Assessment of the Use of Green Stormwater Infrastructure for Flood Mitigation At Berry Brook and impacts of Climate Change

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24 FEBRUARY 2022

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Objective

- How does implementation of green stormwater infrastructure at the watershed scale address watershed hydrology and urban flooding?

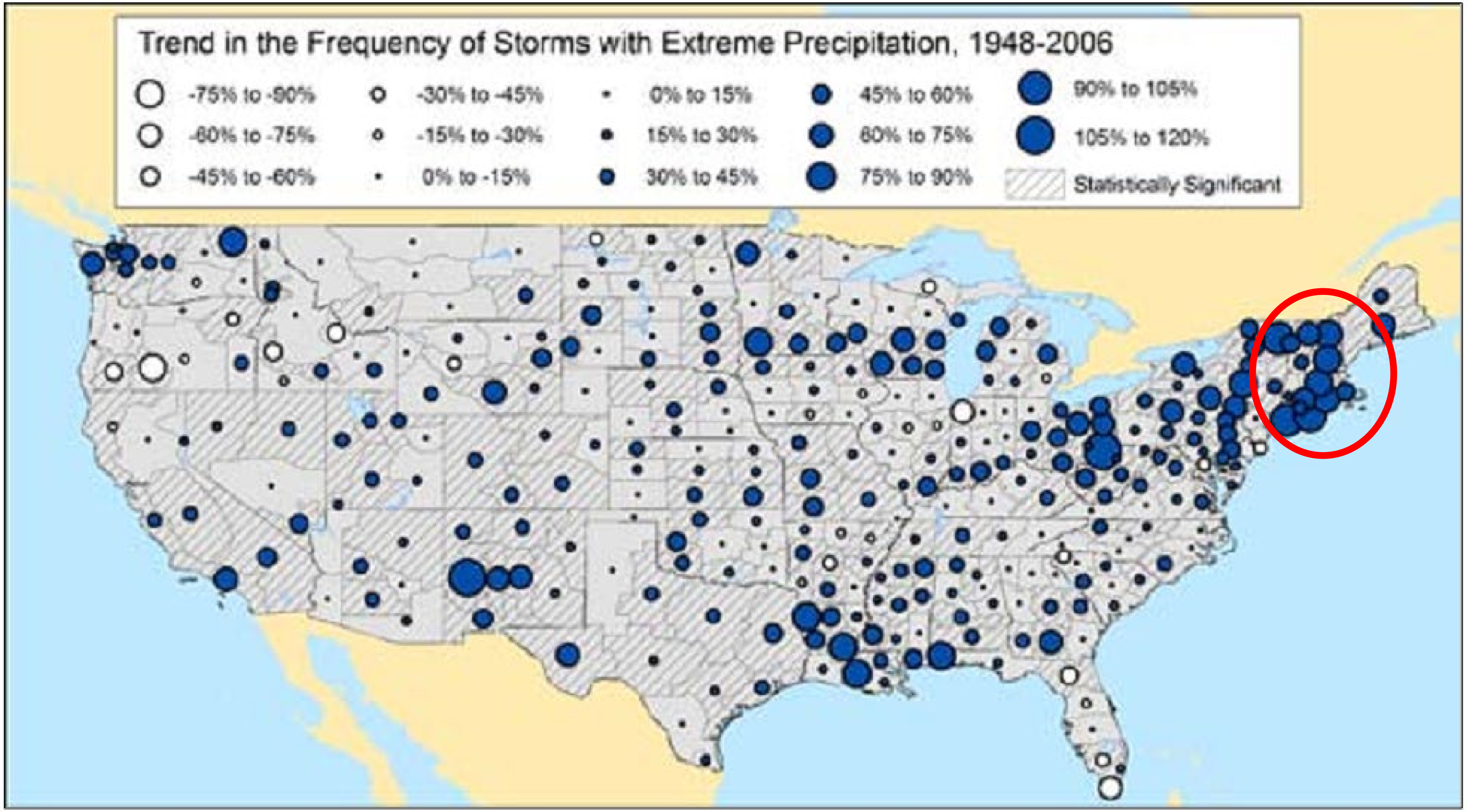
- In the context of infrastructure planning and design, which is more consequential: the increase in impervious area or climate change?

Extreme Precipitation

Extreme precipitation events over most mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent as global mean surface temperature increases.

IPCC, 2014: *Climate Change 2014: Synthesis Report*. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Changing Trends

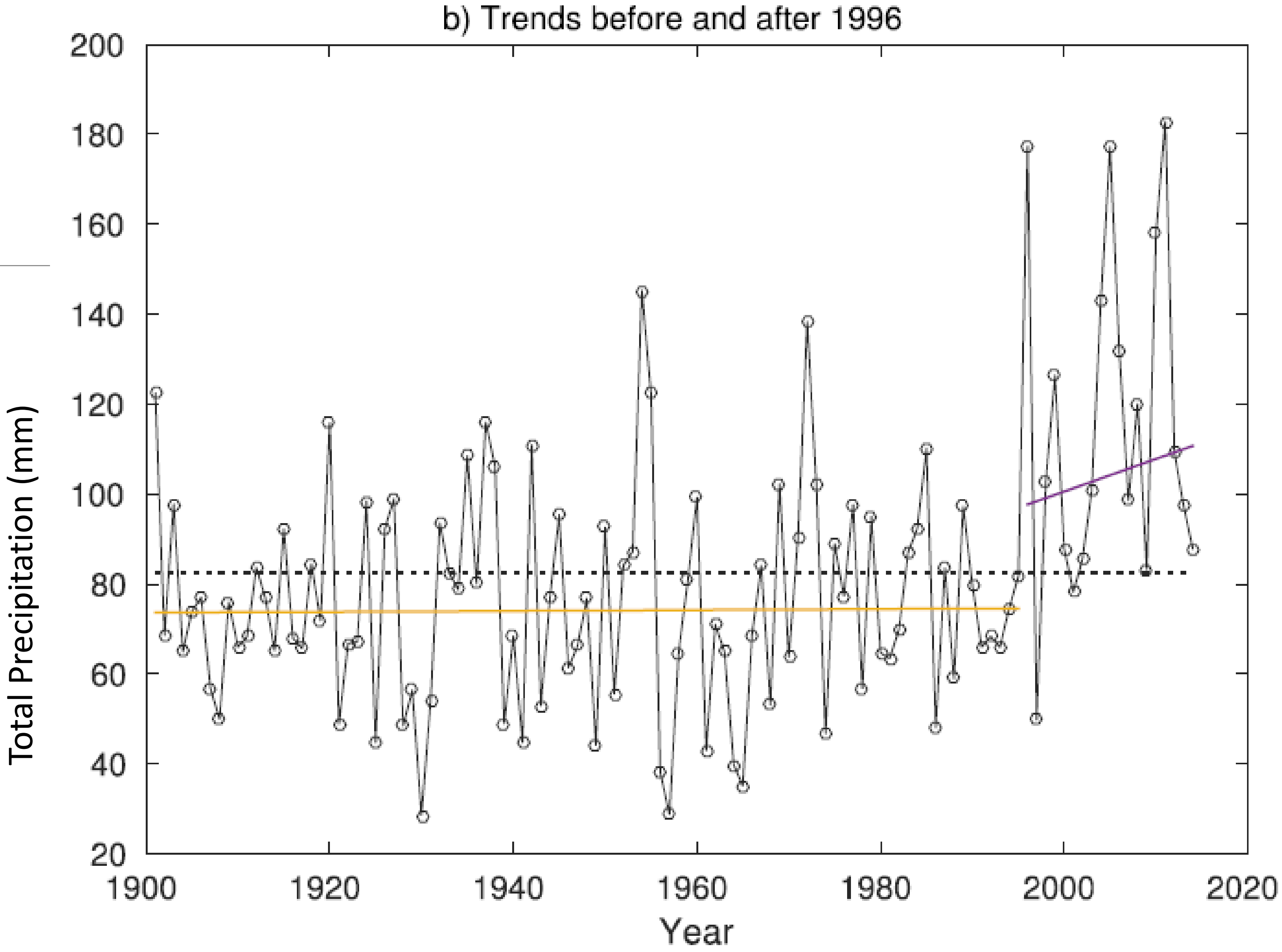


The frequency and intensity of heavy precipitation events has *likely* increased in North America and Europe.

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Annual Northeast USA Extreme Precipitation

Huang, et al, 2017



What About New Hampshire?

- Numbers of days per year with rainfall - about the same
- Average daily rainfall - about the same
  - (mean =0.35 in = 8.9 mm; median = 0.2 in = 5.1 mm)
- Daily rainfall value exceeded 90% of the days when it rains increased ~ 14%
  - Extreme precipitation is increasing

New Hampshire Extreme Precipitation

Return Period (years)	1960 TP-40 24-hr Rain Depth (in.)	2008 NH Stormwater Manual 24-hr Rain Depth (in.)	2021 NRCC 24-hr Rain Depth (in.)	2021 NOAA Atlas 14 Rain Depth (in.)
2	3.0	3.0	3.13 (+4.3%)	3.30
5	3.8	-	3.96 (+4.2%)	4.39
10	4.4	4.3	4.74 (+7.7%)	5.29
25	5.2	5.2	6.00 (+15%)	6.54
50	5.7	5.7	7.19 (+26%)	7.45
100	6.4	6.4	8.60 (+32%)	8.45

Common "Design" Life for Our Structures

20 to 50 years (looking out to 2040 to 2060)

- Precipitation increase of ~10-30%
- Flood peak increase of ~10 – 80%
- Temperature increase of 1-2 degrees F

Present guidance in New Hampshire is to increase extreme precipitation estimates of today by **15%** to account for the anticipated climate changes to extreme precipitation by the end of the century (2100)

