

Visualizing Hydrologic Flood Models in Virtual Reality:

Bridging the gap between technical experts
and community stakeholders

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**LANDSCAPE
ARCHITECTURE**
Department of Plant Science
and Landscape Architecture

Climate change

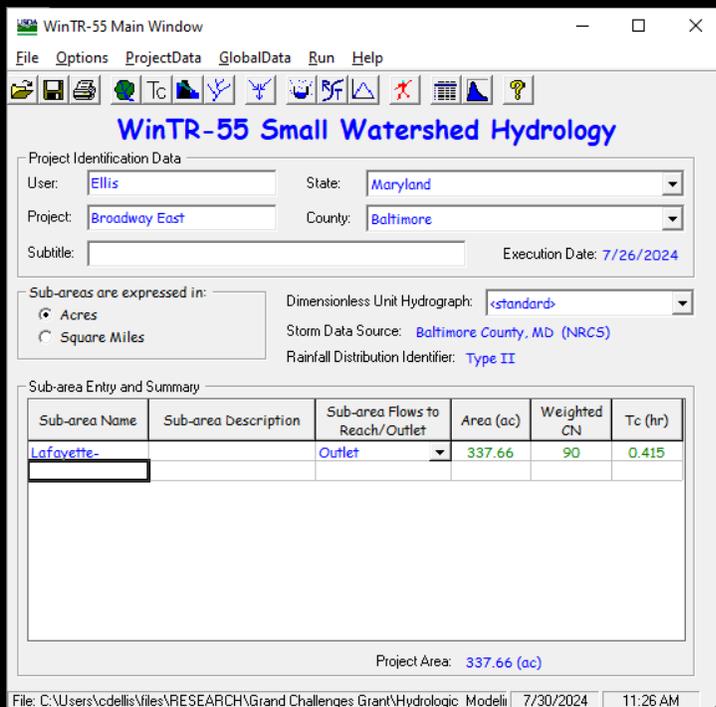
- Climate change led to increases in flash floods, river floods and coastal floods in urban areas ([UNEP, 2022](#); [Climate.gov, 2018](#)).
- Flooding due to climate change is the leading cause of both natural disasters and death (by natural disaster) in the U.S. (Doocy, 2013).

Climate Change in Maryland

- Of the 34 storm related disasters in the state of Maryland since 1953, 16 (nearly half) of those occurred in the last 10 years (FEMA, 2022).
- There is an average of 123 flooding events annually in Maryland with an average FEMA claim of \$52,000 (~\$6.4 million per year; FEMA, 2022).
- People affected by flooding report increased stress levels, lost work hours, lost valuables, loss of property, and negative health effects (SAMHSA, 2017).

Visualizing Hydrologic Flood Models

- The hydrologic modeling presented here is for the purposes of visualization research.



Visualizing Hydrologic Flood Models

- We hope to bridge the gap between experts with technical knowledge of flood modeling, and stakeholders who might be at risk of flooding but do not have the technical knowledge to fully understand the data.



Visualizing Hydrologic Flood Models

- These 3D visualizations translate the technical model (WinTR-55) into realistic flood images that a stakeholder can understand more readily than the technical model data.
- The images were produced for viewing in VR headsets to give viewers the sensation of being there.



Flooding in Baltimore 2019

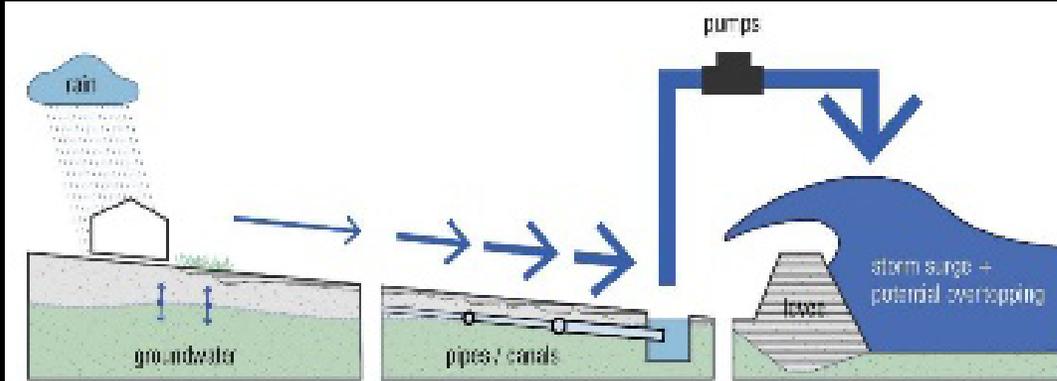


Flood Visualization



Sea Level Rise Protection Plan, St Michaels, MD, 2020

Flood Visualization



Pave

Urban surfaces, including streets and parking lots, are paved with impervious materials that shed stormwater directly into storm drains and prevent that water from soaking into the ground.

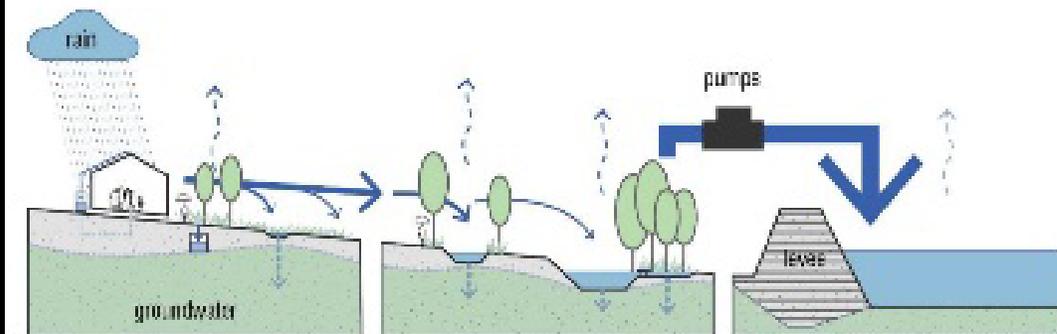
Pipe

Underground pipes and culverts are often overwhelmed by stormwater, causing backed-up storm drains to overflow into streets. These pipes do not allow stormwater flowing through them to infiltrate into surrounding soils.

Pump

Fed by drainage pipes and canals, powerful pumps at the perimeter of each basin lift stormwater over the levees into Lake Pocomochartrain, the Inner Harbor, and the Central Wetlands Unit.

Proposed



Slow

Rooftops, driveways, streets, and sidewalks can be redesigned to catch rain where it falls, and to allow some of that water to soak into the ground. A healthy urban tree canopy also slows the flow of water and improves environmental quality.

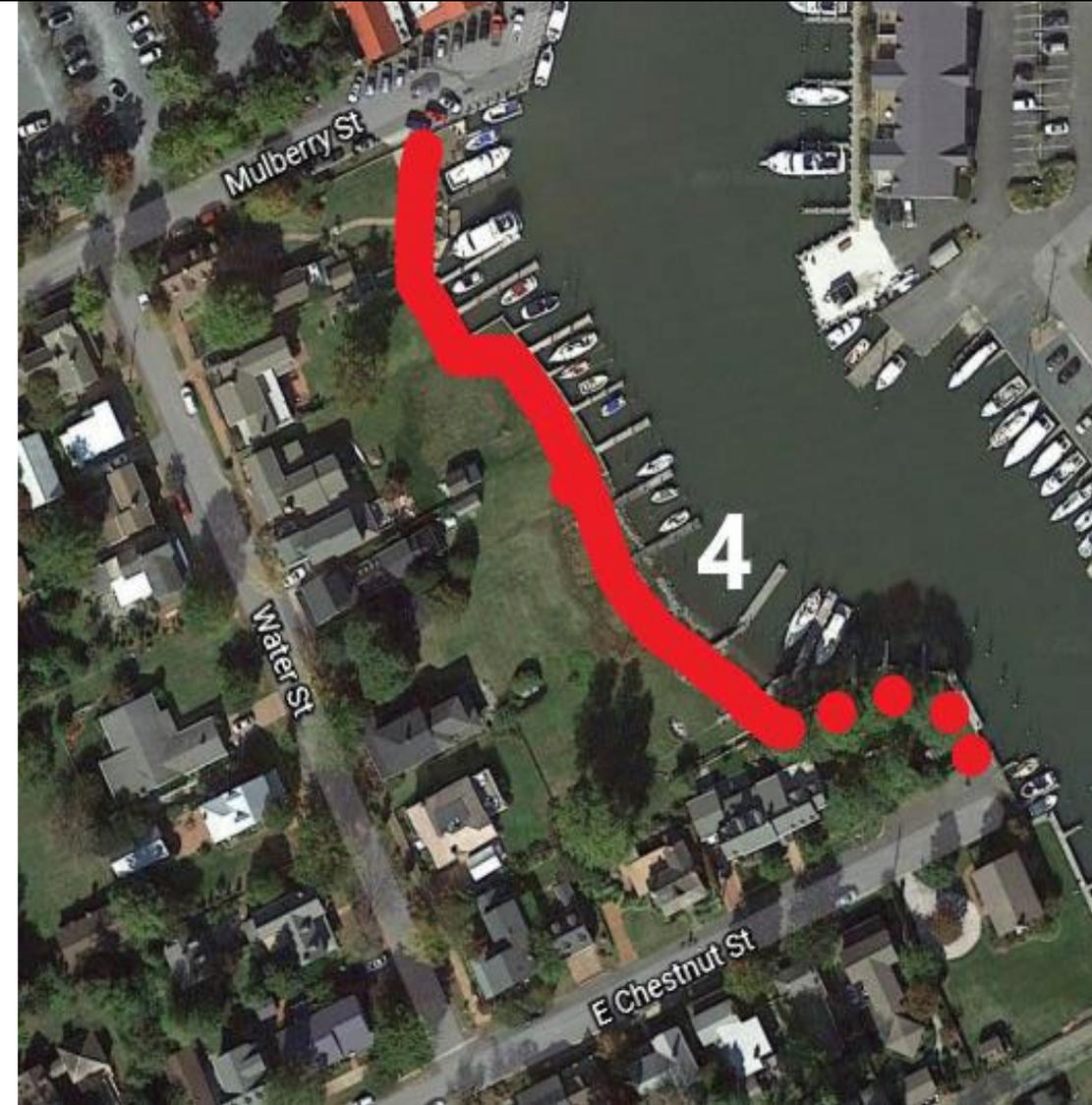
Store & Use

Large-scale detention and retention features integrated into canal networks and public spaces provide additional storage capacity. Stored water can be used for irrigation, recreation, and other purposes.

