Hartford and East Hartford, CT Section 216 Levee Rehabilitation Flood Risk Management Feasibility Study

Draft Feasibility Report & Draft Environmental Assessment

APPENDIX 2-H
INFRASTRUCTURE AND INSTALLATION RESILIENCE

U.S. Army Corps of Engineers

North Atlantic Division
New England District

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ECB 2026-1 Analysis of Infrastructure/Installation Resilience

Executive Summary

This is an evaluation of potential hydrological vulnerabilities facing the rehabilitation of the Hartford Levee systems in Hartford and East Hartford, Connecticut. The levees are situated along the Connecticut River in Hartford and East Hartford, Connecticut. The system comprises levees, floodwalls, closure structures, storage ponds, conduits, and pumpstations. Hartford is the capital of Connecticut State in southern New England.

Rehabilitation of the system is intended to achieve the goals of:

1. Reducing potential life loss in the communities of Hartford and East Hartford that are protected by the FRM systems related to flooding resulting from the failure of those systems.
2. Reducing damages to residences, business, and critical infrastructure caused by flooding resulting from the failure of the FRM systems.
3. Supporting the resiliency of the communities protected by the FRM systems.

The following summarize the assessment conclusions for the Hartford Levee rehabilitation system.

Mean temperatures are projected to rise in Connecticut by up to 11 °F during the 21st Century. With the rising temperatures, there would be fewer winter days below freezing, and the proportion of rain to snow is expected to increase. Summer rainfall is expected to decrease, although there is a pattern of more frequent intense storms such as tropical cyclones and extreme precipitation days. The expected pattern of change in streamflows was less clear in the literature and projections. The watershed is currently near the median values for watersheds in the United States, and it is expected to become slightly more vulnerable, relative to the other watersheds, for the mid-century or late-century epochs. The Hartford region is subject to limited coastal influence from the mouth of the Connecticut River: relative sea-level rise of 1 to 5 feet is expected this century, with conservative projections up to 8 feet (limited certainty).

Coastal change has been reviewed as a potential concern for the levee systems, but coincident frequency analysis by the H&H team (See Appendix 2-B2 of the main report) indicates that the tidal influence is marginal, since it is decoupled from (has negligible correlation with) upstream storm influences. The picture with respect to inland storm drainage is less clear. Qualitative analysis (as opposed to quantitative analysis) is deemed to be sufficient for review of inland flows. Flows in the Connecticut River and the relevant tributaries were reviewed in Appendix 2-B2, but the options in the design were based on a current-day assessment of needs. The records of flows in the system did not indicate any increase in peak or average flows.

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Table 7: Residual Risk to Hartford/East Hartford Levee System Due to Projected Hydrological Trends

LIST OF ACRONYMS

Acronym	Meaning
°C	Degree Celsius (or degree Centigrade)
°F	Degree Fahrenheit
AEP	Annual Exceedance Probability
BCSD	Bias Corrected Spatially Disaggregated
CHAT	Comprehensive Hydrology Assessment Tool
CMIP	Coupled Model Intercomparison Project
CONUS	Contiguous/Conterminous/Continental United States
CT-DEP	Connecticut Department of Environmental Protection
CWVAT	Civil Works Vulnerability Assessment Tool
ECB	Engineering Construction Bulletin
EWL	Extreme Water Level
FRM	Flood-Risk Management
FS	Feasibility Study
GCM	Global (or General) Circulation Model
HUC	Hydrological Unit Class (or classification)
IIR	Infrastructure and Installation Resilience
IQ Range	Interquartile range – statistical summary range is from 25% of observations, up to 75% of observations (discards the upper and lower 25% of observations).
NAVD/ NAVD88	North American Vertical Datum of 1988
NGVD/ NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration

Acronym	Meaning
NSD	Non-Stationarity Detection
NTDE	National Tidal Datum Epoch (“Present” NTDE as of May 2024 is 1983-2001)
RCC	Reservoir Control Center
RCM	Regional Circulation Model
RCP	Representative Concentration Pathway (RCPs 4.5 and 8.5)
SLAT	Sea-Level Analysis Tool
TST	Time Series Tool
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USGS	US Geological Survey
VA	Vulnerability Assessment
VIC	Variable Infiltration Capacity
WOWA	Weighted-Order, Weighted-Average

Background

The study area is located on the Connecticut River Watershed. The Connecticut River is ~410 miles in length and flows through four states (New Hampshire, Vermont, Massachusetts, and Connecticut), connecting 148 tributaries. It is the largest watershed (~11,000 square miles) and the largest freshwater ecosystem, covering 7.2 million acres, in New England. There are numerous flood control projects within the watershed. Fourteen of these, all upstream of Hartford, are owned and managed by the USACE.

The study area is located in the Middle Connecticut River, which stretches between Amherst, Massachusetts and Middletown, Connecticut. This region is densely populated, with approximately 2 million residents. Tidal influence reaches from the river's mouth to 58 miles (93 km) north at the Enfield Rapids in Windsor Locks, CT. This includes the study area.

The study area includes areas within both the Hartford & East Harford FRM (levee) Projects, so involves land within both municipalities (**Figure 1**).

Hartford is the capital of Connecticut. The city is located on the right bank (west bank) of the Connecticut River. The city is 18.05 sq mi (46.76 km^2) in area and has a population of 121,054 (2020 US Census), with a density of 6,965.1 people/sq mi (2,689.5/km^2). The city is urban and highly developed, including public, commercial, residential, and industrial properties. Significant critical infrastructure can be found in the city, including the Brainard Airport, railways, and interstate highway systems (I-84 and I-91 interstate highways).

The town of East Hartford is located directly across the Connecticut River from Hartford on the left (East) bank. The town is approximately the same size as Hartford (18.7 sq mi (48.5 km^2) but has a smaller population and is less dense. As of the 2020 US Census, East Hartford has a population of 51,045 and a density of 2,837 people/sq mi (1,095.4/km^2). The town is highly developed, with public, commercial, residential, and industrial land. As with all urban areas, critical infrastructure can be found throughout the town and study area.

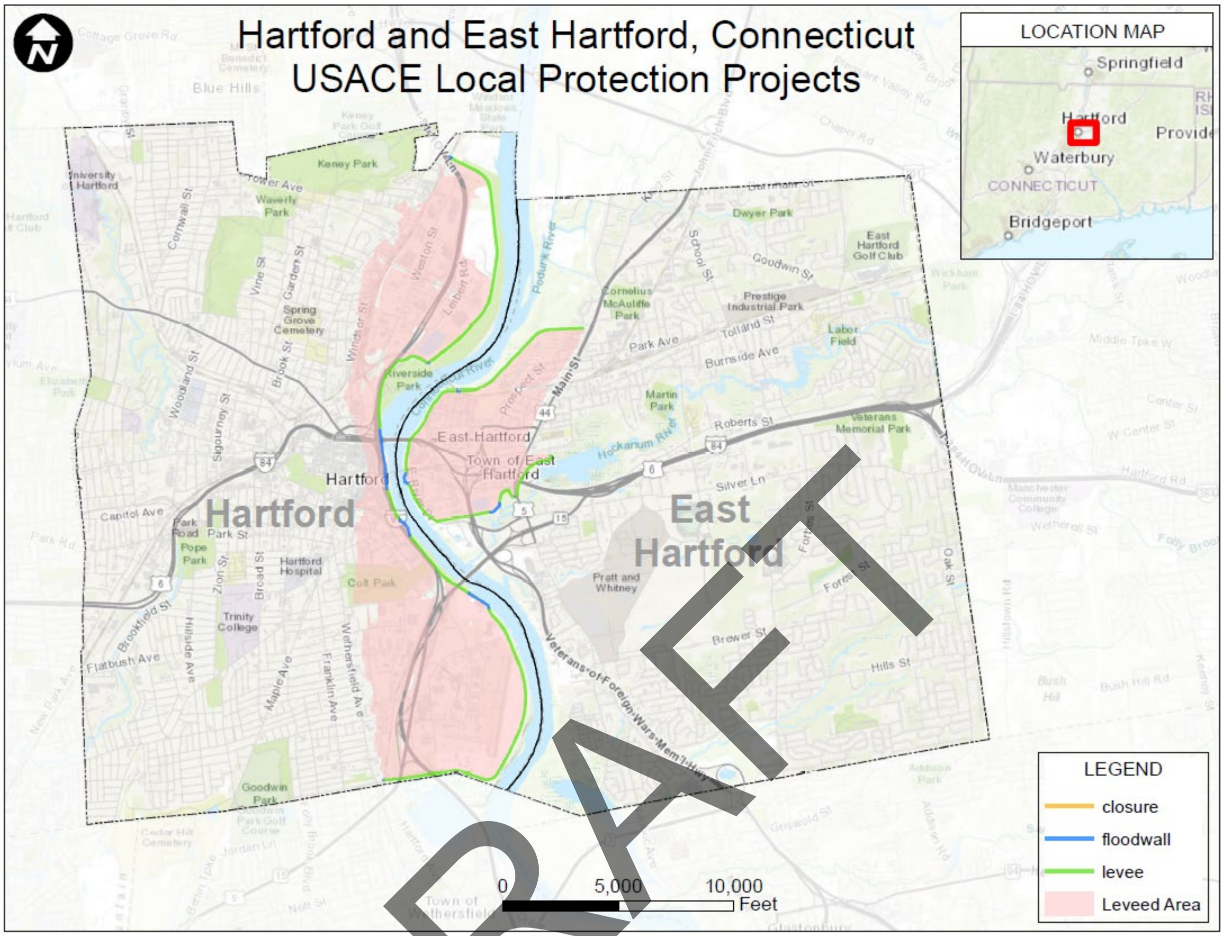


Figure 1: The Hartford/East Hartford, CT Section 216 Levee Rehabilitation Study Area

The Hartford/East Hartford, CT Section 216 Levee Rehabilitation Study Area

The Hartford and East Hartford Flood Risk Management Projects are two separate levee systems but are being investigated under one feasibility study (FS).

The Hartford FRM (Levee) system (**Figure 2**) was constructed to provide protection for 3,000 acres of land from flooding of the Connecticut River, Park River, North and South Branches of the Park River, Cully Brook, and Folly Brook. The "Hartford" FRM project can be divided into two separate but integrated systems – Main Stem Connecticut River and Park River.

The Main Stem Connecticut River system stretched from high ground near the Hartford-Windsor town limit south to high ground below the Hartford-Wethersfield boundary. This system was initially constructed by USACE between 1938 and 1944. Additional construction took place from 1956 through 1981. Some elements of the system date back to the 1938-44 construction period. Currently, the City of Hartford owns, operates, and maintains the FRM Project.

Figure 2: The Hartford FRM (Levee) System

The East Hartford FRM (levee) system is located along the east bank of the Connecticut River and the north bank of the Hockanum River in East Hartford. It provides flood damage reduction for approximately 760 acres of East Hartford from flooding of the Connecticut and Hockanum Rivers. The system was constructed by USACE between 1938 and 1943 ($2.4 million - 1943 dollars). Upon completion the project was turned over to the Town of East Hartford. Some elements of the system date back to the original 1938-43 construction.

Rehabilitation of the system is intended to achieve the goals of:

1. Reducing potential life loss in the communities of Hartford and East Hartford that are protected by the FRM systems related to flooding resulting from the failure of those systems.
2. Reducing damages to residences, business, and critical infrastructure caused by flooding resulting from the failure of the FRM systems.
3. Supporting the resiliency of the communities protected by the FRM systems.

Project constraints are listed as follows:

- Should not increase or induce flooding outside of the Hartford/East Hartford area and on the other levee system.
- Should avoid and minimize environmental impacts within the project area to the maximum degree practicable.
- Should not adversely impact threatened or endangered species, and their habitat within the study area.
- Should avoid or minimize negative impacts to wetlands and Essential Fish Habitat.
- Should avoid or minimize impacts that negatively affect authorized navigation projects downstream of the project area.
- Should avoid or minimize impacts that contribute to poor water quality in the Connecticut River.
- Should avoid or minimize effects on cultural resources and historic structures, sites, and features within the project area.
- Must comply with constraints of the Section 216 authority.
- Consider local responsibilities of the Levee Safety Program and SWIF plan.
- Avoid sites with HTRW contamination.
- Consider the complicated real estate considerations.
- Consideration of economically stressed communities.
- Minimize impacts to community cohesion.

Although Hartford is approximately 45 miles upstream of the mouth of the Connecticut River, the tidal signal from the Atlantic Ocean is observed at the system, and flood risk reduction was identified as the primary purpose.

Operators at the pump stations in Hartford and East Hartford have reported an increase in the frequency with which the outlets of the pump stations are above the trigger levels set to initiate pumping and/or operate gates on their outlet works.

Literature Review

Per ECB 2026-1 a literature review was performed. The review outlines the current hydrometeorology, and evidence of ongoing or projected changes in the project area. Relevant and reputable documents were used outlining the scope of trends that might affect the Hartford Levee systems.

The Crimmins et al (eds) (2023) report (NCA5) reviewed recent trends in published observed temperatures, precipitation, and the results of projected future hydrological conditions based on the outputs of Global and Regional Circulation Models (GCMs and RCMs). Crimmins et al (2023) included reviews of how forests, urban development, and oceans were being affected, and how ecological and societal systems were adapting, or were projected to need to adapt, to changes in the environment. They included regional reports in chapters dedicated to each of ten broad regions of the United States. These included a report on the Northeast, which included the six New England states as well as Delaware, Maryland, New Jersey, New York, Pennsylvania, West Virginia, and Washington DC.

A January 2015 literature synthesis conducted by the USACE Institute for Water Resources (USACE 2015b) summarizes the available technical literature for this region, covering both observed and projected changes. These include temperature, precipitation, and streamflow. Dupigny-Giroux, L.A. et al (2018) reviewed hydrological trends in progress in the United States in an earlier nation-wide assessment (NCA4). The USACE literature synthesis, Crimmins et al (2023), and Dupigny-Giroux et al (2018) are the major sources of the information referenced in this literature review. The focus of these references is on summarizing trends identified within historical and observed temperature, precipitation, and streamflow records, as well as providing an indication of future hydrometeorology based on the outputs from GCMs and RCMs. In this assessment, background on observed and projected temperature and precipitation is provided as context for the impact that these parameters have on observed and projected streamflow.

Temperature

Temperature Observations

Marvel K. et al, 2023 (in Ch 2 of Crimmins et al 2023) report a trend of fewer days below freezing (6.7 fewer days per year in the Northeast Region) and 2.1 more warm nights (above 70 deg F) per year. There were 1.3 fewer hot days reported for this region, when the period 2002-2021 was compared to the period 1901-1960. **Figure 3** was provided to illustrate the point:

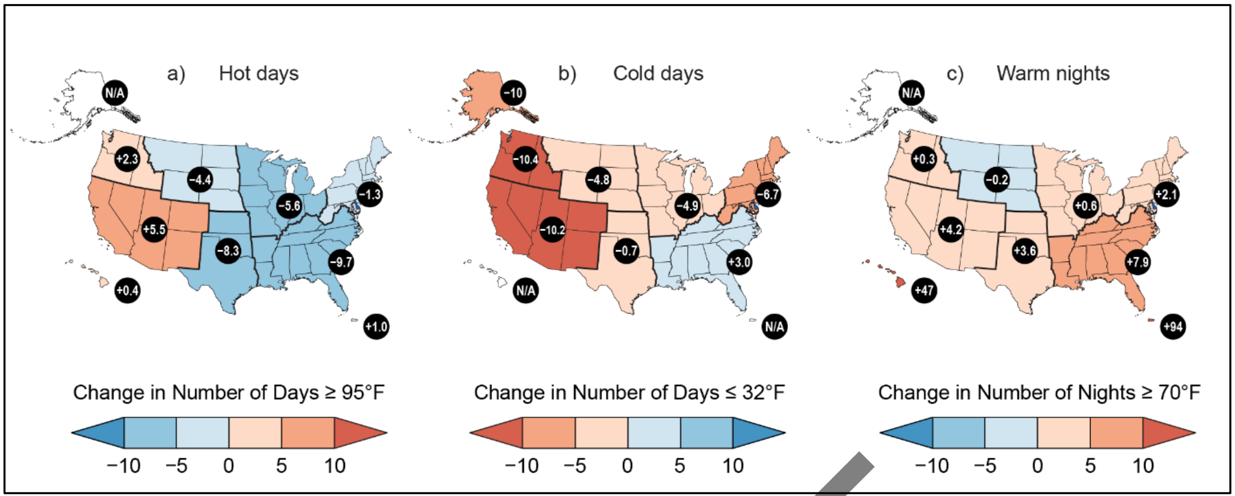


Figure 3: Observed Changes in Hot and Cold Extremes 1901 to 2021

Observed changes in annual average temperature for the Northeast Region have increased by 1.43 °F for the 1986-2016 period relative to the 1901-1960 period. Observed annual average maximum and annual average minimum temperature has increased by 1.16 °F and 1.70 °F in the Northeast region, respectively (Dupigny-Giroux, L.A. et al (2018)). Observed increases in temperature in the Northeast Region (New England, New York State, Pennsylvania, and New Jersey), including statistically significant increasing trends, have been reported in numerous studies (Hayhoe et al (2008); Burakowski et al 2008; the Frumhoff et al (2017); Brown et al (2010); Huntington et al (2009)). These included increases in summer temperatures, an average increase of temperature of 1.5 °C during the 20th Century, and a doubling of the number of days per year exceeding 32 °C (90 °C) since 1970.

More specifically, in New England, a general warming trend has been observed, with a rising trend of 0.8 to 3.0 °C per century, although two studies also detected a cooling trend for the months of December to February. Spring warming since 2001 appears to be occurring 0 to 4 days earlier than it did during the 1950's which indicates a potential change in seasonality. In a review of 361 station records over the period 1930 to 1996, only 4 stations had records of decreasing temperatures, and none of these results was statistically significant. These studies are included in Wang et al (2009); Westby et al (2013); Meehl et al (2012); Schwartz et al (2013); DeGaetano et al (2002); Horton et al (2014).

Trombulak and Wolfson (2004) reviewed temperature data at 36 locations in New England and New York State for 1903-2000, reporting an average increase of 3 °C per century for the region, without reporting on significance. For Hartford in the Coastal Connecticut watershed in western Connecticut, the interpolated rate of temperature-change appeared to be 2 °C to 3 °C per century (See **Figure 4**).

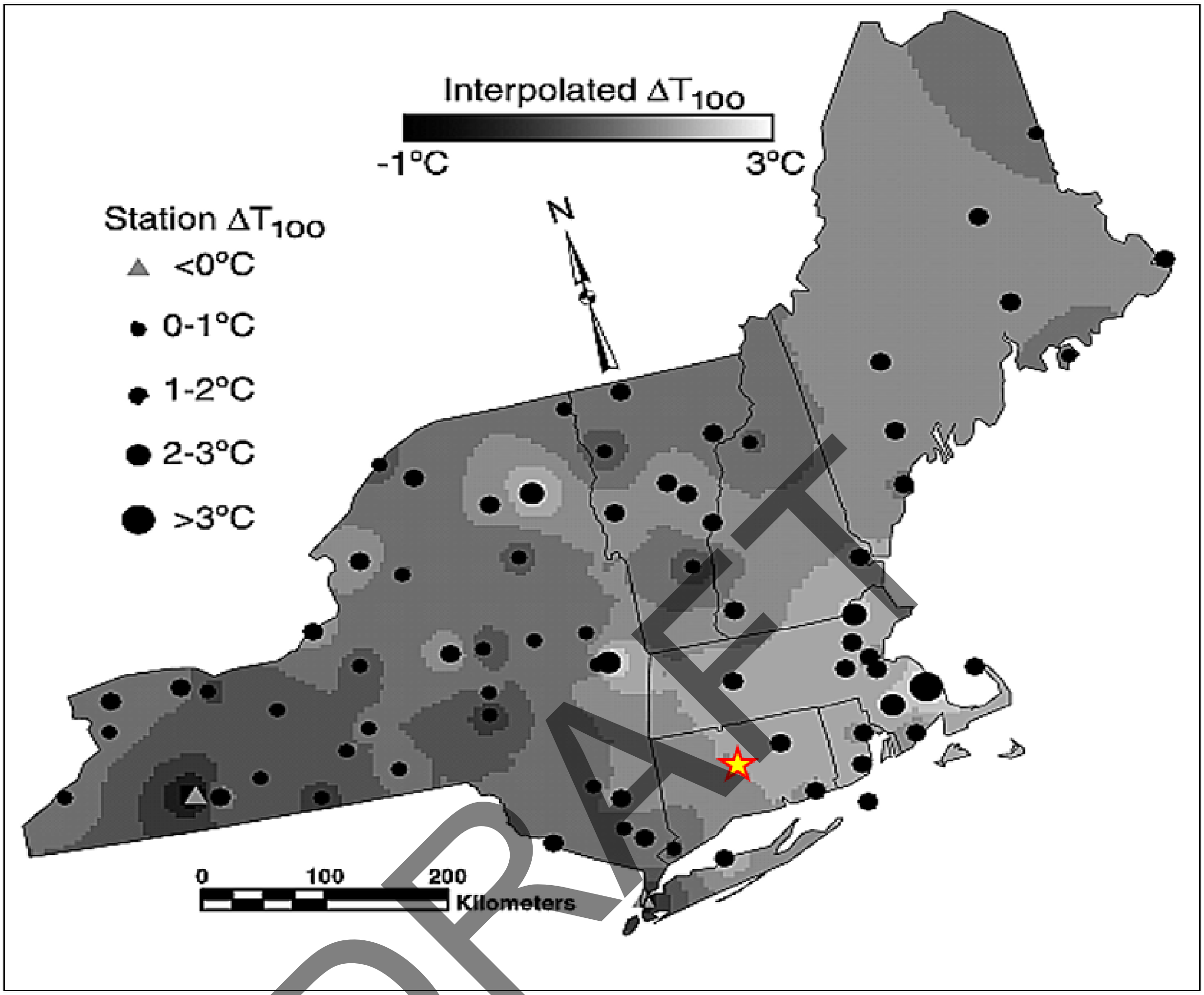


Figure 4: Trombulak and Wolfson 2004 Review of Temperature Changes (°C per 100 years) in the New England-New York Region. The Study Period of Record is 1903 to 2000. Hartford's location is indicated with a red star.

Temperature Projections

Marvel et al 2023 reported that warming in the US was projected to be greater than the global average during the balance of the 21st century. They reported results of projections based on assumed increases of 1.5, 2.0, 3.0 and 4.0 °C (2.7 to 7.2 °F). For the case of a 2.0 °C (3.6 °F) global rise, they presented the maps shown in **Figure 5**.

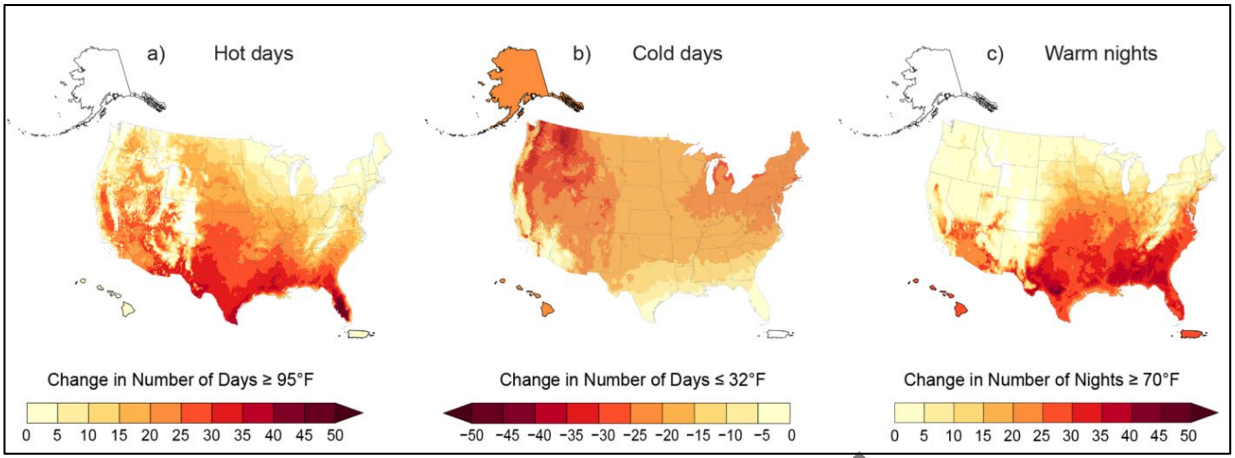


Figure 5 Projected Changes to Hot and Cold Extremes at 2 °C of Global Warming (relative to the period 1991-2020)

For central Connecticut, by the end of the 21st century, under this 2 °C global warming case, there would be up to 5 more days per annum of temperatures above 95 °F; about 20 fewer days of temperatures below freezing; and about 10 more nights of temperatures above 70 °F.

Dupigny-Giroux, L.A. et al (2018) reviewed temperature changes and projections of temperature-change for 7 regions of the US. For the Northeast, they reported on average, minimum, and maximum temperatures and how these were expected to differ from "near-present" (1976-2005) conditions as projected by 32 hydrological models, under two sets of assumed inputs, during the 21st century. Time periods examined were for mid-century (2036-2065) or late-century (2071-2100). The average temperatures were expected to rise by 4.0 to 5.1 °F by mid-century and by 5.3 to 9.1 °F by late-century.

For temperature extremes, Dupigny-Giroux, L.A. et al (2018) reported results for the mid-century (2036-2065) as these were projected to have shifted from the 1976-2005 conditions. For the Northeast, the change in the warmest day of the year was expected to be 6.5 °F; the change in the coldest day of the year was expected to be 9.5 °F. For 5-day periods, the 1-in-10-year coldest spell was expected to be 15.9 °F warmer; the 1-in-10-year warmest spell was expected to be 12.9 °F warmer.

For projections, GCMs are used to simulate future weather conditions. Scherer and Diffenbaugh (2014) used varying assumptions about emissions to model conditions in the United States: their results for New England indicated increased summer and winter temperatures of 5.2 °C (9.4 °F) and 1.7 °C (3.1 °F).

Runkle et al 2017 and Runkle et al 2022 published Connecticut-specific assessments containing information on observed and projected streamflow trends, and past and future conditions of sea level and coastal flooding. Regarding temperatures, Runkle et al 2017 reported as follows:

> *"Temperatures in Connecticut have increased almost 3.5 °F since the beginning of the 20th century. The greatest number of hot days occurred during the last two multiyear periods (2010-2014 and 2015-2020…) The number of warm nights has been consistently above the long-term average since 1995; the most recent multiyear period had the second-highest average… The number of very cold nights has been below average since the mid-1980's, with the lowest multiyear average occurring during the 2010-2014 period."*

Figure 6 provides a summary of the expected changes, based on the two scenarios (RCP4.5 and RCP8.5) in which CO_2 emissions either continue to increase (higher emissions) or increase at a slower rate. Although the figure is taken from Runkle et al 2022, the authors reference work by Vose et al at North Carolina State University in 2014. Historically unprecedented warming is projected to continue (higher emission) through the 21st century. Temperatures have risen almost 3.5 °F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading).

Less warming is expected under a lower emissions future (the coldest years being about 6 °F warmer than the long-term average; green shading) and more warming under a higher emissions future (the hottest years being about 11 °F warmer than the hottest year in the historical record; red shading).

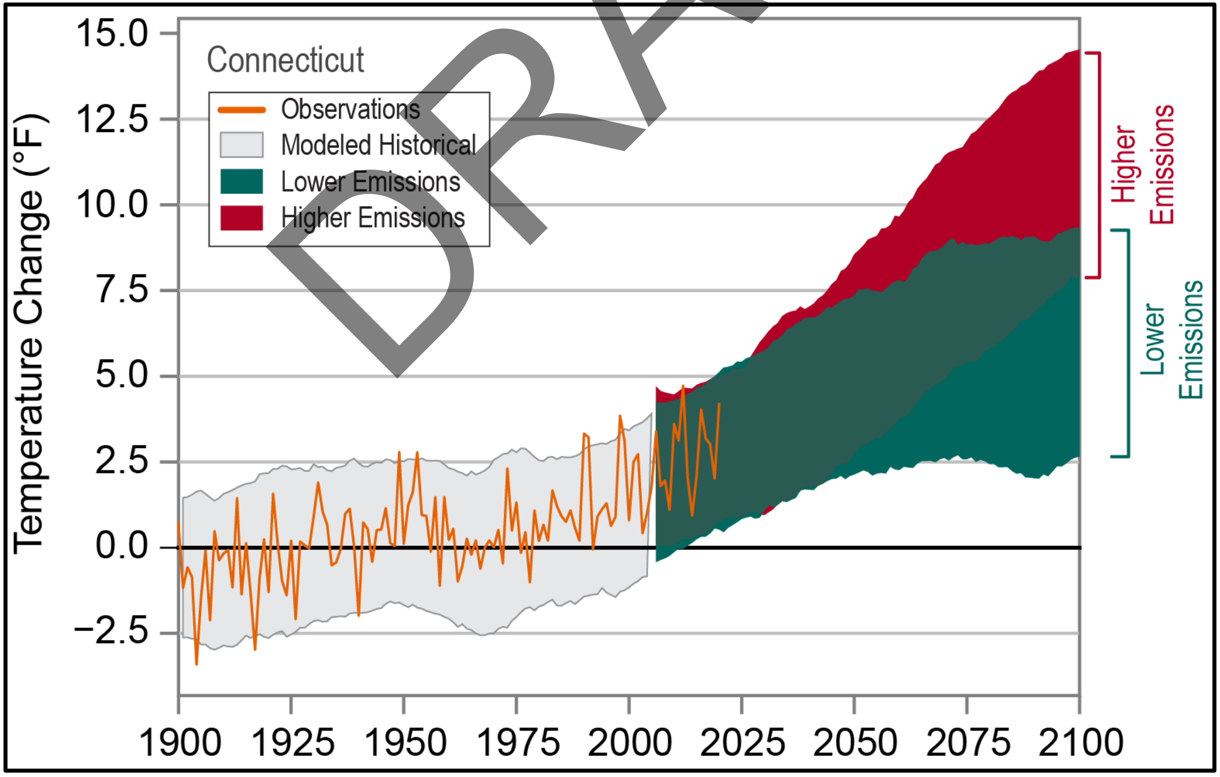


Figure 6 Observed and Projected Temperature Change in Connecticut (Source: Runkle et al (2022)

Precipitation

Precipitation Observations

Whitehead et al (2023) reported in Crimmins et al (2023) that both total precipitation and precipitation intensity extremes appeared to be rising throughout the Northeast United States. This is illustrated in the four charts shown in Figure 7.

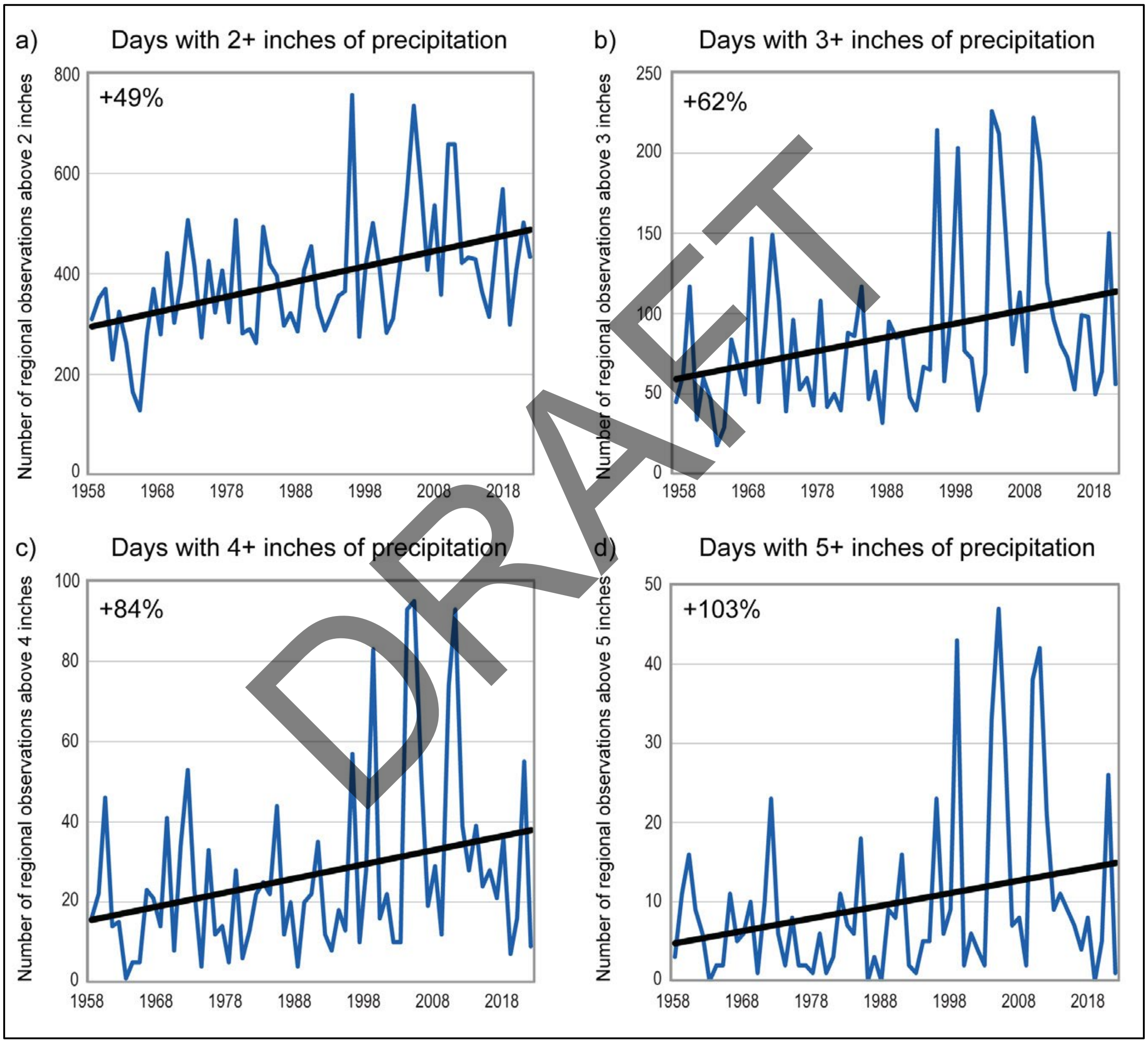


Figure 7: Trends in Extreme Precipitation in the Northeast

Whitehead et al (2023) noted that the percent increases noted in the top left corner of each chart were measured relative to the average result for the period 1958 to 2022. For the number of 2-inch-precipitation days, the 49% total corresponds to an increase over 1958-to-2022 of 98% (essentially, a doubling of the frequency of these events). For 3-

inch, 4-inch, and 5-inch-precipitation days, the percentage increases in frequencies were even higher.