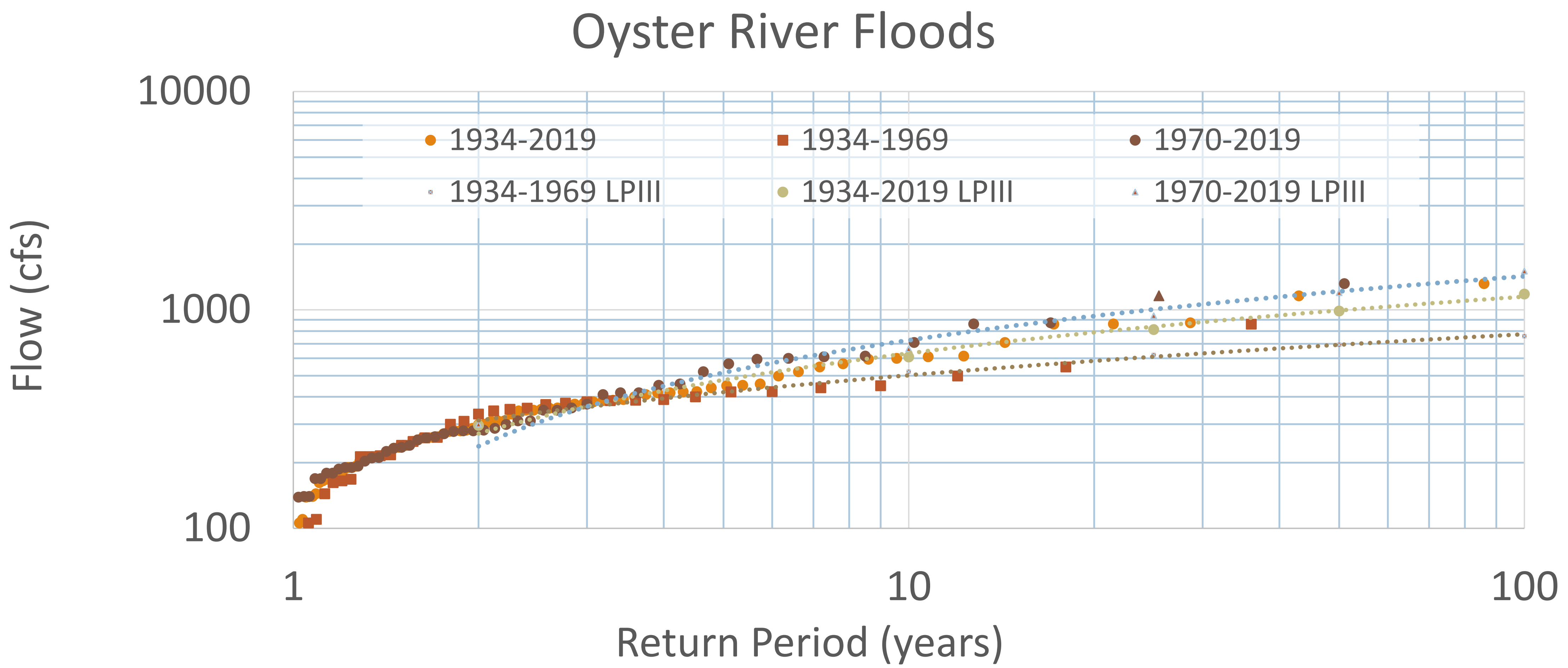
Hydrology and Flooding

More Frequent Floods?

Of the top 10 historic floods on the Oyster River, only one was before 1970. Period of record 1934 - 2021

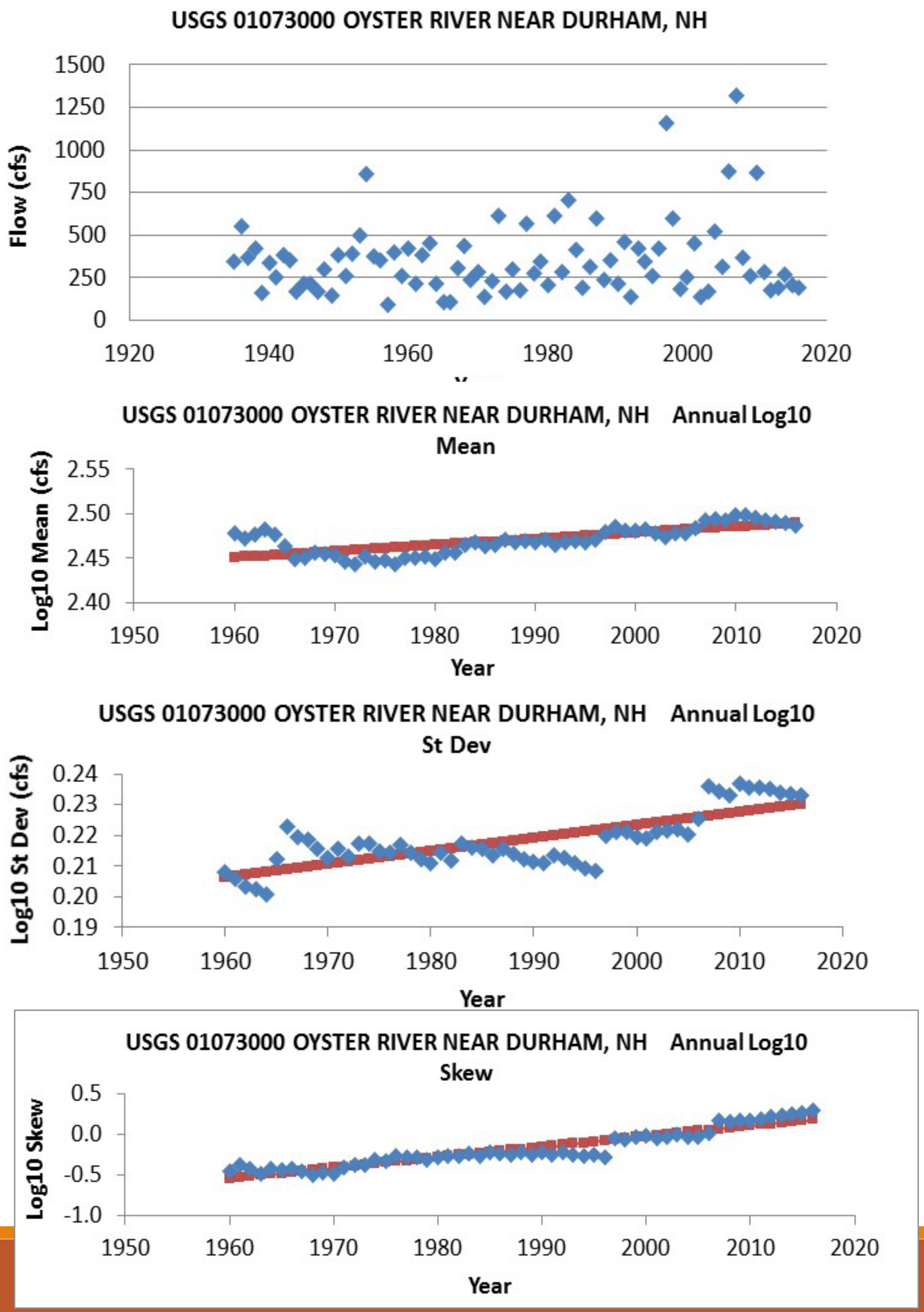
Date	Flow (cfs)
4/16/2007	1320
10/21/1996	1160
5/14/2006	873
2/26/2010	864
9/11/1954	862
3/19/1983	709
2/27/1981	615
4/2/1973	610
4/6/1987	600
6/14/1998	595

Trend in Floods – Oyster River



Oyster River Flood Series (1934 – 2019) LPIII Estimates

Return Period (years)	1934 - 1969	1934 - 1979	1934 - 1989	1934 - 1999	1934 - 2009	1934 - 2019	1970-2019
2	296	290	301	304	307	296	300
10	521	520	544	581	625	609	664
25	623	631	665	734	821	813	941
50	693	711	754	853	984	988	1199
100	758	788	841	976	1160	1182	1507
% Increase in 100-year over 1969	-	4	11	29	53	56	99



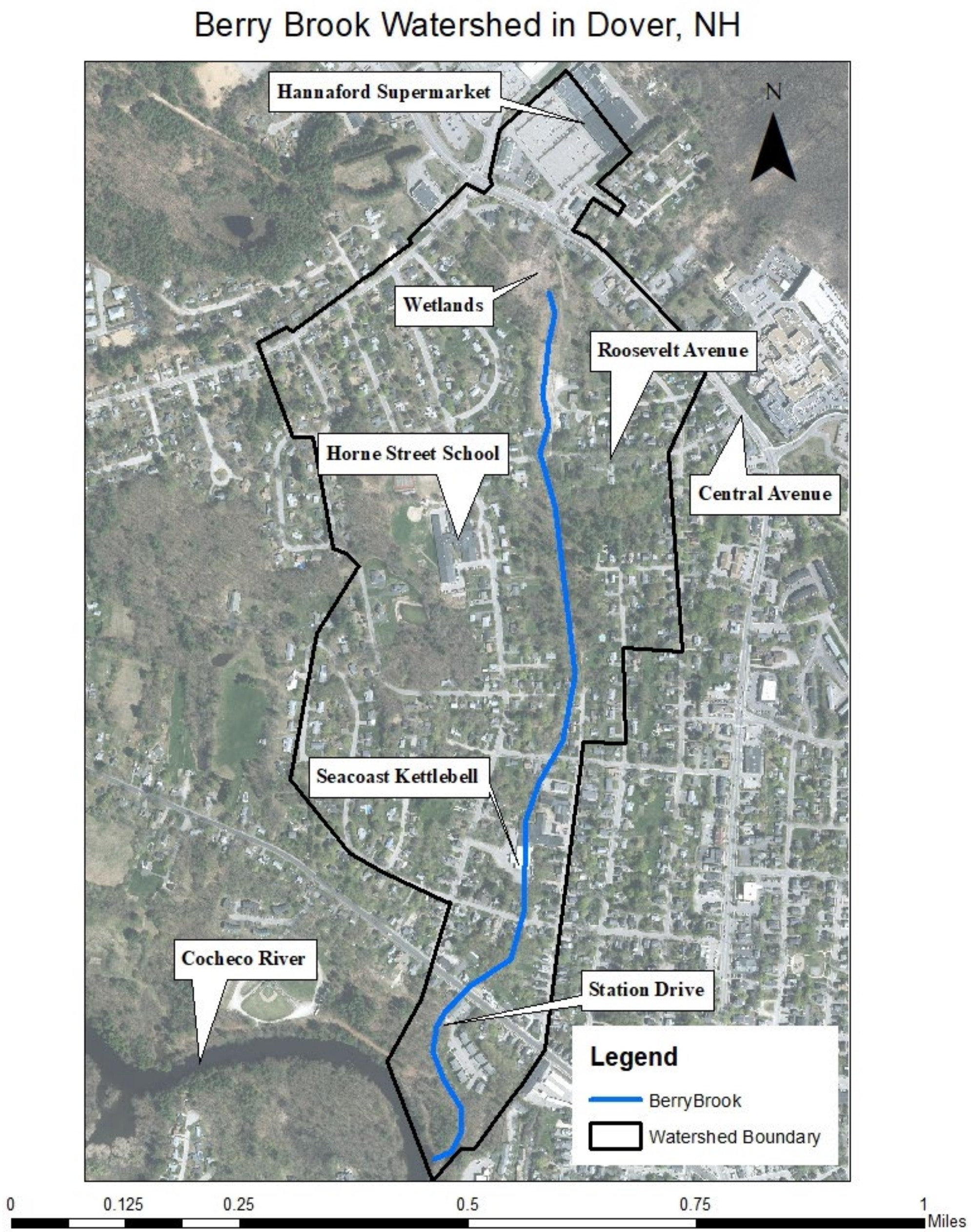
Annual (a) and annually computed log 10 mean (b), standard deviation (c), and skew (d) for the Oyster River annual peak flow series. Red dots are a least-squares-fitted trendline.

