Mitigating Downstream Erosion – the Role of $Q_{critical}$

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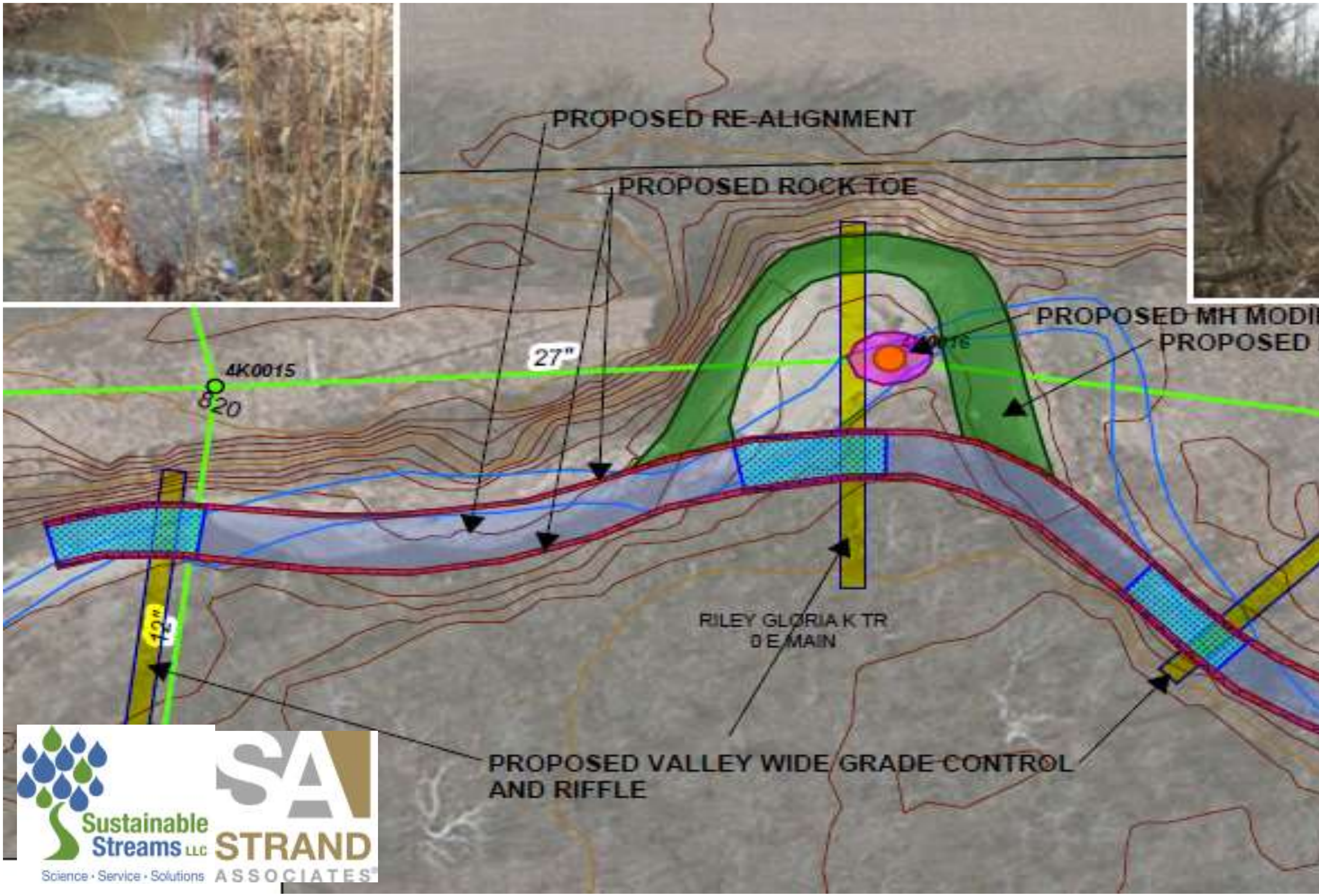
Bob Hawley, PhD, PE

Ohio County Engineers Conference

March 7-8, 2017

Preface – Asset Protection

Preface – Asset Protection



Mitigating Downstream Erosion – the Role of $Q_{critical}$

A preventative approach

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Acknowledgements

G. Vietz, M. Wooten, K. MacMannis, E. Fet, and others

Addressing the urban stream disturbance regime

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Abstract: Thresholds for particle entrainment and natural disturbance frequency vary across hydrogeomorphic settings, but urbanization increases the rate and extent of channel erosion and sediment transport in alluvial channels. The *urban disturbance regime* is a change in the frequency, magnitude, and duration of hydrologically induced disturbance on the stream channel and ecosystem that can lead to geomorphic and ecological degradation. To preserve stream stability and ecological function, stormwater management systems should be optimized to maintain the natural disturbance regime of streambed material within the context of societal and environmental goals. Our proposed framework, based on data from 195 sites across 2 continents, shows that the tools of river mechanics can be used to develop relatively simple, regionally appropriate, streambed-specific guidance for stormwater designers, so that engineers can calibrate stormwater facilities that address the urban stream disturbance regime. In the absence of detailed hydrogeomorphic data, practitioners can use our model to predict an order-of-magnitude approximation of the critical discharge for bed particle entrainment (Q_c) based solely on bed material class (e.g., cobble vs sand) and the respective 2-y peak discharge (Q_2). The estimate also can guide practitioners toward the types of stormwater management strategies that are likely to be most effective at protecting stream stability in a given setting. For example, duration controls for large events ($\geq Q_2$) may be very important for preserving stability in gravel/boulder streams where Q_c is expected to be $>\sim 0.1$ to $1 \times Q_2$, but could have relatively little effect on the overall stability of sand-dominated systems where Q_c is likely to be $<0.01 \times Q_2$ and controls of much more frequent events ($<<Q_2$) may have a greater influence.

Key words: urbanization, stormwater management, fluvial geomorphology, hydromodification, channel stability, ecohydrology, flow regime, streambed sediment, benthic habitat, sediment transport

In the decade since publication of the landmark paper detailing the urban stream syndrome (Walsh et al. 2005), our understanding of urban streams and the primary drivers of their degradation has expanded substantially (e.g., Booth et al. 2016). In urban streams, ecological responses have been documented to impacts on water quality, such as pesticides (e.g., Coles et al. 2012) and road salts (e.g., Wallace and Biastoch 2016); water quantity (e.g., Hawley and Bledsoe 2011); induced habitat alteration (e.g., Vietz et al. 2014); and direct interventions, such as channelization, burial (Roy et al. 2009), and fragmentation via roadway crossings (Chin and Gregory 2001). These responses include relatively direct relationships, such as dependence of biodiversity on flow permanence (King et al. 2016), interactive relationships between macroinvertebrate assemblages and multiple drivers (e.g., Walsh and Webb 2016), and ecosystem functions, such as leaf breakdown (Cook and Hoellein 2016). Investigators have begun documenting that the breadth and severity of the urban stream syndrome varies considerably across space (e.g., Coles et al. 2012) and can cause ecological responses that are counter to conventional wisdom, such as increased (as opposed to decreased) base flow (Bhaskar et al. 2016). Furthermore, we can postulate why some settings appear to show greater resistance to urbanization than others (Utz et al. 2016) and acknowledge the possibility that rehabilitation goals for urban streams may vary based on ecological and socioeconomic contexts (Smith et al. 2016).

Despite our expanded understanding of the mechanisms of urban stream degradation, relatively little measurable progress has been made in the management of urban streams and the associated stormwater runoff generated in their watersheds. Billions of dollars continue to be invested in the physical restoration of urban channels (e.g., Bernhardt et al. 2005), but post-construction studies generally show that restored urban streams tend to have the biological signature of unrestored urban streams (e.g., Violin et al. 2011, Laub et al. 2012), with some exceptions in cases where out-of-stream restoration practices, such as stormwater control measures, have been implemented extensively (Smucker and Detenbeck 2014). A primary explanation for the lack

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When do macroinvertebrate communities of reference streams resemble urban streams? The biological relevance of $Q_{critical}$

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Abstract: The threshold discharge for streambed mobilization ($Q_{critical}$) has been proposed as a mechanistically relevant management target for geomorphic stability and biological integrity. The geomorphic relevance of $Q_{critical}$ (Q_c) is well established, but its influence on biological communities is less documented. In urban watersheds, where increased frequency of Q_c exceedance is nearly ubiquitous (i.e., the urban disturbance regime), excessive streambed disturbance typically co-occurs with other well-established drivers of the urban stream syndrome, such as habitat degradation and poor water quality. Thus, the specific influence of excess streambed disturbance on aquatic communities is not clear. We used a 7-y study of biotic integrity, geomorphic stability, and Q_c exceedance at a reference site (Middle Creek [MDC 5.5]) with excellent habitat and water quality to isolate the effects of streambed disturbance. At MDC 5.5, streambed disturbance was the dominant driver of biotic variability through time, and biological indices and geomorphic stability were significantly correlated with time since a Q_c event. During 2011, a year with particularly high frequency and magnitude of Q_c events, the Macroinvertebrate Biotic Index (MBI) at MDC 5.5 fell to its lowest score on record. In the context of 73 monitoring sites across a gradient of urbanization, the 2011 MDC 5.5 MBI of 30 (poor) was more similar to that of communities in streams draining watersheds with ~30% total impervious area than to reference-stream scores (~60) during more typical sampling years. Our study underscores the contribution of excess Q_c exceedance to poor biological communities. We suggest calibrating stormwater management to maintain the natural streambed disturbance regime in addition to the more common management objectives of water quality and flood control.

Key words: streambed mobilization, biological disturbance, stormwater management, channel instability, urbanization, ecohydraulics, environmental flows

Reduced biological integrity in urban and suburban streams can be attributed to numerous drivers, including direct alterations, such as channelization and burial, and indirect pathways, such as altered delivery and quality of energy sources and water (Booth 2005, Walsh et al. 2005b). Poor quality in urban streams is so ubiquitous that calls for improved stream management are now common in the scientific and regulatory communities (e.g., Roy et al. 2008, NRC 2009, Walsh et al. 2016). Management strategies that target individual drivers of stream degradation are often quite specific, e.g., numeric limits on pollutant loads discharged from wastewater treatment facilities. Similarly prescriptive water-quality treatment requirements for stormwater discharges also have become more common. For example, for more than a decade, the state of Vermont (USA) has required capture and treatment of runoff from up to 90% of the storms in a typical year (VANR 2002).

In other cases, management guidance is based more on narrative than on specific values. For example, Kentucky's general stormwater permit specifies management of stormwater in a way that positively affects overall stream health and reduces stream bank erosion, among other goals (KDOW 2010). Implementation of qualitative guidance is often difficult for managers, and qualitative guidance has typically resulted in management programs that stress water-quality treatment criteria, but lack specific management targets, thresholds, or technical guidance related to other components of stream integrity. The relative importance

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Resources

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Peer-Reviewed Journal Articles

2016

Hawley R.J. and G.J. Vietz. 2016. Addressing the urban stream disturbance regime. *Freshwater Science*, 35(1): 278-292. Read article »

Hawley R.J., Wooten, M.S., MacMannis, K.R., and E.V. Fet. 2016. When do macroinvertebrate communities of reference streams resemble urban streams? The biological relevance of Q critical. *Freshwater Science*, 35(3): 778-794. Read article »

Smith, R.F., **Hawley, R.J.**, Neale, M.W., Vietz, G.J., Diaz-Pascacio, E., Herrmann, J., Lovell, A.C., Prescott, C., Rios-Touma, B., Smith, B. and R.M. Utz. 2016. Urban stream renovation: incorporating societal objectives to achieve ecological improvements. *Freshwater Science*, 35(1): 364-379. Read article »

Utz, R.M., Hopkins, K., Beesley, L., Booth, D., **Hawley, R.J.**, Baker, M., Freeman, M.C., and K. Jones. 2016. Ecological resistance in urban streams: the role of natural and legacy attributes. *Freshwater Science*, 35(1): 380-397. Read article »

2013

Hawley, R.J. and B.P. Bledsoe. 2013. Channel enlargement in semi-arid suburbanizing watersheds: A Southern California case study. *Journal of Hydrology*, 496: 17-30.
Read article »

Hawley R.J., MacMannis, K.R., and M.S. Wooten. 2013. Bed coarsening, riffle shortening, and channel enlargement in urbanizing watersheds, northern Kentucky, USA. *Geomorphology 201: 111-126*. Read article »

2012

Bledsoe, B.P., Stein, E.D., **Hawley, R.J.**, and D.B. Booth. 2012. Framework and tool for rapid assessment of stream susceptibility to hydromodification. *Journal of the American Water Resources Association*, 48(4): 788-808. Read article »

Featured article

Three of Dr. Hawley's recent papers are featured in a special issue of *Freshwater Science* titled Urbanization and stream ecology: Diverse mechanisms of change

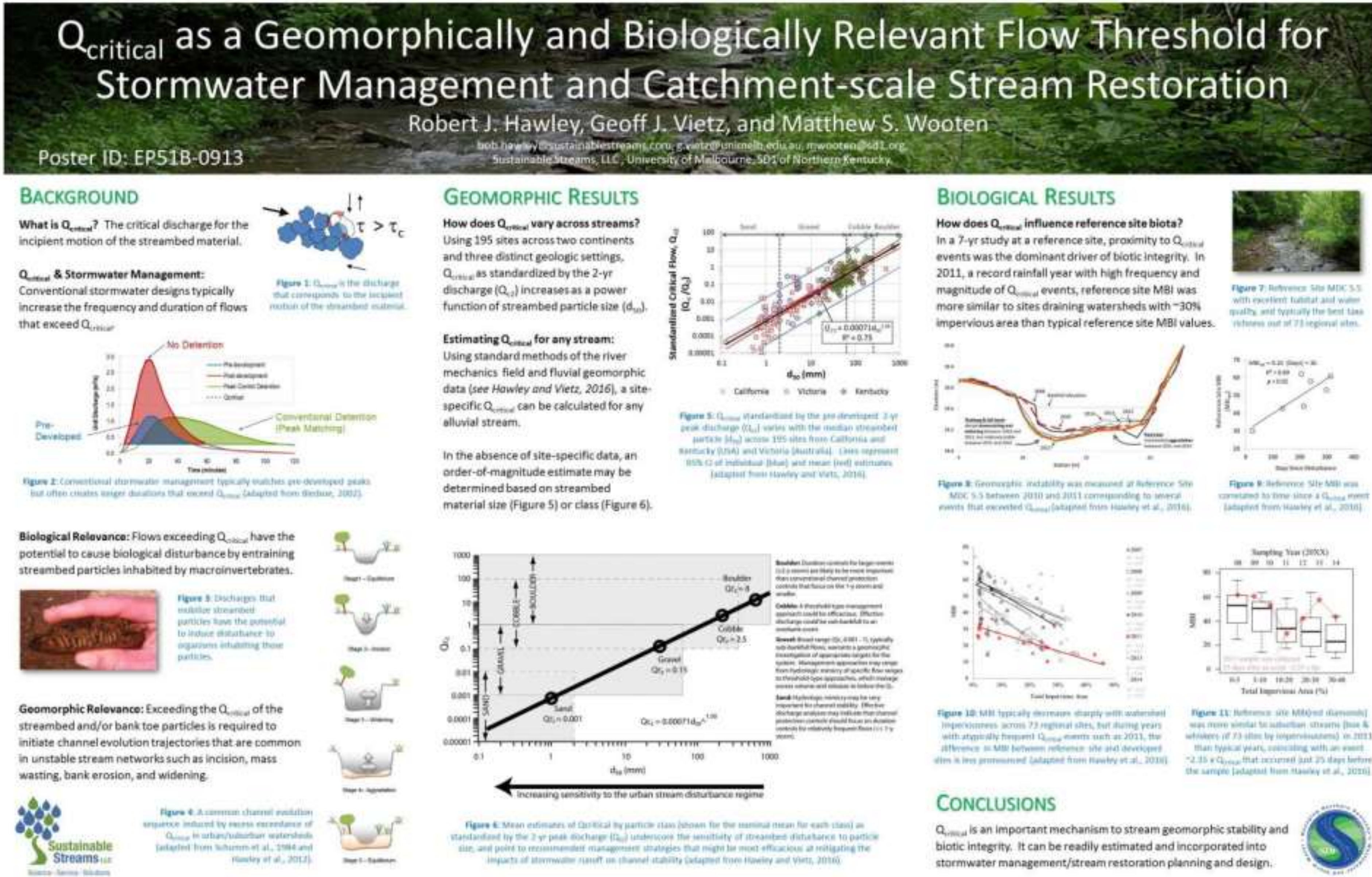
Available online:

Ecological resistance in urban streams »

The urban disturbance regime »

Urban stream renovation »

Resources

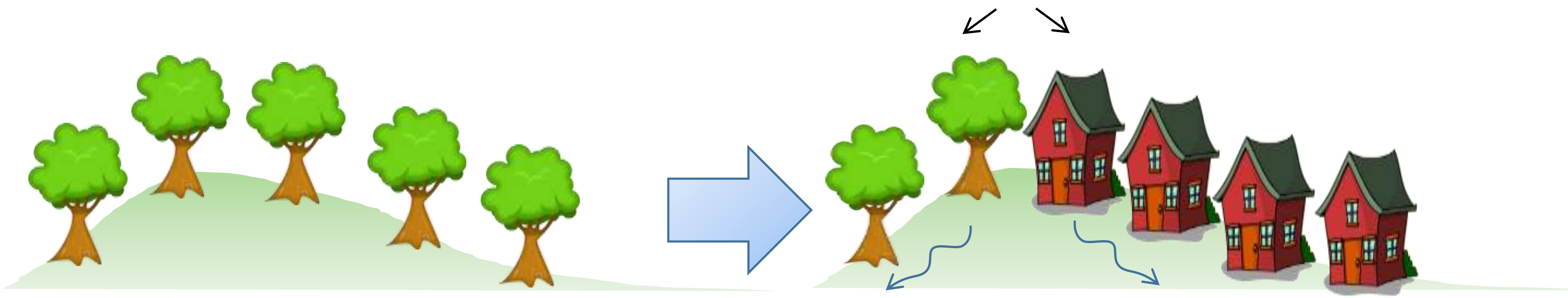


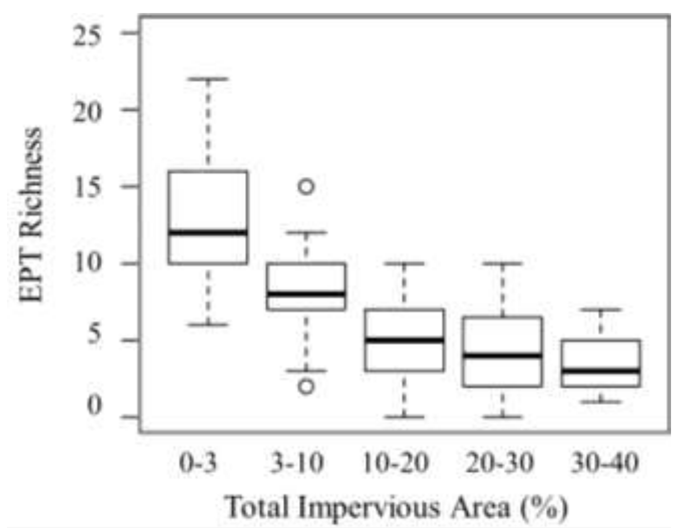
Qcritical as a Geomorphically and Biologically Relevant Flow Threshold for Stormwater Management and Catchment-scale Stream Restoration
Robert J. Hawley, Geoff J. Vietz, and Matthew S. Wooten
Poster ID: EP51B-0913
Sustainable Streams, LLC, University of Melbourne, SD1 of Northern Kentucky
BACKGROUND
What is Qcritical? The critical discharge for the incipient motion of the streambed material.
Qcritical & Stormwater Management: Conventional stormwater designs typically increase the frequency and duration of flows that exceed Qcritical.
No Detention
Pre-Developed
Conventional Detention (Peak Matching)
Biological Relevance: Flows exceeding Qcritical have the potential to cause biological disturbance by entraining streambed particles inhabited by macroinvertebrates.
Geomorphic Relevance: Exceeding the Qcritical of the streambed and/or bank toe particles is required to initiate channel evolution trajectories that are common in unstable stream networks such as incision, mass wasting, bank erosion, and widening.
Sustainable Streams LLC
GEOMORPHIC RESULTS
How does Qcritical vary across streams? Using 195 sites across two continents and three distinct geologic settings, Qcritical as standardized by the 2-yr discharge (Q2) increases as a power function of streambed particle size (d50).
Estimating Qcritical for any stream: Using standard methods of the river mechanics field and fluvial geomorphic data (see Hawley and Vietz, 2016), a site-specific Qcritical can be calculated for any alluvial stream.
In the absence of site-specific data, an order-of-magnitude estimate may be determined based on streambed material size (Figure 5) or class (Figure 6).
Standardized Critical Flow, Qc2 (Qc/Q2)
d50 (mm)
California
Victoria
Kentucky
SAND
GRAVEL
COBBLE
BOULDER
Increasing sensitivity to the urban stream disturbance regime
BIOLOGICAL RESULTS
How does Qcritical influence reference site biota? In a 7-yr study at a reference site, proximity to Qcritical events was the dominant driver of biotic integrity. In 2011, a record rainfall year with high frequency and magnitude of Qcritical events, reference site MBI was more similar to sites draining watersheds with ~30% impervious area than typical reference site MBI values.
CONCLUSIONS
Qcritical is an important mechanism to stream geomorphic stability and biotic integrity. It can be readily estimated and incorporated into stormwater management/stream restoration planning and design.

Survey

How Many of You Know or Work in Suburban Watersheds without Any Impaired Streams?

Pre-developed **Post-developed**





Adapted from Hawley et al. (2016, Freshwater Science)

The Urban Stream Syndrome

(Walsh et al., 2005; Booth, 2005, etc.)

