\$484.27
Mohawk River Valley	\$2.29	\$1.80	\$2.02	\$2.64	\$2.74	\$3.58
New York City	\$5.45	\$5.06	\$5.72	\$7.46	\$8.09	\$10.73
North Hudson	\$13.60	\$10.89	\$12.56	\$17.73	\$18.06	\$25.08
South Hudson	\$101.81	\$98.55	\$103.59	\$116.71	\$121.53	\$142.21
Southern Tier	\$10.37	\$10.12	\$10.58	\$11.72	\$12.30	\$13.79
Statewide	\$447.06	\$425.60	\$459.64	\$553.40	\$583.94	\$728.39

^a No cities were modeled in the Adirondacks, Catskills, Champlain Valley, and St. Lawrence Valley regions.

Table 9-7. Annual Adaptation Costs for Urban Drainage Infrastructure Due to Climate Change by Region (50-Year Storm)

Shows the annual adaptation costs for urban drainage infrastructure due to climate change (millions of 2021 USD) by region over a 50-year storm return period.

Region ^a	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Central/Finger Lakes	\$4.19	\$3.45	\$4.55	\$6.05	\$7.57	\$10.06
Great Lakes	\$19.72	\$18.42	\$23.12	\$32.99	\$36.00	\$52.41
Long Island	\$359.05	\$343.44	\$371.87	\$441.04	\$463.61	\$567.98
Mohawk River Valley	\$2.73	\$2.08	\$2.38	\$2.98	\$3.09	\$4.02
New York City	\$6.75	\$6.33	\$7.13	\$9.09	\$9.78	\$12.76
North Hudson	\$17.58	\$14.28	\$16.75	\$21.94	\$22.44	\$30.28
South Hudson	\$118.82	\$115.36	\$121.53	\$136.26	\$141.44	\$164.40
Southern Tier	\$12.10	\$11.92	\$12.37	\$13.55	\$14.22	\$15.98
Statewide	\$540.95	\$515.28	\$559.70	\$663.89	\$698.14	\$857.90

^a No cities were modeled in the Adirondacks, Catskills, Champlain Valley, and St. Lawrence Valley regions.

Figure 9-8 and 9-9 show annualized urban drainage costs per square mile for the 2050s for each of the counties where the 50 largest cities in New York State are located. The figure reflects the costs and land area only for those cities included in the analysis. Because urban drainage costs are partially a function of a city's total area, examining costs on a per-square-mile basis provides insights into where climate change may put the greatest strain on New York State's urban drainage systems. As shown in Figures 9-8 and 9-9, urban drainage costs per mile of land area are highest on Long Island, New York City, the counties immediately north of New York City, and (for the 50-year storm) Broome County (where Binghamton is located). In addition to spatial differences in the change in rainfall associated with the frequency-duration storm events, this in part reflects the greater imperviousness of the cities located in these counties relative to cities located in other counties.

Figure 9-8. Annualized Adaptation Cost Impacts of Climate Change for Urban Drainage Infrastructure per Square Mile, 2050s, for SSP2-4.5

