Appendix G – Climate Change Considerations

Overview and Purpose

Climate change (i.e., increasing precipitation and temperature and sea level rise) and its implications for stormwater management design and implementation were important considerations during the revision of this Manual for the following reasons:

- Previous guidance regarding design storm precipitation (e.g., 10-, 25-, and 100-year storms) is no longer relevant due to the shift in climate and precipitation that has been observed since the development of the original Connecticut Stormwater Quality Manual.
- Increasing trends in precipitation also include observed and projected increases in average precipitation amounts, which has implications for smaller, more frequent storms including the water quality storm.
- Rising sea levels have begun and are projected to continue to result in rising groundwater levels in coastal areas of Connecticut and elsewhere along the eastern coast of the United States.[115, 116] Rising groundwater has implications for stormwater infiltration and treatment practices along Connecticut's coast.
- The design life of many stormwater BMPs and related stormwater infrastructure is intended to be well over 20 years. Over this period, it is possible the design limits could be exceeded as a result of changing precipitation conditions, thereby reducing the effectiveness of the stormwater BMP or resulting in failure of the stormwater infrastructure.

This Manual incorporates various climate change and resilience considerations for stormwater management design and implementation:

- Preserving pre-development site hydrology using LID site planning and design strategies and structural stormwater BMPs
- Updated design storm precipitation for stormwater quantity and quality control

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[115] Jasechko, S., Perrone, D., Seybold, H. et al. Groundwater level observations in 250,000 coastal US wells reveal scope of potential seawater intrusion. Nat Commun 11, 3229 (2020). https://doi.org/10.1038/s41467-020-17038-2

[116] Bjerklie, D.M., Mullaney, J.R., Stone, J.R., Skinner, B.J., and Ramlow, M.A., 2012, Preliminary investigation of the effects of sea-level rise on groundwater levels in New Haven, Connecticut: U.S. Geological Survey Open-File Report 2012–1025, 46 p., at http://pubs.usgs.gov/of/2012/1025/.

- Sea level rise and other considerations for stormwater BMP siting and design in coastal areas
- Design considerations for mitigating the potential negative impacts of climate change on stream temperatures and nutrient loads.

This appendix provides additional details regarding climate change and stormwater impacts in Connecticut, including the basis for the selected approach to incorporating updated design storm precipitation and other climate change considerations into this Manual.

Evaluating Design Storm Approaches

Approach

During the development of this Manual, the Workgroup evaluated various approaches to updating design storm precipitation in Connecticut by considering: 1) observed changes in precipitation since the release of the original Connecticut Stormwater Quality Manual in 2004, and 2) potential future changes in precipitation, both for projects designed today and at some point in the future, over the design life of the stormwater infrastructure.

The Workgroup evaluated design storm approaches in stormwater manuals of other states within the region. The Workgroup reviewed these approaches both in terms of current design storm precipitation and consideration of future precipitation and climate change (see Table G-1). It is also important to note that while the current versions of the other state stormwater manuals did not explicitly include consideration of climate change and future precipitation, several states had related guidance on resilient infrastructure design accounting for future climate change (e.g., Resilient MA Action Team guidance documents including Climate Resilience Design Standards and Guidelines Tool, and New Jersey Climate Resiliency Strategy) and several states (Massachusetts and New Hampshire) were in the process of updating their manuals and/or design storm precipitation to account for ongoing and future climate change effects. Furthermore, many states were considering creating a more concrete connection between stormwater management and climate change and actively researching potential avenues to do so. The activities of the Governor's Council on Climate Change and associated policy recommendations, as well as research and precipitation projections developed by the Connecticut Institute for Resilience and Climate Adaptation (CIRCA), were also reviewed to inform the design storm approach for Connecticut and the revised Manual. Based on the stated goals of the Manual update and the Workgroup's review, it was clear that Connecticut's revision of this Manual needed to consider both observed and potential future changes in precipitation as a result of climate change.

Table G-1. Design Storm Precipitation Approaches of State Stormwater Management Programs in the Northeast U.S.