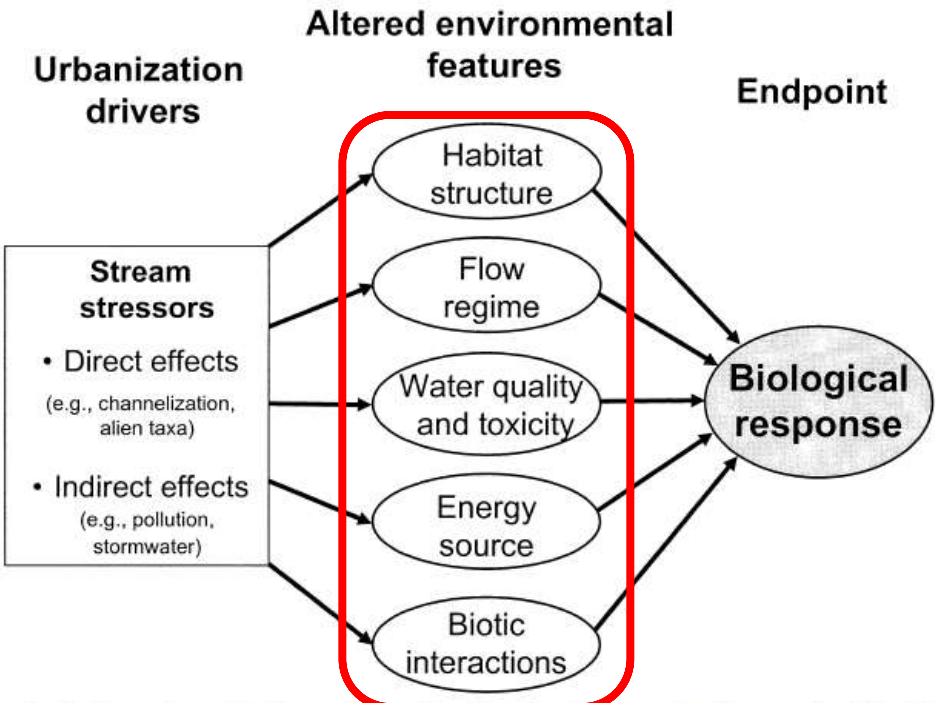


FIG. 1. Five environmental features that are affected by urban development and, in turn, affect biological conditions in urban streams (from Booth et al. 2004, reprinted with permission of the American Water Resources Association; modified from Karr 1991, Karr and Yoder 2004).

Stream Function Pyramid

(Adapted from Harmon et al., 2012)

Biological

Physicochemical

Geomorphology

Hydraulics

Hydrologic

Stormwater Management

Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream

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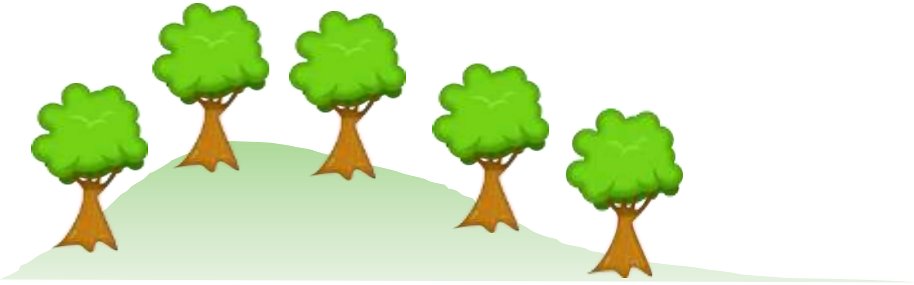
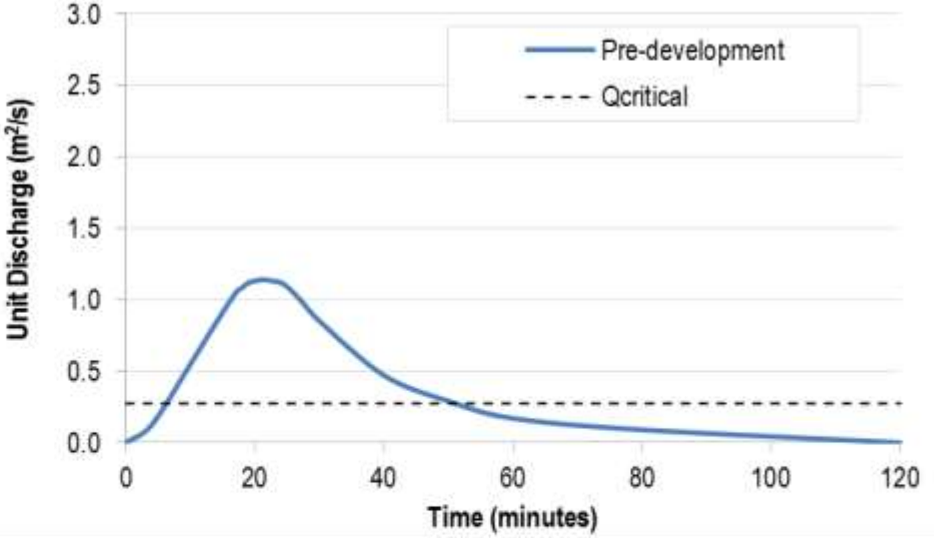
Cooperative Research Centre for Freshwater Ecology, Water Studies Centre, and School of Biological Sciences, Monash University, Victoria 3800, Australia

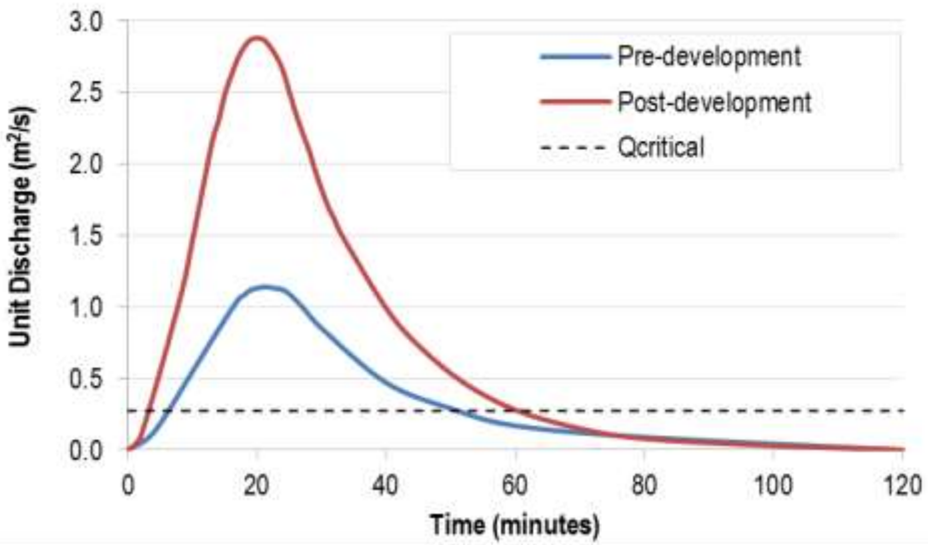
History of Stormwater Management





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

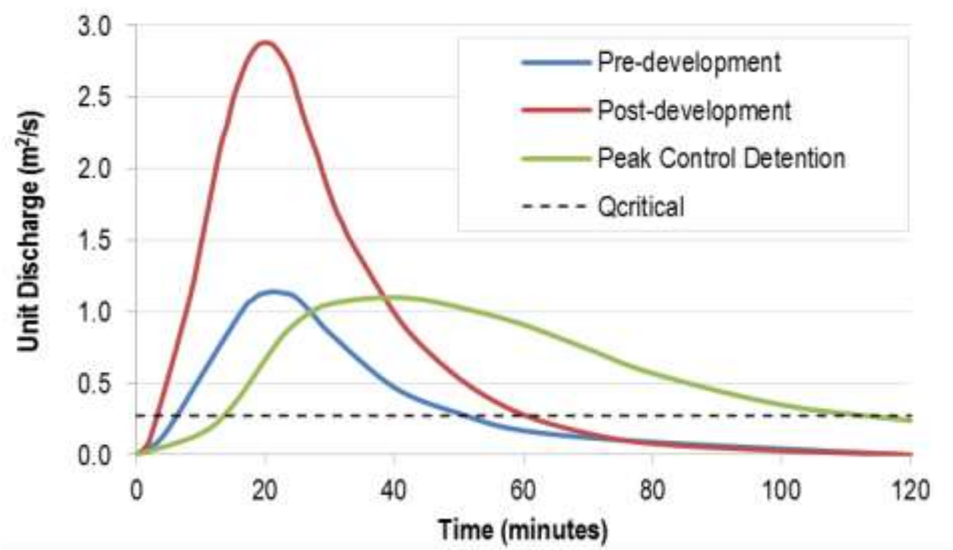
~Pre-1950



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

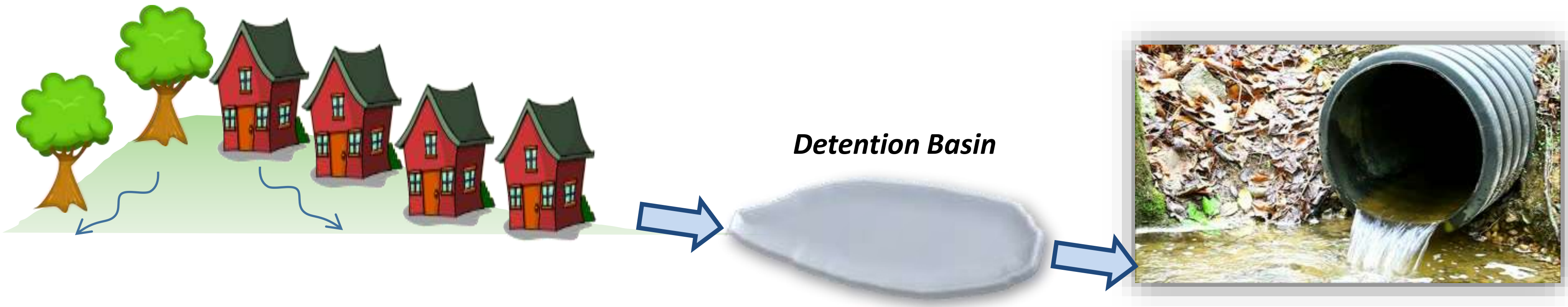
~1980-2000

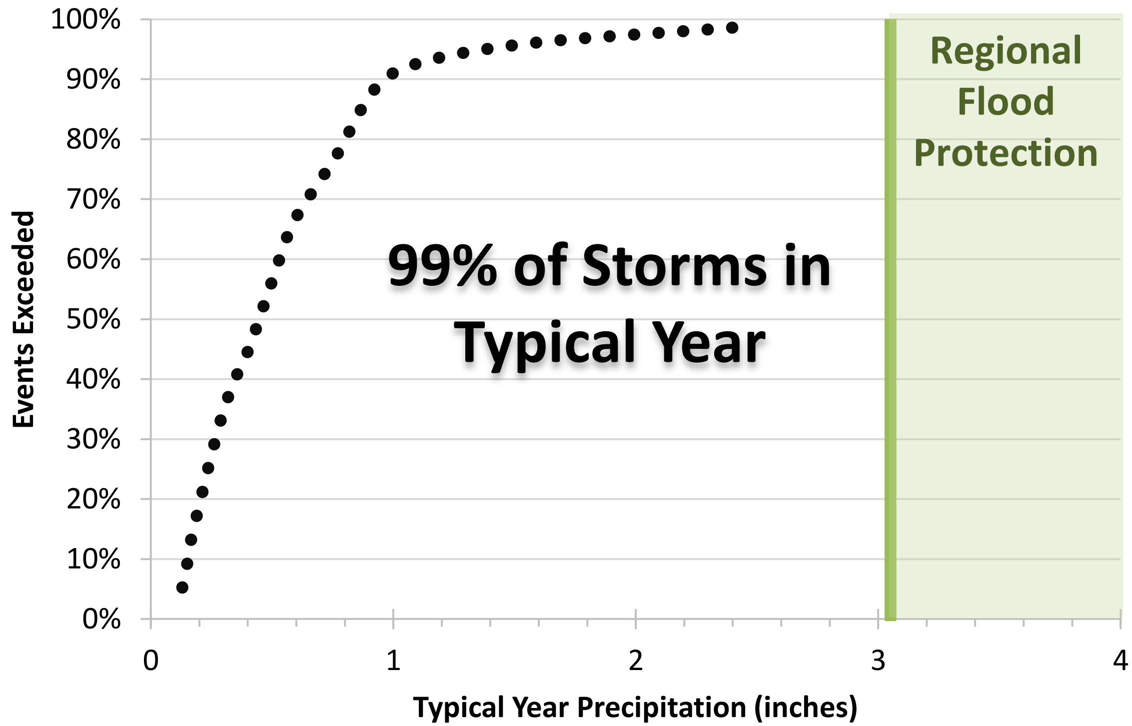
Detention Basin



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

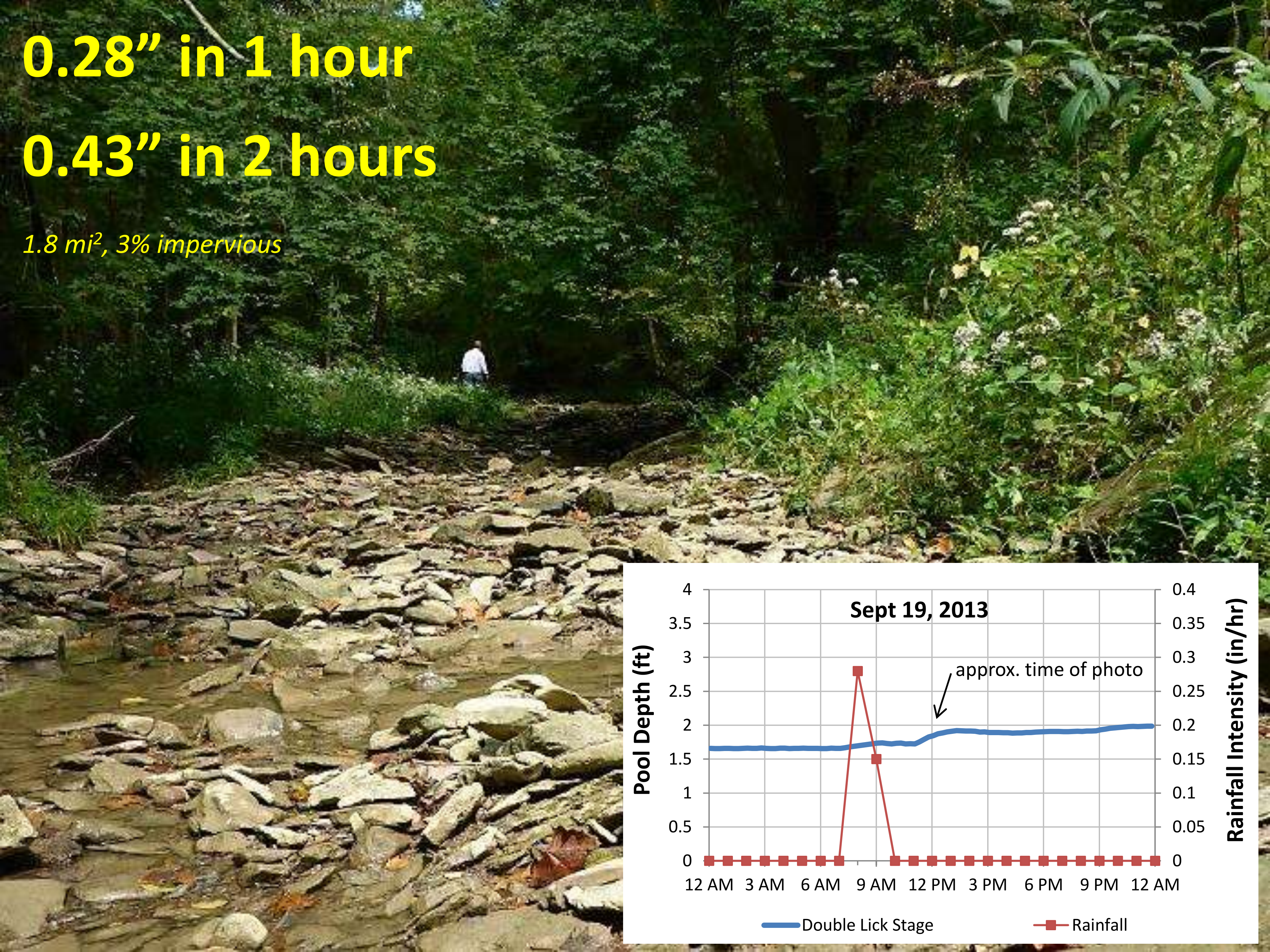
~1980-2000



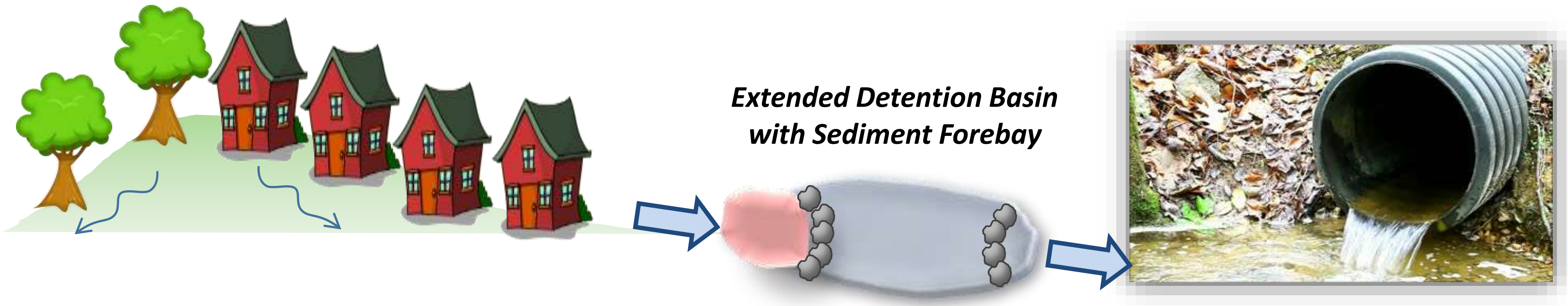


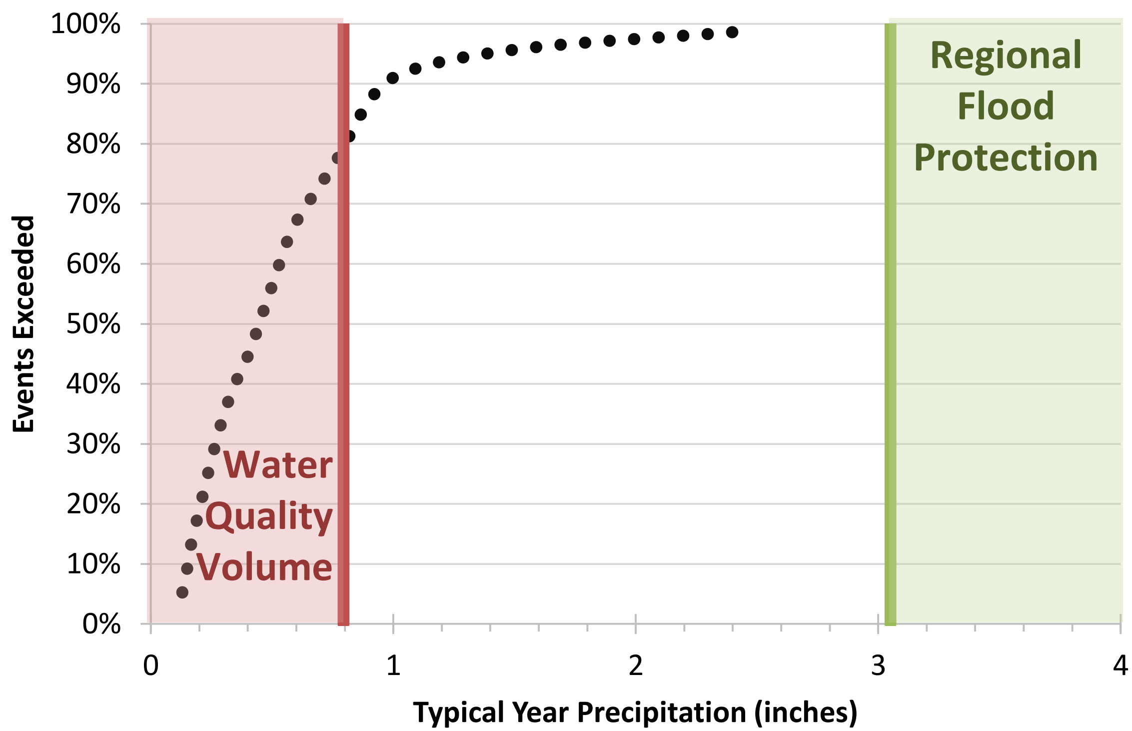
Adapted from Hawley (2012)


0.3” in 1 hour
2.2 mi^2, 29% impervious
06/10/2009 08:26


0.28" in 1 hour
0.43" in 2 hours
1.8 mi2, 3% impervious
Sept 19, 2013
approx. time of photo
Pool Depth (ft)
Rainfall Intensity (in/hr)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
12 AM
3 AM
6 AM
9 AM
12 PM
3 PM
6 PM
9 PM
12 AM
Double Lick Stage
Rainfall

