Hydromodification: a What, Why and How.

A presentation to the

KYTC Annual Partnering Conference

September 9, 2014
Louisville, KY

Matt Wooten, M.S.
Aquatic Biologist, Sanitation District No. 1 (SD1)

Bob Hawley, PhD, PE
Principal Scientist, Sustainable Streams, LLC

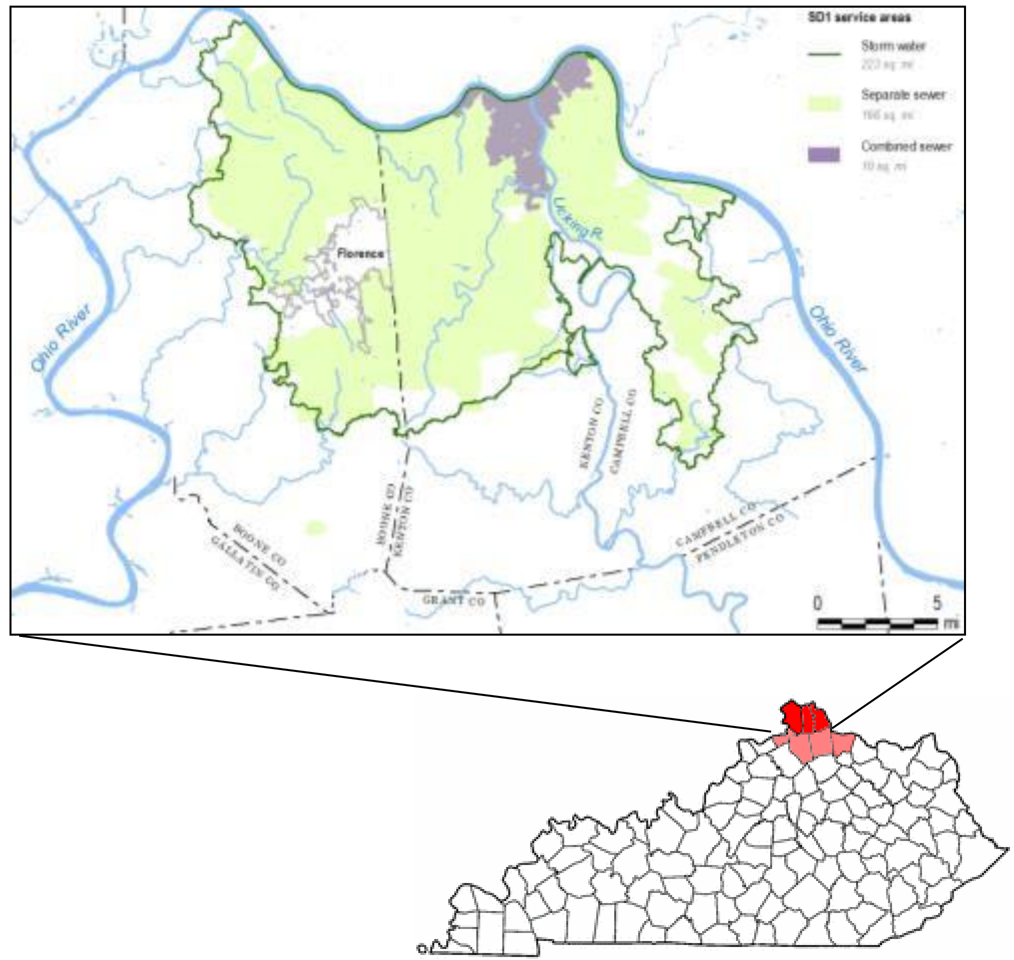
Outline

- Background
- Monitoring
- Hydromodification
- Approach
- Examples

Sanitation District No. 1 (SD1)

Wastewater Utility

- 31 cities and 3 counties
- 176 square mile service area
- 1700 miles of sewer
- 130 pump stations
- 3 Treatment Plans



Storm Water Utility

- 30 cities and 3 counties
- 223 square mile service area
- 400 miles of storm lines
- 30,000 structures

Why do we manage storm water runoff ?

Why do we care about storm water runoff?

- Flooding





Why do we care about storm water runoff?

- Erosion
- Infrastructure impacts
- Excess sedimentation
- Poor water quality, habitat loss, & biological degradation

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What is Hydromodification?

Activities that:

- disturb natural flow patterns
- alter stream geometry and physical characteristics
- erode stream banks
- can cause excess sedimentation

Hydromodification is one of the leading causes of impairments in streams…

EPA, 2007

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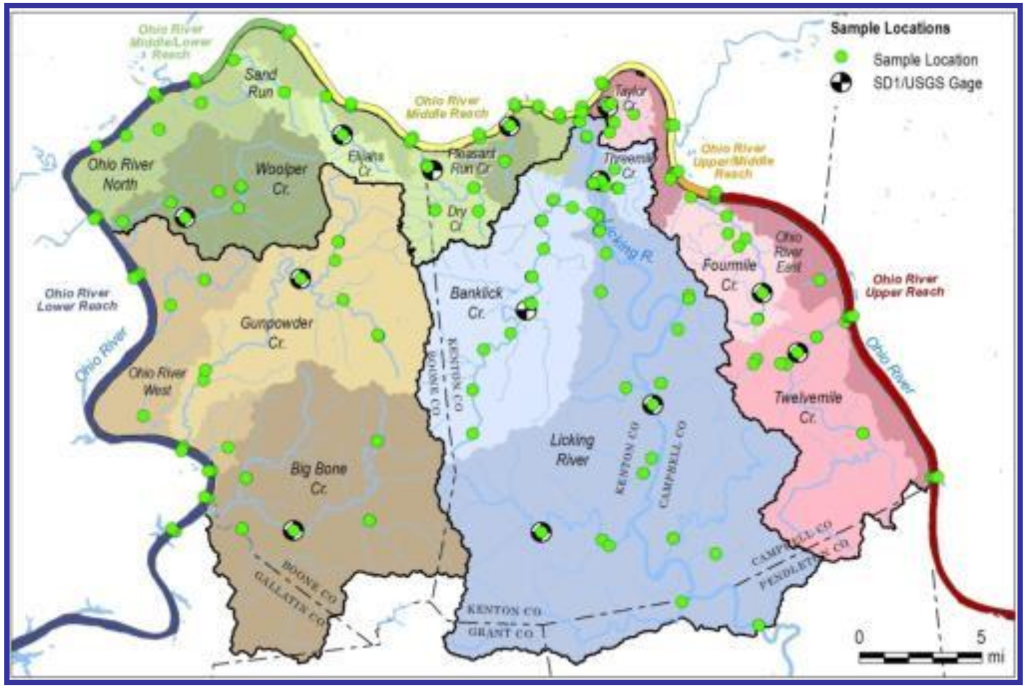
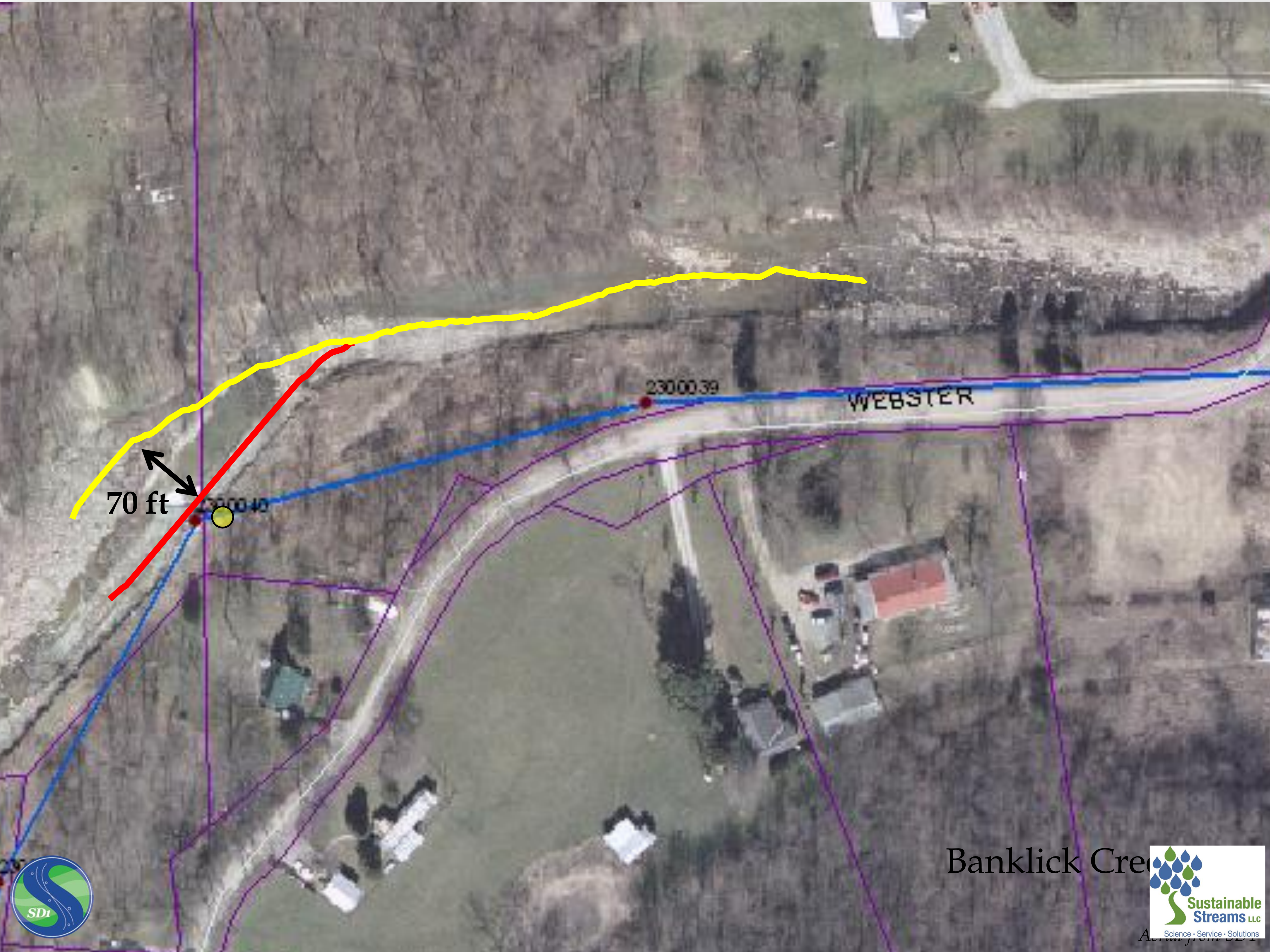
Stream Assessment Program

- ~75 sites:
  - Water Quality
  - Biology
  - Physical Habitat
  - Stream Stability (Hydromod)



Field Monitoring Program Revealed Significant Stream Degradation



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WEBSTER
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Field Monitoring Program Revealed Significant Stream Degradation

Field Monitoring Program Revealed Significant Stream Degradation

Pre-failure

Bank Failure

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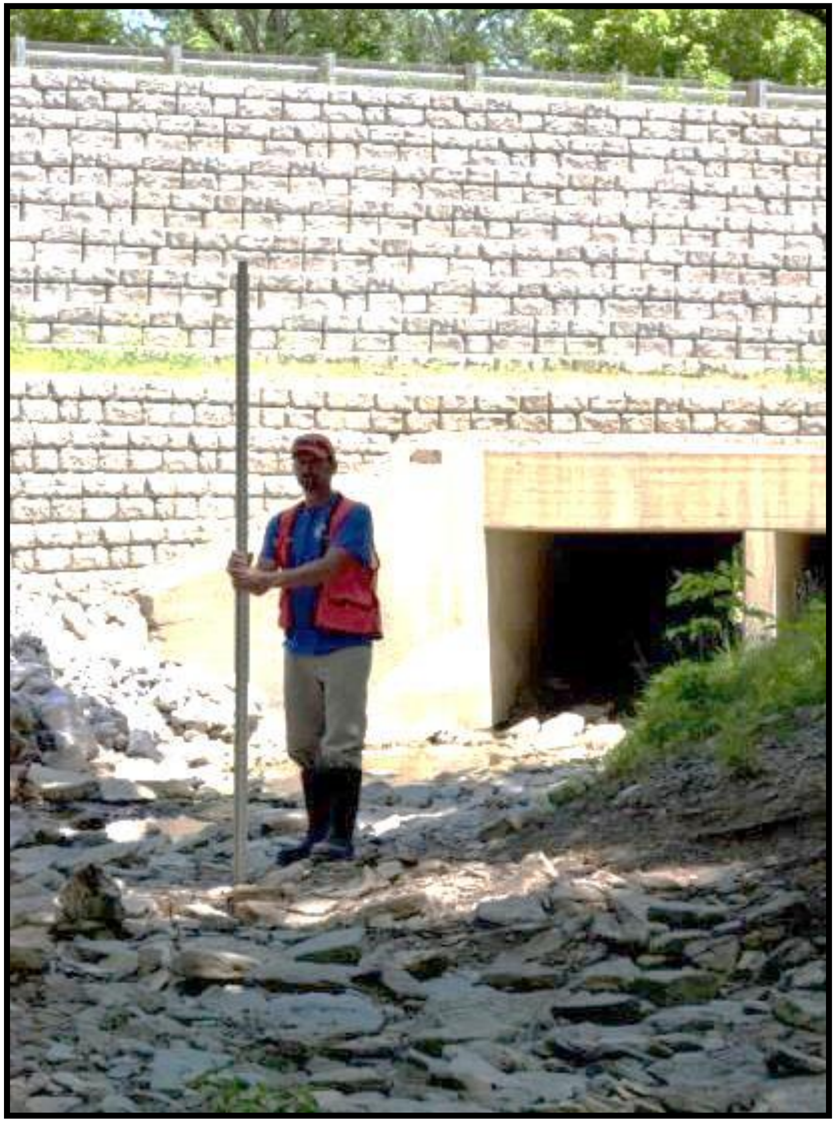
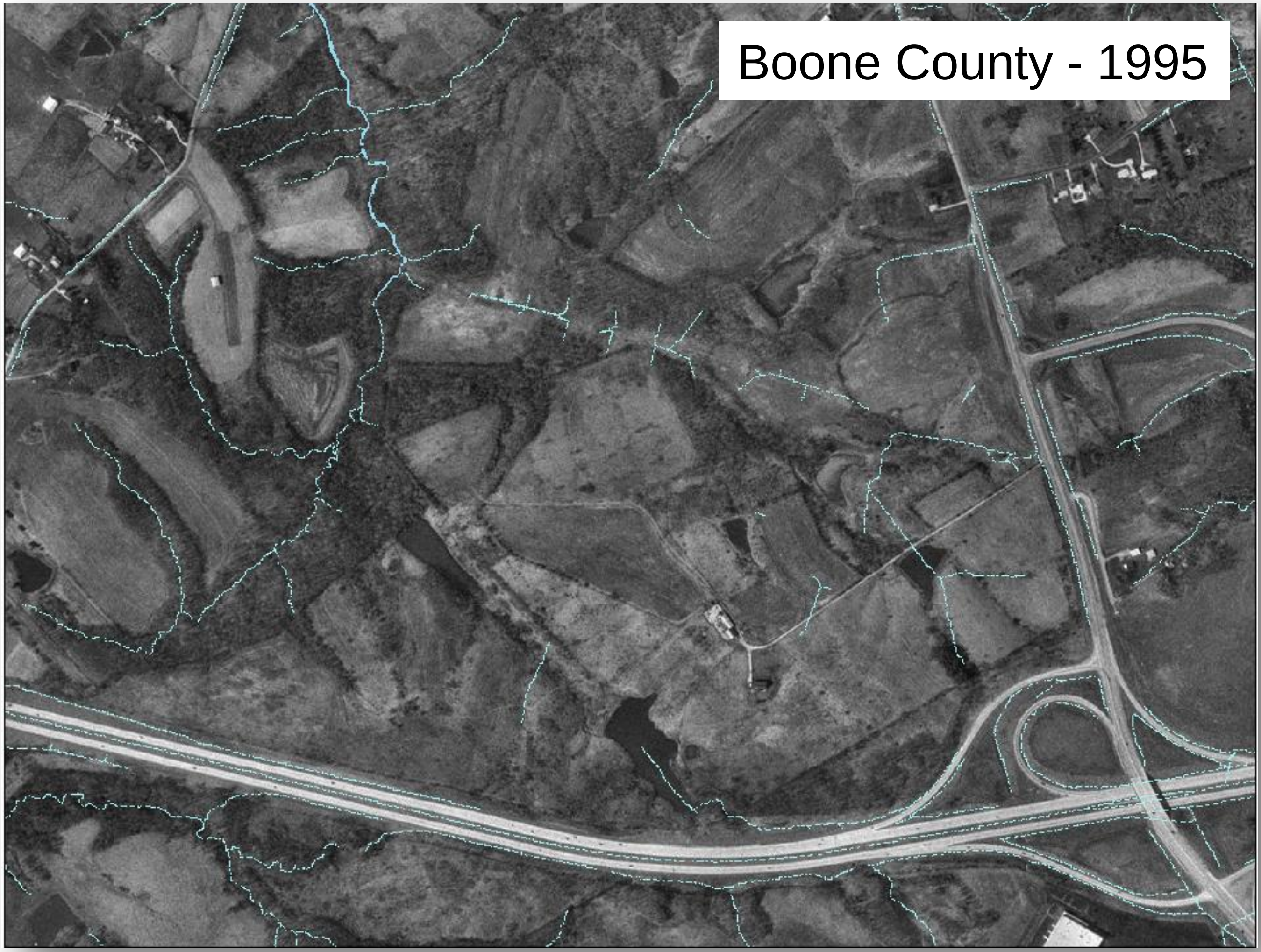
Repair

~ $250,000 cost to fix



Why Is Hydromodification So Prevalent?