State	Stormwater Quantity Control Design Storm		Water Quality Design Storm and Water Quality Volume
	Consideration for Observed Increase in Design Storm Precipitation Due to Climate Change?	Consideration for Future Increase in Design Storm Precipitation Due to Climate Change?	
Connecticut	No (TP-40)	No	Initial 1 inch of rainfall over contributing drainage area, runoff coefficient approach to calculate runoff
Massachusetts	No (TP-40) Proposed NOAA Atlas 14+ in updated guidance	Yes Proposed NOAA Atlas 14+ in updated guidance	Initial 1 inch of runoff from contributing impervious area
Rhode Island	Yes (NRCC)	No	Same as Massachusetts
New Hampshire	Yes (NRCC)	Updated design storms for climate change is a stated goal of the ongoing manual update	Same as Connecticut
Vermont	Yes (NOAA Atlas 14)	No	Same as Connecticut
Maine	Yes (NRCC)	No	Initial 1 inch of runoff from impervious area plus 0.4 inch of runoff from pervious area
New York	Yes (NRCC)	No	Initial 1 to 1.5 inches of rainfall over contributing drainage area, runoff coefficient approach to calculate runoff
New Jersey	Yes (NOAA Atlas 14)	No	1.25-inch, 2-hour rainfall, rainfall runoff modeling to calculate runoff

TP-40: National Weather Service Technical Paper 40 (out of print, last updated for Connecticut in 1977)

NRCC: Extreme Precipitation in New York and New England, Northeast Regional Climate Center

NOAA Atlas 14: NOAA Atlas 14 Volume 10 Version 3, Precipitation-Frequency Atlas of the United States, Northeastern States. NOAA, National Weather Service, 2015, revised 2019. https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

NOAA Atlas 14+: 90% of the upper limit of the 90th percentile confidence interval (NOAA Atlas 14)

Options Evaluated

Stormwater Quantity Control Design Storm

As described above, the Workgroup evaluated several alternative approaches for updating the stormwater quantity control design storm precipitation (24-hour design storm depths) in the revised Manual (Table G-2).

The first three options in Table G-2 utilize NOAA Atlas 14 values (median, 90% of the upper limit of the 90% confidence interval, or the upper limit of the 90% confidence interval), which are readily available from the NOAA Atlas 14 Precipitation Frequency Data Server web tool. NOAA14+ and NOAA14++ reflect the upper range of current extreme precipitation.

The fourth option in Table G-2 is similar to the approach used by Massachusetts in the RMAT Climate Resilient Design Standards and Guidelines Tool in which downscaled GCM precipitation estimates are used to estimate statewide or regional percent increases to the NOAA Atlas 14 median values. To help evaluate this alternative approach for Connecticut, the Connecticut Institute for Resilience & Climate Adaptation (CIRCA) provided downscaled estimates of 24-hour maximum precipitation for Hartford, New London, Bridgeport, and a statewide ensemble average. Downscaled precipitation estimates were provided for baseline (1970-1999) conditions and mid-century (2040-2069) and late century (2070-2099) future planning horizons, as well as for four different return periods (10-yr, 20-yr, 50-yr, and 100-yr). The estimates were derived using the Multivariate Adaptive Constructed Analogs (MACA) climate downscaling method as described in the Connecticut Physical Climate Science Assessment Report (PCSAR).[117] The NOAA Atlas 14 median values were then multiplied by the ratio of future to baseline statewide average downscaled precipitation estimates to derive estimated future 10-year and 100-year 24-hour rainfall depths. This "NOAA14 Future Downscaled" method accounts for anticipated future increases in precipitation associated with climate change projections, using the relative change in downscaled precipitation as the basis for increasing the NOAA Atlas 14 precipitation frequency estimates.

In addition to 24-hour rainfall depths, the rainfall distribution – how rain falls during a storm event – is also important in calculating the peak flow rates of stormwater runoff. Precipitation events typically begin with a lighter intensity, followed by a period of higher-intensity rainfall, and then gently tapering off. The USDA NRCS developed synthetic rainfall distributions from historical records from the different regions of the country based on the assumption that the rain distribution is bell-shaped. The NRCS rainfall distributions were grouped into four types according to the applicable regions. Type III distributions historically have been used in Connecticut, where tropical storms produce large 24-hour rainfall events.