Watershed Hydrology and GSI Methodology

Monitor hydrology of an urbanized watershed, calibrate a hydrologic numerical model for the monitored hydrology, then adjust the model to reflect various levels of GSI Implementation and the effects of GSI on hydrology and flood characteristics

Common Terms

- GSI - Green Stormwater Infrastructure (bioretention, subsurface gravel wetland, etc.)
- BMP – Best Management Practice
- IC - Impervious Cover
- EIC – Effective Impervious Cover: impervious cover unmanaged by GSI
- SWMM – Stormwater Management Model
- DEM – Digital Elevation Model
- LiDAR – Light Detection and Ranging



Berry Brook Watershed

- 200-acre (81 ha) watershed in Dover, NH
- 0.9-mile (1.5 km) 1st order stream
- 2006 – Listed as impaired by EPA
- 2007 – Management Project
- Urbanized (30% EIC) prior to use of GSI

Restoration Efforts

- Daylight 1,100 feet (335 m)of stream
- Restore 500 feet (152 m) of stream
- Create 1-acre (0.4 ha)of new wetland headwaters
- Add multiple GSI systems to reduce watershed EIC from 30% to 10%

Image from City of Dover & UNH, 2017

GSI Installations at Berry Brook

- 12 bioretention systems,
- 1 tree filter,
- 1 subsurface gravel wetland,
- 3 grass-lined swales
- 2 subsurface gravel filters
- 1 infiltration trench system
- 3 innovative filtering catch basin designs

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Model Scenarios and Comparison Variables

- Event-based model (2-year through 100-year events
- Long term model (10 years of precipitation)

- Watershed Modeling – Pre GSI (30% EIC) and Post GSI (10% EIC)
- Simulate reducing impervious cover (Pre GSI: 0% and 15% EIC)
- Simulate climate change (event-based, present precipitation, increase 15%)

- Compare and contrast impacts
  - Peak flow
  - Time to peak flow
  - Runoff depth
  - Total runoff volume

Software Selection - PCSWMM

- SRTC Calibration Tool - calibrate using parameter sensitivity
- Bulk edit capabilities - review all parameters at once
- Kinematic Wave Equation - how water moves over the ground
- Green-Ampt Equation - how water infiltrates the ground
- Compatible with ArcMap - process data over geospatial area
- Compatible with SWMM - Stormwater management model supported by the EPA

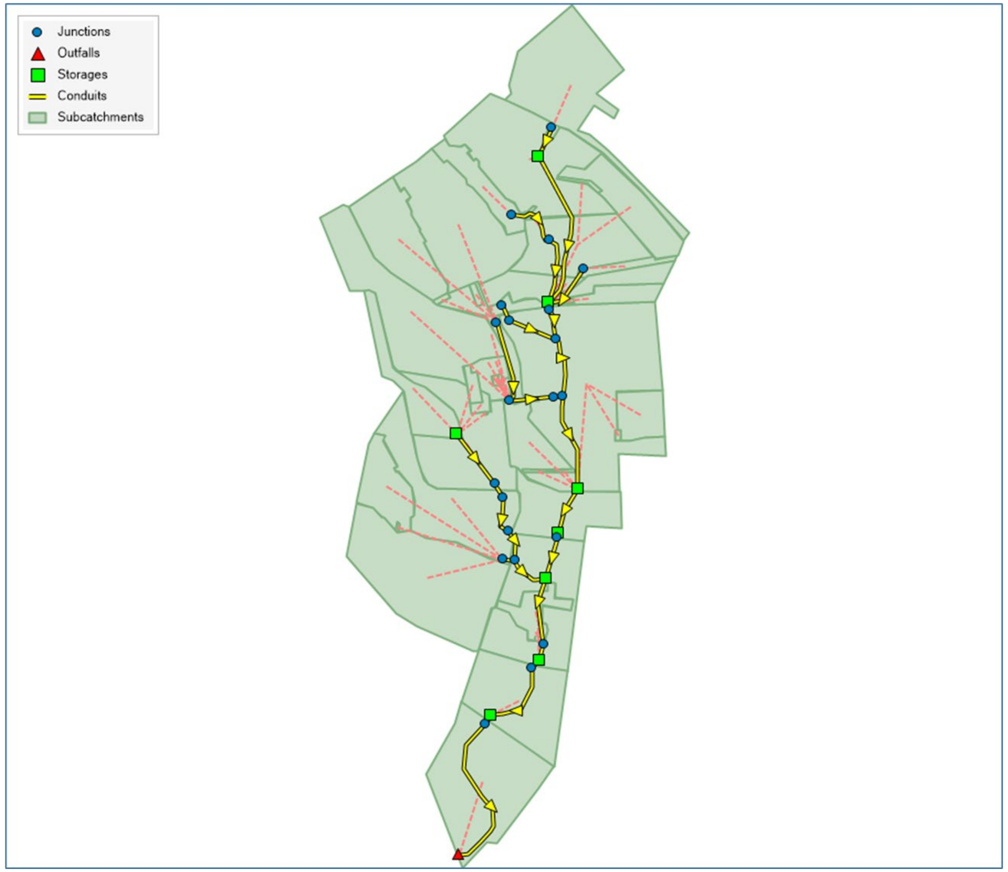
Initial Parameter Estimation

- Subcatchment Area – ArcMap
- Conduit Lengths - ArcMap
- Subcatchment Width – Longest Flowpath
- Elevations – 2011 LiDAR Survey
- Subcatchment Slope – 2011 LiDAR Survey
- Impervious Cover – 2010 Survey
- Catch Basin Depths – Assumed to be 8 feet
- Conduit Roughness – EPA SWMM User's Manual
- Soil Parameters - EPA SWMM User's Manual, Web Soil Survey

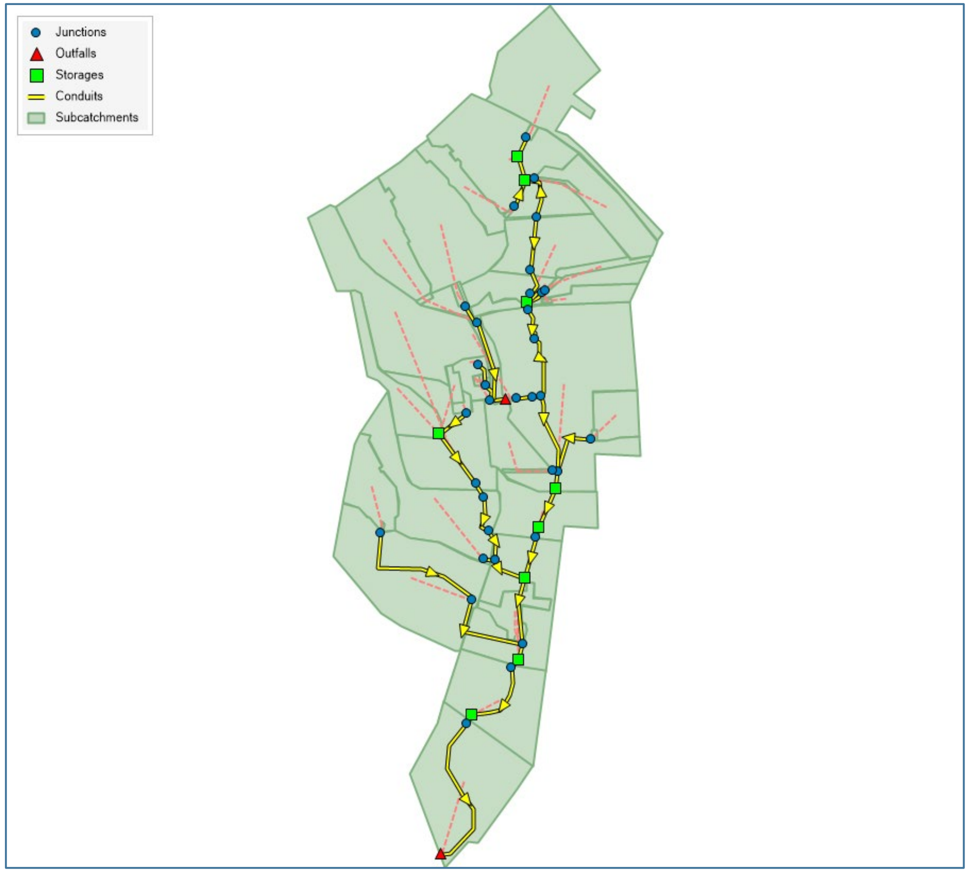
Impervious surface cover in the Berry Brook Watershed