Whitehead et al (2023) noted also that the frequency of droughts had decreased in the Northeast over the years 1901 to 2015. They reported also that heatwaves had been lasting longer, were more severe, and were increasing heat stress, especially in densely populated areas.

Dupigny-Giroux et al (2018) summarized changes that were observed over a period of 115 years from 1901 to 2016, for a grid of latitudes and longitudes that covered the contiguous United States. Maximum daily precipitation was reviewed for this grid, and it was noted that the 20-year-return-level precipitation had increased in each of the four seasons for the Northeast Region. The total increase for winter was 0.08 inches; for spring 0.25 inches; for summer 0.16 inches; for fall 0.23 inches. The same database was reviewed to demonstrate that the size of a 5-day maximum daily precipitation had increased over 1901 to 2016 by 27% in the Northeast, and noted that the frequency of exceedances of the 5-year 2-day precipitation (as it had been at the start of the observation period) had increased by 74%, in the Northeast during this period; when the shorter, more recent period 1958 to 2016, was reviewed, the percentage increased from 74% to 92%. The 99th percentile annual 1-day precipitation had increased by 55% for the Northeast for the period 1958 to 2016.

Observations of summertime weather indicated that although extratropical cyclones seemed to be becoming less frequent since 1979 (by 35%), the associated intensity appeared to be increasing.

Dupigny et al (2018) noted recent increases in rainfall intensity throughout the Northeast, with projected increases in monthly precipitation of about 1 inch during the months December through April by 2100. Although annual minimum streamflows had increased over the previous century, it was expected that late-summer warming might lead to decreases in the minimum streamflows in the late summer and early fall by the middle of the 21st century.

Dupigny et al (2018) also noted that larger cities in the Northeast are deliberately planning to mitigate impacts of more frequent flooding, naming Boston, MA, Burlington VT, **Hartford, CT**, Newark NJ, Manchester NH, New York NY, Philadelphia PA, Pittsburgh PA, Portland ME, Providence RI and Washington DC as cities that had begun to plan for likely meteorological changes and had started to make changes when upgrading aging infrastructure.

Hayhoe et al (2008) reviewed data in the 20th century, developing an estimate for New England of a 5-mm (0.2 inch) per day increase in precipitation, with more intense storms (10 to 15%) occurring more often (12 to 13% more per year), and the wettest annual 5-day period expected to contain 20% more volume by the end of the 21st century.

Runkle et al (2022) reported as follows:

> *"Precipitation in Connecticut is abundant but highly variable from year to year. Generally, annual precipitation has been above average since the 1970s. The driest multiyear periods were the 1960s and the wettest in the late 1970s and late 2000s … The wettest consecutive 5-year interval on record (2007–2011) averaged 53.6 inches per year, while the driest (1962–1966) averaged about 36 inches per year. The single driest year was 1965, with a statewide average of 30.7 inches, while the wettest year was 2011, with 63.7 inches. Seasonal snowfall ranges from between 30 and 35 inches along the coast to 50 inches in the Northwest Hills. The highest number of 2-inch extreme precipitation events was recorded between 2005 and 2014…. Summer precipitation was generally above average in the 2000s and early 2010s … Connecticut experienced extreme drought in 2016–2017 and again in 2020, straining water supplies."*

Runkle et al (2022) also noted that precipitation in the spring (March to May) was expected to increase in Connecticut by mid-Century (by 2050); the projected amounts were in general 5% to 15% increased. The projected increase for Hartford was a 10% increase in spring-time precipitation.

More recently, the precipitation record at nearby dams at Colebrook Dam (26 miles north-west of Hartford in the Lower Connecticut Basin, and at Thomaston Dam 21 miles southwest of Hartford in the nearby Naugatuck Basin, include significant storms in July and September-October 2023, indicating the likely continuation of increasing frequency of 2-inch-plus days per annum in the future.

Precipitation Projections

Dupigny-Giroux et al (2018) reviewed modeling results that indicated increases in precipitation in the New England region of about 10% in all four seasons. They reference Janssen et al. 2016, in a review of modeling results, and summarized the following: extreme heavy precipitation was expected to manifest in a tripling of the frequency of storms previously designated "5-year return period storms" throughout the US, with the greatest increases being in the Northeast. The projected size of a "20-year" storm was expected to increase by 10 to 13% by mid-21st-century, and by 14 to 22% by late-21st century, for the New England region. Trends associated with hurricanes were less clear from the modeling.

Thibeault and Seth (2014) assumed a high CO_2 emissions scenario to develop projections for the Northeast Region, some of which had statistically significant increases of 1.5 mm/day. Rawlins et al (2012) reviewed data since 1971 to develop projections of increases in precipitation through 2070 in New England of 12% in winter, 10% in spring; -2% (less rainy) in summer; and 3% in autumn. For the Hartford area in central Connecticut, the ranges were 8 to 10% in winter, 4 to 8% in spring; no clear change in summer; and 3 to 5% in autumn. These results can be inferred from review of **Figure 8**. The scope of the Rawlins study included New York, New Jersey, and Pennsylvania.

The changes in projected precipitation noted in these seasonal projections suggest a potential shift in flood seasonality. Winter and spring precipitation have important implications for flood risk management as increase in precipitation during this time of year may exacerbate flooding at the Hartford levees.

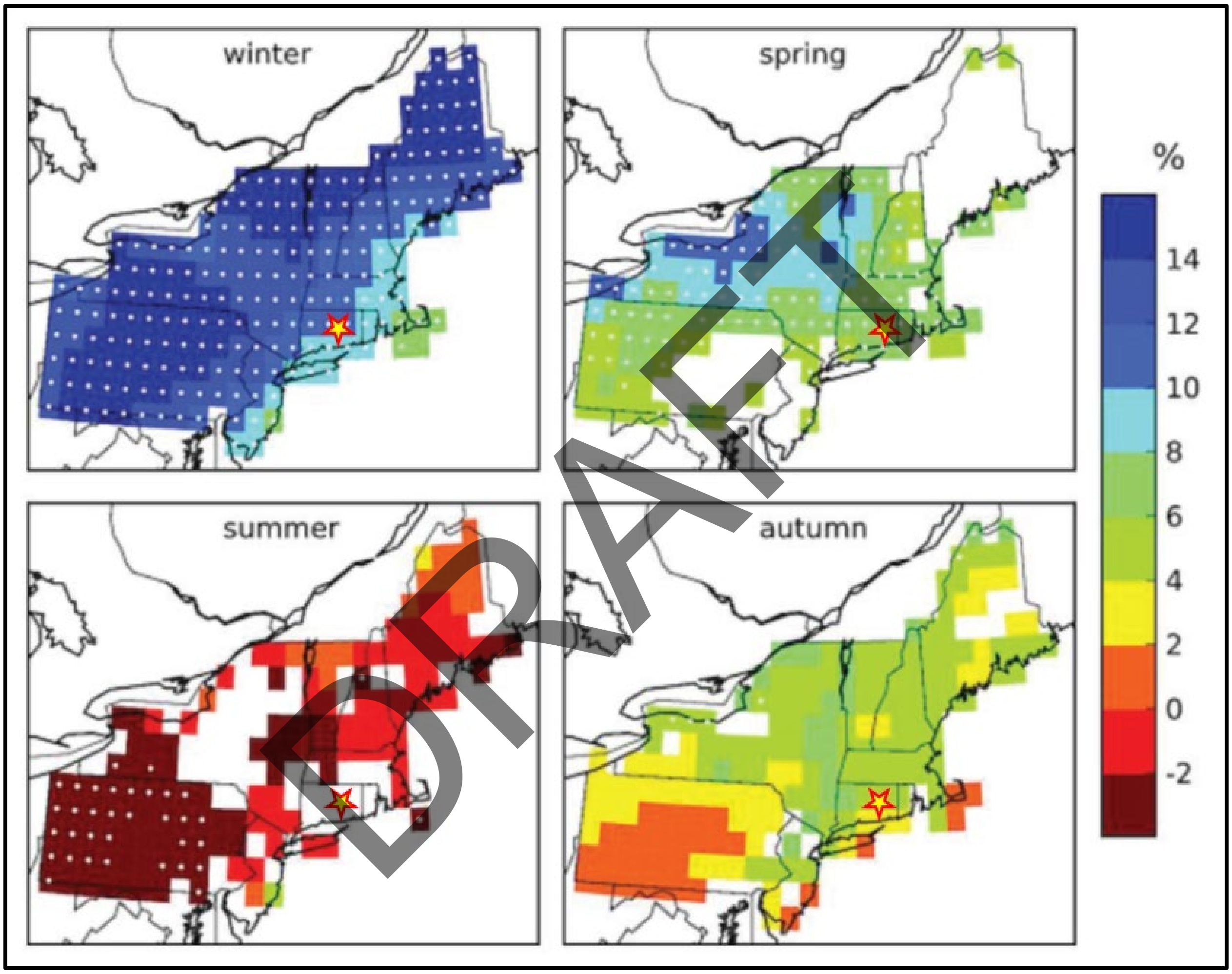


Figure 8: Projected changes in seasonal precipitation volumes, 1971-2000 compared with 2041-2070, as a percent of 1971-2000 precipitation volumes (Rawlins et al. 2012). The central location of Hartford CT is indicated with a red star symbol.

Hayhoe et al (2007) and Hayhoe et al (2008) essentially validated the seasonal findings and projections of Thibeault and Seth (2014) for the New England area, adding their own projections through 2099; their results included an estimate of a 5-mm (0.2 inch) per day increase in precipitation, with more intense storms (10 to 15%) occurring more often (12 to 13% more per year), and the wettest annual 5-day period expected to contain 20%

more volume by the end of the 21st century. Ahmed et al (2013) created two hydrological model ensembles, using data from 1976-1995 and projecting to 2065: the average number of rain-days exceeding 10 mm (0.4 inch) increased by 0 to 4 days per year by 2065 under both scenarios, although the frequency and intensity of big storms were less clear (depended on the location). Huntington et al (2009) noted that an increase of up to 10% in annual precipitation was expected by the end of the 21st century, although there was limited agreement between models; the projected increase in winter precipitation, however, was a common theme, as summarized by Dupigny-Giroux et al (2018).

Runkle et al (2022) reported that precipitation in the spring was expected to increase in Connecticut by mid-Century (by 2050); the projected amounts were in general 5% to 15% increased and approximately 10 % at Hartford.

Streamflow

Whitehead et al (2023) noted that specific hurricanes (Irene, Sandy, the 2019 combination of Henri and Ida, Isaias) had caused flood damage, which had tended to be in areas with less capacity to absorb the losses, but there remained a lack of consolidated information about flooding related to smaller periods of intense rainfall (such as convective thunderstorms), or whether these briefer storms were reliably correlated with flooding issues.

Streamflow Observations

Wehner et al, 2017 (in Wuebbles et al, 2018) indicated a possibility of increased frequency of large storms. The response in runoff to precipitation was less readily apparent:

- The winter snow-deposition season appeared to be shrinking over time, so there would be less snow to melt, generating runoff, in the spring.
- The mix of rain to snow was changing (more rain, less snow, so the sudden rain-on-snow snowmelt runoff events would occur with less total runoff being generated, and more opportunities for water to seep into the soil as opposed to increasing the measured runoff.
- For hurricanes and tropical storms, which are an important driver of flooding events in the eastern United States, the expected drier conditions in the summer months would serve to promote hydrologic losses such that intense thunderstorms might produce substantial precipitation, but more of this would be lost to infiltration.

Wehner et al, 2017 noted that possible deforestation, urbanization, dams, floodwater management activities, or changes in agricultural practices were important factors in statistics connecting runoff and precipitation. The report noted “Projection of future changes is thus a complex multivariate problem.”

Kalra et al (2008) reviewed historical streamflow data for 1951-2001 and found no statistically significant trend in the New England Region for either annual or seasonal streamflow. Small et al (2006) studied flow records in 1948-1997, essentially confirming this “no-trend” finding, but noting also that two stations had a statistically significant decrease in low flows. Armstrong et al (2012) reviewed 23 gage records at “undisturbed” sites and noted that for 22 of the sites, low-magnitude floods were increasing in frequency and magnitude, and that the result was significant at $p<0.1$ for 10 of the stations. Hayhoe et al (2007) reviewed peak spring runoff data since 1950, noting that the peak was occurring earlier by approximately 0.3 days per decade over 1950 to 2000, but with no significance stated; runoff volumes and 7-day annual minimum values presented less clear results.

Hodgkins et al (2003) used a more robust measure of peak flow timing at 27 New England stations (center-of-volume date for the January-through-May winter-spring period and the center-of-volume date for the June-through-December summer-fall period) in the 20th century. Half of these stations (14 of 27) exhibited a $p<0.1$ significant trend of earlier dates for winter/spring; four of the stations also had earlier summer/fall dates. Frumhoff et al, 2007 noted that in the Northeast Region over the 20th century the date of spring thawing of lake ice had shifted by 9 days in the northern part of the region to 16 days over the southern region.

Runkle et al 2022 reported:

> *“Increases in the frequency and intensity of extreme precipitation events are projected, as well as increases in winter and spring precipitation.”*

Streamflow Projections

Wehner et al (2017) referenced a report by Tebaldi et al (2006), prepared for the Federal Insurance and Mitigation Administration of FEMA. Tebaldi et al (2006) had developed a regression-based approach of scaling river gage data based on seven commonly used hydrological indices from the Coupled Model Intercomparison Project (CMIP) database and found that at the end of the 21st century the 1% annual change exceedance floodplain area would increase in area by about 30%. Wehner et al (2017) noted also that AECOM (2013) had indicated that there would be larger changes in the Northeast and Great Lakes regions and smaller changes in the central parts of the country and the Gulf Coast.

Thomson et al (2005) used two GCMs with various input assumptions to model flows across the United States. The results were inconclusive with respect to streamflows in the neighboring Mid-Atlantic Region (west of the Connecticut River basin and the New England region where Hartford is located). For the New England region, the results indicated little to no change over time, and the small change that was indicated, forecast as water yield, was positive in one case and negative in the other, but appeared to register differences smaller than 15 mm in either case.

Hagemann et al (2013) reviewed runoff trends based on a set of GCM simulations. The models indicated runoff increases of up to 3.1 inches per year, with larger increases in the winter and smaller increase in the spring. For the New England region, however, the modeled projections demonstrated appreciable uncertainty, based on setting the starting boundary conditions (seeding), as well as with the models' GCM assumptions.

Frumhoff et al. 2007 noted changes in seasonal timing of runoff (10 days shift for the spring peak flow by 2100), and that the probability of high-flow events may increase by up to 80%, especially in Maine, New Hampshire, and Vermont. Drought frequency was expected to increase due to reductions in summer runoff and soil moisture, with a reduction of 10% for the annual low flow 7Q1 (7-day average annual minimum low flow, with return period 1 year).

USACE (2015) summarized a two-model GCM study with estimates of 60 to 200 mm increase (approximately 2.5 to 8 inches) in annual runoff expected for the USACE planning horizon 2071-2100, compared to the period 1971-2000.

The runoff response to extreme storms (for example, 100-year or larger) was less clear, and USACE 2015 includes the statement "There is little consensus in the literature regarding future projections of annual streamflow volumes, but in general spring streamflow peaks are expected to arrive earlier in the year and may increase in volume."

Both USACE (2015) and CDM Smith (2012) cautioned that hydrologic parameters were a significant source of uncertainty.

Ahearn and Hodgkins (2020) noted in their review of peak flows that "Historical peak-flow trends in and near Connecticut do not offer clear and convincing evidence of the need to incorporate trends into flood-frequency analyses." They did acknowledge the possibility that changes might be necessary in the future with regard to this approach, since Walter and Vogel (2010) had seen evidence of increasing high flows in urbanizing basins in Connecticut, while Hodgkins and Dudley (2005), Collins (2009), and Huntington et al (2009) had found increasing high flows in basins minimally affected by urbanization. Consequently, alterations to the drainage basin areas on the west and east banks of the Connecticut in the City of Hartford and Town of East Hartford may prove more influential in changing the local response of surface water to rainfall than wider stormflow issues.

Seasonality

Seasonality in Temperature – Observations and Projections

Several studies noted that spring warming since 2001 appears to be occurring 0 to 4 days earlier than it did during the 1950's which indicates a potential change in seasonality. These studies are included in Wang et al (2009); Westby et al (2013); Meehl et al (2012); Schwartz et al (2013); DeGaetano et al (2002); Horton et al (2014).

Dupigny-Giroux, L.A. et al (2018) noted that in New England, a general warming trend has been observed, with a rising trend of 0.8 °C to 3.0 °C per century, although they noted two studies that detected a cooling trend for the months of December to February.

Seasonality in Precipitation – Observations and Projections

Rawlins et al (2012) reviewed data since 1971 to develop projections of increases in precipitation through 2070 in New England of 12% in winter, 10% in spring; -2% (less rainy) in summer; and 3% in autumn. For the Hartford area in central Connecticut, the ranges were 8 to 10% in winter, 4 to 8% in spring; no clear change in summer; and 3 to 5% in autumn.

Seasonality in Streamflow – Observations and Projections

Frumhoff et al. 2007 noted that in the Northeast Region over the 20th century the date of spring thawing of lake ice had shifted by 9 days in the northern part of the region to 16 days over the southern region.

Frumhoff et al. 2007 noted changes in seasonal timing of runoff (10 days shift for the spring peak flow by 2100), and that the probability of high-flow events may increase by up to 80%, especially farther north in Maine, New Hampshire, and Vermont. Drought frequency was expected to increase due to reductions in summer runoff and soil moisture, with a reduction of 10% for the annual low flow 7Q1 (7-day average annual minimum low flow, with return period 1 year).

Coastal Effects

Relative Sea Level Change Observations and Projections

Runkle et al (2022) reported a range of projections for global change to sea level during through 2100 of 1 to 8 feet, with a likely range of 1 to 4 feet. These were based on the 6 US Interagency Sea Level Rise Task Force GMSL scenarios. Runkle et al (2022) noted: “Even greater rises are possible for Connecticut”. Their summary chart of the NCA4 sea-level findings (Sweet et al 2017) is reproduced here as **Figure 9**.

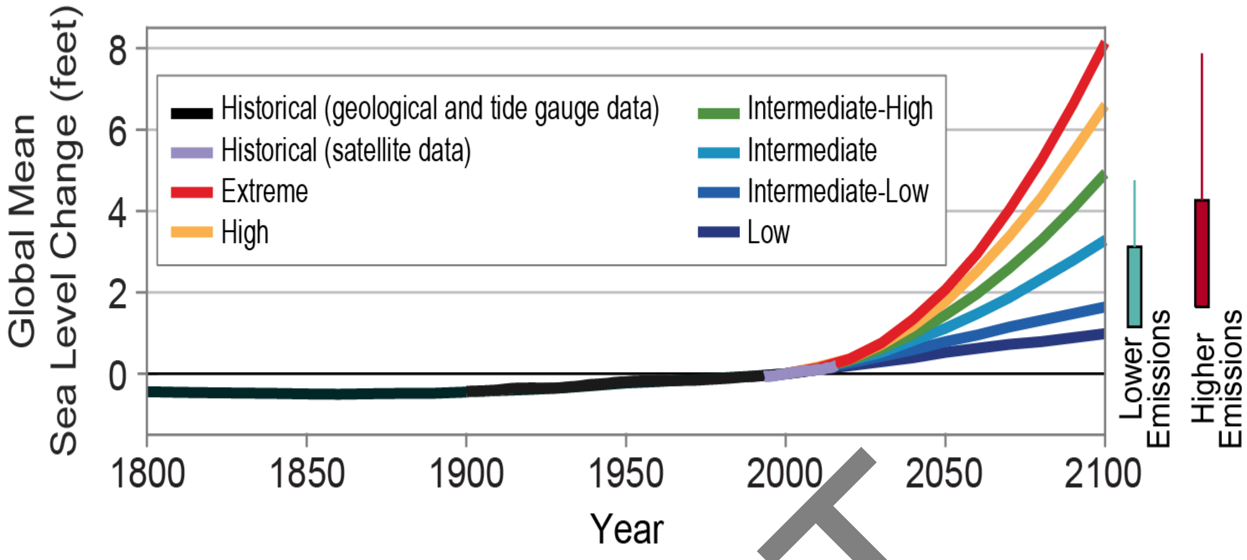


Figure 9: Observed and Projected Change in Sea-Level – from NOAA 2022 (Lower emissions RCP 4.5; Higher Emissions RCP 8.5)

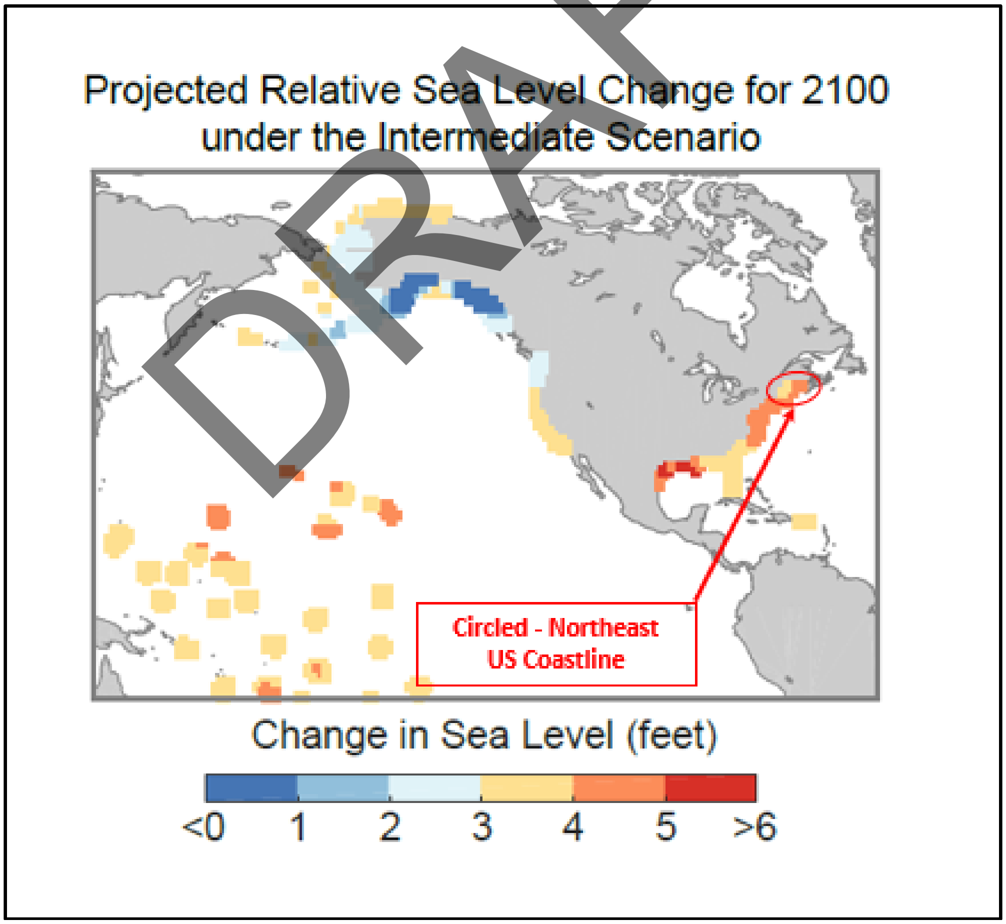


Figure 10: Projected Relative Sea Level Change for 2100 under the Intermediate Scenario (Global 3.3 ft rise by 2100)

Figure 10, taken from Sweet et al 2017 in Dupigny-Giroux et al (2018), indicates an expected range of 3 to 5 feet for RSLC along the Connecticut coast by 2100. The global increase would be larger under an RCP 8.5 model run; and it is expected that Connecticut would experience greater RSLC than the global average. Sweet et al (2017) reported the possibility of up to 8 feet of global rise, but noted that the available data did not allow for a useful assessment of confidence in the 8-foot projection.

Literature Review Summary

Recent technical literature observed increasing mean air temperature trends in the study region. Winter temperatures may be increasing faster than other seasons. The literature points to an increasing trend in the number and temperature of extreme heat days. Total precipitation is increasing over time. **Winter precipitation is expected to increase**. Snowmelt and the spring thaw of lake ice have been observed to occur earlier in the year. Despite the observations of increasing precipitation over the 20th century, there is little evidence of significant increases in streamflow over the same period. Relative sea-level is projected to rise by 3 to 5 feet by 2100.

The USACE literature synthesis findings are summarized in **Figure 11**.

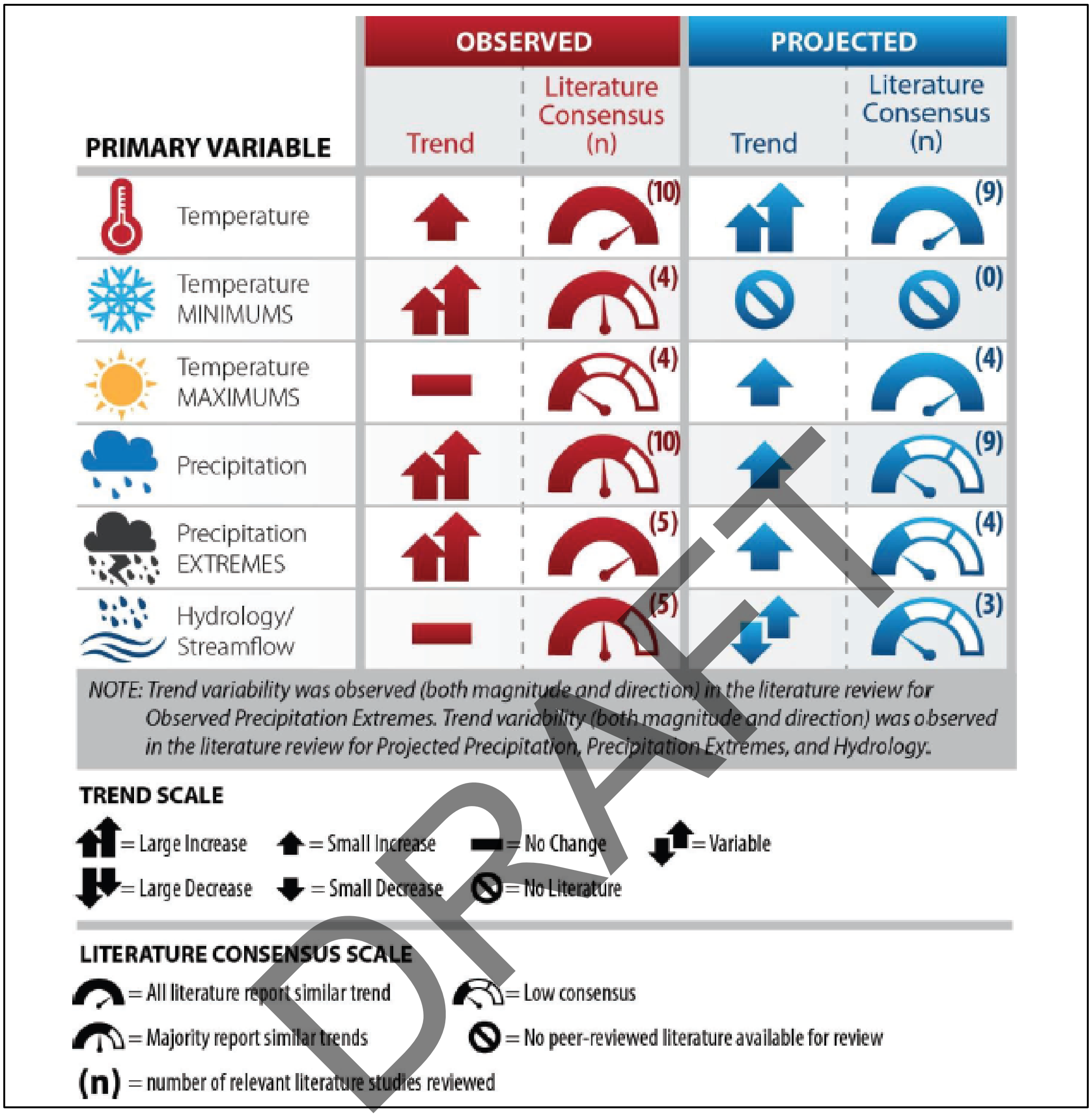


Figure 11: Summary matrix of observed and projected hydrological trends for the New England Region (USACE 2015)

Records of Inflows to the Levee System

The assumption that discharge datasets are stationary (their statistical characteristics are unchanging in time) underlies many traditional hydrologic analyses. Statistical tests can be used to test this assumption. The Nonstationarity Detection (NSD) tool is a web-based tool to perform these tests on datasets of annual peak streamflow at U.S. Geological Survey (USGS) stream gages. The Hartford and East Hartford levee systems are operated for flood risk management. This resilience review is intended to support the rehabilitation study, so the focus of this study is the high flow regime that is best represented by riverine flows in tributaries to the Connecticut River and along the Connecticut River itself in the Hartford and East Hartford region.

As shown in the following subsections Park River, Hockanum River, and Connecticut River sections that follow, the USGS record of peak annual flows, monthly mean flows, and monthly water levels and flows over multiple decades does exhibit evidence of nonstationarities. A strong nonstationarity is one that demonstrates a degree of consensus, robustness, and a significant increase or decrease in the sample mean and/or variance. The CHAT's Time Series Toolbox (TST) performs tests to establish whether mean values **(blue horizontal bars** in the standard TST test results), variance **(orange horizontal bars)** or its derivative parameter the standard deviation **(green horizontal bars)** experienced any abrupt changes (nonstationarities) during the period of record under examination. The TST shows a "statistical tests" heatmap with multiple test results for the mean and variance, with **blue** and **orange** vertical bars located on the chart to show the dates and detection methods used to generate the positive nonstationarity results. In addition to these tests, the CHAT adds light blue bars to note a nonstationarity in the distribution itself when the underlying detection method appeared to be changing, and yellow bars to show when a smoother nonstationarity appeared to be in progress (Smooth Lombard Wilcoxon test). Consensus is achieved when a positive test for nonstationarity in one parameter is supported by another test for the same parameter within 5 years (could be the same year); robustness is achieved when a positive test for uncertainty in one parameter is supported by a positive test for a different parameter within 5 years (could be the same year). A single positive test result for one parameter is typically not adequate to identify a nonstationarity in the record if it is not supported by either consensus or robustness.

Records longer than 30 years are adequate to support nonstationarity testing; nonstationarity-free periods longer than 10 years are required for meaningful review of the associated segment statistics (horizontal bars of mean, variance, and standard deviation in the TST).

In addition to the Connecticut River, river flows of concern in Hartford are: Park River (77 square miles) with its North and South Branches; Folly Brook; and Cully Brook. For the resilience assessment, Park River and its North Branch have been reviewed.

In addition to the Connecticut River, for East Hartford, the concern is with Hockanum River (also 77 square miles), along with its South Branch. The Hockanum River drains portions of Ellington, Rockville, Vernon, South Windsor, Talcottville, Buckley, Waddell, Manchester, and East Hartford communities. There is some regulation in Union Pond, and there is a recreational area over much of the river length through these communities. If the nearby woods and recreation areas were to be developed, then the added urbanization would promote the conversion of rainfall to runoff. For the resilience assessment, the Hockanum River has been reviewed.

Drainage and pump systems discharge to the Connecticut River, which is tidally influenced, although Hartford is 45 miles upstream of the mouth of the river. The drainage area of the Connecticut River at Hartford is 10,500 square miles. In general, tidal influence at Hartford is small.

The USGS StreamStats tool can estimate storm flows for Park River, Hockanum River, and the Connecticut River, although there are warnings in all three cases based on uncertainty regarding regulation. This regulation includes the 14 USACE owned and operated flood risk management dams upstream in the Connecticut River watershed, but also the detention basins and storage dams in Hartford and East Hartford. USACE designed a further two FRM dams that were constructed in the Connecticut River watershed. These are in Connecticut, and are operated by the State of Connecticut. The 16 dams are described briefly in **Table 5**.

For periods longer than 10 years in which no nonstationarities are detected, a meaningful trend analysis can be performed. The TST trend analysis tool computes two straight-line curves (a least-squares or "traditional" regression and also a Sen's slope regression) and performs three statistical tests on the data set to establish whether the trend (slope) is significantly greater or smaller than zero.