2050s | 10-Year, 24-Hour Storm, SSP2-4.5

2050s | 25-Year, 24-Hour Storm, SSP2-4.5

2050s | 50-Year, 24-Hour Storm, SSP2-4.5

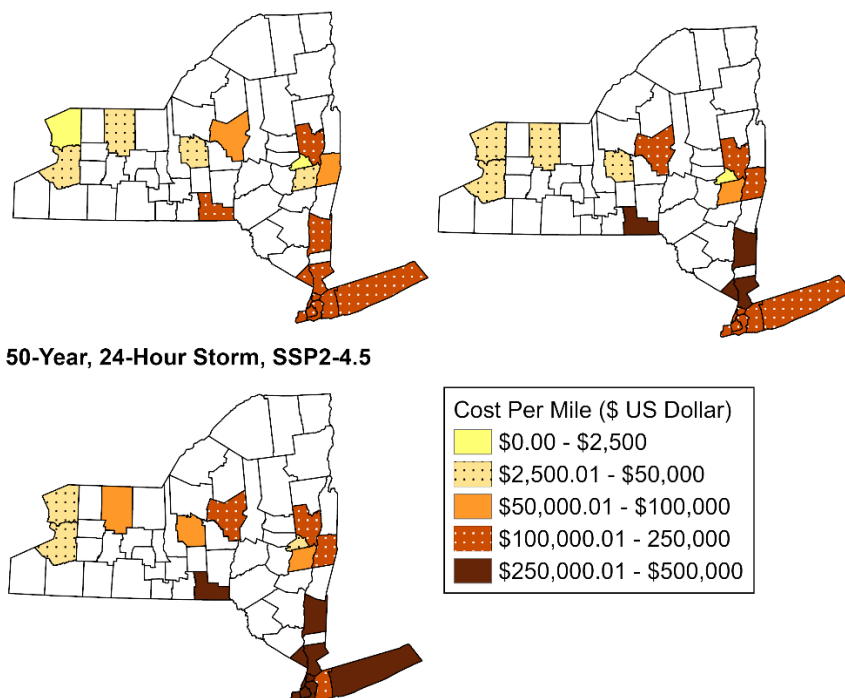
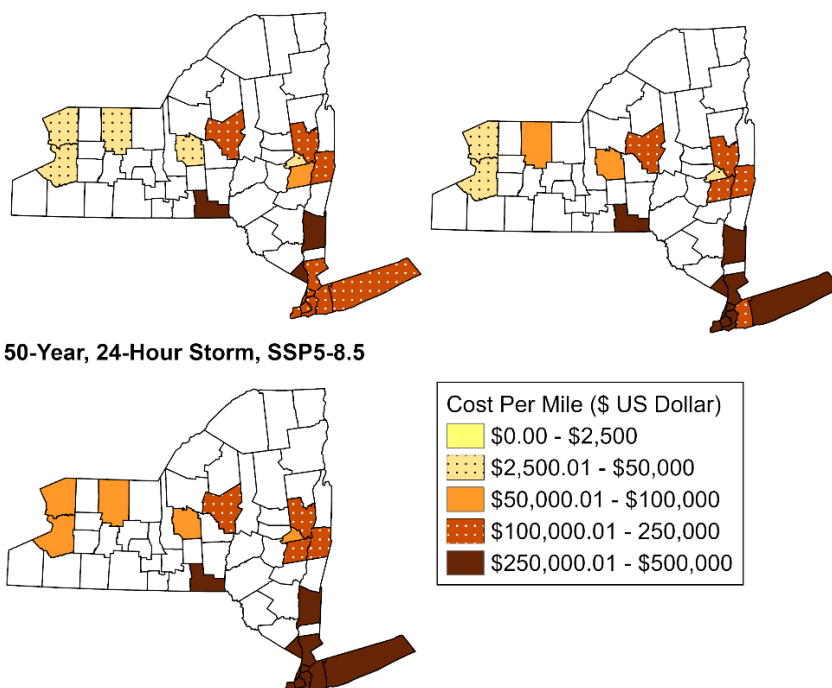


Figure 9-9. Annualized Adaptation Cost Impacts of Climate Change for Urban Drainage Infrastructure per Square Mile, 2050s, for SSP5-8.5

2050s | 10-Year, 24-Hour Storm, SSP5-8.5

2050s | 25-Year, 24-Hour Storm, SSP5-8.5

2050s | 50-Year, 24-Hour Storm, SSP5-8.5



To provide insight into urban drainage costs relative to the population of affected areas, Figures 9-10 and 9-11 present these costs on a per capita basis for each of the counties where the 50 cities are located. Similar to the maps above showing costs per mile, Figures 9-10 and 9-11 focus on the 2050s era. They also reflect costs and population only for the 50 listed cities; they do not include costs and population for other cities. Based on Figures 9-10 and 9-11, costs per capita are highest (between \$250,000 and \$500,000 per capita) in many of the same areas where costs per square mile are highest, with a few exceptions. Specifically, costs per capita are highest in urbanized counties, such as those in and around New York City, Albany, Syracuse, and, under some scenarios, Binghamton. Costs per capita on the western end of Long Island, however, are not as significant relative to costs per capita for other areas.

Figure 9-10. Annual Adaptation Costs of Climate Change for Urban Drainage Infrastructure per Capita by City, 2050s, for SSP2-4.5