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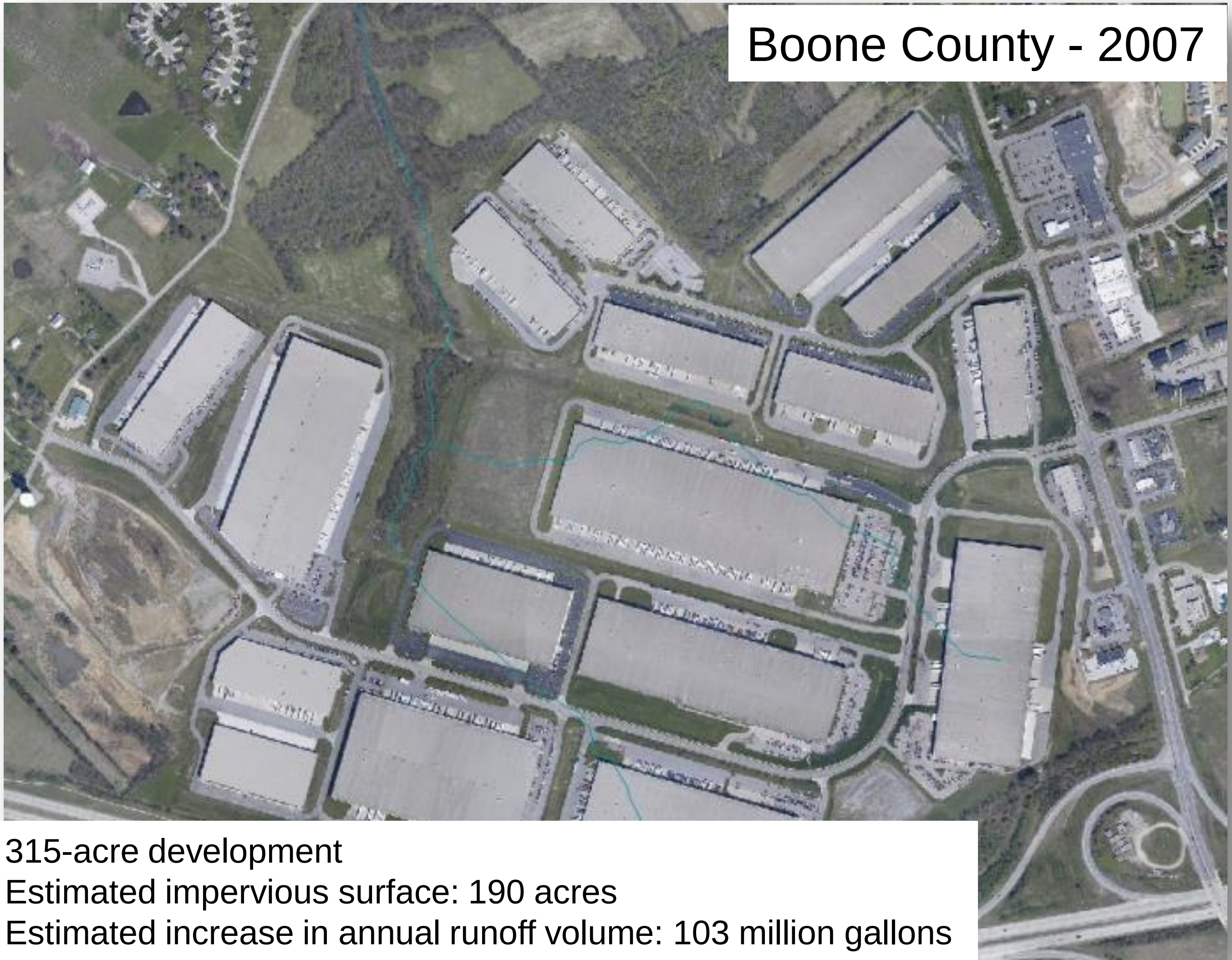
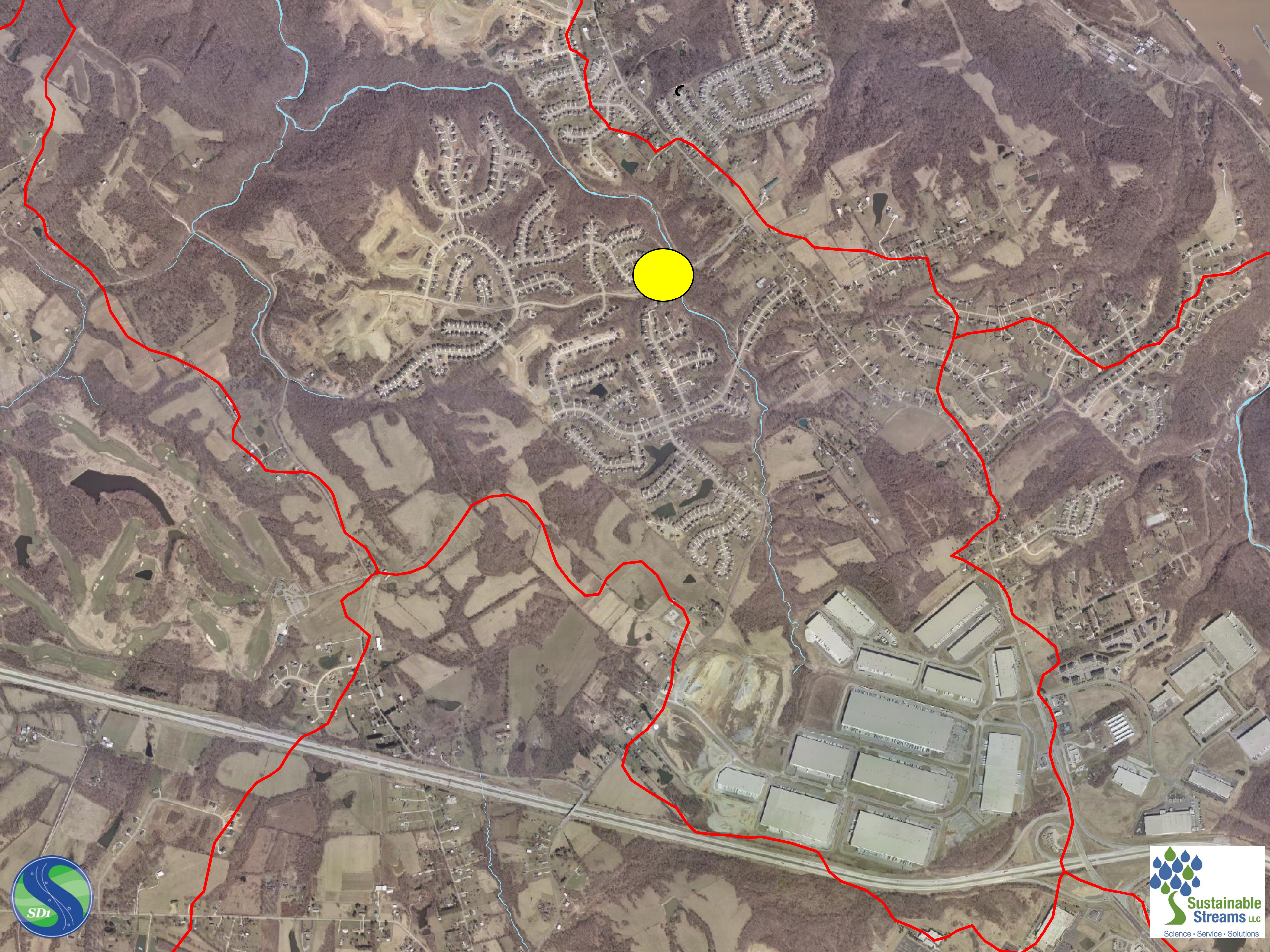
Change in Land Cover Impacts Hydrologic Cycle



315-acre development
Estimated impervious surface: 190 acres
Estimated increase in annual runoff volume: 103 million gallons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Sand Run
08/28/2008 11:14
SD1
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0.3” of rain in 1 hour
06/10/2009 08:26
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How Sensitive are the Systems to Improperly Managed Storm Water?

Rain Event – 11/16/10
Magnitude – 0.45”
Duration – 2 hours

< 2-month storm
(2-hour/2-month = 0.81”)

~100-acre basin

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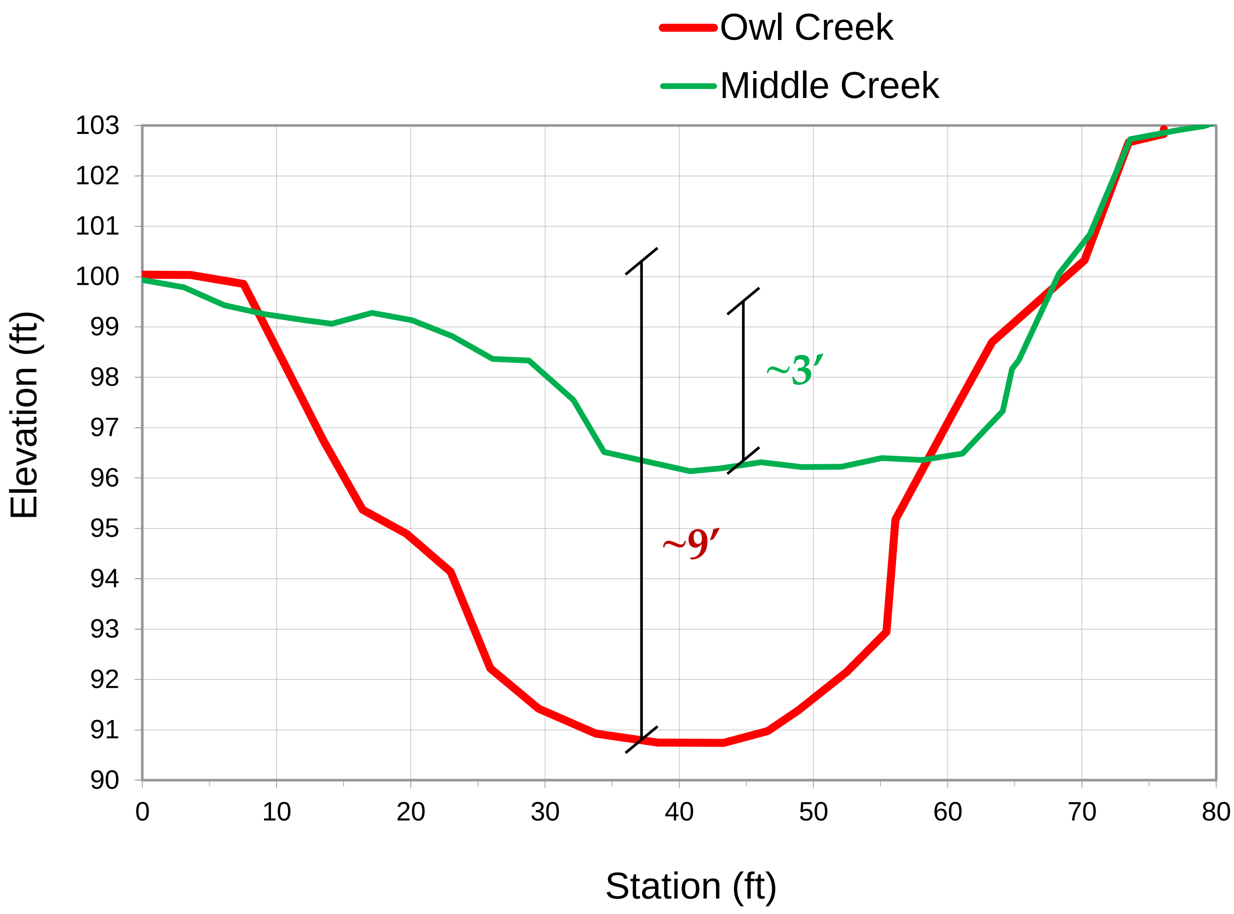
Undeveloped vs. Developed Watersheds

Middle Creek (3.3 mi^2)
Undeveloped (0.6% Impervious)

Owl Creek (3.7 mi^2)
Developing (9% Impervious)

Undeveloped vs. Developed Watersheds

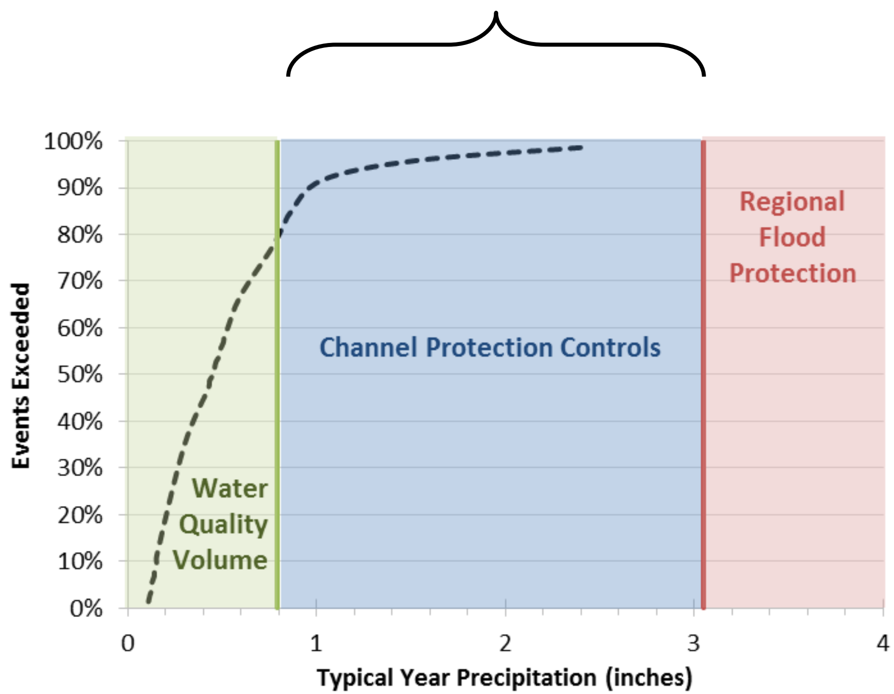


Conceptual Framework of Channel Protection Controls

Channel erosion likely begins in a range that is <u>less than</u> the 2-yr design storm

Peak flow detention that focuses on the 2-yr storm has little to <u>no attenuating effect</u> on **97-99% of precipitation volume in a typical year**

(Emerson et al., 2003, In Proceedings of ASCE's Water and Environment Resources Congress)



Typical year rainfall and recurrence probabilities for Northern Kentucky

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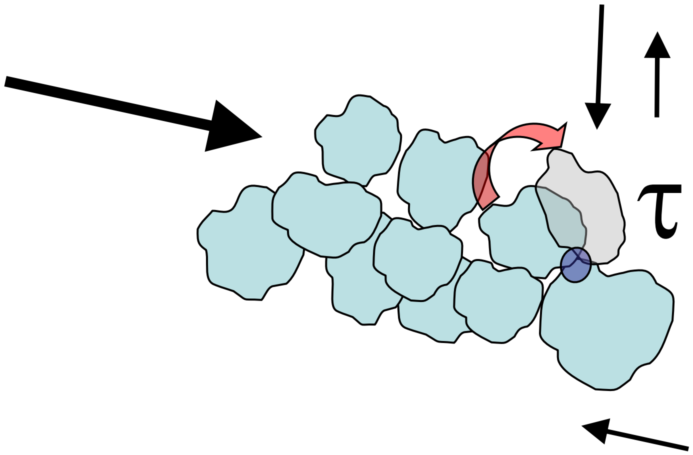
Introduction of $Q_{critical}$

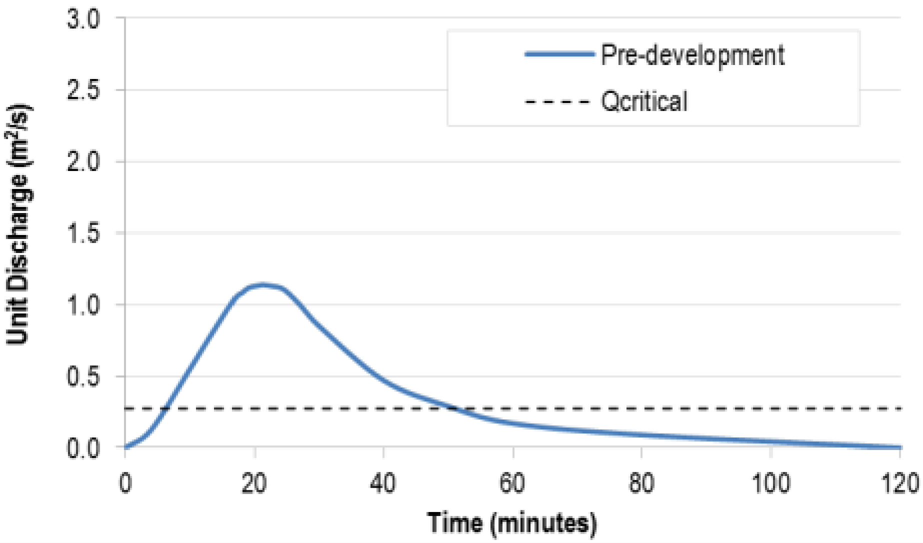
The Critical Flow ($Q_{critical}$) for Bed Material Mobility is both Geomorphically and Ecologically Relevant

(Poff, 1992; Townsend et al., 1997; Holomuzki and Biggs, 2000; Suren and Jowett, 2006)



$$\tau > \tau_c$$

Example of Flow Control for Channel Protection from Bledsoe (2002)



Analysis of the 2-yr, 2-hr storm from Fort Collins, CO by Bledsoe (2002), Journal of Water Resources Planning and Management

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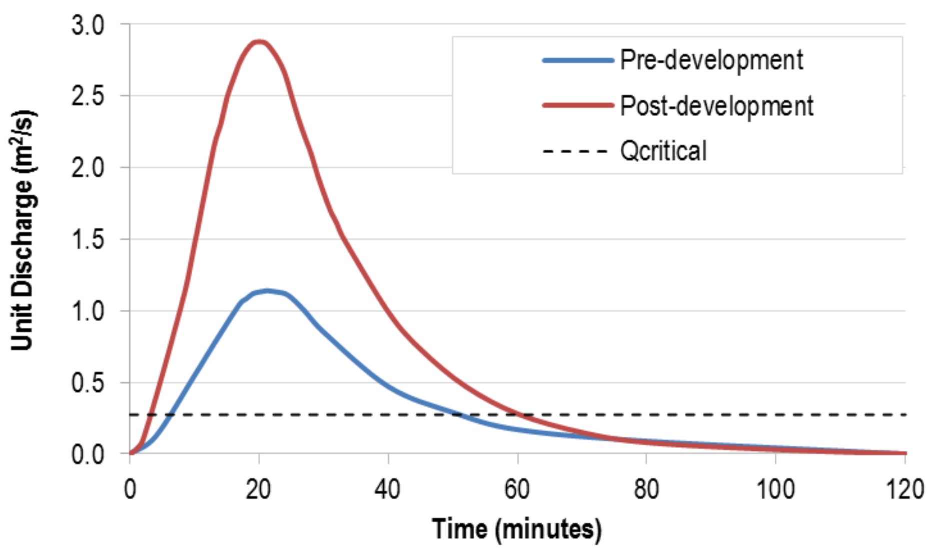

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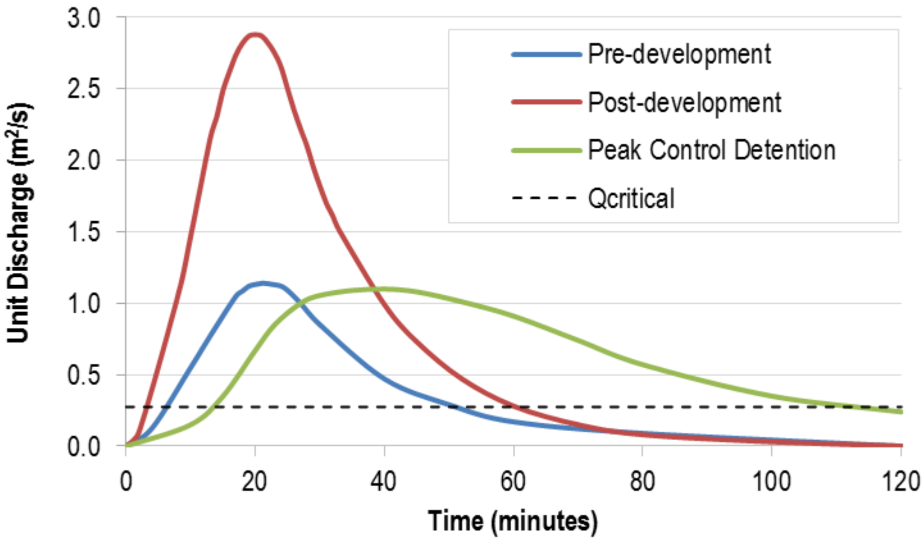

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Frequency of $Q_{critical}$ in Developed vs. Undeveloped Conditions