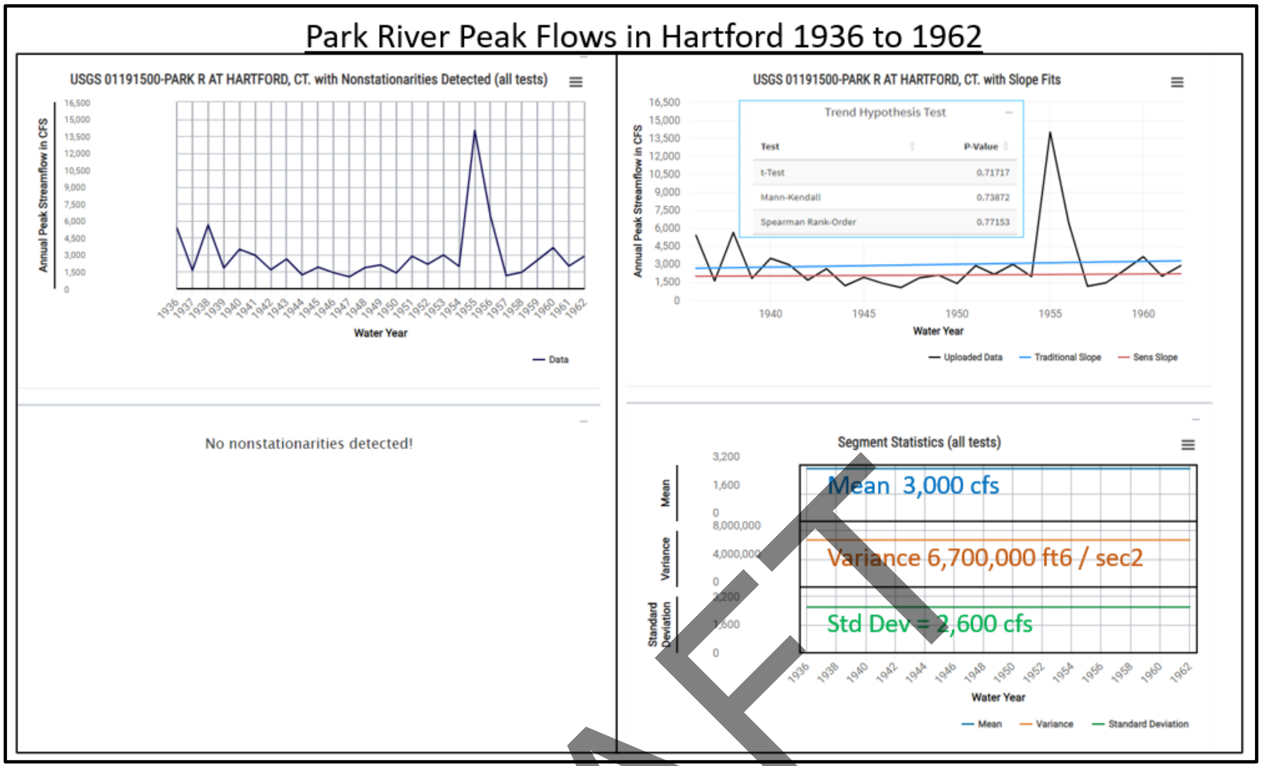
Statistical test results with P-values (or alpha values) smaller than 0.05 (confidence more than 95%) indicate test detections of a monotonic trend, that is, the flows are changing (either increasing or decreasing) over the time period being examined. **In general**, for the flow data reviewed, slopes (values of change in annual peak flow in cfs over time) were small, and it was possible to choose a timespan to "force" either positive or negative slopes, but statistical tests showed that the trends (slopes) were not "significantly" detected at the 0.05 level.

Park River – Nonstationarity Detection and Trend Analyses

The Park River in Hartford was monitored at USGS gaging station 01191500 for the years 1936 to 1962. The drainage basin area at the gage is 72.5 square miles.

The North Branch of the Park River (drainage basin area 26.8 square miles) has been monitored at gaging station 01191000 from 1936 through 2022, with gaps from 1986-1994 and 1997-2014.

Figure 12 shows a summary of the CHAT's nonstationarity and trend analyses for the Park River.



No nonstationarities detected!

Trend Hypothesis Test

Test	P-Value
t-Test	0.71717
Mann-Kendall	0.73872
Spearman Rank-Order	0.77153

Mean 3,000 cfs

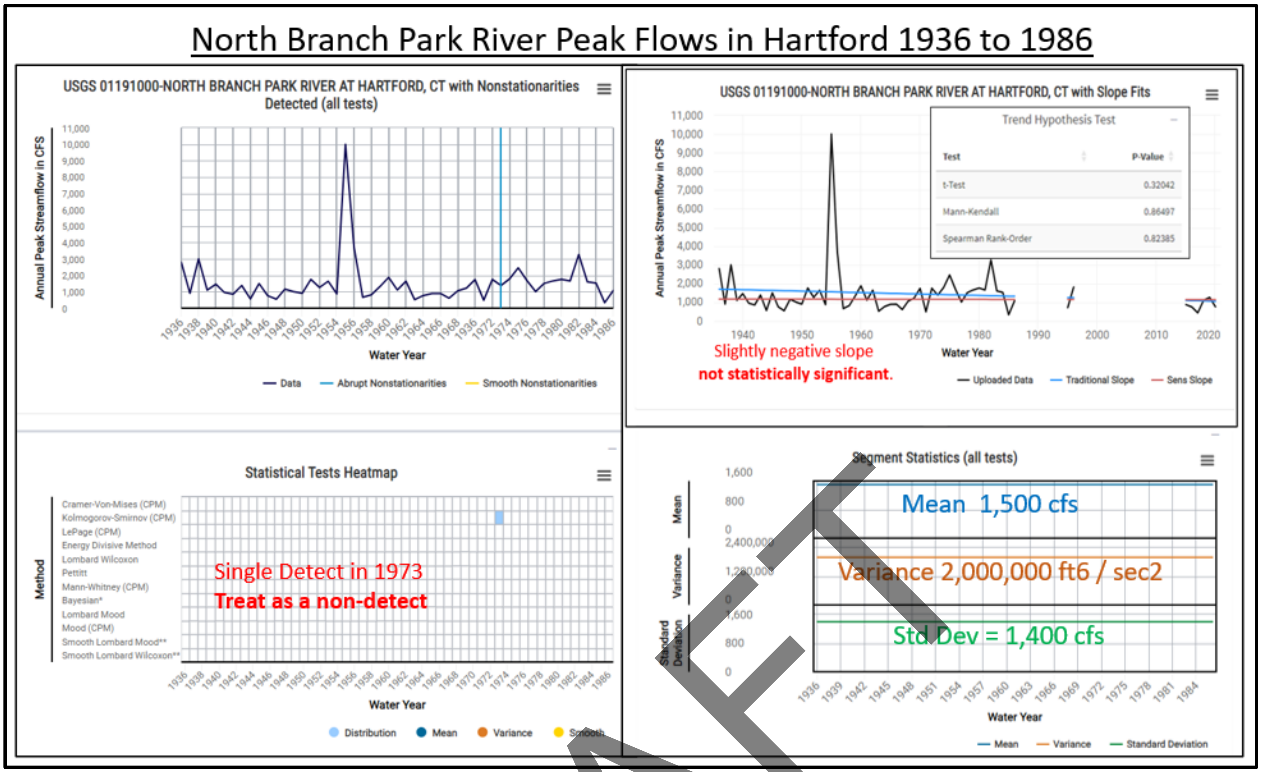
Variance 6,700,000 ft6 / sec2

Std Dev = 2,600 cfs

Figure 12: Park River - Analysis of Peak Annual Flows 1936 to 1962

No nonstationarities were detected, and no trend was found in the period 1936 to 1962. A mean annual peak flow of 3,000 cfs was indicated.

For more recent data, the record at the North Branch Park River was reviewed. **Figure 13** has been prepared to summarize the review with respect to annual peak streamflows.



Trend Hypothesis Test

Test	P-Value
t-Test	0.32042
Mann-Kendall	0.86497
Spearman Rank-Order	0.82385

Figure 13: North Branch Park River at Hartford CT 1936-2022 – Trend Analysis 1936-1984 and Nonstationarity Test Results and Trend Analysis 1936-2020

The North Branch record of annual peak streamflows is reliable for the years 1936 to 1986. It indicates one distribution-based nonstationarity detection in 1973 with no supporting nonstationarity detections. The 1973 date indicated falls in the years 1956-1981 when improvements were in progress on the Hartford Levee System.

The associated segment statistics indicated a mean annual peak value of 1,500 cfs, with a standard deviation of 1,400 cfs. Trend analysis over the period 1936-1986 led to t-test p-value 0.917, Mann-Kendall test p-value 0.314 and Spearman Rank-Order p-value 0.290. That these values exceeded 0.05 indicated that there was no trend detected at the 95% significance level.

The same trend analysis was performed for the years 1936-2020, as included in the top right quadrant of Figure 10, with similar results (p-values 0.320, 0.865, and 0.824 indicating no trend at the 95% significance level). There were no further nonstationarities detected in the longer time period, although the large gaps after 1986 suggest that more recent inferences should be used with caution.

Neither the Park River nor its tributary the North Branch Park River could be used with confidence for data more recent than 1986, due to extensive gaps in the available data set (not due to detections of nonstationarities in the available data). The lack of any strong trend (trend detections with significance tests greater than 0.05) leads to a reasonable assumption of peak annual flows neither increasing nor decreasing over time in their respective most recent “long” (over 10 years with no nonstationarity detections) segments. These results support the assertion of a stationary data set after 1986.

The mean annual peak values of 3,000 cfs for the Park River (drainage area 72.5 square miles) and 1,500 cfs for the North Branch Park River (drainage area 26.8 square miles) are consistent with the summary:

Park River Basin Mean Annual Peak Flow (cfs)=123 x [Drainage Area (sq mi)]^0.75)

The exponent 0.75 for a median annual peak flow, cited in the 2011 FEMA Flood Insurance Study for Hartford County, is consistent with a storm event. For a more typical normal (not storm) flow, the exponent would be expected to be closer to 1.0 (flow in direct proportion to drainage area).

Although StreamStats does develop estimates for flows with smaller exceedance probabilities (up to the 0.2% AEP event or 500-year storm), the StreamStats values are of limited value in the more urban Hartford and East Hartford settings. The median annual peak flow is often used to estimate likely channel capacity, but for storm drainage or any other utility lines, the systems are likely to commingle during larger storms. The reader is referred to Appendix 2-B2 (Interior Drainage) of the main report for assessments of flows at the salient pump stations.

Based on observations at the site, the Park River annual peak flow does not appear to be changing over time.

Hockanum River – Nonstationarity Detection and Trend Analyses

In East Hartford, the Hockanum River has been monitored at USGS gaging station 01192500, rendering a verified record from 1920 to 2022, with a gap in the record from 1922 to 1928. The gage has a contributing basin area of 73.4 square miles. It is located approximately five miles upstream of the pump station.

Figure 14: shows a summary of the CHAT’s nonstationarity and trend analyses for the Hockanum River.

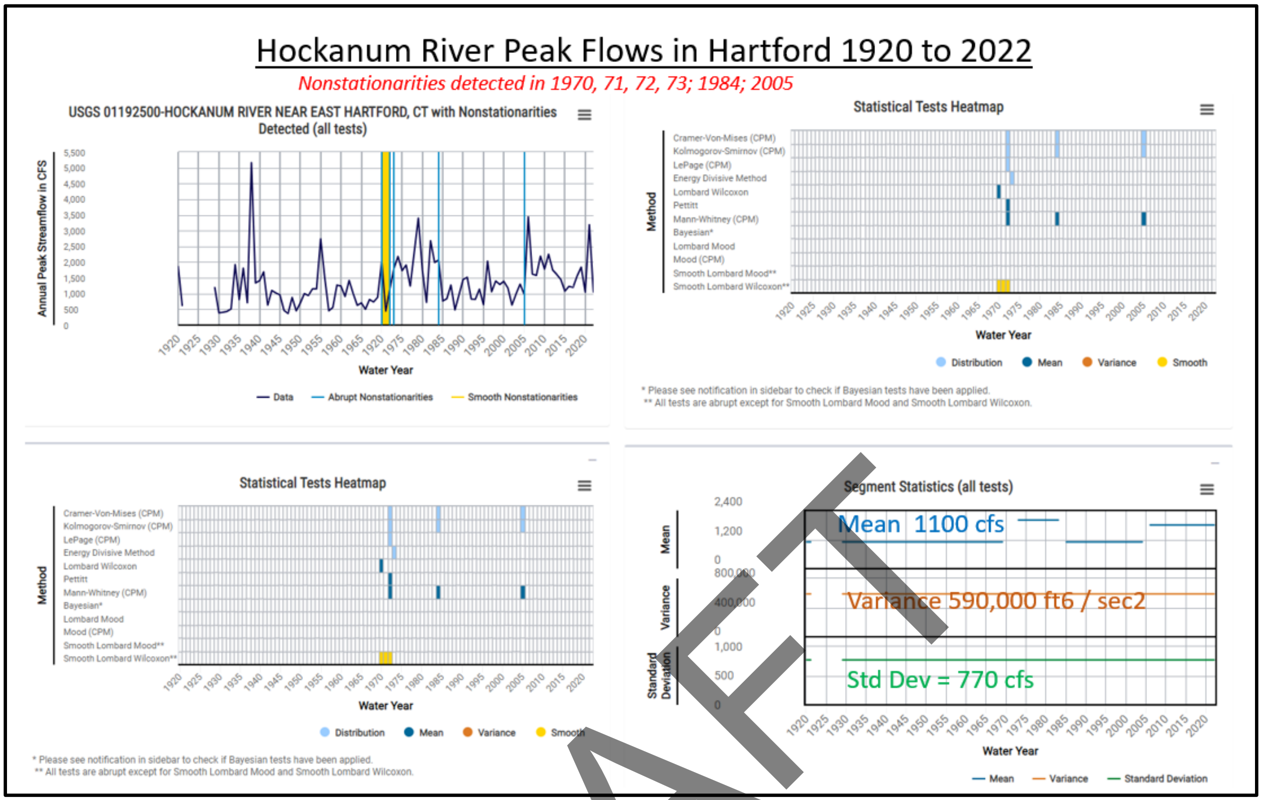
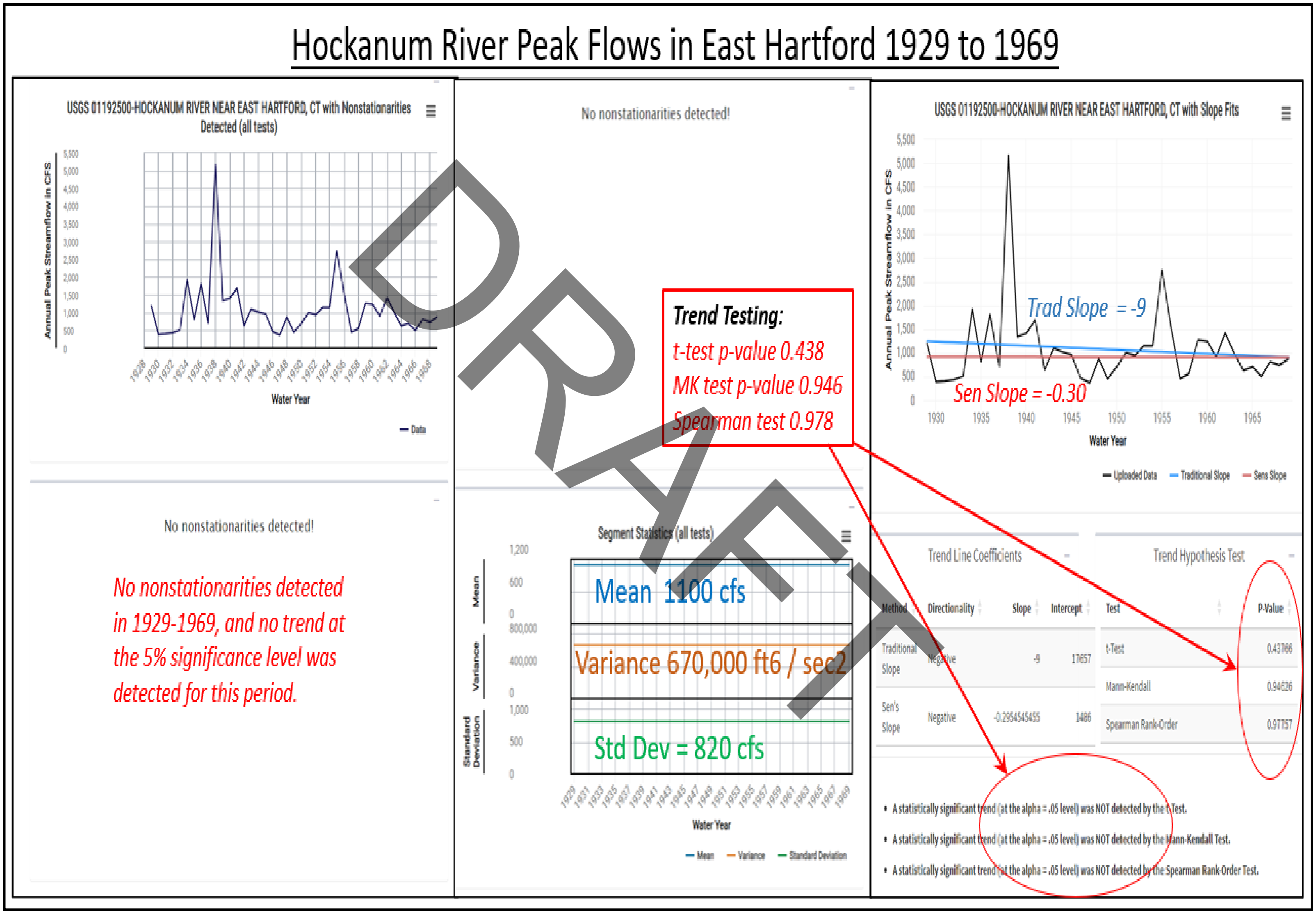


Figure 14: Hockanum River Peak Annual Flows – Trend Analysis and Segment Statistics 1920 to 2022

Given the gap in the record 1922-1928, and the multiple detections of nonstationarities in 1970-72, 1984, and 2005, the parameters highlighted in the lower right quadrant of the figure were limited to the most defensible segment of the analysis 1929 to 1969.

Figure 15 shows a summary of the CHAT's nonstationarity and trend analyses for the Hockanum River, for this smaller 41-year segment of the record.



Hockanum River Peak Flows in East Hartford 1929 to 1969

No nonstationarities detected!

No nonstationarities detected!

No nonstationarities detected in 1929-1969, and no trend at the 5% significance level was detected for this period.

Trend Testing:
t-test p-value 0.438
MK test p-value 0.946
Spearman test 0.978

Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Negative	-9	17657
Sen's Slope	Negative	-0.2954545455	1486

Trend Hypothesis Test

Test	P-Value
t-Test	0.43766
Mann-Kendall	0.94626
Spearman Rank-Order	0.97757

- A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.
- A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.
- A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.

Figure 15: Hockanum River Peak Annual Flows – Trend Analysis and Segment Statistics 1929 to 1969

In summary, based on observations at the site, the Hockanum River annual peak flow does not appear to be changing over time.

In East Hartford, the pump station of particular concern is at Meadow Hill. This was designed in 1941 with an assumed contributing basin area of 1,100 acres or 1.72 square miles. The station discharges to the Hockanum River, immediately upstream of its confluence with the Connecticut River. Elevations at the Hockanum gage have been reviewed in concert with the record of flows in the Connecticut River upstream of Hartford (USGS gage 01184000) at Thompsonville, CT. There is a strong correlation between these data streams, as outlined in Appendix 2-B2. The annual peak flows at Thompsonville have been falling slightly over time, although there is limited statistical evidence associated with the finding. The record in Hartford is also one of gently reducing flows over time, as seen in **Figure 20**.

Connecticut River Flows – Nonstationarity and Trend Analyses

The Connecticut River is monitored in Hartford at USGS gaging station 01190070. The drainage basin area is 10,487 square miles. The USACE New England District operates 14 dams in the Connecticut River Basin, with the primary purpose of flood risk management. They were completed from 1941 to 1969 and have a combined contributing drainage area of 1,721 square miles (16% of the drainage basin area of the USGS gage of 10,487 square miles). The dams' construction, any test pools or renovations would provide a reason for observed regulation, and their FRM purpose reduces storm flows to bank flows except when the reservoir capacity exceeds 5.3 to 8.3 inches of storage (the amount varies from project to project). The introduction of the regulation at each dam therefore provides a potential nonstationarity in the flow record.

The USACE FRM dams are not the only FRM dams in the basin. Dams constructed for other purposes (such as water supply, hydroelectric dams, or recreation) also regulate flows. The USACE FRM dams, with a summary of construction dates FRM volumes, are listed in **Table 1**.

Table 1: USACE FRM Dams in the Connecticut River Basin Upstream of Hartford and East Hartford Connecticut

Dam	Year Construction Completed	FRM Storage		Basin Area (square miles)
		Acre-Feet	Inches	
Birch Hill Dam	1941	49,900	5.34	175
Knightville Dam	1941	49,000	5.69	162
Surry Mountain Dam	1941	31,694	5.94	100
Tully Lake Dam	1949	21,500	8.06	50
Union Village Dam	1950	38,000	5.65	126

Dam	Year Construction Completed	FRM Storage		Basin Area (square miles)
		Acre-Feet	Inches	
Barre Falls Dam	1958	24,000	8.2	55
Otter Brook Lake Dam	1958	17,600	7.0	47
North Springfield Dam	1960	50,000	5.93	158
Ball Mountain Dam	1961	54,450	5.92	172
North Hartland Dam	1961	68,750	5.86	220
Townshend Dam	1961	32,900	5.81	278
Mad River Dam*	1963	9,510	10.0	18.2
Littleville Dam	1965	23,000	8.32	52
Conant Brook Dam	1966	3,740	9.0	7.8
Colebrook Dam	1969	50,200	7.98	118
Sucker Brook Dam*	1971	1,480	8.1	3.41
* FRM Dams constructed by USACE but operated by the State of Connecticut				

The Connecticut River flow record at Hartford and East Hartford includes USGS-validated observations in 1683, 1692, 1801, 1828, 1838-1839, 1841, and the more systematic record 1843 to 2020.

There were positive detects of nonstationarities in average annual peak value in 1959 and of distribution in 1961. These detections were made within a five-year span and so the results should be taken as a positive detection. This result is shown in **Figure 16**. The detection was made as three large FRM reservoirs were reaching construction-completion (Ball Mountain, North Hartland, and Townshend Dams); the then-recent (1955) record storms and subsequent drought in the mid-1960s helped to set up this nonstationarity detection in 1959-61.

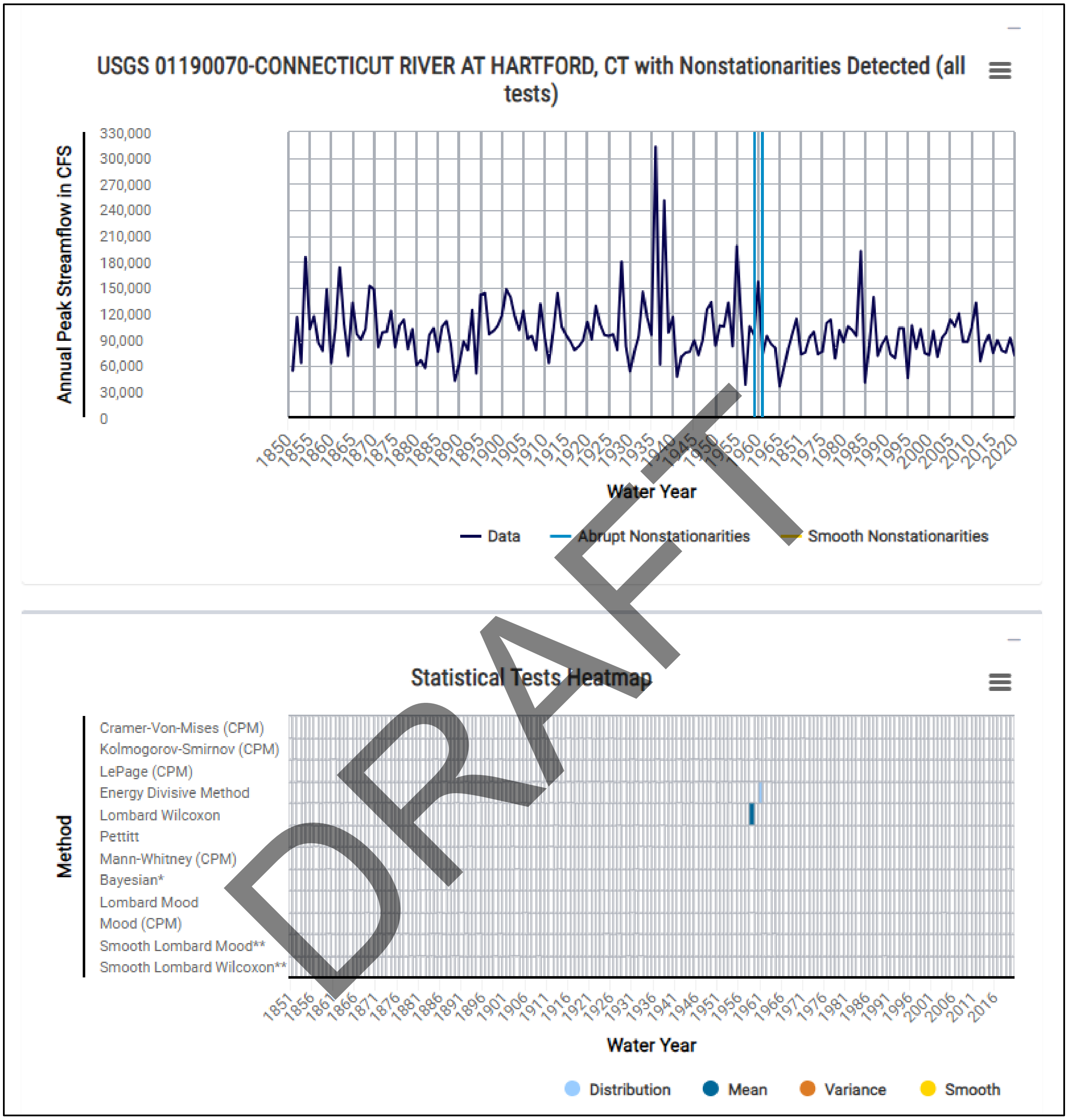


Figure 16: Connecticut River Observed Annual Peak Flows at Hartford USGS Gage and Nonstationarity Detection

The record of peak flows through 1958 indicated no nonstationarities and an average annual peak value of 100,000 cfs. This result is shown in **Figure 17**.

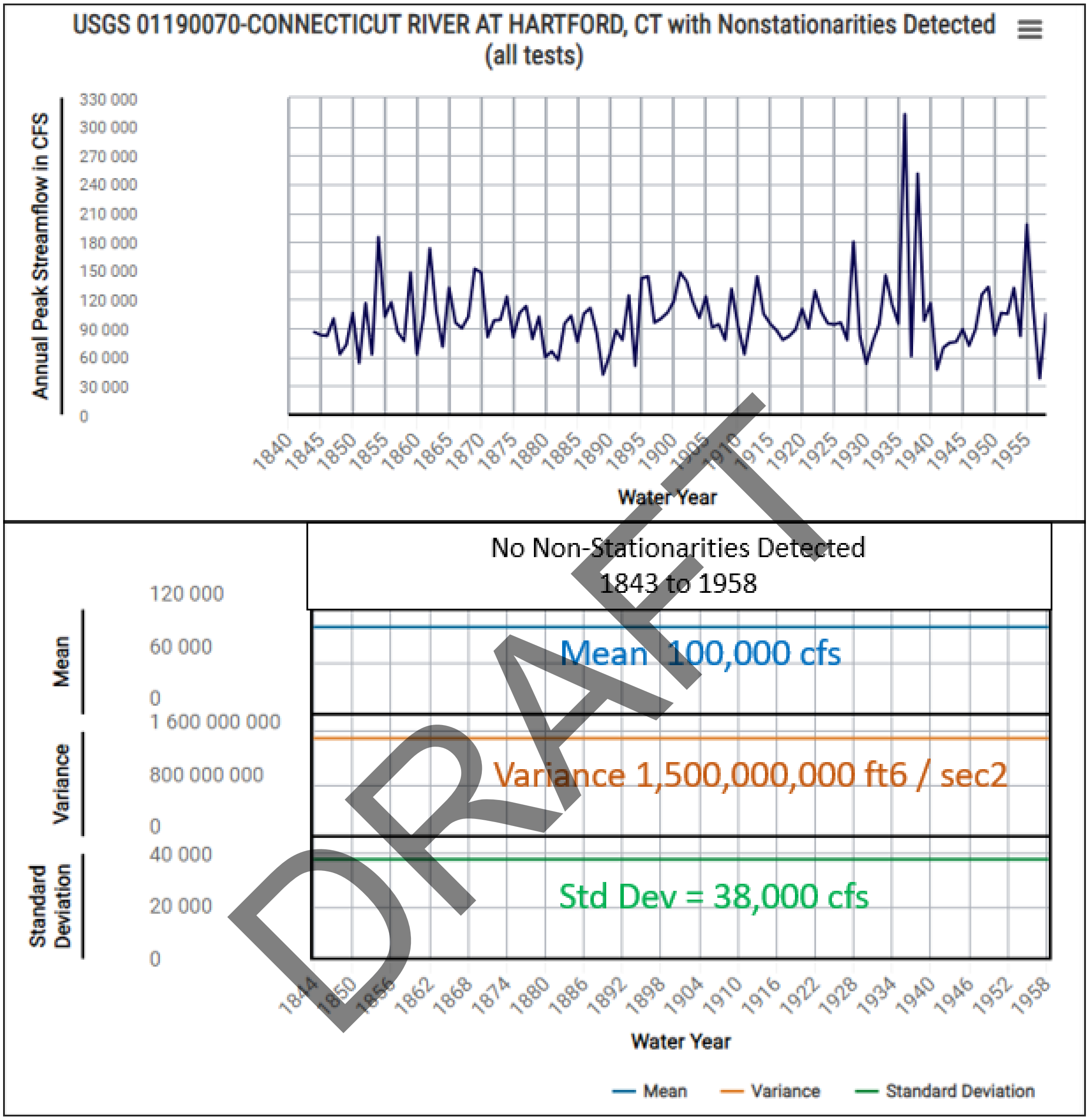


Figure 17: Connecticut River Peak Flows at Hartford, CT from 1843 to 1958. No nonstationarities detected; mean 100,000 cfs, Variance 1,500,000,000 ft^6 s^{-2} for this segment of the record.

After 1969, there was a period with no nonstationarities detected through 2020. The annual average peak was 91,000 cfs. This result is shown in **Figure 18**.

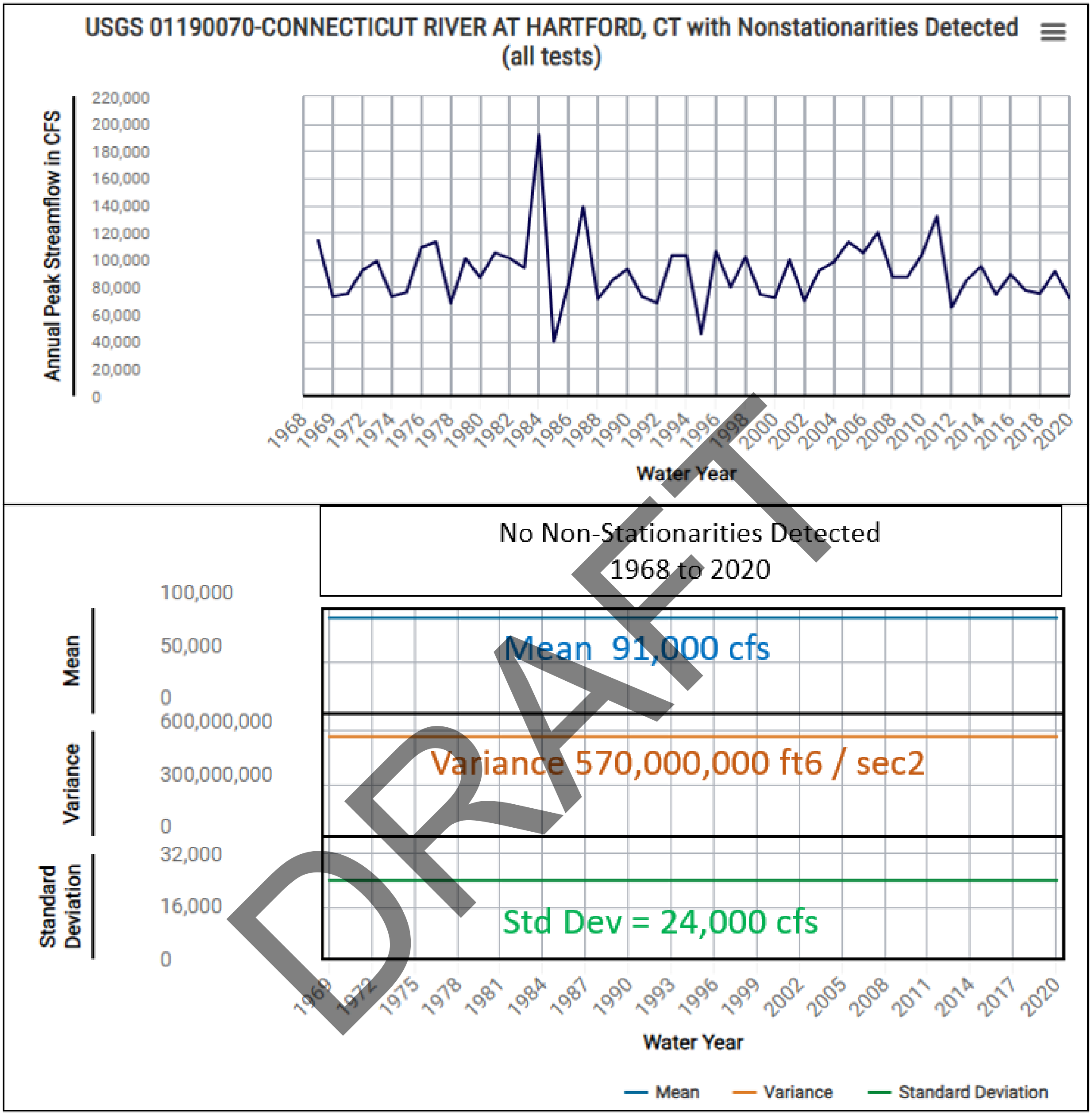


Figure 18: Connecticut River Peak Flows at Hartford, CT from 1968 to 2020. No nonstationarities detected; mean 91,000 cfs, Variance 570,000,000 $ft^6 s^{-2}$ for this segment of the record.

The lower average annual peak flow of 91,000 cfs in the period 1969 to 2020 (lower than in 1843 to 1958) appears at least in part to be a result of the increasing regulation at USACE FRM dams during the twentieth century.

In summary, based on observations at the site, the Connecticut River annual peak flow does appear to have decreased over time, possibly as a result of the network of FRM dams in the basin, but longer-term flux may also have affected the result. In the period since the last USACE FRM dam was completed, there have been no nonstationarities detected and there has been no statistically significant trend in the annual peaks.