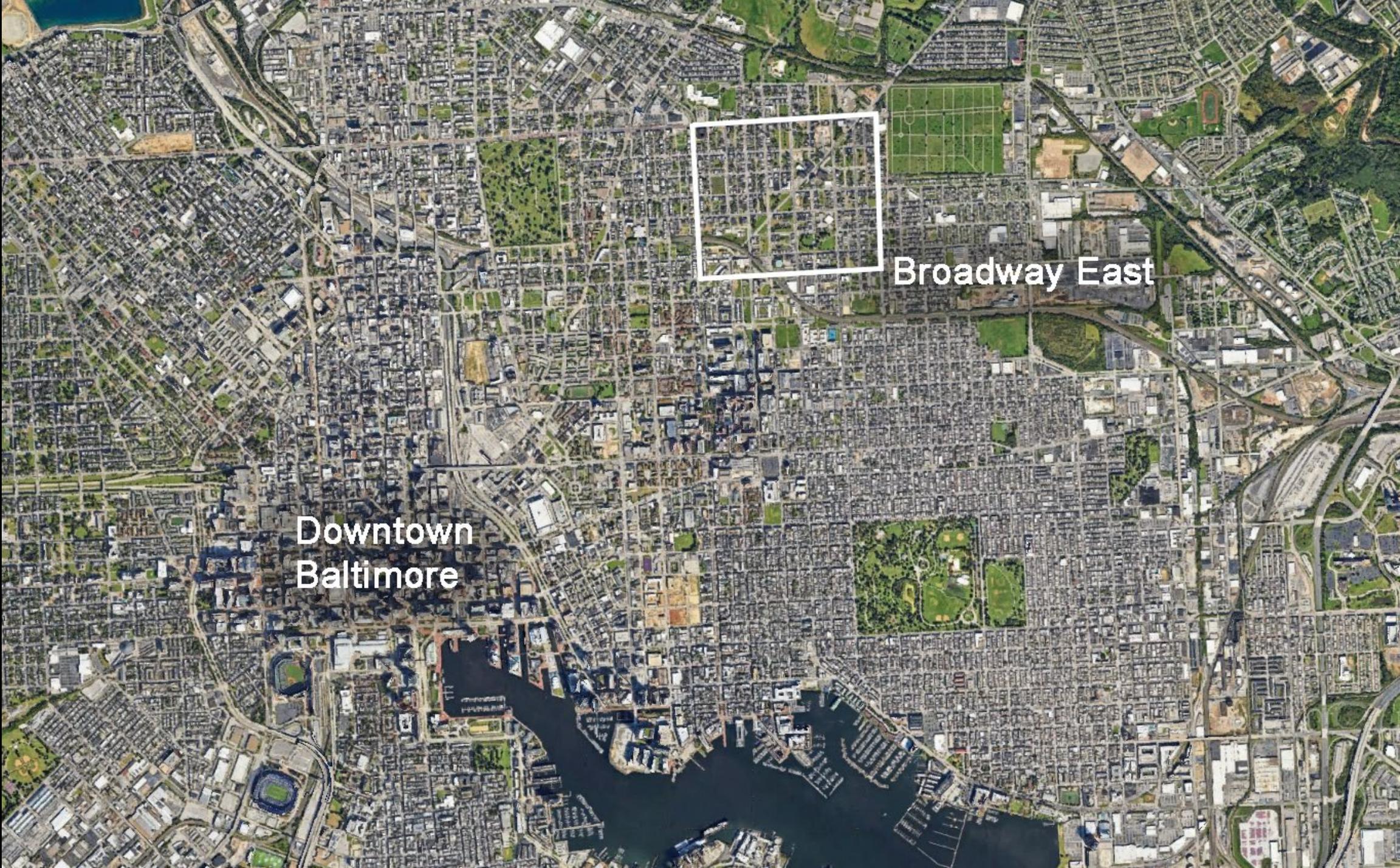
Drain When Necessary

Pumping should not be the only solution for managing stormwater. Slow & Store features lessen loads on pumping stations, provide additional factors of safety, and enhance the capacity of drainage systems overall.