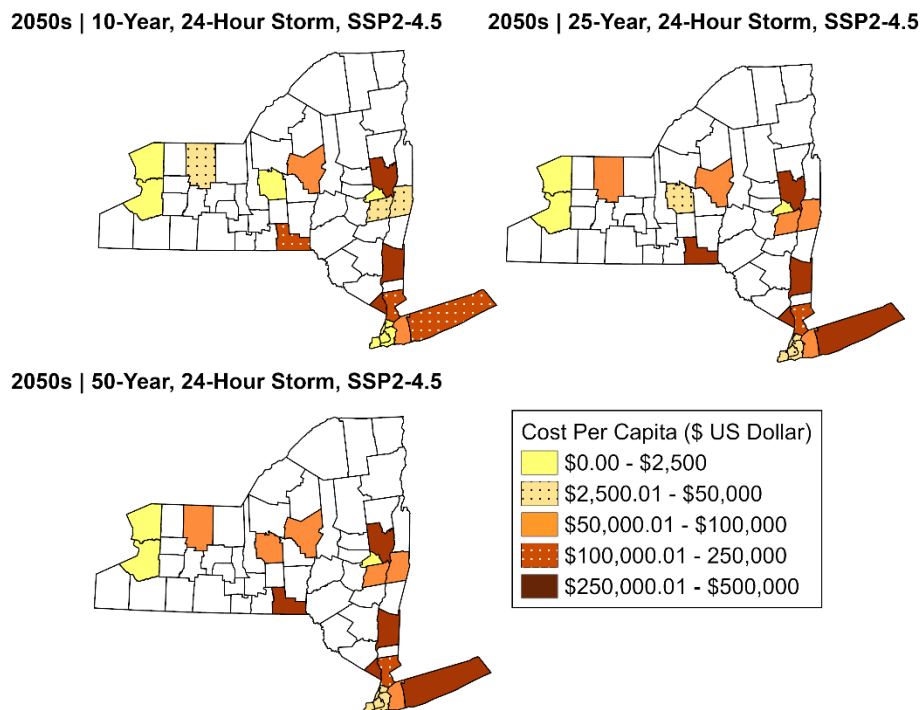
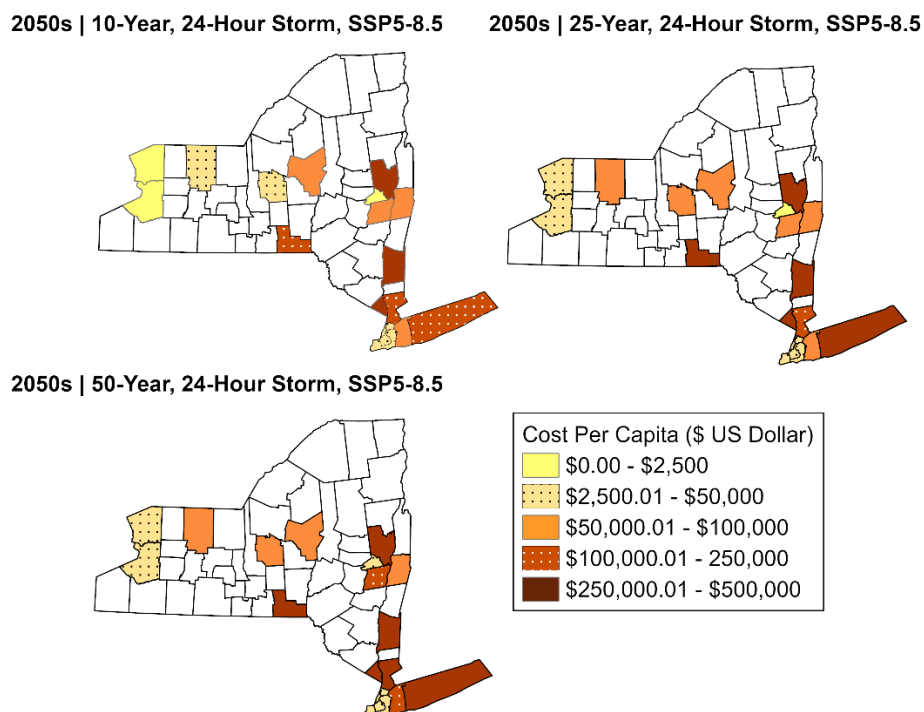


Figure 9-11. Annual Adaptation Costs of Climate Change for Urban Drainage Infrastructure per Capita by City, 2050s, for SSP5-8.5



2.3.3 Limitations

This analysis includes several limitations related to data, modeling assumptions, and scope, which may affect the interpretation and generalizability of the results.

- Because of the difficulty in monetizing damages from overwhelmed urban drainage systems, this analysis does not consider the costs of urban flooding damages due to climate change, only the cost of adapting. Therefore, the costs of climate change in this subsector are underestimated.
- Estimates presented here reflect only the 50 largest cities in New York State. Costs could be higher if all cities in the State were included.
- The underlying analysis assumes that the systems can manage runoff associated with historical climate conditions and estimates the costs of implementing the adaptation measures necessary to manage increased runoff due to climate change. There may be instances where the current systems are not able to handle even historical or current conditions. Under those circumstances, costs to manage increased runoff would be even higher.
- This analysis focuses on the potential for urban drainage flooding associated with rainfall events estimated in GCMs. It excludes potentially high-rainfall events associated with tropical cyclones, which have grown in rainfall intensity over recent years (e.g., Hurricane Ida's impacts on New York City in 2021). A different methodology and additional analysis would be required to estimate impacts from rainfall associated with tropical cyclone events.