Connecticut River Water Levels – Nonstationarity and Trend Analyses

For purposes of draining or pumping from the Hartford or East Hartford municipalities to the Connecticut River, the water level at the Connecticut River tailwater is a preferred parameter (rather than flow in the Connecticut River). The validated stage record runs from 2006 to 2020, with 2 missing one-month data points. The record of Connecticut River stages was found to have nonstationarities detected: in 2012 for distribution (not supported by other tests); there was a more substantial "stronger" detection in 2016 (5 tests for distribution, 2 tests for mean value, 3 tests for variance); and one test for mean value in 2020.

Ignoring the shorter period after 2016, the period was re-analyzed for nonstationarities 2006 to 2015. This indicated a nonstationarity in 2012, in that the distribution and mean value appeared to have changed (1 test for mean; 4 tests showed changing distribution), although the variance before 2012, and the variance after 2012, were equal. A summary of water levels at the Connecticut River USGS gage in East Hartford is shown in **Figure 19**.

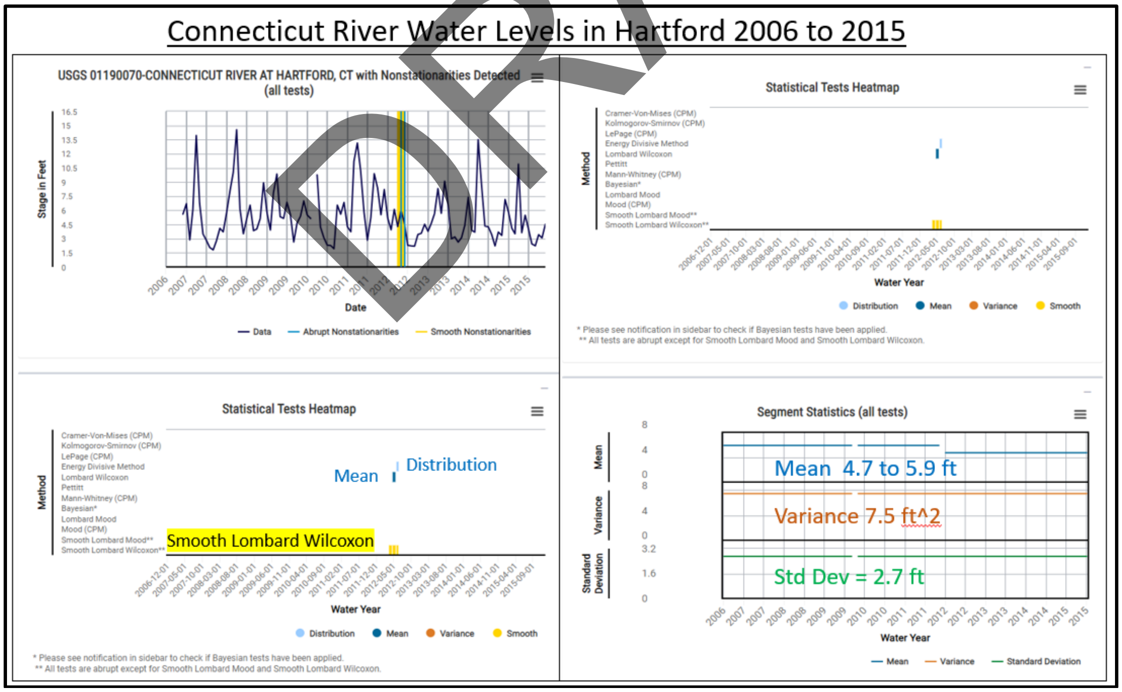
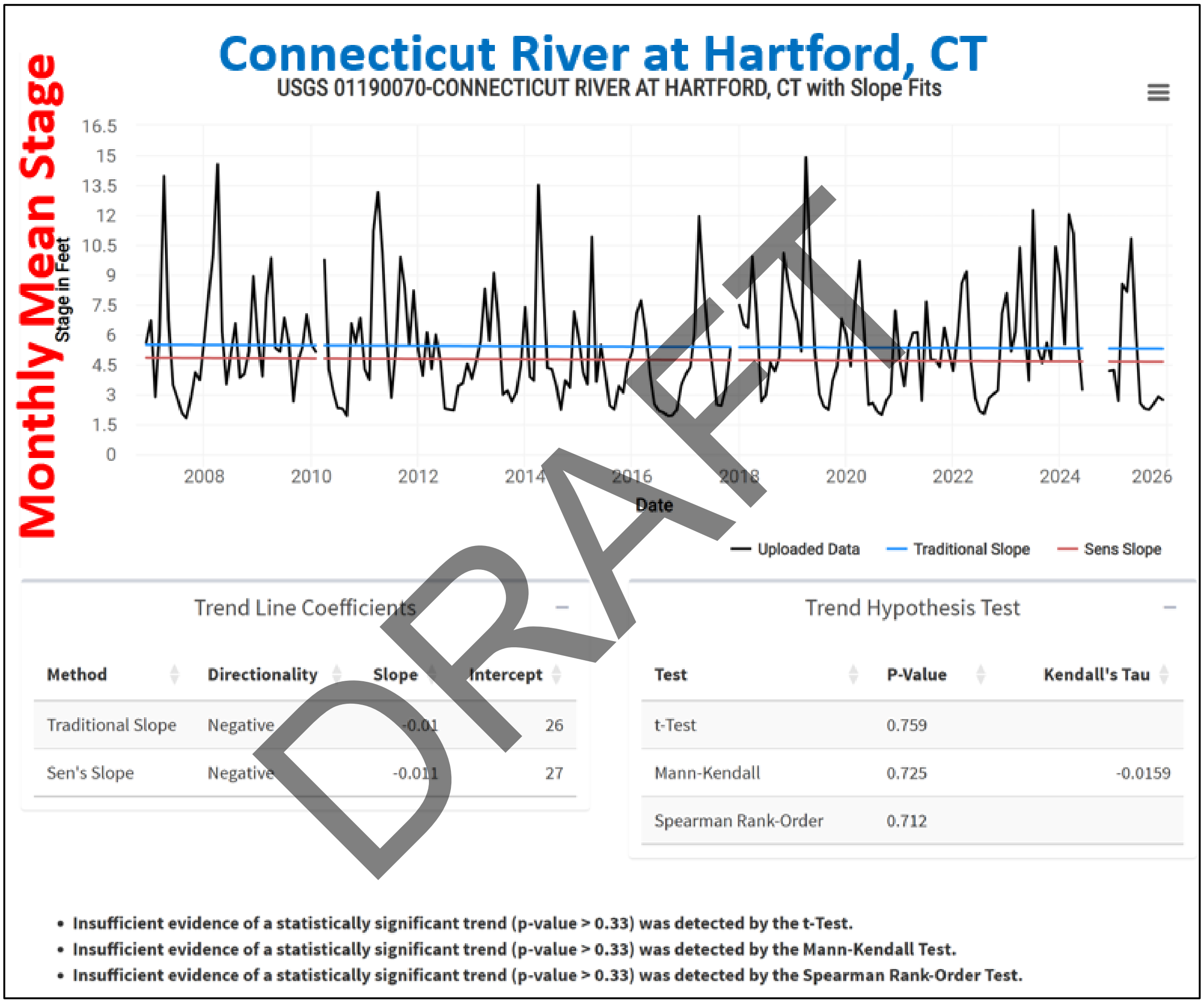


Figure 19: Connecticut River Stages at Hartford, CT from 2006 to 2015. Nonstationarities detected in 2012; mean 5.9 ft reducing to 4.7 ft; variance 7.5 ft^2 during this period.

The period 2006 to 2022 was analyzed to generate a trace for the monthly average stages. This was, admittedly, a short period, but the intention was to use available information to generate a useful determination of how the water levels might be changing. The recent trend record is summarized in **Figure 20**.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Negative	-0.01	26
Sen's Slope	Negative	-0.011	27

Trend Hypothesis Test

Test	P-Value	Kendall's Tau
t-Test	0.759	
Mann-Kendall	0.725	-0.0159
Spearman Rank-Order	0.712	

- **Insufficient evidence of a statistically significant trend (p-value > 0.33) was detected by the t-Test.**
- **Insufficient evidence of a statistically significant trend (p-value > 0.33) was detected by the Mann-Kendall Test.**
- **Insufficient evidence of a statistically significant trend (p-value > 0.33) was detected by the Spearman Rank-Order Test.**

Figure 20: Connecticut River at Hartford CT: Monthly Water Stage 2006-2025. No trend detected at 95% confidence level.

Although there was a slight downward slope in the regression curves for monthly average stages, the trend was not statistically significant.

Review of **Figure 20** leads to a stage of 5.3 ft as a current (end of 2025) average value of tailwater.

Actual RMS regression stages ranged from 5.60 ft on 12/1/2006 to 5.29 ft on 12/1/2025. Given that the trend detected is not statistically significant, the selection of a static average stage of 5.3 feet is sensible. As shown in **Figure 21**, there is some response to tides, but the tidal influence is small, and is completely lost when there is a large inland storm. The non-storm water levels are seen in July 2024 to be at gage height 2 ft to 4 ft.

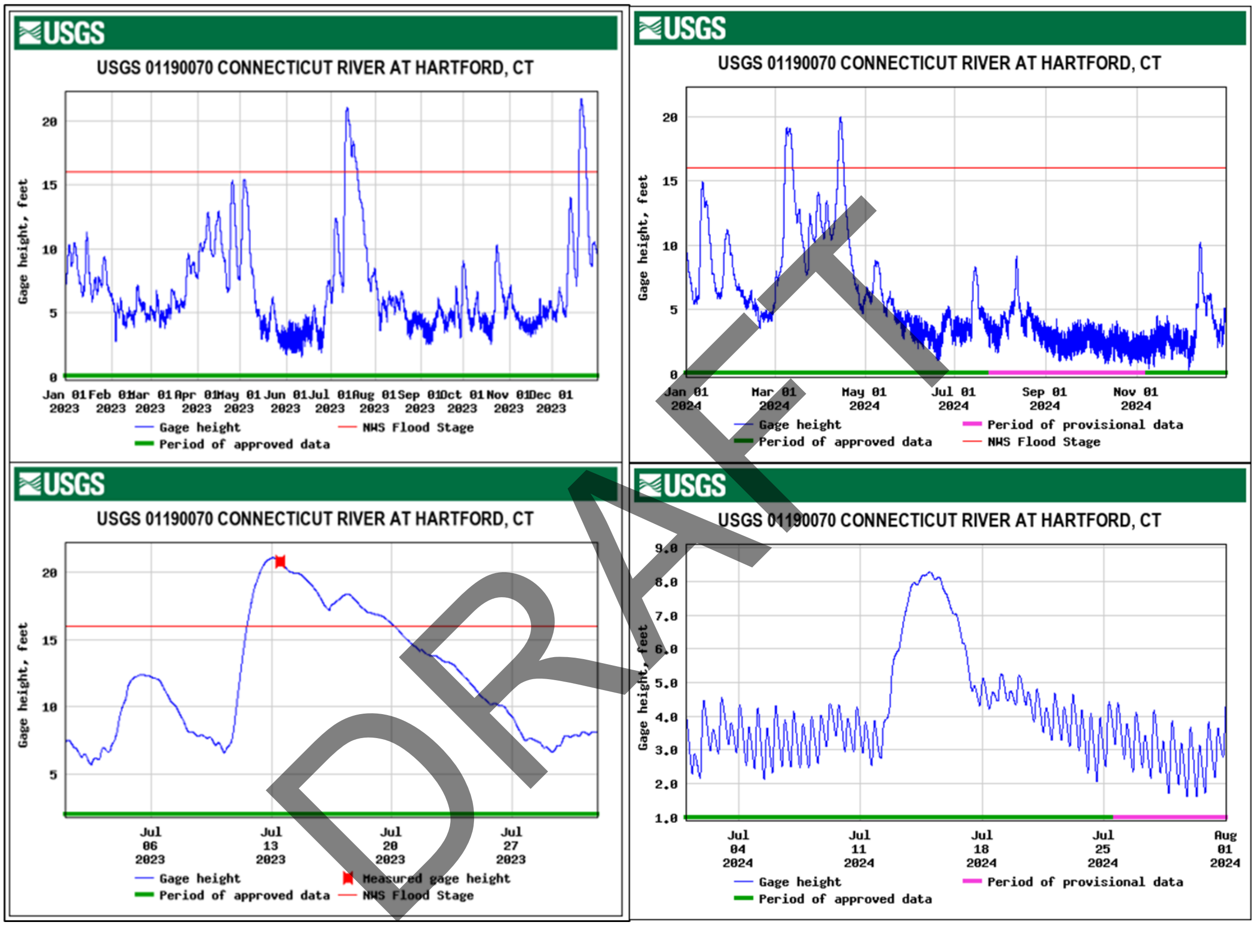


Figure 21: Connecticut River at Hartford, CT – Gage Water Levels in 2023 and 2024 (note minimal tidal influence during July 2023 period (stormy month) and typical tidal influence below 5-ft elevation during July 2024 – more typical pattern)

Given the potential range of tailwater, from low water on the Connecticut River to higher water on the Connecticut, a coincident frequency analysis was prepared in Appendix 2-B2. Results were specific to the various pump stations, with flows batched for gravity drainage, and for two different indexed ranges of required pumping against the tailwater. Greater detail is found in **Appendix 2-B2.**

Review of Inflow Summaries at Hartford/East Hartford

City of Hartford: Park River Flows: An annual average peak flow of 3,000 can be assigned, based on the available record. The peak flow is consistent with the smaller peak flow noted at the North Branch Park River. It is noted that these records are based on gage records through 1986. StreamStats review indicated smaller peak flow, but the StreamStats tool was based on regional regressions and could not take into account the level of urbanization in the basin.

Town of East Hartford: Hockanum River Flows: A mean value for the annual peak flow of 1,100 cfs has been inferred from the available information, with an acknowledgment that there have been gaps and nonstationarities in the record after 1970. The peaks appeared to be falling over time, but the trend was not found to be significant.

Connecticut River Flows: Following the introduction of 14 FRM reservoirs in the Connecticut River Basin upstream of Hartford/ East Hartford, the Connecticut River annual peak flow appears to be, on average, 91,000 cfs. Information from 1968 to 2020 (post-dam-construction) was used to develop the assessment. Review of trends did not detect a significant ongoing trend in the 91,000 cfs flow.

Connecticut River Water Levels: The water level has been seen to be falling over time, but the trend detected was not found to be significant. A value of 6.0 feet can be assumed.

Connecticut River and Tidal Influence: In absence of a major inland storm event, the water level at Hartford is sensitive to sea-level fluctuations. The SLAT tool has been used for the record at New London NOAA Tide Gauge 8461490 in New London CT to confirm a recent rise in coastal water levels. The SLAT projected continued rising coastal water levels that, with moderate storm surge (2-year to 10-year coastal storms), would reach the 6-ft level at Hartford, possibly as soon as 2030 or as late as 2100, depending on which projected sea-level-change assumptions are considered. This quick analysis does not allow for the drop in water levels along the Connecticut River from Hartford to the coast. Assuming that the system is designed for a 50-year design life, the expected tidal levels of 2075 assuming the intermediate rate of expected relative sea-level rise could be seen as early as 2045.

Comprehensive Hydrology Assessment Tool

The USACE Comprehensive Hydrology Assessment Tool (CHAT) can be used to assess projected changes to streamflow in the watershed. Projections are at the spatial scale of a HUC-8 watershed, with flows generated using the U.S. Bureau of Reclamation (USBR) Variable Infiltration Capacity (VIC) model from temperature and precipitation data statistically downscaled from GCMs using the Bias Corrected, Spatially Disaggregated (BCSD) method. The USBR VIC model is set up to simulate unregulated basin conditions. The Hartford/East Hartford Rehabilitation project is in HUC 0108 (in the Lower Connecticut basin, stream segment 01081148). The City of Hartford is, however, close to the boundary between the Lower Connecticut and the Middle Connecticut, and there are several defined river segments in the city, differentiating the main Park River and its North and South Branches.

Connecticut River Hydrometeorology

Figure 22, **Figure 23**, and **Figure 24** show the mean of the annual (water year based) time series derived from 32 CMIP5 Global Circulation Models (GCMs). The figures also display the inter-model spread. In the figures the bold line represents the inter-model mean and the shaded area represents the inter-model range (the inter-model minimum to the inter-model maximum). For both the historic period and the future period, hydroclimatic outputs are generated using simulated GCM outputs, thus CHAT output should not be directly compared to observations. The range of data is indicative of the uncertainty associated with projected hydrologic trends.

The selected output parameters were chosen to support the project objectives of a more "typical" outflow (maximum value of the monthly mean or the average 1-day streamflow).

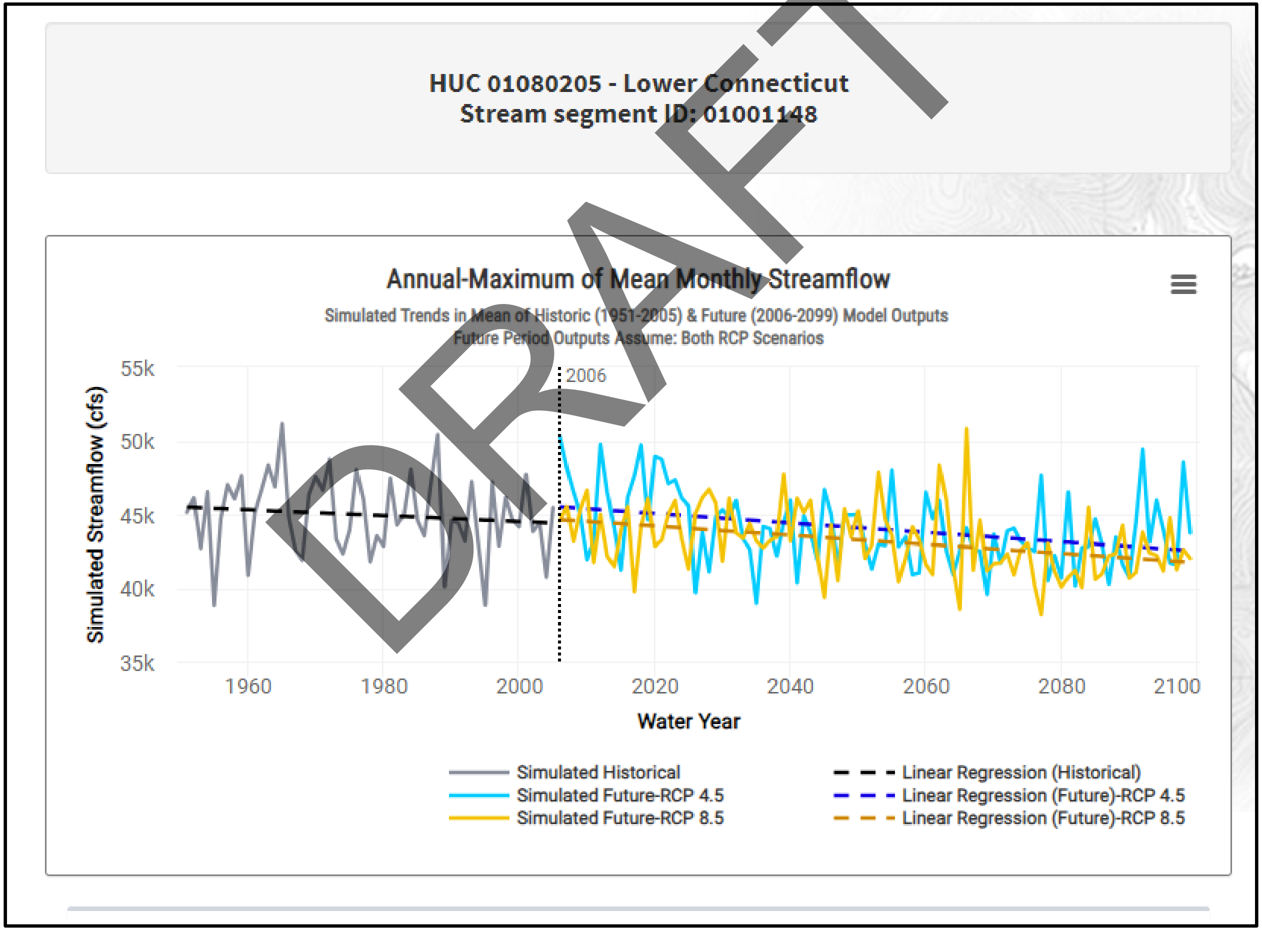


Figure 22: Range of 32 Projected Hydrology Model Outputs for Lower Connecticut (HUC 01080205), Stream Segment 01001148: Annual Maximum of Mean Monthly Streamflow. Projected Future Gradients -32.1 cfs/yr (RCP 4.5) or -31.2 cfs/yr (RCP 8.5).

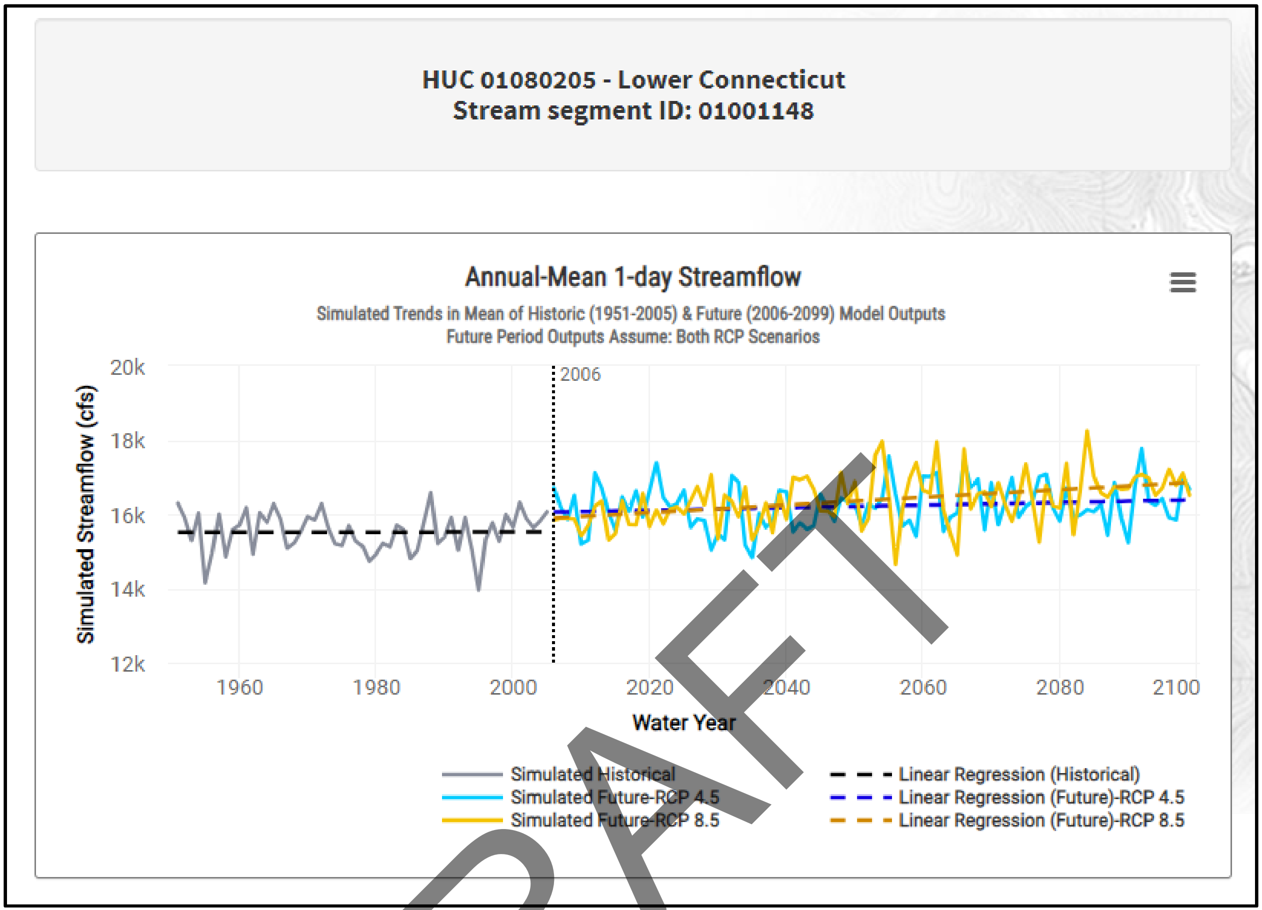


Figure 23: Range of 32 Projected Hydrology Model Outputs for Lower Connecticut (HUC 01080205), Stream Segment 01001148: Annual Mean 1-day Streamflow. Projected Future Gradients 3.47 cfs/yr (RCP 4.5) or 10.3 cfs/yr (RCP 8.5).

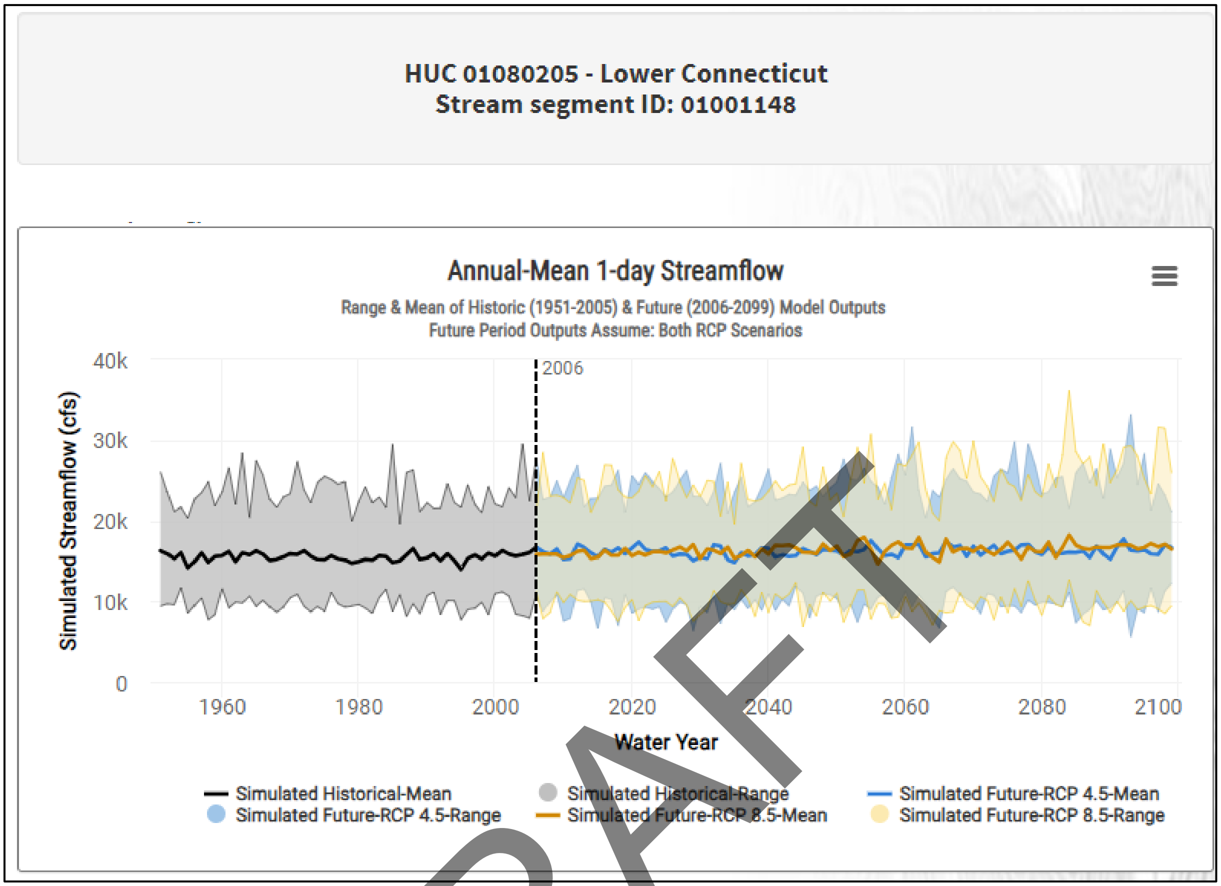


Figure 24: Range of 32 Projected Hydrology Model Outputs for Lower Connecticut (HUC 01080205), Stream Segment 01001148: Annual Mean 1-day Streamflow (includes color-coding of the projected RCP 4.5 and RCP 8.5 ranges)

It was noted that for these cases the flow parameter is forecast to have a non-zero trend, with p-values smaller than 0.001 for either the RCP 4.5 or the RCP 8.5 case (statistical certainty of the direction of the slope).

The CHAT provides streamflow and precipitation outputs analyzed comparatively by describing simulated changes in monthly and annual streamflow and precipitation between a baseline epoch (1976 to 2005) and two future epochs: 2035 to 2064 (mid-century) and 2075 to 2099 (end of century). The tool presents epoch-based monthly and annual change in streamflow and precipitation using boxplot visualizations. The monthly boxplots provide insight into the seasonality of changes in streamflow and precipitation over time.

Figure 25 and **Figure 26** present changes in epoch mean of simulated monthly mean streamflow for stream segment 01001148 in the Lower Connecticut watershed (HUC 01080205). For the stream segment of the Connecticut River analyzed, it appears that for both emission scenarios and for both the mid-century and end-century epochs, winter flows (December through March) are increasing most substantially. There are projected reductions in flow in May and June, with smaller changes projected for the months April and July-through-November. When used to evaluate the change in the epoch mean of simulated annual mean streamflow, the CHAT calculates the median change from the base Epoch (1976 to 2005) to the mid-century epoch (2035 to 2064) is 7 percent under the RCP 8.5 scenario. By the end-century epoch (2070 to 2099), the change relative to the base period is still 7 percent under the RCP 8.5 scenario, although the range of the projections extends upwards to include an estimated maximum of 28 percent.

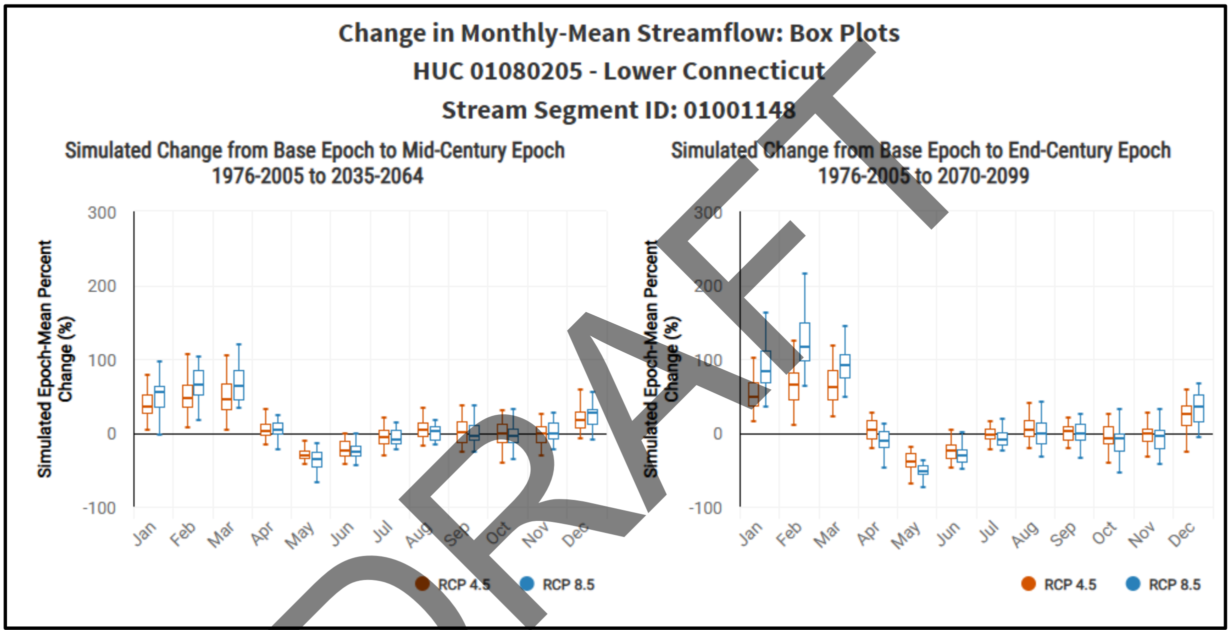


Figure 25: Change in epoch mean of simulated monthly mean streamflow – HUC 01080205 – Stream Segment 01001148 Connecticut River (river reach in Hartford CT/East Hartford CT).

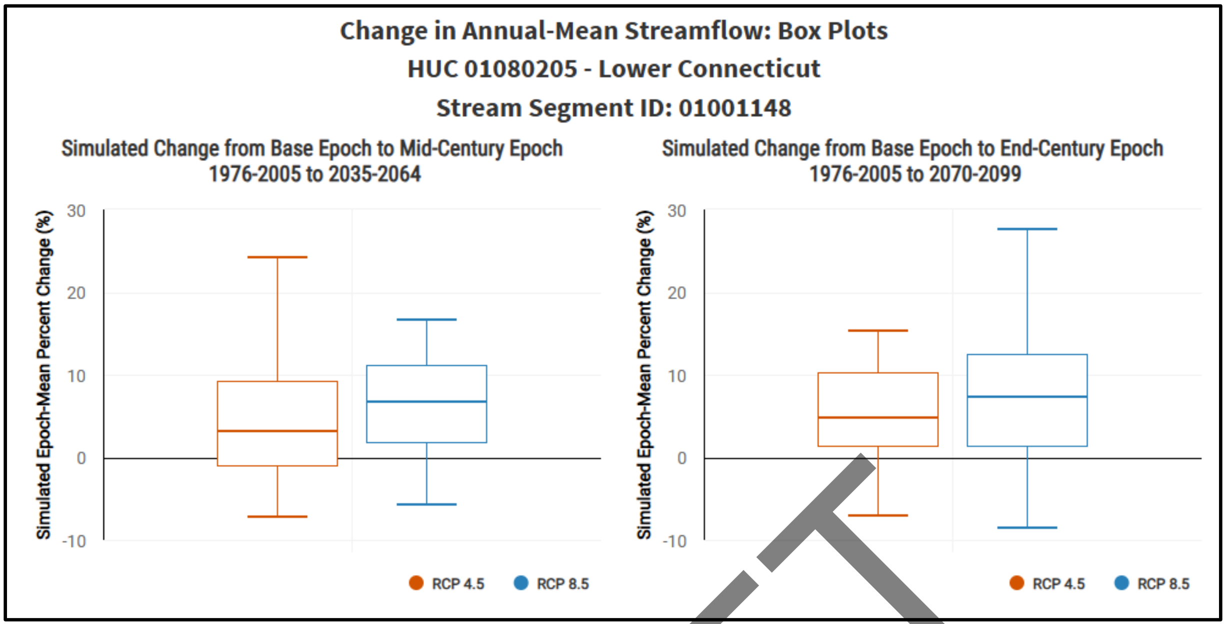


Figure 26: Change in epoch mean of simulated annual mean streamflow – HUC 01080205 – Stream Segment 01001148 Connecticut River (river reach in Hartford CT/East Hartford CT).