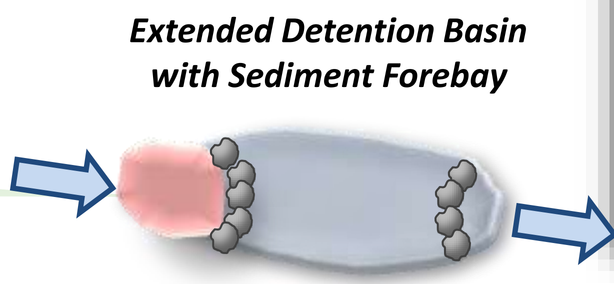
~2000-2015

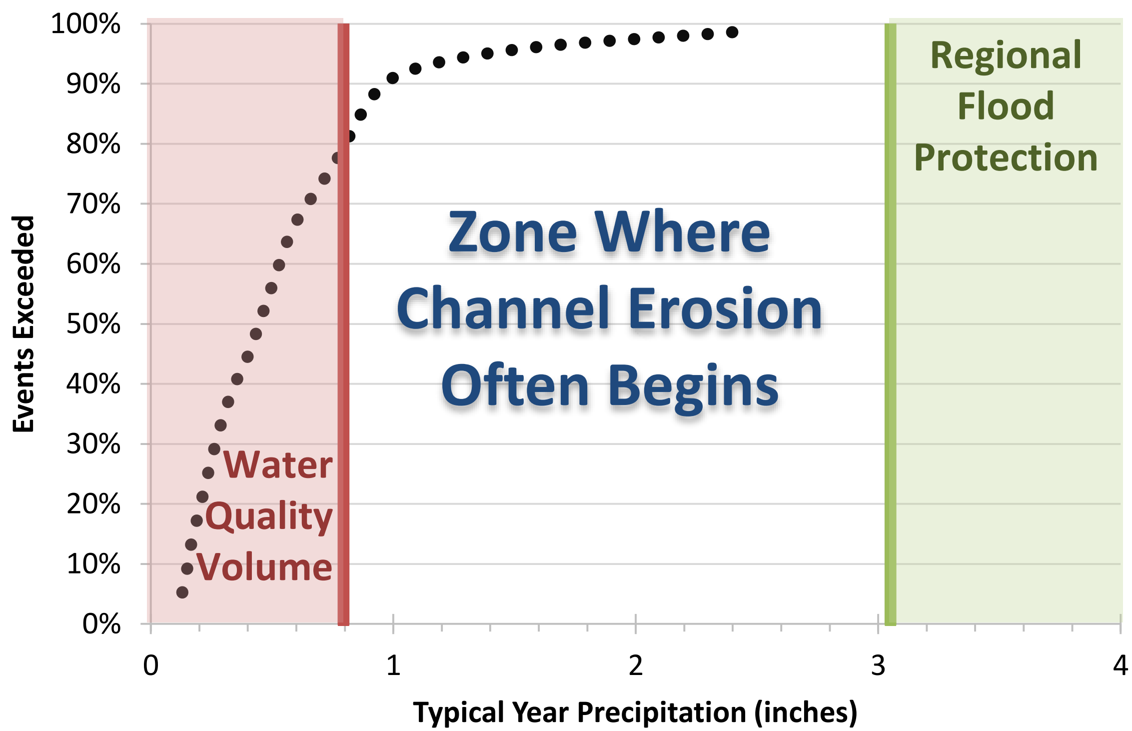




Adapted from Hawley (2012)

~2000-2015

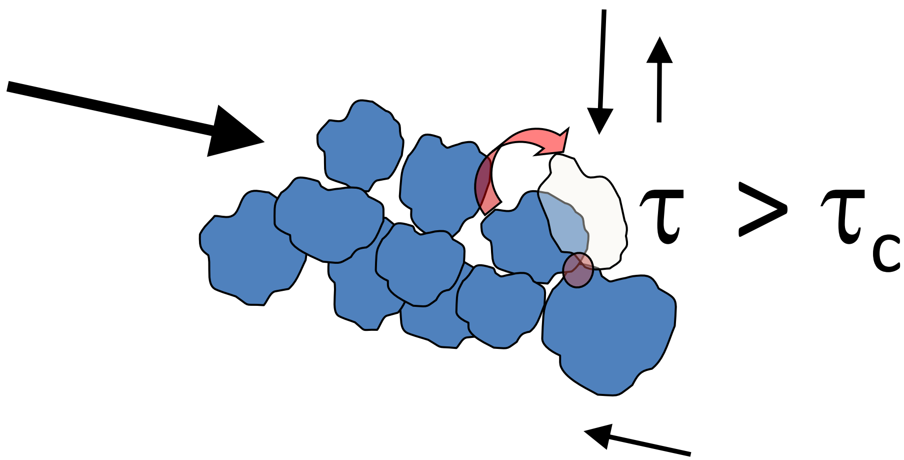




Adapted from Hawley (2012)

Introduction of $Q_{critical}$

The Critical Flow for Stream Bed Erosion



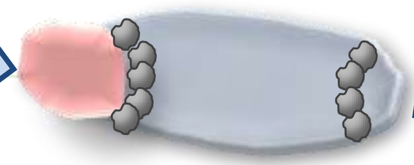
Bed Material Transport & Incipient Motion

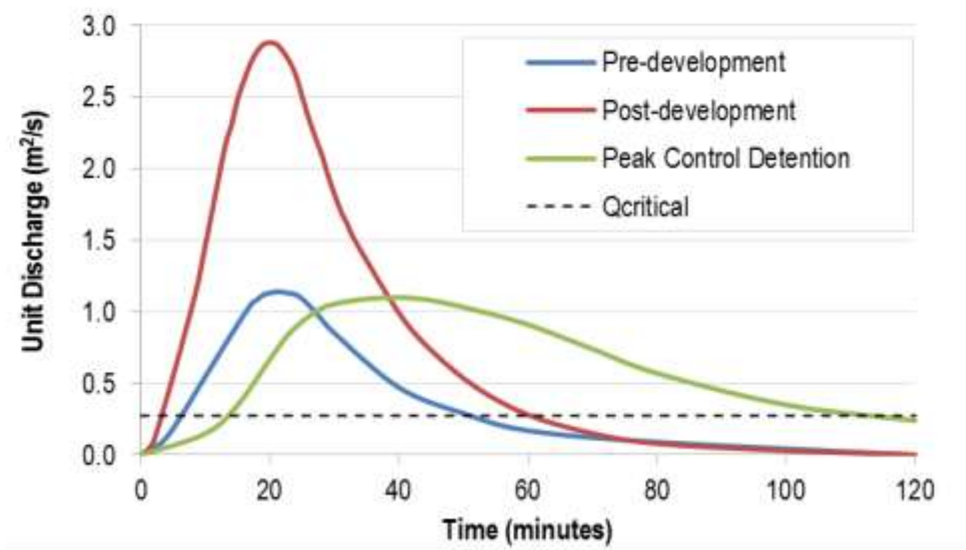
Video Courtesy of John Gaffney (2009) SAFL & NCED, U.Minn

http://www.youtube.com/watch?v=W9plc_diQQE

~2000-2015

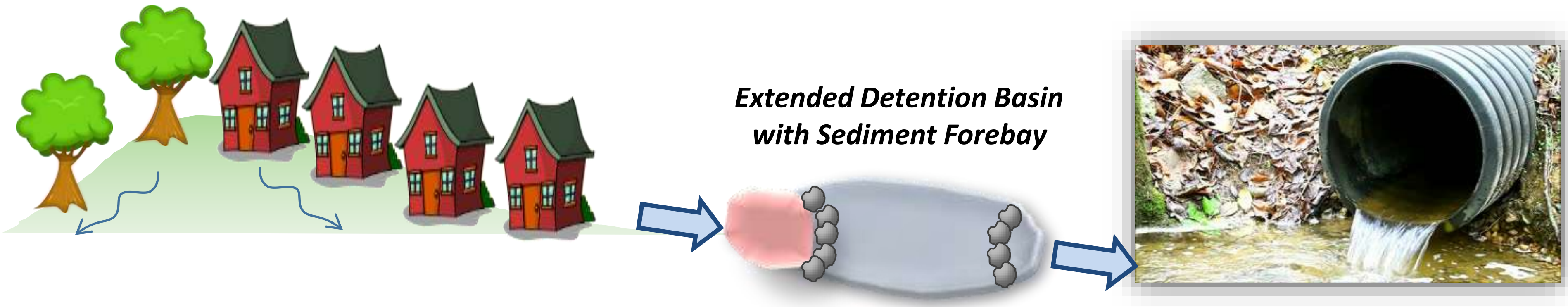
Extended Detention Basin with Sediment Forebay

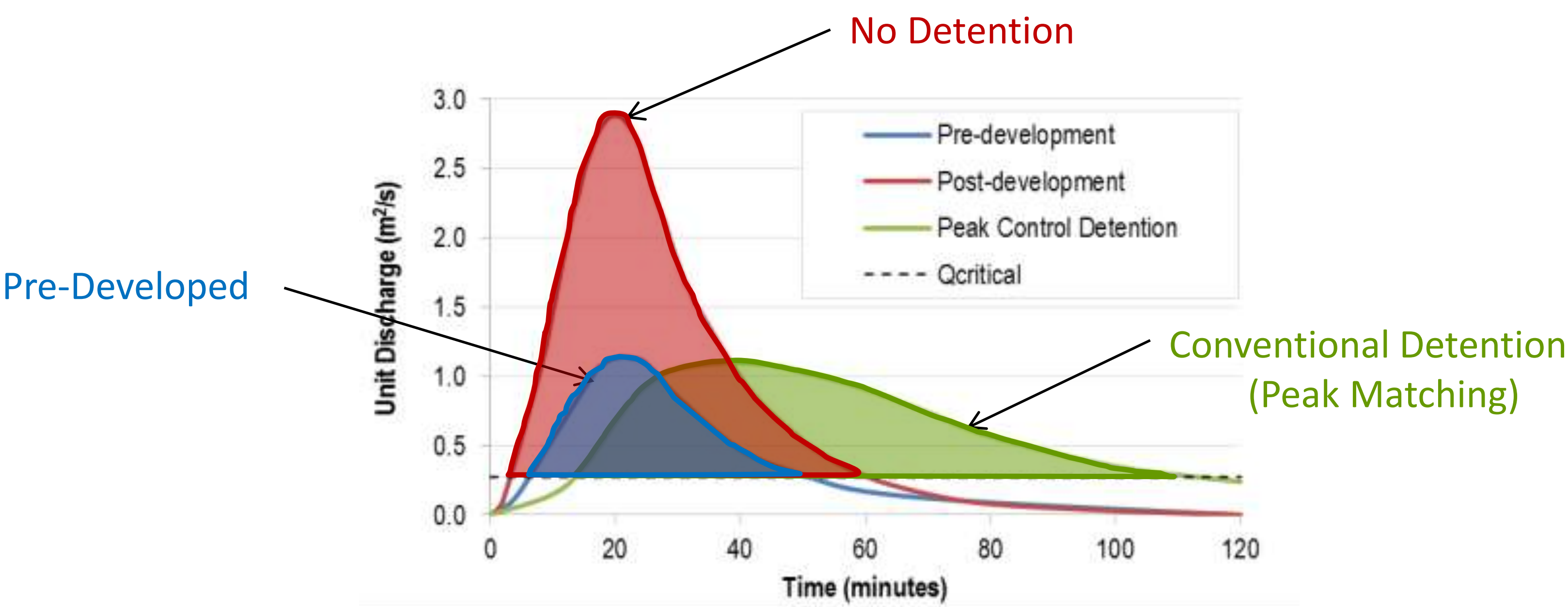




Analysis of the 2-yr, 2-hr storm from Fort Collins, CO by Bledsoe (2002), Journal of Water Resources Planning and Management

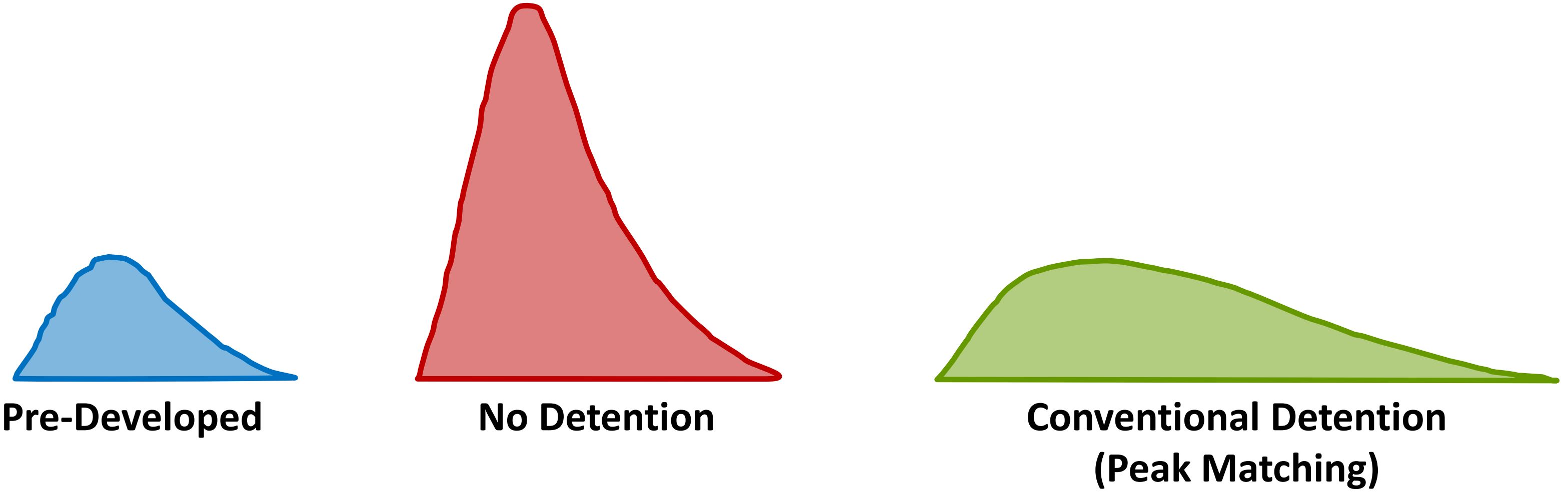
~2000-2015





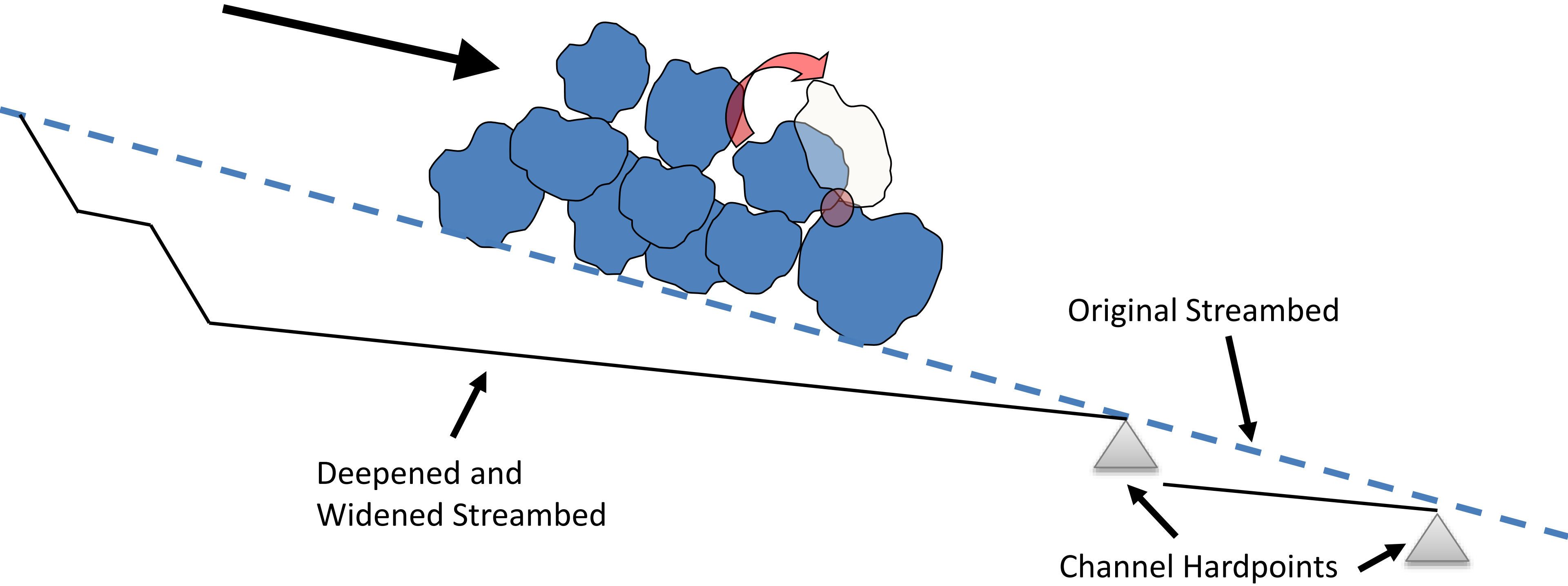
Analysis of the 2-yr, 2-hr storm from Fort Collins, CO by Bledsoe (2002),
Journal of Water Resources Planning and Management

Conventional Detention = ***More Erosion*** than Pre-Developed Conditions

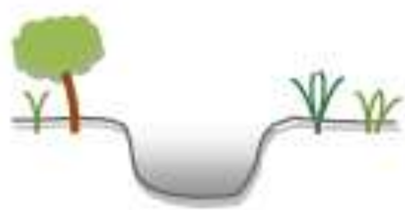


Excess Erosion of Streambed Can Lead to:

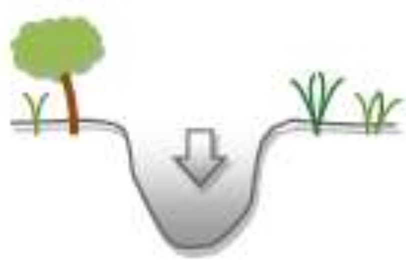
- **Stream Deepening & Widening**
- **Property & Tree Loss**
- **Water Quality Impacts**



Increased Bed Erosion → Incision (Downcutting)

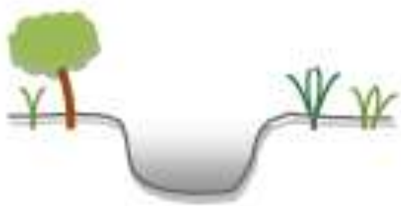


Stage1 – Equilibrium

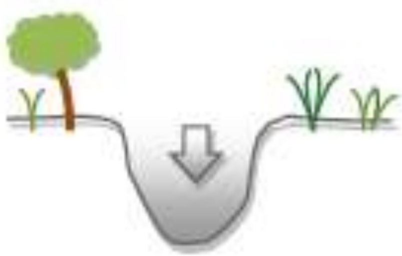


Stage 2– Incision

Incision → Taller Banks → Bank Failure



Stage1 – Equilibrium

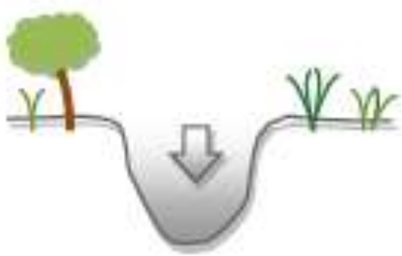


Stage 2– Incision

Stage 3 – Widening

Bank Failure → Widening

Stage1 – Equilibrium

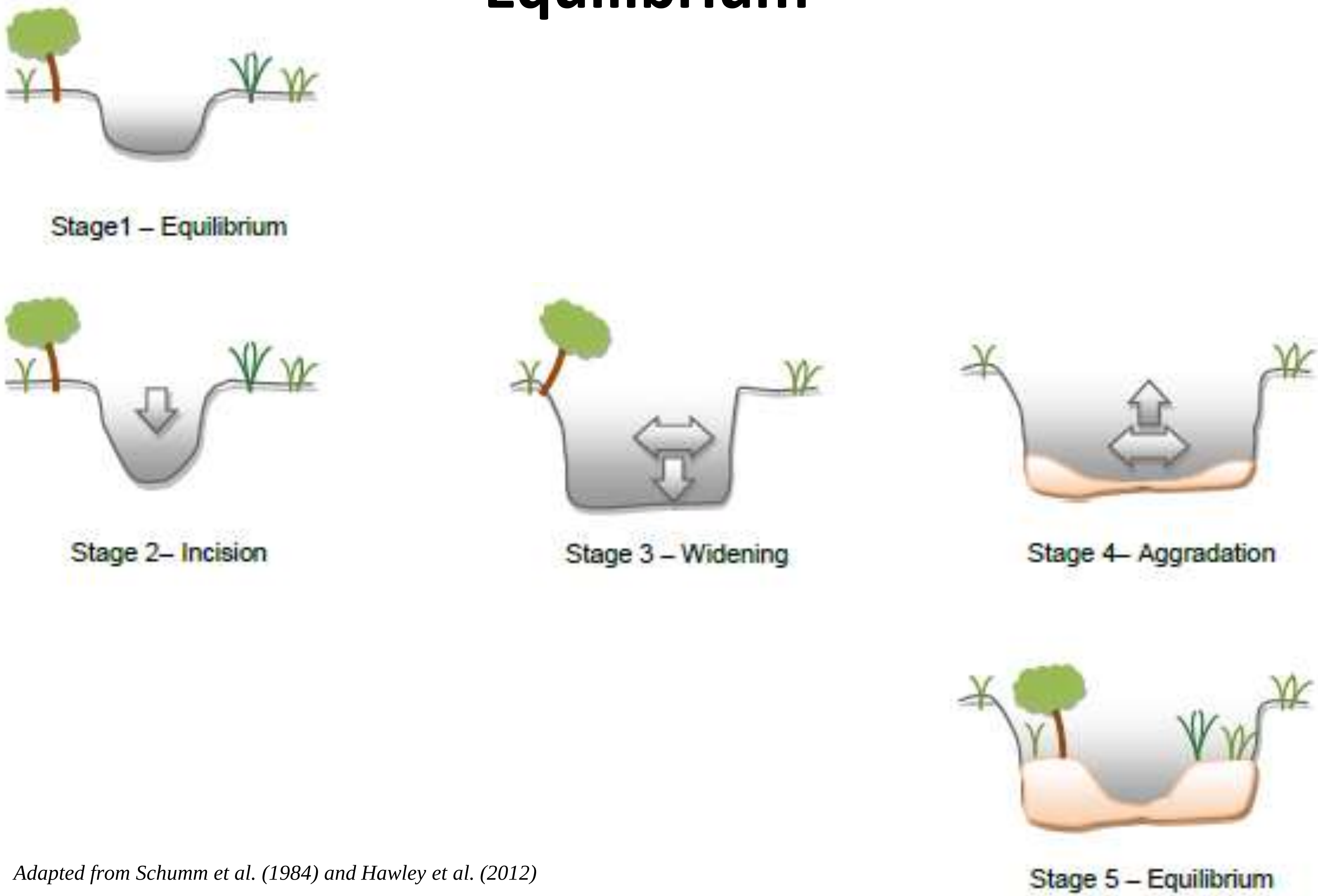


Stage 2– Incision

Stage 3 – Widening

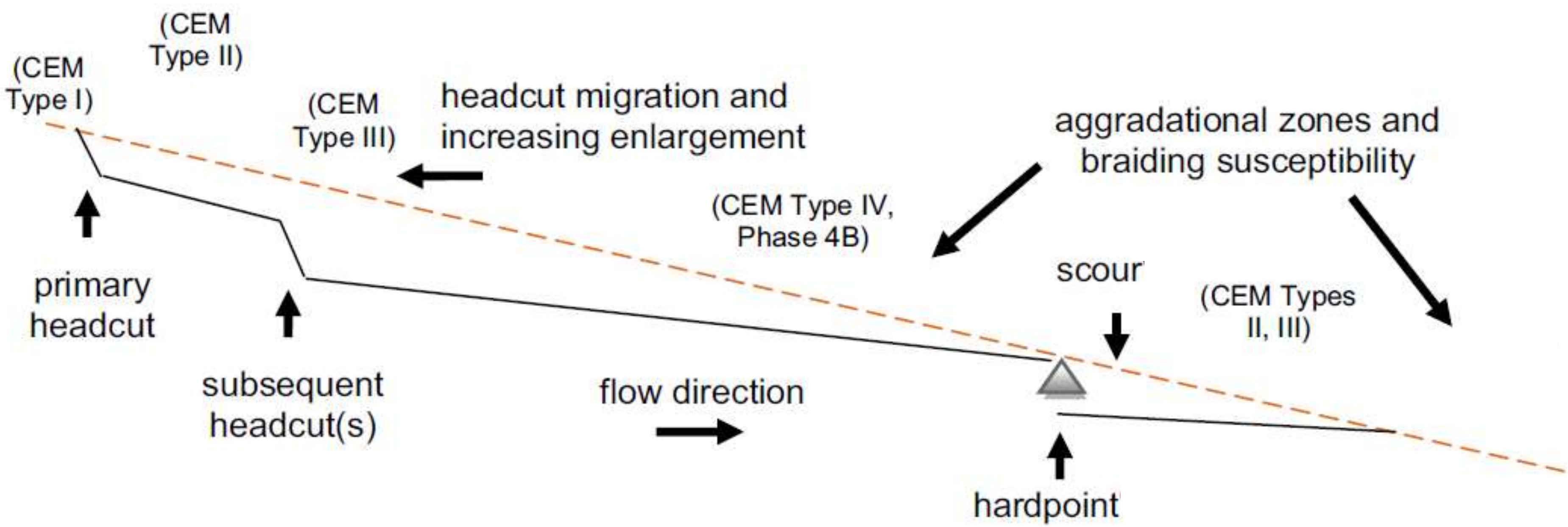
Stage 4– Aggradation

→Large Amounts of Erosion Before Returning to Equilibrium



Adapted from Schumm et al. (1984) and Hawley et al. (2012)