Current



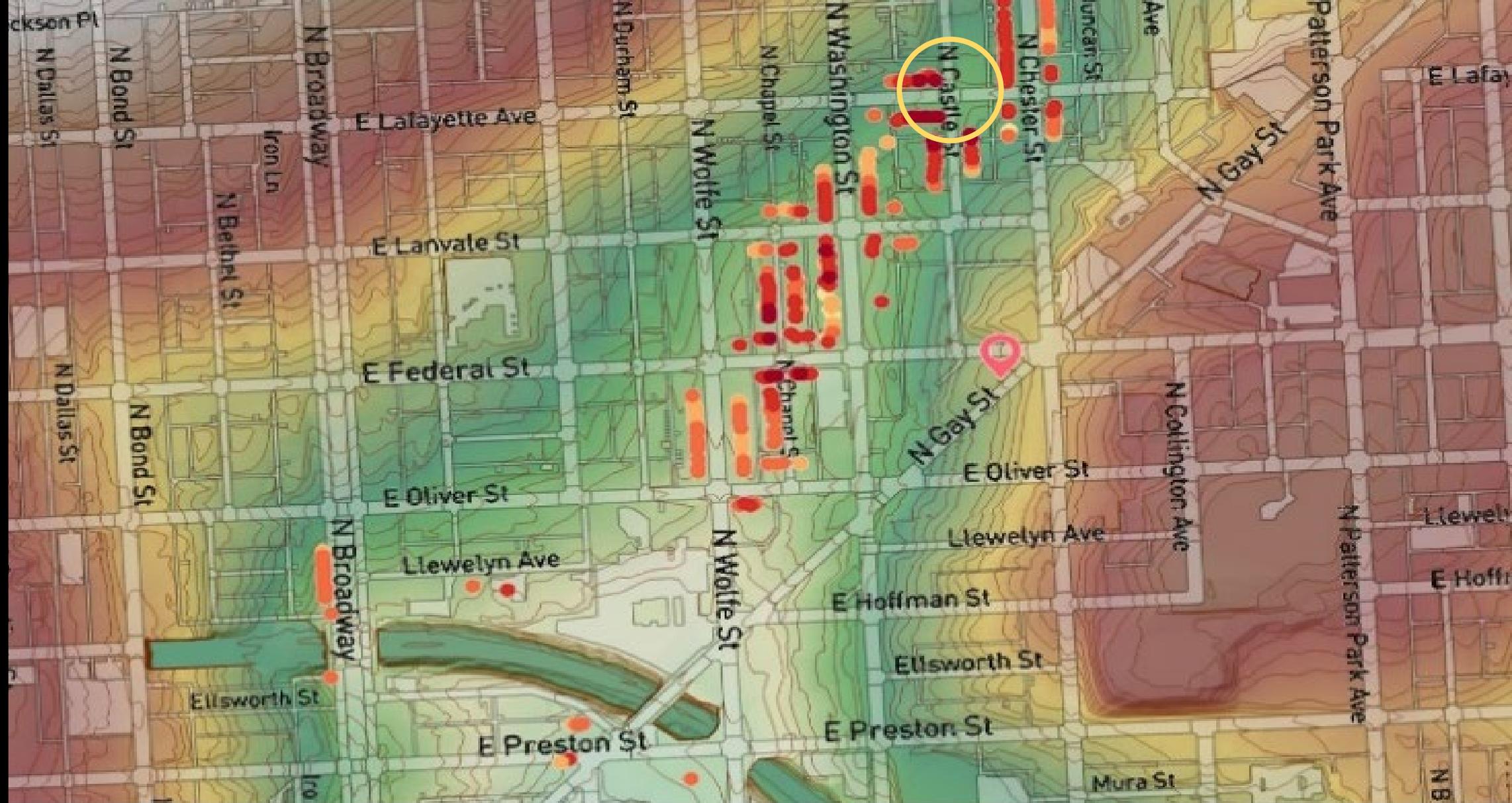
Broadway East Neighborhood



Downtown
Baltimore

Broadway East

Flooding Potential in Broadway East

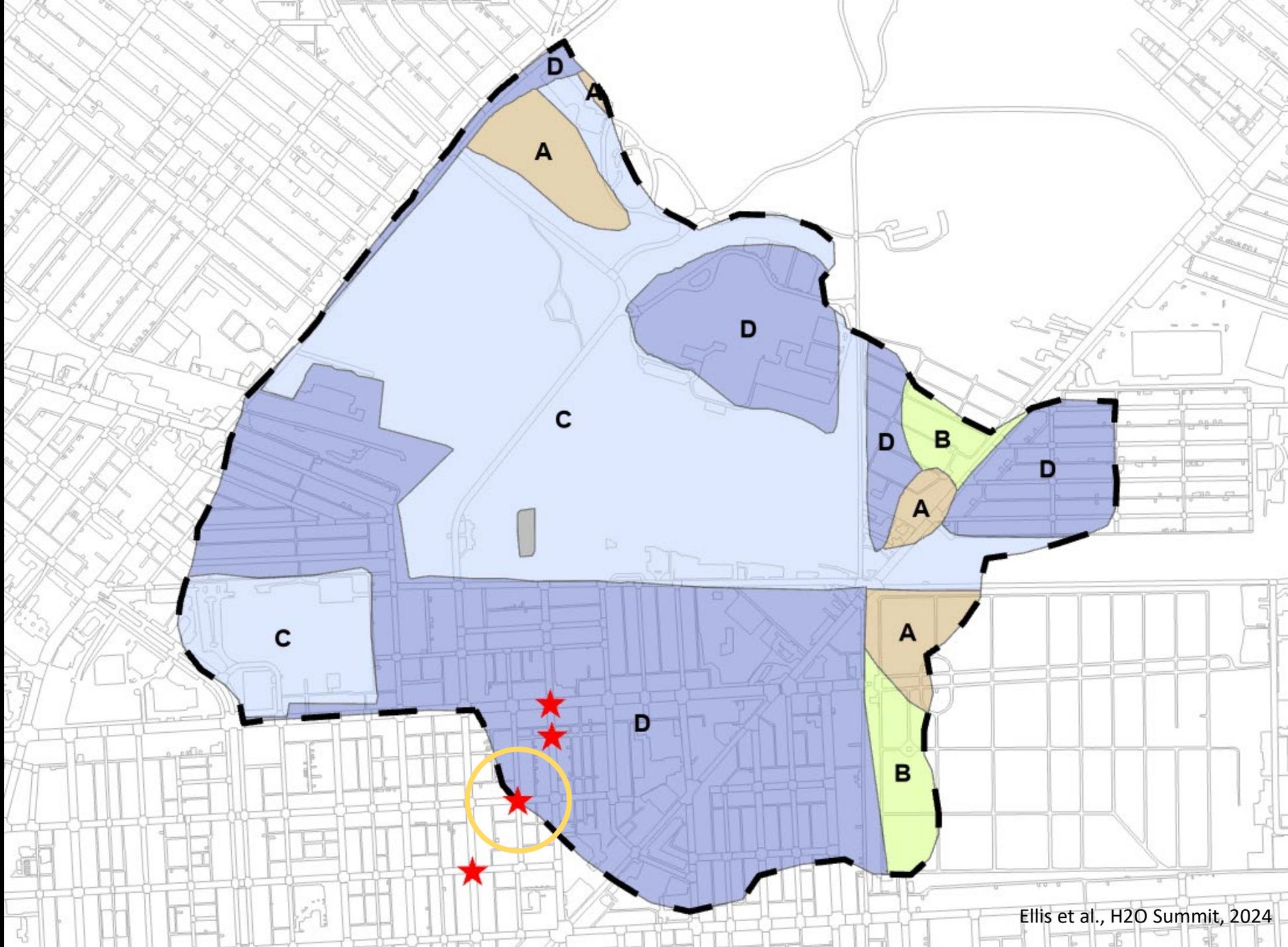


Catchment Area for the Intersection
of E. Lafayette Ave & N. Castle St



Hydrologic Soil Groups

- A: low runoff potential (>90% sand and <10% clay)
- B: moderately low runoff potential (50-90% sand and 10-20% clay)
- C: moderately high runoff potential (<50% sand and 20-40% clay)
- D: high runoff potential (<50% sand and >40% clay)



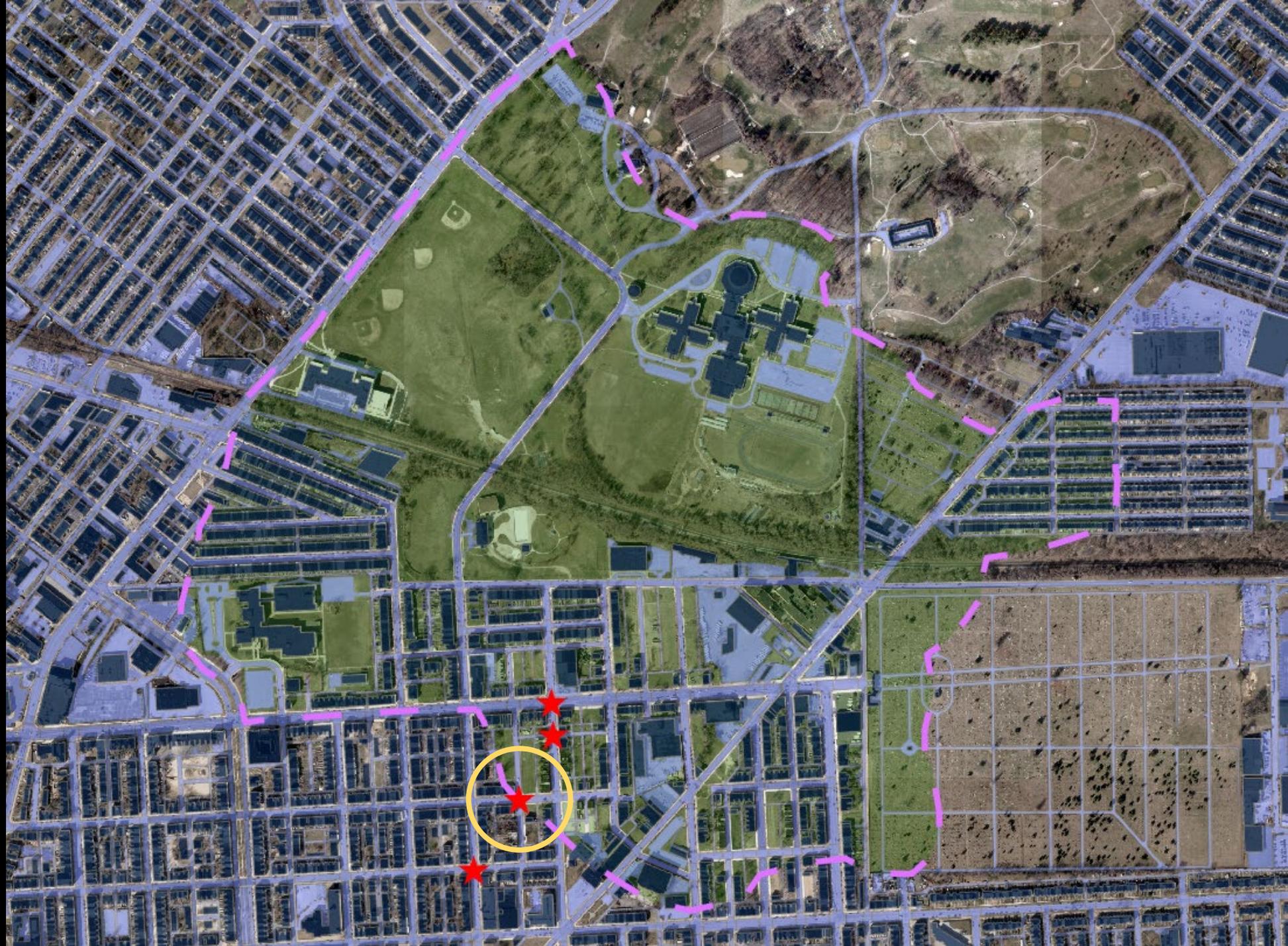
Landcover Analysis

- Buildings
- Impervious Surface
- Open Space



Landcover Analysis

- Buildings
- Impervious Surface
- Open Space



WinTR-55 Hydrologic Model

WinTR-55 Main Window

File Options ProjectData GlobalData Run Help

WinTR-55 Small Watershed Hydrology

Project Identification Data

User: State:

Project: County:

Subtitle: Execution Date: 7/24/2024

Sub-areas are expressed in:

Acres Square Miles

Dimensionless Unit Hydrograph:

Storm Data Source:

Rainfall Distribution Identifier:

Sub-area Entry and Summary

Sub-area Name	Sub-area Description	Sub-area Flows to Reach/Outlet	Area (ac)	Weighted CN	Tc (hr)
Lafayette-		Outlet	337.66	90	0.415

Project Area: 337.66 (ac)

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WinTR-55 Hydrologic Model

WinTR-55 Main Window

File Options ProjectData GlobalData Run Help

WinTR-55 Small Watershed Hydrologic Model

Land Use Details

Sub-area Name: Lafayette

User: Ellis

Project: Broadway East

Sub-area Entry and Summary

Sub-area Name: Lafayette-

Project Area: 337.66 (ac)

