

Implications of Cloudburst Intensification and Areal Reduction Factors for Stormwater Design

Insights from 24 Years of Radar Rainfall Observations in Baltimore

Xin Zhou^{1*}, James G. Hunter¹

¹Department of Civil and Environmental Engineering, Morgan State University, 1700 E. Cold Spring Lane, Baltimore, MD 21251, USA

* Corresponding author email: xin.zhou@morgan.edu

Highlights

- The frequency of cloudburst-like rainfall events increased from 2.9 events per year during 2000–2009 to 8.9 events per year during 2010–2019 across 10 flood-prone hotspots in Baltimore.
- Median annual maximum 1-hour rainfall increased by 54% at the point scale and 40% at the watershed scale.
- Empirical ARFs (0.64–0.94) quantify point-to-area rainfall scaling; the framework can serve as a local benchmark for upcoming NOAA Atlas 15.

Introduction

NOAA Atlas 14 DDF curves remain the foundation of stormwater design in the United States, yet two assumptions warrant evaluation: temporal stationarity of extreme rainfall and the applicability of point-based rainfall estimates to watershed-scale analyses. Using 24 years (2000–2023) of high-resolution radar rainfall observations and NHDPlus catchment data across Baltimore, this study examines changes in short-duration extreme rainfall and derives empirical Areal Reduction Factors (ARFs) linking point and watershed-average rainfall. The goal is to assess how recent observations compare with existing design assumptions and to quantify the implications for stormwater modeling and infrastructure design.

Methodology

The HydroRainfall dataset provides 15-minute, 1-km rainfall estimates across Baltimore from 2000 to 2023. Ten flood-prone hotspots were analyzed. Cloudburst-like events were defined using a Baltimore-specific threshold of 75 mm/hr hourly-equivalent intensity derived from 15-minute observations, and individual storms were separated using a 3-hour inter-event criterion. NHDPlus catchments and flowline topology were used to construct upstream contributing drainage networks for each hotspot. Contributing drainage areas ranged from approximately 12 km² to 179 km². Radar grid cells were spatially linked to catchments, and area-weighted rainfall time series were computed to derive watershed-average precipitation for each contributing drainage area.

Annual Maximum Series (AMS) were calculated for durations ranging from 15 minutes to 6 hours for both point rainfall and watershed-average rainfall. Observed AMS values were compared among decades and evaluated relative to NOAA Atlas 14 reference curves.

ARF was computed as: $ARF = P_{areal}/P_{point}$

where P_{areal} is the watershed-average rainfall depth and P_{point} is the point rainfall depth at the hotspot location.

Key Findings

Cloudburst Intensification

A total of 130 cloudburst-like events were identified using the Baltimore-specific 75 mm/hr threshold. Event frequency increased by approximately 200%, from 2.9 events per year during 2000–2009 to 8.9 events per year during 2010–2019. Heavy rainfall events exceeding 25 mm/hr also increased from 86 to 112 events per year. The seasonal peak shifted toward mid-to-late summer, with August accounting for a larger fraction of annual extreme rainfall events in recent decades.

Shifts in DDF Characteristics

Median annual maximum 1-hour rainfall increased from 27.1 mm during 2000–2009 to 41.6 mm during 2010–2019 at the point scale, representing a 54% increase. At the watershed scale, median annual maximum 1-hour rainfall increased from 23.4 mm to 32.8 mm, corresponding to a 40% increase. Both point-based and watershed-average rainfall distributions shifted toward higher NOAA Atlas 14 return-period categories over time, indicating increasingly intense short-duration rainfall conditions.

Areal Reduction Factors

ARFs decrease with increasing drainage area and decreasing storm duration. At the 1-hour duration, ARFs range from 0.83 to 0.94, while 15-minute ARFs range from 0.64 to 0.91. Consequently, direct application of point-based rainfall estimates can overestimate watershed-average rainfall by approximately 6–17% at the 1-hour duration and by up to 36% at the 15-minute duration.