Model Development

PRE



POST

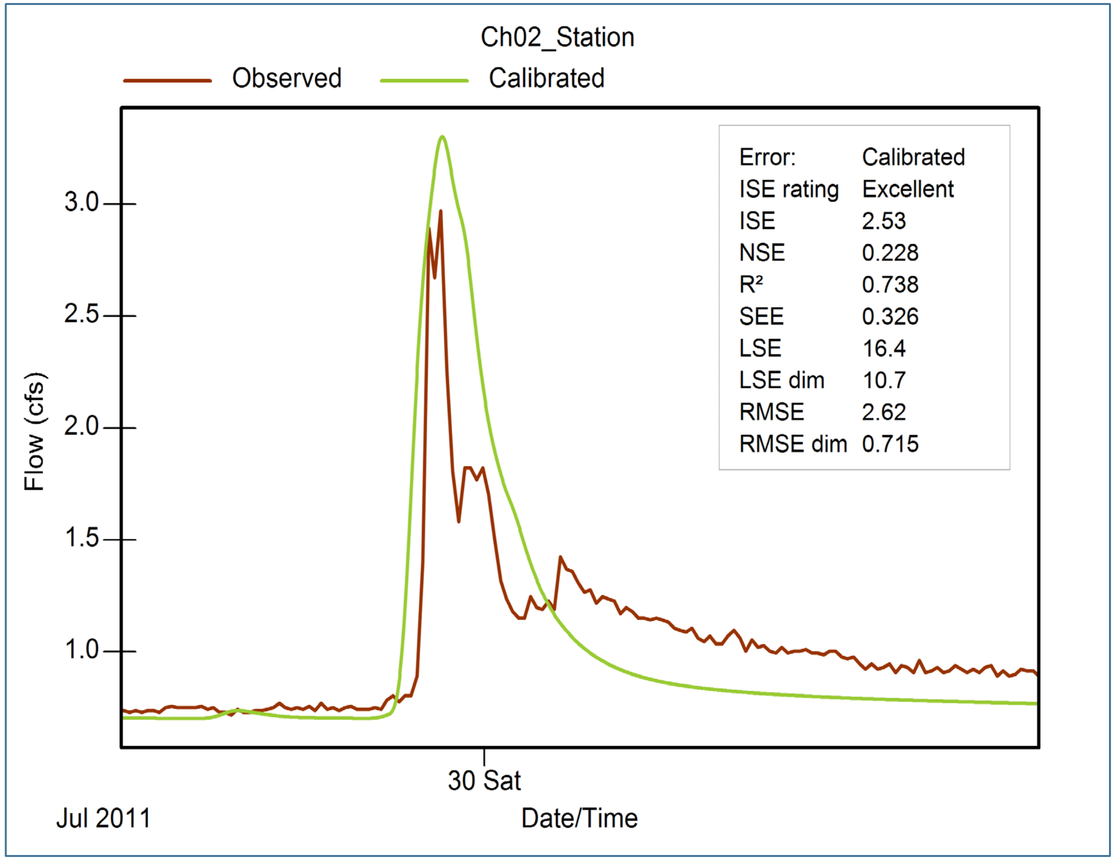


Model Calibration

- Hlas (2011 – Pre GSI) and Johnson (2017-2018 – Post GSI) Data
- UNH Morse Hall precipitation gage 7 miles (11 km) from site
- Major calibration parameters:
  - Subcatchment width
  - Conduit roughness
  - Conduit length
  - Manning's n

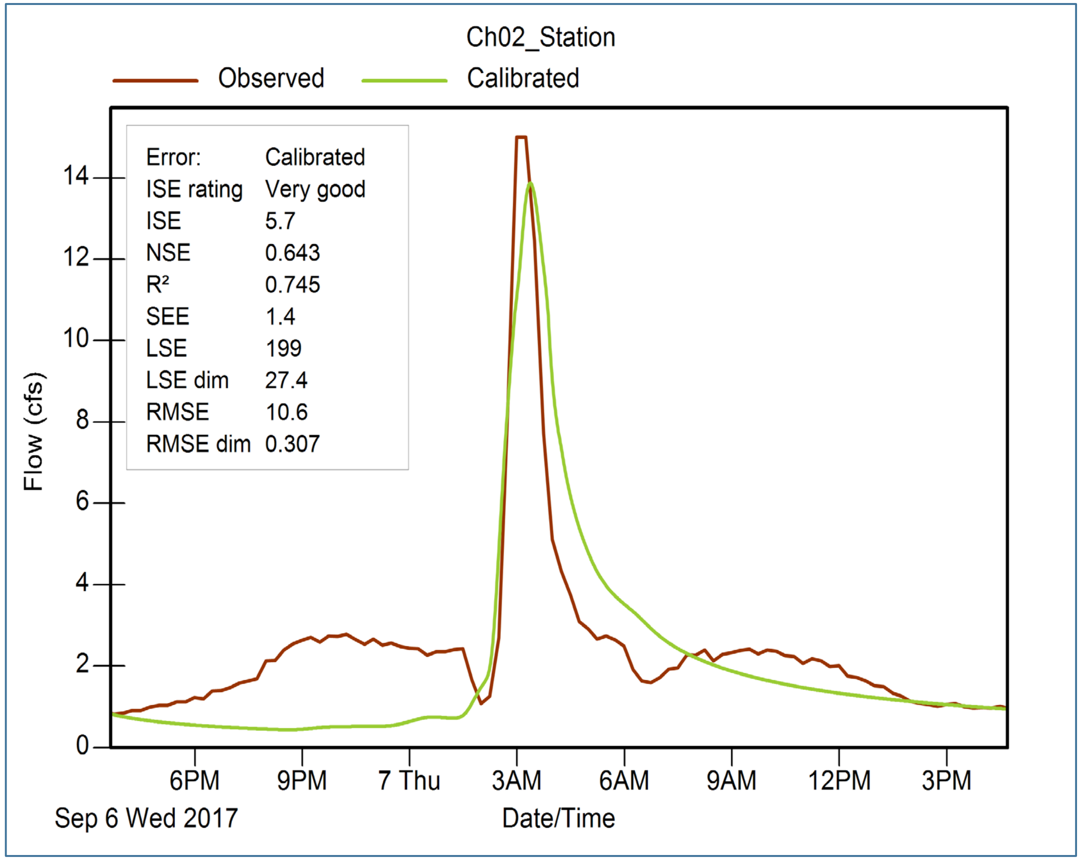
Event-Based Calibration

PRE-IMPROVEMENTS



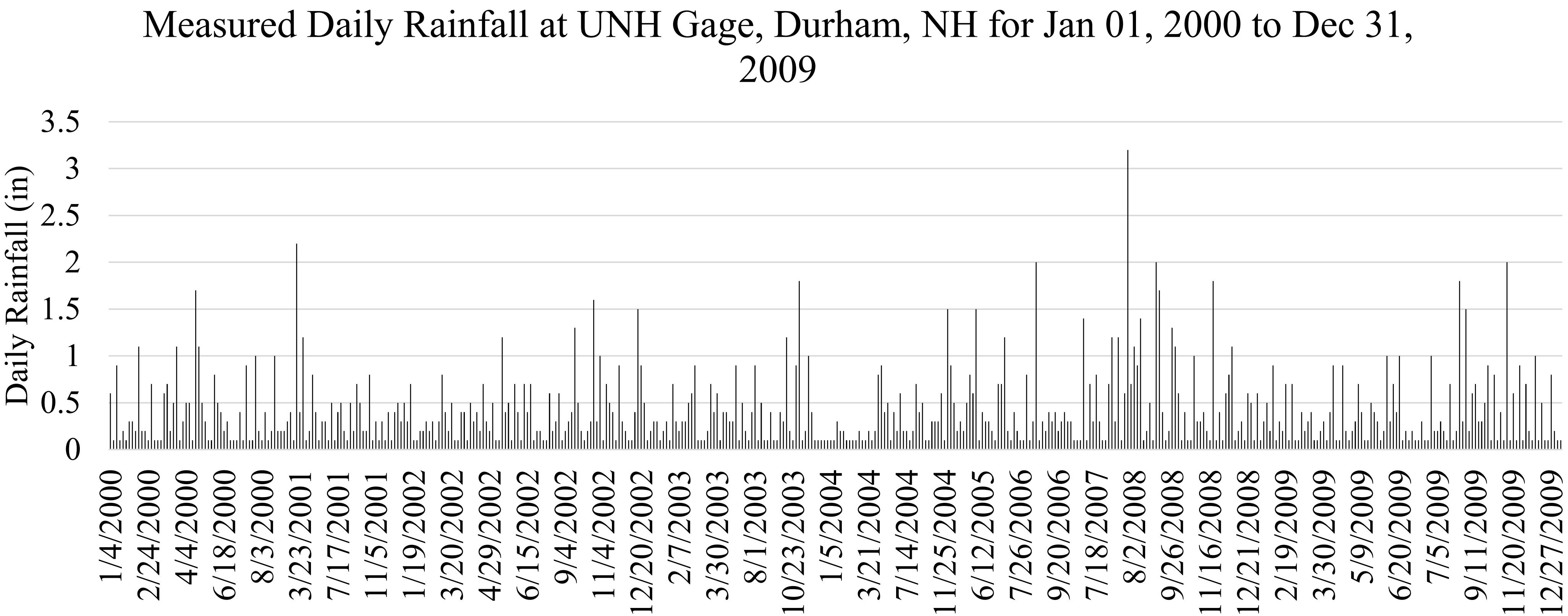
Rainfall: 0.23 inches (5.8 mm)

POST-IMPROVEMENTS

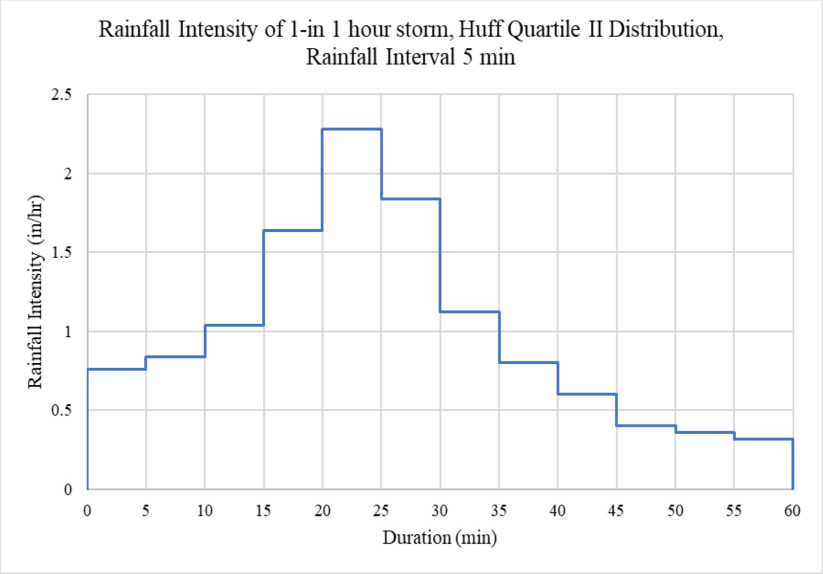


Rainfall: 0.85 inches (21.6 mm)

