Nitsch Engineering

Adapting Stormwater Infrastructure to Climate Change: A Comprehensive Review

Peabody Square Green Infrastructure
Dorchester, MA

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Introduction

As climate change intensifies, the challenges of managing urban stormwater are becoming increasingly apparent. Flash flooding, driven by more frequent and severe storms, poses a significant threat to urban infrastructure, particularly in areas with outdated drainage systems. A research project led by a team of Nitsch Engineering staff sought to address these challenges by evaluating current stormwater infrastructure design standards and exploring innovative solutions to adapt to climate change.

The heart of the research focused on closed drainage systems—components like gutters, inlets (grates), and pipes—that play a vital role in managing runoff from impervious surfaces in urban settings. As cities expand and impermeable surfaces increase, these systems face escalating pressure during heavy rainfall events. Historically, closed drainage systems were designed based on climatic conditions that are now outdated, leaving many cities vulnerable to the impacts of climate change.

The research aimed to determine whether existing design practices, largely based on older rainfall data, are still effective or if substantial updates are required to meet the new demands imposed by more frequent and intense storms. The study's focus on these systems reflects the growing recognition that traditional stormwater management approaches need significant revision in light of evolving climate patterns. The research further validated the benefit of coupling green infrastructure as part of a comprehensive approach to urban drainage.

Methodology and Models

A critical aspect of the research was the development and application of a wholistic methodology that considered the interaction of several different variables and their combined impacts on the modeling. The team conducted an extensive literature review, examining both historical and current industry practices, methodologies, and climate projections to ensure that the research was grounded in the most up-to-date and relevant information available.

This review had four primary objectives:

1. Research scientific data documenting predicted future weather patterns (precipitation depth, intensity, and frequency), including National Oceanic and Atmospheric Administration (NOAA) and Northeast Regional Climate Center (NRCC) at Cornell University.

2. Document current industry best practice design standards for closed drainage systems including gutter flow calculations, drainage pipe sizing, and inlet grate capacity.

3. Review the Rational Method vs. other design methods and equations for closed drainage systems.

4. Review alternative hydraulic modeling programs for closed drainage analysis, including the performance of Autodesk's SSA (Storm Sanitary Analysis) platform under higher intensity storms.

Increasing Intensity of Precipitation

During the latter half of the 20th century, Technical Paper 40 (TP-40), Rainfall Frequency Atlas of the United States, became the primary source of rainfall estimates for engineering and design. In the last two decades, publications by the Northeast Regional Climate Center (NRCC) at Cornell University and the National Oceanic and Atmospheric Administration (NOAA) provided updated precipitation frequency statistics. Despite these more current estimates, under current Massachusetts Department of Environmental Protection (DEP) Regulations, TP-40 is still the standard. However proposed Massachusetts regulations, expected to be adopted in the near future, make the switch to NOAA Atlas 14. Some municipalities have already adopted NOAA Atlas 14 or Cornell data as the basis for stormwater design in their local regulations.

A comparison of these different rainfall estimates confirmed that storms are increasing in both volume and intensity, and as a result ***using historical rainfall data for projects might underestimate design parameters***. Furthermore, Intensity-Duration-Frequency (IDF) curve models, which determine how much rain falls when and for how long, are changing (**Figure 1**).

Some local groups have investigated this further and developed additional projections for future rainfall depths. These projections reinforce the notion that in planning and design of future development, historic—or even current—rainfall data, will underestimate the potential for flooding. For example, the City of Cambridge's Climate Change Vulnerability Assessment provides precipitation projections for typical design storms for two future timeframes, indicating that the baseline (2015) 100-year storm event will be comparable to the projected 2070 25-year storm (**Figure 2**).

City, County, and State	TP-40	NOAA Atlas 14	Difference between NOAA Atlas 14 - TP-40	% Change between NOAA Atlas 14 and TP-40
Wolcott, New Haven, Connecticut	7.00	9.29	2.29	25%
Coxsackie, Greene, New York	7.00	7.18	0.18	3%
Smithfield, Providence Rhode Island	7.00	7.96	0.96	12%
Leesburg, Lake, Florida	10.00	10.60	0.60	6%
Chickamauga, Chattanooga, Georgia	7.60	8.66	1.06	12%
Knoxville, Knox, Tennessee	6.50	6.25	-0.25	-4%
Coshocton, Coshocton, Ohio	5.00	5.98	0.98	16%
Raleigh, Wake, North Carolina	8.05	7.60	-0.45	-6%
Estacia, Torrance, New Mexico	4.00	3.44	-0.56	-16%
Minneapolis, Hennepin, Minnesota	6.00	7.90	1.90	24%
Rapid City, Pennington, South Dakota	4.60	5.70	1.10	19%