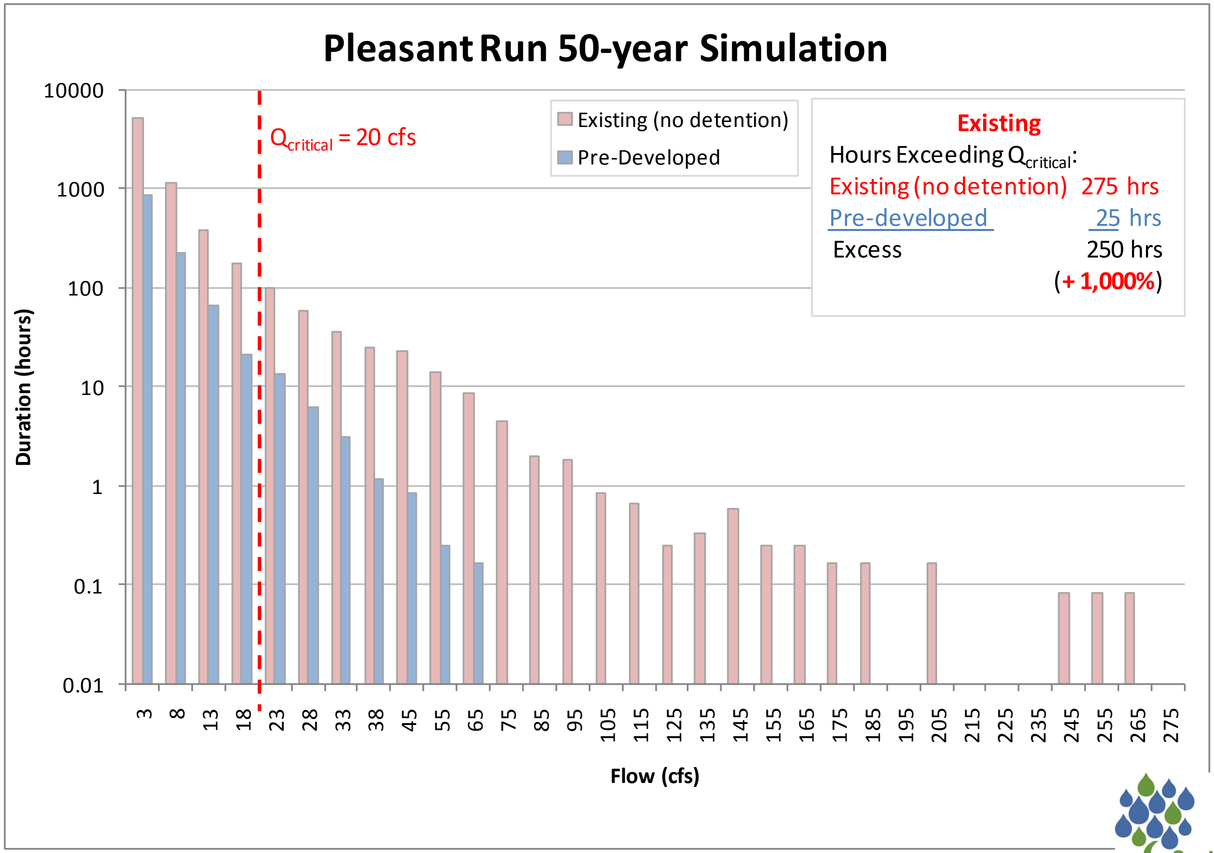
(developed land cover with no detention)

Predeveloped:

- $Q_{critical}$ exceeded **1 hour every 2 years**

Developed:

- $Q_{critical}$ exceeded **1 hour every 2 months**



Hawley et al. (2012)

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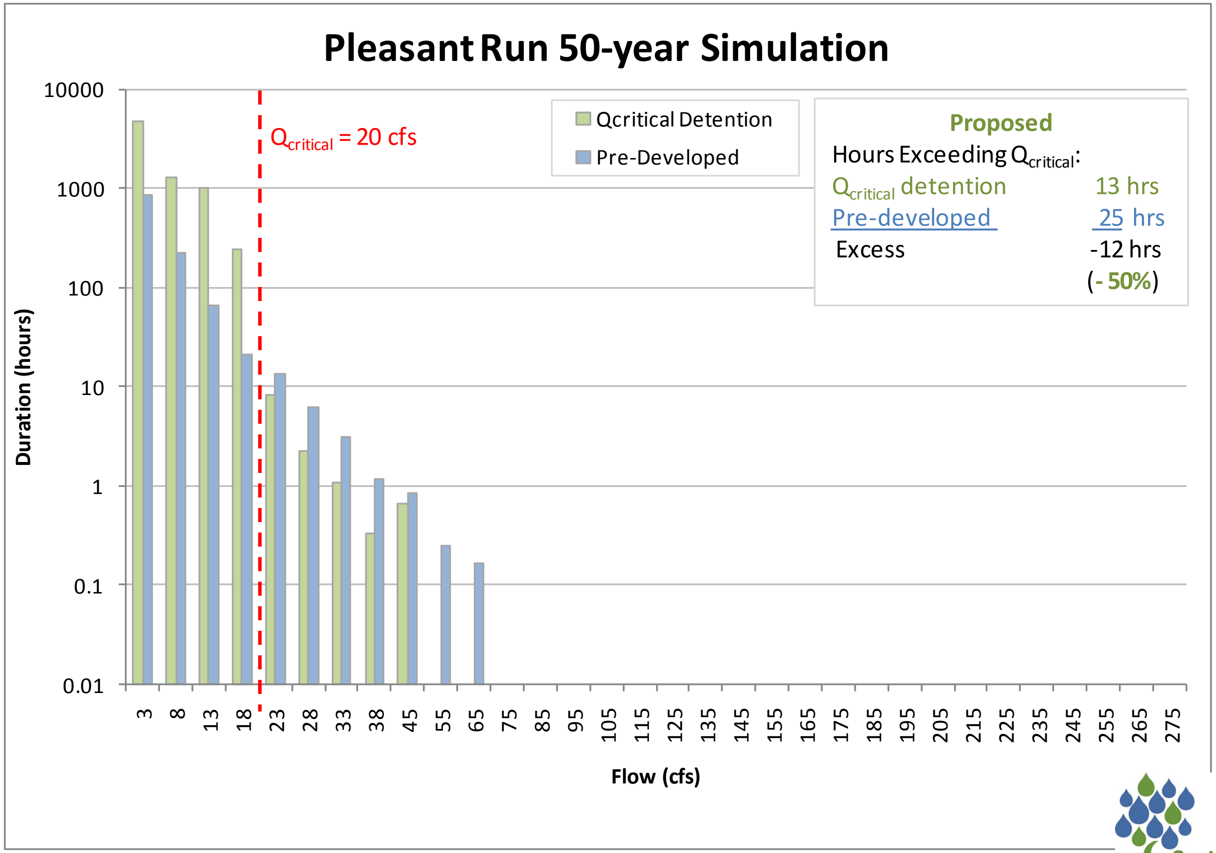
Preferred Approach Focuses on All Flows > $Q_{critical}$

Match the **Cumulative Duration** and Erosion Potential of those Flows that Exceed $Q_{critical}$
(to the extent possible/practical)



Adapted from Hawley et al. (2012)

What is the connection?

Biological

Physiochemical

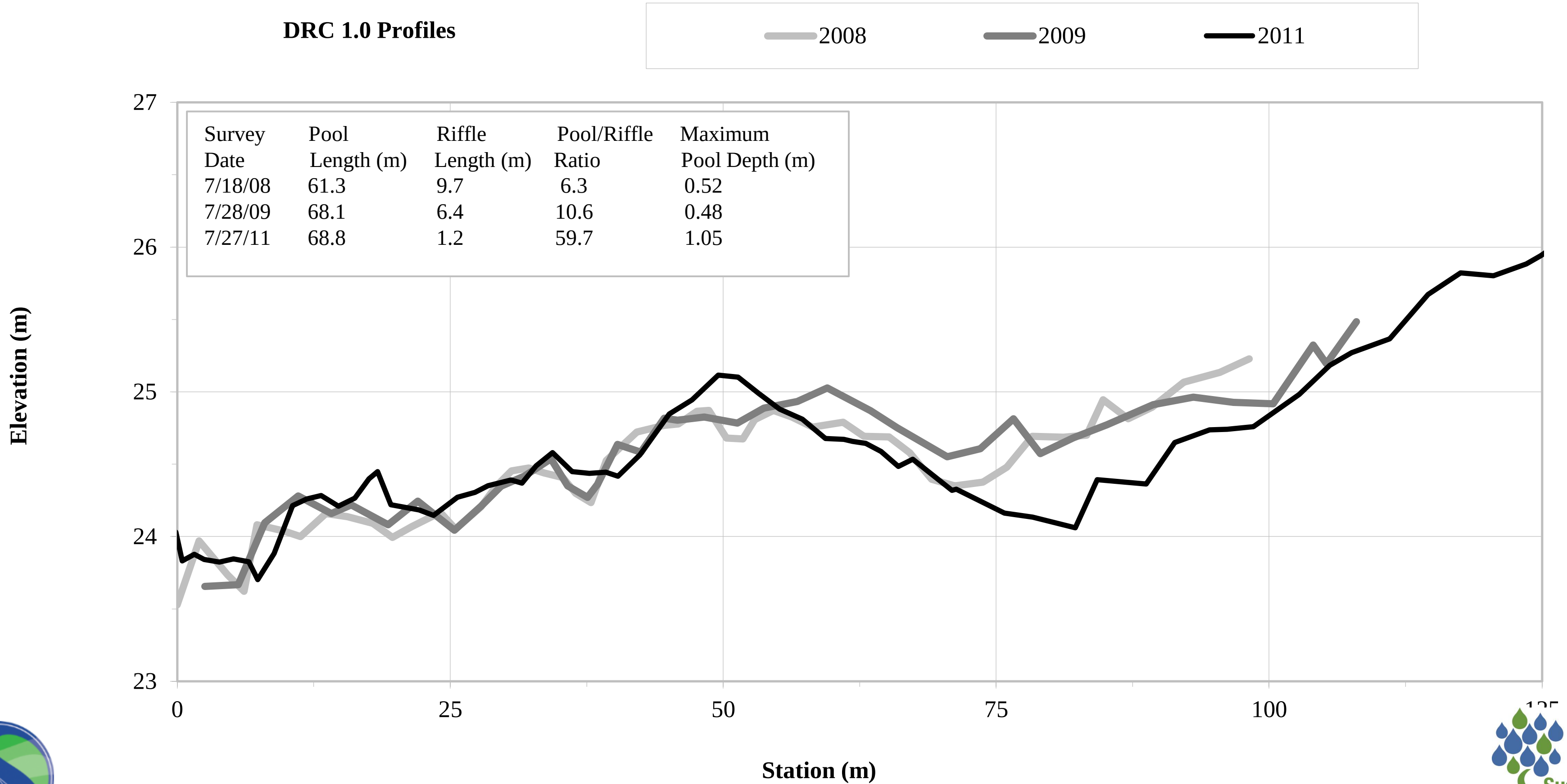
Geomorphology

Hydraulics

Hydrologic

Stream Function Pyramid (CWP)

Shorter Riffles
Deeper and Longer Pools



Survey Date	Pool Length (m)	Riffle Length (m)	Pool/Riffle Ratio	Maximum Pool Depth (m)
7/18/08	61.3	9.7	6.3	0.52
7/28/09	68.1	6.4	10.6	0.48
7/27/11	68.8	1.2	59.7	1.05

Hawley et al., Geomorphology, July 2013

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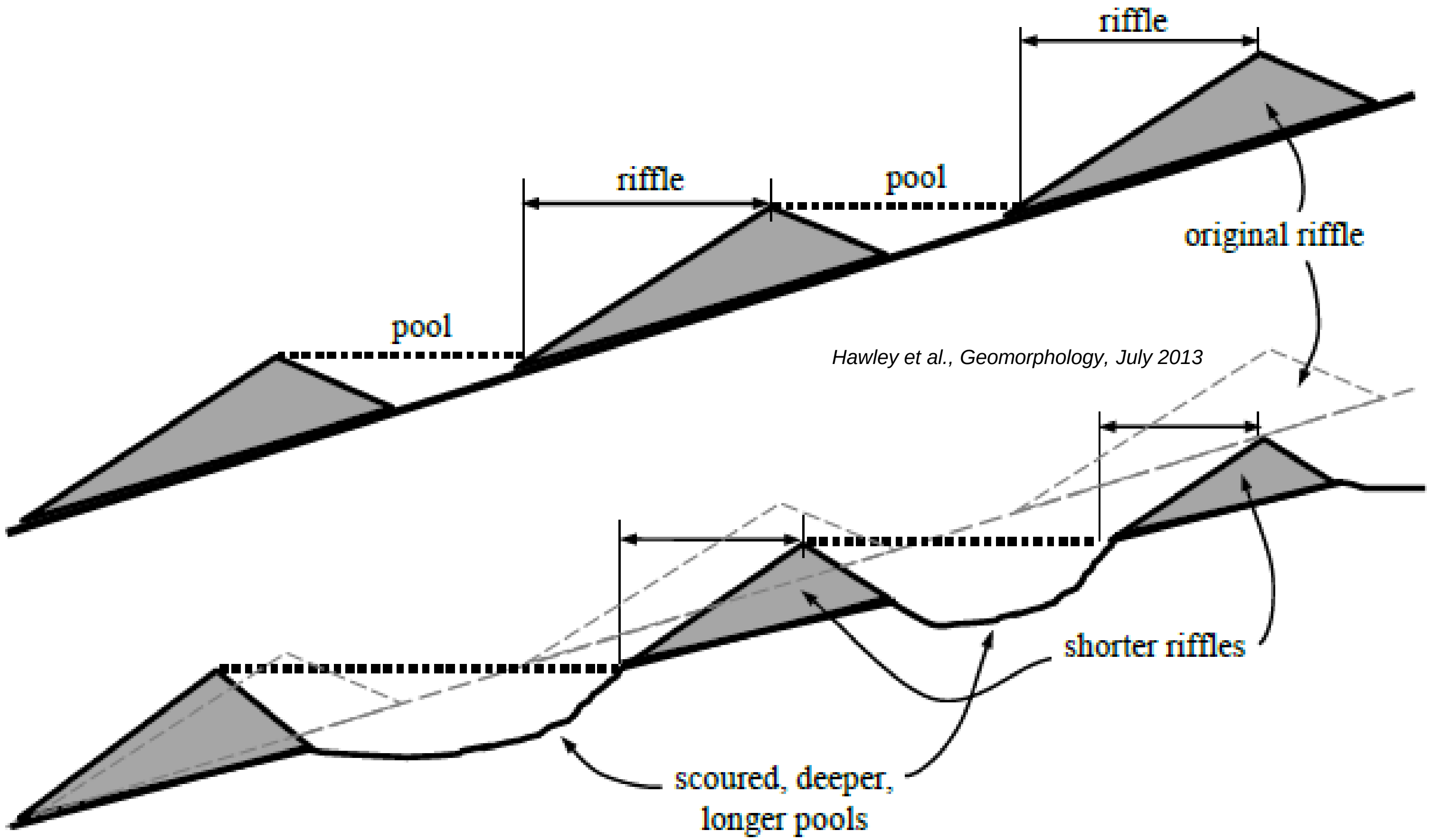
Shorter Riffles
Deeper and Longer Pools



Hawley et al., Geomorphology, July 2013

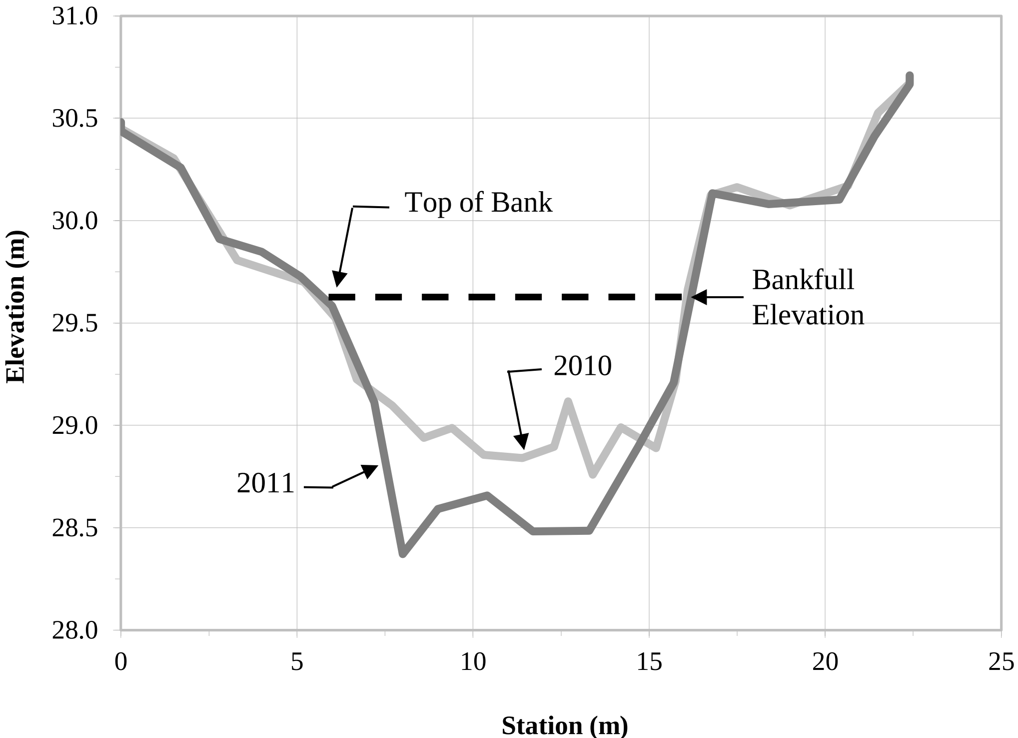
Findings of
Stream Monitoring Effort

Imperviousness causes:

- Channel Enlargement
- Bed Coarsening
- Shorter Riffles
- Longer/Deeper Pools
- Stream Instability

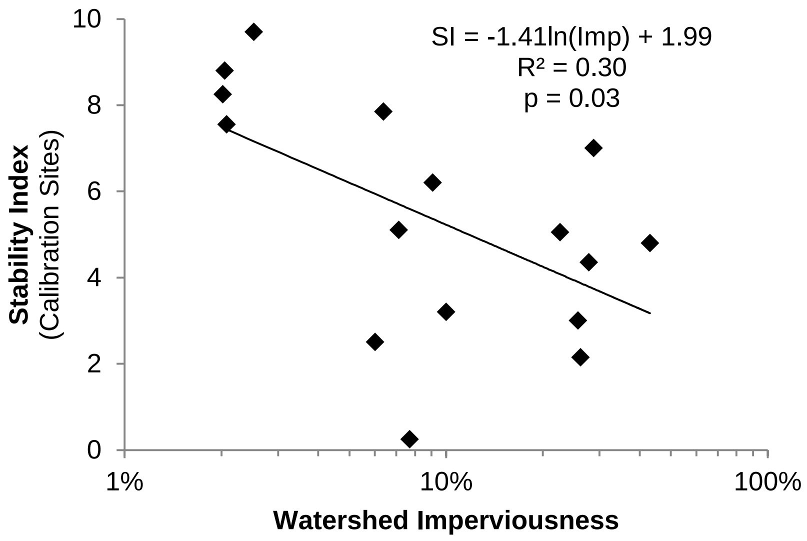
p ≤ .05 except for bed coarsening (*p* = 0.15)