Long-Term Analysis



Precipitation

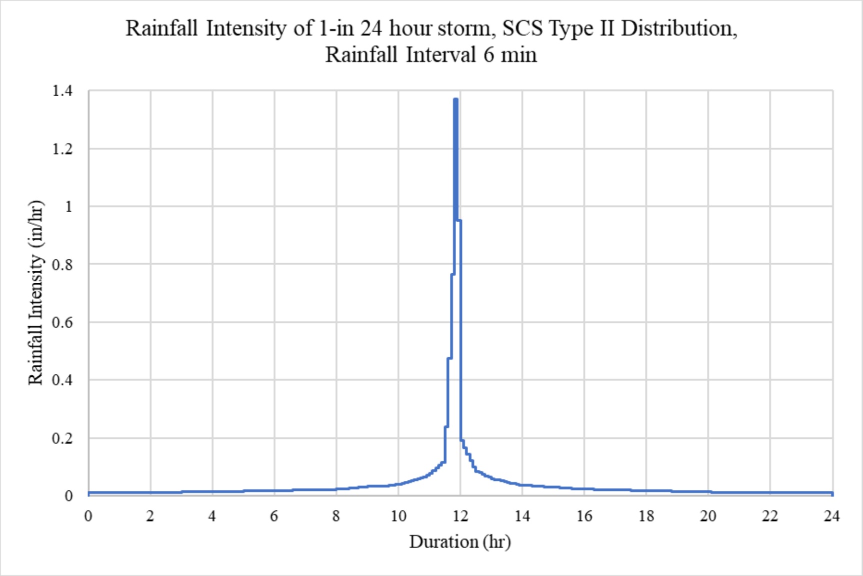


Atlas 14 Precipitation Data

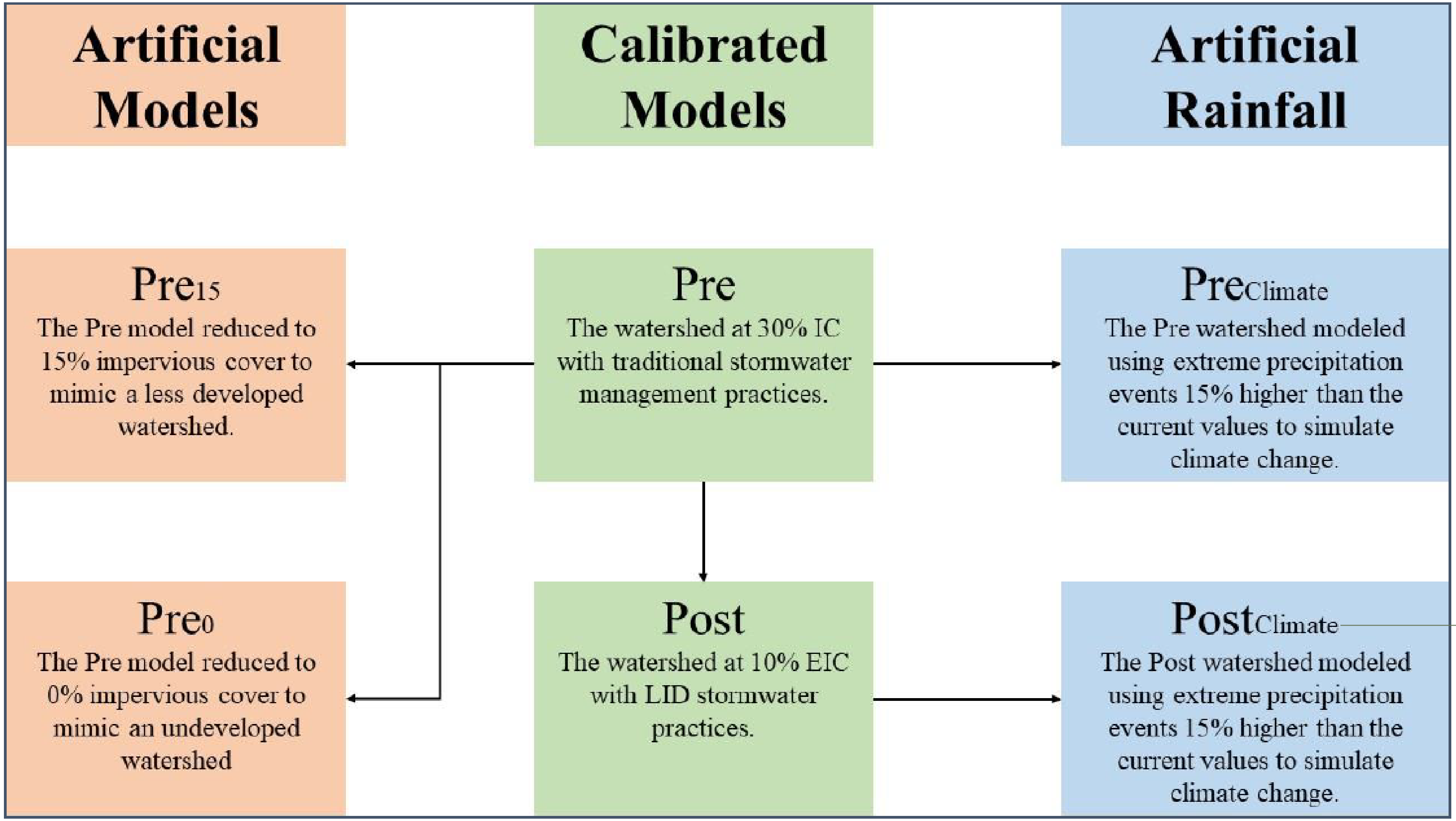
Storm Duration	2-yr	10-yr	50-yr	100-yr
1 hr	0.98	1.49	2.04	2.28
24 hr	3.23	5.18	7.29	8.29

Climate-Adjusted Precipitation Data

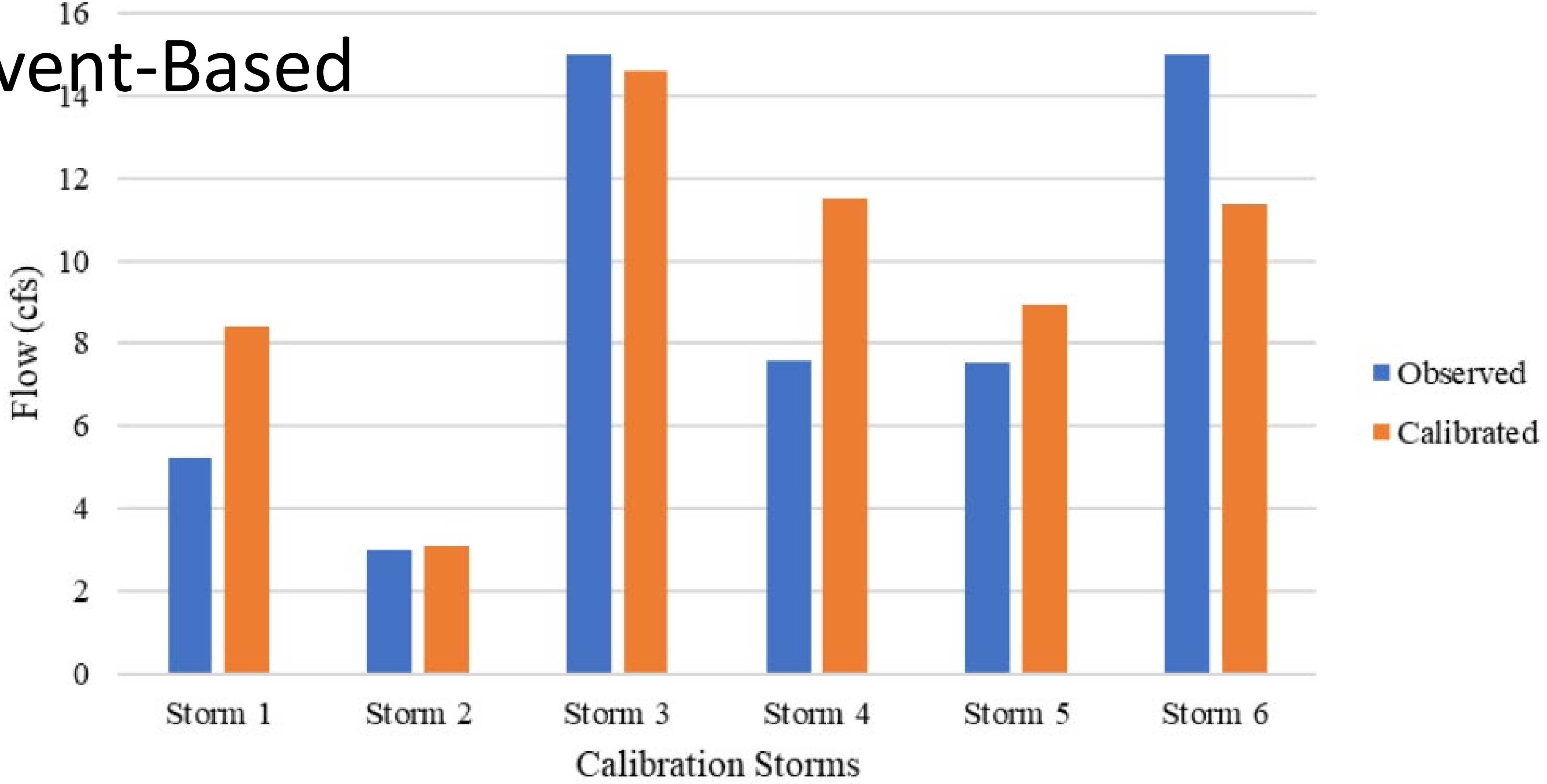
Storm Duration	2-yr	10-yr	50-yr	100-yr
1 hr	1.13	1.71	2.34	2.63
24 hr	3.71	5.95	8.38	9.51