- The approach in Price et al. (2016) is a reduced form estimation, which has the advantage of broader applicability in more New York State cities but does not reflect detailed site-specific modeling of each drainage system and is subject to estimation uncertainty.

2.3.4 Potential for Adaptation to Reduce Impacts

In addition to expanding the capacity of urban drainage systems, there are many other adaptation resources available for buildings potentially vulnerable to urban drainage flooding, including building design and retrofitting toolkits and guidelines for homeowners and renters. Nature-based stormwater management tools, including permeable pavements, rain gardens, bioswales, tree filters, and other bioretention systems, can also be implemented. Zoning and building code updates are commonly mentioned in some adaptation plans and represent a key pathway for facilitating adaptation for vulnerable areas at larger scales. Along the same lines, implementing higher floodplain management standards at the local level also has the potential to reduce urban flooding. Near-term implementation of these regulatory changes, combined with creative funding and incentive structures, such as FEMA's Community Rating System, could increase the pace of adaptation and lessen the already increasing impacts of urban drainage.

3 Partially Quantified and Qualitative Damages

Partially quantified impacts are those for which some aspects could be modeled quantitatively, but not robustly enough to be included in the total economic impacts for this sector. Partially quantified impact categories for the water resources sector are harmful algal blooms (HABs) and saltwater intrusion on drinking water resources. HABs are associated with higher water temperatures in freshwater bodies and can be toxic to people in recreational settings or if the waterbody is used for drinking water supply. The economic impacts, however, are incompletely quantified. Saltwater intrusion can lead to the need to incur costs to replace the water supply contaminated by saltwater, and while existing literature can be used to estimate the extent of future well contamination associated with changes in sea level, economic impacts for water supply source replacement have not been quantified.

3.1 Harmful Algal Blooms

Although marine red tides were among the first HABs to draw public attention to harmful algae (Hallegraeff 2003), the phenomenon is much broader. For example, cyanobacterial algal blooms (cyanoHABs) in the world's freshwater systems are far more ubiquitous. Chapra et al. (2017) added a module to the water quality model used for the water quality impact described elsewhere in this chapter

(Fant et al. 2017) to simulate competition between algal groups with a focus on cyanobacteria growth and the likelihood of cyanobacterial harmful algal blooms (cyanoHABs) in freshwater systems. That analysis did not result in an economic impact analysis, but the potential physical effects of increased temperature and changes in precipitation patterns on algal growth for New York State watersheds are described below.

Table 9-8. Summary of Climate Change Impacts on Harmful Algal Blooms

Element	Description
Description of Impacts	Increased air and water temperatures and changes in precipitation patterns could provide more favorable conditions for the growth of harmful algal blooms, which in turn could affect human exposures to toxins or limit the recreational or drinking water supply use of affected water bodies.
Primary Climate Stressors	• Temperature (increased damages) • Seasonal droughts (increased damages)
Economic Values	• Lost recreational opportunities (if water recreation advisories are issued) • Health effects associated with recreational or drinking water exposure
Primary Affected Regions	Freshwater ponds and lakes in the South Hudson and Southern Tier regions
Potential Magnitude of Impact in New York State	Unknown

3.1.1 Relevant Literature

To model competition between algae, researchers divided the phytoplankton assemblage into four functional groups: a pair of beneficial algae (diatoms and greens) and a pair of harmful algae (N₂-fixing and non-N₂-fixing cyanobacteria). In most lakes and impoundments, a typical successional pattern evolves during the growing season, with the spring beginning with diatoms, progressing to greens and “others,” and finally leading to the development of blue-green algae in late summer and fall. The system’s trophic state influences the relative magnitude of each of these groups, as well as their total biomass. Nutrient-poor lakes tend to be dominated by diatoms, greens, and other non-harmful phytoplankton. In contrast, when lakes become over enriched, cyanobacteria predominate, especially during the late summer and early fall. It is known that the growth of each phytoplankton species has a different temperature tolerance. In lakes, cold-adapted diatoms and flagellates often are the first algae to exhibit growth in the early spring. In the summer, greens and cyanobacteria make up more of the assemblage and during the warmest times of the year, with the latter particularly dominant in eutrophic systems (Paerl et al. 2011, Paerl and Huisman 2009). Harmful cyanobacteria have been found to have an optimal temperature for growth and photosynthesis at, or above, 25 degrees Celsius (°C) (Reynolds 2006, Jöhnk et al. 2008, Paerl and Huisman 2009). Chapra et al. (2017) detail how cyanobacteria are simulated.