Land Use Categories: Urban Area

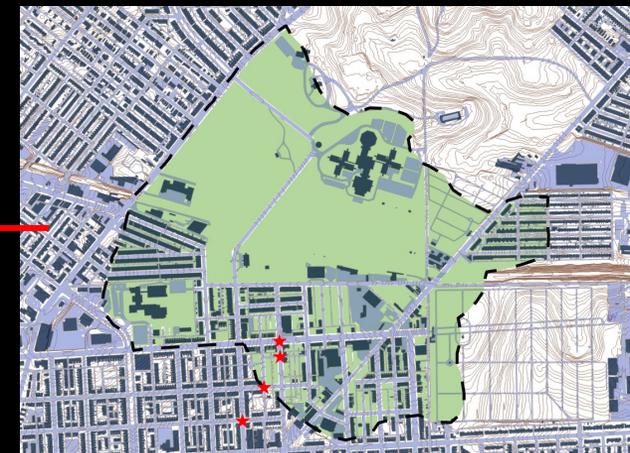
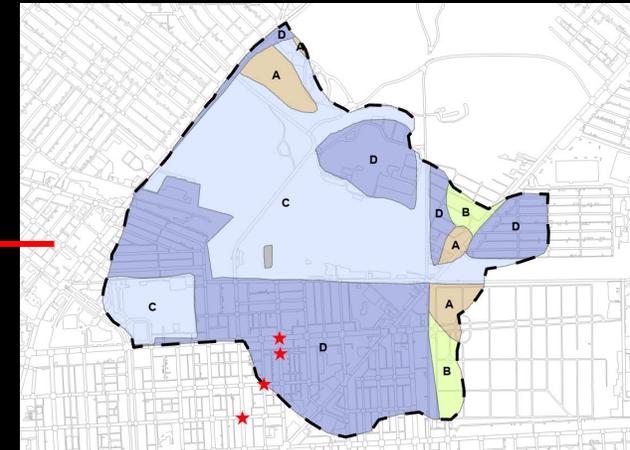
Area (Acres) for Hydrologic Soil Groups

Cover Description	Condition	Area (Acres) for Hydrologic Soil Groups							
		A	CN	B	CN	C	CN	D	CN
FULLY DEVELOPED URBAN AREAS (Veg Estab.)									
Open space (Lawns, parks, etc.)									
Poor condition; grass cover < 50%		15.200	68	10.449	79	116.136	86	74.171	89
Fair condition; grass cover 50% to 75%		49		69		79		84	
Good condition; grass cover > 75%		39		61		74		80	
Impervious Areas:									
Paved parking lots, roofs, driveways		1.992	98	2.061	98	21.812	98	95.836	98
Streets and roads:									
Paved; curbs and storm sewers		98		98		98		98	
Paved; open ditches (w/right-of-way)		83		89		92		93	
Gravel (w/ right-of-way)		76		85		89		91	
Dirt (w/ right-of-way)		72		82		87		89	
Urban Districts									
Project Area(ac)		Summary Screen		Sub-Area Area (ac)		Weighted CN:		Avg % Imperv	
337.66		<input checked="" type="radio"/> Off <input type="radio"/> On		337.66		90			

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Project Area: 337.66 (ac)

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WinTR-55 Hydrologic Model



WinTR-55 Small Watershed Hydrology

Project Identification Data

User: **Ellis**

Project: **Broadway East**

Subtitle:

Sub-areas are expressed in:

Acres

Square Miles

Sub-area Entry and Summary

Sub-area Name	Sub-area Description
Lafayette-	

Land Use Details

Sub-area Name: Lafayette-

Land Use Categories: Urban Area Developing Urban Cultivated Agriculture Other Agriculture Arid Rangeland

Cover Description	Area (Acres) for Hydrologic Soil Groups							
	A	CN	B	CN	C	CN	D	CN
FULLY DEVELOPED URBAN AREAS (Veg Estab.)								
Open space (Lawns, parks etc.)	15.200	68	10.449	79	116.136	86	74.171	89
Poor condition; grass cover < 50%	49		69		79		84	
Fair condition; grass cover 50% to 75%	39		61		74		80	
Good condition; grass cover > 75%								
Impervious Areas:								
Paved parking lots, roofs, driveways	1.992	98	2.061	98	21.812	98	95.836	98
Streets and roads:								
Paved; concrete								
Paved; asphalt								
Gravel (w/curb)								
Dirt (w/curb)								
Urban District								
Project Area	337.6							

Time of Concentration Details

Sub-area Name: Lafayette-

2-Year Rainfall (in): 3.2

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft ²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0800	Grass-Range, Short (0.15)					0.094
Shallow Concentrated	1437	0.0473	Unpaved					0.114
Shallow Concentrated								
Channel	3631	0.0105		0.025	77.00	108.00	4.873	0.207
Channel								
Total	5168						3.4592	0.415



TOC = 25 Minutes

Velocity = 3.45 feet per second

WinTR-55 Hydrologic Model



WinTR-55 Land Use Details

Project Identification Data

User:

Project:

Subtitle:

Sub-areas are expressed in:

Acres

Square Miles

Sub-area Entry and Summary

Sub-area Name	Sub-area Description
Lafayette-	

Project Area:

Summary Screen: Off

File: C:\Users\cdellis\files\RESEARCH\Grand Challenges Grant\Hydrologic_Modeling\03 Three\Catchment_3.w55

Land Use Details

Sub-area Name:

Land Use Categories:

Urban Area

Developing Urban

Cultivated Agriculture

Other Agriculture

Arid Rangeland

Cover Description: **FULLY DEVELOPED URBAN AREAS (Veg Estab.)**

- Open space (Lawns, parks etc.)
- Floor condition; grass cover < 50%
- Fair condition; grass cover 50% to 75%
- Good condition; grass cover > 75%

Impervious Areas:

- Paved parking lots, roofs, driveways

Streets and roads:

- Paved; curbs and storm sewers
- Paved; open ditches (w/right-of-way)
- Gravel (w/ right-of-way)
- Dirt (w/ right-of-way)

Urban Districts

Project Area(ac):

Summary Screen: Off

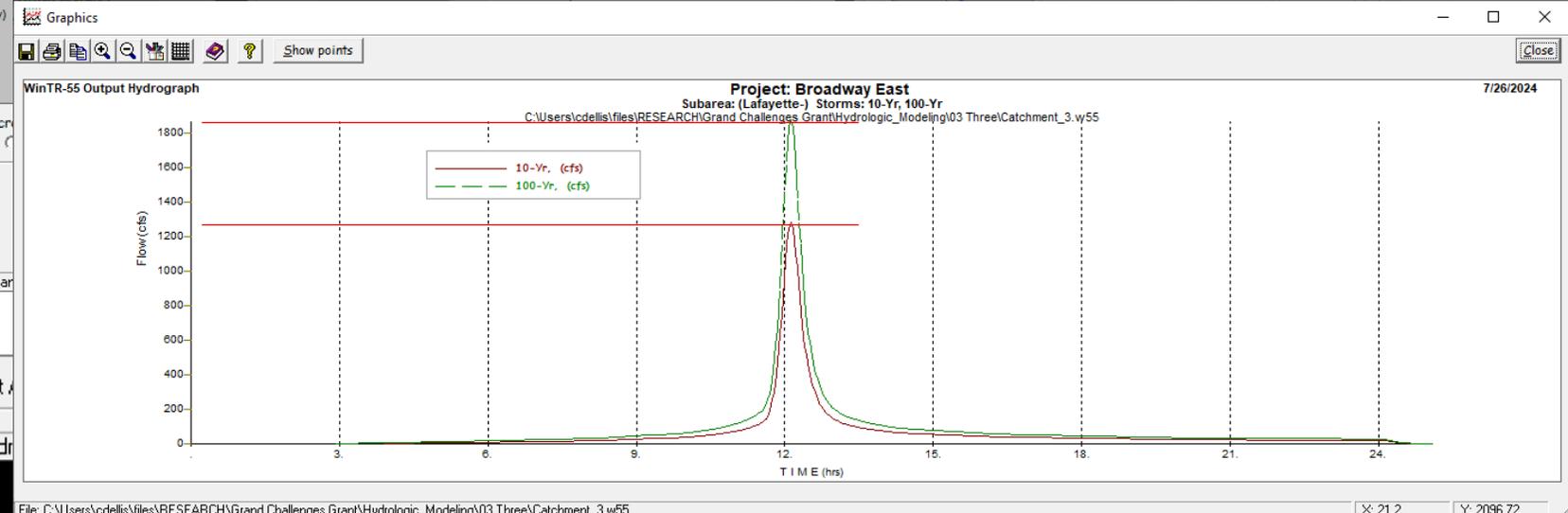
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Time of Concentration Details

Sub-area Name:

2-Year Rainfall (in):

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft ²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0800	Grass-Range, Short (0.15)					0.112
Shallow Concentrated	1437	0.0473	Unpaved					0.114
Shallow Concentrated								



WinTR-55 Hydrologic Model



WinTR-55 Land Use Details

Project Identification Data
 User: Ellis
 Project: Broadway East
 Subtitle:

Sub-areas are expressed in:
 Acres
 Square Miles

Sub-area Entry and Summary

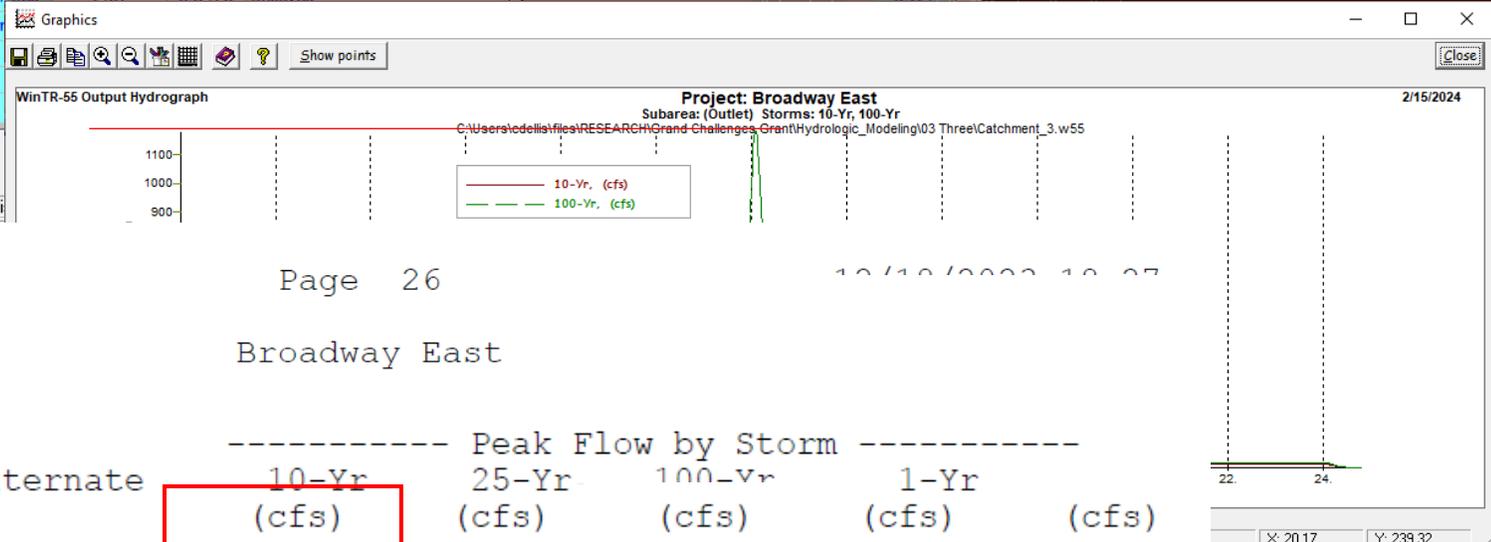
Sub-area Name	Sub-area Description
Lafayette-	

Project Area(ac): 337.66

Time of Concentration Details

Sub-area Name: Washington 2-Year Rainfall (in): 2.26

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft ²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0800	Grass-Range, Short (0.15)					0.112
Shallow Concentrated	1437	0.0473	Unpaved					0.114



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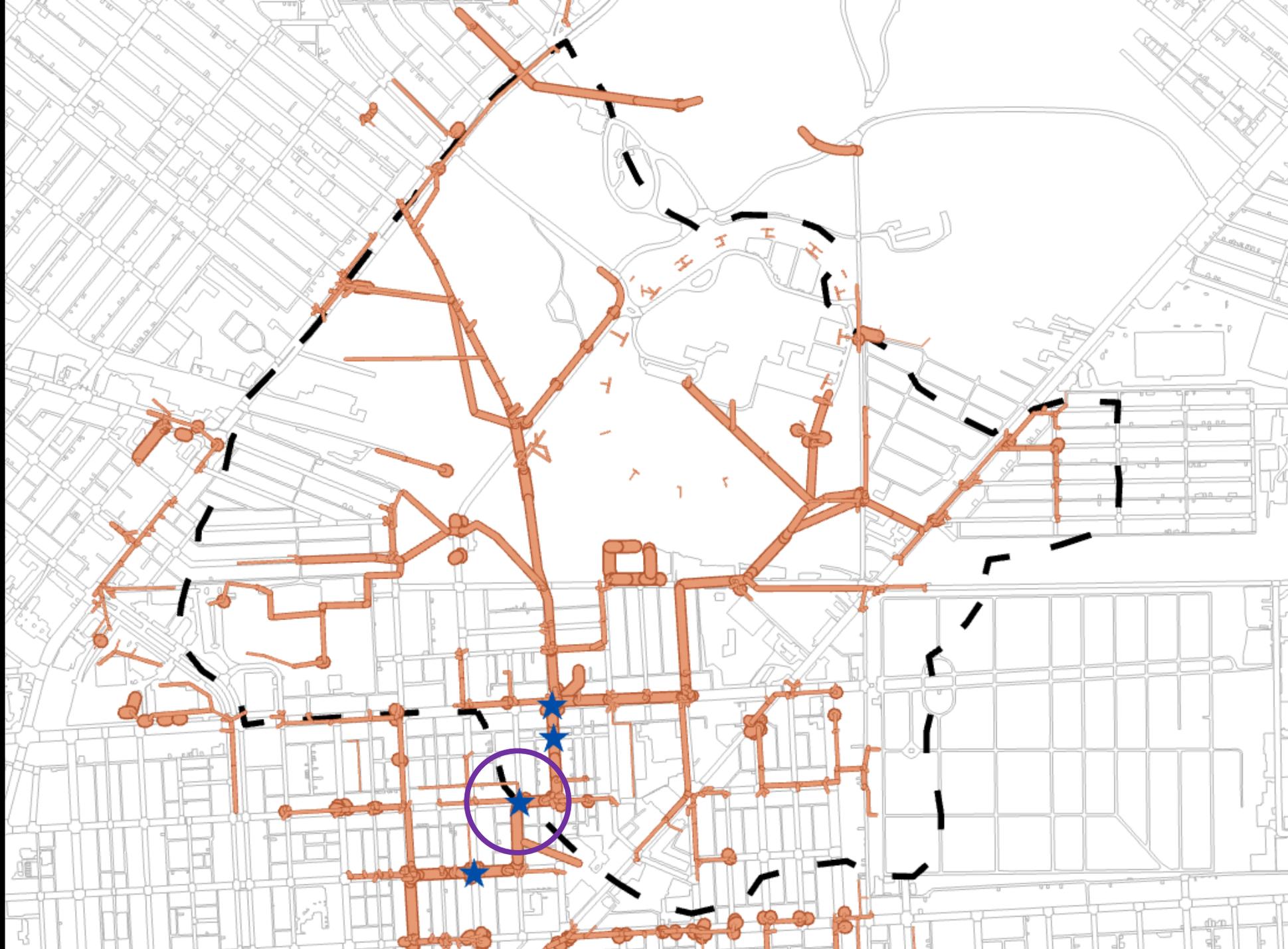
Broadway East

Reach Identifier	Drainage Area (sq mi)	Peak Flow by Storm			
		10-Yr (cfs)	25-Yr (cfs)	100-Yr (cfs)	1-Yr (cfs)
Lafayette-	0.528	1281.58	1400.61	1869.24	536.37
OUTLET	0.528	1281.58	1400.61	1869.24	536.37

Total Peak Flow

STORM	TR-55 PEAK FLOW	UNITS	VOLUME
1-yr	Peak Flow Rate	ft ³ /s	536
10-yr	Peak Flow Rate	ft ³ /s	1282
25-yr	Peak Flow Rate	ft ³ /s	1401
100-yr	Peak Flow Rate	ft ³ /s	1869