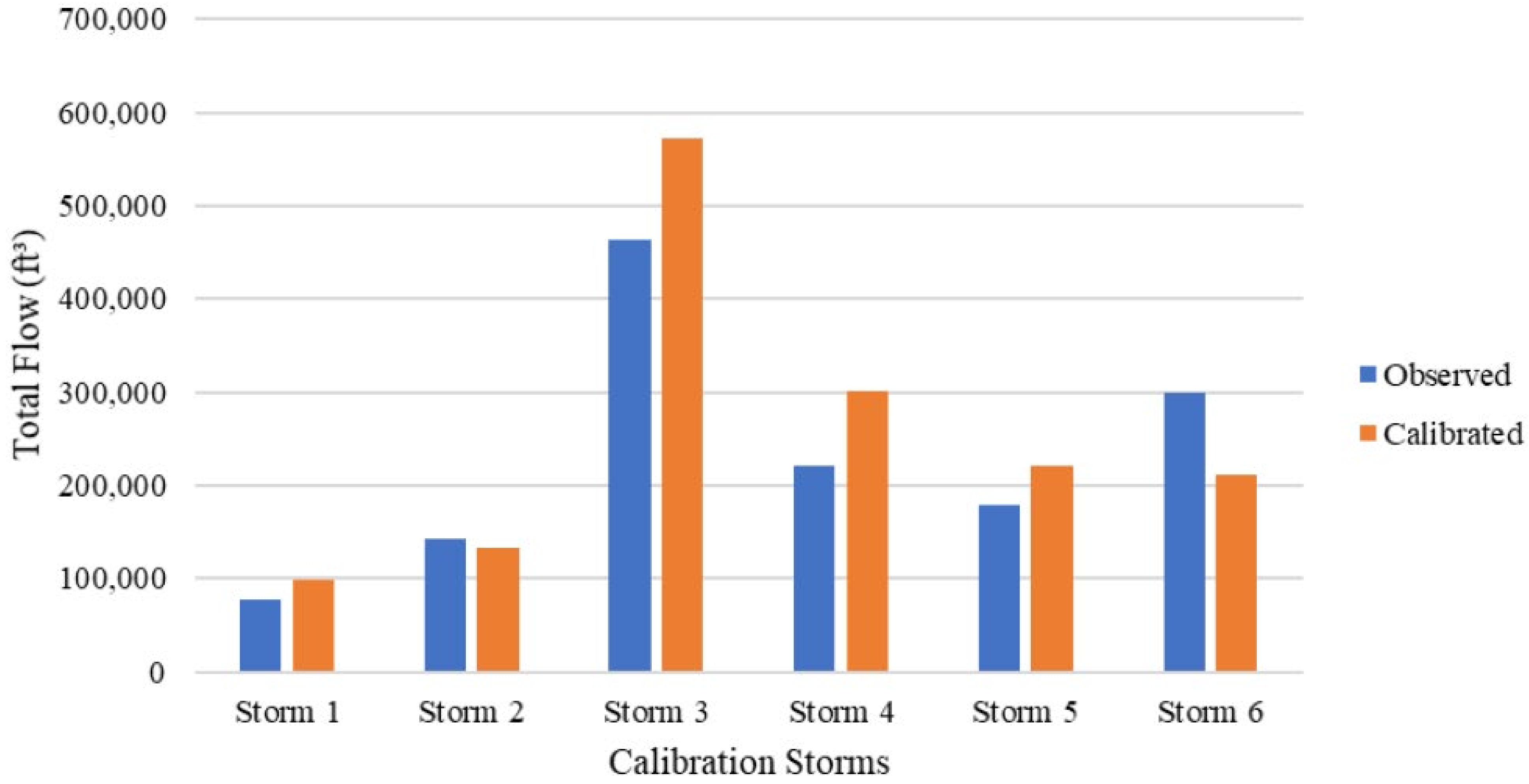
The Models


Artificial Models
Calibrated Models
Artificial Rainfall
Pre15
The Pre model reduced to 15% impervious cover to mimic a less developed watershed.
Pre
The watershed at 30% IC with traditional stormwater management practices.
PreClimate
The Pre watershed modeled using extreme precipitation events 15% higher than the current values to simulate climate change.
Pre0
The Pre model reduced to 0% impervious cover to mimic an undeveloped watershed
Post
The watershed at 10% EIC with LID stormwater practices.
PostClimate
The Post watershed modeled using extreme precipitation events 15% higher than the current values to simulate climate change.

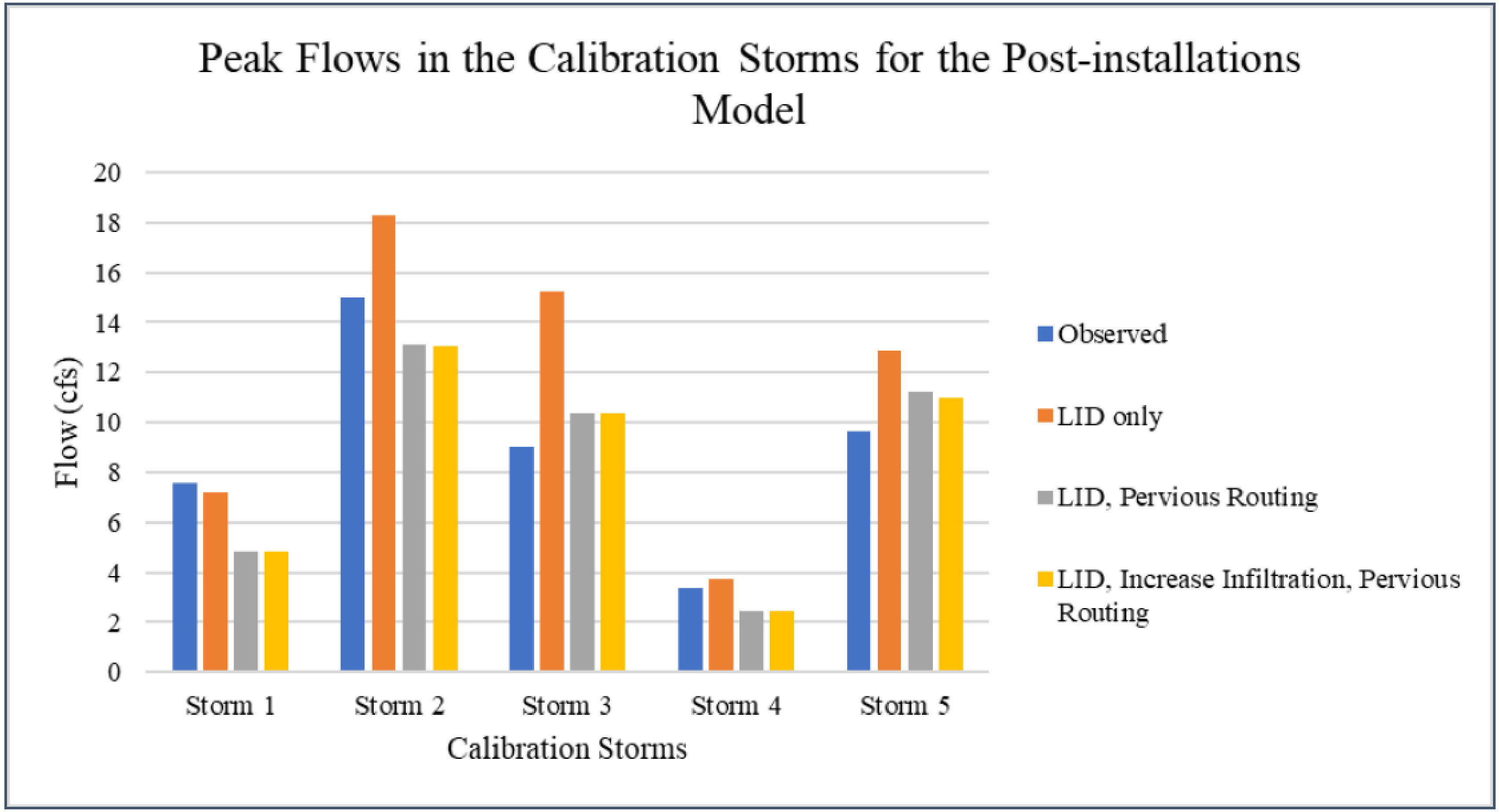
Pre GSI Watershed (30% EIC) Peak Flow Calibration
Event-Based



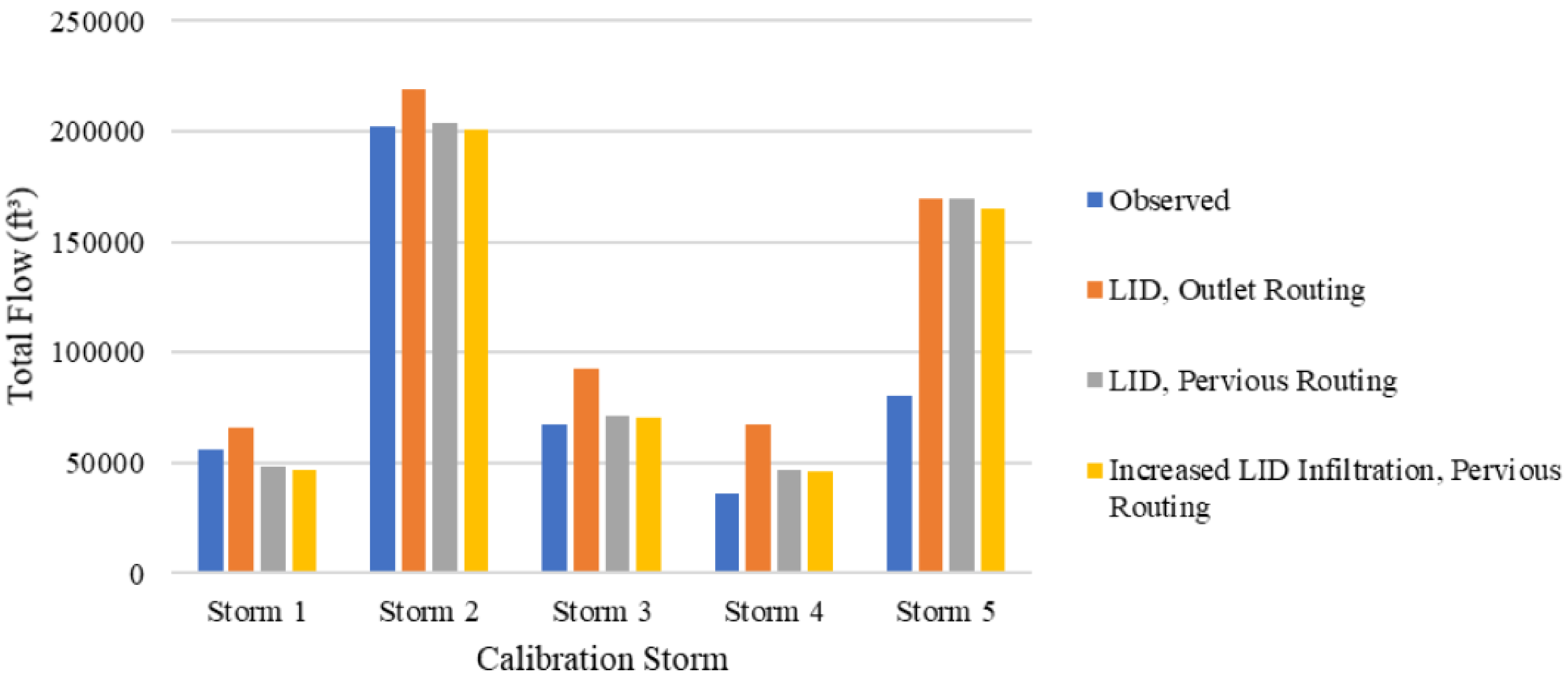
Pre GSI Watershed (30% EIC) Hydrograph Volume Calibration