If cyanoHABs release toxins and there is an exposure pathway (e.g., ingestion), they have the potential to cause a variety of health impacts in people and other mammals, including pets. For some people, exposure to the cyanobacteria themselves can impact health. The impacts on recreational activity are based on thresholds defined by the World Health Organization (WHO) guidelines around the relative probability of potential health effects attributable to HABs (WHO 1999). The WHO guidelines establish 20,000 cells per milliliter (cells/ml) as a threshold for which the probability of adverse health effects is relatively low but where short-term health effects might occur in some populations; 100,000 cells/ml is a threshold where there is a moderate probability for longer-term adverse health effects resulting from exposure for the general population.

Figure 9-12 and Tables 9-9 and 9-10 show the changes in annual mean cyanobacteria concentrations in waterbodies due to climate change, as well as additional days above the hazardous thresholds defined by the WHO.³ While changes in the annual mean concentrations of cyanobacteria are indicative of potential blooms throughout the year, additional days above these thresholds indicate daily peaks that often occur in the late summer, and so may not fully align with trends in annual mean concentrations. The largest changes in cyanobacteria concentrations occur in the eastern and southern parts of the state (basins 203, 204, and 205).

For SSP2-4.5, there are additional days exceeding the 20,000 cells/mL threshold, but the 100,000 cells/mL threshold is less commonly exceeded by 2050. For SSP5-8.5, there are many more additional days above 100,000 cells/mL ranging from nearly zero to more than 20 days. Higher cyanobacteria concentrations in these reservoirs may result in localized HABs along the shores and in shallower sections of the reservoirs and lakes that are not captured in the mean concentrations. The areas where the model estimates more occurrences of exceeding 100,000 cells/mL are basins 203, which includes the greater New York City area (including Long Island), and basin 205, which is a fairly large basin along the northern edge of Pennsylvania.⁴

³ Note that New York State does not have a numeric ambient water quality standard for cyanobacteria but instead uses a different methodology to determine HAB occurrence, as described in the NYSDEC's *Harmful Algal Blooms Program Guide* (https://dec.ny.gov/sites/default/files/2025-05/habsprogramguide_2025.pdf). NYSDOH has a drinking water threshold for cyanotoxins that is used to trigger water advisories and is measured in ug/L, based on EPA guidance on drinking water health advisories for cyanotoxins. The model used in this analysis estimates algal cell count, as used in the underlying Chapra et al. (2017) study, and so we used the WHO cell-count-based thresholds.

⁴ NYS-specific data was not used to characterize baseline concentrations in the model described in Chapra et al. (2017). Instead, a generalized approach to estimating both baseline and climate-influenced

Figure 9-12. Map Key for Four-Digit Hydrologic Unit Codes and Hydrologic Basins

The map shows basin location, along with the 4-digit HUC-4 code. Numbers shown in map represent the last three digits of the HUC-4 code; the first digit of the HUC-4 codes in New York State are always “0.”

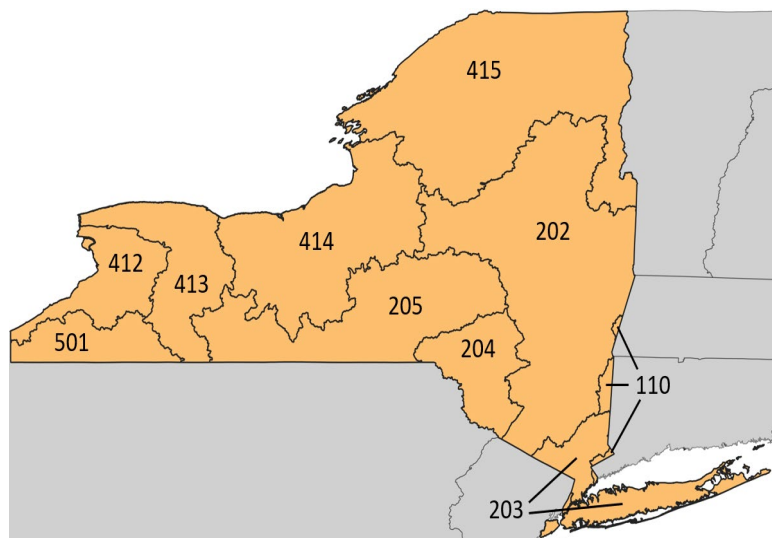


Table 9-9. Changes in Cyanobacteria Concentrations in Harmful Algal Blooms due to Climate Change, by Hydrologic Basin, 2050s

Change from baseline. Changes in average annual cyanobacteria concentration as a physical indicator of HAB risk due to climate change, without adaptation considerations. While these impacts are not monetized, results are reported as the annual mean increase in cyanobacteria concentrations across all waterbodies and averaged across GCMs. Hydrologic basin denoted by HUC-4 unit code. Values may not sum due to rounding.