Figure 27 and **Figure 28** present changes in epoch mean of simulated monthly accumulated precipitation for the Connecticut River watershed (HUC01080205) and peak 1-day precipitation estimated for the same time periods. Results for both the mid-century epoch (2035 to 2064) and the end-century epoch (2070 to 2099) indicate an increase in precipitation for the months November through March and in August. Changes to precipitation in the months April to July and September-October do not appear as substantial, although the projections for September-October include high upper tails. The annual maximum 1-day precipitation was examined for the same river reach. The CHAT summarized the median change from the base epoch (1976 to 2005) to the mid-century epoch (2035 to 2064) as 0 to 0.30 inch (interquartile range (IQ Range), median 0.1 inch) for RCP 4.5, and 0.1 to 0.35 inch for RCP 8.5 (median 0.25 inch). Corresponding results for comparison with the later end-of-century results were 0.1 to 0.35 inch (median 0.2 inch) for RCP 4.5, and 0.30 to 0.55 inch (median 0.4 inch).

When used to evaluate the change in epoch mean of simulated annual maximum 1-day precipitation, the CHAT calculates the median change from the base epoch (1976 to 2005) to the mid-century epoch (2035 to 2064) is 4.5 inches for RCP 4.5 (IQ Range 3.5 to 5.5 inch) and 6.0 inches for RCP 8.5 (IQ range 5 to 7 inch). By the end-of-century epoch (2070 to 2099), the change relative to the base period is 6 inches for RCP 4.5 (IQ Range 5 to 7), and 11 inches (IQ range 8.5 to 12) for RCP 8.5.

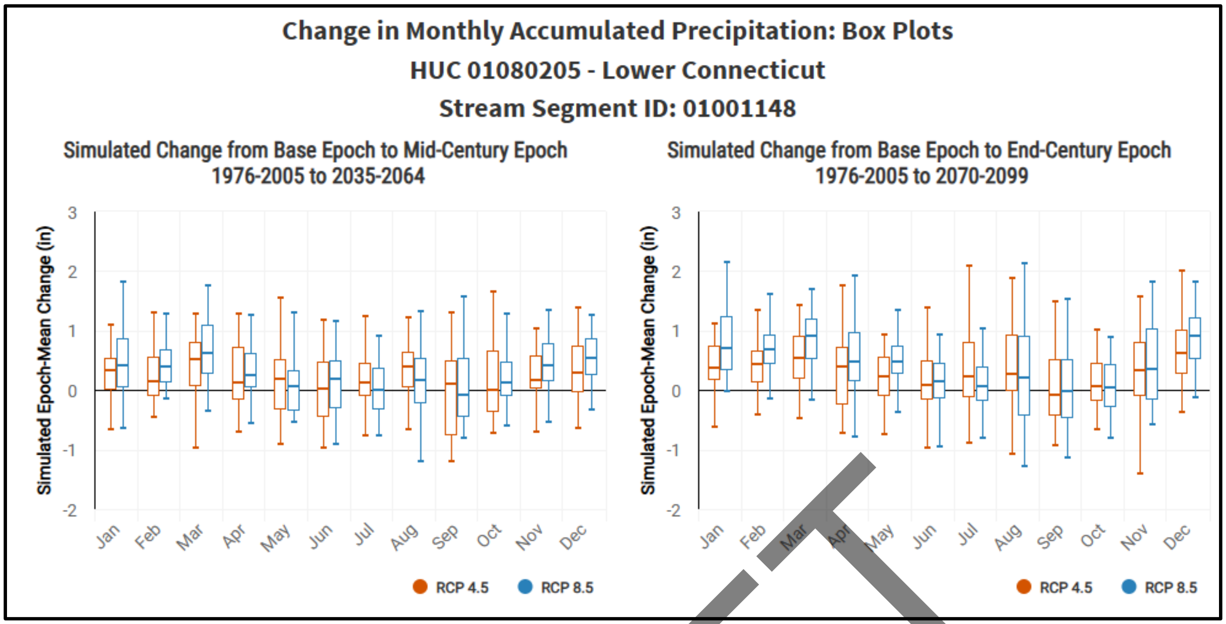


Figure 27: Change in epoch mean of simulated monthly accumulated precipitation – HUC 01080205 – Lower Connecticut – stream segment ID: 01001148.

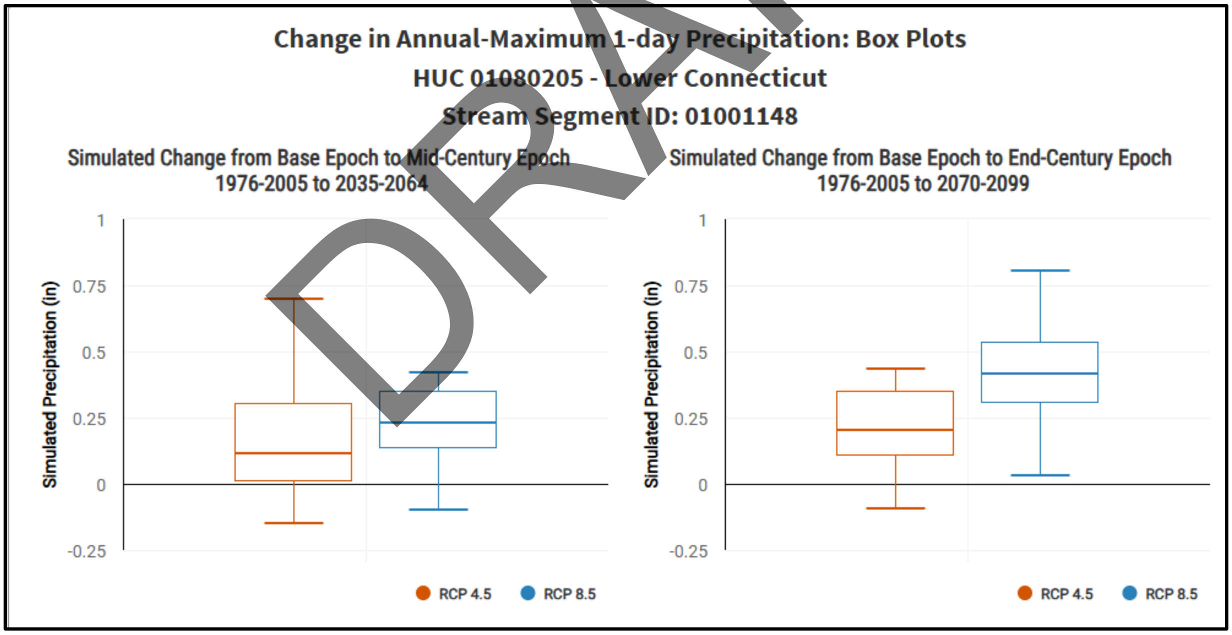


Figure 28: Change in epoch mean of simulated annual maximum 1-day precipitation – HUC 01001148 – Lower Connecticut.

The briefer 1-day maximum precipitation result was selected from the CHAT options for the annual summary because of the likely need to respond to shorter-term storms over smaller areas that require pumping and/or storage in the protected regions on the "land-side" of levees and floodwalls.

The annual maximum of mean monthly Connecticut River streamflow value (a mild high-flow parameter) is projected to fall over time, while the annual mean flow is projected to rise over the same period.

Hartford and the Park River Hydrometeorology

The defined river segments in the CHAT correspond to Park River, the North Branch of the Park River, and the South Branch of the Park River. The combined segment "Park River" has been analyzed in this section.

The segment is in HUC 01080205 (Lower Connecticut), Stream Segment 01001424. For this segment, the projected annual mean 1-day streamflow is shown in **Figure 29**.

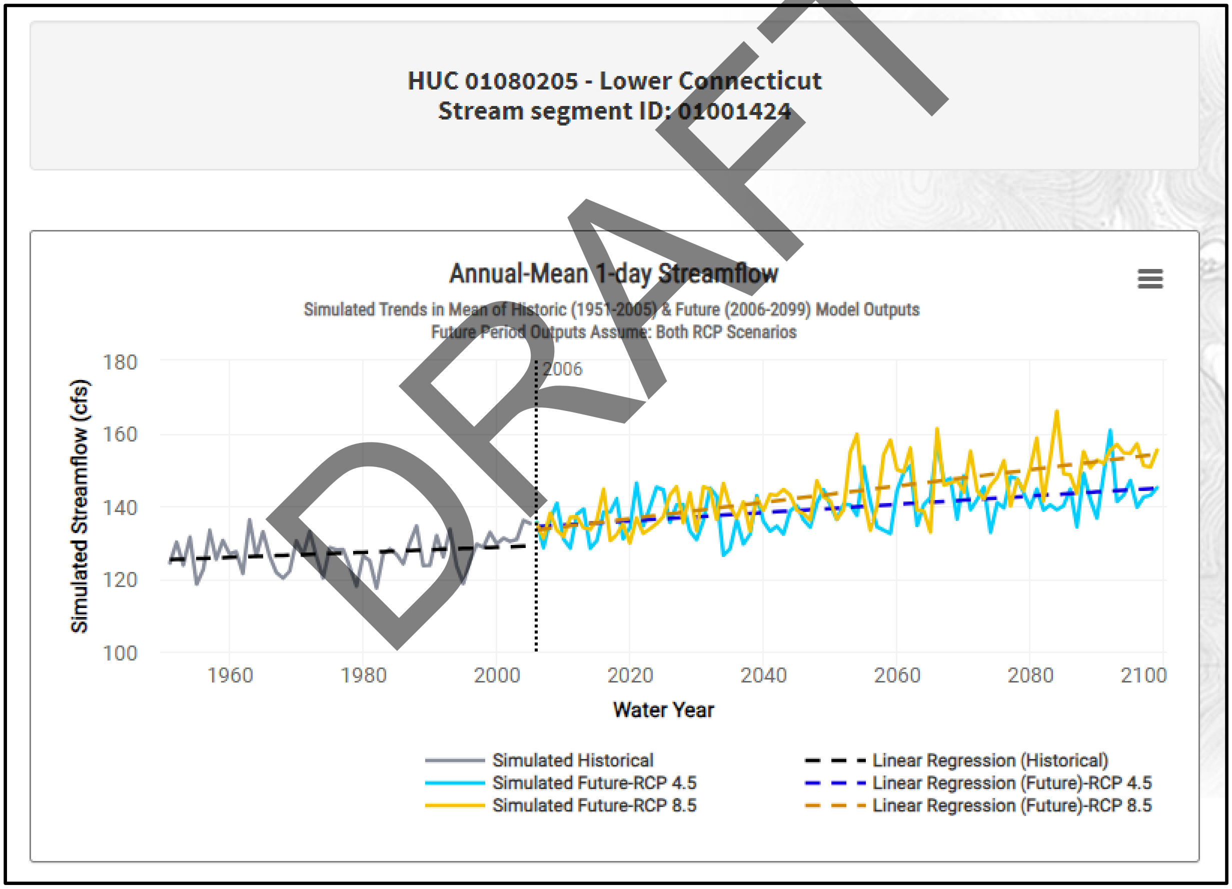


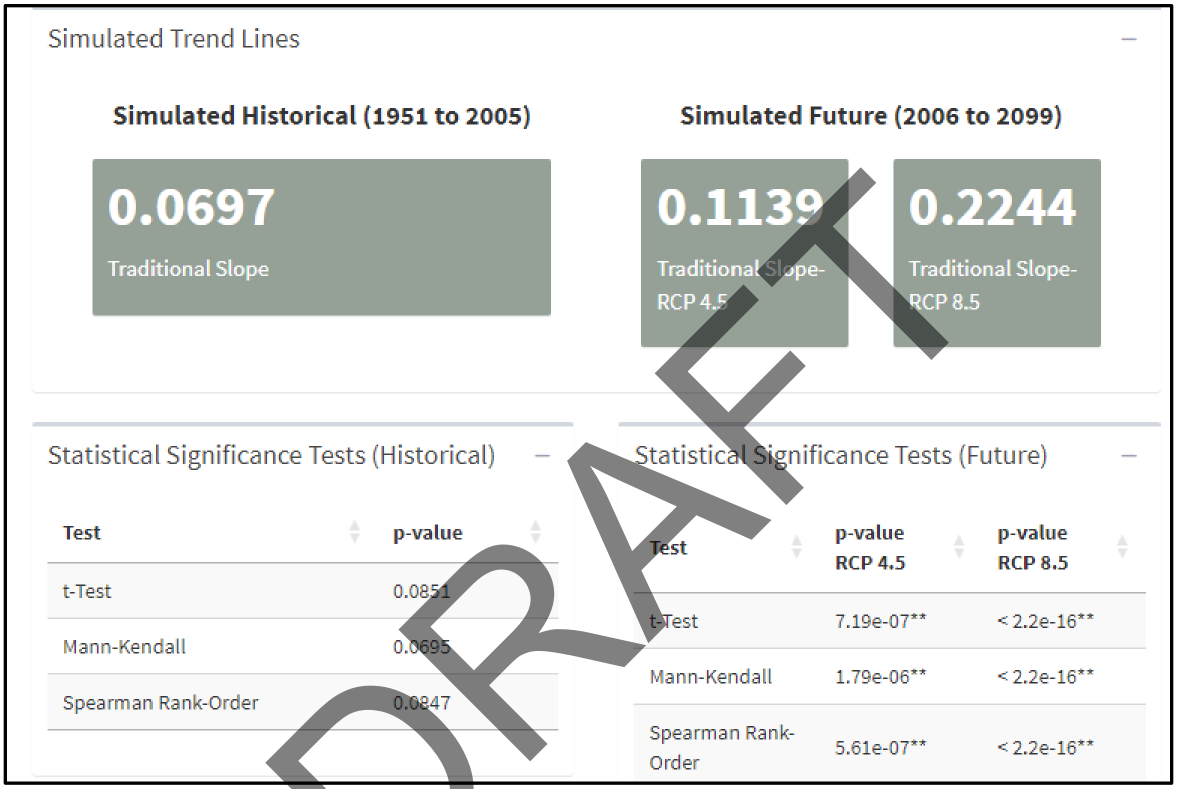
Figure 29: Park River Projected Hydrology Assessment – mean daily flow.

The record 1951 to 2005 was hindcast to have a positive slope, but the three significance tests for the trend (slope) were all between 0.05 and 0.10 (that is, not significant at the

95% level, but significant at the 90% level). Practically, though, this was a failure at the standard 95% level.

The projections for 2006 to 2100 had a greater slope and the three tests were all significant, with p-values smaller than 10^{-5}. For the RCP 4.5 case, the gradient was 0.114 cfs per year; for RCP 8.5, the gradient was 0.224 cfs/yr.

These statistical results are listed in **Figure 30**.



Simulated Trend Lines

Simulated Historical (1951 to 2005)

0.0697
Traditional Slope

Simulated Future (2006 to 2099)

0.1139
Traditional Slope-RCP 4.5

0.2244
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

Test	p-value
t-Test	0.0851
Mann-Kendall	0.0695
Spearman Rank-Order	0.0847

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	7.19e-07**	< 2.2e-16**
Mann-Kendall	1.79e-06**	< 2.2e-16**
Spearman Rank-Order	5.61e-07**	< 2.2e-16**

Figure 30: Statistical Summary of Projected Hydrology Analysis for Annual Mean 1-Day Streamflow at Park River in Hartford, CT

The peak flows were reviewed in a similar fashion and the CHAT graph for the estimated annual maximum of mean monthly streamflow is shown in **Figure 31**.

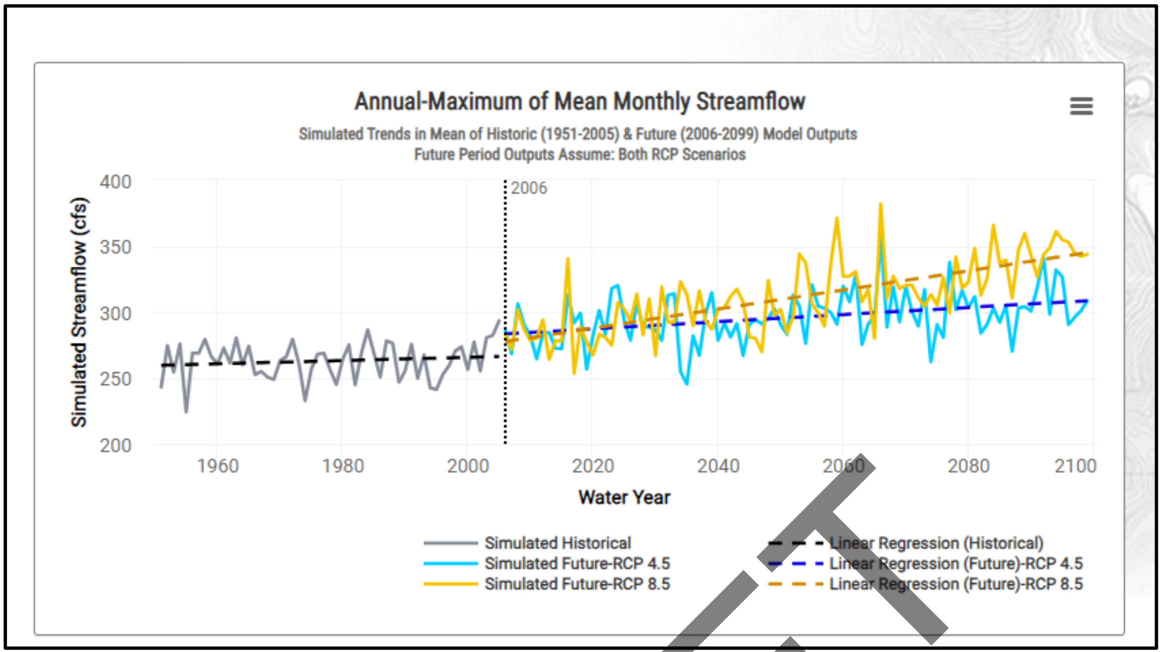
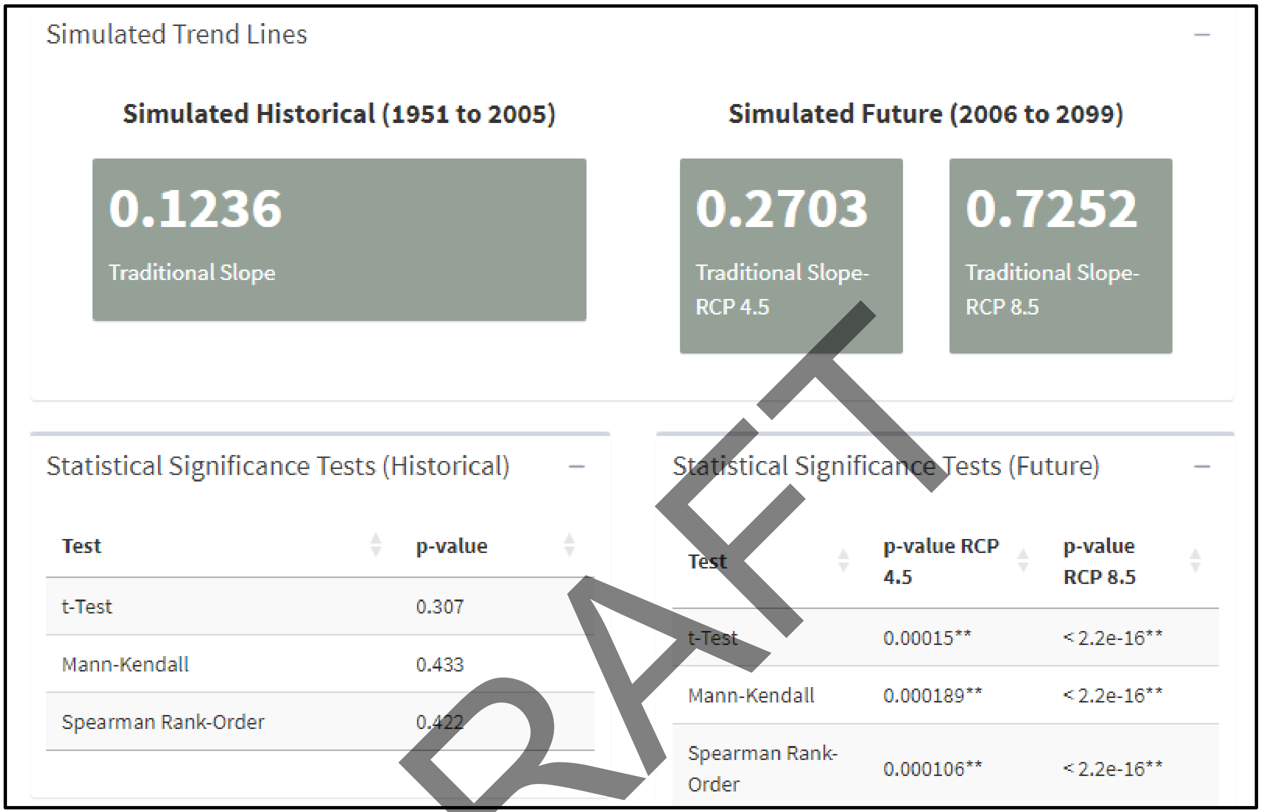


Figure 31: Park River Projected Hydrology Assessment – annual maximum of mean monthly streamflow flow.

The record 1951 to 2005 was hindcast to have a slight positive slope, but the three significance-tests for the trend (slope) were all larger than 0.05 and so not significant at the 95% level.

The projections for 2006 to 2100 had a greater slope and the three tests were all significant, with p-values smaller than 0.001. For the RCP 4.5 case, the gradient was

0.270 cfs/yr; for RCP 8.5, the gradient was 0.725 cfs/yr. The statistical analysis is summarized in **Figure 32**.



Simulated Trend Lines

Simulated Historical (1951 to 2005)

0.1236
Traditional Slope

Simulated Future (2006 to 2099)

0.2703
Traditional Slope-RCP 4.5

0.7252
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

Test	p-value
t-Test	0.307
Mann-Kendall	0.433
Spearman Rank-Order	0.422

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.00015**	< 2.2e-16**
Mann-Kendall	0.000189**	< 2.2e-16**
Spearman Rank-Order	0.000106**	< 2.2e-16**

Figure 32: Statistical Summary of Projected Hydrology Analysis for Annual Max of Mean Monthly Streamflow at Park River in Hartford, CT.

Upper and lower limits of the simulated data sets are shown in **Figure 33**.

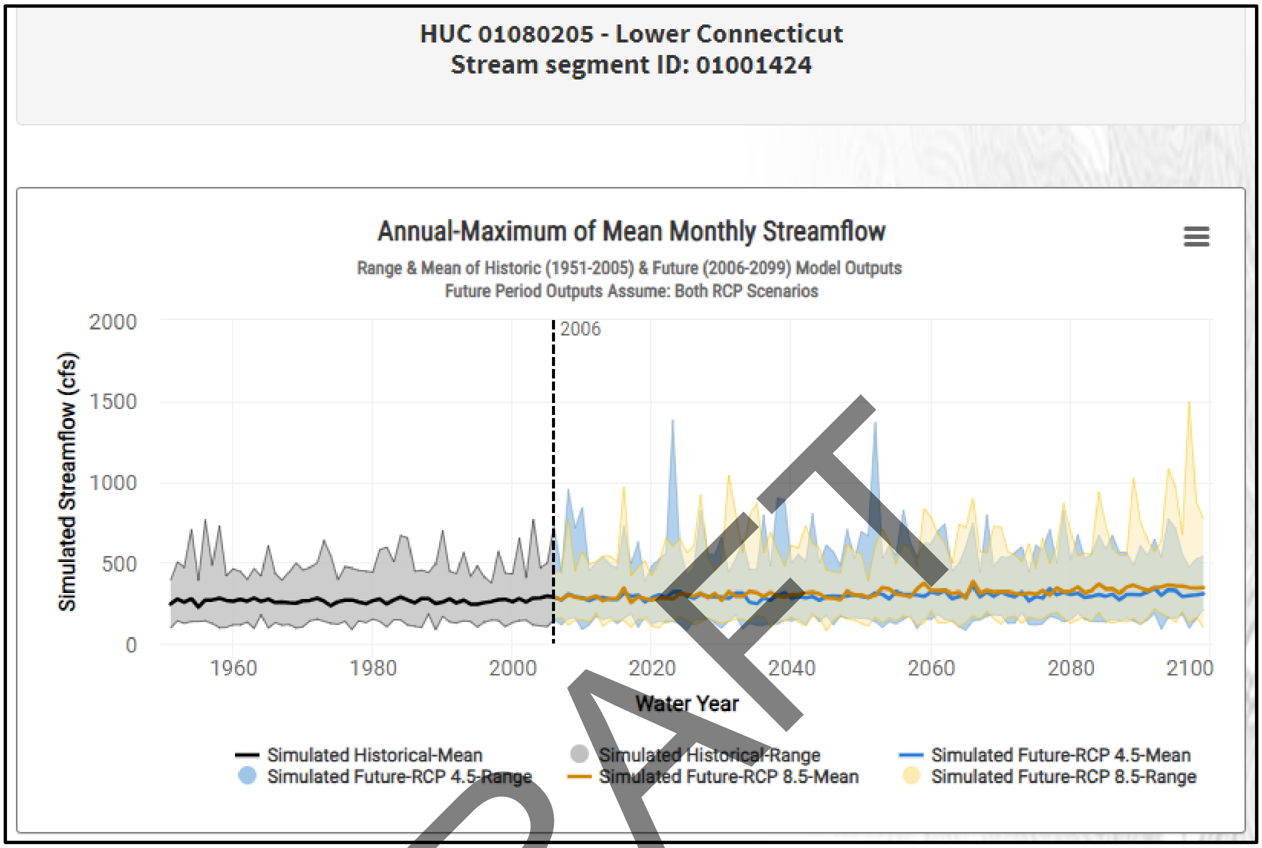


Figure 33: Range of 32 Projected Hydrology Model Outputs for Lower Connecticut (HUC 01080205), Stream Segment 01001148: Annual Maximum of Mean Monthly Streamflow (includes color-coding of the projected RCP 4.5 and RCP 8.5 ranges).

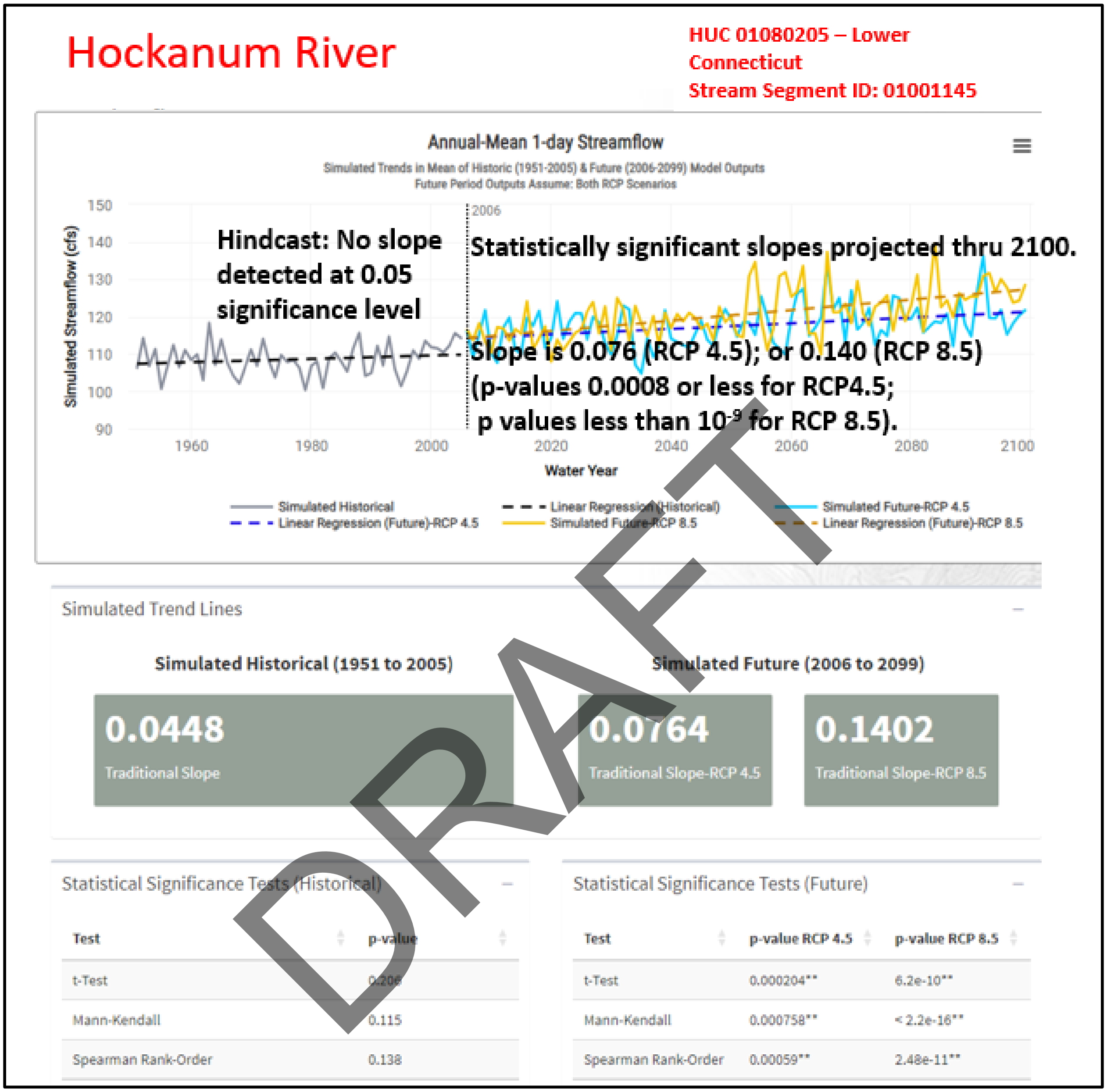
The post-2006 projections in **Figure 33** appear to show little change in slope from the pre-2006 hindcast, but the reason is that the vertical scale has been extended to allow for flow extremes (maximum and minimum values of the forecast peak (annual-maximum of mean monthly streamflow) values). Consequently, the positive slopes of the projections appear less striking in **Figure 33** than they do in **Figure 31**.

In summary, for the Park River system, the average flow is projected to increase through 2100; and annual monthly peak flows are projected to increase at a greater rate.

East Hartford and Hockanum River Hydrometeorology

The defined river segments in the CHAT for East Hartford include the Hockanum River, which is analyzed in this section.

The segment is in HUC 01080205 (Lower Connecticut), Stream Segment 01001145. For this segment, the projected annual mean streamflow is shown in **Figure 34**.



Hindcast: No slope detected at 0.05 significance level

Statistically significant slopes projected thru 2100.

Slope is 0.076 (RCP 4.5); or 0.140 (RCP 8.5) (p-values 0.0008 or less for RCP4.5; p values less than 10^{-9} for RCP 8.5).

Simulated Trend Lines

Simulated Historical (1951 to 2005)

Simulated Future (2006 to 2099)

0.0448
Traditional Slope

0.0764
Traditional Slope-RCP 4.5

0.1402
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

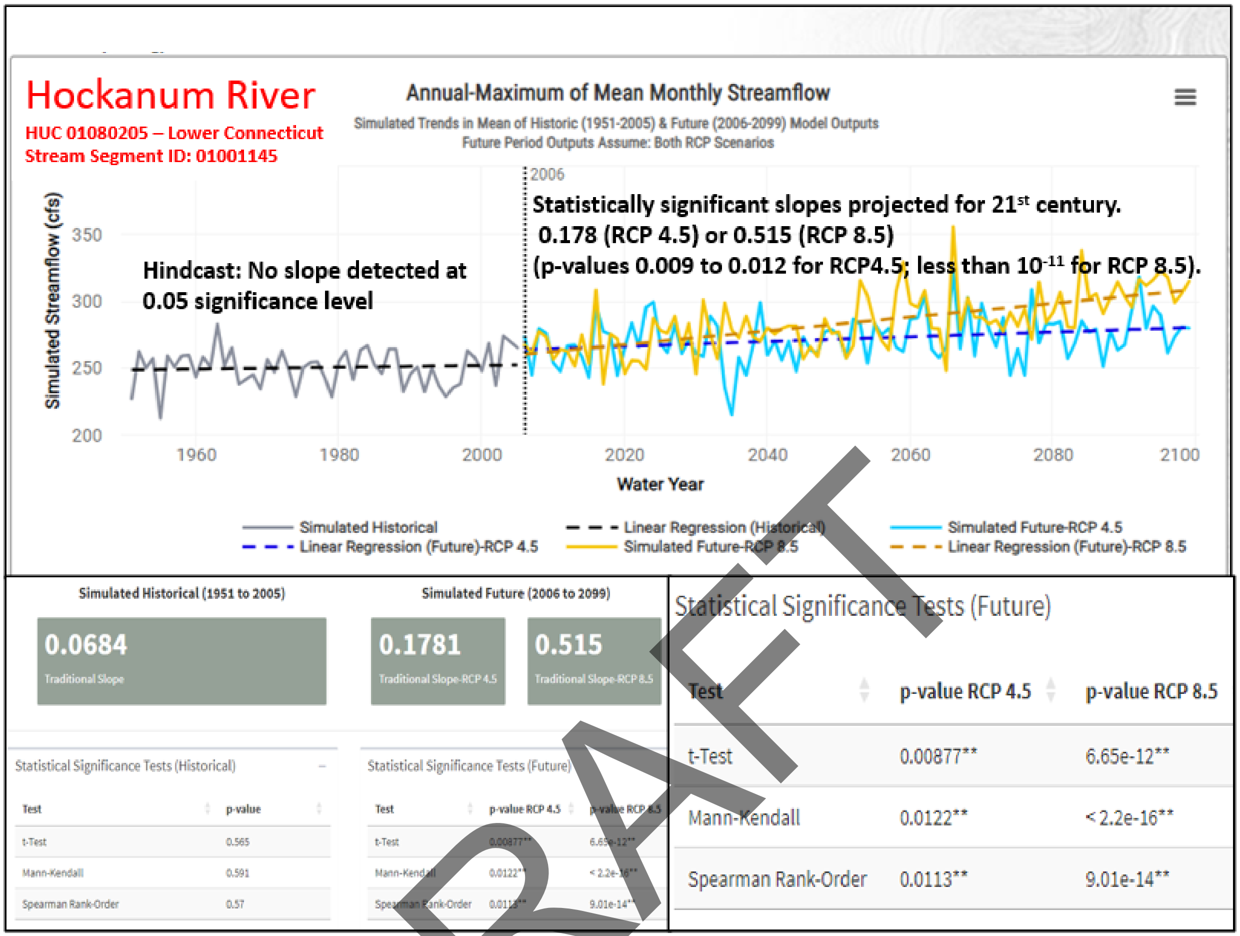
Test	p-value
t-Test	0.206
Mann-Kendall	0.115
Spearman Rank-Order	0.138

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.000204**	6.2e-10**
Mann-Kendall	0.000758**	< 2.2e-16**
Spearman Rank-Order	0.00059**	2.48e-11**

Figure 34: Hockanum River Projected Hydrology Projections of Annual Mean 1-Day Streamflow

The annual peak of monthly mean values is shown in Figure 35.