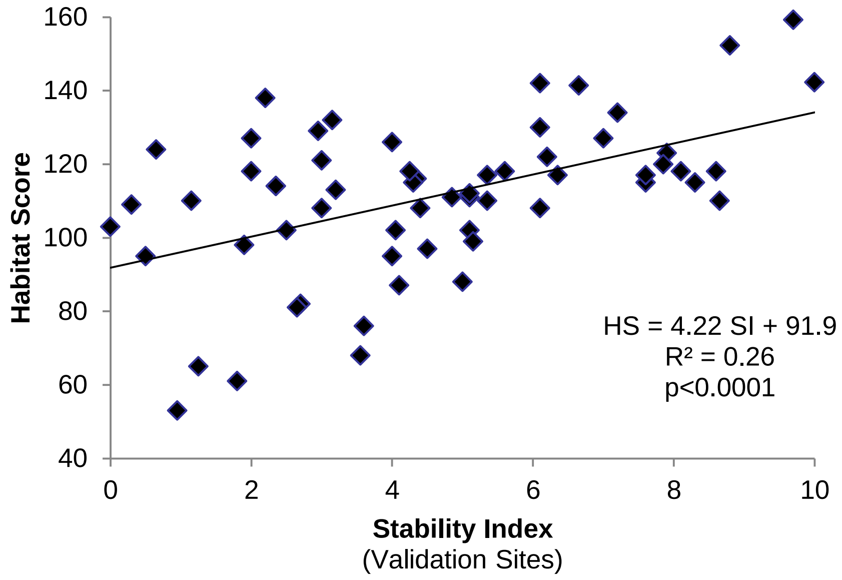
Channel Enlargement
Lodor's Creek



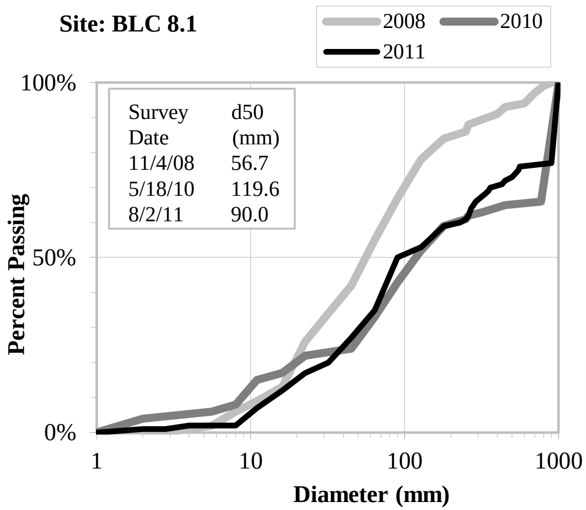
Hawley et al., Geomorphology, July 2013

Similar Trends with Hydromodification as measured by stream stability





Bed Coarsening



More homogenous habitat

Hawley et al., Geomorphology, July 2013

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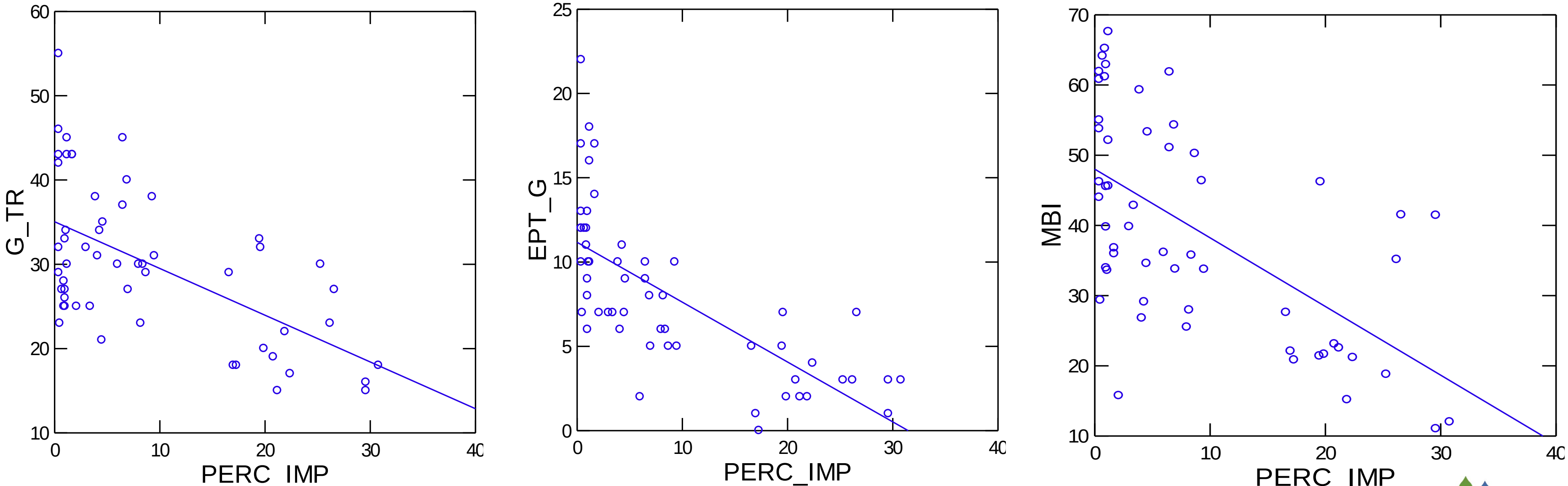
Biological Survey Findings

Biological integrity decreases with watershed imperviousness:

- Overall Taxa Richness
- Sensitive Taxa (EPT) Richness
- Macroinvertebrate Biotic Index
- Community Structure



(Wooten and Hawley, In prep)

p<0.01 for each

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What are the Overall Impacts?

Biological

Physiochemical

Geomorphology

Hydraulics

Hydrologic

Conventional Stormwater Controls / Hydromodification

Decreased biotic integrity, dominance of **'weedy'** species

Increased Suspended Solids and **Sedimentation**

More **homogeneous** & unstable habitat

More frequent, severe, & prolonged **disturbance** events

Stream Function Pyramid (Adapted from Harmon et al., 2012)

SDI

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So, How Do We Implement?

- New Roads

- Resurfacing/Widening

- Urban Corridors

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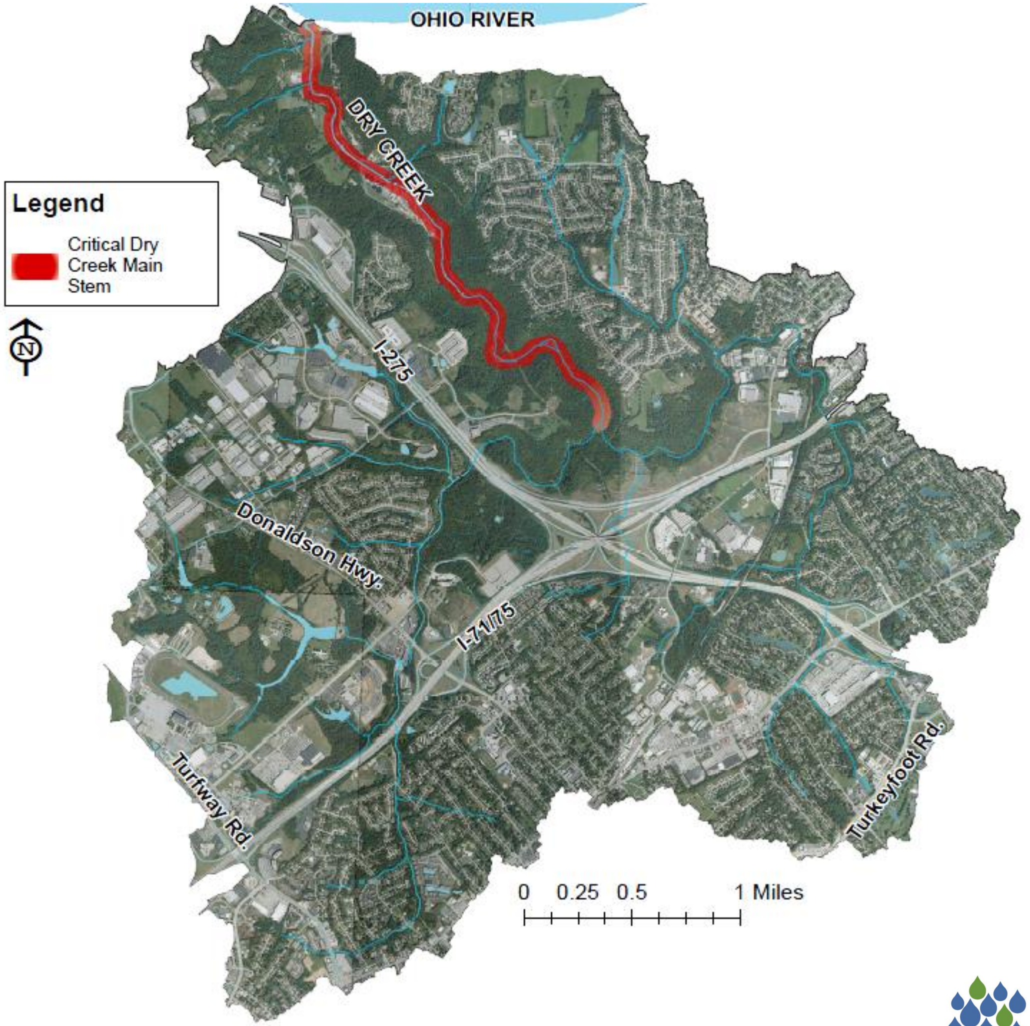
Case Studies

- Watershed Scale
  - Dry Creek Concept Plan

- Project Scale
  - Road extension

Dry Creek

- 12.4 square miles
- 30% impervious



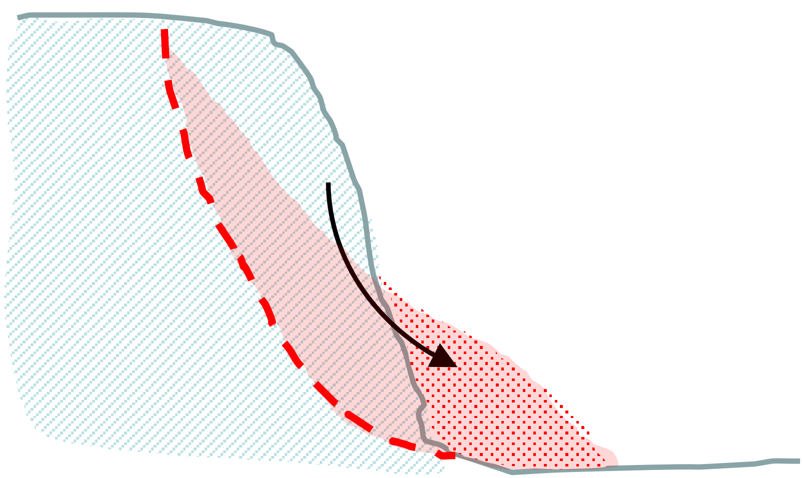
Condition of Dry Creek

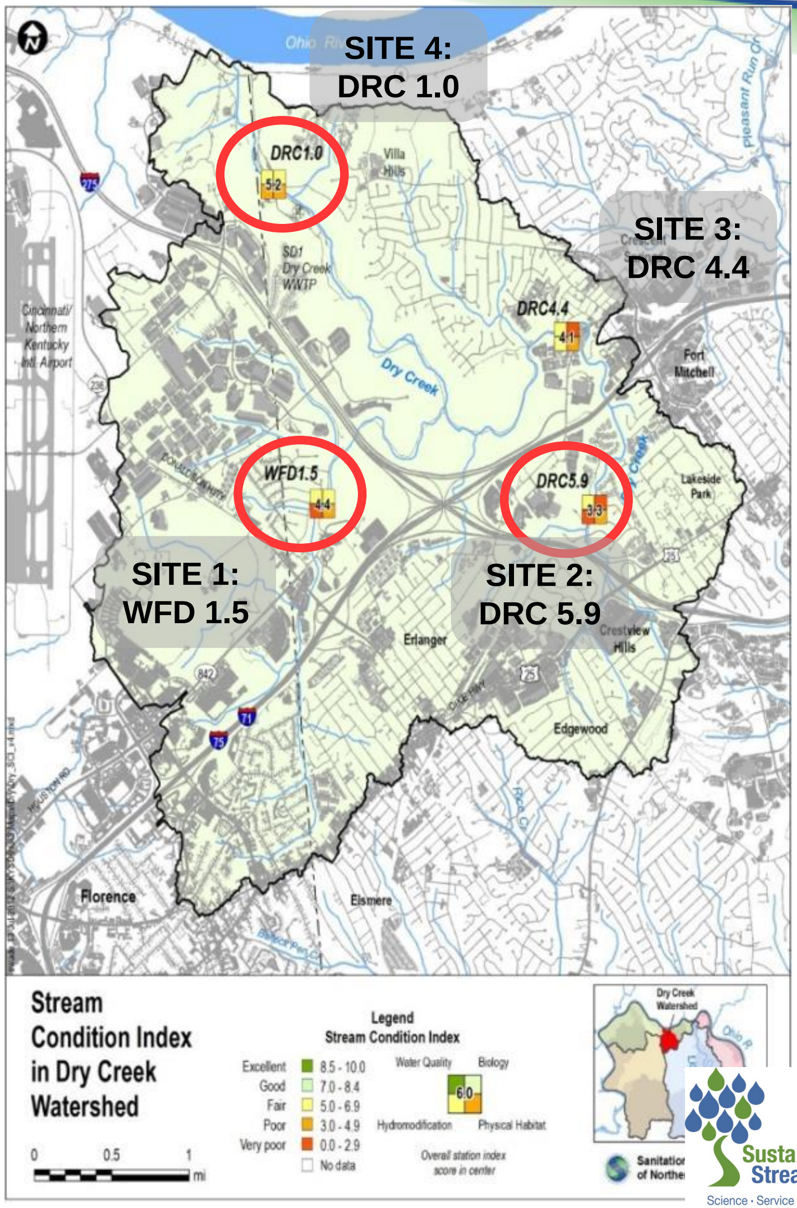
- Storm water runoff:
  - Pre-development: ~1.8 billion gallons
  - Post-development: ~3.4 billion gallons

- Monitoring at 4 sites
  - Rapid downcutting
  - Severe bank erosion

Stream Bank Failure

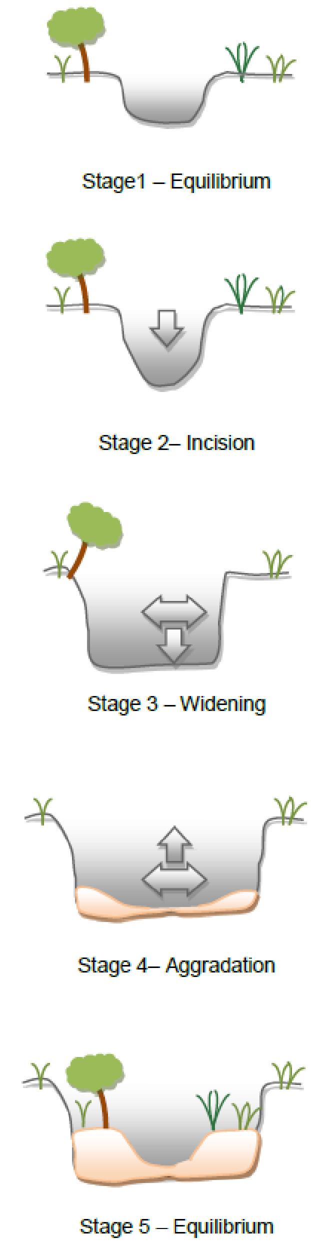
- Geotechnical instability
  - Failure by its own weight





Bank Failure Likely to Continue

- Active incision and weathering of bedrock
- Continued incision → more bank instability



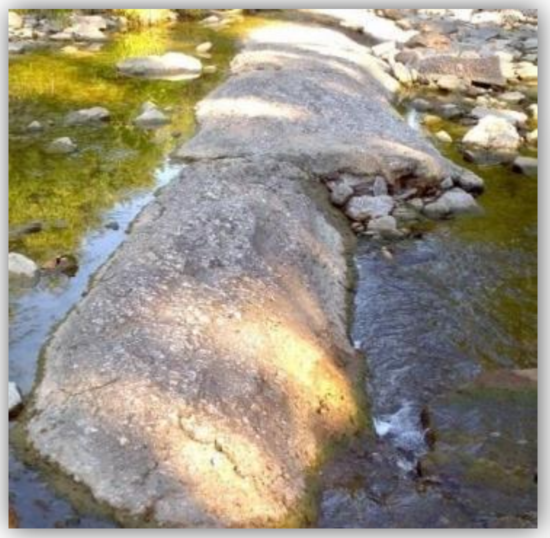
Channel Evolution Sequence in Response to Increased Flows from Urbanization, Adapted from Schumm et al. (1984) and Hawley et al. (In Press)

Recent Infrastructure Damage within Dry Creek Watershed

Entity	Dollars Spent*	Type of Damage and Notes
Boone County	$193,700	
Kenton County	> $385,000	Multiple repairs: slippages, bridges, and ditch cleaning
City of Florence	$20,000	Bank stabilization
City of Crestview Hills	$30,000	Bridge repair
City of Crescent Springs	$170,000	Road repair
SD1	> $1,260,000	Stream restoration project, repairs, and stabilizations
GCWW	$250,000	Bank stabilization
Duke Energy	$320,000	Gas and electric line stabilization and repair
TOTAL	**> $2,629,000**	

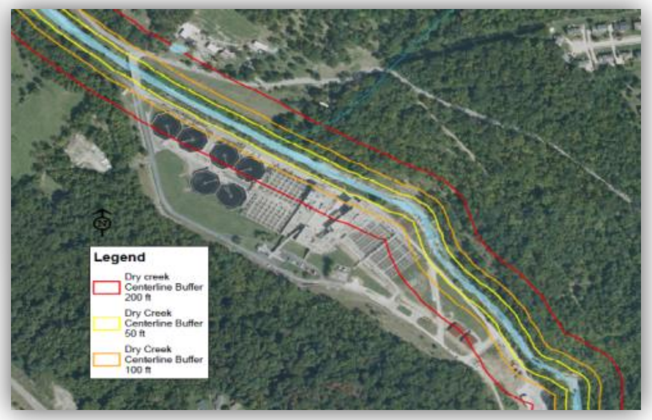
**Conservative estimate of expenditures over the last 5-7 years*

Damages within Dry Creek Watershed



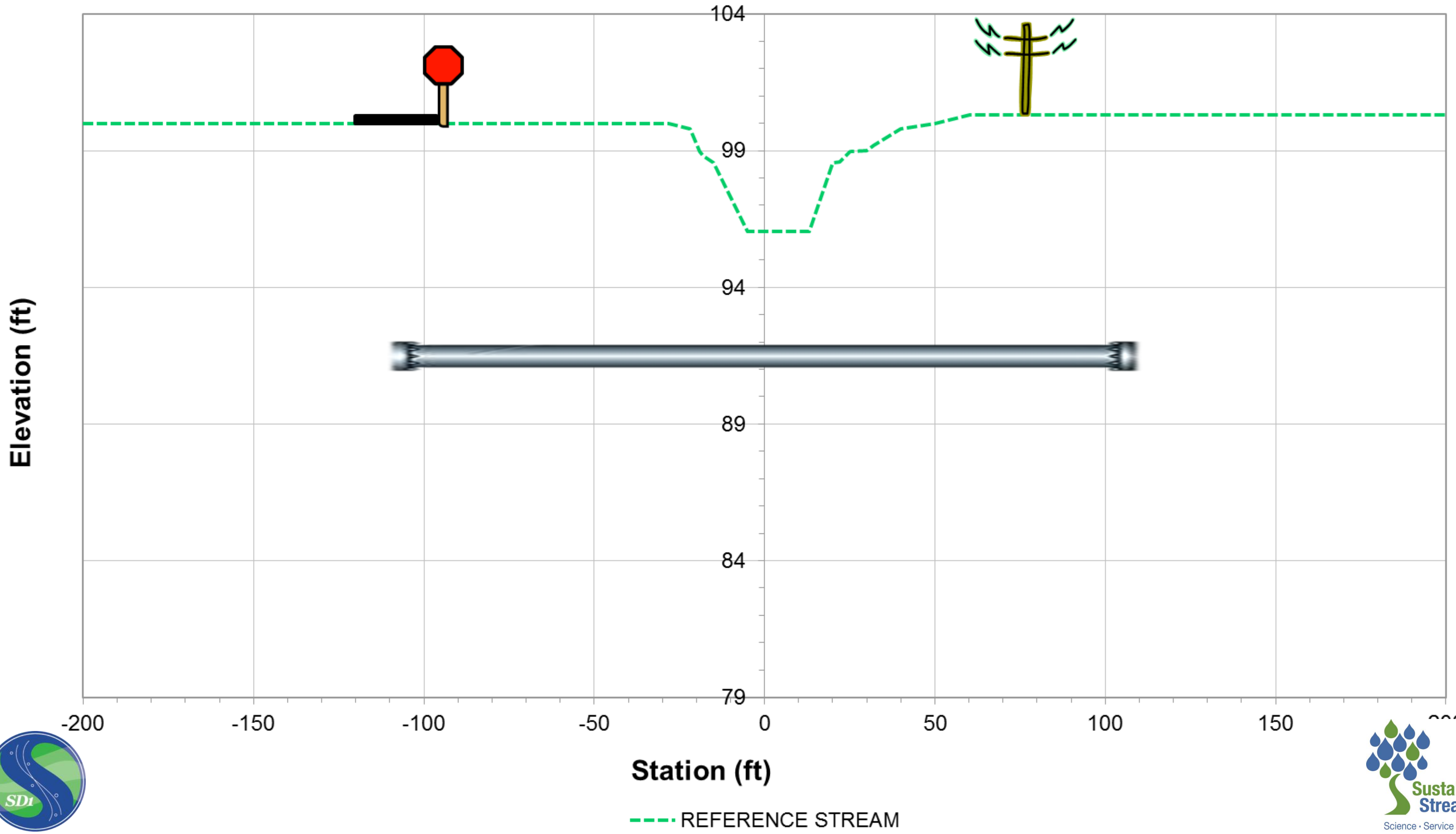
Exposed sanitary sewer crossing upstream of Dry Creek WWTP