Post GSI Watershed (10% EIC) Peak Flow Calibration

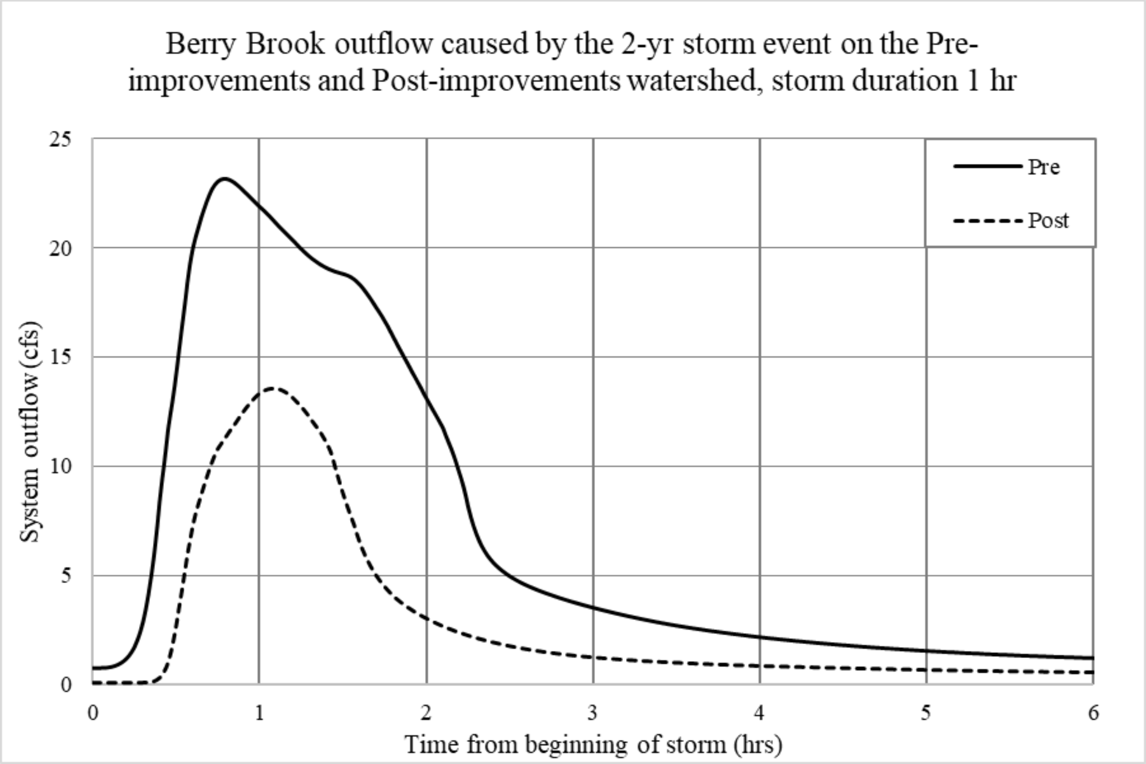


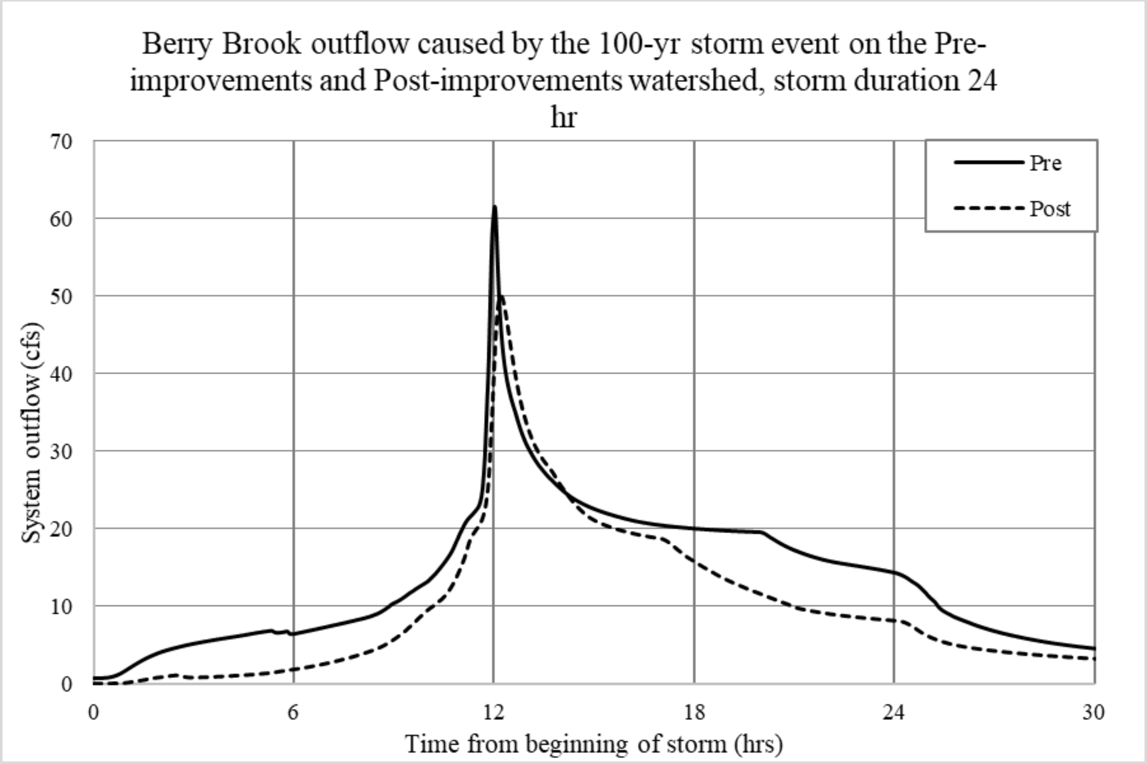
Post GSI Watershed (10% EIC) Hydrograph Volume Calibration



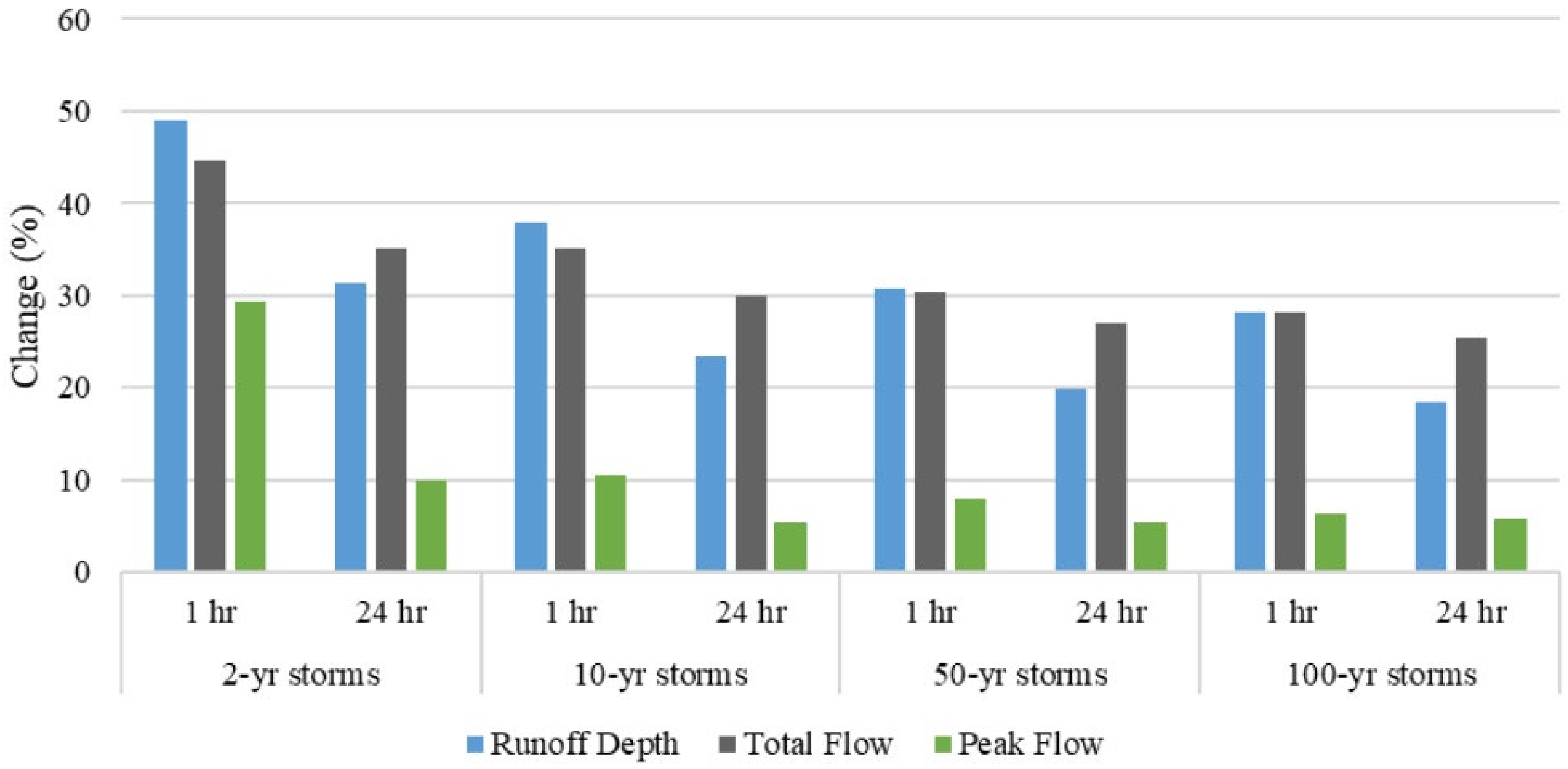
Extreme Precipitation Event Analysis of the Berry Brook Watershed