Erosion Can Migrate Up and Downstream and Last for Decades or Longer



(natural bedrock or artificial grade control)

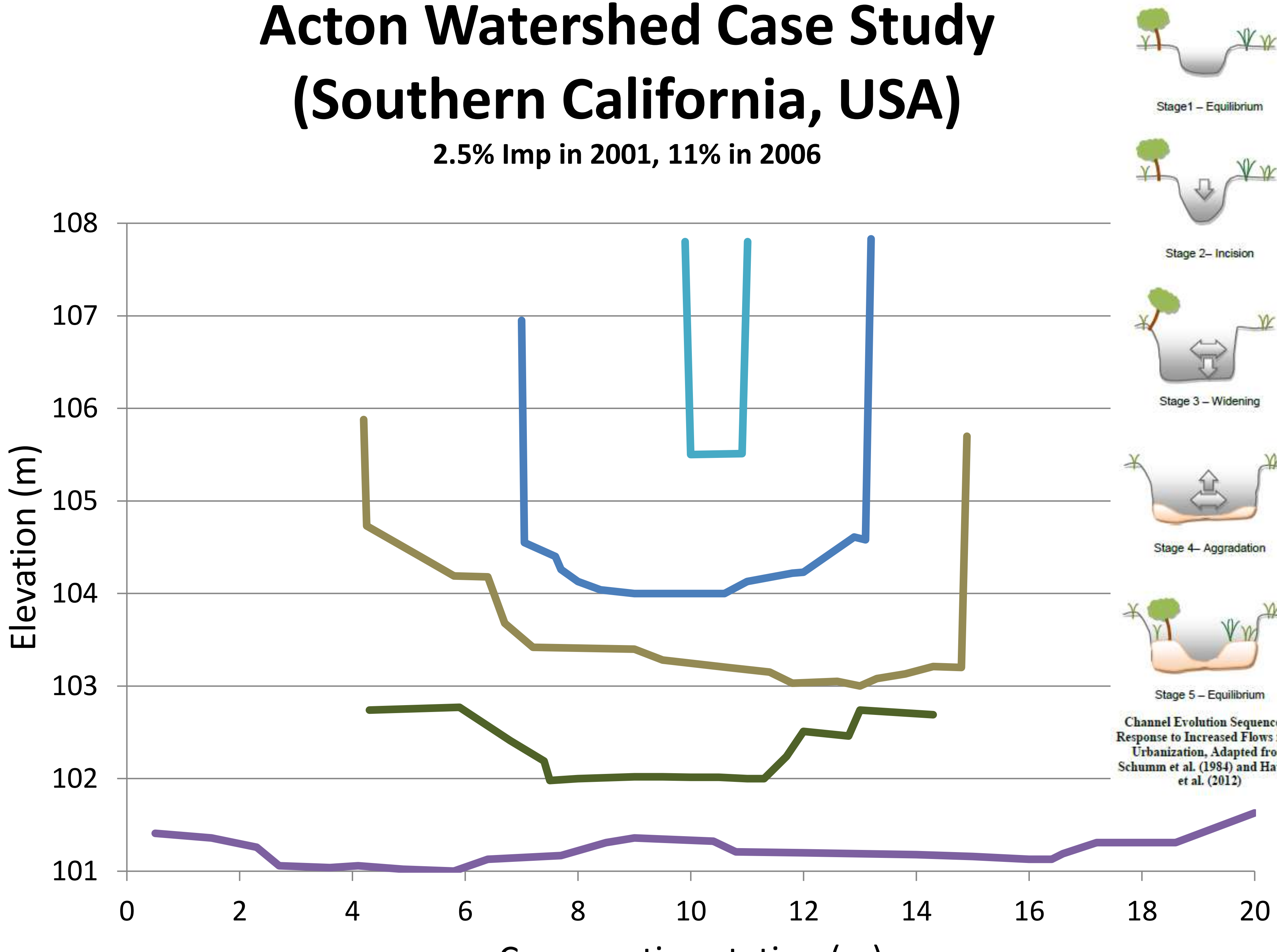
Adapted from Hawley et al. (2012)

Acton Watershed Case Study
(Southern California, USA)

2.5% Imp in 2001, 11% in 2006

Acton Watershed Case Study (Southern California, USA)

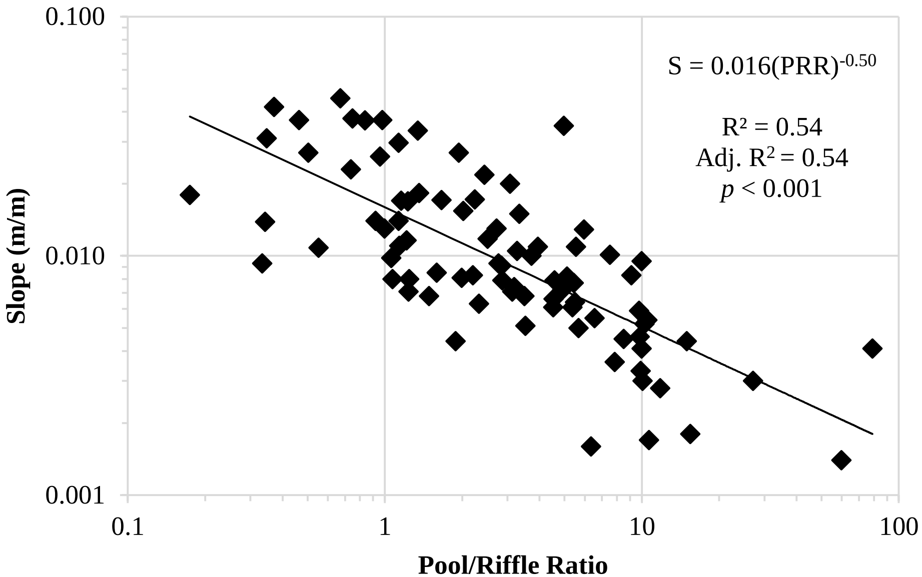
2.5% Imp in 2001, 11% in 2006



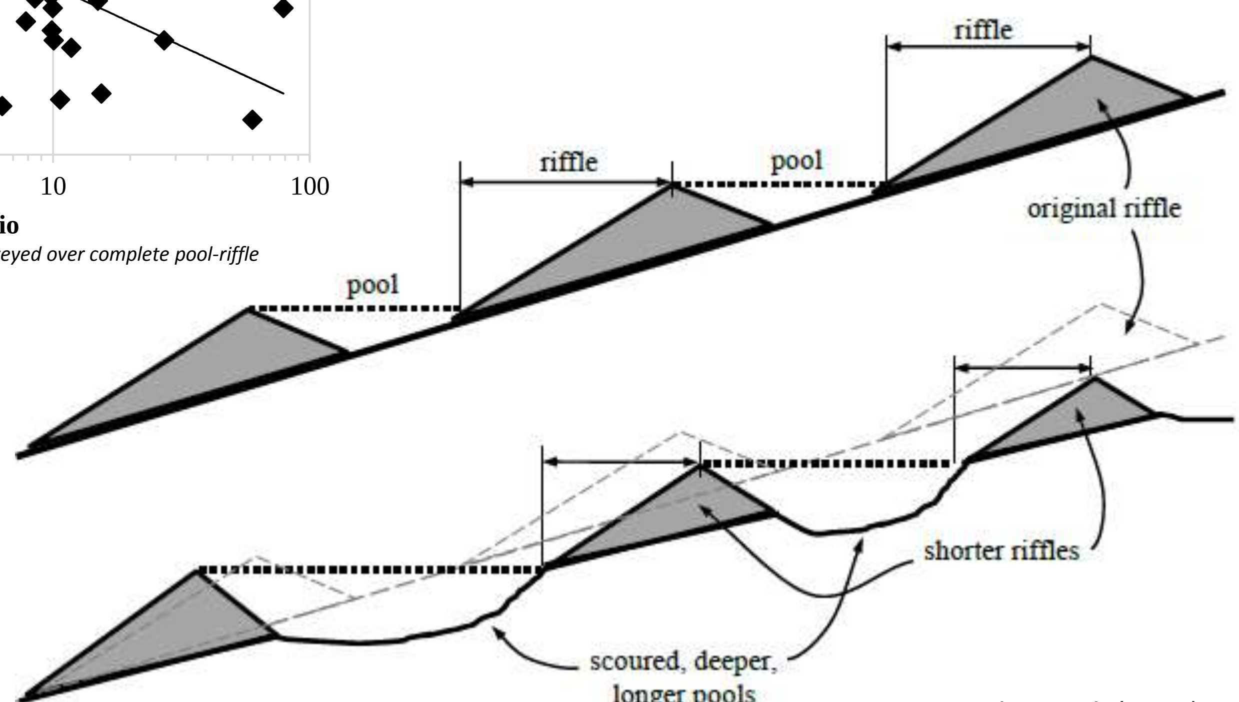
Channel Evolution Sequence in Response to Increased Flows from Urbanization, Adapted from Schumm et al. (1984) and Hawley et al. (2012)

Adapted from Hawley and Bledsoe (2013)

Headcutting → Flatter Slopes → Shorter Riffles & Longer Pools



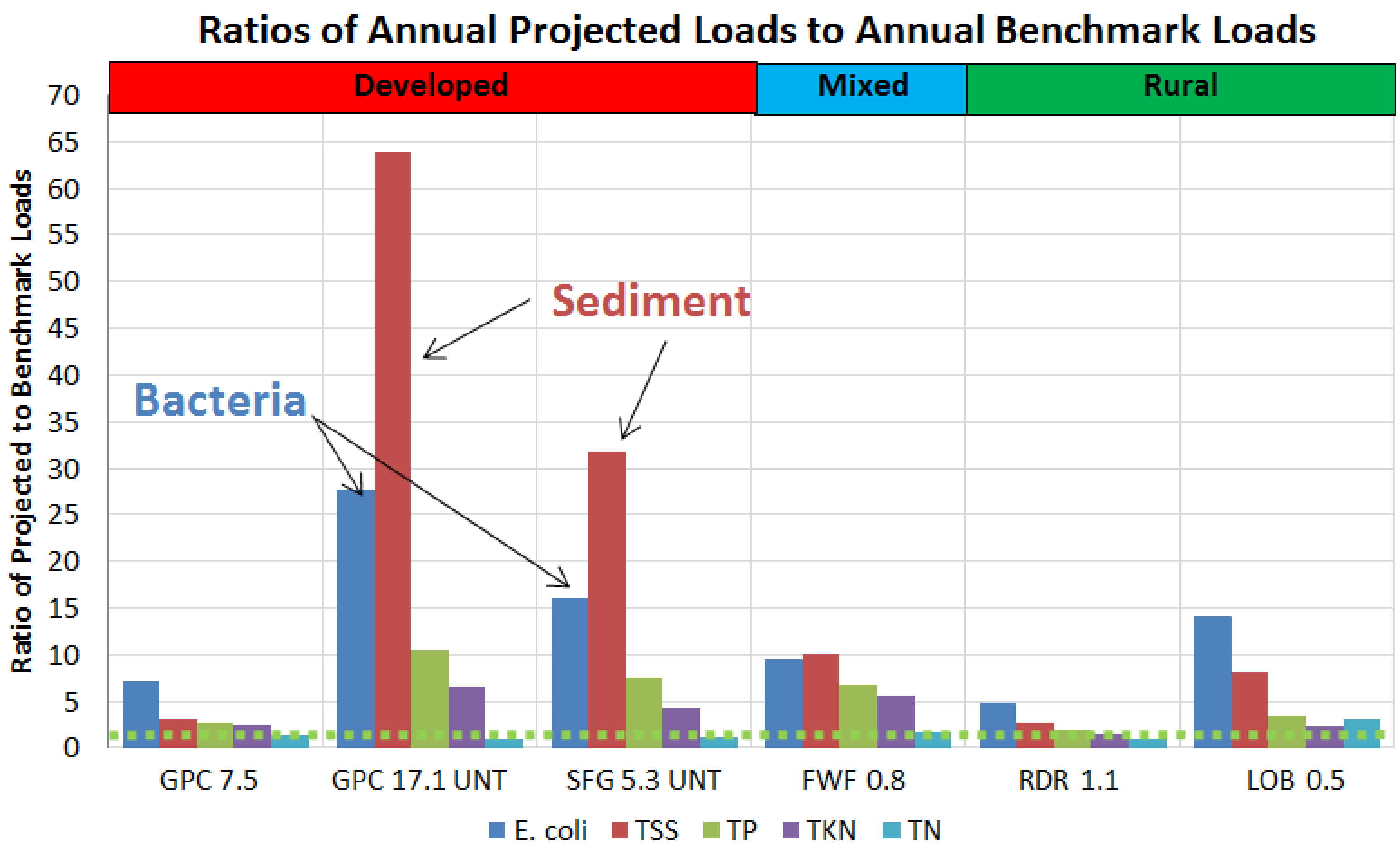
n = 86. Figure and trend includes all profile data surveyed over complete pool-riffle reaches.



Hawley et al. (2013)

Bank Instability → Fine Sediment Loads
Sediment Is a Leading Impairment of U.S. Waterways

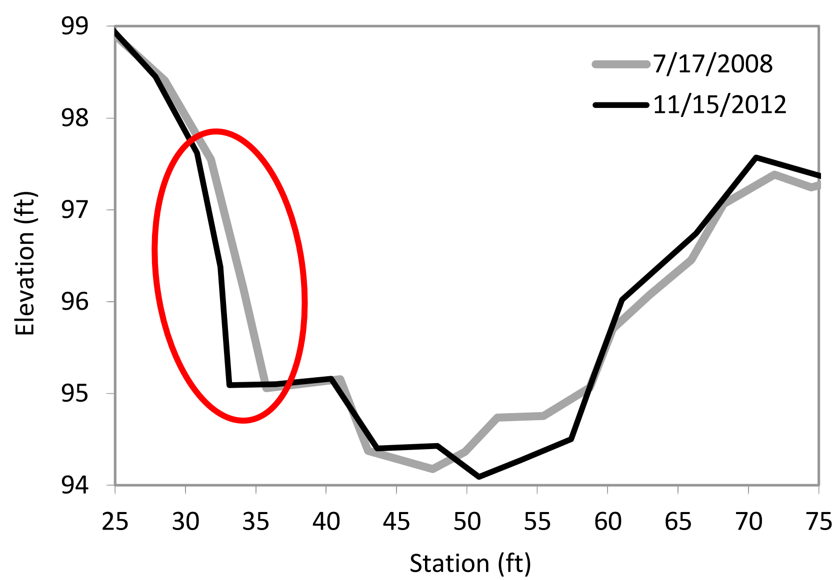
Gunpowder Creek Watershed Case Study (Northern Kentucky, USA)



SFG 5.3 - DS

28% impervious

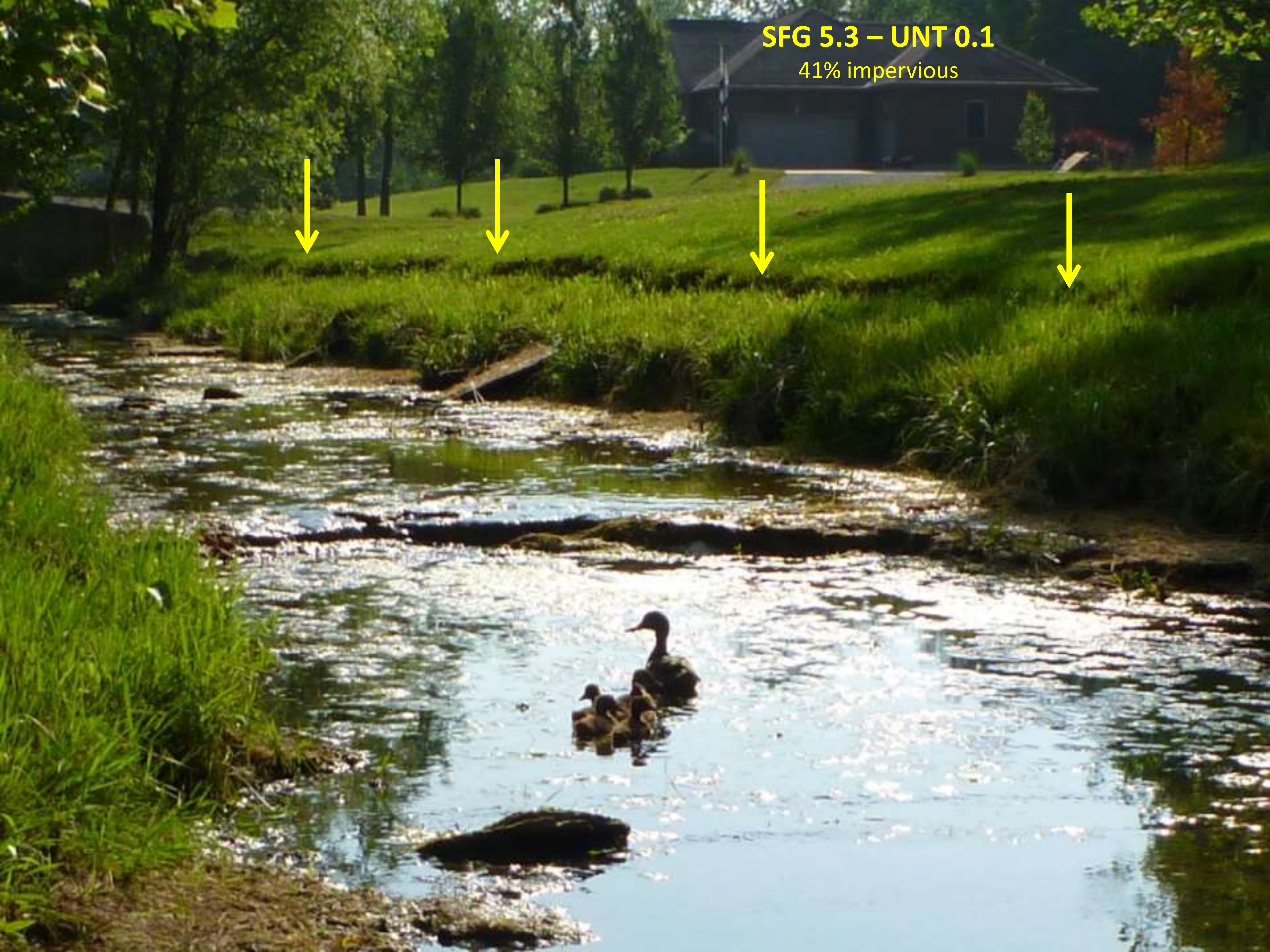
Bank Erosion and Tree Loss



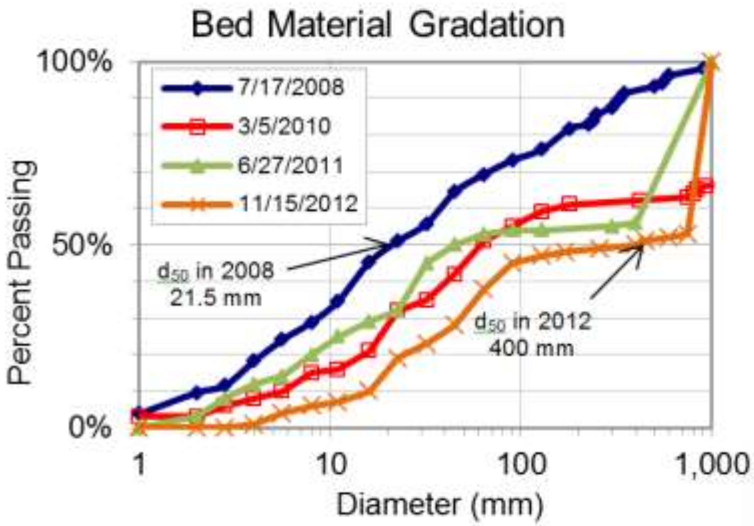
Monitoring Confirms Bank Erosion as a Dominant Source of TSS

Site Name	Projected TSS Yield Due to Bank Erosion (lb/mi^{2}yr)	Projected TSS Yield From Water Column Samples (lb/mi^{2}yr)	Percent of Projected Load from Bank Erosion
FWF 0.8	76,669	287,089	27%
GPC 7.5	420,123	106,375	395%
LOB 0.5	97,225	192,618	50%
RDR 1.1	148,349	73,749	201%
GPC 17.1 UNT[a]	0	2,203,207	0%
SFG 5.3 UNT	1,770,761	704,334	251%

[a]Bank erosion can be observed at locations throughout the un-named tributary (UNT); however, a log jam at the monitoring site induced sediment deposition and a corresponding bank erosion load of 0. By contrast, the measured bank erosion loads at all other monitoring sites is significant, and in some cases explains more than 100% of the corresponding TSS yields, which supports the treatment of the log jam at GPC 17.1UNT as an outlier.