Concrete blocks installed in an attempt to stabilize the stream bank near Duke Energy gas main



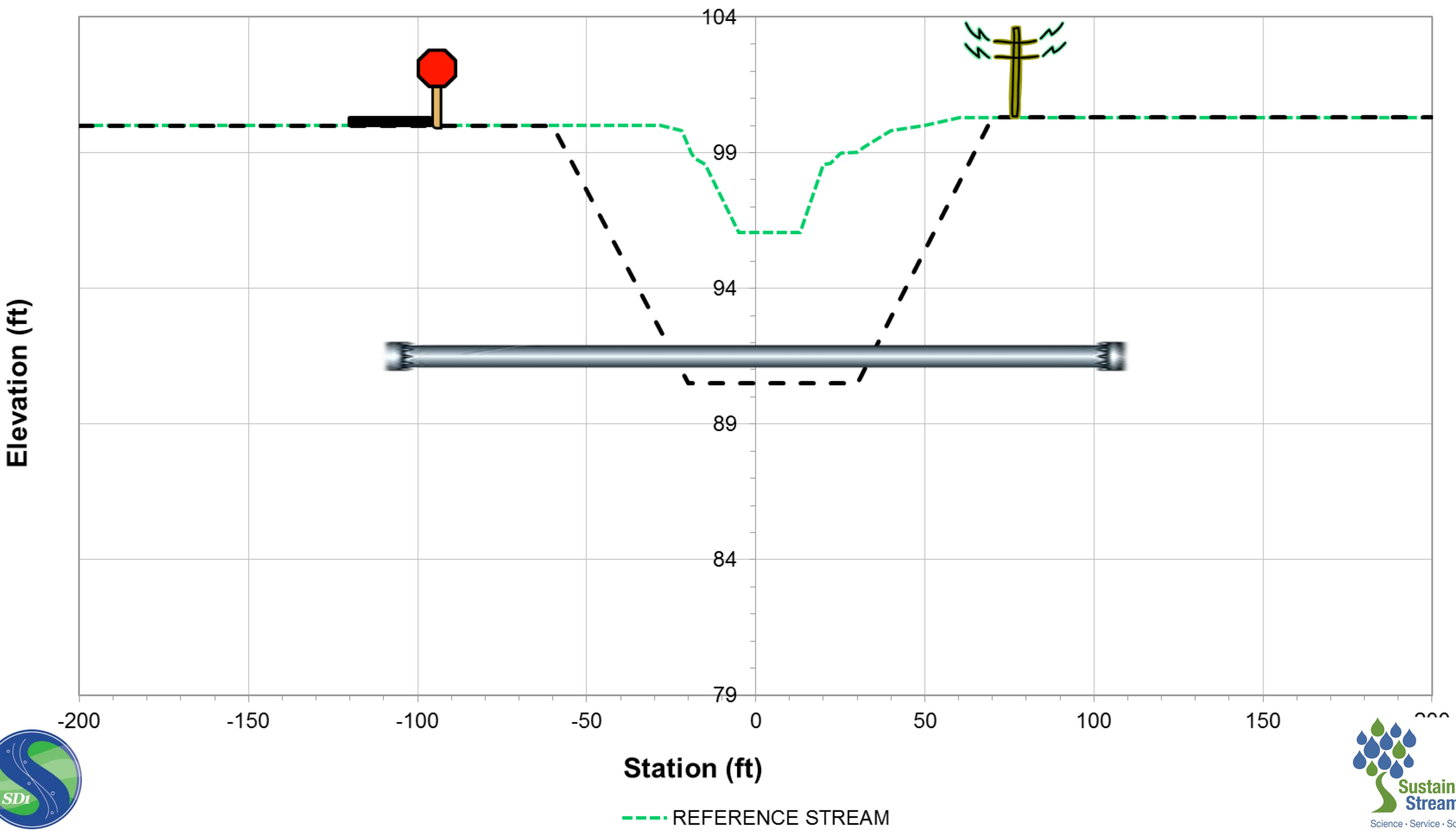
Proximity of Dry Creek WWTP to stream

Risk Zones



Elevation (ft)
104
99
94
89
84
79
-200
-150
-100
-50
0
50
100
150
Station (ft)
REFERENCE STREAM

Risk Zones



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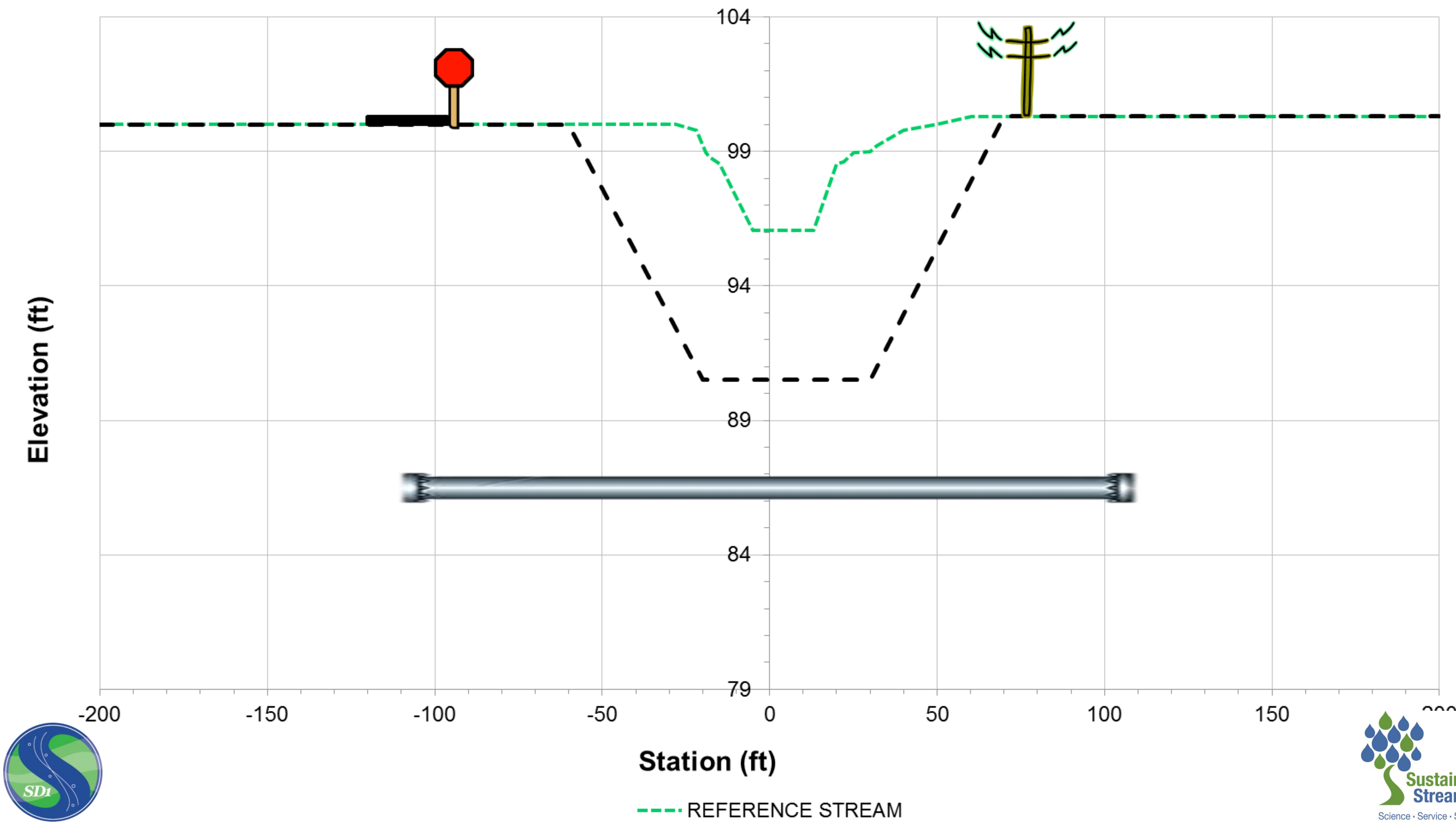
Risk Zones



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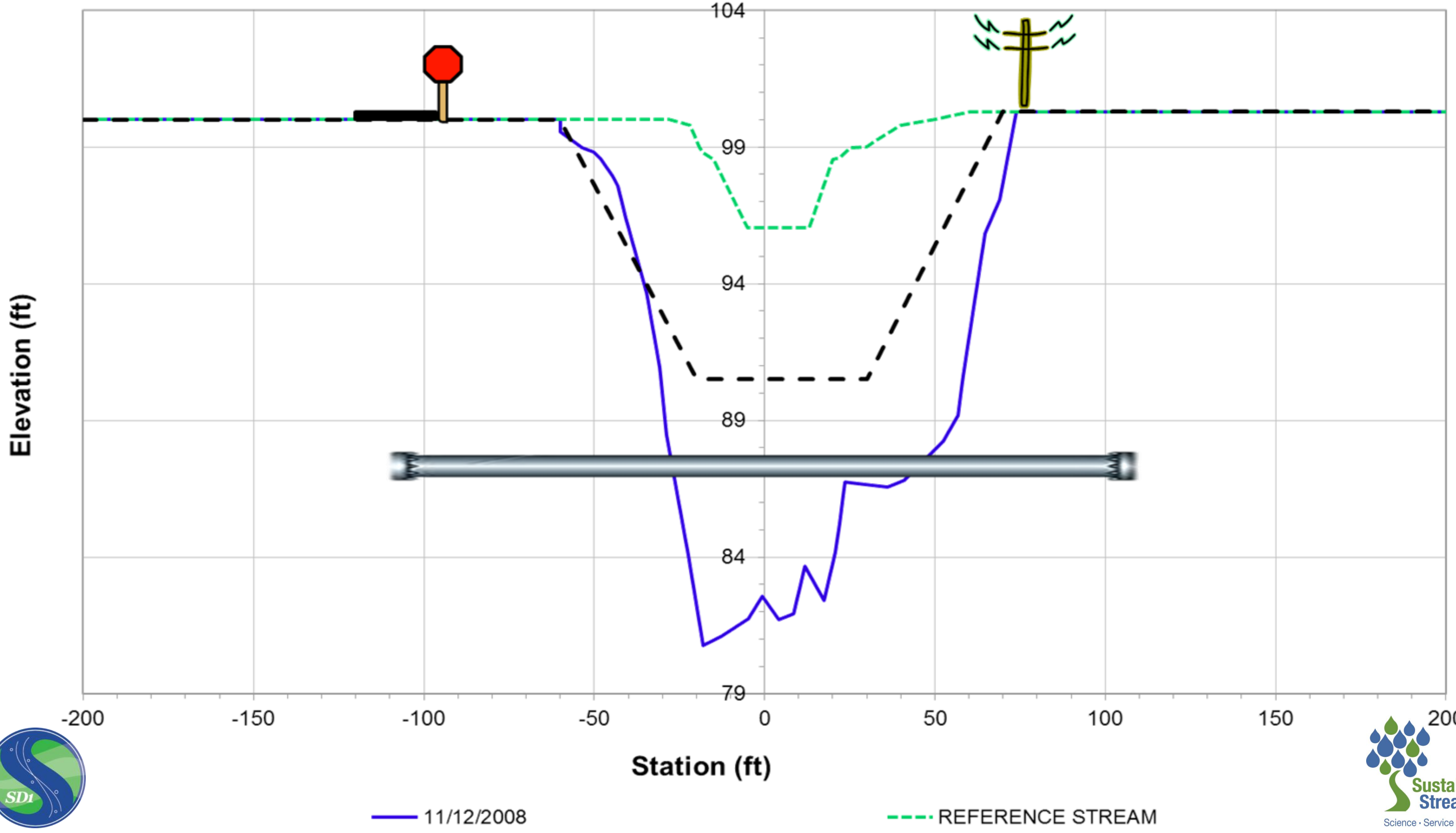
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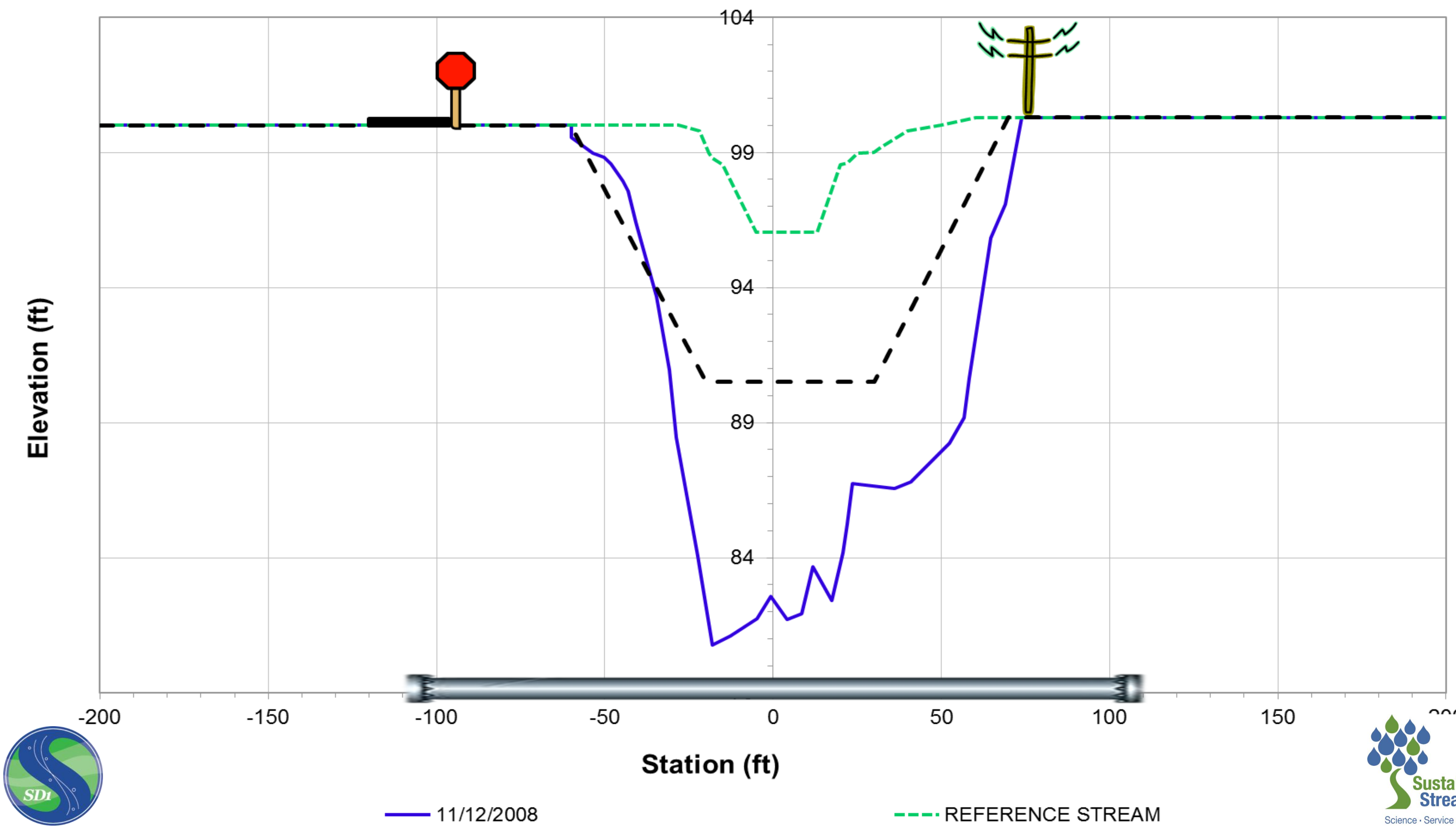
Elevation (ft)
Station (ft)
11/12/2008
REFERENCE STREAM

Risk Zones



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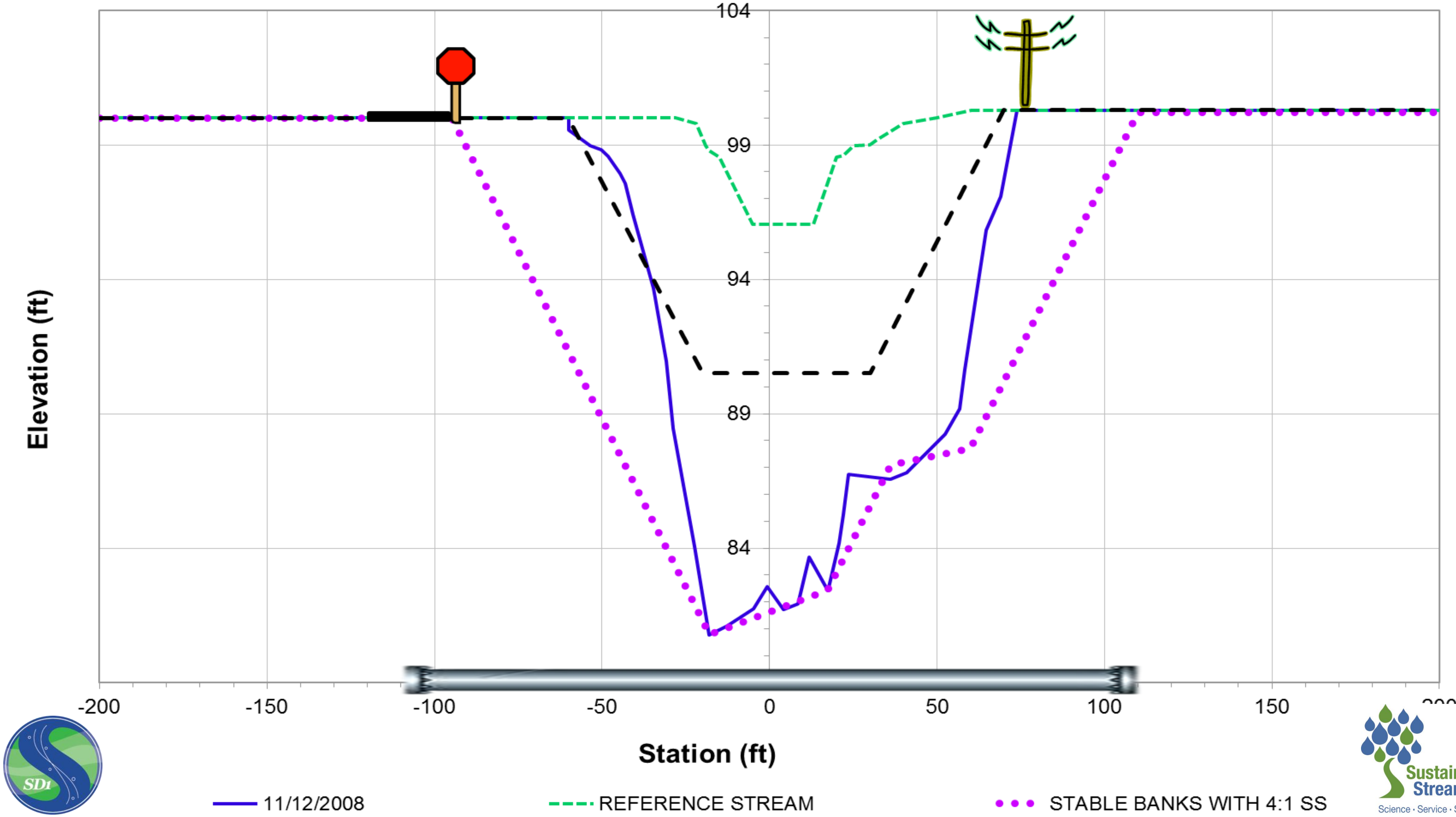