[117] Connecticut Physical Climate Science Assessment Report (PCSAR), Observed trends and projections of temperature and precipitation, August 2019, Connecticut Institute for Resilience and Climate Adaptation and University of Connecticut Atmospheric Sciences Group.

Table G-2. Alternative Approaches Considered for Updating Stormwater Quantity Control Design Storm Precipitation

<table>
<tr><th>Alternative</th><th>Description</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>NOAA Atlas 14</td><td>NOAA Atlas 14 (median values)</td><td>• Reflects observed increases in precipitation to date (e.g., 2014)
• Easy to use - values reported directly from Atlas 14 website
• Values already adopted in CT DEEP Stormwater General Permits and by CTDOT</td><td>• Does not account for anticipated future increases in precipitation associated with climate change projections</td></tr>
<tr><td>NOAA Atlas 14+</td><td>90% of the upper limit of the 90th percentile confidence interval</td><td rowspan="2">• Reflects upper range of current expected storms
• Generally consistent with anticipated future increases in precipitation associated with climate change projections
• Provides greater resilience for infrastructure than NOAA Atlas 14 median values
• Larger stormwater controls better able to accommodate runoff from larger storms, less localized urban flooding
• Easy to use - 90th percentile confidence interval values reported from Atlas 14 website</td><td rowspan="2">• Results in larger, more expensive stormwater quantity controls such as stormwater basins or subsurface storage (peak flow attenuation)</td></tr>
<tr><td>NOAA Atlas 14++</td><td>Upper limit of the 90th percentile confidence interval</td></tr>
<tr><td>NOAA Atlas 14, Future Downscaled</td><td>NOAA Atlas 14 median values multiplied by the ratio of future to baseline downscaled GCM precipitation estimates developed by CIRCA for mid-century and late-century planning horizons</td><td>• Accounts for anticipated future increases in precipitation associated with climate change projections
• Provides greater resilience for infrastructure than NOAA Atlas 14 median values
• Larger stormwater controls better able to accommodate runoff from larger storms, less localized urban flooding
• Increase in NOAA Atlas 14 values tied to CT-specific future precipitation estimates</td><td>• Results in larger, more expensive stormwater quantity controls such as stormwater basins or subsurface storage (peak flow attenuation)
• Requires periodic update of downscaled precipitation estimates by CIRCA</td></tr>
</table>

In 2015, the Northeast Regional Climate Center (NRCC) developed updated NRCS rainfall distributions for the Northeast states, including Connecticut. These NRCC rainfall distributions were then replaced in 2018 for use in the NRCS WinTR-55 computer program in CT, as NRCS derived four new regional rainfall distributions (Types N10 A, B, C, and D) from the NOAA data to cover the NOAA Atlas 14, Volume 10 study area, which supersede all previous distributions. Connecticut NRCS recommends the use of the Type N10_D regional rainfall distribution to represent the entire state of Connecticut in WinTR-55. This or site-specific rainfall distributions can be used with the NOAA Atlas 14 estimates of 24-hour precipitation depths. The NRCS Type N10_D rainfall distribution is also recommended for use with other common rainfall runoff and stormwater design programs such as HydroCAD.

Water Quality Design Storm

In Connecticut, the water quality design storm is defined by 1 inch of rainfall over a 24-hour period. The 1-inch rainfall depth was selected as the event whose precipitation total is greater than or equal to 90 percent of all 24-hour storms on an average annual basis. During development of the original Connecticut Stormwater Quality Manual in 2004, rainfall data from the Northeast U.S. indicated that the 90th percentile 24-hour rainfall event was equal to approximately 1 inch. Several of the states in the northeast, including Connecticut, adopted the 1-inch rainfall event in their stormwater manuals.