Figure 1: *Summary of 24-Hour Rainfall Values (Inches) for the 100-Year Storm Event NOAA Atlas 14 Volume 10 compared to TP-40*
Source: Michael J. Mastroluca, PE, www.stormcom.com

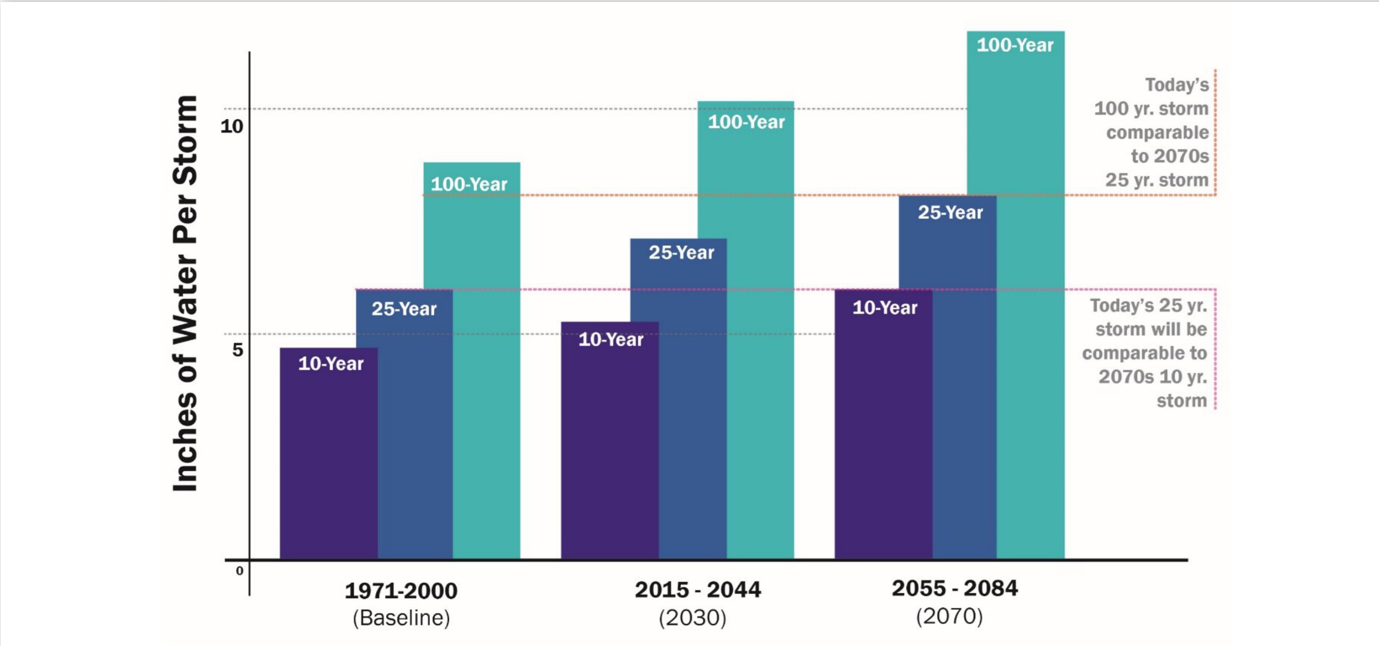


Figure 2: *Precipitation Projections, CCVA Part 1, City of Cambridge, Nov. 2015*

Basics of Modeling Closed Drainage Systems

Current standard practice of modeling closed drainage systems in urban settings includes three primary components: gutter flow capacity, grate/inlet capacity, and storm drain pipe capacity.

The driving principle behind pipe conveyance is ensuring that pipe capacity matches or exceeds the peak runoff rate as determined via the Rational Method. The limitation with this approach is the Rational Method assumes a peak rainfall intensity at ***an instantaneous moment in time***. However, intensity is not constant during a storm event, which makes it difficult to ensure that systems are adequately sized for the entire duration of the storm.