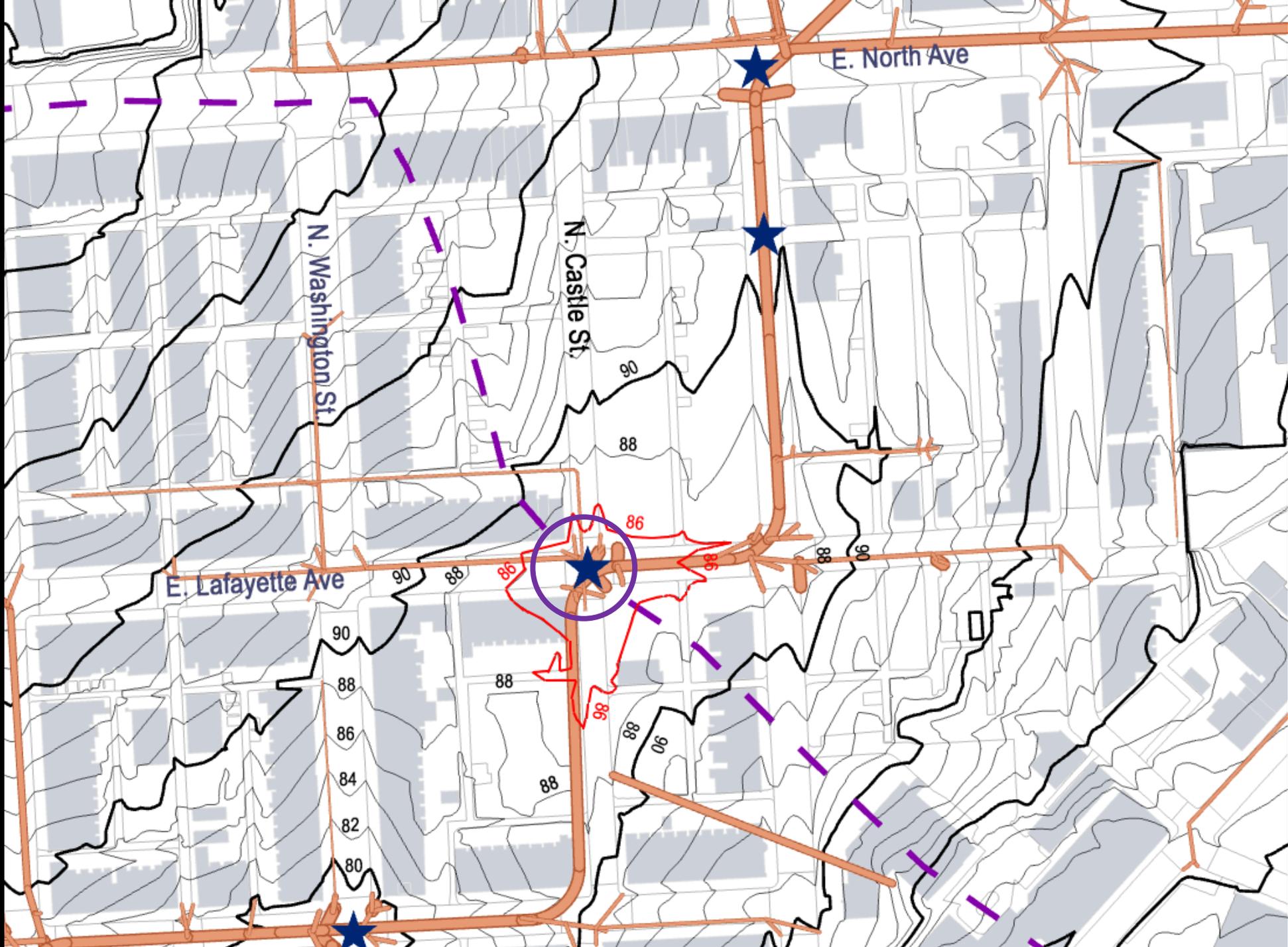
Stormwater Pipe System



Landform Depression at E. Lafayette Ave & N. Castle St



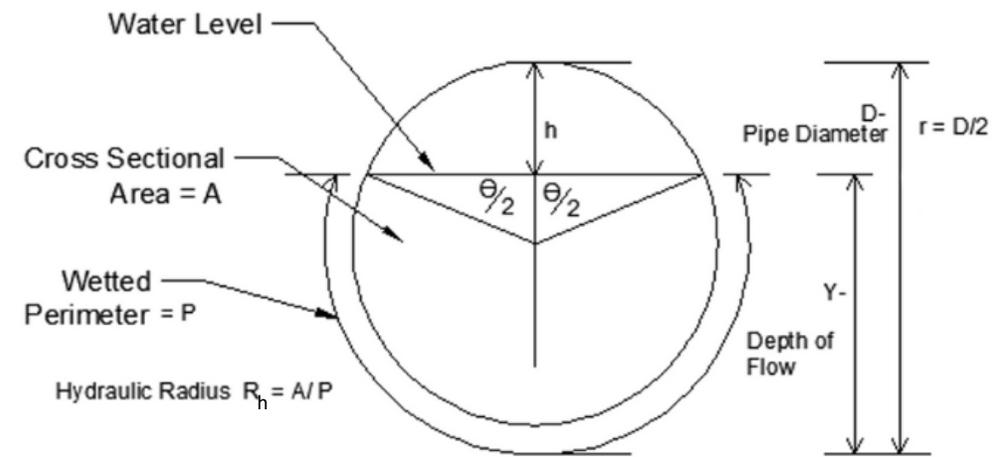
96 Inch Pipe through Intersection At E. Lafayette Ave & N. Castle St



Manning's Pipe Flow

Conversion Factor (SI to Imperial), u		1.49	1.49
Manning Roughness Coefficient, n		0.018	0.025
Cross-Sectional Area of Flow, A	ft ²	48.96	48.96
Hydraulic Radius, R_h	ft	2.32	2.32
Wetted Perimeter, P_w	ft	21.09	21.09
Slope, S	%	1	1
Flow Velocity, V	ft/s	14.47	10.42
Full Pipe Flow Rate, Q	ft ³ /s	659	474

$$Q = \frac{u}{n} A R_h^{2/3} S_o^{1/2}$$



S = Slope of pipe for steady state flow.

TOTAL FLOW – PIPE FLOW = SURFACE FLOW

TR-55		TOTAL PEAK FLOW	
1-yr	Peak Flow Rate	ft ³ /s	536
10-yr	Peak Flow Rate	ft ³ /s	1282
25-yr	Peak Flow Rate	ft ³ /s	1401
100-yr	Peak Flow Rate	ft ³ /s	1869

CHANNEL FLOW	
Velocity	f/s 3.45

UNDERGROUND PIPE FLOW	
Manning's n	
0.018	Full Pipe Flow Rate, Qf ft ³ /s 659
0.025	Full Pipe Flow Rate, Qf ft ³ /s 474
Hazen-Williams C	
90	Flow Discharge ft ³ /s 738
100	Flow Discharge ft ³ /s 819

SURFACE PEAK FLOW (ft³/s)

	TR-55 – MANNINGS (cfs)		TR55 - HAZEN/WILLIAMS (cfs)	
	0.018	0.025	90	100
1-yr	-123	62	-202	-283
10-yr	622	807	543	462
25-yr	741	926	662	581
100-yr	1210	1395	1131	1050

PIPE DIAMETER

8 ft (96 in)

PIPE SLOPE (estimated)

13 Elevation Change ft (North/Chester. to Washington/Lanvale)

1325 Pipe Distance ft

0.00981 Slope

HAZEN-WILLIAMS C - Brick Sewer

90-100

MANNING'S n - Brick/Stone

.015-.025

TOTAL FLOW – PIPE FLOW = SURFACE FLOW

TR-55		TOTAL PEAK FLOW	
1-yr	Peak Flow Rate	ft ³ /s	536
10-yr	Peak Flow Rate	ft ³ /s	1282
25-yr	Peak Flow Rate	ft ³ /s	1401
100-yr	Peak Flow Rate	ft ³ /s	1869

CHANNEL FLOW		
Velocity	f/s	3.45

UNDERGROUND PIPE FLOW			
Manning's n			
0.018	Full Pipe Flow Rate, Qf	ft ³ /s	659
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Hazen-Williams C			
90	Flow Discharge	ft ³ /s	738
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SURFACE PEAK FLOW (ft³/s)

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1325 Pipe Distance ft

0.00981 Slope

HAZEN-WILLIAMS C - Brick Sewer

90-100

MANNING'S n - Brick/Stone

.015-.025

How does this translate into a floodplain?



$$\frac{\text{Peak Flow (ft}^3\text{/s)}}{\text{Velocity (ft/s)}} = \text{ft}^2$$

$$\frac{543 \text{ ft}^3\text{/s}}{3.45 \text{ ft/s}} = 157 \text{ ft}^2$$

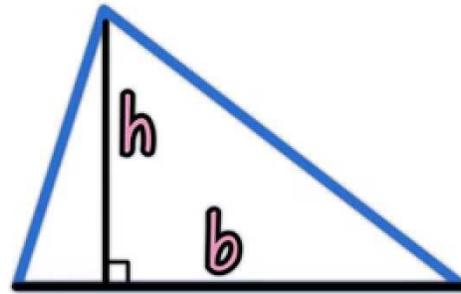
157 ft² ~ 150 ft² (simplified)

SURFACE PEAK FLOW (ft ³ /s)				
	TR-55 – MANNINGS (cfs)		TR55 - HAZEN/WILLIAMS (cfs)	
	0.018	0.025	90	100
1-yr	-123	62	-202	-283
10-yr	622	807	543	462
25-yr	741	926	662	581
100-yr	1210	1395	1131	1050

CHANNEL FLOW				
	Velocity		f/s	
				3.45

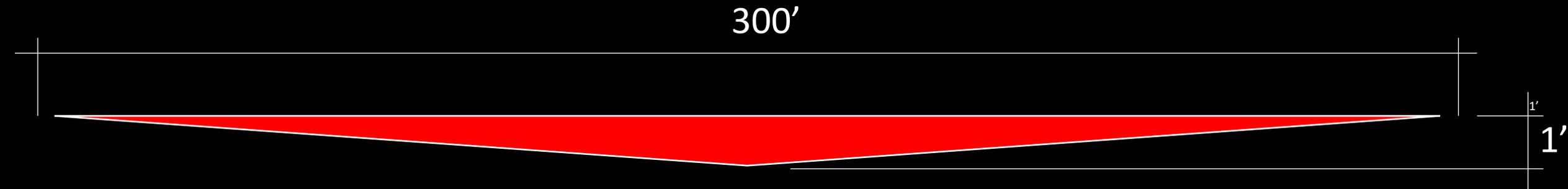
CROSS SECTION AREA (Surface Peak flow/Velocity)				
	TR-55 – MANNINGS (ft ²)		TR55 - HAZEN/WILLIAMS (ft ²)	
	0.018	0.025	90	100
1-yr	-36	18	-59	-82
10-yr	180	345	157	134
25-yr	215	268	192	168
100-yr	351	404	328	304

Area of a Triangle



$$\text{Area} = \frac{1}{2} \times b \times h = \frac{bh}{2}$$

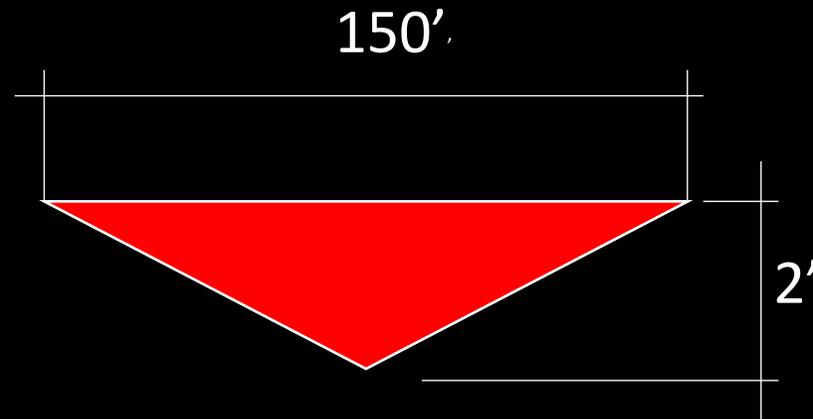
Area of a Triangle



$$\begin{aligned}\text{Area} &= \text{base} * \text{height} / 2 \\ &= (300 * 1) / 2 \\ &= 150 \text{ ft}^2\end{aligned}$$