The volume of runoff generated by the 1-inch rainfall is defined as the Water Quality Volume (WQV) in the 2004 manual, and by reference in the Soil Erosion and Sediment Control Guidelines and the CT DEEP Stormwater General Permits. Conceptually, the WQV is the volume of stormwater runoff from any given storm that should be captured and treated to remove a majority of stormwater pollutants on an average annual basis. The equation used to calculate the WQV uses a volumetric runoff coefficient as a function of impervious area, a rainfall depth of 1 inch, and the drainage area to the specified design point.

The WQV and 90th percentile rainfall concepts were originally developed to <u>treat</u> the majority of 24-hours storms and the associated average annual pollutant load in stormwater runoff. In 2009, EPA released technical guidance on implementing stormwater management requirements for certain federal projects, emphasizing the use of green infrastructure (GI) and low impact development (LID) to preserve pre-development hydrology as closely as possible.[118] The 2009 EPA guidance proposed the use of green infrastructure and LID practices that manage rainfall on-site, and prevent the off-site discharge of runoff from events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible. According to the EPA guidance, the 95th percentile storm event appears to best represent the volume that is fully infiltrated in a natural condition and thus should be managed on-site to restore and maintain pre-development hydrology for duration, rate and volume of stormwater flows.

[118] USEPA. Section 438 Technical Guidance December 2009. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. EPA 841-B-09-001. December 2009. www.epa.gov/owow/nps/lid/section438

Retaining runoff from all storms up to and including the 95th percentile storm event (i.e., retention standard) serves to maintain or restore pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites, in addition to providing treatment or pollutant removal. The volume reduction benefits provided by this retention standard result in greater overall pollutant load reduction, since pollutant loads are the product of pollutant concentration and runoff volume.

In 2018, the Northwest Conservation District, working with the Northwest Hills Council of Government through a CIRCA Matching Grant, developed a model Low Impact Development design manual to address stormwater management and the impacts climate change. The Morris, CT manual, a model for other small communities in the state, adopted a locally-applicable 95th percentile rainfall (1.3 inches) as the water quality design storm.

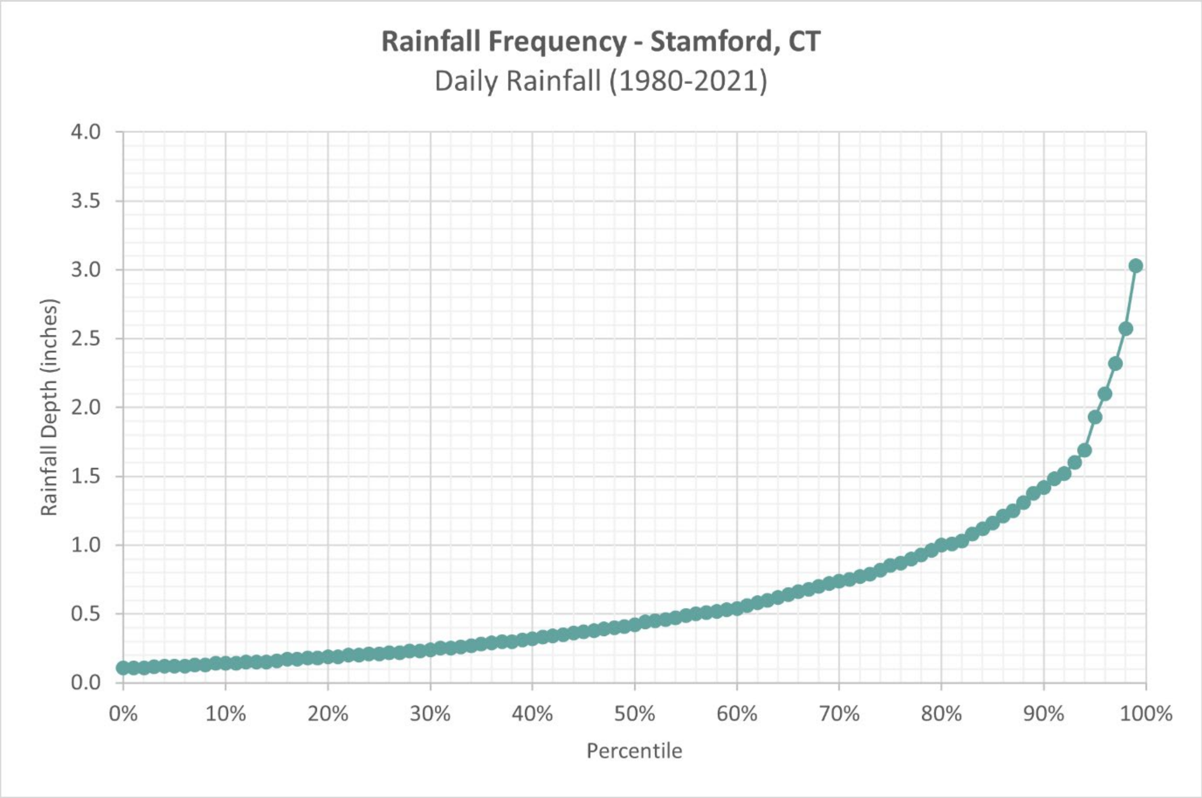
The Workgroup evaluated two options for updating the water quality design storm and associated Water Quality Volume in the revised Manual. The two options, including advantages and disadvantages of each, are summarized in Table G-3.