Basin HUC-4	Mean Annual Average Baseline Cyanobacteria Concentrations (thousand cells/mL)	Mean Increase in Cyanobacteria Concentrations, 2050s (thousand cells/mL)	
		SSP2-4.5	SSP5-8.5
110	0.02	3.37	5.21
202	0.42	1.49	2.26
203	18.36	15.12	28.38
204	2.69	8.24	10.87
205	3.91	7.85	15.09
412	0.03	0.15	0.25
413	0.00	0.08	0.03
414	0.88	1.83	4.74
415	0.02	0.24	0.53
501	0.14	1.21	4.78

cyanobacteria concentrations for all of CONUS within the QUALIDAD model used in that study, was applied. See the supplemental information in Chapra et al. (2017) for more details.

Table 9-10. Changes in Days above WHO Thresholds for Cyanobacteria Concentrations in Harmful Algal Blooms due to Climate Change, by Hydrologic Basin, 2050s

Change from baseline. Changes in days above WHO threshold cyanobacteria concentrations as a physical indicator of HAB risk due to climate change, without adaptation considerations. While these impacts are not monetized, results are reported as the mean days above WHO thresholds across all waterbodies and averaged across GCMs. Hydrologic basin denoted by HUC-4 unit code. Values may not sum due to rounding.

Basin HUC-4	Baseline Climate Days above WHO Threshold (thousand cells/mL)		Additional Days above 20,000 cells/mL		Additional Days above 100,000 cells/mL	
	Baseline Days above 20,000 cells/mL	Baseline Days above 100,000 cells/mL	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
110	0.00	0.00	2.09	9.21	1.32	3.12
202	0.00	0.00	0.00	6.39	0.00	1.52
203	23.75	7.30	6.07	33.85	3.17	23.85
204	4.23	0.00	2.28	35.62	0.00	8.41
205	8.31	0.00	9.48	24.71	5.55	10.58
412	0.00	0.00	0.00	0.20	0.00	0.20
413	0.00	0.00	0.00	0.02	0.00	0.02
414	0.00	0.00	0.00	13.18	0.00	3.24
415	0.00	0.00	0.00	0.29	0.00	0.29
501	0.00	0.00	0.36	8.99	0.36	3.26

3.1.2 Conclusions

A broad literature base exists to support the conclusion that climate change can lead to a higher risk of cyanoHABs in freshwater systems. The physical impacts of these effects can be quantified and changes in cyanobacterial concentrations can be compared to international guidelines for relative probability of acute health effects through recreational exposure in affected water bodies. What is missing to quantify economic impacts is a better understanding of the human response to these risks. Additional research is needed to characterize the extent of waterbody monitoring for these risks, whether existing monitoring is adequate to prevent contamination of drinking water sources and recreational water bodies where exposure to toxins could be encountered, and how these monitoring and risk prevention systems can adapt to the more favorable conditions for bacterial growth presented by future climate change.

3.2 Saltwater Intrusion

The threat of sea-level rise on water supply in the coastal regions of New York State has historically been noted as a concern by the USGS. On Long Island, a primary concern is that a rise in sea level will affect the depth to the freshwater–saltwater interface and promote the intrusion of saltwater into public

groundwater supply wells (private wells that supply individual residences or establishments may also be affected but are not analyzed here). Pumping water from wells sourced from coastal aquifers lowers the water table with respect to sea level. This decreases the depth that saltwater and freshwater interact beneath the pumping well and increases the potential for saltwater intrusion into groundwater. This contaminates historically used wells and decreases the amount of freshwater otherwise available for M&I (and other) processes.

Economic impacts of saltwater intrusion could result from the need to find new sources of freshwater supply. Costs to construct new private wells or new commercial drinking water supply wells in uncontaminated aquifers, or to find or import new sources of water from other nearby regions, vary substantially and depend critically on complex, site-specific conditions. Costs would almost certainly be higher in situations where multiple wells might be contaminated. Unfortunately, no existing study quantifies these economic impacts of saltwater intrusion for this region. It is not currently possible to quantify the amount of water that might be affected by saltwater intrusion, or the annual water shortage for M&I uses, and as a result, it is also not possible to estimate the economic impact of saltwater intrusion. However, the method used here can characterize the number of total wells at risk, serving as an indirect indicator of the potential economic damage from this climate change–induced hazard. To better understand saltwater intrusion, the NYSDEC is currently working with the USGS on the Long Island Groundwater Sustainability Project and recently released the results of Phase 1 of the project.