Example: Extreme Precipitation Events





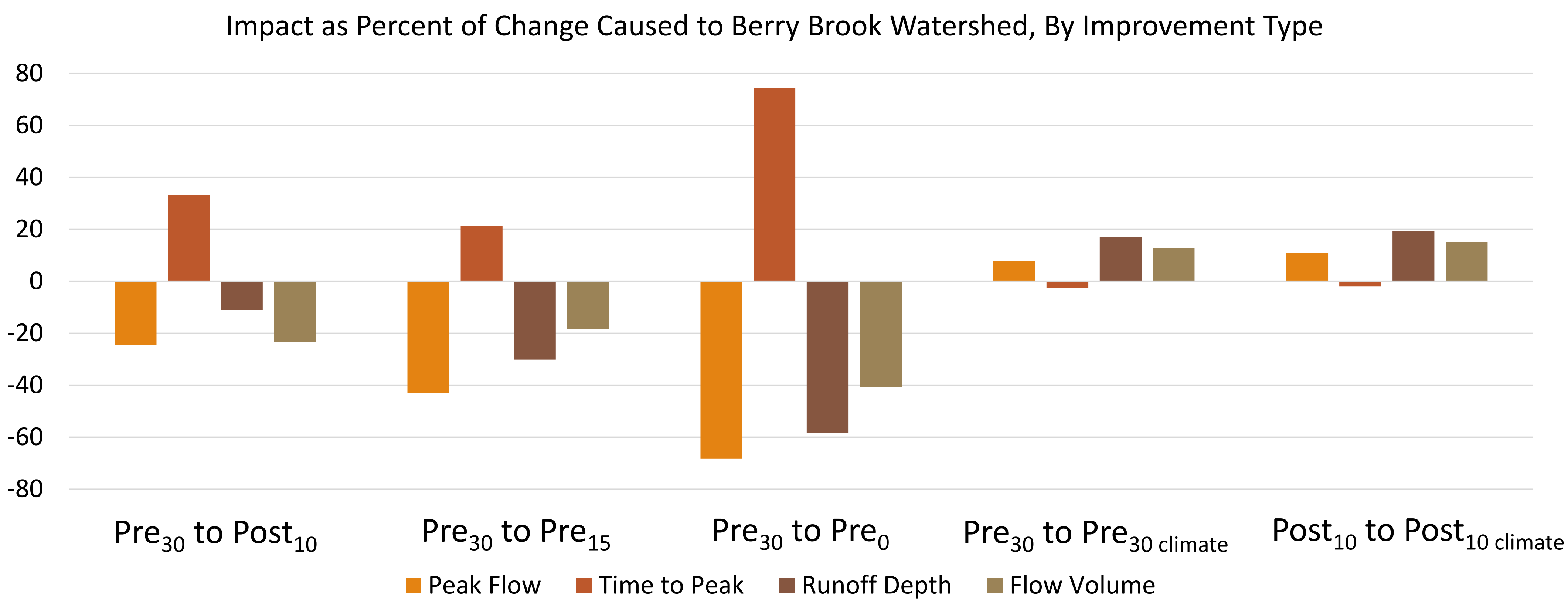
Percent Change in Runoff Depth, Total Flow, and Peak Flow Caused by GSI Implementation to 10% EIC in a 30% IC Watershed



GSI Effect on Peak Flows

Event	Duration	Rain (in)	Peak Flow (cfs)				Time to Peak (hr)		
			Pre	Post	Change	% Change	Pre	Post	Change
2-yr storms	1 hr	0.98	22	13	9	-40.9%	0.78	1.08	38.5%
	24 hr	3.23	34	27	7	-20.6%	12.05	12.45	3.3%
10-yr storms	1 hr	1.49	28	20	8	-28.6%	0.65	1.05	61.5%
	24 hr	5.18	44	35	9	-20.5%	12.03	12.27	2.0%
50-yr storms	1 hr	2.04	35	25	9	-28.6%	0.60	1.05	75.0%
	24 hr	7.29	55	45	10	-18.2%	12.02	12.22	1.7%
100-yr storms	1 hr	2.28	37	28	9	-24.3%	0.57	1.03	80.7%
	24 hr	8.27	61	50	11	-18.0%	12.02	12.20	1.5%

Percent Change Caused by Alteration to the Berry Brook Watershed



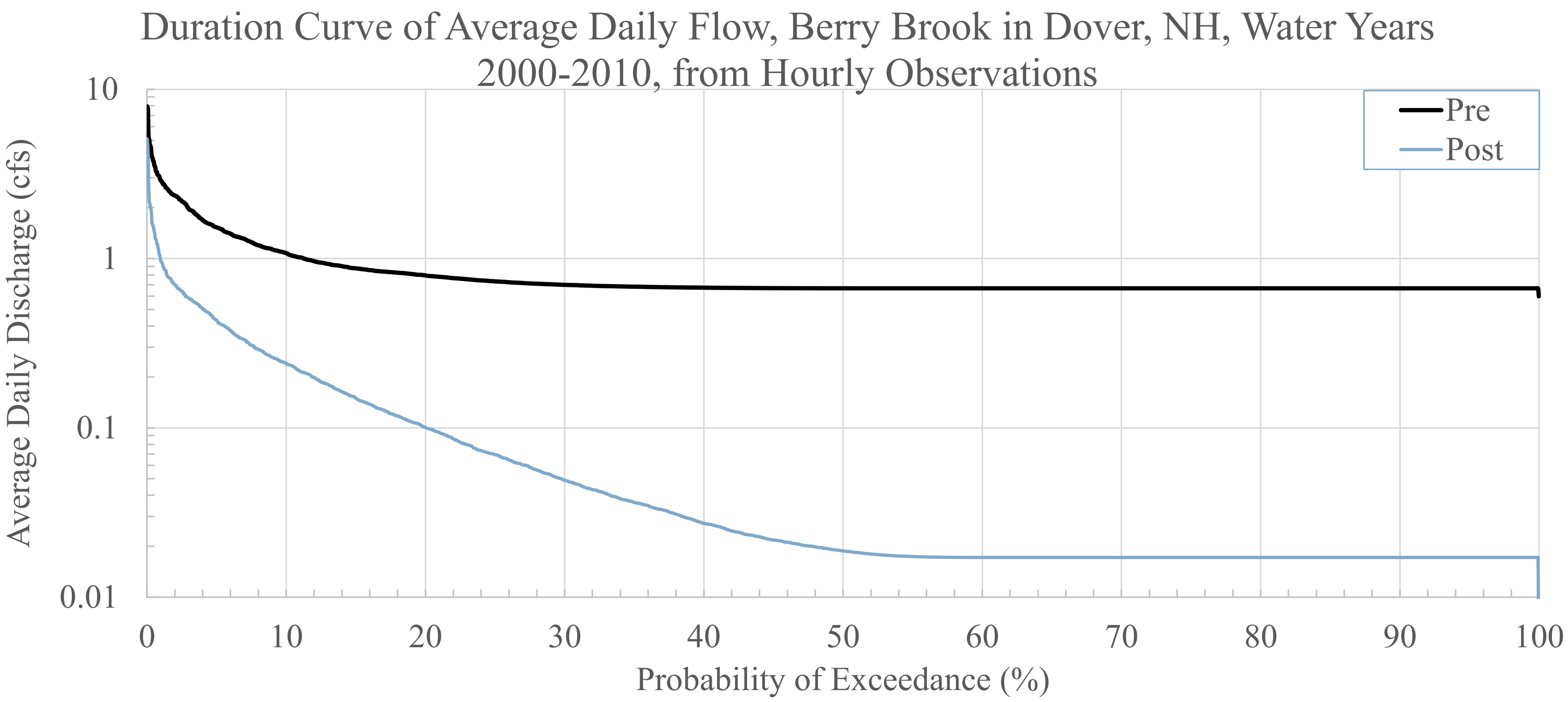
Climate change is not as important an issue in flooding as impervious cover

Extreme Precipitation Events- Conclusions

- Reduce IC to 15% without GSI
  - Peak Flow reduced 43%
  - Runoff depth reduced 30%
- Reduce IC to 0% without GSI
  - Peak Flow reduced 68%
  - Runoff depth reduced 58%
- GSI Implementation
  - Peak Flow reduced 24%
  - Runoff depth reduced 11%
- Increase Precipitation by 15% without GSI
  - Peak Flow increased 11%
  - Runoff depth increased 18%
- Increase Precipitation by 15% with GSI
  - Peak Flow increased 8%
  - Runoff depth increased 17%
  - **Reductions decrease with return period**

Long-Term Analysis of the Pre-Improvements and Post-Improvements Watersheds

Long-Term Analysis: Frequency-Duration Curves



Long-Term Analysis: Annual Maximum Wet Weather Flows

Water Year	Maximum Flow (cfs)		Decrease	
	Pre	Post	Peak Flow (cfs)	Peak Flow (%)
2000	21	11	9	45
2001	17	6	11	64
2002	21	9	12	58
2003	15	5	10	66
2004	23	16	7	32
2005	25	20	5	20
2006	22	15	6	29
2007	19	7	12	64
2008	26	24	1	5
2009	23	13	10	43
2010	25	22	3	10

- Average Decrease: 40%
- Median Annual Maximum Rainfall: 1.8 in

Long-Term Analysis: Infiltration and Surface Runoff

	Inches of Water		Change	Change	
	Pre	Post	inches	%	Type
Total Rainfall	211	211	0	0	N/A
Infiltration	148	180	32	22	Increase
Surface Runoff Depth	58	29	29	50	Decrease

GSI / BMP Implementation

- Extreme Precipitation Events
  - Peak Flow reduced 24% - Reduction decreases with return period
  - Runoff depth reduced 11% - Reduction decreases with return period
- Long-Term Analysis – Wet Weather Flows
  - 40% decrease in peak flow
  - 22% increase in infiltration
  - 50% decrease in storm runoff depth

Research Questions

- What are the effects of green stormwater infrastructure on reducing flooding in urban areas?

GSI reduces peak flow and total runoff depth in extreme precipitation events and in a long-term analysis.

- Which is more extreme: effect on flooding caused by impervious cover or the effect on flooding expected by climate change?

Reducing impervious cover in the watershed reduces peak flow and total runoff depth in extreme precipitation events, with more reduction in more frequent events. Decreasing IC or EIC has a greater impact than climate change an urbanized with or without GSI.

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Questions?