SFG 5.3 – UNT 0.1
41% impervious

Bed Coarsening and Habitat Homogenization



SFG 5.3 – DS
29% impervious

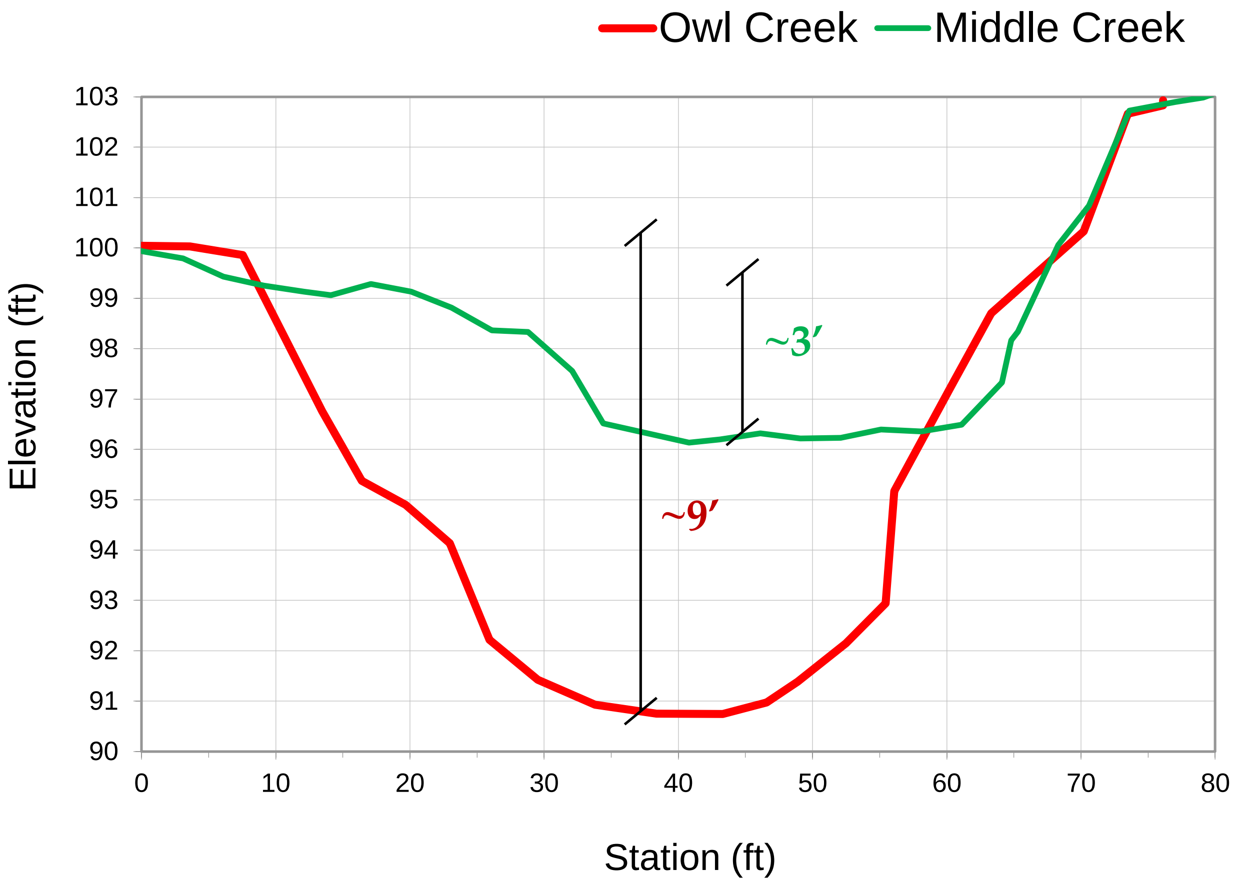
More homogenous habitat

Conventional Storm Water Designs → Unstable Streams

Middle Creek (3.3 mi^2)
0.6% Impervious

Owl Creek (3.7 mi^2)
9% Impervious

Conventional Storm Water Designs → Unstable Streams

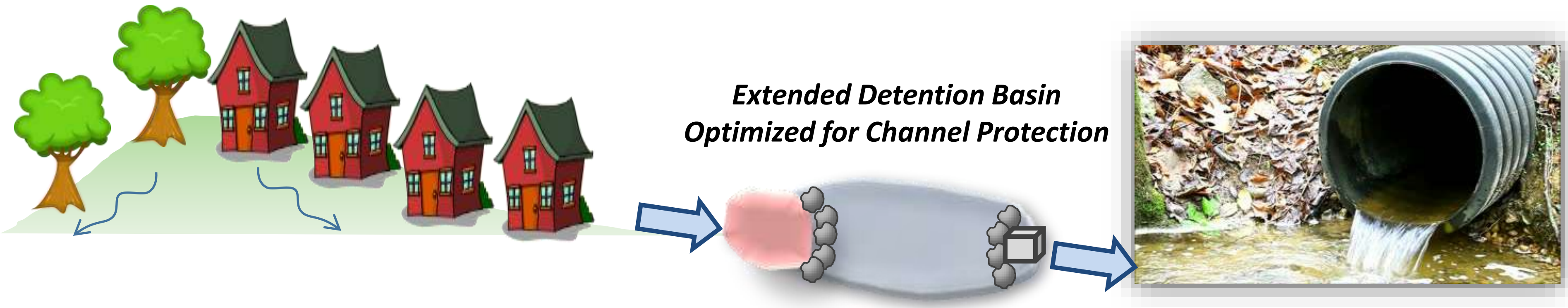


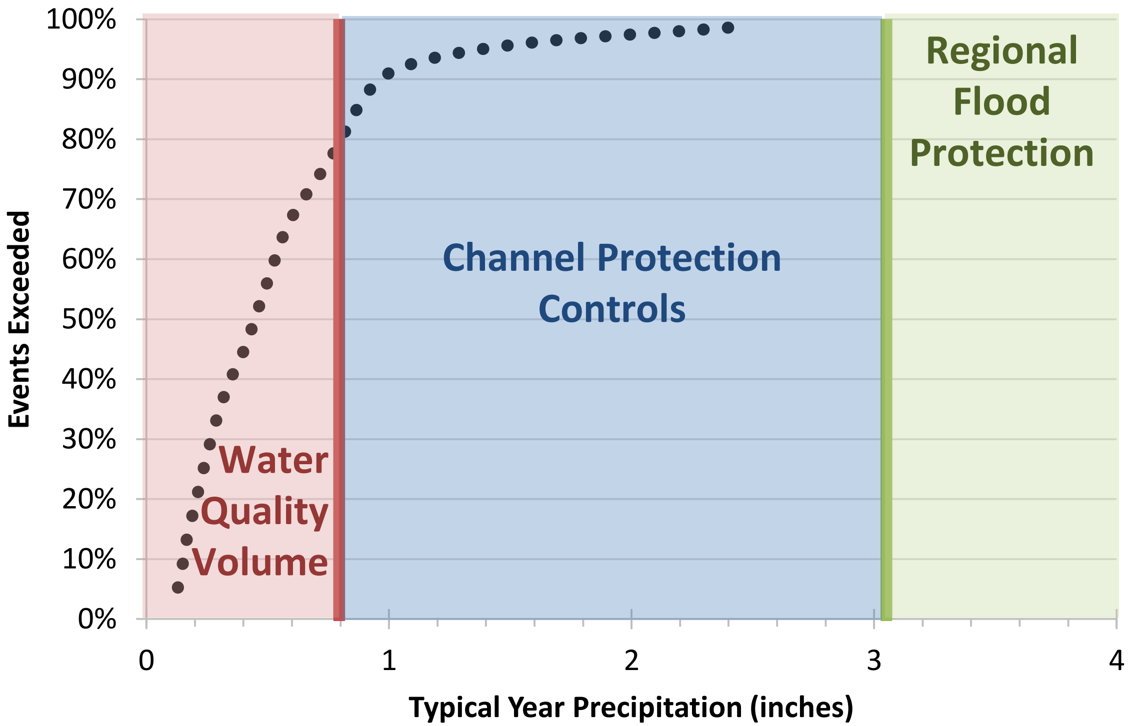
Unstable Streams
Impact Resources and Waste $$$

- Aquatic habitat
- Water quality
- Private property
- Infrastructure

Impacts to Public Infrastructure

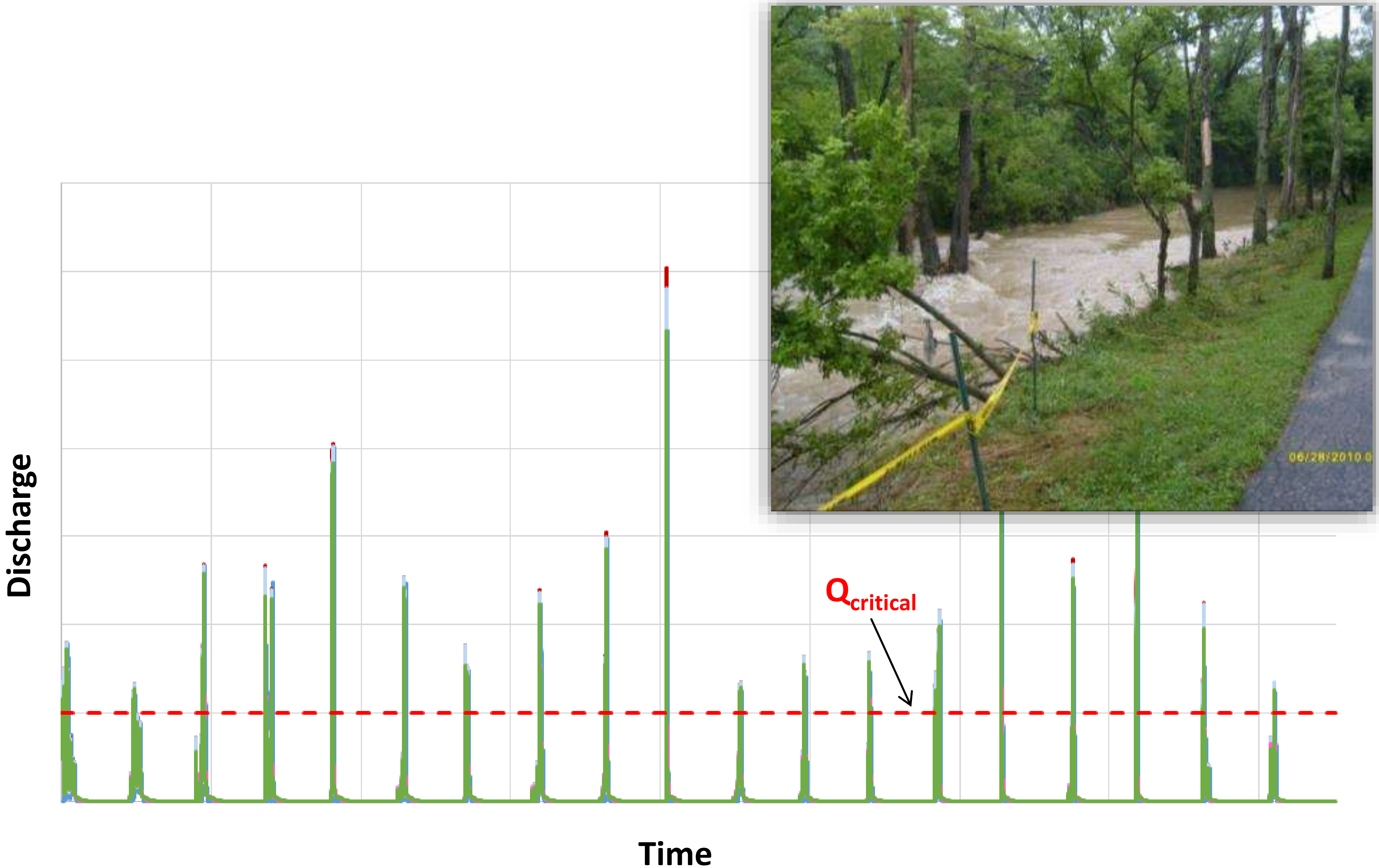
Future of Stormwater Management



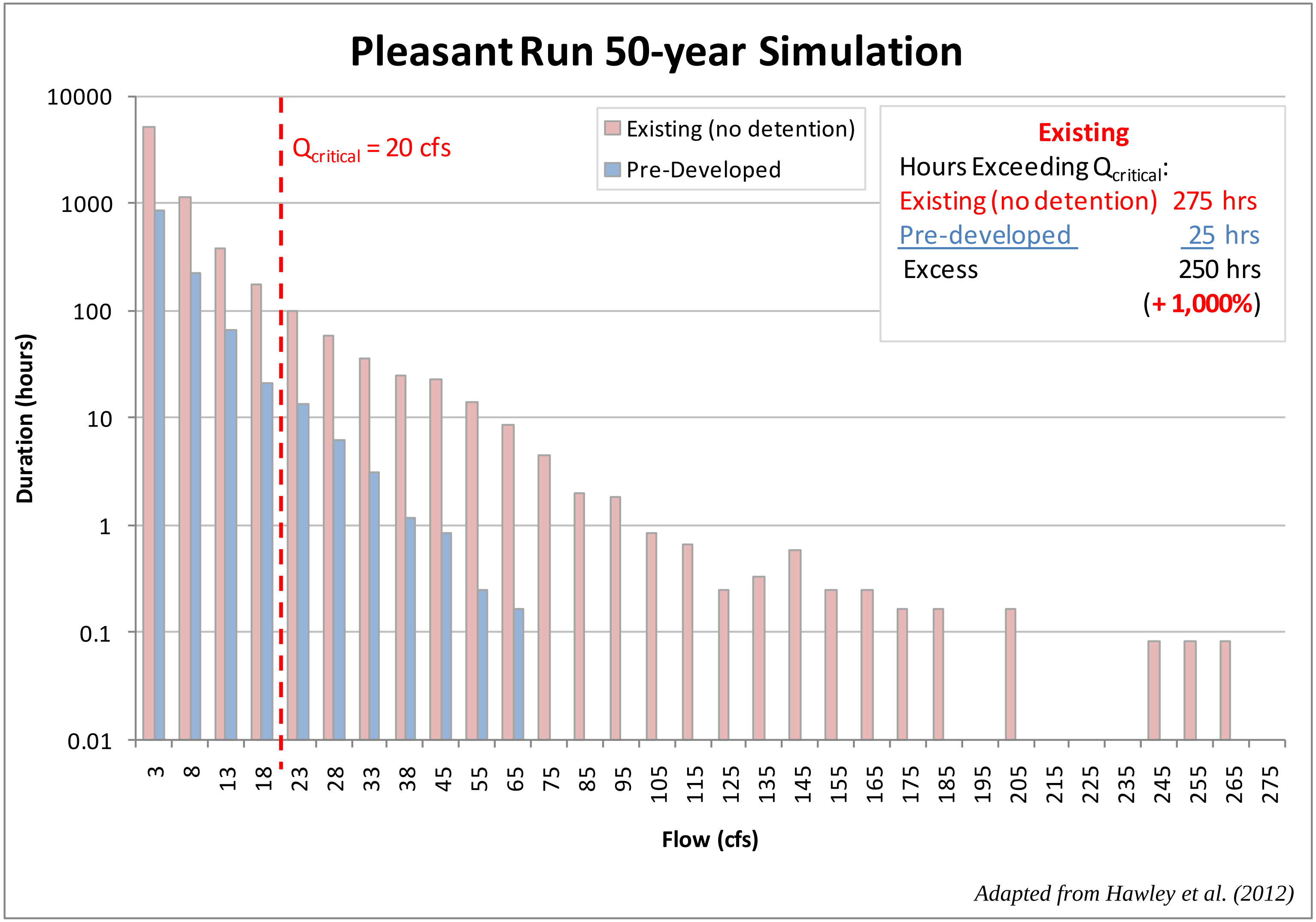


Adapted from Hawley (2012)

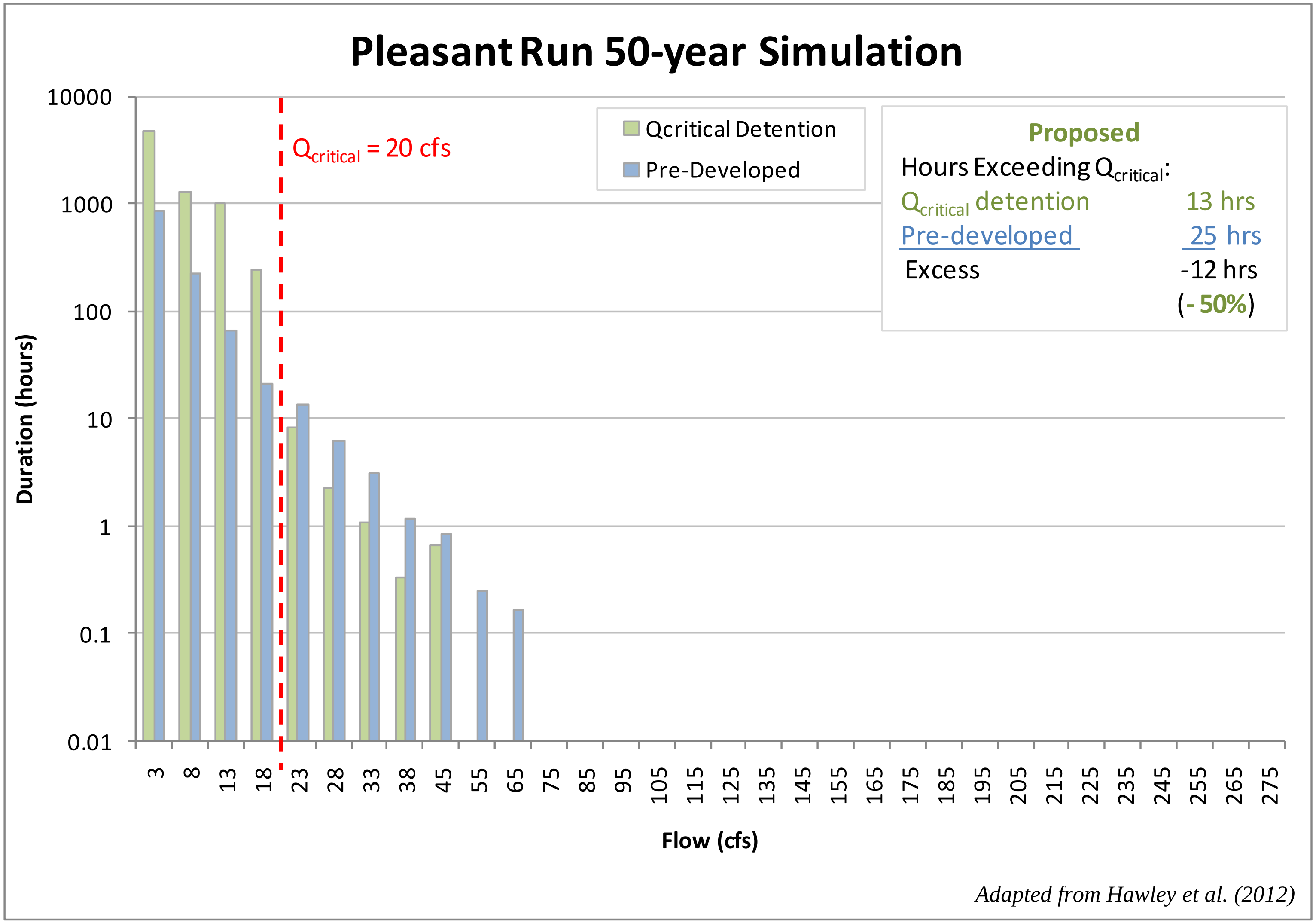
Consider All Storms > $Q_{critical}$



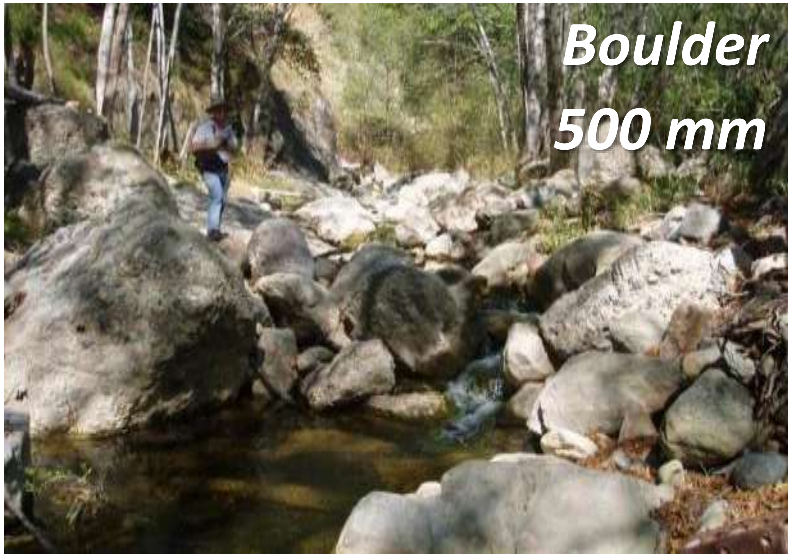
$Q_{critical}$ Design Target = "Safe Release Rate"

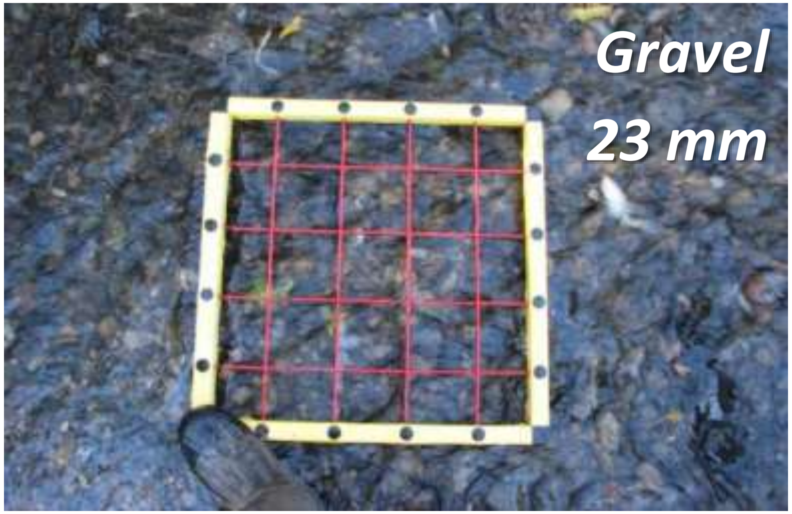


If Excess Volume Is Released Below $Q_{critical}$ →No Excess Erosion or Biological Disturbance