Table 9-11. Summary of Climate Change Impacts on Saltwater Intrusion

Element	Description
Description of Impacts	Drinking water aquifers in coastal areas may be susceptible to saltwater intrusion and contamination as rising sea levels shift the freshwater–saltwater interface.
Primary Climate Stressors	• Sea-level rise (increased damages) • Rising sea levels lead to increased risk of saltwater intrusion
Economic Values	• Lost drinking water resources • Cost of replacement
Primary Affected Regions	Long Island
Potential Magnitude of Impact in New York State	Unknown

3.2.1 Relevant Literature

Coastal wells in New York State consider wells in the following counties: Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, Suffolk, and Westchester. In total, wells in these counties represent 13.6% of the State total, with most of them located in Suffolk (11%) and Nassau (2.2%) counties. To estimate the number of wells exposed to saltwater intrusion due to increasing sea level, a buffer around the point location was intersected with sea-level rise estimates at one-foot intervals. The point location of wells was obtained from New York State's Geographic Information System (GIS) database, maintained by the New York State Department of Environmental Conservation (DEC).

Jasechko et al. (2020) found that 44% of well water level observations within 1 kilometer (0.6 miles) of the U.S. coast are below sea level and therefore at risk of saltwater intrusion. Following their findings, a 1-kilometer buffer was constructed around each point location, determining the area-at-risk of potential saltwater intrusion. The exposed wells were then multiplied by 44%. Using sea-level rise thresholds for SSP2-4.5 (25th and 75th percentiles) and SSP5-8.5 (25th, 75th, and 90th percentiles), the exposure for wells at each level was calculated, interpolating between integer values where necessary. These values were assigned to the central years in the eras used in this assessment (2030s, 2050s, and 2080s). Under current conditions (i.e., baseline), 24% of the wells in the study area fall within 1 kilometer of the coastline.

Exposed capacity was calculated as a proxy for groundwater demand at risk using the available data (16% for the baseline). However, data on capacity are not available for all wells and cannot be assumed to represent groundwater withdrawals.⁵ Wells were classified by use using land-use information. Wells used for irrigation were assumed to be those that fall within irrigated land. The remainder was classified into three categories: M&I, agricultural, and other.⁶ Irrigated wells were grouped with all other agricultural wells. Results are presented for the total wells in the study area, as well as for these categories.

⁵ Well capacity was obtained from the original New York State GIS data and analyzed as a proxy for groundwater withdrawals; however, the data were incomplete, and well capacity may not accurately represent actual withdrawal volumes.

⁶ Land use for wells, categorized as crop, pasture, developed, or natural, was determined using land use/land cover data from the U.S. Department of Agriculture (USDA) CropScape database (CSISS, N.d). M&I wells include those located in developed (built-up) areas. Agriculture wells include those situated in croplands, pastures, and other grasslands. Other wells encompass natural areas (e.g., forests) and unspecified locations.

Table 9-12. Saltwater Intrusion Analysis Data Sources

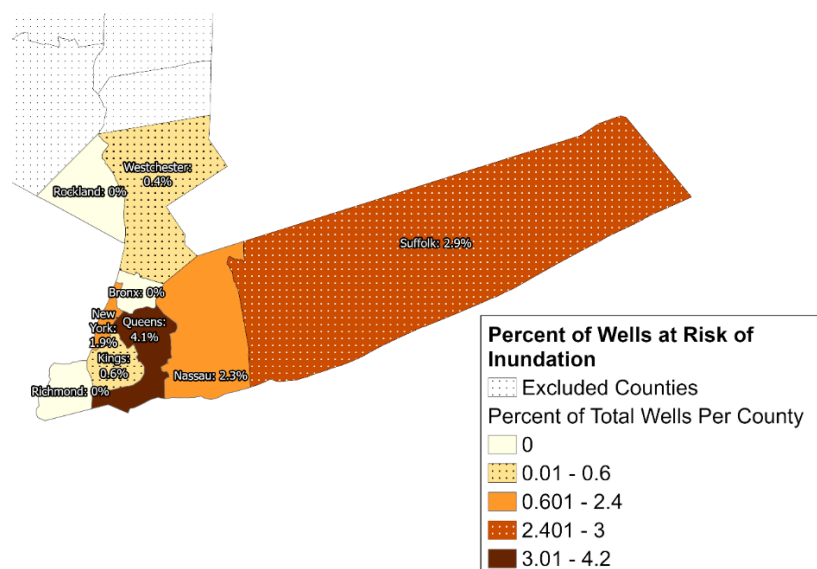
Data	Description	Source
Well Location Data	Locations of wells in coastal counties.	Daly (2022). Wells in Kings, Queens, Nassau, and Suffolk counties obtained from Long Island DEC via a FOIL request.
Sea-Level Rise Predictions	A prediction of sea-level rise contours for different heights of sea-level rise.	NOAA (2022).
Metropolitan Statistical Areas	The population in metropolitan statistical areas.	U.S. Census (2020).