Table G-3. Alternative Approaches Considered for Updating Water Quality Design Storm Precipitation

Alternative	Description	Advantages	Disadvantages
Updated 90th Percentile 24-hour Rainfall	Update the 90th percentile 24-hour rainfall based on the latest CT rainfall data (at least a 30-year period)	• Reflects current Connecticut rainfall amounts • Better preserves pre-development hydrology (runoff duration, rate, volume, and temperature and groundwater recharge) as the basis for the retention standard in the CT DEEP Stormwater General Permits and this Manual	• Stormwater management cost increases noted as a potential concern
95th Percentile 24-hour Rainfall	Switch to the 95th percentile 24-hour rainfall	• Closer alignment with EPA Guidance • Even more effective in preserving pre-development hydrology	• Would be even more costly and, in some cases, difficult to achieve for constrained sites

The 90th and 95th percentile rainfall events were estimated for three Connecticut locations with long-term daily rainfall records – Hartford, Groton, and Stamford – using daily precipitation observations over an approximately 40-year period of record (1980-2021) and the procedure cited in the 2009 EPA guidance. Small rainfall events (0.1 inch or less and snowfall events that do not immediately melt) were removed from the data sets since these events do not typically cause runoff and could potentially cause bias in the estimates. Figure G-1 shows a cumulative frequency distribution of daily rainfall for one of the three locations analyzed (Stamford).

Figure G-1. Cumulative Frequency Distribution of Daily Rainfall for Stamford, CT (1980-2021)



The 90th percentile rainfall amounts vary from 1.25 to 1.42 inches, with an average of approximately 1.3 inches for the three locations analyzed. This is consistent with the 90th percentile rainfall amounts for New York State (1.0-1.5 inches) estimated by NYSDEC in 2013, as well as 90th percentile rainfall estimates for Boston, MA for the period 1948-2004 (approximately 1.3 inches).[119] The 95th percentile rainfall amounts are generally 30% to 35% higher than the 90th percentile amounts for the Connecticut locations evaluated.

[119] Stormwater Best Management Practices (BMP) Performance Analysis. Revised Document: March 2010 (Original Document: December 2008). Prepared for United States Environmental Protection Agency - Region 1 by Tetra Tech, Inc.

Conclusions

Stormwater Quantity Control Design Storm

The revised Manual replaces the TP-40 24-hour rainfall depths with the NOAA Atlas 14 (and subsequent generations of NOAA precipitation-frequency products[120]) precipitation frequency estimates, at a minimum, for consistency with the CT DEEP Construction Stormwater General Permit and CTDOT design practice. While consideration was given to the use of larger design storm depths to account for observed and projected future increases in precipitation, such as the upper range of current expected storms (e.g., NOAA14+ or NOAA14++) or future climate projections, the Workgroup was concerned that adopting such an approach could be cost-prohibitive and potentially result in site designs with over-engineered stormwater controls rather than greater emphasis on use of non-structural LID site planning and design techniques. CT DEEP will continue to consider new climate resources and tools to inform future updates of design storm precipitation, including adoption of future generations of NOAA precipitation-frequency products, which are expected to reflect increasing trends in observed and future precipitation over time.