Gutter flow is defined as the depth and spread of water in the gutter and extension into the roadway. Gutter spread impacts the ability for inlets to capture water and high gutter flow will cause water to bypass an upstream catch basin (on grade) which increases the flow rate to a downstream catch basin (on sag) (**Figure 3**).

Inlet capacity is dependent on the cross slope of the pavement, size of grate, open area of grate, and flow velocity. Grate efficiency is reduced when the gutter flow spread is greater than the width of the grate, or the total flow velocity exceeds the "splash-over" velocity of the grate. In many cases, current industry standard practice for modeling inlet capacity is based on "Rules of Thumb." For example, a single catch basin grate can convey up to two cubic feet per second (cfs) and a double catch basin grate can convey up to four cfs.

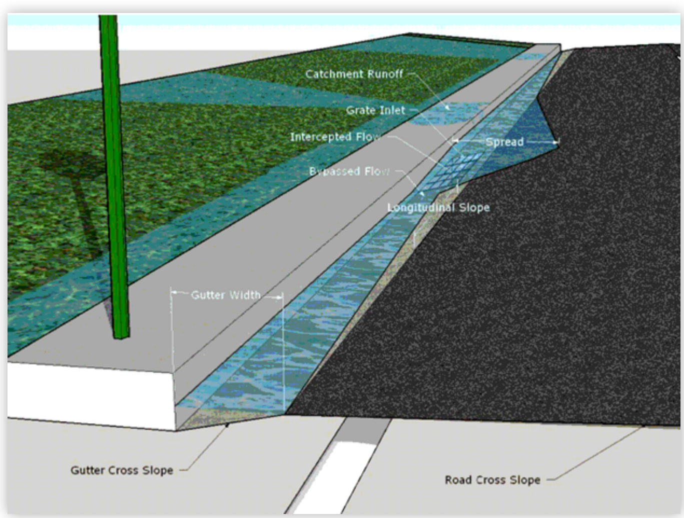


Figure 3: *Gutter flow capacity*

The Hydraulic Modeling Approach

Using Storm and Sanitary Analysis (SSA) software, the Nitsch team created detailed hydraulic models built on the three components discussed above to simulate the behavior of urban drainage systems under various storm conditions. These models were based on a hypothetical standard city block in Boston, a city known for its complex stormwater management challenges. The decision to model a standard block allowed the researchers to create a controlled environment in which various scenarios could be tested.

Additionally, the team employed a real-world case study of Codman Academy Charter School in Boston, which had a documented history of flooding issues in the adjacent roadway. This case study provided a practical context for the research, enabling the team to test the applicability and effectiveness of their models in a real-world setting.

The hydraulic model analysis tested hypotheses from the literature review phase and current practice, including the viability of different computational methods for determining rainfall intensity (i.e. Steel vs. Atlas 14 vs. Future IDF), and compared inlet capacity for different grate styles under different precipitation events to understand the capture efficiency.

The modeling process involved not only simulating current conditions but also projecting future scenarios based on climate models that predict more intense and frequent rainfall events. By doing so, the research provided a comprehensive view of how closed drainage systems might perform under future climate conditions, offering critical insights for urban planners and engineers as they consider resilient infrastructure.

The Case Study: Codman Academy

The case study of Codman Academy Charter School proved to be one of the most insightful aspects of the research. Located in an area prone to flooding in Dorchester, MA, the school served as an ideal test site for evaluating the effectiveness of various stormwater management strategies. The research team used the school's existing drainage issues as a baseline to test both traditional and innovative approaches to managing stormwater (**Figure 4**).

Figures 4 and 5: *Codman Academy Charter School, Dorchester, MA*

The research demonstrated that traditional closed drainage systems were often inadequate to manage the volume of runoff generated during intense storms. In particular, the inlets and pipes struggled to handle the rapid influx of water, leading to surcharging, overflow, and localized flooding. This finding was consistent with observations across many urban areas, where existing drainage infrastructure is increasingly unable to cope with the demands placed upon it by changing weather patterns (**Figure 5**).

However, the research did not stop at identifying the problem. The team explored the potential of green infrastructure as a solution. Green infrastructure refers to practices that use or mimic natural processes to manage stormwater, such as rain gardens, permeable pavements, and green roofs. When these elements were integrated into the stormwater management system at Codman Academy, the results were significantly improved. The green infrastructure was effective in reducing runoff volumes, delaying peak flows, and mitigating downstream flooding. These findings underline the potential for green infrastructure to complement traditional systems, offering a more resilient approach to managing stormwater in urban environments.