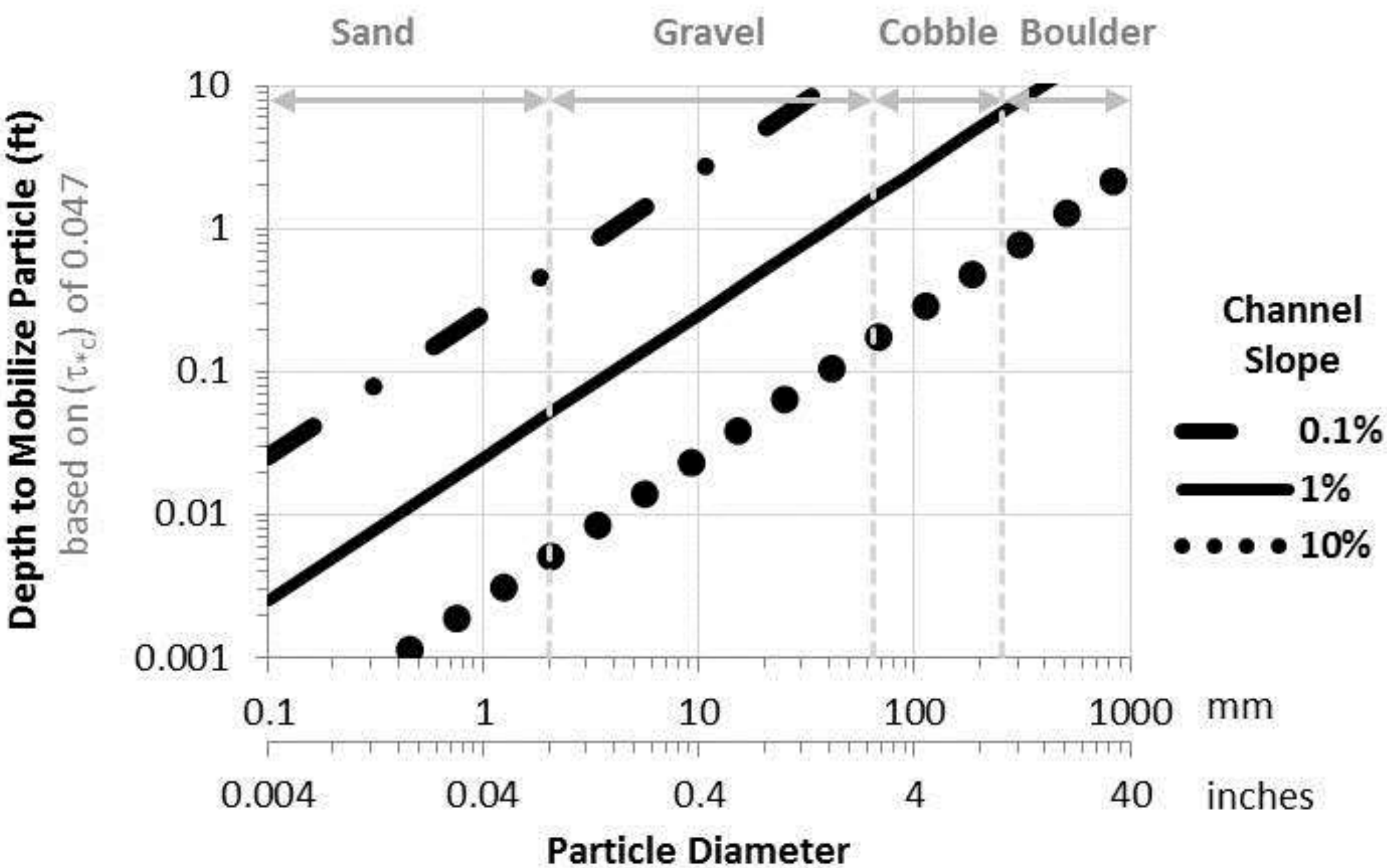


$Q_{critical}$ Varies by Stream Resistance



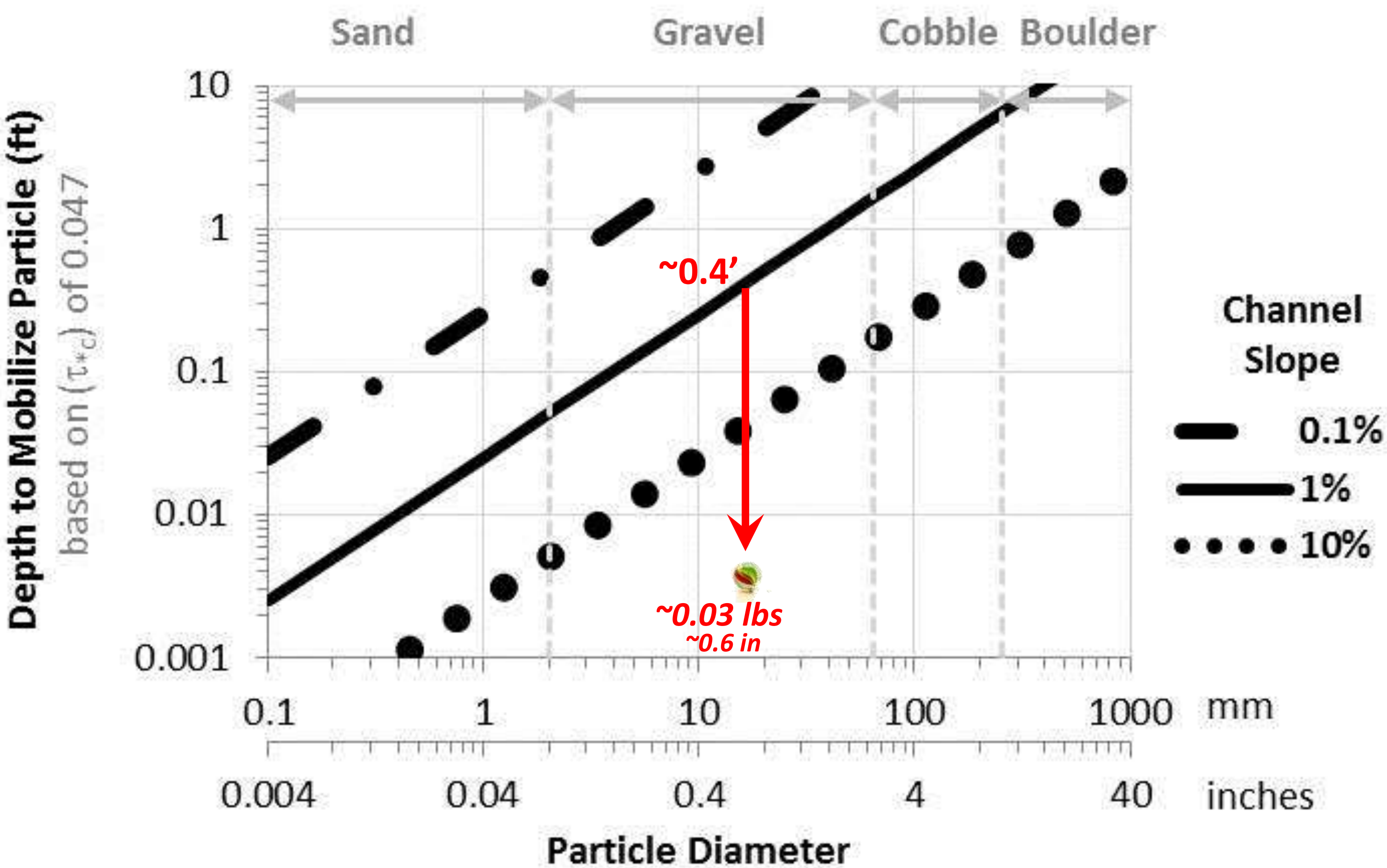


Resistance Increases with Particle Size and Decreases with Slope



Adapted from Hawley and Vietz (2016, Freshwater Science)

Resistance Increases with Particle Size and Decreases with Slope



Adapted from Hawley and Vietz (2016, Freshwater Science)

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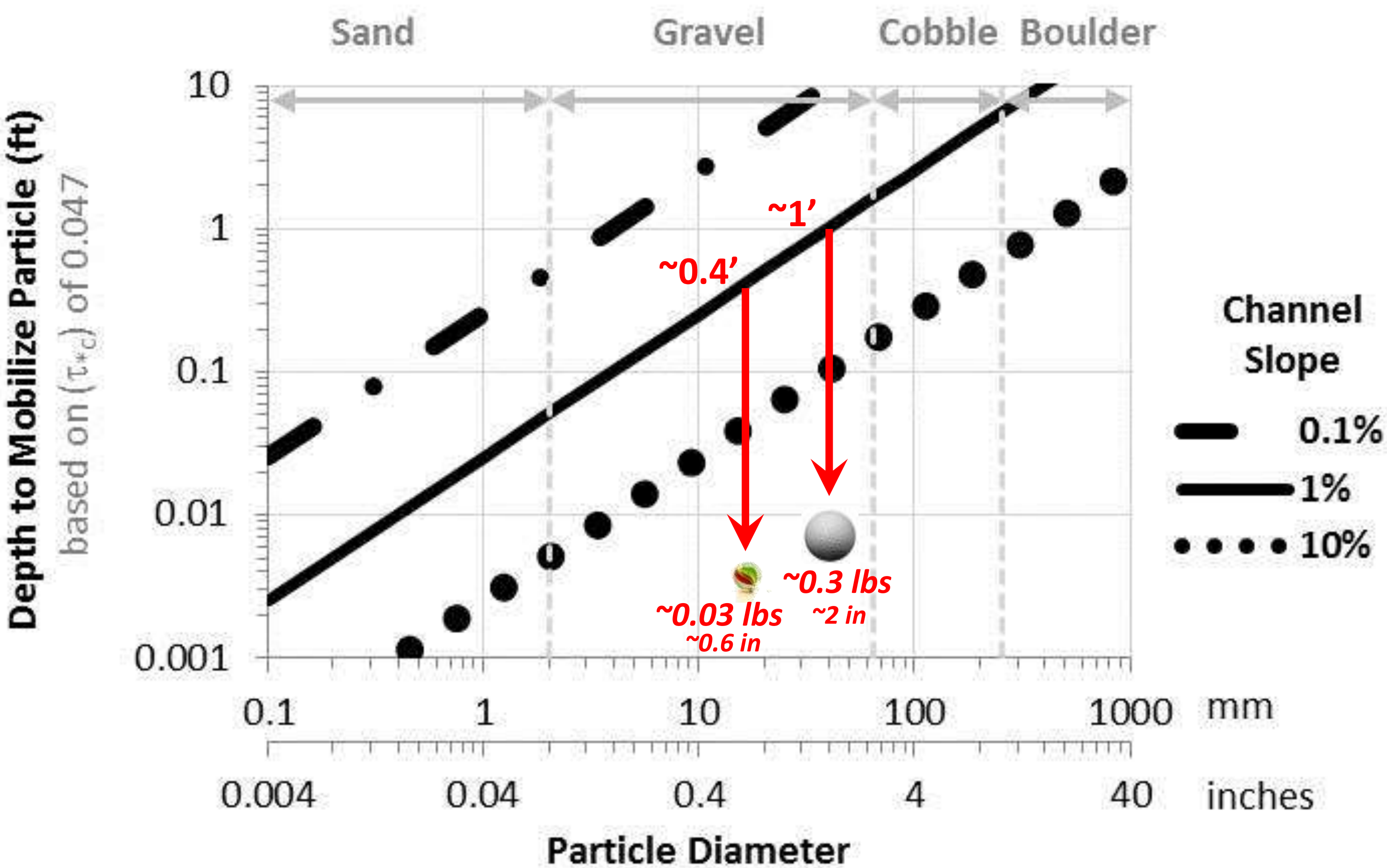

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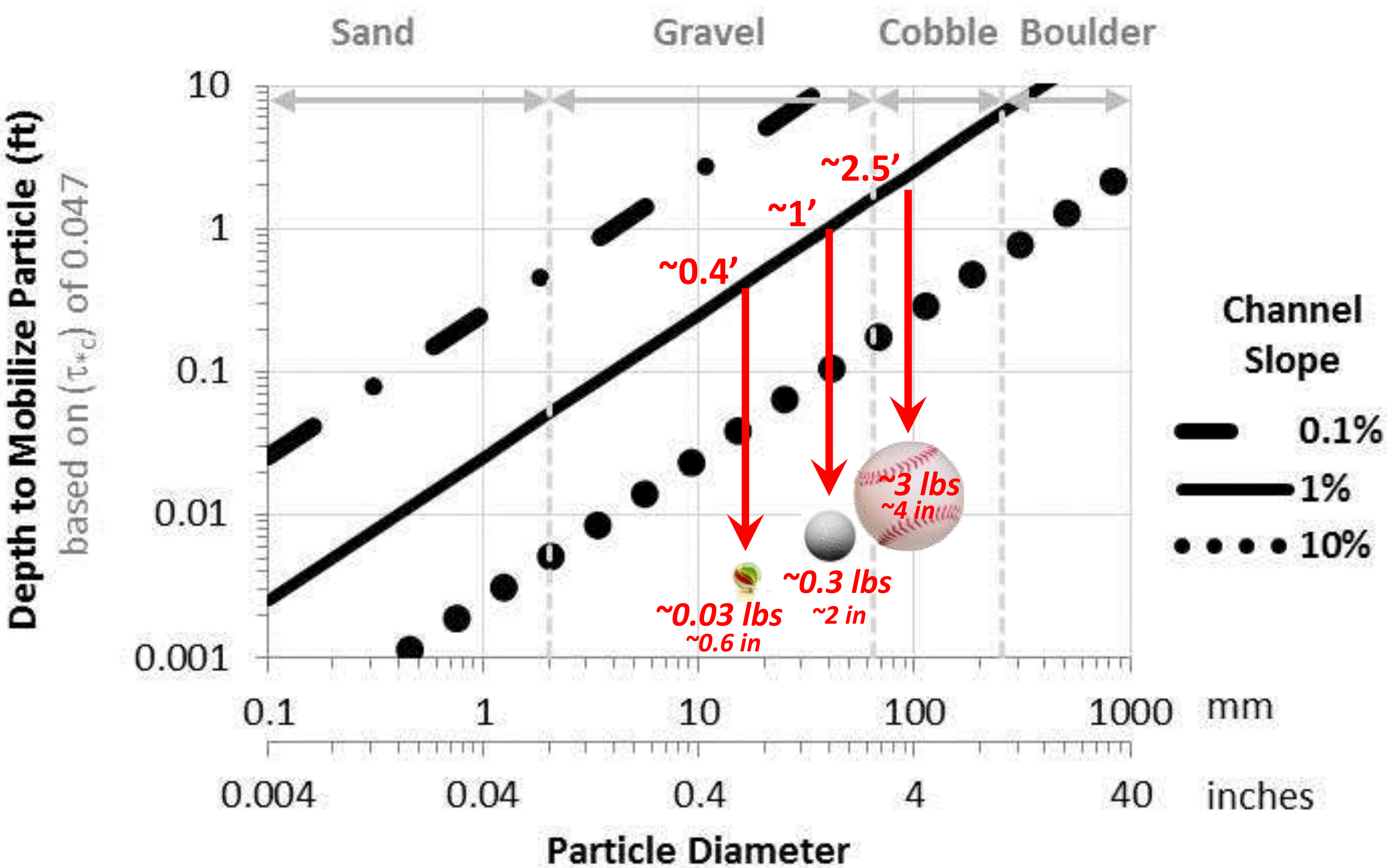

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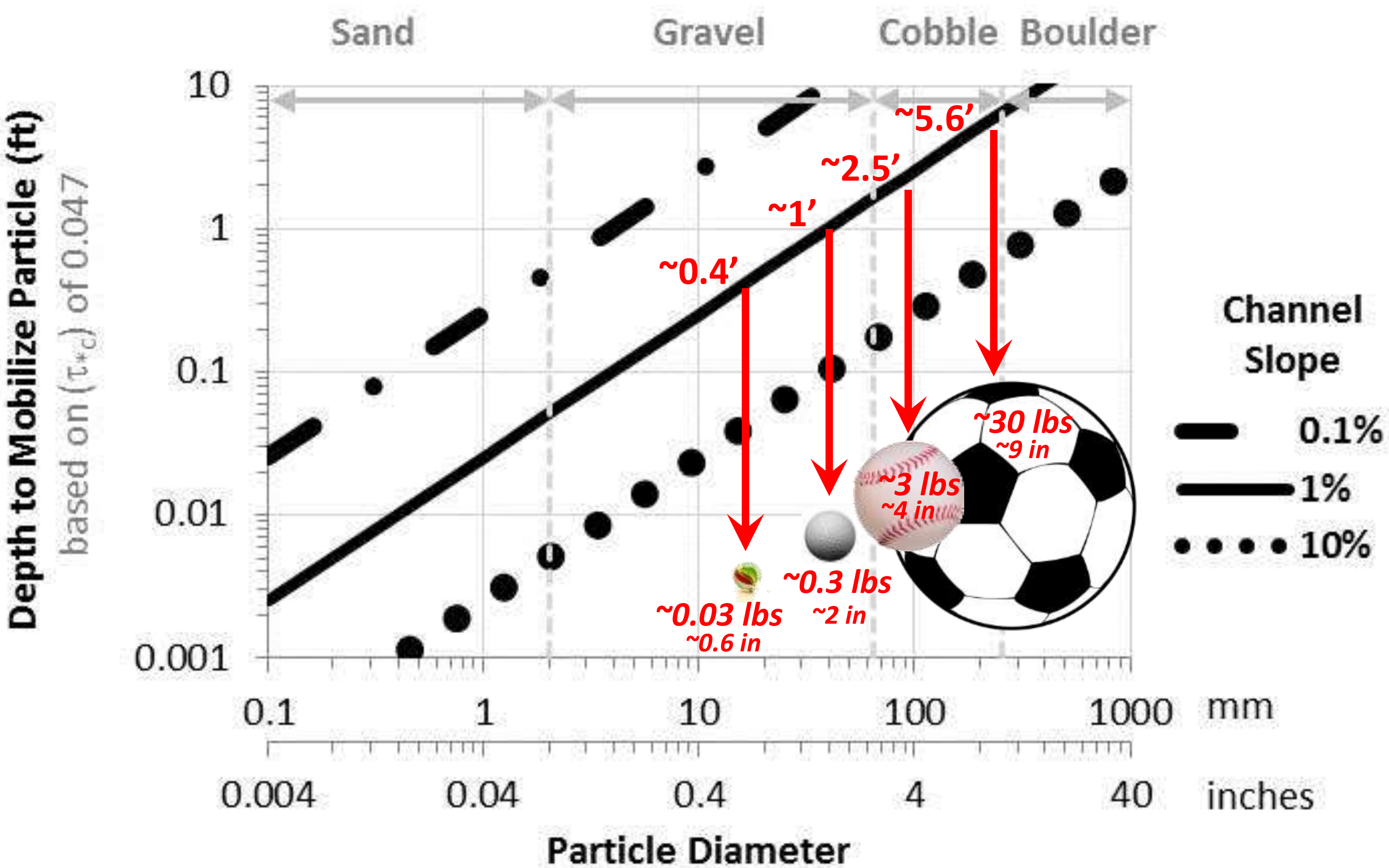
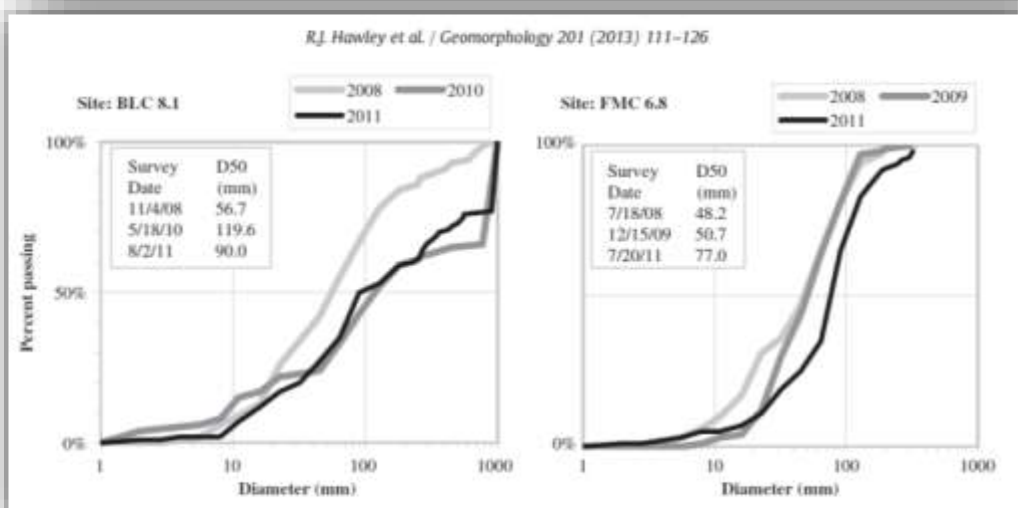
Resistance Increases with Particle Size and Decreases with Slope