Hindcast: No slope detected at 0.05 significance level

Statistically significant slopes projected for 21st century. 0.178 (RCP 4.5) or 0.515 (RCP 8.5) (p-values 0.009 to 0.012 for RCP4.5; less than 10^{-11} for RCP 8.5).

Simulated Historical (1951 to 2005)

0.0684
Traditional Slope

Simulated Future (2006 to 2099)

0.1781
Traditional Slope-RCP 4.5

0.515
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

Test	p-value
t-Test	0.565
Mann-Kendall	0.591
Spearman Rank-Order	0.57

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.00877**	6.65e-12**
Mann-Kendall	0.0122**	< 2.2e-16**
Spearman Rank-Order	0.0113**	9.01e-14**

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.00877**	6.65e-12**
Mann-Kendall	0.0122**	< 2.2e-16**
Spearman Rank-Order	0.0113**	9.01e-14**

Figure 35: Hockanum River Projected Hydrology for Annual-Maximum of Mean Monthly Streamflow

Upper and lower limits of the simulated data sets are shown in **Figure 36**.

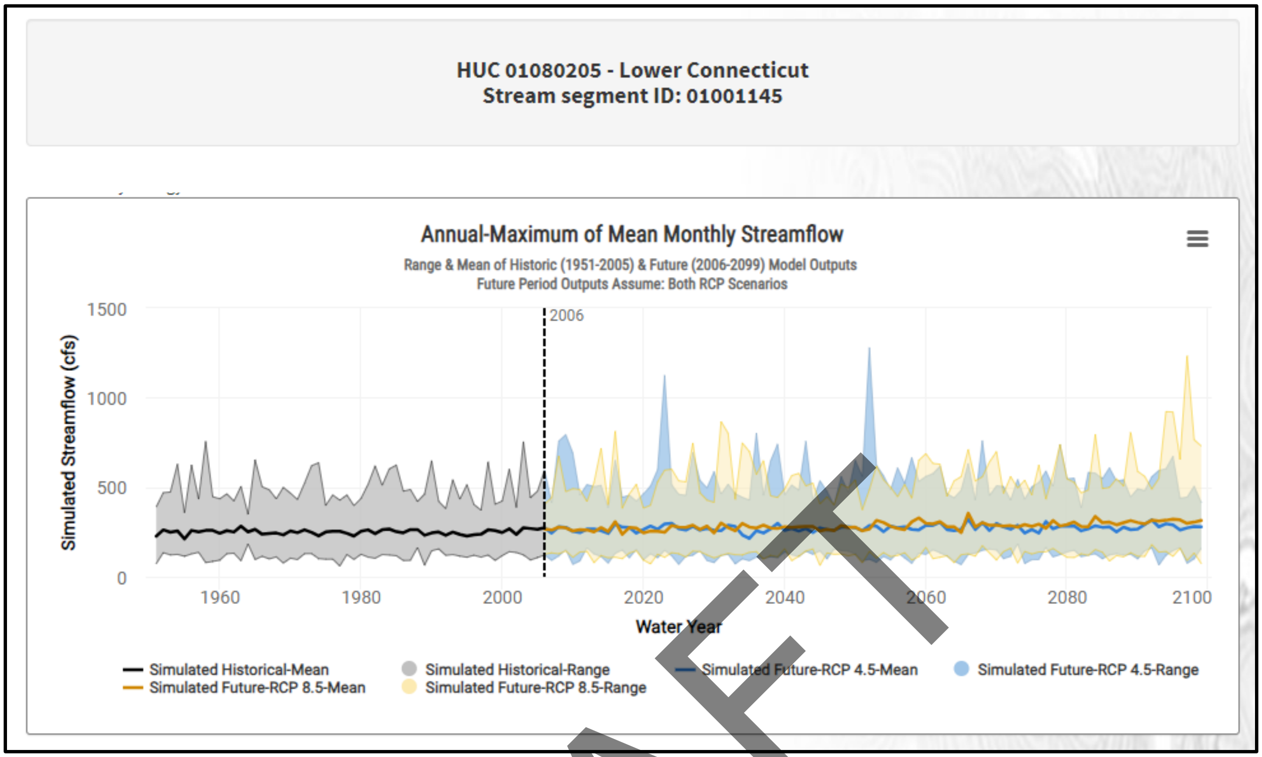


Figure 36: Hockanum River Hydrology Projections of Annual-Maximum of Mean Monthly Streamflow, with Estimates of Annual Max and Min Values

The post-2006 projections in **Figure 36** appear to show little change in slope from the pre-2006 hindcast, but the reason is that the vertical scale has been extended to allow for flow extremes (maximum and minimum values of the forecast peak (annual-maximum of mean monthly streamflow) values). Consequently, the positive slopes of the projections appear less striking in **Figure 36** than they do in **Figure 35**.

In summary, for the Hockanum River system, the average flow is projected to increase through 2100; and annual monthly peak flows are projected to increase at a greater rate.

Review of CHAT Projections for Connecticut, Park River, and Hockanum River

Connecticut River: The annual maximum of mean monthly Connecticut River streamflow value (a mild high-flow parameter) is projected to fall during the 21st century, while the annual mean flow is projected to rise over the same period.

Park River: For the Park River system (City of Hartford), the average flow and annual monthly peak flow are projected to increase through 2100.

Hockanum River: For the Hockanum River system (Town of East Hartford), the average flow and annual monthly peak flow are projected to increase through 2100.

Sea Level Change

Background

Global sea level change (SLC) is often caused by the global change in the volume of water in the world's oceans in response to three climatological processes: 1) ocean mass change associated with long-term forcing of the ice ages ultimately caused by small variations in the orbit of the earth around the sun; 2) density changes from total salinity; and most recently, 3) changes in the heat content of the world's oceans, which recent literature suggests may be accelerating due to global warming. Global SLC can also be caused by basin changes through such processes as seafloor spreading. Thus, global sea level, also sometimes referred to as global mean sea level, is the average height of all the world's oceans.

Relative (local) SLC is the local change in sea level relative to the elevation of the land at a specific point on the coast. Relative SLC is a combination of both global and local SLC caused by changes in estuarine and shelf hydrodynamics, regional oceanographic circulation patterns (often caused by changes in regional atmospheric patterns), hydrologic cycles (river flow), and local and/or regional vertical land motion (subsidence or uplift).

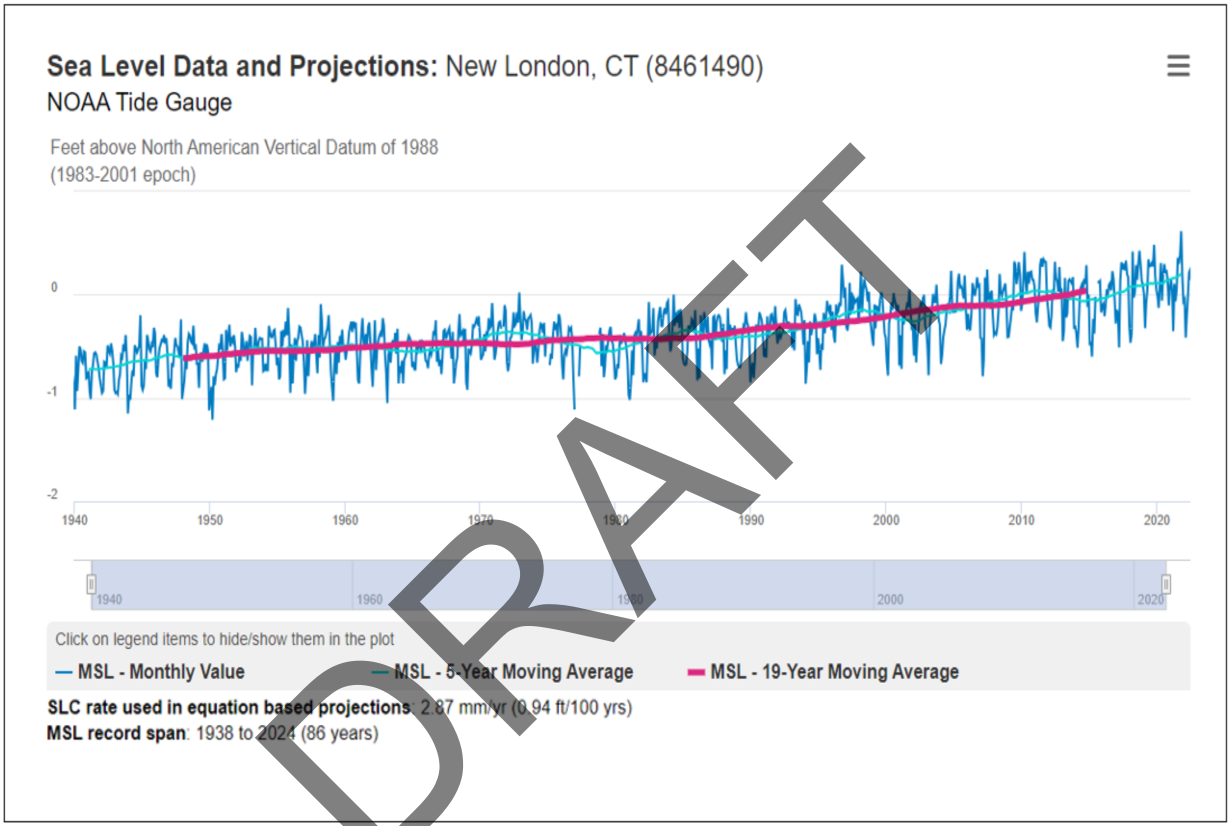
USACE Guidance

In accordance with ER 1100-2-8162, potential effects of relative sea level change (RSLC) were analyzed over a 50-year economic period of analysis and a 100-year planning horizon. USACE guidance states "the period of analysis shall be the time required for implementation of the lesser of: 1) the period of time over which any alternative plan would have significant beneficial or adverse effects, 2) a period not to exceed 50 years" (ER 1105-2-100). However, because infrastructure often stays in place well beyond the economic period of analysis, a 100-year adaptation planning horizon is used to address robustness and resilience in the time of service of the project that can extend past its original design life. Research indicates continued accelerated change for the 21st century and possibly beyond, which could cause a continued or accelerated rise in global mean sea level. ER 1100-2-8162 states that planning studies will formulate alternatives over a range of possible future rates of SLC and consider how sensitive and adaptable the alternatives are to SLC.

ER 1100-2-8162 requires planning studies and engineering designs to consider three future sea level change scenarios: low, intermediate, and high. The historic rate of SLC represents the low rate. The intermediate rate of SLC is estimated using the modified National Research Council (NRC) Curve I. The high rate of SLC is estimated using the modified NRC Curve III. The high rate is within the range of values published in peer-reviewed articles since 2007.

Historical Sea Level Change

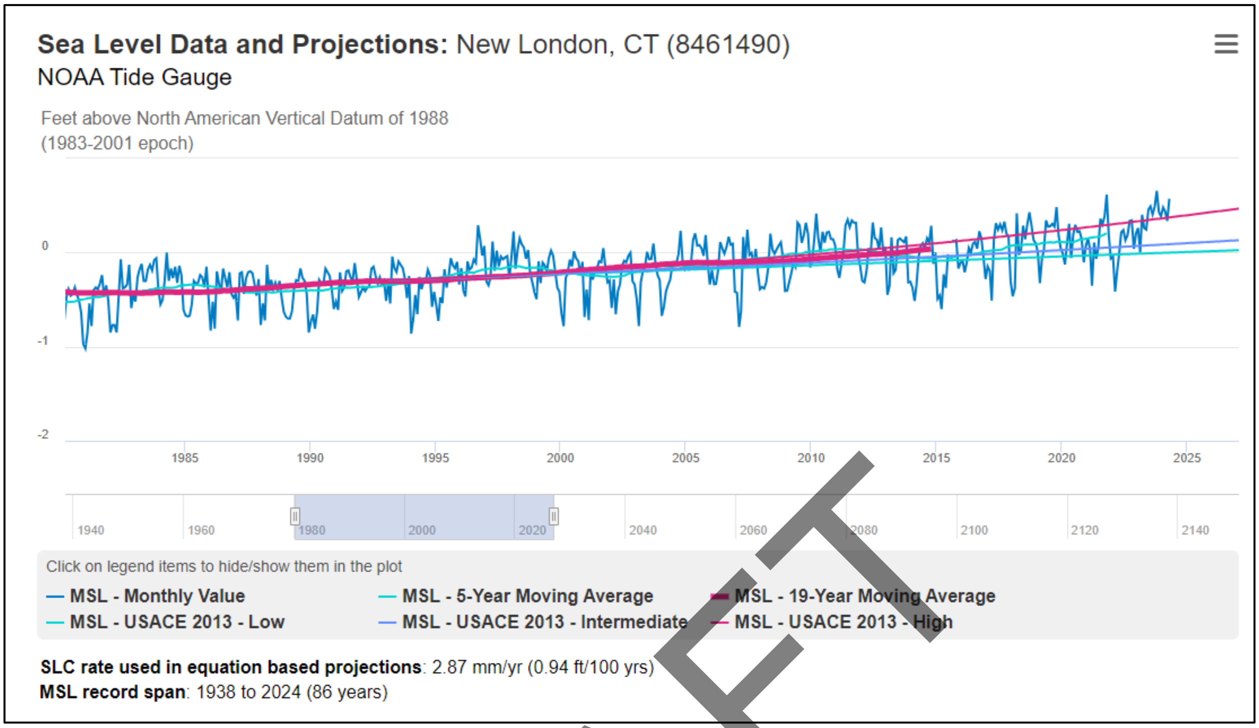
The nearest long-term tide station to the mouth of the Connecticut River is NOAA New London Gauge 8461490 at the mouth of the Thames River in New London, CT, approximately 13 miles east of the Connecticut River mouth. The New London gauge has an 86-year (1928-2024) record with a historical rate of RSLC of (2.87 mm/yr or 0.00942 ft/yr). The full historical record with the 5- and 19-year moving averages is shown in **Figure 37**. It is apparent that over long timescales (19 years) mean sea level is steadily increasing. However, over shorter timescales mean sea level may increase or decrease. The monthly mean sea level (blue), for instance, goes up and down every year capturing the seasonal cycle in mean sea level. The 5-year moving average (cyan) captures the interannual variation (2 or more years).



SLC rate used in equation based projections: 2.87 mm/yr (0.94 ft/100 yrs)
MSL record span: 1938 to 2024 (86 years)

Figure 37: Historical RSLC at New London, CT NOAA tide gauge 8461490

The USACE Sea Level Analysis Tool (SLAT) was also used to visualize historical SLC relative to the three USACE sea level change curves. **Figure 38** shows the historical record for the since 1980 with the three USACE SLC curves which originate in 1992, the midpoint of the present National Tidal Datum Epoch (1983-2001).



Sea Level Data and Projections: New London, CT (8461490)
NOAA Tide Gauge

SLC rate used in equation based projections: 2.87 mm/yr (0.94 ft/100 yrs)
MSL record span: 1938 to 2024 (86 years)

Figure 38: Historical RSLC at New London, CT with three USACE SLC curves

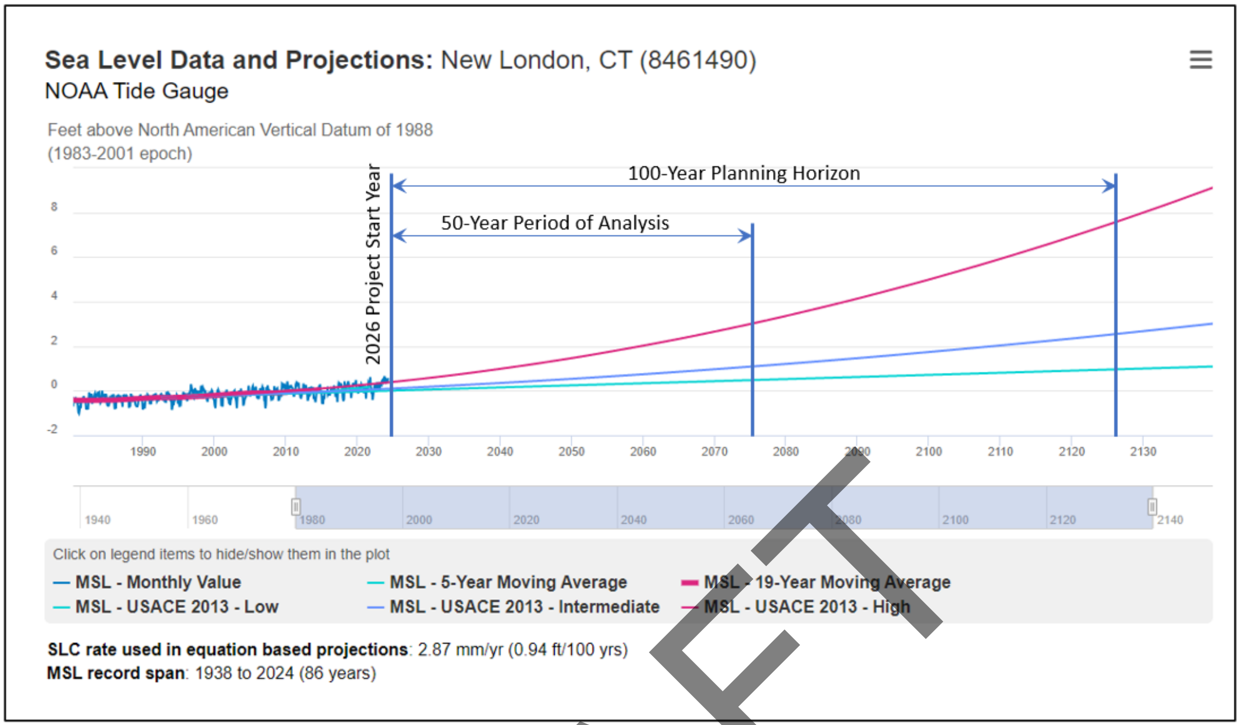
USACE SLC Scenarios

USACE low, intermediate, and high SLC scenarios through the 100-year planning horizon at New London, CT are presented in **Table 2** and **Figure 39**. For this resilience assessment, it is anticipated that the levee rehabilitation project would be complete by 2026. Using projections for the years 2026 and 2076, it is estimated that mean sea level in 2076 will be between 0.47 and 2.67 feet higher than the end-of-construction (2026) estimate. At the end of a 100-year period of analysis, mean sea level is projected to be 0.95 to 7.18 feet higher than the end-of-construction (2026) estimate.

Table 2: USACE Sea Level Projections: New London, CT

Year	Low	Intermediate	Resilience Assessment	High
1992	-0.30	-0.30	-0.30	-0.30
2020	-0.04	0.03	0.14	0.25
2021	-0.03	0.05	0.17	0.28
2022	-0.02	0.07	0.20	0.32
2023	-0.01	0.08	0.22	0.35
2024	0.00	0.10	0.25	0.39
2025	0.01	0.12	0.27	0.42
2026	0.02	0.13	0.29	0.45

Year	Low	Intermediate	Resilience Assessment	High
2030	0.06	0.19	0.34	0.59
2040	0.15	0.36	0.69	1.01
2050	0.25	0.55	1.02	1.49
2060	0.34	0.75	1.40	2.05
2070	0.43	0.98	1.84	2.69
2075	0.48	1.10	2.08	3.05
2076	0.49	1.12	2.12	3.12
2080	0.53	1.22	2.31	3.40
2090	0.62	1.48	2.83	4.18
2100	0.72	1.75	3.40	5.04
2110	0.81	2.05	4.01	5.97
2120	0.91	2.36	4.67	6.98
2125	0.96	2.53	5.03	7.52
2126	0.97	2.56	5.10	7.63
2130	1.00	2.69	5.38	8.06
2140	1.09	3.04	6.13	9.21
2150	1.19	3.41	6.93	10.44
	Units: Feet above NAVD88 (1983-2001 epoch midpoint taken as -0.30 in 1992)			



SLC rate used in equation based projections: 2.87 mm/yr (0.94 ft/100 yrs)
MSL record span: 1938 to 2024 (86 years)

Figure 39: USACE Sea Level Projections for New London, CT

SLC Impacts

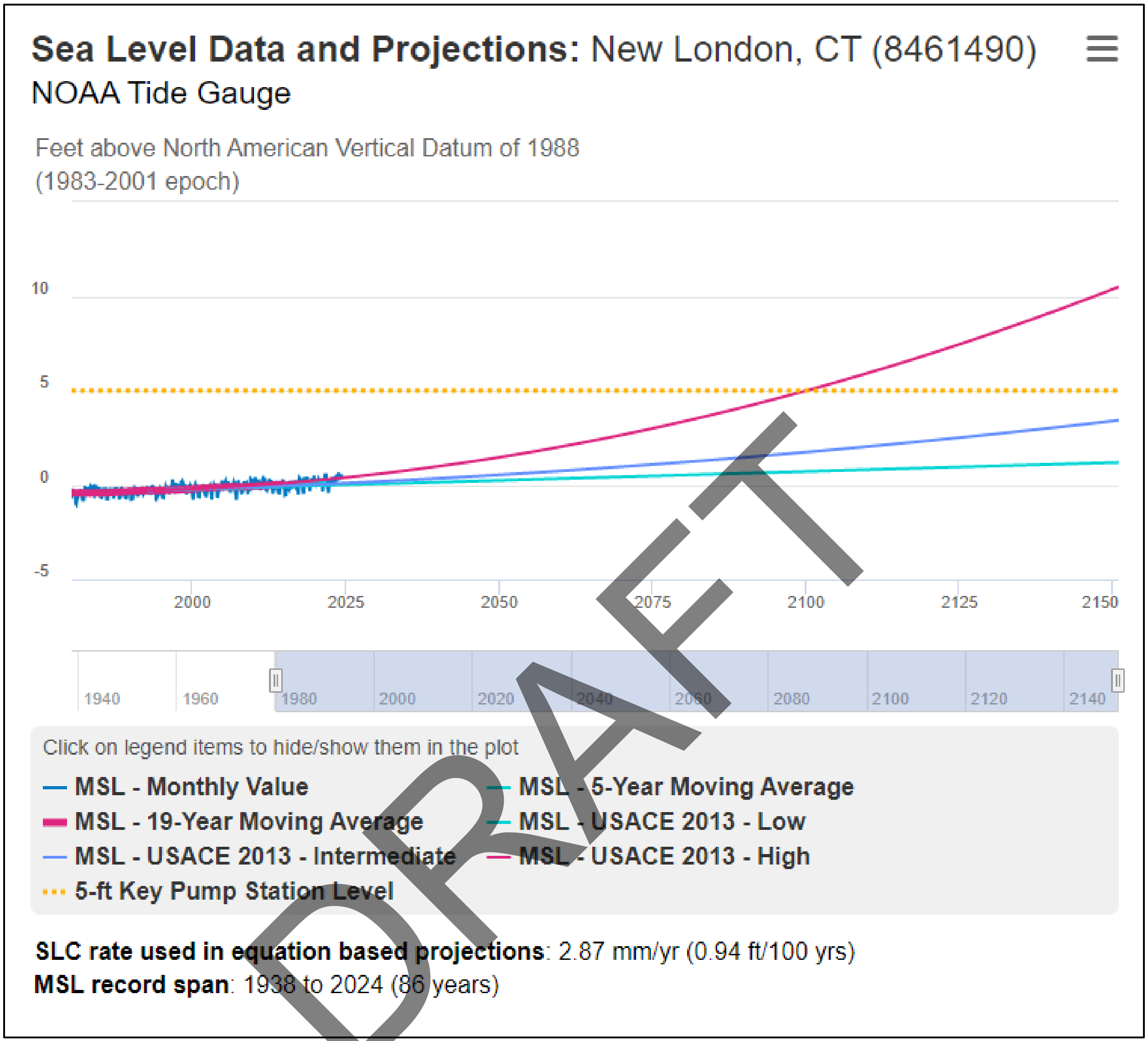
The Connecticut River is currently tidally influenced below the confluences with Stoughton Brook (east bank) and the Farmington River (west bank), approximately 2.5 miles upstream of the Route 291 crossing over the Connecticut River in Windsor and East Windsor, CT. Typical stream elevations just upstream of the confluence rise to approximately 10 feet NAVD88, whereas the present NTDE Mean Higher High Water (MHHW) is approximately 1.2 feet NAVD88.

There are pump station outfall inverts set at approximately 5 ft NAVD. For Connecticut River water elevations above that level, there is interference in free-flow at these stations, leading potentially to gates being adjusted or pumping being initiated. The 5-ft level is therefore a useful level to use as a quick check on whether “normal” conditions are possible, or as a starting point for gate or pumping operations. A major concern with MHHW reaching the outflow structures is the frequency with which non-gravity-flow drainage will be required. Greater detail on gate and pumping operations for various tailwater levels is included in Appendix 2-B2.

With SLC, tides are predicted to rise, approaching the structures, as shown in **Figure 40**. MHHW is not projected to exceed 5 feet NAVD88 within the 50-year period of analysis under any of the three USACE sets of assumptions (low, medium, or high rates of change). Under the high SLC scenario, MHHW is projected to reach 5 feet NAVD88 in the year 2110. However, MHHW is not projected to exceed the 5-ft NAVD88 elevation under the low and intermediate SLC scenarios within the 100-year planning horizon.

Similarly, extreme astronomical tides and storm surges will also reach the 5-ft elevation and extend upstream more frequently and or require more frequent pumping with SLC. **Figure 41** shows how a range of present-day annual exceedance frequency event water levels, from 1-year to 100-year events, will change due to SLC. The likelihood of the key 5-ft elevation being reached under storm events will increase with SLC and what is currently a lower probability event will become more frequent. However, given that the pump station outfall inverts are at approximately 5 feet NAVD88, astronomical tides and surges are not projected to extend that far upstream within the 50-year period of analysis although they could reach the 5-ft level during the 100-year planning horizon.

Ultimately, as sea level change occurs, water levels will interfere more frequently in the pump station operations. To date, however, the gage records in Hartford, East Hartford, and Thompsonville indicate falling, not rising, elevations over time. Any changes due to coastal effects are not yet apparent at the pump stations.



Sea Level Data and Projections: New London, CT (8461490)
NOAA Tide Gauge

SLC rate used in equation based projections: 2.87 mm/yr (0.94 ft/100 yrs)
MSL record span: 1938 to 2024 (86 years)

Figure 40: Mean Higher High Water Projections with SLC relative to 5 ft NAVD key pump station level.

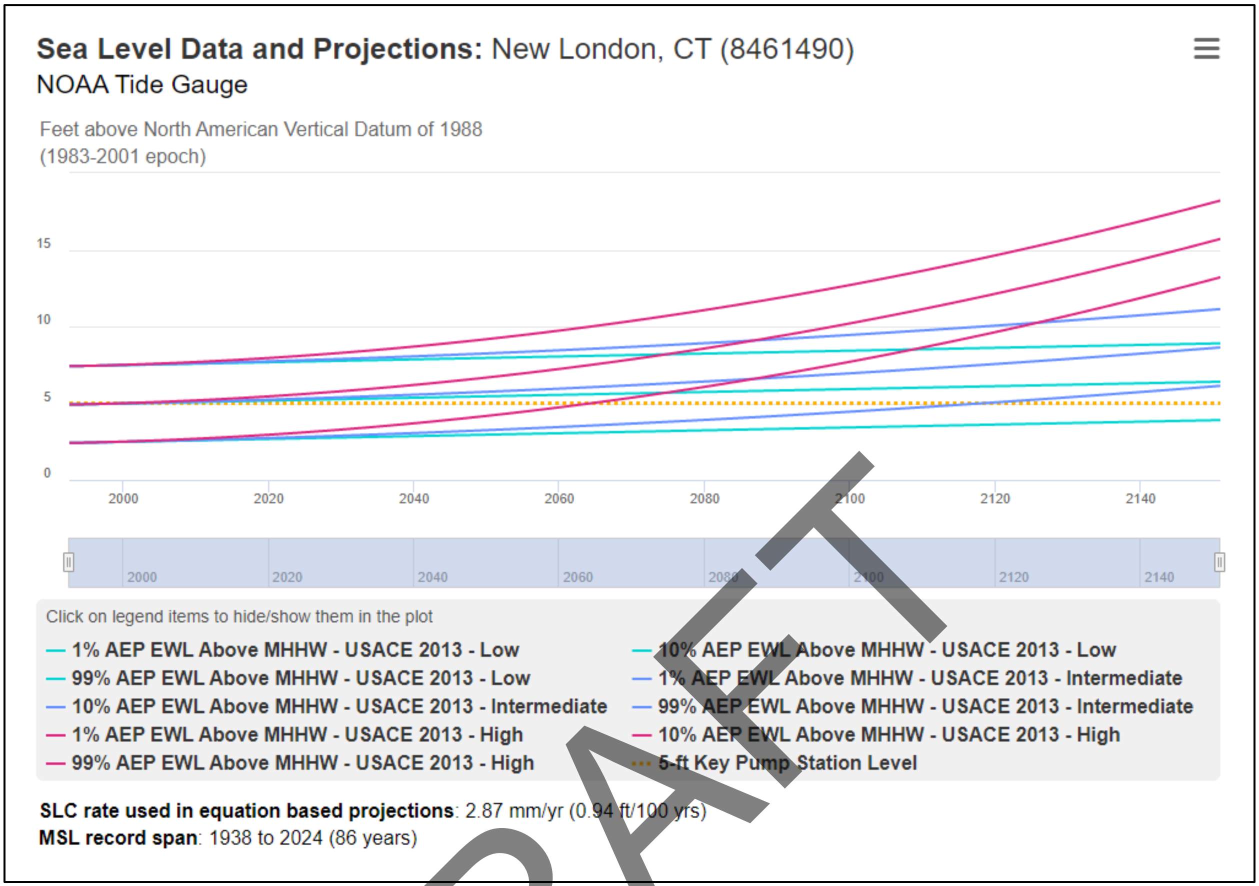
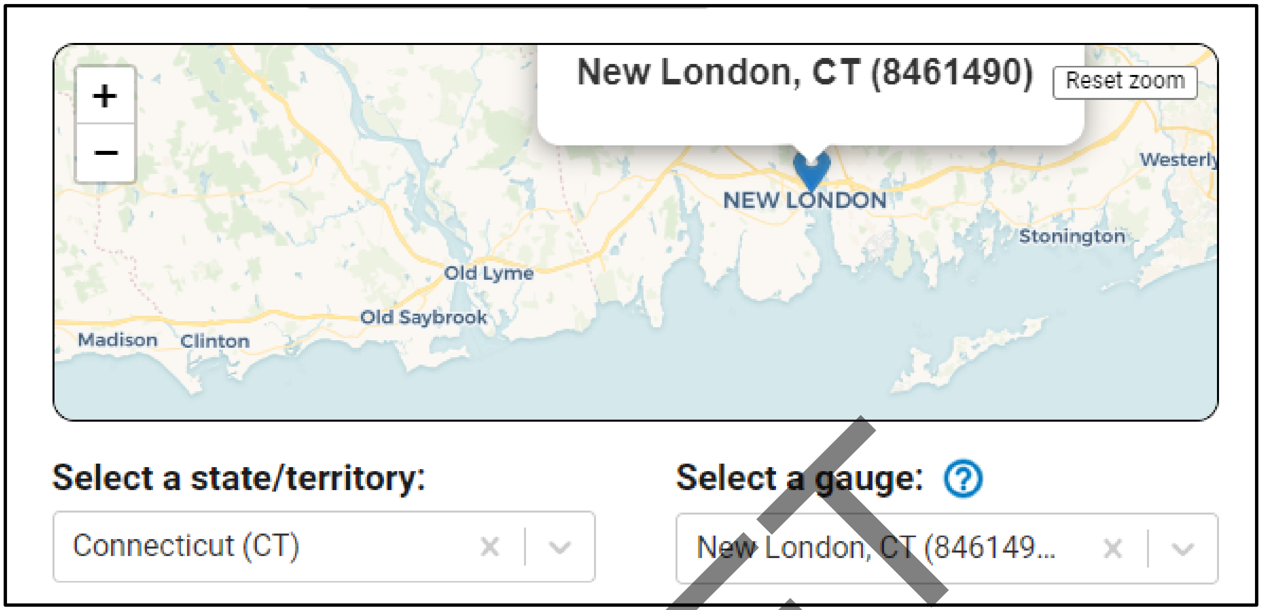


Figure 41: Annual Exceedance Frequency (AEF) Event Water Levels with SLC relative to 5-ft NAVD Reference Elevation.