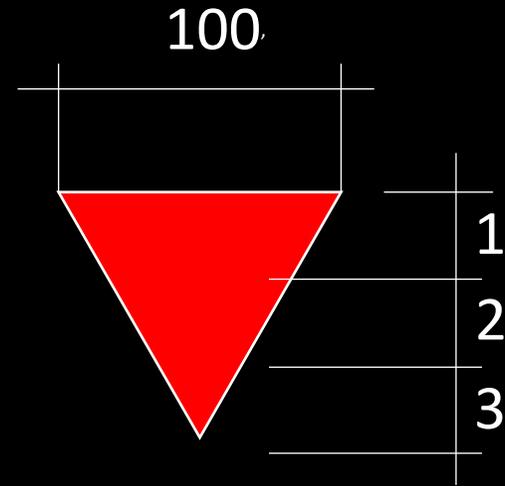
Area of a Triangle

$$\begin{aligned}\text{Area} &= bh/2 \\ &= (150 \cdot 2)/2 \\ &= 150 \text{ ft}^2\end{aligned}$$

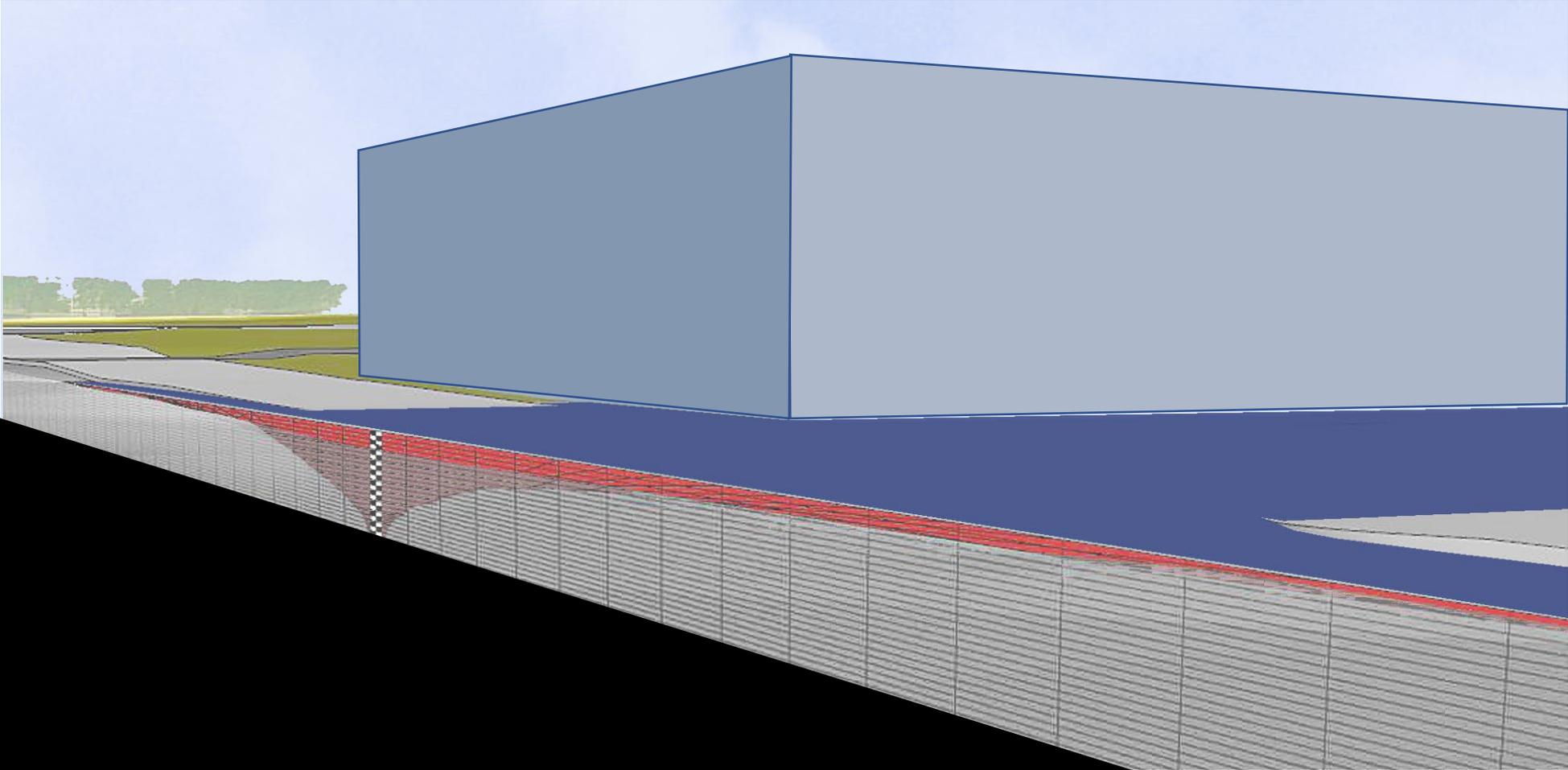
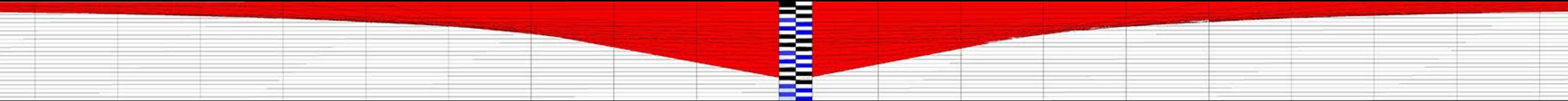


Area of a Triangle

$$\begin{aligned}\text{Area} &= bh/2 \\ &= (100 * 3)/2 \\ &= 150 \text{ ft}^2\end{aligned}$$



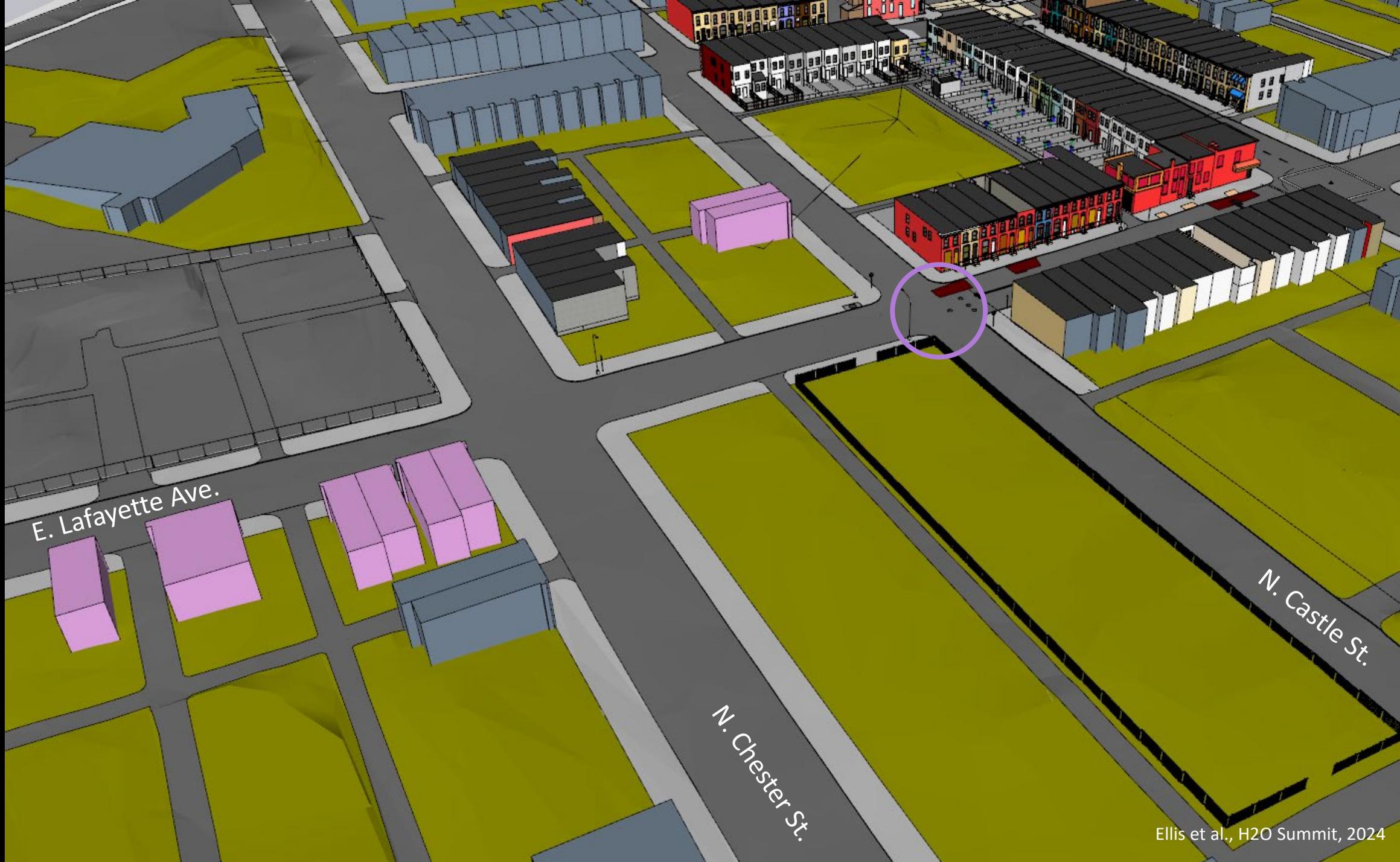
Setting the Peak Surface Flow Edges



Refined Cross Section (N. Chester St.)