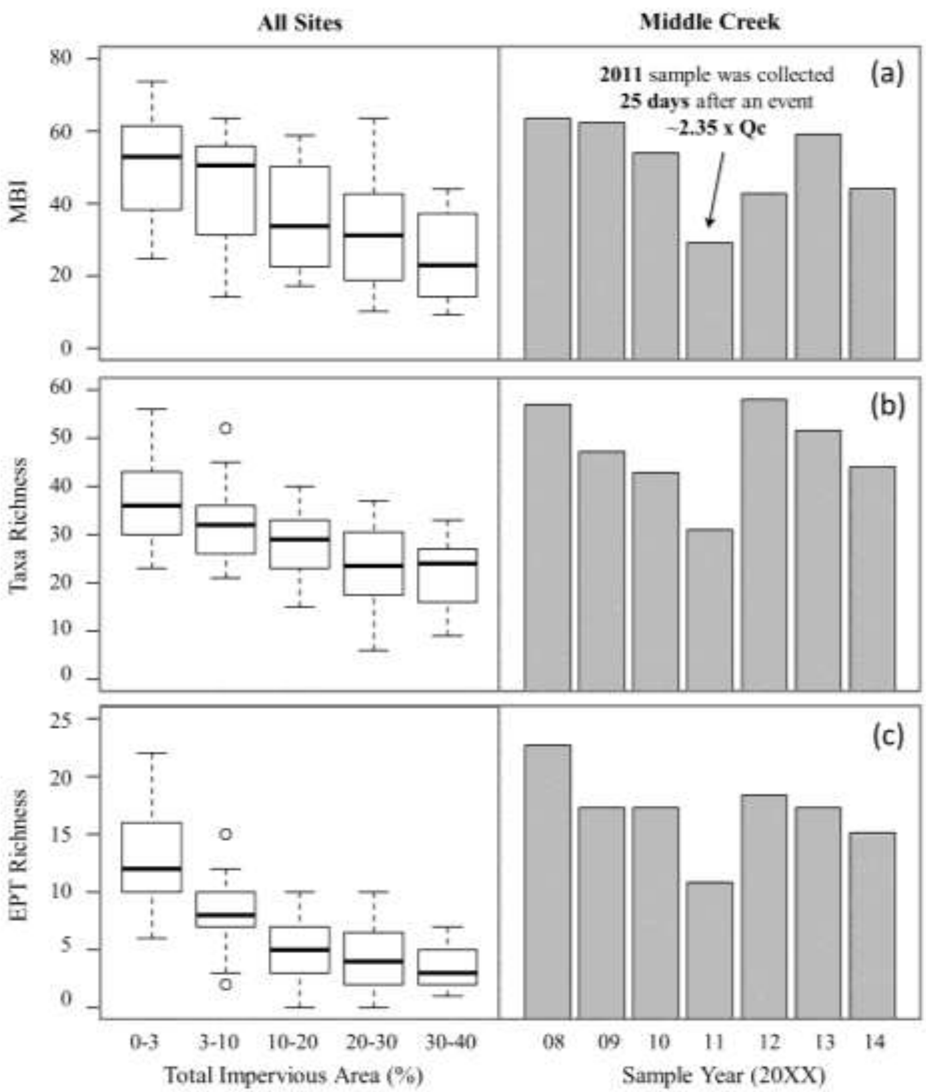


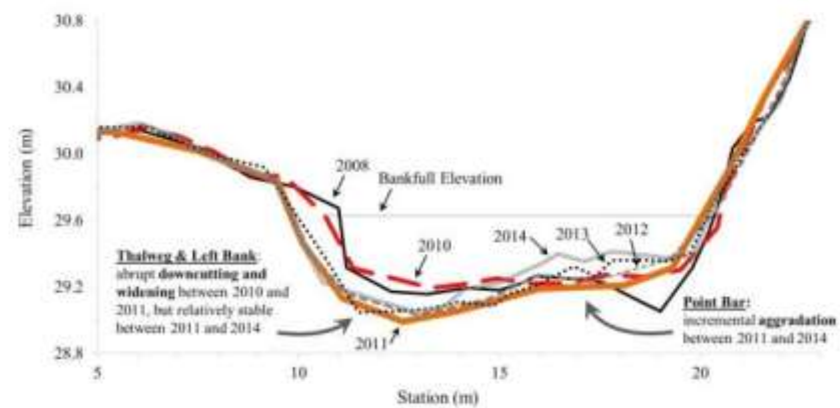
Adapted from Hawley and Vietz (2016, Freshwater Science)

$Q_{critical}$ Needs to Be Calibrated to Stream/Region



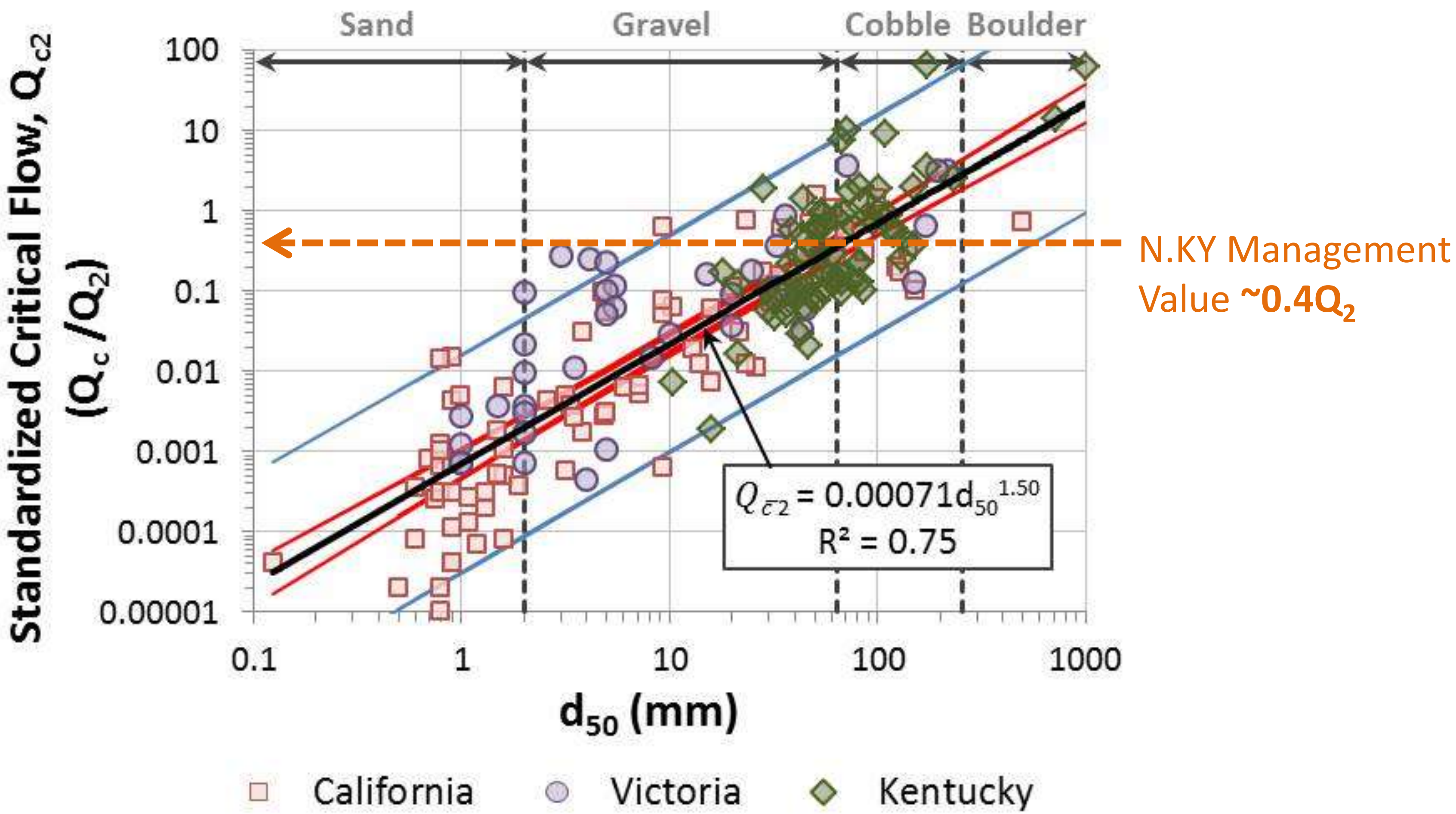
The Importance of $Q_{critical}$ is even Evident at Reference Sites





Adapted from Hawley et al. (2016, Freshwater Science)

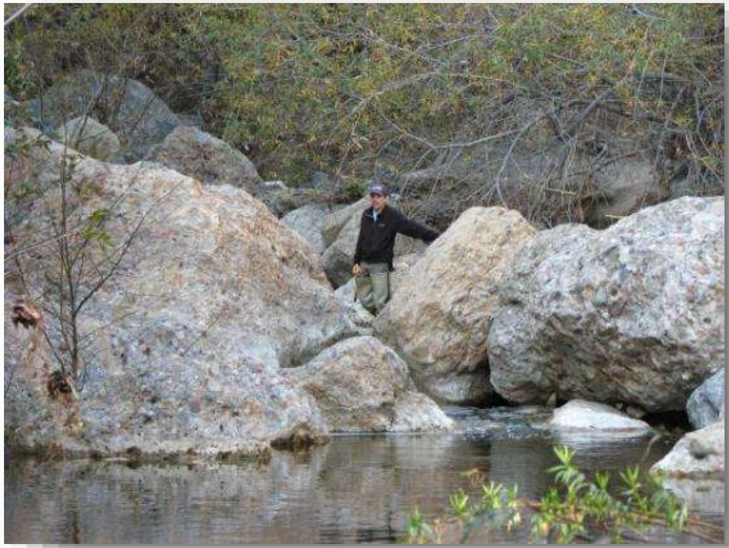
$Q_{critical}$ Needs to Be Calibrated to Stream/Region



Adapted from Hawley and Vietz (2016, Freshwater Science)

Regionally Calibrated $Q_{critical}$ Values

- **Santa Clara, CA** = 10% of Q_2
- **San Diego, CA** = 10, 30, or 50% of Q_2
  depending on channel susceptibility after Bledsoe et al. (2012)
- **Northern KY** ~ 40% of Q_2



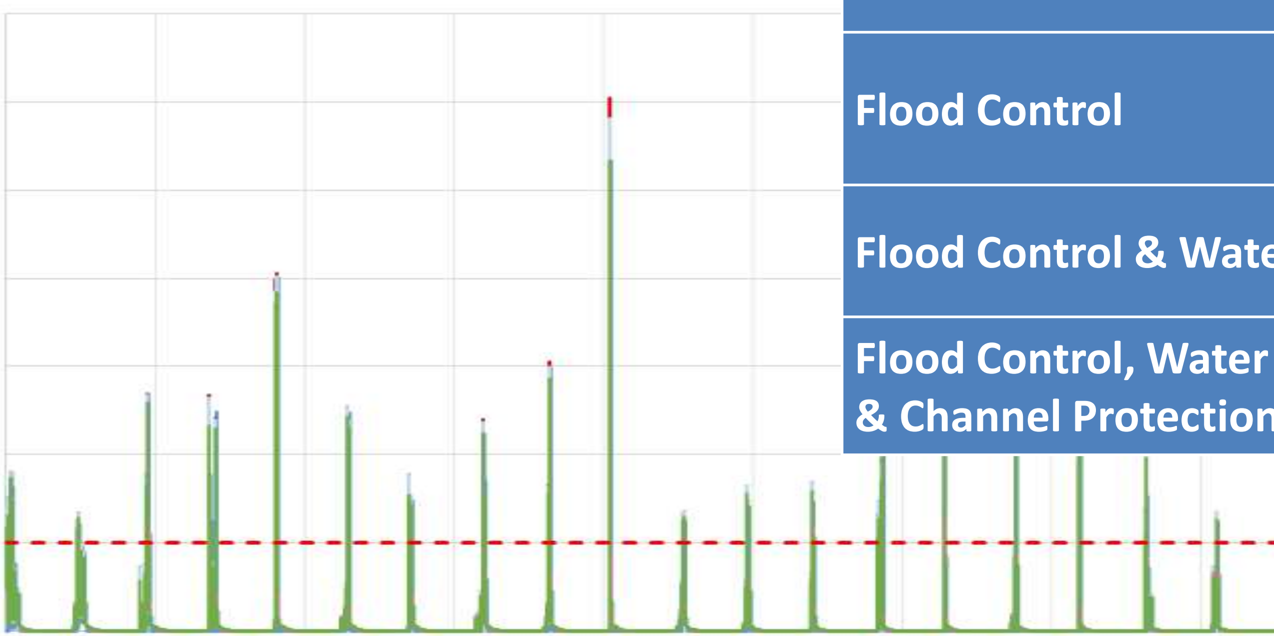
Stream-specific Requirements

- **New York:** Detailed geomorphic analysis required on projects > 50 acres with > 25% imperviousness
- **San Diego, CA:** Screening-level analysis required on all projects
- **Northern KY:** Recommended/required on facilities draining > 100 acres and on stormwater master planning efforts

Sediment Transport Modeling Used to Find Right Approach for a Stream Network

Management Strategy	Cumulative Tons of Sediment Transport
	% Diff. from Pre-developed
Post-developed, No Control	1145%
Flood Control	290%
Flood Control & Water Quality	197%
Flood Control, Water Quality, & Channel Protection	-11%

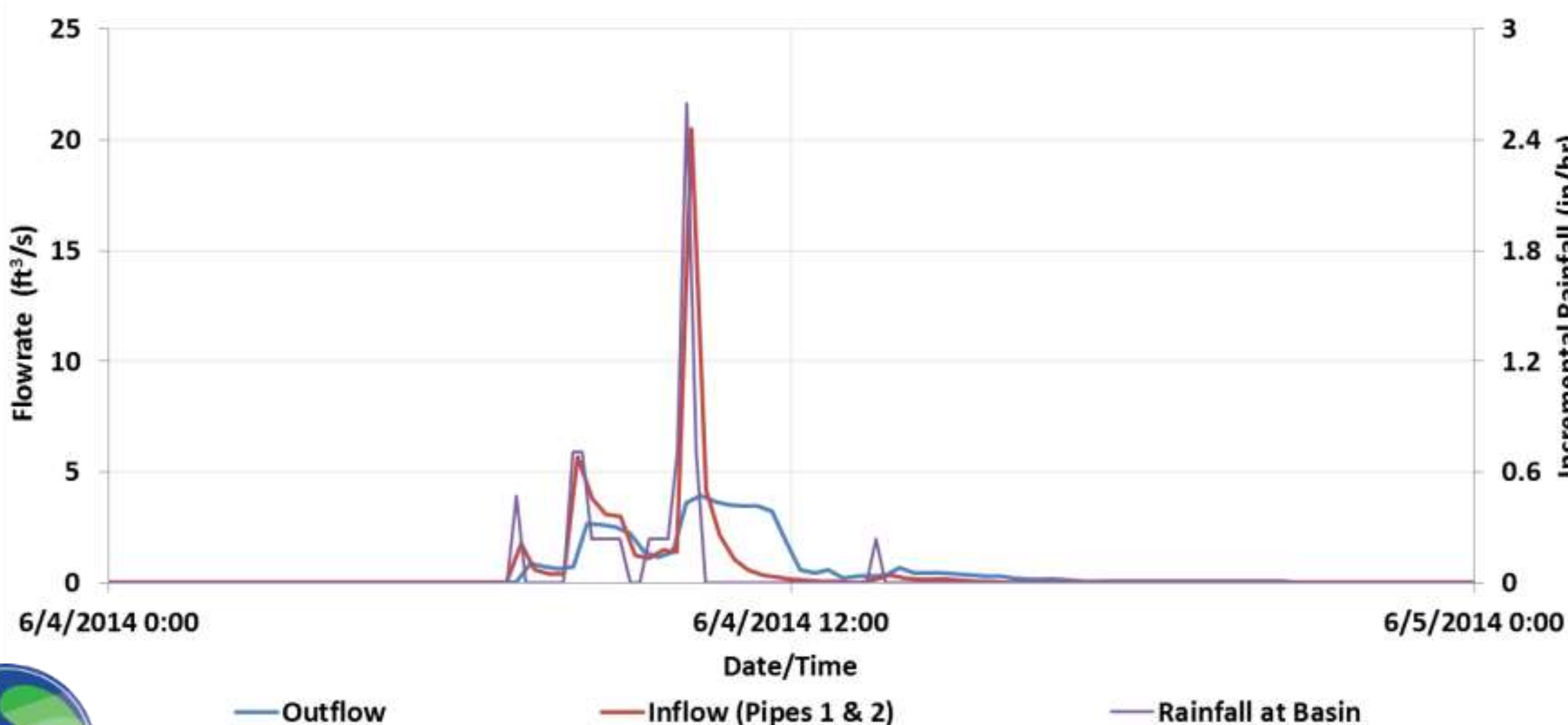
Top 20 Events (1993-2012)



Adapted from Hawley et al. (In prep)

Can Lead to Simple Design Target Appropriate for Setting

In N. KY, Design Facilities Draining ≤ 100 acres to ***Release 2-yr Storm at a Peak Discharge*** *≤ 0.4 cfs/acre*



Adapted from Hawley et al. (In review)

Outreach, Training, and Credit Policies all incorporated into Policy Role Out

SD1
Managing Northern Kentucky's Wastewater and Storm Water

July 23, 2015

To whom it may concern:

Sanitation District No. 1 (SD1) is the regional storm water utility charged with managing storm water runoff in Northern Kentucky. The purpose of this letter is to inform you of a minor adjustment to storm water design criteria that most development projects in the separate storm system will be required to meet starting Oct. 1, 2015 in order to comply with the Northern Kentucky storm water rules and regulations. SD1 has presented the premise behind this minor adjustment at numerous workshops and meetings over the past three years, including the December 2014 reThink Storm Water Engineering and Design Workshop. As a general reminder, the best course of action for any development project is to contact SD1 early in the process to determine exactly what is required for a given project.

One of the many objectives in the Kentucky Storm Water General Permit (KYG20) related to protecting overall stream health is to ensure that storm water controls are adequately designed to protect the water quality of receiving streams.

Elements of the current design criteria - contained within the document titled, Northern Kentucky Regional Storm Water Management Program, Rules and Regulations - were intended to fulfill this permit objective. However, data collected in Northern Kentucky streams in recent years has demonstrated that the existing post-construction control requirements are not adequately achieving this permit objective. Stream erosion continues to be a significant issue in the region and is a dominant source of sedimentation and siltation, which is Kentucky's primary water quality impairment.

Additionally, stream erosion has also been documented as a significant cause of damage to infrastructure, including roads, sewers, electric lines and gas lines, as well as property loss across the region.

Fortunately, local data and analyses show that, on most sites, a simple adjustment to just one of the design criteria should be adequate to meet the intent of this permit objective and better protect both public and private property from excess stream erosion. The adjustment involves optimizing storm water management facilities to release runoff from all storms up to and including the **two-year design storm at a maximum rate of 0.4 cfs/acre**. This can typically be accomplished by making adjustments to the size and placement of openings on the outlet control structure that manages the release of water from the basin. Projects that are currently meeting or will meet this requirement could qualify to receive up to a 40 percent storm water credit reducing the storm water fee associated with the property. This storm water credit is only available upon receipt and approval of a storm water credit application.

SD1 • 1045 Eaton Drive • Ft. Wright, KY 41017 • phone 859-578-7450 • fax 859-331-2436 • www.sd1.org

Page 2 of 2

This target flow rate is termed the **Critical Flow ($Q_{critical}$) for stream erosion**. Although the threshold can vary by stream, in most cases in Northern Kentucky, **the design target for $Q_{critical}$ can be approximated as 0.4 cfs per acre of drainage area.**

SD1 strongly encourages designers to verify design requirements for a particular site prior to making substantial investments in site designs. However, for most storm water management facilities with drainage areas less than ~100 acres, the following table can be used as a quick guide to help facilitate compliance with the rules and regulations:

Design Storm	Design Target	Comparison to Previous Approach
0.8 inches	Management of entire volume through approved storm water management facility (see Northern Kentucky BMP Manual)	No change
2-year	**Max discharge ≤ 0.4 cfs per acre of drainage area**	Design target changed from Q_2 to 0.4 cfs/acre
10-year	Max discharge ≤ pre-developed 10-year peak discharge (Q_{10})	No change
25-year	Max discharge ≤ pre-developed 25-year peak discharge (Q_{25})	No change
50-year	Max discharge ≤ pre-developed 50-year peak discharge (Q_{50})	No change
100-year	Max discharge ≤ pre-developed 100-year peak discharge (Q_{100})	No change

For more information related to how storm water management facilities can be optimized to meet the $Q_{critical}$ design criterion without substantial increases in facility size or cost relative to previous approaches, please contact SD1 about workshop and training opportunities in the near future.

One of these upcoming workshops will be at a Northern Kentucky Society of Professional Engineers meeting on August 13 at 11:30 a.m. at SD1's main office, 1045 Eaton Drive, Ft. Wright. To register for the meeting, please RSVP online at www.kspenky.org.

If you have any questions regarding this adjustment to storm water design procedures, please contact Andy Aman, SD1 Environmental Compliance Administrator, at 859-578-6880.