Connecticut River Water Levels – Tidal Influence and Relative Sea-Level Change

At Hartford, Connecticut, the Connecticut River is tidally influenced. The USACE Sea Level Analysis Tool (SLAT) has been used to demonstrate the possible effect of sea-level rise on the water level at Hartford, based on the assumed current average water level of 6 feet NAVD, as developed in the previous section. The analysis is crude in that there are approximately 45 miles of river channel between Hartford and New York Sound, in which friction losses play a role. Consequently, the effects at the downstream end (New York Sound) do not translate linearly upstream to Hartford and East Hartford. A more rigorous review of coastal effects on the water levels in Hartford is included in **Appendix 2-B2.**

The NOAA New London Gauge 8461490 at the mouth of the Thames River was used as a surrogate for the water level at the mouth of the Connecticut River. The selected gauge is approximately 13 miles east of the mouth of the Connecticut River at Lyme and Old Saybrook as shown in **Figure 42**.

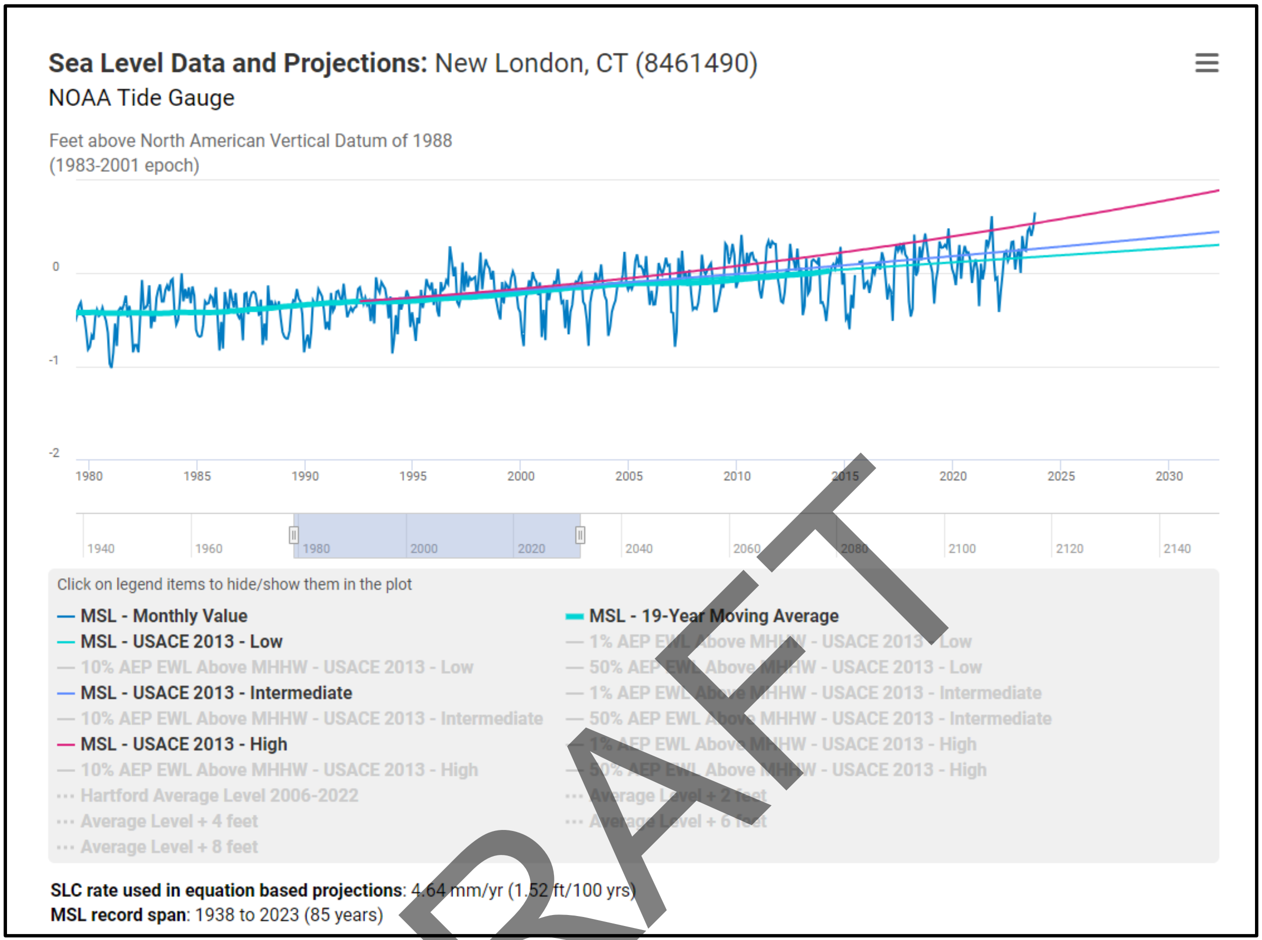


Select a state/territory: Connecticut (CT)

Select a gauge: New London, CT (846149...

Figure 42: Location of New London NOAA Tide Gauge 8461490 in New London CT relative to the mouth of the Connecticut River at Old Lyme and Old Saybrook CT (from USACE SLAT)

USACE has adopted three different global sea-level rise curves, based on projections of ice-melt and ocean warming due to different atmospheric emissions scenarios, much like the NOAA projections summarized earlier in **Figure 9**. The sea-level record, and the low, intermediate, and high projections specific to the coastal region that includes the mouth of the Connecticut River (Gauge is 13 miles east at the mouth of the Thames River) are shown in **Figure 43**. The chart has been simplified to show how the actual sea level has been tracking relative to the projections, from 1980 through 2022.



SLC rate used in equation based projections: 4.64 mm/yr (1.52 ft/100 yrs)
MSL record span: 1938 to 2023 (85 years)

Figure 43: New London CT NOAA Gauge Data and USACE Projections 1980 to 2030

Given the monthly range at this site (essentially scatter in the record), it is not yet clear which of the three curves is most appropriate, although recent guidance has been to discard the low projection and assume that the truth is in the range of the higher two curves. For the resilience assessment, a value midway between these estimates is reviewed with respect to mean sea level. A resilience assessment column has been inserted into **Table *2*** as a useful summary of this midway level for the various sea level projections for a range of dates from 1992 (observed) through 2150 (projected).

A more detailed chart showing water levels at the site, including projected tide and coastal storm surge extreme water levels (EWL) through 2100 is shown in **Figure 44.** The SLAT does allow for extensions through 2140, although the range through the end of the current century is typically taken as adequate for a riverine resilience report.

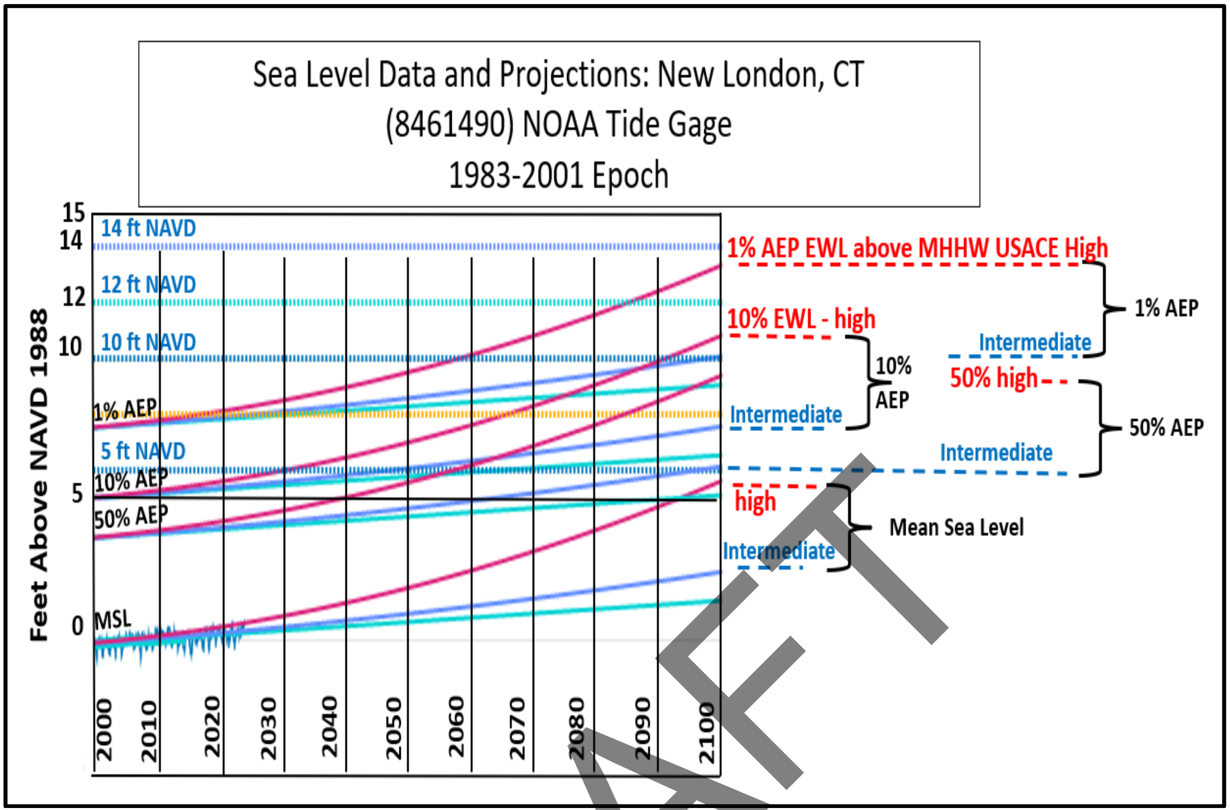


Figure 44: New London CT NOAA Gage Data and USACE Projections 2000 to 2100 with Selected Water Levels Based on Possible Stage Records at Hartford, CT

Appendix 2-B2, in its Table 12, lists elevations at which gravity gates need to be closed. The lowest elevations are 5.0 ft NAVD at South Meadows Pump Station in Hartford and 5.2 ft for both North Meadows in Hartford and Meadow Hill in East Hartford. Pumps are automatically turned on starting with South Meadows at 4.2 ft NAVD (Hartford) and turned off at even lower elevations, for example for South Meadows(Hartford) and Meadow Hill (East Hartford) at 2.2 ft NAVD and Pitkin Street (East Hartford) at 2.4 ft. A useful measure of pump station operations' sensitivity is therefore taken as the 5 ft NAVD water level for the Connecticut River in Hartford.

The "mean sea level" case is below 5 feet NAVD, regardless of which projected curve is assumed, through 2090. The high estimate of MSL rises above the 5-ft level in the 2090-2100 decade, but does not reach 6 ft during the 21st century. The other selected cases are for Mean Higher High Water (MHHW) in conjunction with storm surge conditions that would occur with return probabilities of 50%, 10% or 1% (2-year, 10-year or 100-year return period surge conditions). Review of **Figure 21** indicates that the current (2024) level of tidal influence in Hartford is in the range 2 to 4 ft NAVD, and that this influence is drowned out during high flow events from farther upstream in the Connecticut River watershed. There are approximately 45 miles of river channel between Hartford and the mouth of the river, with ample opportunities for short-term fluctuations to be diluted through hydraulic headloss.

Appendix 2-B2 (Interior Drainage) includes a more detailed assessment with HEC RAS modeling of how the water levels in Hartford are affected by combinations of inland storms and tidal influences. Selected coincident frequency analyses have shown that the Connecticut River water levels in Hartford and East Hartford are not greatly impacted by effects of coastal storms. For increasing storm size, the tidal influence is of the order of 1.2 feet, while the inland influence may be greater than 20 feet.

Vulnerability Assessment

The USACE Watershed Comprehensive Vulnerability Assessment (VA) Tool facilitates a screening-level, comparative assessment of the vulnerability of a given business line and HUC-4 watershed to the impacts of projected hydrological change, relative to the other HUC-4 watersheds within the continental United States (CONUS). It uses the Coupled Model Intercomparison Project (CMIP5) GCM-BCSD-VIC dataset (2014) to define projected hydrometeorological inputs, combined with other data types, to define a series of indicator variables to define a vulnerability score.

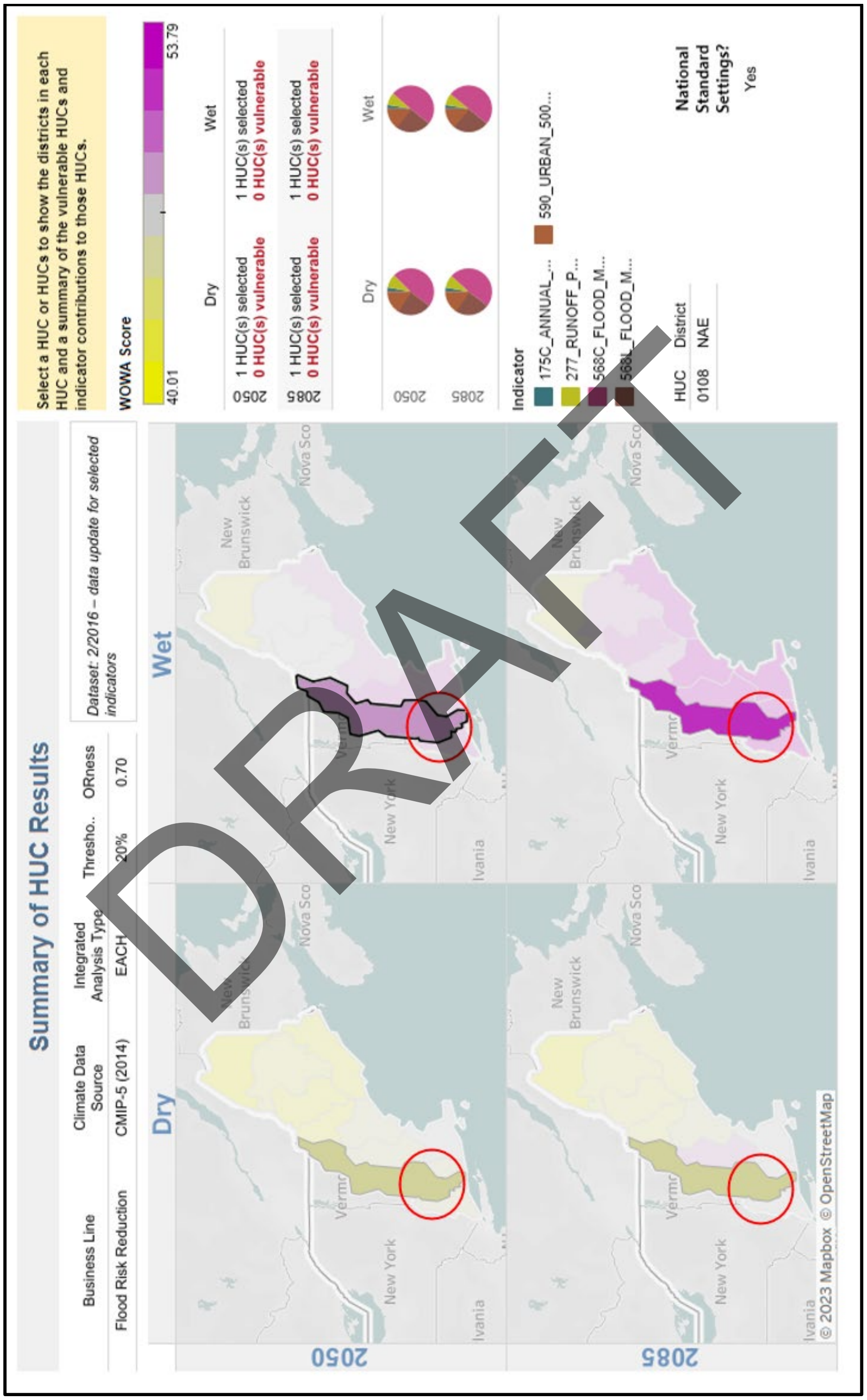
Vulnerabilities are represented by a weighted-order, weighted-average (WOWA) score generated for two subsets of simulations (wet—top 50% of cumulative runoff projections; and dry—bottom 50% cumulative runoff projections). Data are available for three epochs. The epochs include the current time period ("Base") and two 30-year, future epochs (centered on 2050 and 2085). The Base epoch is not based on projections and so it is not split into different scenarios. For this application, the tool was applied using its default, National Standards Settings. In the context of the VA Tool, there is some uncertainty in all of the inputs to the vulnerability assessments. Some of this uncertainty is already accounted for in that the tool presents separate results for each of the scenario-epoch combinations rather than presenting a single aggregate result.

As shown in **Figure 45**, the Connecticut River Basin (HUC 0108) watershed is not considered vulnerable to projected hydrology impacts for the flood risk reduction business line, since it is not among the 20% most vulnerable watersheds for this business line in the CONUS (202 HUC04s). This is true for both the wet and dry scenarios and both the 2050 and 2085 epochs. Although the HUC 0108 watershed is not considered vulnerable in a relative sense to impacts from projected hydrological trends, it may still be vulnerable in an absolute sense.

The primary drivers of this flood risk vulnerability assessment for wet scenarios under the two epochs are indicator **568C** coupled with **568L**, both titled Flood Magnification (**C**umulative or **L**ocal). **568C** is a ratio of flood runoff to monthly runoff exceeded 10% of the time (including freshwater inputs); **568L** is the same ratio, but it does not include upstream watershed freshwater inputs). Other indicators were: **590**, the number of urban acres within the 500-year floodplain; **277** the runoff-precipitation ratio; and **175C** annual covariance (an index comparing monthly mean runoff and monthly mean precipitation).

In both projected epochs, and for both the wet and dry scenarios, the VA/WOWA score remained below the level of the top 20% of vulnerabilities. The scores increased by approximately 2% (dry) to 7% (wet) between the earlier and the later epochs. The increases over time indicate that there might be a later epoch (than the late 21st century) in which the vulnerability of the Connecticut Coastal watershed (HUC 0108) to projected trend impacts with respect to the flood risk business line would result in a “vulnerable” assessment, scored in comparison to other HUC-4 basins. The scores are summarized in **Table 3**, and the indicators themselves are listed in **Table 4**.

Other important contributors at this location include runoff precipitation and urban development within 500-year floodplains.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Thresho..	ORness
Flood Risk Reduction	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

40.01 53.79

	Dry	Wet
2050	1 HUC(s) selected **0 HUC(s) vulnerable**	1 HUC(s) selected **0 HUC(s) vulnerable**
2085	1 HUC(s) selected **0 HUC(s) vulnerable**	1 HUC(s) selected **0 HUC(s) vulnerable**

Indicator

- 175C_ANNUAL_...
- 277_RUNOFF_P...
- 568C_FLOOD_M...
- 568L_FLOOD_M...
- 590_URBAN_500...

HUC	District
0108	NAE

National Standard Settings?
Yes

© 2023 Mapbox © OpenStreetMap

Figure 45: Output of the VA Tool indicates the Connecticut River Basin watershed is not among the 20% most vulnerable CONUS watersheds for the Flood Risk

Reduction business line under wet and dry scenario projections in both the 2050 and 2085 epochs.

Table 3: Projected Vulnerability with Respect to Flood Risk Reduction

Connecticut River Basin Watershed (HUC 0108)	Projected Vulnerability with Respect to Flood Risk Reduction			
	Flood Risk Reduction Vulnerability Score			
	2050 Dry	2050 Wet	2085 Dry	2085 Wet
568C Flood Magnification – change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream inputs) to 571 in base period. *See **Footnote***	1.1037	1.2390	1.1430	1.3222
568L Flood Magnification – change in flood runoff: ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period. *See **Footnote***	1.1037	1.2390	1.1430	1.3222
590 Urban 500-year Floodplain Area – Acres of urban area within the 500-year floodplain	13.45	13.45	13.59	13.59
277 Runoff Precipitation – Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation	1.7371	1.7471	1.6721	1.7145
175C Annual Covariance – long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative)	0.21343	0.20985	0.20991	0.21589

***Footnote**:*

The 568C (**C**umulative) and 568L (**L**ocal) *indicator values* have similar definitions, but their *importance weights* are different. The overall WOWA score (vulnerability score) accounts for the *indicator value* and the *importance weights* to compute the vulnerability score. This is why the WOWA scores listed in the VA tool have different values.

"Some indicators are more directly relevant to a business line than others, so giving every indicator the same weight would be inappropriate – Instead, the tool uses subjective weights that assign more weight to indicators that are highly relevant or important." – VA User Manual

Table 4: Comparison of Different Indicators for the Connecticut River Basin Hydrological Unit

Connecticut River Basin Hydrological Unit (HUC 0108)				
Indicator	**Indicator Contributions to WOWA Flood Risk Reduction Vulnerability Score (percentages)**			
	2050 Epoch		**2085 Epoch**	
	Dry	**Wet**	**Dry**	**Wet**
568C Flood Magnification – change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream inputs) to 571 in base period. *See **Footnote***	2.94	2.66	2.83	2.60
568L Flood Magnification – change in flood runoff: ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period. *See **Footnote***	9.45	8.71	9.01	8.20
590 Urban 500-year Floodplain Area – Acres of urban area within the 500-year floodplain	47.86	49.38	48.43	50.18
277 Runoff Precipitation – Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation	24.19	24.95	24.47	25.35
175C Annual Covariance – long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative)	15.56	14.30	7.04	13.67

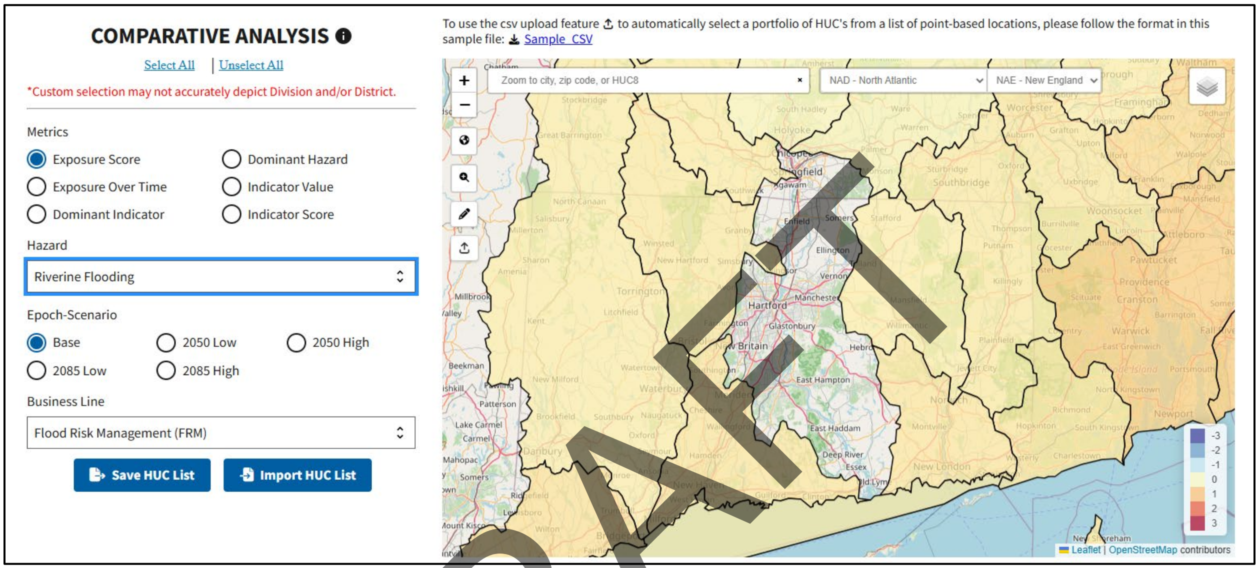
***Footnote**:*

The 568C (**C**umulative) and 568L (**L**ocal) *indicator values* have similar definitions, but their *importance weights* are different. The overall WOWA score (vulnerability score) accounts for the *indicator value* and the *importance weights* to compute the vulnerability score. This is why the WOWA scores listed in the VA tool have different values.

"Some indicators are more directly relevant to a business line than others, so giving every indicator the same weight would be inappropriate – Instead, the tool uses subjective weights that assign more weight to indicators that are highly relevant or important." – VA User Manual

Civil Works Vulnerability Assessment

The CWVAT is an assessment tool, introduced for USACE use in 2025, that compares vulnerability in 8-digit-HUC-specific watersheds. This update to the previous tool reviews a wider range of the United States, including locations outside the continental US to include, for example, locations in Hawaii and Alaska. For the Hartford/East Hartford Levee/Pumpstation project, the relevant location map is included in **Figure 46**.



COMPARATIVE ANALYSIS

Select All | Unselect All

*Custom selection may not accurately depict Division and/or District.

Metrics
● Exposure Score ○ Dominant Hazard
○ Exposure Over Time ○ Indicator Value
○ Dominant Indicator ○ Indicator Score

Hazard: Riverine Flooding

Epoch-Scenario
● Base ○ 2050 Low ○ 2050 High
○ 2085 Low ○ 2085 High

Business Line: Flood Risk Management (FRM)

To use the csv upload feature to automatically select a portfolio of HUC's from a list of point-based locations, please follow the format in this sample file: Sample_CSV

Figure 46: CWVAT Location Map Highlighting the Lower Connecticut "HUC-8" 01080205

CWVAT General Assessment

The HUC is noted with a red star in **Figure 47**, showing the location in the eastern United States.

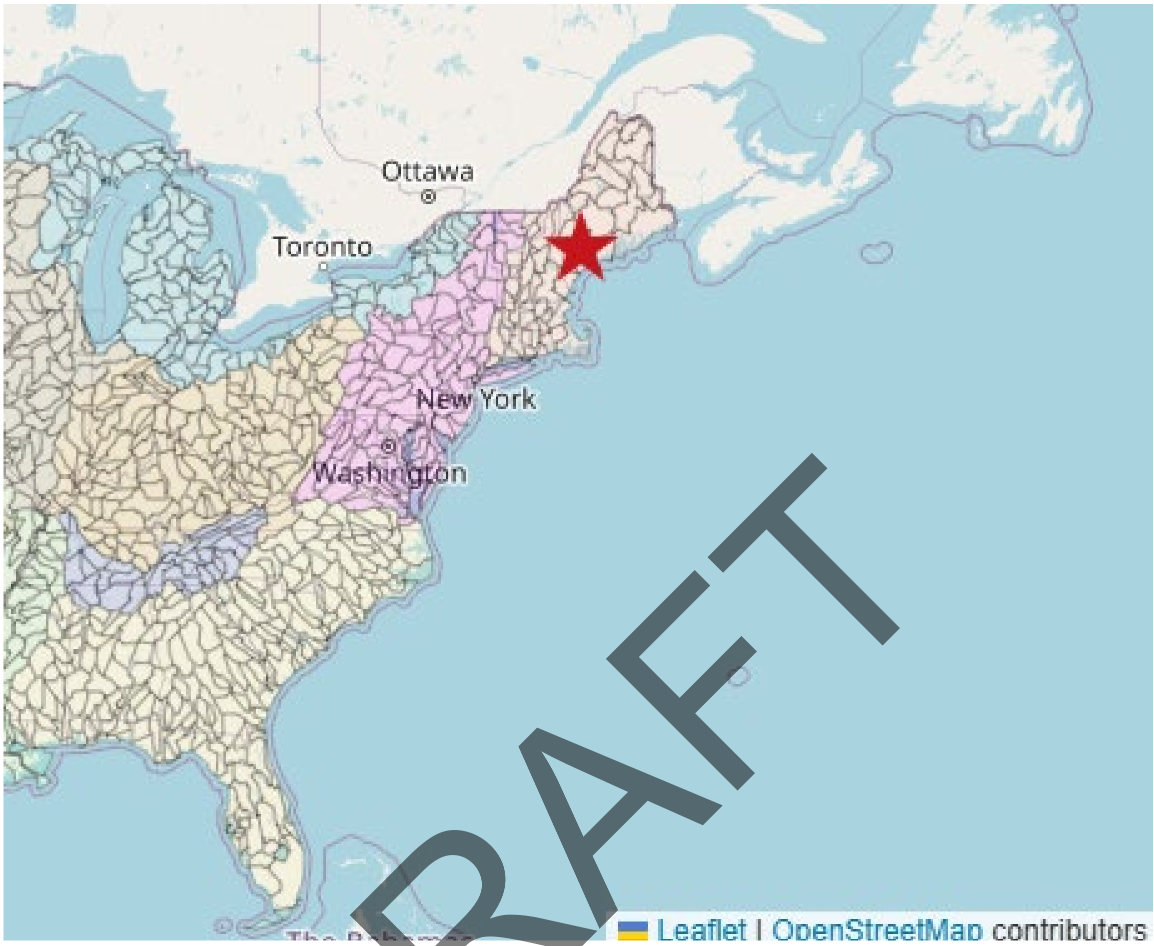


Figure 47: CWVAT Map Showing the Location of the Lower Connecticut 01080205 HUC

The Exposure Score metric shows the spread of exposure scores for the selected watersheds and epoch-scenario. See **Figure 48**. The metric helps evaluate how exposure ranges across the watersheds. The “All Hazards” dropdown has been selected after review of the objectives and the available data. This subsection deals with the less specific general assessment. The accompanying visualization in **Figure 49** shows a box plot with the minimum and maximum values across all watersheds. The overlaid points represent where the selected watersheds fall within the entire population of exposure score values.

This project area vulnerability assessment report was created on 07/25/2025 and focuses on the impacts of eight hazard categories on the General business line for the Hartford Levees/ Pumpstations. The first section of the report, the project area vulnerability assessment, provides an overview of the overall exposure, dominant hazards, and dominant indicators for the selected project area. The second section, the hazard vulnerability assessment, focuses on the impacts of all eight hazard categories on the General business line for the selected project area.

Because this assessment is focused on the General business line, more focused attention on mean annual runoff, riverine flooding, and extreme precipitation follow the CWVAT's standard write-up for the "General" case. Anticipated updates to the CWVA Tool will support a more direct focus on a given business line (in the case of the Lower Connecticut River Watershed HUC, a **flood risk reduction** business line is of great importance).

Overall Exposure

The Hartford Levees/ Pumpstations project has an overall exposure ranging from Medium to Medium-High across all epoch-scenarios with exposure scores ranging from −0.07 to 1.29. These exposure scores place the project in the 10th to 40th deciles across all epoch-scenarios. Additionally, the watershed or project area is most exposed during the 2085 High epoch-scenario. The exposure for the watershed or project area during this epoch-scenario is Medium-High (z-score of 1.29). The watershed or project area sees the largest change in overall exposure between the 2050 High and 2085 High epoch-scenario with a change in z-score from 0.57 to 1.29. This comparison considers only the difference between consecutive epoch-scenarios (e.g., Base to 2050 and 2050 to 2085). For a comparison across all epoch-scenarios, refer to **Figure 49**. Z-scores are a measure of how many standard deviations the exposure for this watershed or project area is above the median exposure score of all watersheds across the continental US (CONUS), Alaska (AK), and Hawaii (HI). Shown graphically in **Figure 48** are the z-scores for the five epoch scenarios and a table of the corresponding exposure scores, change in exposure scores between epochs, and the percentile in which the exposure score falls for each epoch-scenario.

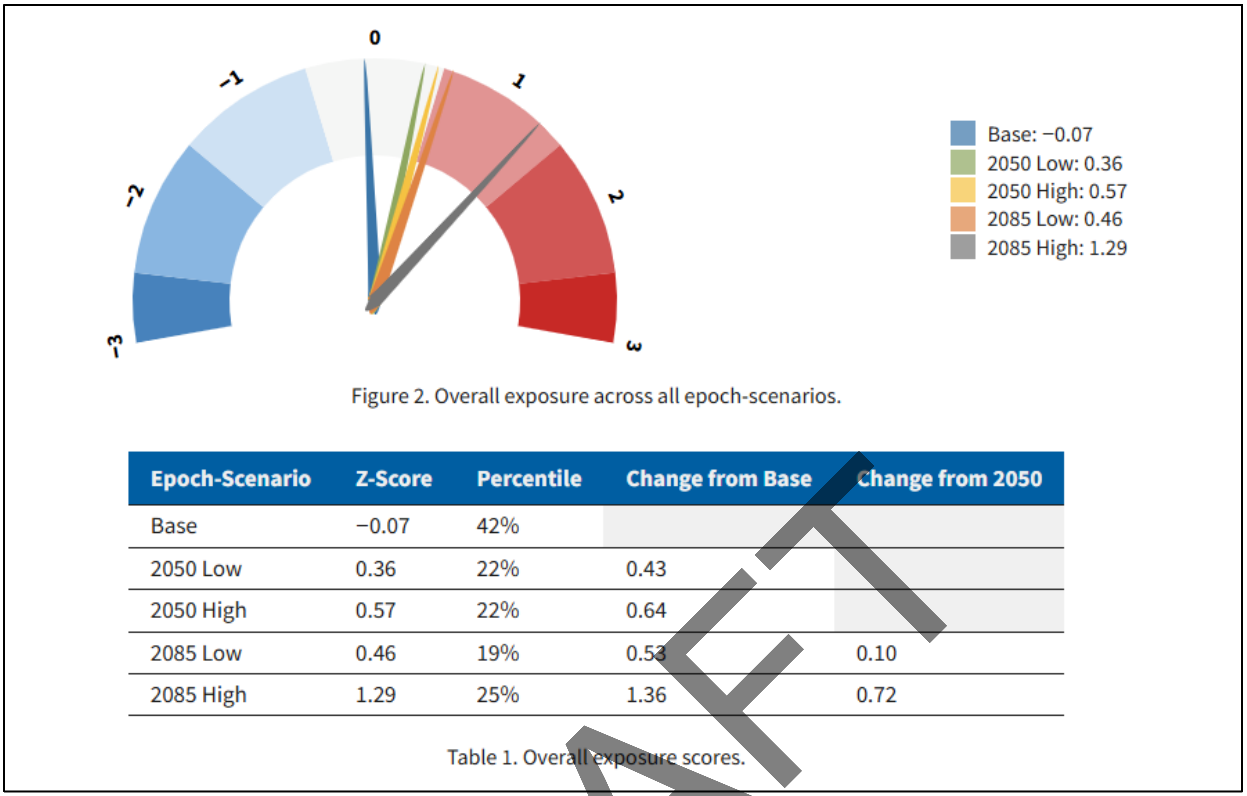


Figure 2. Overall exposure across all epoch-scenarios.