Water Quality Design Storm

The revised Manual replaces the 1.0-inch water quality storm with the updated 90th percentile rainfall depth of 1.3 inches to: 1) reflect current Connecticut rainfall amounts, and 2) better preserve pre-development hydrology (runoff duration, rate, volume, and temperature and groundwater recharge) as the basis for the retention standard (using the same WQV calculation method as used in the original manual) in the CT DEEP Stormwater General Permits and this Manual. This revision was deemed to be consistent with more recent rainfall data for Connecticut without being overly burdensome in meeting the stormwater retention and treatment standard for most sites.

Additional Climate Considerations

Ongoing and future projected climate changes will continue to impact stormwater management in Connecticut, as well as related environmental, infrastructure, and community resources, in the following ways:

- More frequent and intense storms can increase stormwater runoff, which can cause more frequent and extreme flooding events and can exacerbate existing, or introduce new, pollution problems. Overwhelmed stormwater management systems can lead to backups that cause localized flooding or lead to greater runoff of contaminants such as trash, nutrients, sediment, and bacteria into local waterways.

[120] As of the writing of this manual, NOAA was developing the "next generation" precipitation-frequency product that is expected to replace NOAA Atlas 14. The new product (NOAA Atlas 15) is anticipated to update current Atlas 14 precipitation frequency estimates based on historical data and reflect the increasing trend in observed precipitation, as well as account for future precipitation information.

- More frequent and intense downpours can also challenge cities with combined stormwater and wastewater drainage systems. These systems can be overwhelmed by large amounts of rainfall or snowmelt and lead to more combined sewer overflows (CSOs) into waterways. An increase in CSOs can reduce water quality and make meeting water quality standards more difficult.

- Increased stormwater runoff and transport of pollutant loads to waterbodies can diminish water quality and threaten drinking water sources. Projected increases in the number of days of precipitation over 1 inch, as well as the total amount of precipitation falling in the heaviest 1% of rainfall events are important factors in determining future pollutant loads to waterbodies.

- Warming air and water temperatures combined with increased precipitation and stormwater pollutant loads will increase the potential for harmful algal blooms, loss of high-quality headwater streams and cold-water habitat, further degradation of impaired waters, and negative impacts on recreational use of waters.

- More frequent, intense, and longer-lasting periods of drought, combined with new land development, can exacerbate loss of groundwater recharge, reducing streamflow and affecting water quality, stream ecology, recreational use of waters, and drinking water supplies.

- Sea level rise and increased frequency and intensity of coastal storms has implications for stormwater management systems along the Connecticut coast and tidally influenced areas. According to projections by the Connecticut Institute for Resilience & Climate Adaptation (CIRCA), sea level rise is expected to increase water levels in Long Island Sound by up to 20 inches by 2050 and to continue increasing after that. Continued rising sea levels will result in more regular coastal flooding, increased water depths will result in greater potential for wave and storm surge propagation further inland during storms, and groundwater elevations will rise in areas that are directly influenced by coastal

Summary of Climate Change & Its Impacts in Connecticut

- By 2050, average temperatures are expected to increase about 5°F, with increases thereafter dependent on emissions choices now.
- Average precipitation is expected to increase about 8% (4 inches/year).
- Indices of hot weather, summer drought, and extreme precipitation are expected to increase.
- Sea level is expected to rise by up to 20 inches by 2050 and continue increasing after that.
- Small changes in mean sea level have a big impact on the frequency of flooding.
- Areas that experience flooding every few years now should expect flooding multiple times a year by 2050.

Source: Connecticut Institute for Resilience & Climate Adaptation (CIRCA) Fact Sheets

Temperature and Precipitation

Sea Level Rise

waters. Stormwater management systems in these areas are vulnerable to rising sea levels and, backwatering and submerging of outfalls, rising groundwater and reduced infiltration, storm surge inundation of facilities, and additional wind, sand, and salt exposure.