Analysis using the 1-kilometer buffer that defines the area of wells potentially at risk from Jasechko et al. (2020) shows the wells at risk of saltwater intrusion are expected to remain roughly the same throughout all scenarios and eras. The largest increase in the number of wells at risk under the SSP5-8.5 90th percentile 2080s scenario (highest sea-level rise) is in Suffolk and Nassau counties, with 606 and 74 additional wells at risk relative to the baseline, respectively. This incremental number of inundated wells represents 2.9% of the wells in Suffolk County and 2.3% in Nassau County. Figure 9-13 shows a map of the percentage of wells at risk of inundation under SSP5-8.5 90th percentile during the 2080s (i.e., worst-case scenario). Impacts under SSP5-8.5 are consistently greater than impacts under SSP2-4.5.

Results of saltwater intrusion on total well capacity, while unreliable due to insufficient data, show an additional 1.8% of groundwater well capacity at risk under the worst-case scenario during the 2080s.

Figure 9-13. Percent of Additional Wells at Risk of Inundation, SSP5-8.5 90th Percentile, 2080s

Data shows the additional wells at risk of inundation from the baseline values for the SSP5-8.5 90th percentile scenario in the 2080s era.



M&I wells represent the majority of wells in the study area, (about 80%), in total. most of them are located within Suffolk County (81%), followed by Nassau County (16%). Within the study area, 533 additional M&I wells are at risk of intrusion under the SSP5-8.5 90th percentile 2080s scenario, (Table 9-12), representing an additional 2.7% of wells at risk. Agricultural and other wells account for 10.4% and 16.3% of total wells, respectively, with an additional 4.1% wells at risk relative to the baseline for agricultural wells and 2.8% more at risk for other wells in the same worst-case scenario.

Table 9-13. Wells at Risk of Saltwater Intrusion under Worst-Case Scenario, SSP5-8.5 90th Percentile

Change from baseline. This scenario represents a worst-case scenario in which sea-level rise has the largest effect on saltwater intrusion into coastal wells.

County	Baseline	2030s	2050s	2080s
Bronx	3	—	—	—
Kings	33	—	—	1
Nassau	399	11	37	73
New York	—	—	—	0
Queens	16	0	0	5
Richmond	1	—	—	—
Rockland	3	—	—	—
Suffolk	4,233	331	344	453
Westchester	11	0	0	0
Statewide	4,699	343	381	533

Table 9-14. Wells at Risk of Saltwater Intrusion under Best-Case Scenario, SSP2-4.5 25th Percentile

Change from baseline. This scenario represents a best-case scenario in which sea-level rise has the least effect on saltwater intrusion into coastal wells.

County	Baseline	2030s	2050s	2080s
Bronx	3	—	—	—
Kings	33	—	—	—
Nassau	399	1	3	28
New York	—	—	—	—
Queens	16	0	0	0
Richmond	1	—	—	—
Rockland	3	—	—	—
Suffolk	4,233	23	80	240
Westchester	11	0	0	0
Statewide	4,699	24	83	269

3.2.2 Conclusions

The results presented above provide an initial indication of the potential for sea-level rise to contaminate drinking water wells on Long Island. Data on the volume of groundwater abstracted from wells and whether the wells are actively being used, however, are not available. As a result, the mostly qualitative saltwater intrusion analysis considers only the number of wells at risk. In addition, the 44% of wells at risk is a proxy based on countrywide observations. More detailed modeling is required to estimate the risk of saltwater intrusion for a particular well.

Due to data limitations, the saltwater intrusion analysis only considers public, municipally owned and operated wells. Additional impacts of saltwater intrusion, of unknown extent, could also occur for private wells, for which no consistent data currently exist.

A potential indirect impact of saltwater intrusion on New York State's water supply arises from the need for periodic New York City supply reservoir drawdown to maintain aquifer water quality downstream in the Delaware River Basin, where out-of-state water supplies (such as those for Philadelphia) are located. This effect is complex and has not yet been sufficiently studied to assess the possible impact on New York State water supplies.

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