Epoch-Scenario	Z-Score	Percentile	Change from Base	Change from 2050
Base	−0.07	42%		
2050 Low	0.36	22%	0.43	
2050 High	0.57	22%	0.64	
2085 Low	0.46	19%	0.53	0.10
2085 High	1.29	25%	1.36	0.72

Table 1. Overall exposure scores.

Figure 48: CWVAT Exposure Overview for Lower Connecticut River Basin HUC-8.

Hazard Exposure
The CWVAT evaluates a watershed's or project area's total exposure to eight hazards: Wildfire, Drought, Coastal Flooding, Riverine Flooding, Extreme Temperature, Energy Demand, Land Degradation, and Historic Extreme Conditions. Note, the Historic Extreme Conditions hazard consists of static indicators which measure historic extremes.

Figure 48 (above) and **Figure 49** (below) show the hazard exposure scores across the five evaluated epoch-scenarios (current base or four future cases) for all eight hazards.

For Base and 2050 Low epoch-scenarios, the watershed or project area is most exposed to Historical Extreme Conditions.

For 2050 High, 2085 Low, and 2085 High epoch-scenarios, the watershed or project area is most exposed to **Riverine Flooding**.

While multiple hazards may appear to have the same score in visualizations and tables, this is a result of rounding and does not indicate identical underlying values.

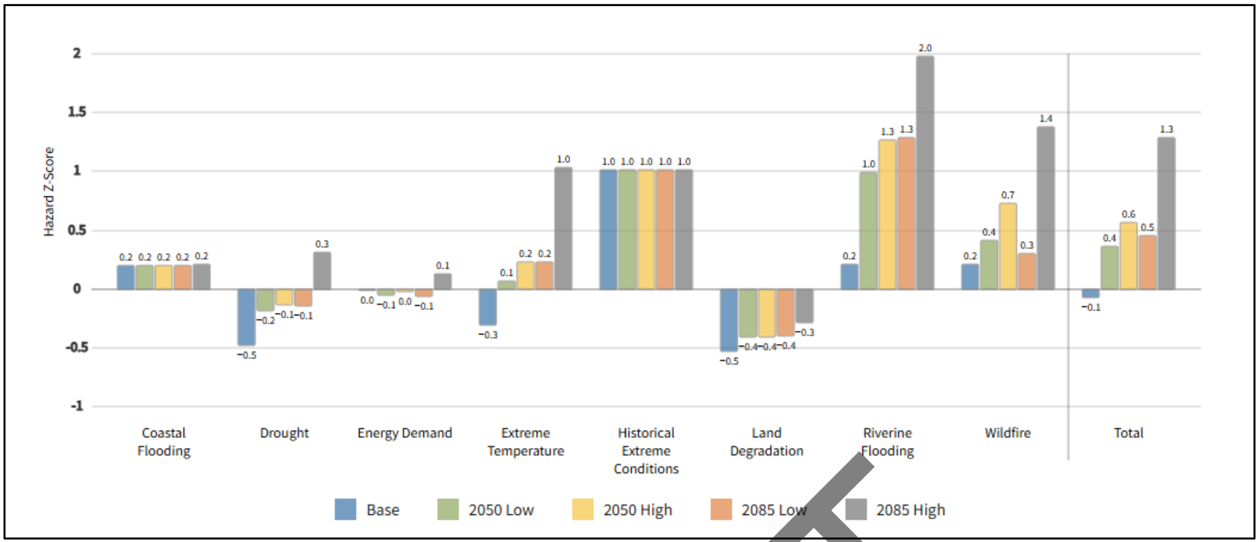


Figure 49: Hazard Scores for Lower Connecticut 01080205 HUC

Indicator Scores

For the Base and 2050 Low epoch-scenarios, Ice Jam Occurrence is the indicator with the highest normalized indicator score. Ice jam occurrence is the number of ice jams observed on rivers within the watershed over the period from 1900 to 2020.

For the 2050 High, 2085 Low and 2085 High epoch-scenarios, Extreme Precipitation Days is the indicator with the highest normalized indicator score. Extreme Precipitation Days is the average annual number of days that precipitation in a future epoch scenario is greater than what would have been considered an extreme precipitation day historically (the historic period 1% annual chance event storm). Extreme precipitation days measures how often rainfall in future storms exceeds that in the most extreme storms historically for a given location.

Table 5 shows the top ten indicators for all hazards across the five epoch-scenarios, for the Lower Connecticut River Watershed (HUC 01080205).

Table 5: Top Ten Indicators for All Hazards across the Five Epoch-Scenarios, for the Lower Connecticut River Watershed (HUC 01080205).

Rank	Base	Z-score	2050-Centered Epoch Indicators and Z-scores				2085-Centered Epoch Indicators and Z-scores			
			Low	Z	High	Z	Low	Z	High	Z
1	Ice Jam Occurrence	1.81	Ice Jam Occurrence	1.81	Extreme Precipitation Days	1.99	Extreme Precipitation Days	2.06	Extreme Precipitation Days	3.46
2	Wildland Urban Interface	1.45	Extreme Precipitation Days	1.50	Ice Jam Occurrence	1.81	Ice Jam Occurrence	1.81	High Heat Days	2.17
3	Tropical Cyclone Frequency	1.26	Wildland Urban Interface	1.45	Wildland Urban Interface	1.45	Wildland Urban Interface	1.45	Ice Jam Occurrence	1.81
4	Ice Storms Occurrence	1.19	Tropical Cyclone Frequency	1.26	Tropical Cyclone Frequency	1.26	Tropical Cyclone Frequency	1.26	Flash Drought Frequency	1.59
5	Tropical Cyclone Destructive Winds	0.91	Ice Storms Occurrence	1.19	Ice Storms Occurrence	1.19	Ice Storms Occurrence	1.19	Wildland Urban Interface	1.45
6	Tropical Cyclone Maximum Precipitation	0.87	Tropical Cyclone Destructive Winds	0.91	Tropical Cyclone Destructive Winds	0.91	Tropical Cyclone Destructive Winds	0.91	Tropical Cyclone Frequency	1.26
7	Heating Degree Days	0.64	Tropical Cyclone Maximum Precipitation	0.87	Ignition Rate	0.91	Tropical Cyclone Maximum Precipitation	0.87	Ignition Rate	1.19
8	Ignition Rate	0.63	Ignition Rate	0.70	Tropical Cyclone Maximum Precipitation	0.87	High Heat Days	0.86	Ice Storms Occurrence	1.19
9	Frost Days	0.52	Maximum 1-Day Precipitation	0.60	High Heat Days	0.87	Ignition Rate	0.74	Tropical Cyclone Destructive Winds	0.91
10	5-Day Minimum Temperature	0.51	High Heat Days	0.58	Flash Drought Frequency	0.72	Maximum 1-Day Precipitation	0.69	Maximum 1-Day Precipitation	0.88

In these ranking scores, selected normal probabilities are presented in **Table 6** to help with interpretation. Although the measures may not be normally distributed, the normal distribution is a useful indicator of whether an observation is near to, or far from, the central median value.

Table 6: Normal Distribution Key – for review of Lower Connecticut River Watershed (HUC 01080205), compared to other HUC-8 regions in the CW VAT database

Variate Z	Percent Greater	Variate Z	Percent Greater
-0.07	53% (base condition for the HUC-8).	**1.64**	5% (1-in-20)
0.0	50% (median value; 1-in-2; exceeded by half of the HUC-8 watersheds).	**1.96**	2.5% (1-in-40)
0.25	40% (2-in-5)	**2.33**	1.0% (1-in-100)
0.53	30% (3-in-10)	**2.57**	0.5% (1-in-200)
0.68	25% (1-in-4) (upper band of the interquartile range or shaded “box” in a typical box-and-whisker plot)	**3.09**	0.1% (1-in-1,000)
0.84	20% (1-in-5)	**3.29**	0.05% (1-in-2,000)
1.28	10% (1-in-10)	**3.46**	0.027% (1-in-3,700) High projected result for extreme precipitation days, 2085 epoch

For all three indicator scores (base, 2050 epoch, and 2085 epoch), the top 10 indicators are greater than 0.00 (all scores are above their respective median values). The weighted average of all scores (not just the top 10) is slightly below 0.00 for the base case (Z= -0.07 is exceeded by 53% of a population); although the top-ten tabled values are in general greater than the aggregate results for 2050 or 2085, there is an emerging pattern of the basin scores moving further away from the central value as the value of the projections extends further into the future or in moving from the “low” to the ”high” projected value.

The pattern of increasing variate Z leads to a 2085-epoch high value of Z=1.29, which is exceeded by only 10% of the HUC-8 watersheds, following a “normal distribution” assumption (the CWVAT result reports 25% in **Figure 48**, which would indicate that the result is at the upper end of the interquartile range).

Riverine Flooding

For the Lower Connecticut River Basin 01080205 HUC, the projected vulnerability is tied to riverine flooding, as shown in **Figure 50**.

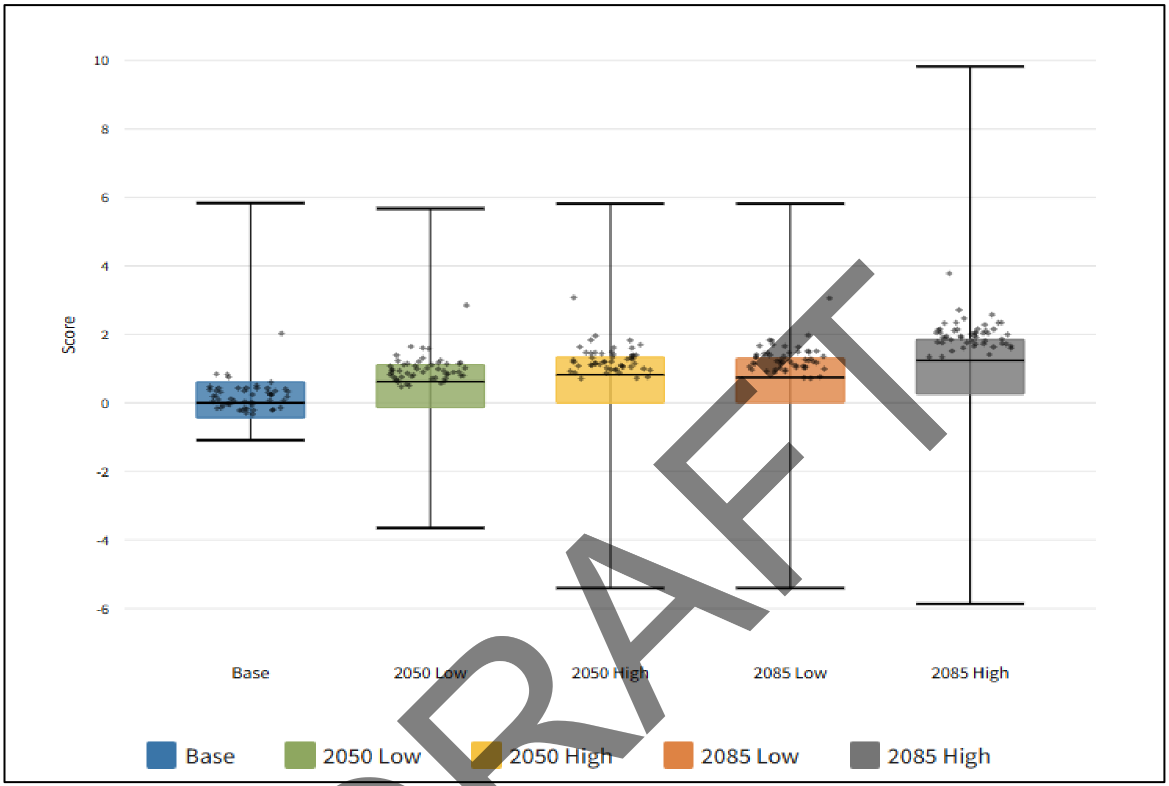


Figure 50: Riverine Flooding Exposure Scores

In the box-and-whiskers chart, the upper and lower limits of observations (or projections) represent the highest and lowest observations for the results from all the HUC-8 locations in the database, denoted with solid black horizontal lines. For each epoch scenario, there is a central colored rectangle to show the limits of the upper and lower quartiles (25% of the observations are above the rectangle, and 25% are below the rectangle). The score for the Lower Connecticut River Watershed HUC is shown with a solid horizontal line. For this HUC, the HUC score falls inside the colored rectangle, indicating that it falls within the range of the central 50% of observations, for both the base case and the four epoch scenarios (the 2050 high and low cases, and the 2085 high and low cases).

It should be noted that although the watershed is more vulnerable to flooding in the projected future epochs (scores rising), the Z-scores for the HUC remain close to the middle of the central rectangle, which is projected to rise over time. Consequently, although the vulnerability does increase, the increase is smaller relative to that of the other HUCs.

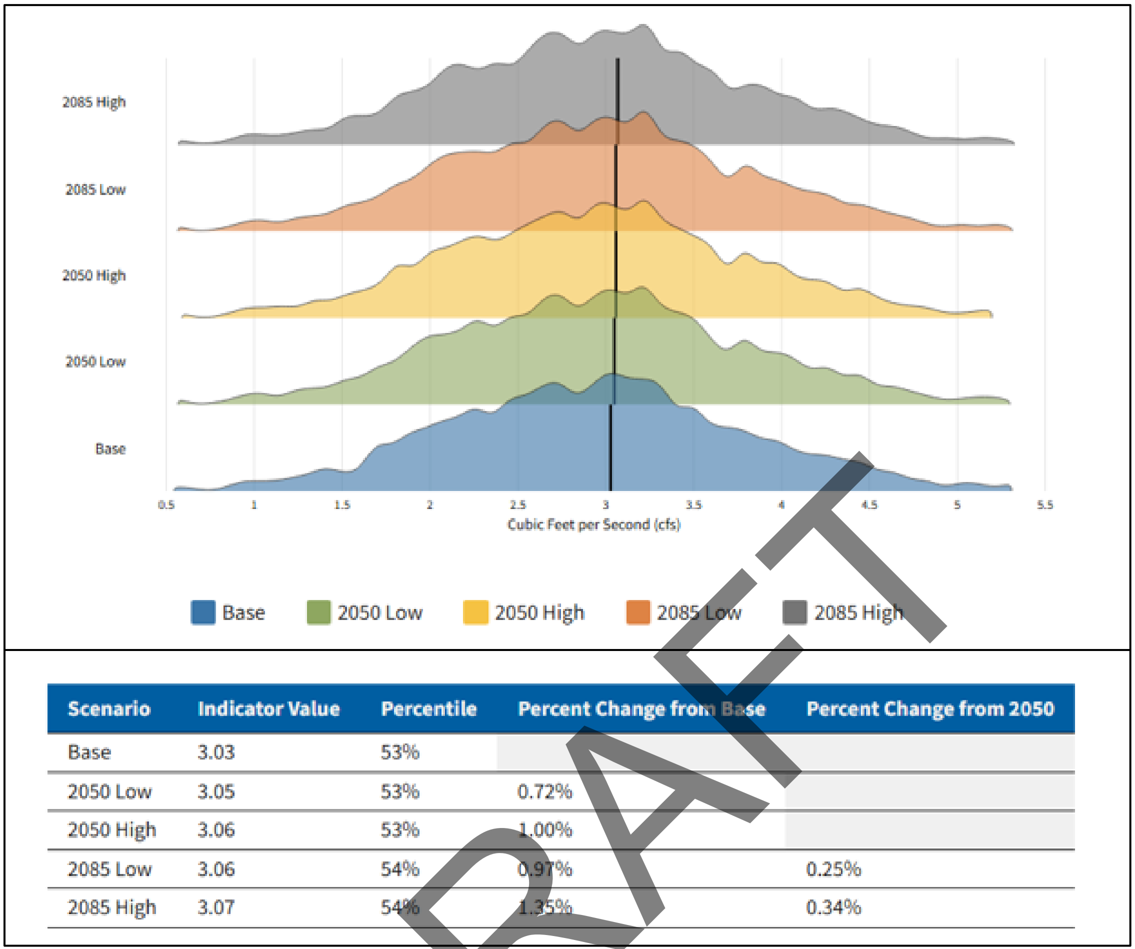
Two parameters have been reviewed for their potential contributing effects to the increasing riverine flooding projections. These are **mean annual runoff** and **extreme precipitation days**.

Mean Annual Runoff

The mean annual runoff is of value in establishing whether the watershed is susceptible to changes that might affect water-related activities such as navigation, hydroelectricity, and water supply (urban or agricultural). While any increase in MAR would have some association with increased flooding, this does not appear to apply for the Lower Connecticut River Watershed. As shown in **Figure 51**, there is minimal change in the MAR projections for either the 2050 or 2085 epochs.

Mean Annual Runoff is the average annual discharge (volume of water) from the entire watershed upstream of the downstream-most boundary of the Hydrologic Unit Code Level 8 (HUC8) for the largest river in this watershed. This is an estimate of unregulated flows, meaning the effects of water storage and flood releases are not taken into account. This indicator is based on cumulative inflows from watersheds upstream of this specific HUC-8 watershed.

Units: Cubic Feet per Second (CFS) (Normalized to cfs per square mile).



Scenario	Indicator Value	Percentile	Percent Change from Base	Percent Change from 2050
Base	3.03	53%		
2050 Low	3.05	53%	0.72%	
2050 High	3.06	53%	1.00%	
2085 Low	3.06	54%	0.97%	0.25%
2085 High	3.07	54%	1.35%	0.34%

Figure 51: MAR Summary Views for Lower Connecticut River Basin 01080205 HUC

The increasing riverine flooding scores, shown in **Figure 50**, is therefore derived more from sudden changes such as storm events. Extreme Precipitation Days, which are highlighted in **Table 5**, are therefore reviewed in the next subsection.

Extreme Precipitation Days

The increasing value of the number of extreme precipitation days per year increases from a current (base) value of 3.6 days, up to 4.8-to-5.1 days per year for the 2050 epoch to 5.2-to-6.2 days per year in the 2085 epoch. This is shown in **Figure 52**.

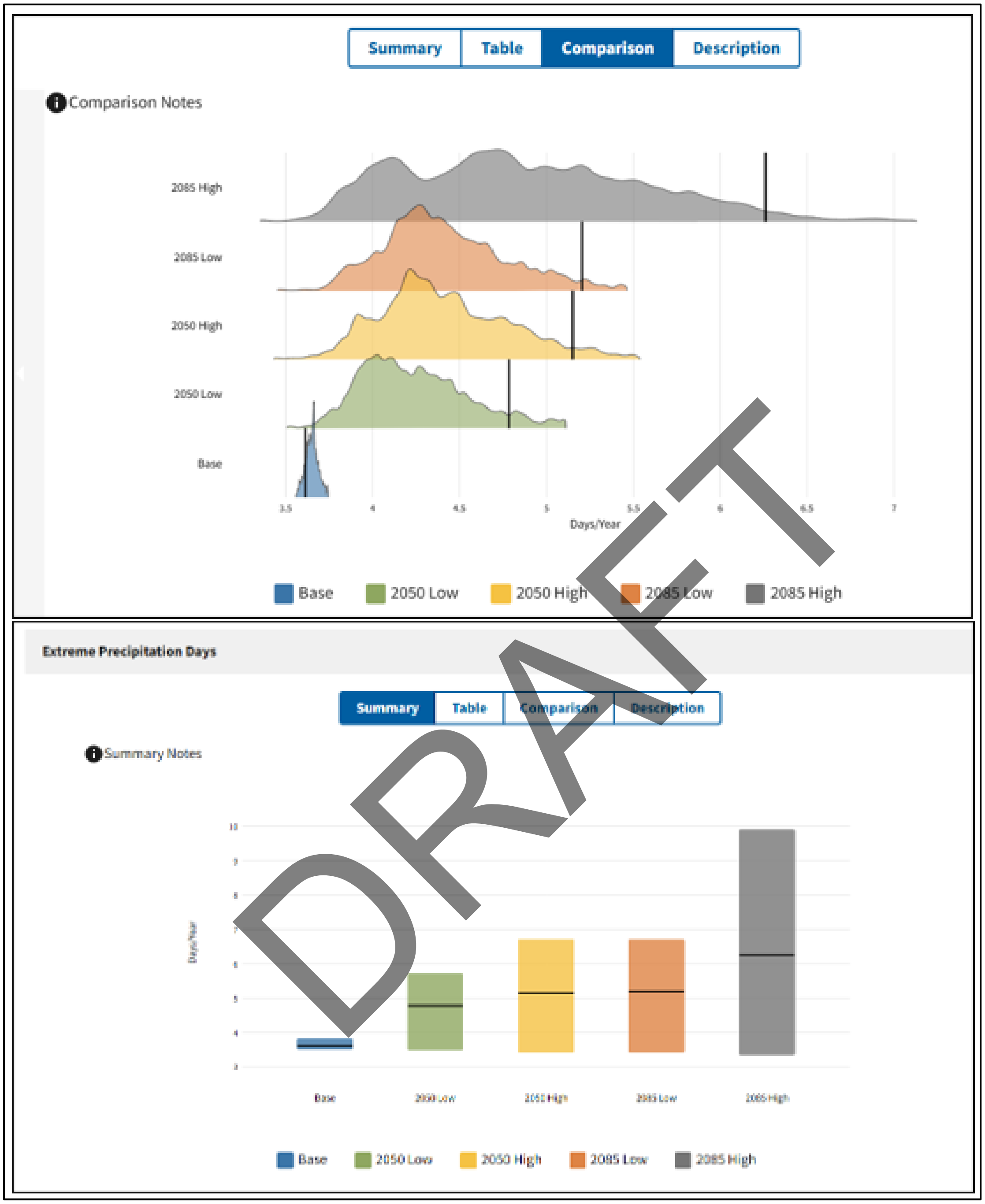


Figure 52: Extreme Precipitation Days Summary Views for Lower Connecticut River Basin Watershed (HUC 01080205)

Extreme Precipitation Days is the average annual number of days that precipitation in a future epoch scenario is greater than what would have been considered an extreme precipitation day historically (the historic period 1% annual chance event storm). Extreme precipitation days measures how often rainfall in future storms exceeds that in the most extreme storms historically for a given location.

Units: Days/Year

CW VAT Summary

The Connecticut River Basin HUC-8 (01080205) results are noted to be affected largely by cold weather, indicated by ice jams, ice storms, and frost days (color-coded in light blue in **Table 5**), and these are expected to have a major influence in the total vulnerability of the watershed, relative to the rest of the Hydrologic Units that were assessed. Projecting into the future, the effects of ice diminish to lower positions on the ranking lists, while rain events (listed as Extreme Precipitation Days, Tropical Cyclone Frequency, Tropical Cyclone Maximum Precipitation, Tropical Cyclone Destructive Winds, and Maximum 1-Day Precipitation - yellow color-coding) play a greater role in the projected indicators. Heating does contribute to the vulnerability assessment (green coding for heating degree days, ignition rate, high heat days, flash drought frequency), and this may have an effect on ice jam occurrence.

The focus of this report is on flood risk management, and so attention is directed to Extreme Precipitation Days (days with rainfall above what in the base period has been listed as the 100-year case), which are listed high in the 2050 and 2085 rankings, and generated scores of 1.50 to 1.99 in the 2050 epoch (at the top 7 to 2 percent of HUC-8 results for this parameter), rising to 2.06 to 3.46 in the 2085 epoch (at the top 2 to 0.03 percent of results).

While vulnerability to **mean annual runoff** is not projected to change significantly relative to other HUCs in the database, the **extreme precipitation days'** (**Figure 52**) contribution to the increased **riverine flooding** (**Figure 51**) indicators are projected to increase relative to the rest of the database.

Conclusion

Recent technical literature indicates trends of rising mean and extreme temperatures. The literature indicates precipitation mean and extreme values show rising trends. The literature is ambiguous, however, on stream runoff trends. As a result, projections of future streamflows are mixed and depend on the selected model and its assumptions. Observed trends in streamflow vary by season, but some evidence exists of increasing flows on average.

There were strong nonstationarities (affirmative detections of a non-stationarity, by a minimum of two standard tests in the Time Series Tool, each at the 95% confidence level ($p<0.05$), for a given 1-to-5-year period), and one overall monotonic trend detected for the computed data set for mean and peak annual inflows (detection of a trend for a rising or falling flow or water level over a period of years, confirmed by at least one standard statistical test in the TST, at the 95% confidence level ($p<0.05$)). The trends of increasing or decreasing flows over time for various subsets of the data **prior to completion of the**

upstream network of USACE FRM dams have been discounted. It was not clear from local records whether the more recent trend-free periods continued; the lack of clarity is due both to gaps in the records and to nonstationarities. Local peak flows in Hartford and East Hartford appear to have been neither rising nor falling, although, for the record in the more rural East Hartford drainage area, changes in land use may increase the likely surface-flow response to rainfall events.

Local streamflows are projected to increase the average and peak streamflow in drainage areas on both east and west sides of the Connecticut River during the 21st century. This effect would likely be exacerbated by changes to infrastructure that might include extended urban development.

Runkle et al (2022) reported that the frequency of 2-inch-plus precipitation days had been increasing in Connecticut in recent decades. Experience in 2023 at nearby USACE dams supports this assessment.

As a result, projections of future streamflows are mixed and depend on the selected model and its assumptions (the literature review rather than the site-specific data review). Observed trends in streamflow vary by season, but some evidence exists of increasing local flows on average (Park and Hockanum drainage areas).

Nonstationarities and monotonic trends were detected at the gages most relevant to the leveed systems. For the Connecticut River, upstream construction of substantial USACE FRM dams on tributaries to the mainstem Connecticut River was completed in 1969, and so earlier nonstationarities and monotonic trends can be ignored, but the post-1969 situation needs to be well understood. The post-1969 record does include nonstationarities and so the subsequent record is taken to show a static water level at 6.0 ft NAVD, rather than the gently falling water level that results from data regression; but the "gently falling" regression had less than 95% certainty (p-values greater than 0.05). Gaps in the records added to the uncertainty concerning recent trends in average and monthly annual peak values of mean monthly flows.

The Connecticut River watershed, which includes significant drainage basin area in Vermont, New Hampshire, and Massachusetts as well as Connecticut, is not vulnerable in the flood risk management business line compared to other CONUS watersheds, with a major vulnerability being the population residing in the 500-year floodplain. The overall vulnerability, measured "small" (not in the top 20% of CONUS watersheds), was shown to be rising over time. This leads to the possibility that the HUC will at a later time (later than the 2085 epoch) be classified "vulnerable" relative to the rest of CONUS watersheds.

The more recent Civil Works Vulnerability Assessment Tool, with a focus on a smaller watershed area (the Lower Connecticut basin, ending roughly at the Massachusetts border with New Hampshire and Vermont), supports the earlier VAT assessment, although it does raise the estimate of vulnerability for the 2085 epoch, under the "high" estimate, to between "top 10%" and "top 25%" vulnerability relative to the rest of the assessed HUC-8 watersheds.

As indicated in **Table 7**, the projected hydrology has potential to result in increased hazard to system operations, primarily in relation to relative sea-level rise during the 21st century. The table outlines how named measures under consideration in the study might affect the flood mitigation mission of the USACE in Hartford and East Hartford.

Table 7: Residual Risk to Hartford/East Hartford Levee System Due to Projected Hydrological Trends

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Improvements to floodwalls and levees. e.g., address seepage at embankments	Reduced seepage through the levees to the rivers leads to increased flow into the town/city drainage systems and pump stations. Inland storm upstream on the Connecticut River. Coastal storm in the Atlantic and its effect on the Connecticut River.	Requires changes in timing for pumping. Upstream storm raises the Connecticut River water level, requires either more storage or increased pump capacity. Downstream tide/surge raises the Connecticut River water level, requires either more storage or increased pump capacity.	Population of 121,000 in Hartford (3,000 acres) or 51,000 in E. Hartford (760 acres) have more exposure to water from local drainage and rivers. Expect more roads to flood unless there is a plan to remove this water.	**Unlikely:** Low probability that floodwall improvements would create a new hazard. **Adaptive/Resilience notes**: **Floodwall design** could be wider to allow for the walls to be raised later as necessary. **Levee embankments** could be improved through better field placement techniques, improved soil grading curves, or river-side or land-side sloped surface design (rip-rap materials or sod materials). **Pump stations** could be designed for extra, or larger, pumps to be installed later as necessary. Detention storage could offset some pumping needs.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Increased pumping capacity. The issue of adequate pumping capacity was reviewed in Appendix B2 (hydraulics/ hydrology) but the team discovered that the pumping capacity was adequate and no further capacity was needed.	**Assuming inadequate pumping capacity, then the following issues could arise:** Inland storm flow in LPP area needs more pumping. Inland storm upstream on the Connecticut River. More on-site fuel storage. **Given that the capacity is adequate, however, the option to increase this was removed from the suite of viable improvement options.**	Increased reliance on the pumps. Infrastructure development close to inundated areas seen as more acceptable. Fuel leaks.	Population 121 k (3,000 acres), 51 k (760 acres) at risk of flooding. Increased pumping maintenance and costs. Cleanup costs if there are leaks.	**Unlikely:** Low probability that pumping improvements would create a new hazard. The pump capacity should be set, based on likely conditions. The system of USACE/Connecticut FRM dams having been completed in 1971, the system as a whole was at that time (1970s, 1980s) understood to be in good shape with limited concerns about pump station capacities. **Adaptive/Resilience notes**: **Pump stations** could be designed for extra, or larger, pumps to be installed later as necessary. Detention storage could offset some pumping needs.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Increase the detention storage adjacent to pump station(s)	Inland storm flow in LPP area needs more detention. High tailwater from the Connecticut River leads to more frequent low-level flooding.	Possible changes in timing for pumping. Less reliance on pumping: maintenance might be overlooked.	Population 121 k people (in 3,000 acres), or 51 k people (760 acres) at risk of flooding. Increased risk of drowning at the detention areas. Increased time with standing water for mosquitoes/flies to breed. Increased landscaping needs/costs.	**Unlikely.** Possible (moderate probability) that detention basin improvements would increase the frequency and depth of standing water. **Adaptive/Resilience notes**: **Handrail design** could limit danger to trespassers. **Flapgate design** could take into account a higher water level in the Connecticut River. Expect only a few days to a week of post-storm standing water in extreme events. Design needs to account for both the potential of rising tides and increases in urban development.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Increased urban development especially in East Hartford might increase the typical flow in storm events.	System designed with incorrect sizing for assumed flow from Hartford/ East Hartford to the Connecticut River. Note that site-specific projections from the CHAT indicate that the annual peak flows are expected to increase, regardless of infrastructure changes in the Hartford/ East Hartford drainage basins.	Pump capacity inadequate during high-flow storm events in Hartford (or more likely East Hartford).	Population 121 k people (in 3,000 acres), or 51 k people (760 acres) at risk of flooding. Increased flooding potential if the hydrological conditions (precip to runoff) change.	**Likely**. Likely to be an issue for East Hartford if the area is developed: The pump capacity should be set, based on likely conditions. The existing record of flows at East Hartford (Hockanum Rvr) indicates a much smaller average annual peak inflow than for Hartford (Park Rvr), for a similar drainage basin area. The East Hartford area may develop, and flow increases would result. The system of USACE/Connecticut FRM dams having been completed in 1971, the system as a whole was at that time (1970s, 1980s) understood to be in good shape with limited concerns about pump station capacities. **Adaptive/Resilience notes**: Pump station design could allow for more pumps or bigger pumps in the future, or for more detention immediately upstream of the stations.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Repair sluice gates at pump stations and along the Park River. The Park River runs through the City of Hartford and the relevant elevations for opening and closing gates are higher along this route than for stations near the Connecticut and Hockanum Rivers This is evidenced in the higher key elevations for Bushnell Station (gravity closure at 14.7 ft NAVD; pumps on at 14.2 ft NAVD; pumps off at 9.2 ft (from App 2-B2 Table 12)).	High flow in local drainage (e.g., along the Park River) or high water in the Connecticut River overwhelm the designed system. Pumps turn on more frequently, and need more maintenance.	Timing/amount of pumping changes. If the system is overwhelmed, then there would be unacceptable inundation. When the water levels in the local drainage systems are high, in response to local prolonged and/or intense rainfall, or when Connecticut River water levels are high, there is potential for a greater duration of pumping. Detention storage would become more important as a means of reducing pumping costs.	Population 121 k people (in 3,000 acres), or 51 k people (760 acres) at risk of flooding. The population in the City of Hartford would be greatly inconvenienced by misoperation of the gates on the Park River system. Although the pump stations run along the line of the Park River, including an open park area, the potential remains for increasing flooding in more built-up areas that are not directly attached to the pump stations. Pumping costs will rise when the water level is high in the Connecticut. Standing water in detention basins could become a health issue.	**Neutral to likely:** Comprehensive Hydrology Assessment Tool (CHAT) indicates the Connecticut River will rise, although site-specific gage data since the early 20th century indicates patterns of decreasing flows and water levels. Appropriate sluice gate operations would maintain adequate water head differences between the LPP protected areas and the Connecticut River. **Adaptive/Resilience notes**: Sluice gates in parallel channels would allow for future increases in flow.

Although many of the risks to this project are identified as “unlikely” (Qualitative Likelihood Column 5 in **Table 7**), potential adaptation actions for projected new hydrology still exist. The system might be overwhelmed by the combined high water in the Connecticut and high flow in the (Park and Hockanum) local drainage areas. The Connecticut River is certain to rise in coming years, in response to rising sea levels. Potential adaptation actions to address project vulnerabilities include altering management of the regional water resource system. The most immediate change would be an increase in pumping hours per month. Although **Table 7** indicates a low likelihood that projected changes would affect the normal operations or the listed features with respect to storm runoff operations, it is noted that the potential for change in the high-flow runoff patterns may become apparent with the collection of more years of runoff and/or relative sea-level-rise data and/or further hydrological modeling.

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