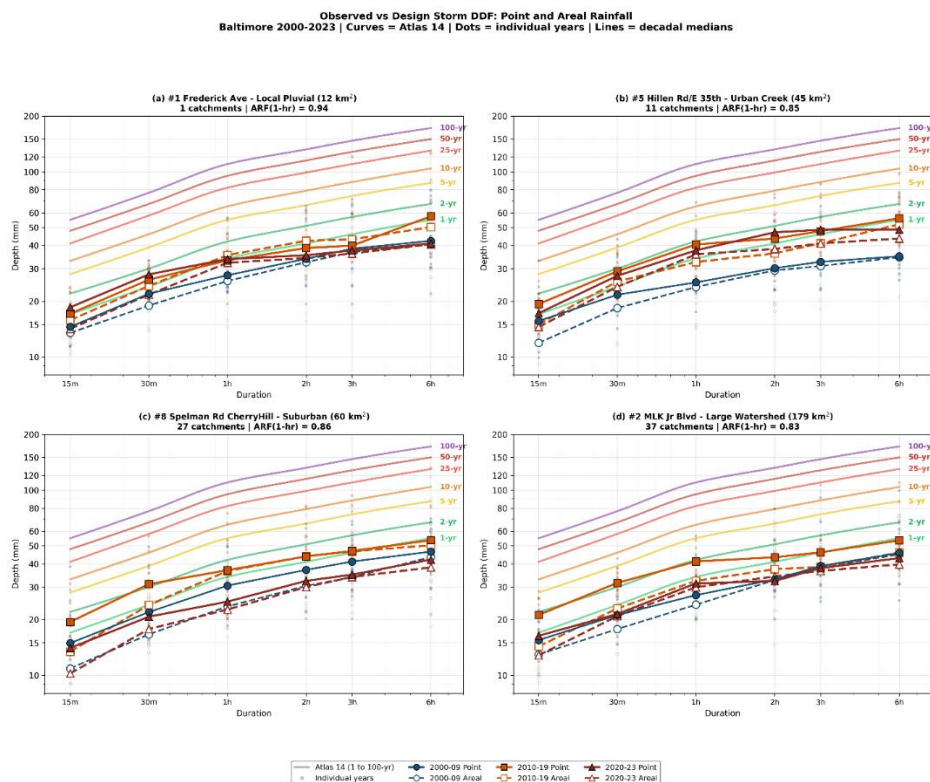


Figure 1: Point-based and watershed-average DDF curves for representative Baltimore catchments, showing both long-term intensification and point-to-area rainfall scaling effects.

Recommendations

NOAA Atlas 14 remains an essential engineering reference, but recent observations indicate increasing short-duration rainfall intensity in Baltimore. For watershed-scale applications, appropriate Areal Reduction Factors should be considered to account for spatial rainfall variability. Incorporating both temporal rainfall trends and point-to-area scaling effects may improve stormwater design, flood modeling, and climate resilience planning.

Reference

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Abstract Title: GSI Impact Hub: Capturing the Multiple Benefits of Green Infrastructure

Abstract:

Many cities throughout the U.S. are adopting green stormwater infrastructure (GSI) and nature-based approaches to reduce polluted stormwater runoff and meet water quality-related regulatory requirements. Unlike conventional or “gray” infrastructure, GSI can provide many additional economic, social, and environmental benefits that advance a community’s livability and resilience to climate change.

While GSI has proven effectiveness as a stormwater management strategy, it is not always the least cost option. GSI may also represent a significant departure from “business-as-usual” and can be difficult to implement in municipalities or utility service areas with competing resource needs and funding priorities. To further support GSI implementation, stormwater practitioners have expressed a need for information to help them better understand and evaluate its multiple benefits.

To meet this need, The Nature Conservancy (TNC), One Water Econ, and utility representatives from the Green Infrastructure Leadership Exchange (GILE) developed the [GSI Impact Hub](#), a comprehensive online resource of tools and guidance that allow users to capture the values of GSI co-benefits. The GSI Impact Hub was launched in 2025 and includes:

- **A compendium of existing “co-benefit” tools.** An increasing number of tools are available to help practitioners evaluate, quantify, and/or value GSI co-benefits; however, navigating these various resources can be a daunting task for stormwater practitioners. The various tools require different inputs, incorporate different methods, and require varying levels of stormwater management and/or economic expertise. The compendium is intended to help stormwater practitioners navigate the suite of available tools and utilize those that best meet their needs.
- **An online GSI co-benefit calculator.** The GSI Impact Calculator allows users to quantify and monetize 12 co-benefits of GSI and compare those benefits to costs over a specified timeframe. The Calculator is designed for use at the city block-scale; it is location-specific and calculates benefits based on city- or region-specific data using standard economic valuation approaches.
- **Five in-depth co-benefit guides** related to flood risk, urban heat, job creation and economic development, urban habitat and biodiversity, and transportation-related benefits. Based on case studies, interviews, and in-depth research, these guides include a review of academic studies related to each benefit, describe processes/key GSI design elements necessary for achieving the benefit, provide guidance for quantifying and monetizing the benefit, and identify relevant funding sources and financing strategies.

Together, these resources equip practitioners, policymakers, and advocates with evidence-based tools to design and implement GSI projects that maximize priority benefits.

Title: "ASSESSMENT OF HISTORICAL MICROPLASTICS REMOVAL IN TWO BIORETENTION SYSTEMS OF DIFFERENT AGES"

Authors: Erica R. Forgione, Ph.D.^{1,*}, Kelly D. Good, Ph.D.¹

¹ Department of Civil and Environmental Engineering, Villanova University, Villanova, PA, USA

*Corresponding author email: erica.forgione@villanova.edu

Urban stormwater is a major source of microplastics (MPs), including tire and road wear particles (TRWPs), which are of concern due to their potential to cause negative human and environmental health effects. While bioretention systems have been shown to be effective at removal of particulate matter overall, little research has evaluated their removal of MP particles specifically. If bioretention systems are successfully removing MP particles as stormwater flows through them, MPs should accumulate in bioretention basins over time. This hypothesis was explored in a study of two infiltrating bioretention systems with similar land use: 1) one at Villanova University (24 years old) and one at Abington Friends School (5 years old). In 2025, soil cores from the top layer of bioretention media were collected in triplicate at the inlet side of each basin as well as a background soil core from outside of each basin. Three depths (0 to 3-cm, 6 to 9-cm, and 12 to 15-cm) were processed via a 6-step extraction procedure and analyzed for MPs >50- μm and $\geq 1.4 \text{ g/cm}^3$ density. Visual microscopy and Raman spectroscopy were used to quantify and identify particles.

Results for each site will be compared including evaluation of results compared to site age and land use, including for potential TRWPs, which cannot be confirmed via Raman. Additionally, quality control methods used to determine which data are above detection will be demonstrated. The data indicate that most of the large particles (>212- μm) were retained in the 0 to 3-cm depth of the bioretention basins and TRWPs are suspected to be a major fraction of stormwater MPs based on visual observations. The methods used to isolate MPs likely had an effect on which MPs were observed based on density and size. The presence of an artificial turf field next to the Villanova site will also be discussed as an additional source of potential TRWP observations.