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-50
0
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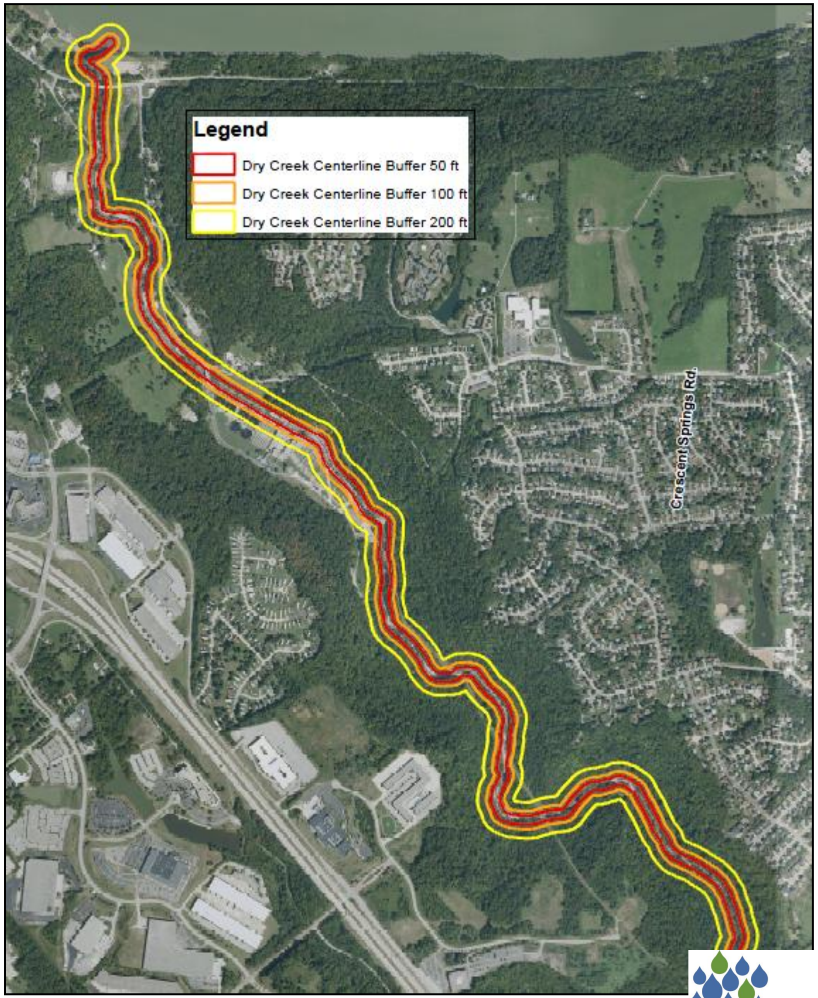
100
150
Elevation (ft)
Station (ft)
11/12/2008
REFERENCE STREAM
STABLE BANKS WITH 4:1 SS

Risk Zones

- Extreme Risk
  - Stream crossings
  - 50-foot stream centerline offset
- High Risk
  - 100-foot stream centerline offset
- Moderate Risk
  - 200-foot stream centerline offset



Dry Creek Main Stem At-Risk Infrastructure

Asset (Within 200 Feet of Main Stem)	Amount	Value*
TRANSPORTATION ASSETS		**$3,000,000**
Culverts	17 EA	$300,000
Bridges	2 EA	$1,600,000
Roads	6,500 LF	$1,100,000
SD1 CONVEYANCE ASSETS		**$12,440,000**
Pump Stations	2 EA	$800,000
Sanitary Structures	34 EA	$170,000
Storm Structures	34 EA	$170,000
Sanitary Lines	19,000 LF	$3,800,000
Storm Lines	30,000 LF	$7,500,000
WATER ASSETS		**$10,600,000+**
Water Lines	6,000 LF	$600,000
Trunk Main and PS Crossing Ohio River	Length Unknown	$10,000,000+
OTHER KNOWN ASSETS		**$100,000,000+**
Gas and Electric	Length Unknown	Unknown
Airport Fuel Line	Length Unknown	Unknown
Dry Creek WWTP	WWTP	$100,000,000+
TOTAL APPROXIMATE AT RISK ASSETS		**$126,000,000+**

** Dollar values are approximate and are based on assumed unit prices for newly built infrastructure.*

SD1

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Dry Creek Concept Plan

Potential Regional Storm Water Management Opportunities

- Retrofit existing detention basins to reduce the erosive power of the flow regime, particularly of the intermediate storm events (<2 year event), which contribute to frequent periods of erosion in the channel.
- Provide new storm water detention features through partnerships with large developed areas.
- Provide floodplain storage in key locations.
- Explore cost-effective ways to incorporate improved storm water management on routine construction/maintenance projects, such as KYTC roadway projects and SD1 flood control and I/I projects.

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OTHER KNOWN ASSETS		**$100,000,000+**
Gas and Electric	Length Unknown	Unknown
Airport Fuel Line	Length Unknown	Unknown
Dry Creek WWTP	WWTP	$100,000,000+
TOTAL APPROXIMATE AT RISK ASSETS		**$126,000,000+**

** Dollar values are approximate and are based on assumed unit prices for newly built infrastructure*

Legend

- Potential Partnership/Large Development
- Potential Floodplain Storage
- Existing Detention Basins (Tier 2 Priority)
- Existing Detention Basins (High Priority)
- Threatened Infrastructure Zone (200ft of Stream Centerline)
- SD1 Sampling Sites
- Pump Stations
- Water Line

Sewer Lines

- Sanitary Gravity
- Sanitary Force Main
- Sanitary Gravity Main Trunk

Storm Lines

- Culvert Pipe
- Storm Sewer
- Waterbodies
- Streams
- rivers

0 0.25 0.5 1 Miles

Dry Creek Watershed Facts

- Dry Creek is one of the most unstable streams in all of Northern Kentucky.
- Millions of dollars of infrastructure is being threatened by the eroding stream banks in this watershed.
- More than $2.5 Million has been spent recently by various entities to repair infrastructure damaged by Dry Creek stream bank erosion.
- Approximately 3.4 billion gallons of storm water runoff is generated in this watershed annually, nearly double the pre-development runoff volume.
- There is a severe shortage of storm water management facilities in the watershed, and the detention basins that do exist were not designed to protect Dry Creek from excess erosion.
- The Stream Condition throughout the watershed (evaluated based on water quality, biology, hydromodification, and physical habitat) received condition scores of "Fair", "Poor", and "Very Poor".

Severely unstable and eroding banks along the main stem of Dry Creek. (Person for Scale)

DRY CREEK WATERSHED REGIONAL STORM WATER MANAGEMENT CONCEPT PLAN

SANITATION DISTRICT NO. 1 OF NORTHERN KENTUCKY

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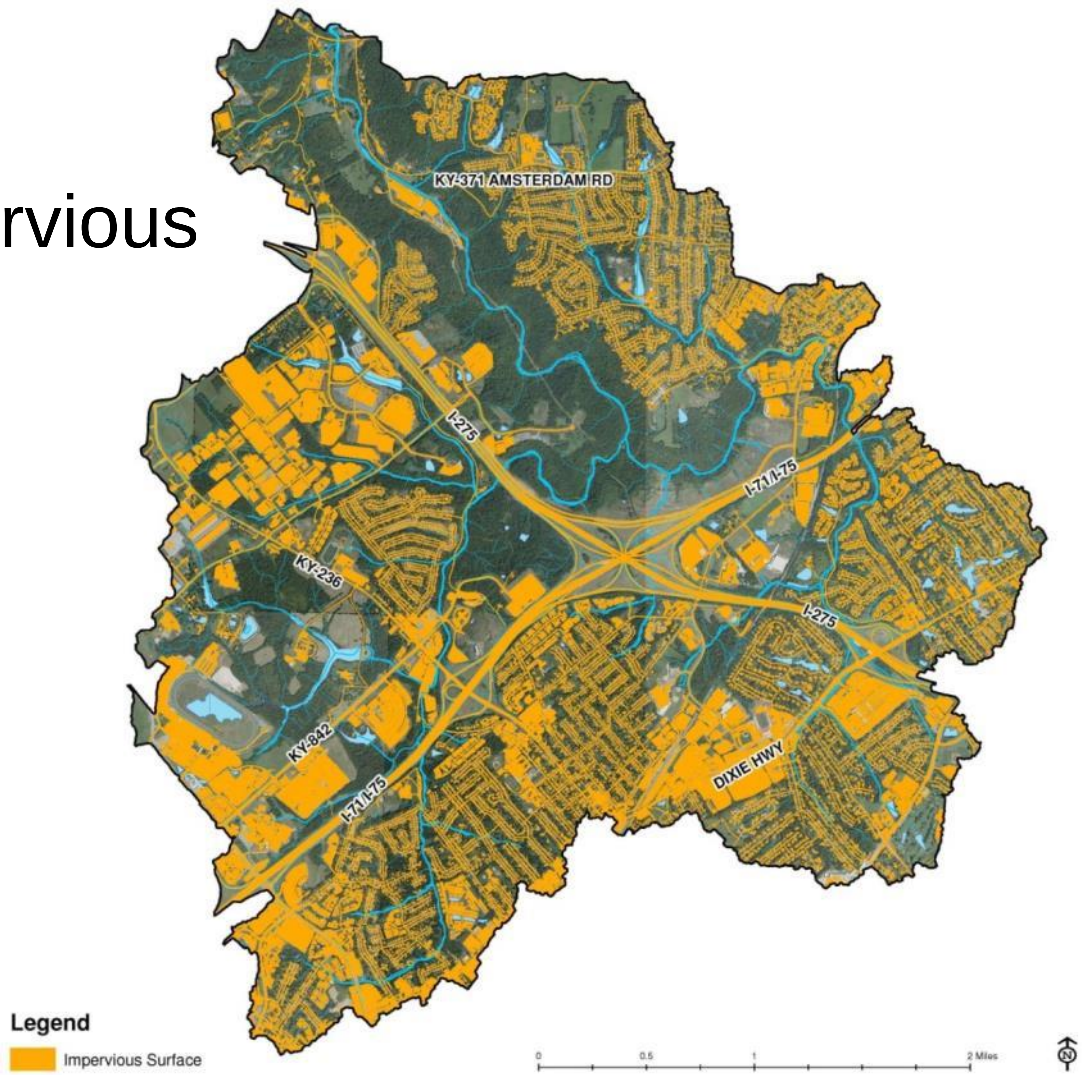
Watershed Analysis

30% Impervious



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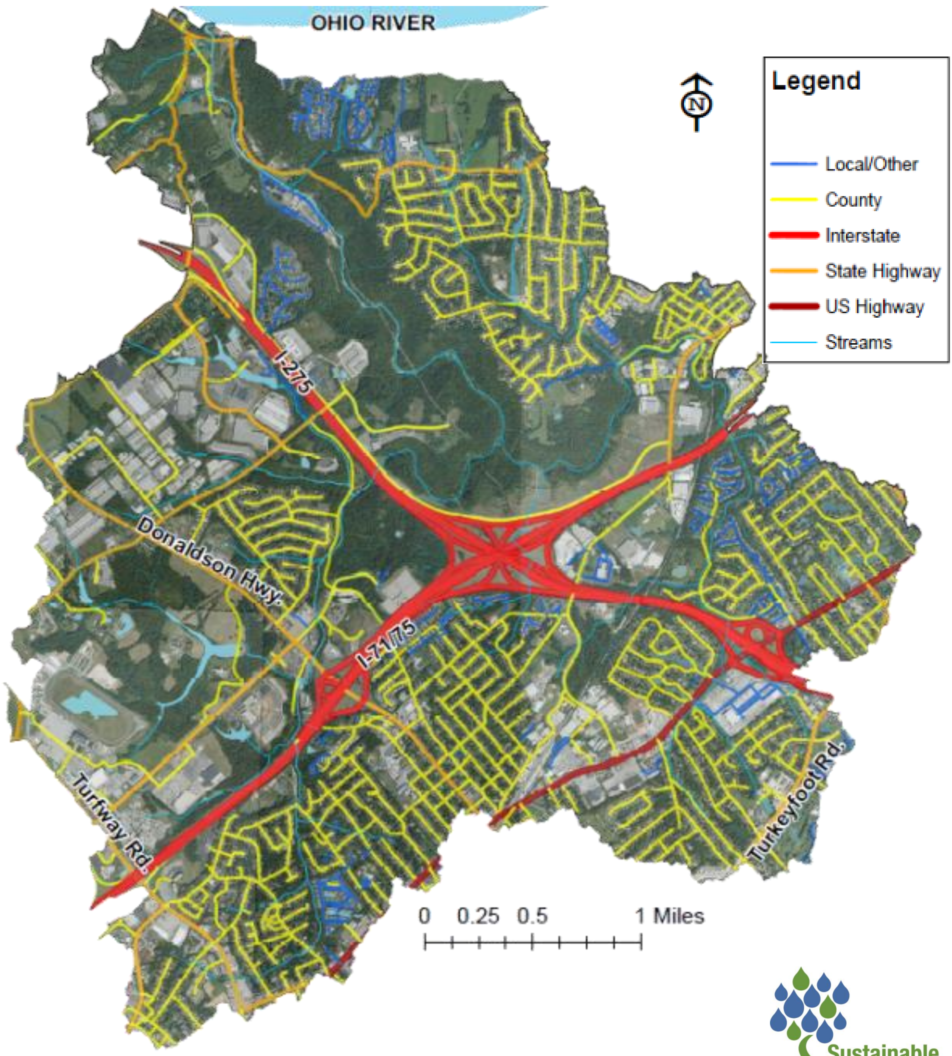
Opportunities: Roadways

- 8% of watershed
- Nearly **25% of total impervious area**
- Typically lack storm water detention
- Right-of-way areas may have room for controls



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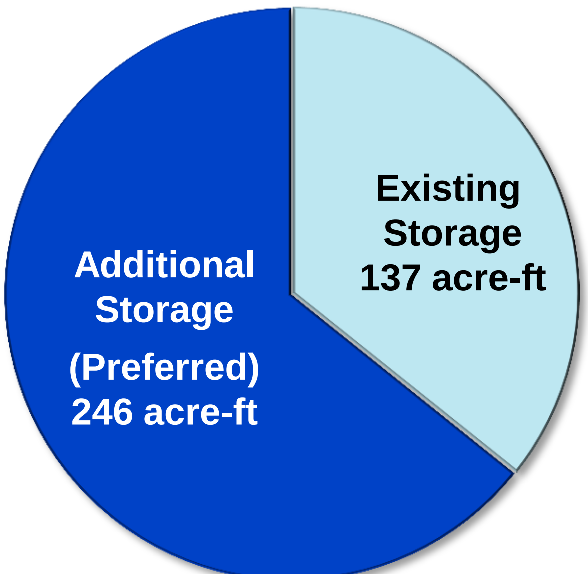
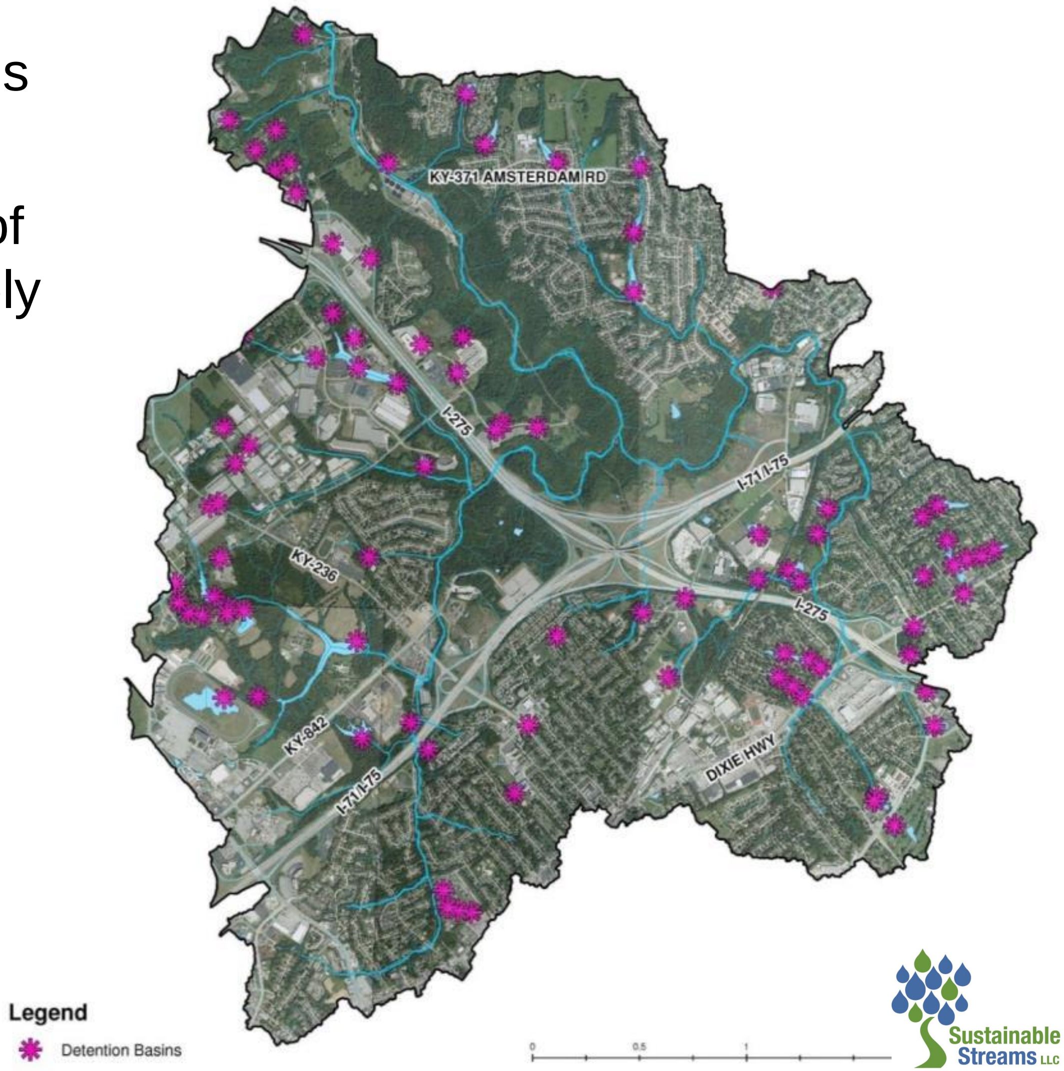
Existing Storm Water Management

- 107 existing detention basins
- Watershed only has **~35%** of storage volume to adequately protect against erosion