Key Findings and Recommendations

The research project yielded several key findings that have important implications for urban stormwater management.

One of the most critical discoveries was the inadequacy of traditional rules of thumb for catch basin capacity. Historically, stormwater systems have been designed based on general guidelines that assume a certain level of capacity for inlets and pipes. However, the research demonstrated that these assumptions are often flawed, particularly in the context of more intense and frequent storms.

The research team found that the primary issue was not with the capacity of the pipes themselves but with the inlet capacity of drainage systems. In many cases, the inlets—the points where water enters the drainage system—were unable to handle the volume of water during heavy rain events. This bottleneck effect led to overflows and flooding, even when the downstream pipes had sufficient capacity to carry the water away. The research also concluded that gutter spread can also factor into additional flooding due to water bypassing the grates altogether. ***These findings suggest that improving the design, placement, and configuration of inlets could significantly enhance the performance of stormwater systems.***

Another critical finding was the inadequacy of outdated rainfall data in stormwater design. Many existing systems were designed using metrics like TP-40, which are based on historical rainfall patterns that no longer reflect current realities. The research team ***recommends a transition to more current data sets***, such as NOAA's Atlas 14, which provide a more accurate representation of current and future rainfall patterns. Atlas 14 includes data on rainfall intensity and frequency that accounts for the impacts of climate change, making it a more reliable basis for designing stormwater systems that can withstand future conditions.

Figure 6: *Key Findings and Recommendations*

Figure 7: *Bioretention Curb Extension in Codman Square, Dorchester, MA*

The research also reinforces the necessity of considering future climate projections in infrastructure design, the need for a forward-thinking approach, and importance of advising clients to account for future rainfall data projections in the design life of their sites. This approach ensures that infrastructure remains resilient in the face of escalating climate challenges, rather than being rendered obsolete by changes in weather patterns.

The research team emphasized the potential benefits of integrating green infrastructure into urban stormwater management plans. ***While traditional closed drainage systems remain necessary, green infrastructure offers a complementary approach that can enhance the resilience of urban areas to flooding.*** Green infrastructure provides capacity to retain and detain surface runoff from impervious surfaces, which helps mitigate the impacts of intense storms and reduce the burden on traditional drainage infrastructure (**Figure 6**).

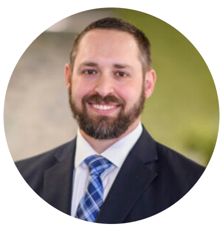
Looking Ahead: The Future of Stormwater Management

The implications of this research extend far beyond the immediate findings. As cities around the world continue to grapple with the challenges posed by climate change, the need for innovative and adaptive stormwater management solutions is becoming increasingly urgent. The integration of green infrastructure into urban planning represents a significant shift in how cities can manage stormwater more effectively.

The research underscores the importance of updating engineering practices and regulations to reflect current and future climate conditions. The transition from outdated data sets to more accurate and current information, such as NOAA's Atlas 14, is crucial for ensuring that stormwater infrastructure is designed to meet the demands of a changing climate. As noted in the discussion, regulatory updates are anticipated to incorporate these newer data sets, which will further drive the adoption of more resilient stormwater management practices.

Moreover, the research highlights the importance of interdisciplinary collaboration in addressing the complex challenges of climate change. The partnership between civil engineers and resilience planners was instrumental in the success of the project, allowing for a comprehensive approach that considered both technical and practical aspects of stormwater management. As cities around the world grapple with the challenges posed by climate change, the findings of this research highlight the importance of continual adaptation and innovation in infrastructure design. The future of urban resilience depends on our ability to integrate findings like these into everyday practice, ensuring that our cities are prepared for whatever the future may bring (**Figure 7**).

Research Team



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Nitsch Engineering

Mission Statement

At Nitsch Engineering, we are guided by our purpose, "Building better communities with you." This mantra goes beyond words on paper – it represents our commitment to building stronger and more resilient communities through client collaboration and advocacy.

We define ourselves by why we do what we do – to positively impact our clients, employees, and communities by conducting ourselves with integrity and focusing on our core values; paying close personal attention to the needs and goals of our clients and employees; modeling professional behaviors and standards; focusing on inclusion and belonging; embodying a high level of corporate citizenship; and demonstrating, at all times, a caring attitude.