No Flow Condition

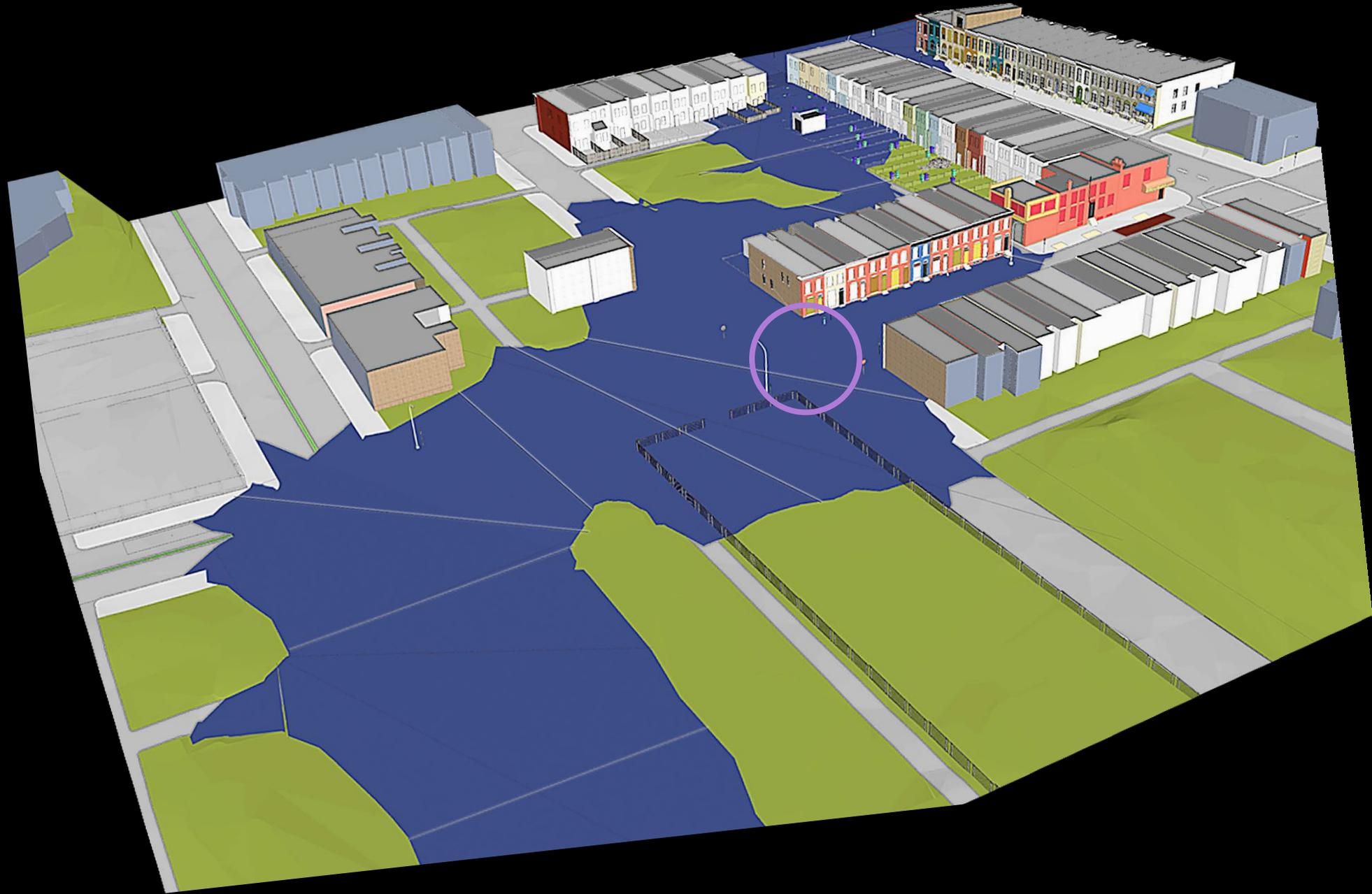


E. Lafayette Ave.

N. Chester St.

N. Castle St.

100-yr Peak Surface Flow









3D Street Level Image



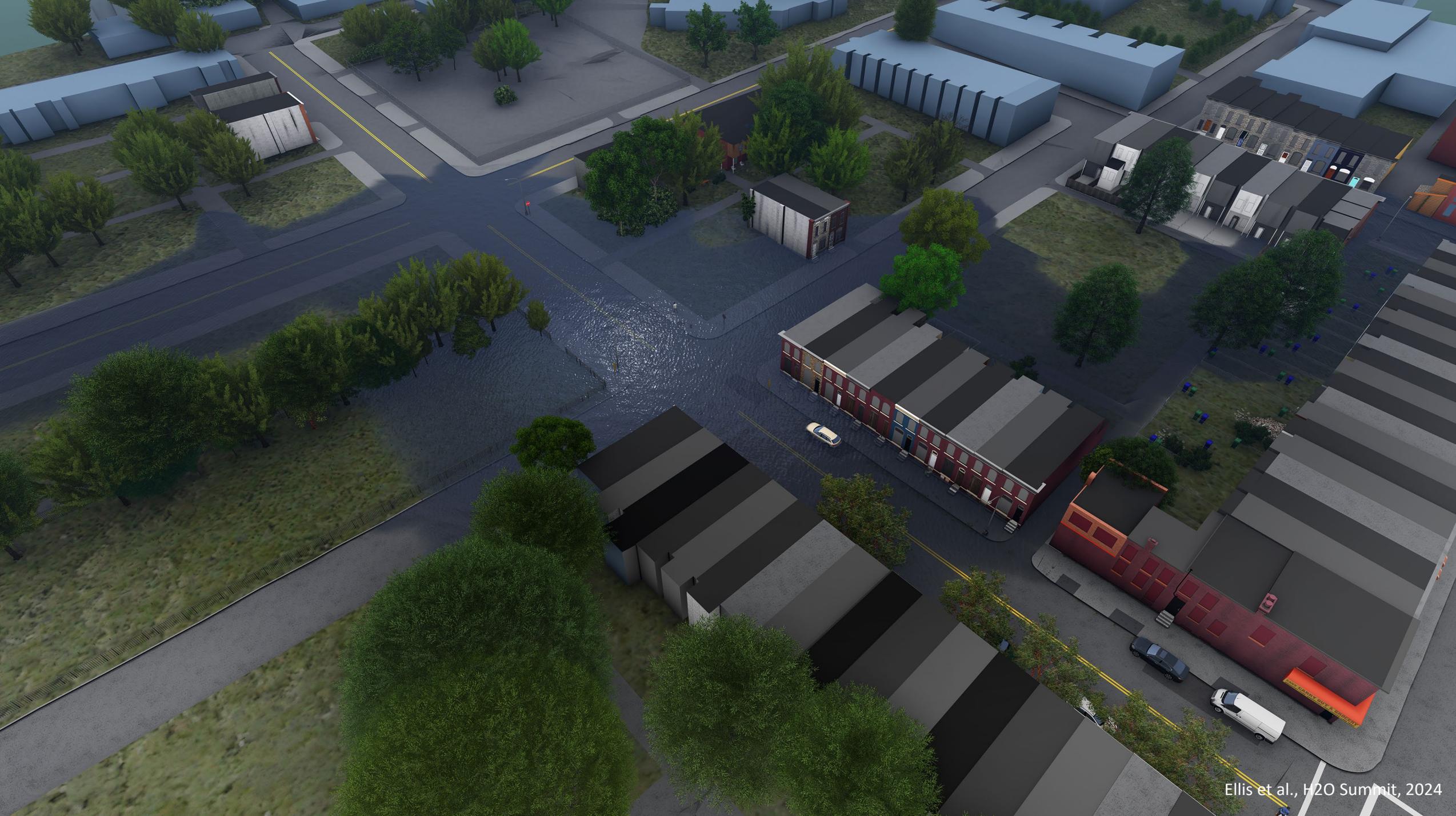
3D Street Level Image





















Research Proposition

Realistic 3D visualizations that display modeled flood data in ways that effectively communicate flood risks to non-technical stakeholders can enable better participation in risk assessment and abatement.

Research Proposition

From Elected officials to community stakeholders, being better informed about flood risks through realistic visualization can lead to better preparedness, and guide development decisions that:

- avoid loss of life
- reduce negative health effects
- protect against damage to property
- Lower costs to communities

Research Experiment (IRB approved)

- The purpose is to investigate the strengths of different data visualization techniques in assessing flood risk.
- It includes viewing images in virtual reality.
- Participants are shown different views of data related to flooding, and will answer questions about them.



Research Experiment (IRB approved)

- The experiment takes about 45 to 50 minutes to complete.
- We will come to a location convenient to you, w/ boxed lunch.
- Contact: Elliott Kenney (ekenney9@umd.edu) or Chris Ellis (cdellis@umd.edu)



Visualizing Hydrologic Flood Models in Virtual Reality:

Bridging the gap between technical experts
and community stakeholders

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**LANDSCAPE
ARCHITECTURE**
Department of Plant Science
and Landscape Architecture





Visualizing Hydrologic Flood Models

- The project focuses on an intersection located in Broadway East, Baltimore, MD and uses GIS data provided by Open Baltimore and Baltimore Department of Public Works (some data collected by project leaders).
- The TR-55 model is suitable for small watersheds where quick, preliminary runoff estimates are needed. TR-55 is widely used for planning and regulatory compliance.
- Manning's and Hazen-Williams equations for pipe flow are both commonly used although Hazen-Williams is generally preferred for water distribution systems.

PARAMETERS			
Intersection			
A	Elevation @ North & Chester	93 ft	
B	Elevation @ Lanvale & Washington	80 ft	
	Change in elevation A-B (Drop)	13 ft	
	Distance from A to B (pipe length)	1399.57 ft	
	Average slope	0.01 %	
	Pipe Material	Brick and Stone	
	Manning's n	0.018	0.025
	Hazen-Williams Roughness Coef	90	100
	Pipe diameter	96 in	