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Veterans Way Extension

Amended Swale Alternative to Achieve Channel Protection

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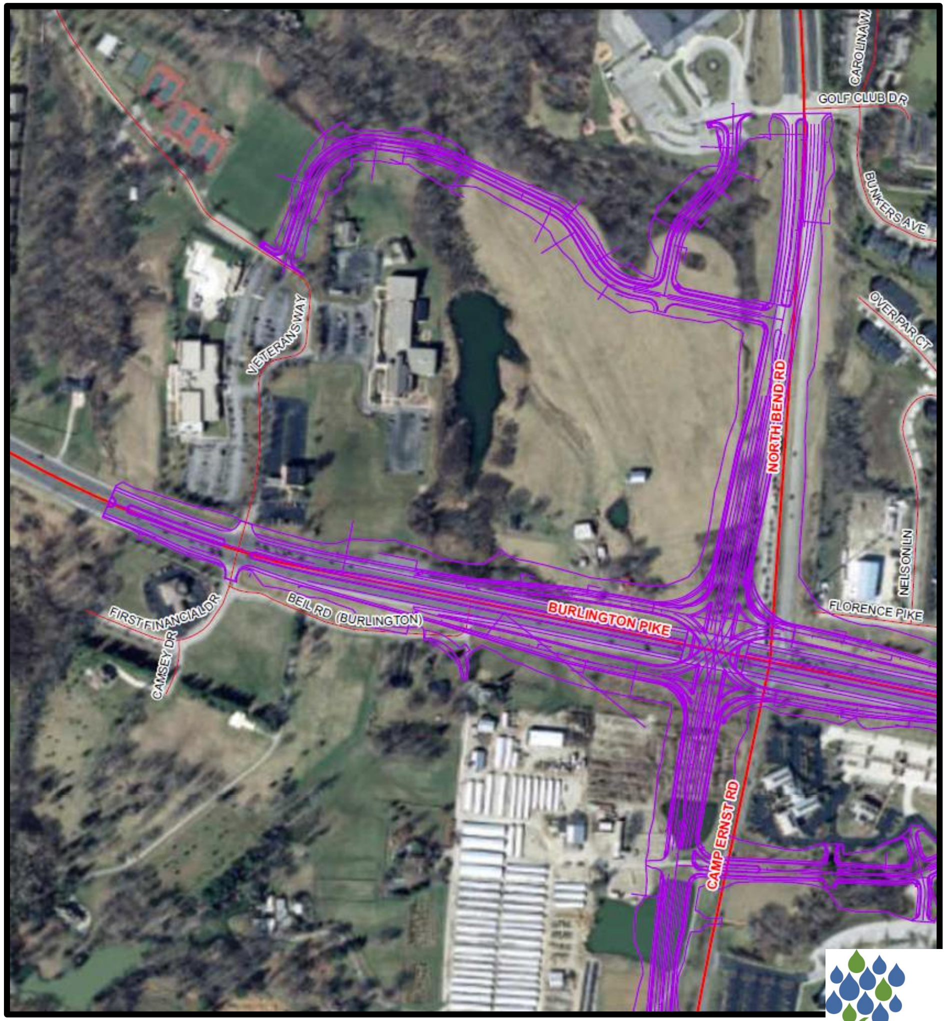
Veterans Way Extension: Current Plans

- Curb and gutter with storm sewer

- Drains to tributary of Allen Fork
  - Conventional flood conveyance design
  - No water quality treatment
  - No channel protection



Allen Fork

- Impaired waterway: 303(d) listed stream
- Stream Restoration (FILO) project immediately downstream:
  - $467,582 invested to restore:
    - 4,400 feet of stream
    - 0.2 acres of storm water wetlands

Stream re-establishment in Boone Woods Park
(Photos: NKU CER)

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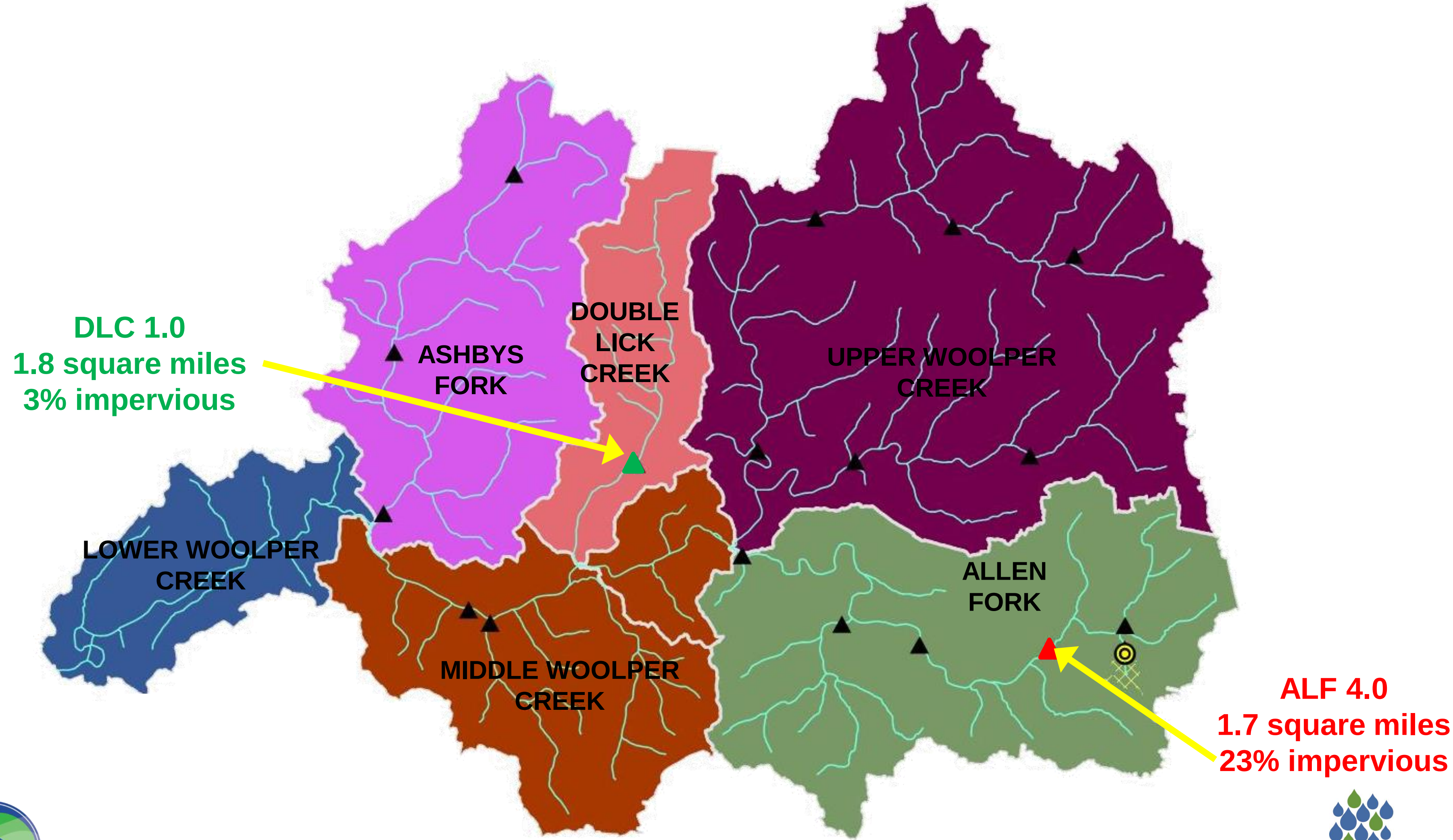
Data Indicate Stream Stability Is A Concern



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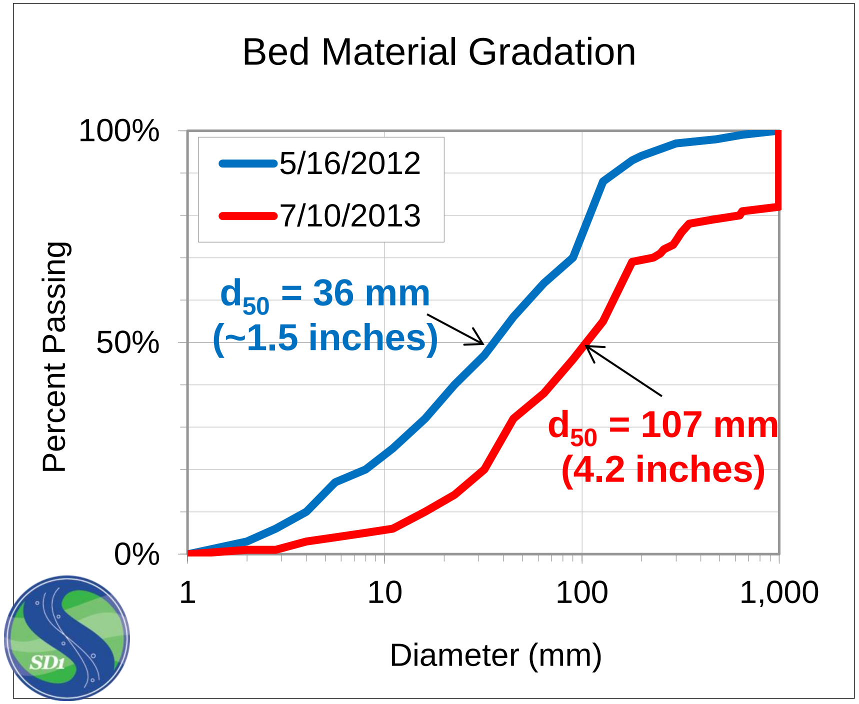
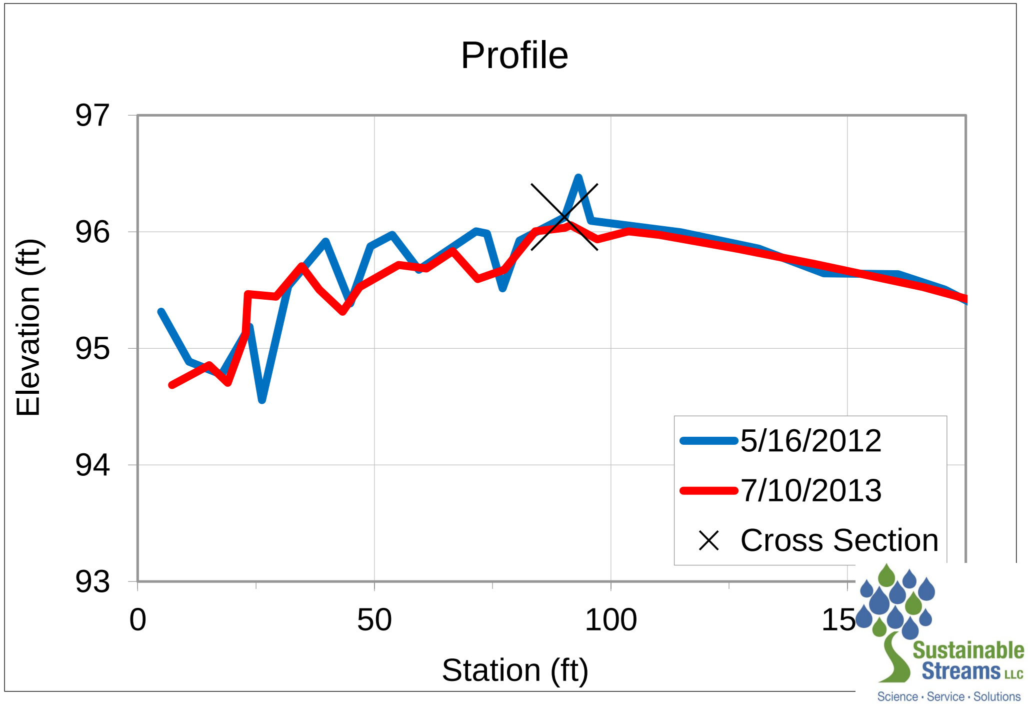
Allen Fork
ALF 4.0
23% impervious

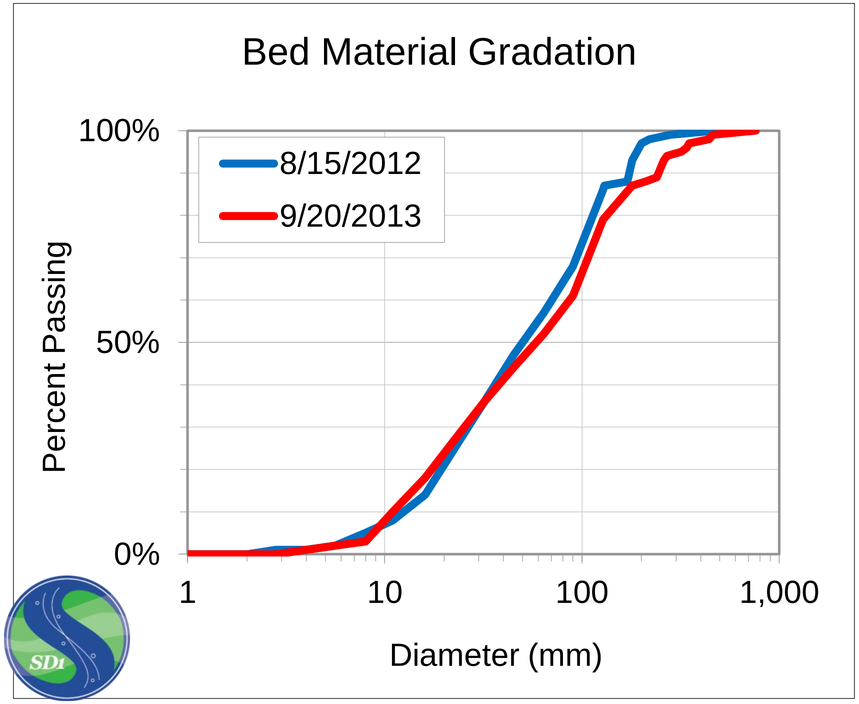
Bed material coarsening:
d_{50} increased by ~200%
Streambed erosion & downcutting

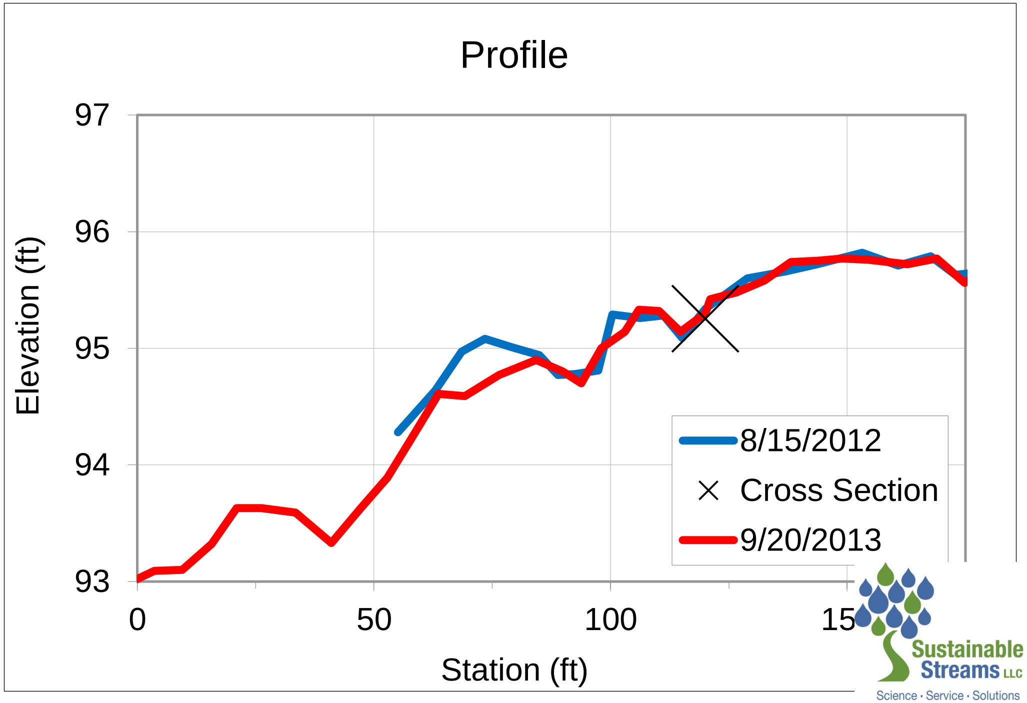




Double Lick Creek
DLC 1.0
3% impervious

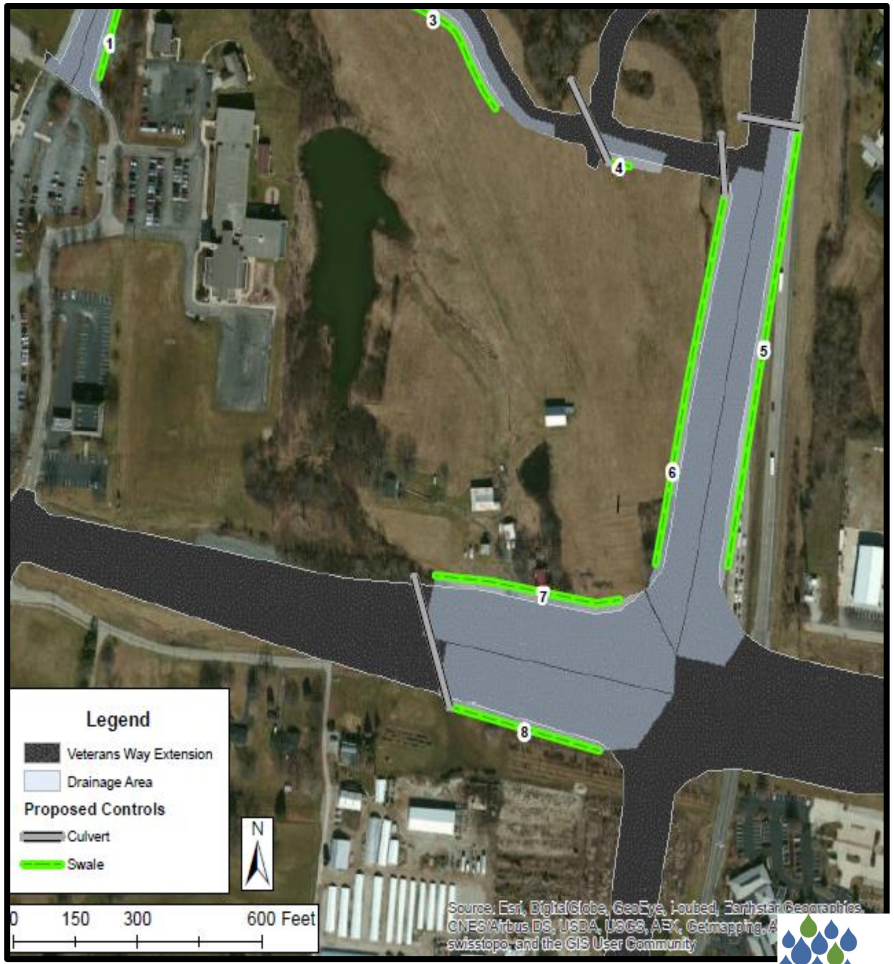
Very stable channel geometry and bed material between 2012 and 2013 (17% increase in d_{50})





Project Alternative for Channel Protection

- Use of amended swale to achieve:
  - Flood control
    - Post ≤ Pre (2, 10, 25, 50, 100-yr)
  - Water Quality Treatment
    - First 0.8 inches filtered
  - Channel Protection
    - 2-year flow released at a rate less than the critical flow



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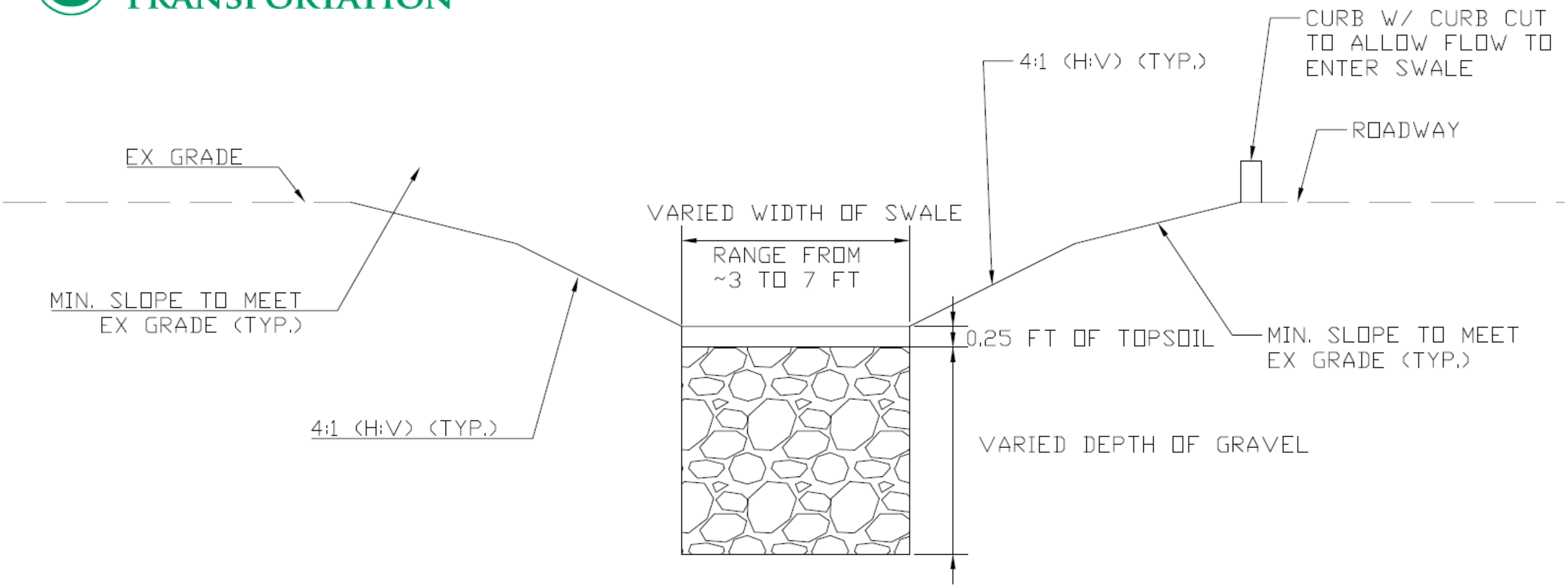
Enhanced Swale Cross Section

Illinois Department of Transportation

Ohio Department of Transportation



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Enhanced Swale Components

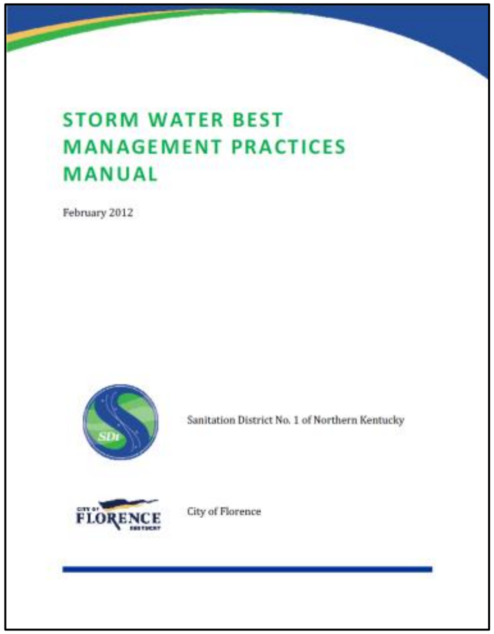
- Appendix 2-B in N. Ky Storm Water BMP Manual
- Top Soil
  - ¾”: 98% passing
  - Sand: 50-75% passing
- Gravel
  - Clean, washed No. 57 stone with 100% passing the 1-½” sieve
- Vegetation
  - Fescue or equivalent turf
  - Native Forbs/Grasses could reduce maintenance/mowing costs

Enhanced Swale Sizing

- Reference: SD1/Florence Storm Water BMP Manual
  - Biofiltration Swale

1. Size swale for water quality flow rate

2. Check sizing for flood control design flow rate


STORM WATER BEST MANAGEMENT PRACTICES MANUAL

February 2012

Sanitation District No. 1 of Northern Kentucky

City of Florence

Enhanced Swale Sizing

- Reference: SD1 Rules and Regulations
  – Channel Protection Credit Policy

3. Model for channel protection
   – Generate pre-development 2-year flow
   – Apply the $Q_{critical}$ parameter
   – Adjust sizing as needed to match post-development 2-year flow to $Q_{critical}$

NORTHERN KENTUCKY
REGIONAL STORM WATER
MANAGEMENT PROGRAM

RULES AND REGULATIONS

SANITATION DISTRICT NO. 1
1045 EATON DRIVE
FORT WRIGHT, KY 41017

AUGUST 2011

Preliminary Results

Swale/ Roadway	Drainage Area	Pre Q_2	$Q_{critical}$ (44% Q_2)	Post Q_2	Post Q_2 Control	Swale Length	Bottom Width	Gravel Depth	Gravel Volume
	acres	cfs	cfs	cfs	cfs	ft	ft	ft	CY
Veterans Way									
1	0.35	0.81	0.36	1.13	0.30	213	4.5	2.5	89
2	0.46	0.84	0.37	1.52	0.26	132	10.0	2.5	123
3	0.80	1.30	0.57	2.74	0.32	541	5.25	2.25	237
4	0.19	0.31	0.14	0.66	0.12	54	32.0	1.00	64
North Bend Road									
5	2.15	5.50	2.42	8.04	2.38	956	5.5	2.5	487
6	2.06	3.75	1.65	6.26	1.58	810	5.5	2.5	412
Burlington Pike									
7	2.11	4.91	2.16	8.33	1.43	451	6.75	4.75	536
8	1.74	4.26	1.87	6.88	1.40	375	6.5	5.0	452

- ✓ Pre ≥ Post: 2-yr, 10-yr, 25-yr, 50-yr, 100-yr
- ✓ Water Quality Volume treated
- ✓ $Q_{critical}$ controlled for 2-yr, 24-hr storm

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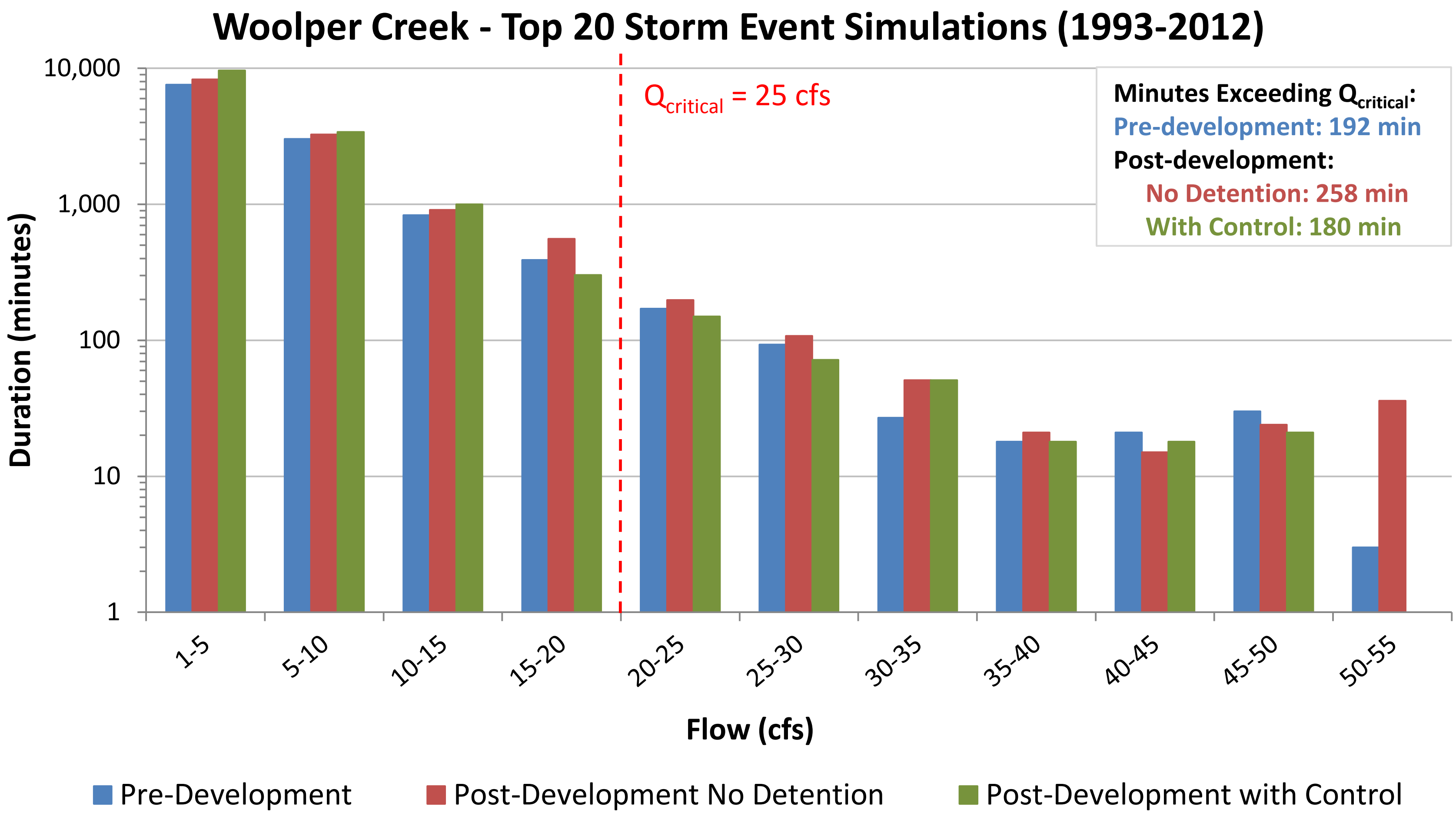
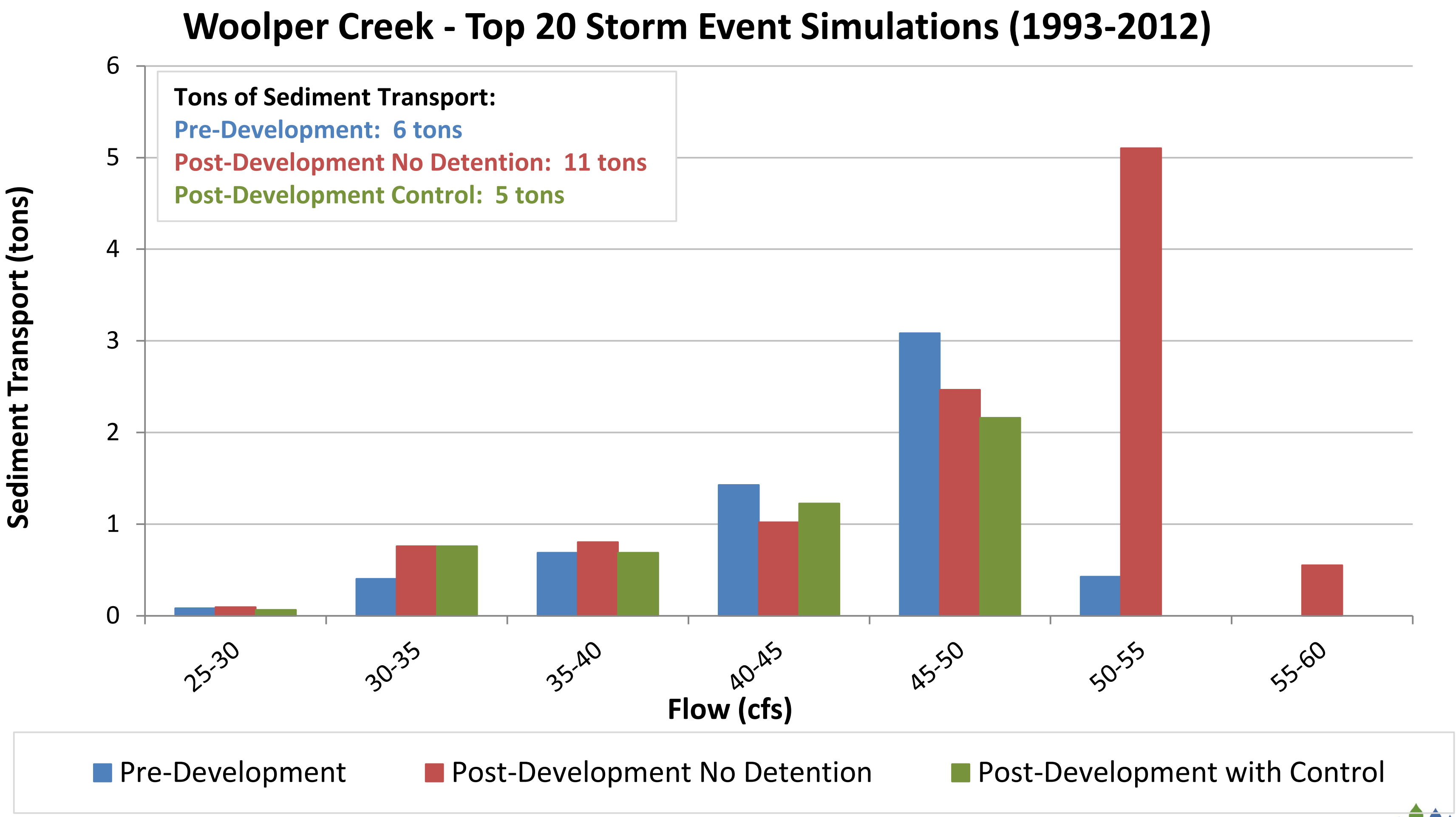
Preliminary Results



Preliminary Results



Preliminary Results

Compared to pre-developed conditions, the enhanced swale has:

- Fewer minutes exceeding $Q_{critical}$
- Reduced sediment transport capacity

	Pre-Developed	Post-Developed	
		No Control	Control
Peak Flow (cfs)	51	56	49
Minutes > $Q_{critical}$	192	258	180
Sediment (tons)	6	11	5

% Change from Pre-Developed	Pre-Developed	Post-Developed	
		No Control	Control
Peak Flow (cfs)	-	11%	-3%
Minutes > $Q_{critical}$	-	34%	-6%
Sediment (tons)	-	83%	-17%

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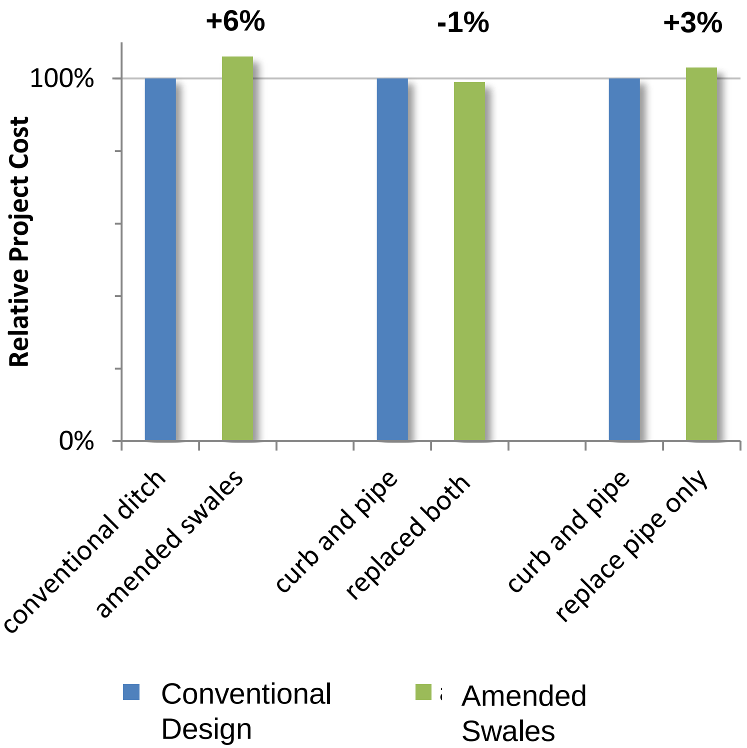
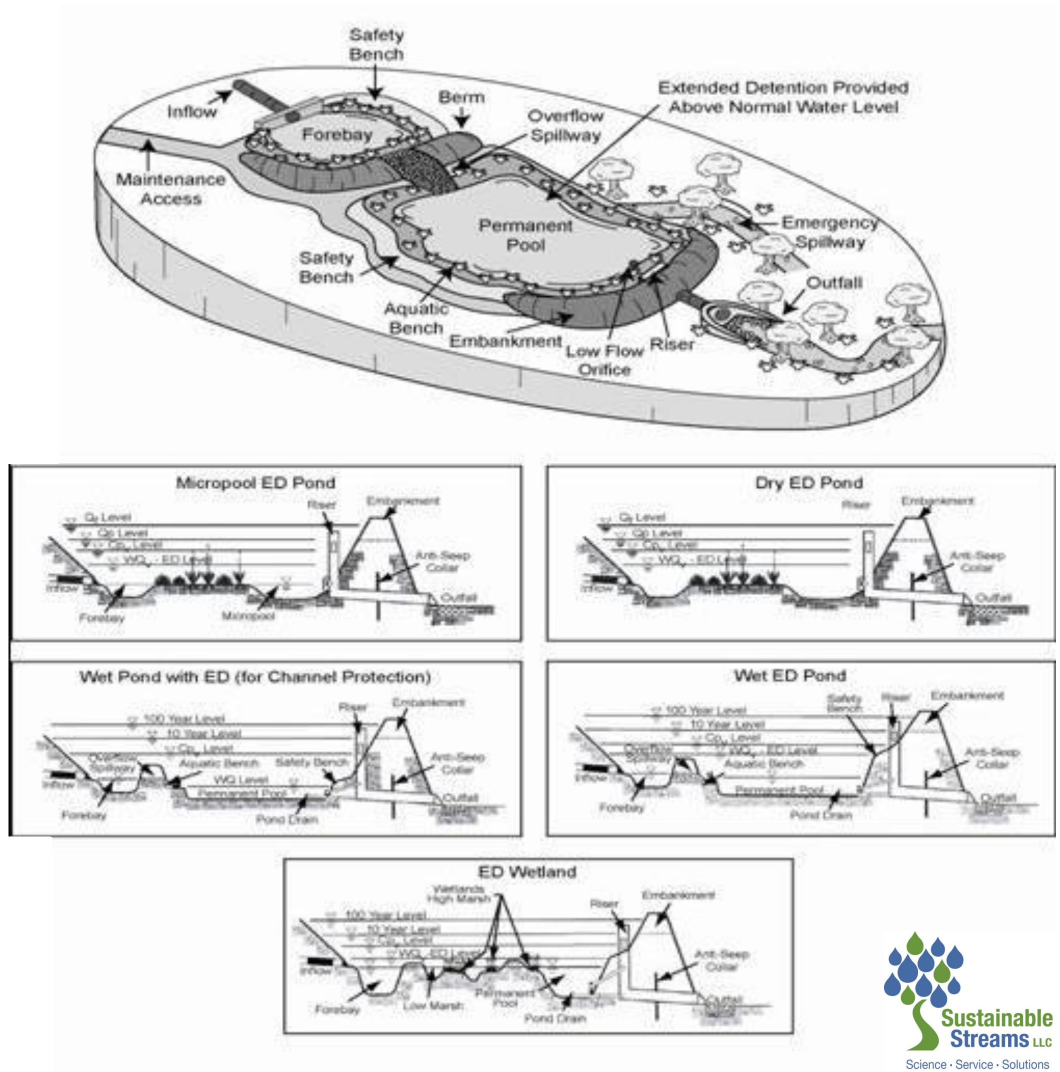
Cost Considerations

- Average amended swale:
  - ~$22 per lane-foot
  - ~$116,000 per lane-mile
- Average highway project:
  - ~$375 per lane-foot
  - ~$2,000,000 per lane-mile
- Potential savings on highways planned with curb/sewers:
  - 15" storm sewer ~$130-190 per foot
  - Curb and gutter ~$20 per foot



Addressing Site Constraints

- Install alternative BMPs
- Consider over-control in some areas to achieve overall goals



Channel Protection on Roadway Projects

- Amended swales provide alternative to basins
- ~10 acres of pavement on Veterans Way Project:
  - Swales could provide **savings of ~$11,000**
    - **~$3.40 per lane-foot** (**~1%**)
  - Keeping curb/gutter would increase costs ~$37,500
    - ~$11.70 per lane-foot (~3%)

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Questions?

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