Sincerely,

Brooke Shireman
Environmental Compliance Manager
Integrated Watershed Management Department

Outreach, Training, and Credit Policies all incorporated into Policy Role Out

Design Storm	Design Target	Comparison to Previous Approach
0.8 inches	Management of entire volume through approved storm water management facility (see Northern Kentucky BMP Manual)	No change
2-year	**Max discharge ≤ 0.4 cfs per acre of drainage area**	Design target changed from Q_2 to 0.4 cfs/acre
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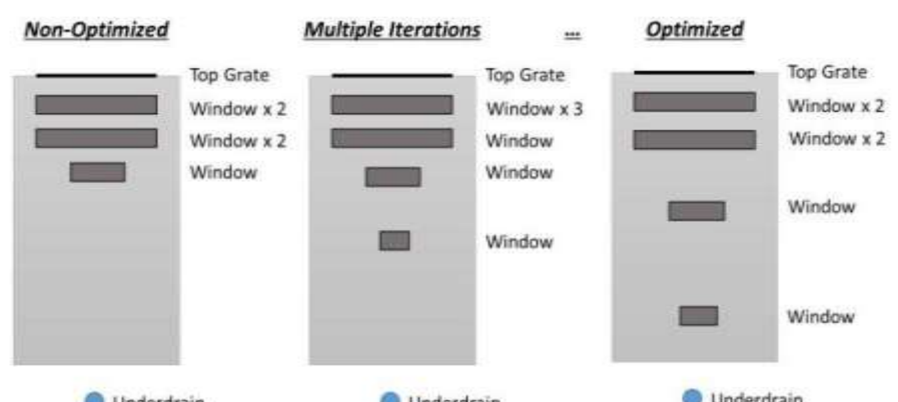
50-year	Max discharge ≤ pre-developed 50-year peak discharge (Q_{50})	No change
100-year	Max discharge ≤ pre-developed 100-year peak discharge (Q_{100})	No change

Typical Optimization Sequence:

Flood Control → Water Quality → $Q_{critical}$



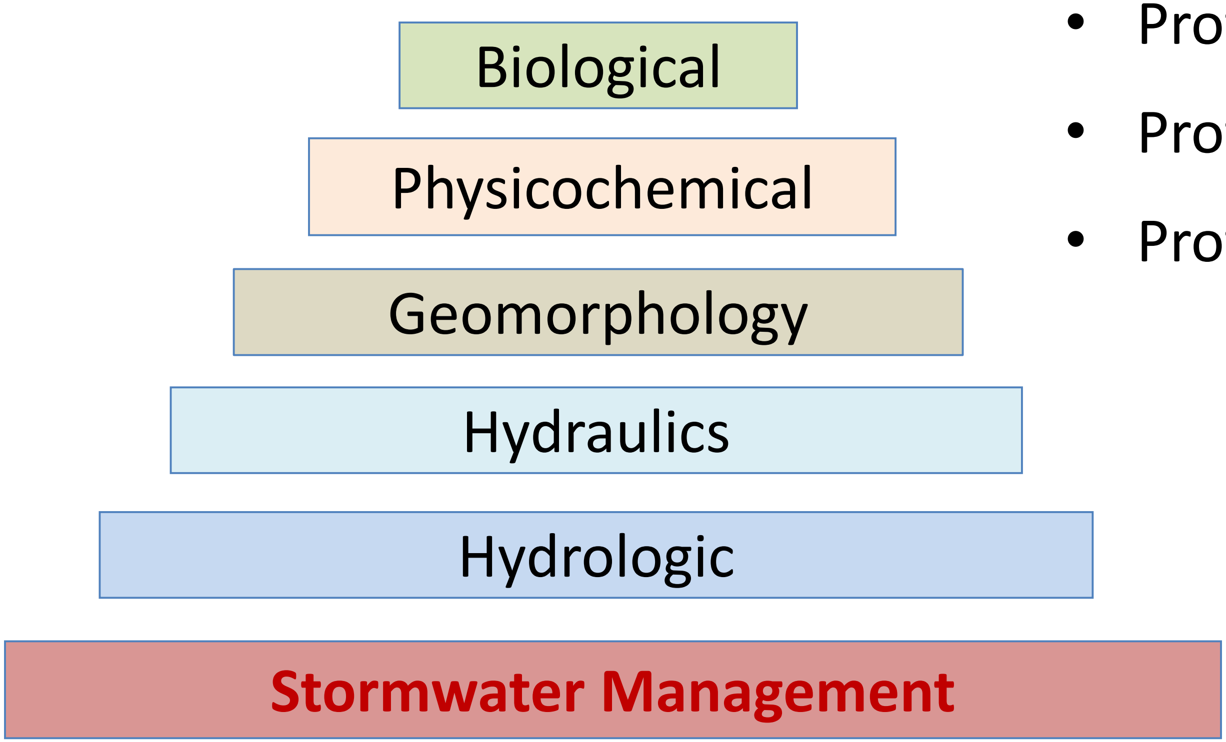
Find an Appropriate Approach for Your Community

1. **Prevent Future Problems:**
   - Optimize Post Construction Rules & Regs to Protect Your Streams

2. **Mitigate Existing Problems:**
   - Find Cost-effective Solutions to Mitigate Existing Impacts

Channel Evolution Sequence in Response to Increased Flows from Urbanization, Adapted from Schumm et al. (1984) and Hawley et al. (2012)

Conclusion



It all starts here

Successfully Managing Stream Stability:

- Protects Natural Resources
- Protects Infrastructure
- Protects Property

Questions?

Photo by Mark Jacobs (Boone County Conservation District)

Sustainable Streams LLC
Science · Service · Solutions

bob.hawley@sustainablestreams.com

Example 1
Bioretention Basin

Bioretention Basin

Bioretention Basin

- **Step 1: Flood Control**
  - Post ≤ Pre for 2-, 10-, 25-, 50-, and 100-year events
- **Step 2: Water Quality Requirements**
  - 0.8 inches of rainfall infiltrates through bioretention soil
- **Step 3: Channel Protection/$Q_{critical}$**
  - Predevelopment 2-year Peak Flow: 17.89 cfs
  - $Q_{critical} = 0.4*Q_2$
  - $Q_{critical} = 0.4*17.89\text{cfs} = 7.16\text{ cfs}$

Non-optimized Bioretention Basin

Step	Basin Type	Outlet Structure Optimized?	Basin Footprint (SF)	Estimated Excavation (CY)
1. Flood Control Only	Traditional DB	Yes	3,848	2,510
2. Flood/Water Quality	Bioretention	Yes	**3,318**	**2,832**
3. Flood/WQ/$Q_{critical}$	Bioretention	**No**	**5,027**	**3,846**

Poor Optimization from Flood Control and Water Quality Only

- ~50% larger footprint
- ~35% larger volume
- ~0.5 additional design hours

Optimized Bioretention Basin

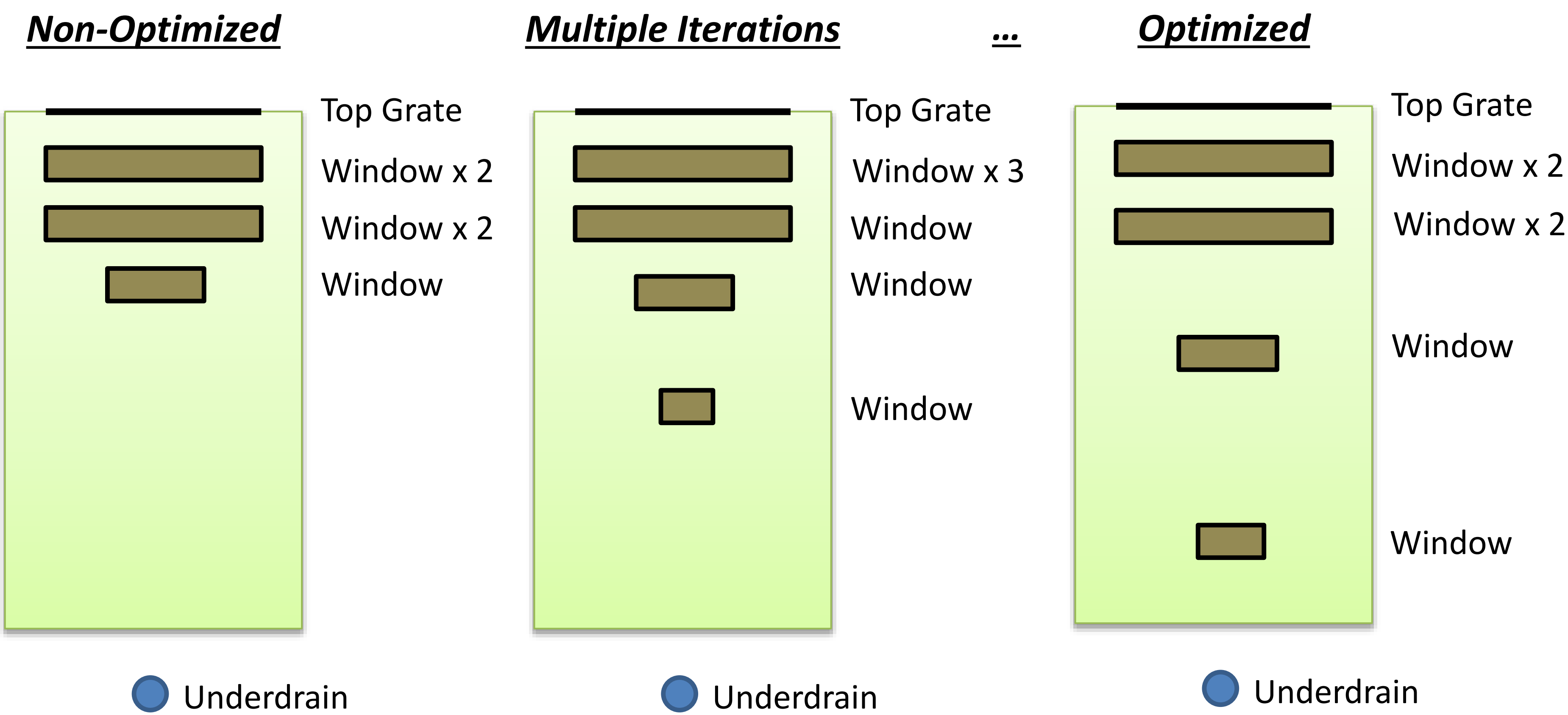
Step	Basin Type	Outlet Structure Optimized?	Basin Footprint (SF)	Estimated Excavation (CY)
1. Flood Control Only	Traditional DB	Yes	3,848	2,510
2. Flood/Water Quality	Bioretention	Yes	**3,318**	**2,832**
3. Flood/WQ/$Q_{critical}$	Bioretention	**Yes**	**3,318**	**2,832**

Good Optimization to Meet $Q_{critical}$

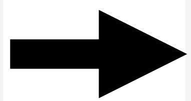
- 0% larger footprint
- 0% larger volume
- 2 additional design hours

Bioretention Basin

Optimization of Outlet Control Structure

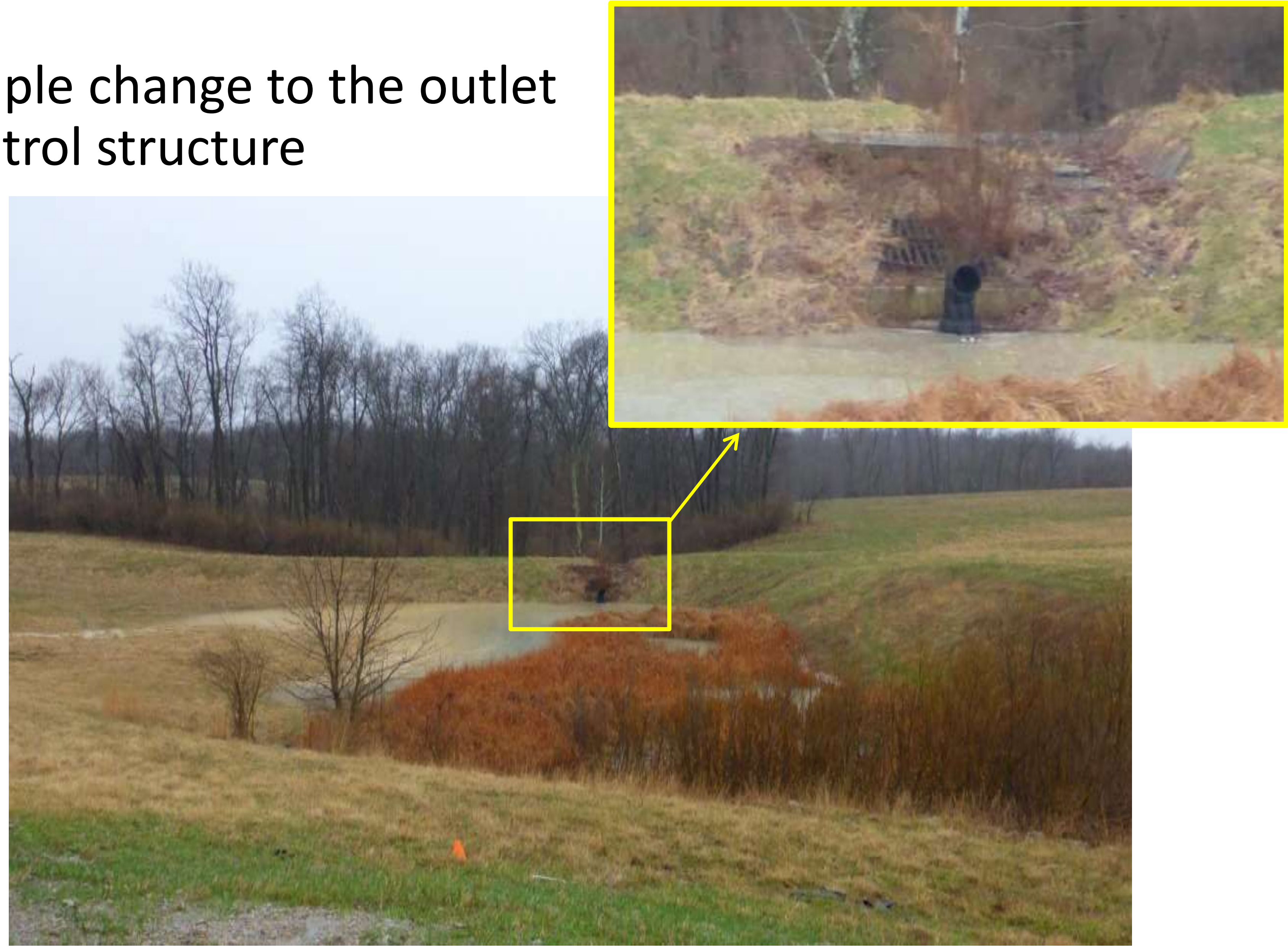


Example 2
Detention Basin Retrofit



Detention Basin Retrofits

Simple change to the outlet control structure



Detention Basin Retrofit

- Maintain Flood Control
- Include Channel Protection
  - $Q_{critical} = 0.4 * 51$ cfs = 20.6 cfs

Rain Events		Pre-Development	Post-Development with Existing Detention Basin				Post-Development with Modified Detention Basin			
Return Period	Duration	Inflow (cfs)	Inflow (cfs)	Outflow (cfs)	Elevation (feet)	Storage (cubic-feet)	Inflow (cfs)	Outflow (cfs)	Elevation (feet)	Storage (cubic-feet)
3-Month	24-Hour	7.49	31.24	15.16	834.60	13,060	31.24	6.55	835.35	25,234
6-Month	24-Hour	18.63	44.33	17.92	835.19	22,040	44.33	12.84	835.84	35,136
1-Year	24-Hour	34.03	59.55	21.08	835.75	33,259	59.55	16.04	836.41	48,430
2-Year	24-Hour	51.51	74.87	23.80	836.29	45,572	74.87	20.43	836.96	62,060
10-Year	24-Hour	104.63	115.77	35.21	837.55	78,844	115.77	34.31	838.20	97,925
25-Year	24-Hour	139.40	140.28	43.12	838.21	98,422	140.28	40.54	838.89	120,219
50-Year	24-Hour	168.00	159.72	48.23	838.71	114,329	159.72	45.69	839.40	138,214
100-Year	24-Hour	198.52	180.01	52.84	839.22	131,607	180.01	50.35	839.92	156,978

Notes	Notes	Notes
Pre-Development DA = 34.26 acres with CN = 74	Post-Development DA = 22.35 acres with CN = 91 Outlet Pipe Invert (Lower): 832.12 feet Outlet Pipe Invert (Upper): 836.21 feet Spillway Invert: 839.96 feet	The modeling scenario of modified detention basin includes: 1. Flow restriction = 75% through filter media 2. Diameter of bypass wye connection = 18 inches 3. Elevation of bypass wye connection = 835.12 feet

Adapted from Hawley et al. (In review)

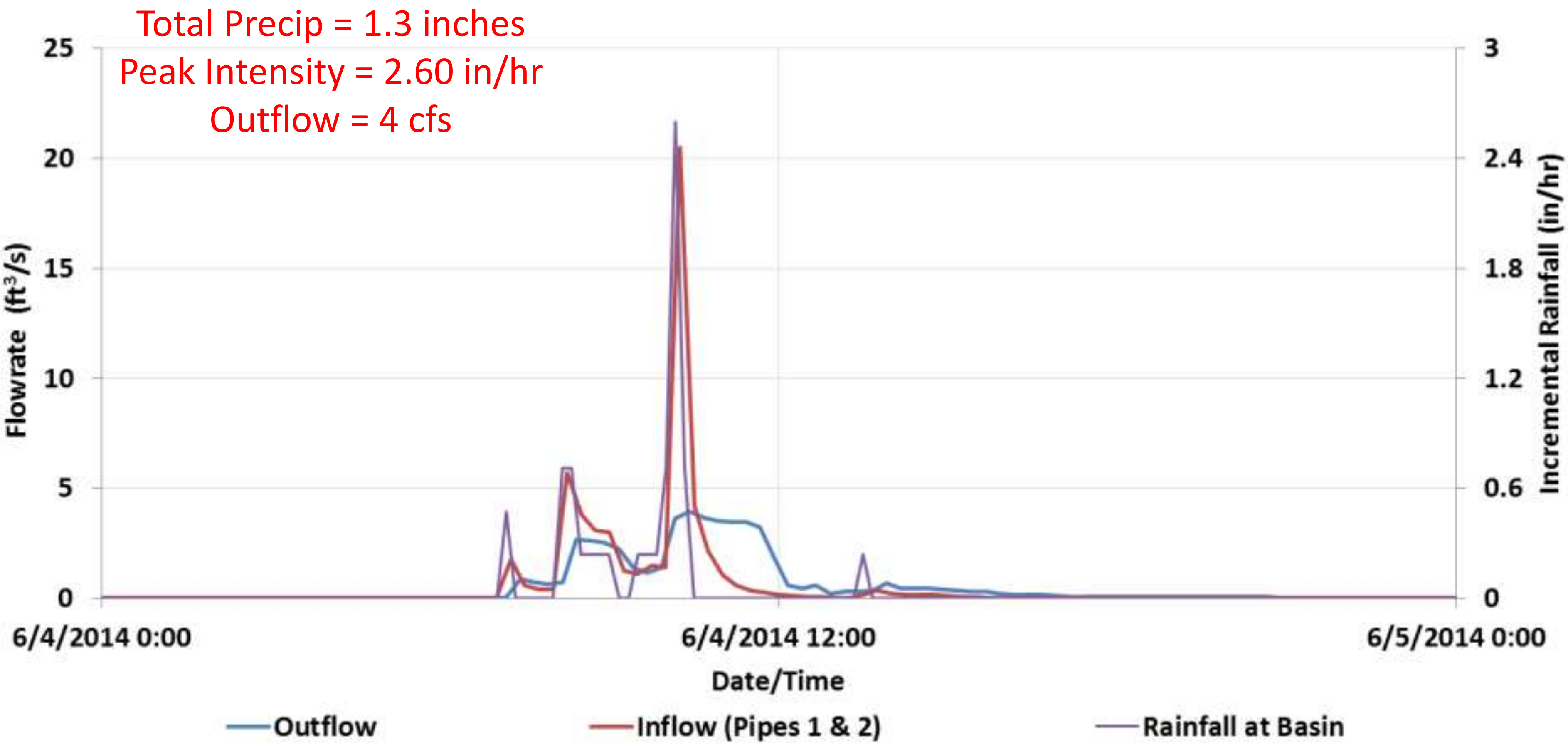
Post-retrofit outflow:

All design storms < pre-retrofit outflow

1-yr and 2-yr storms < $Q_{critical}$ (20.6 cfs)

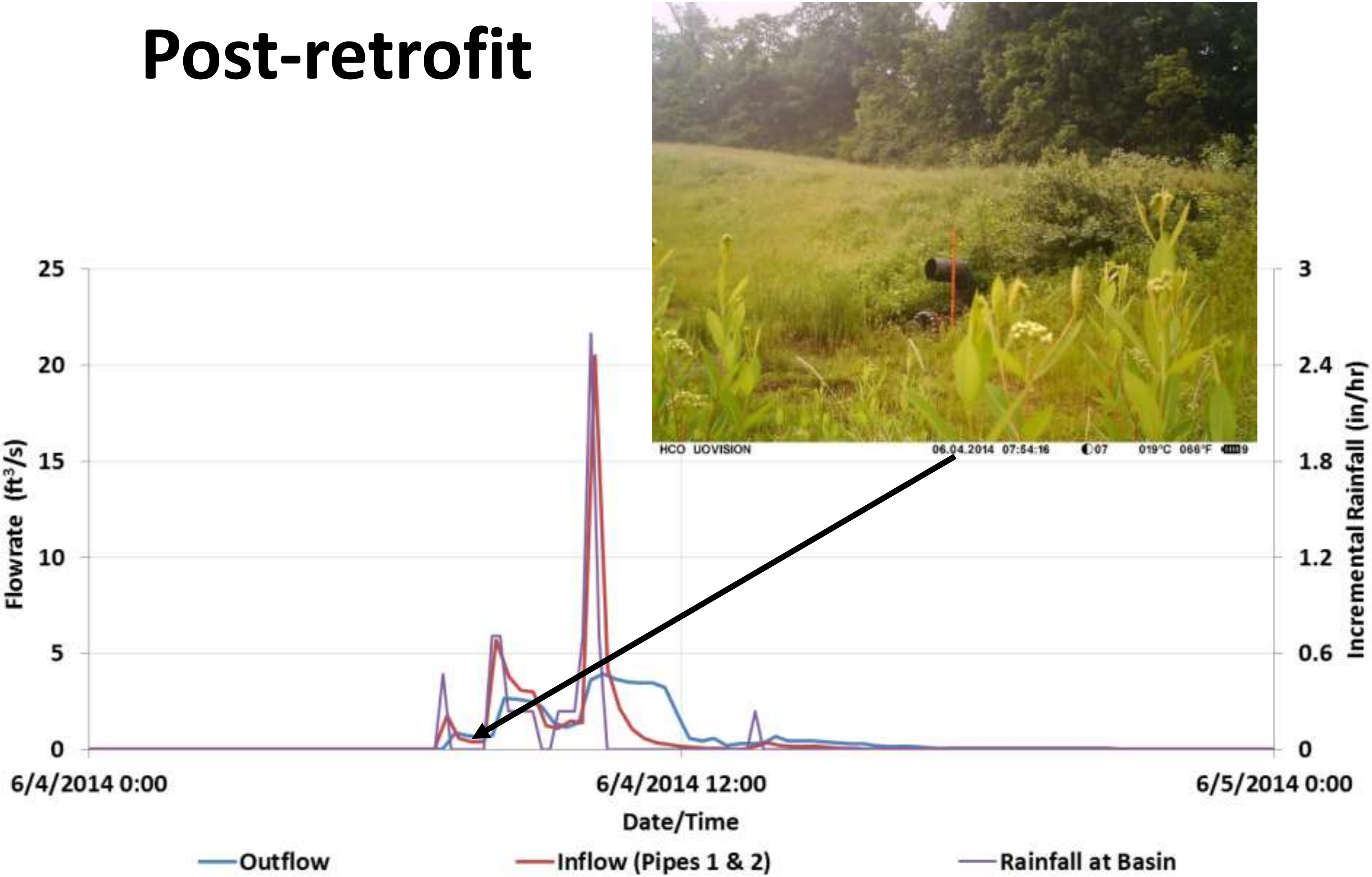
Detention Basin Retrofit

Post-installation Monitoring



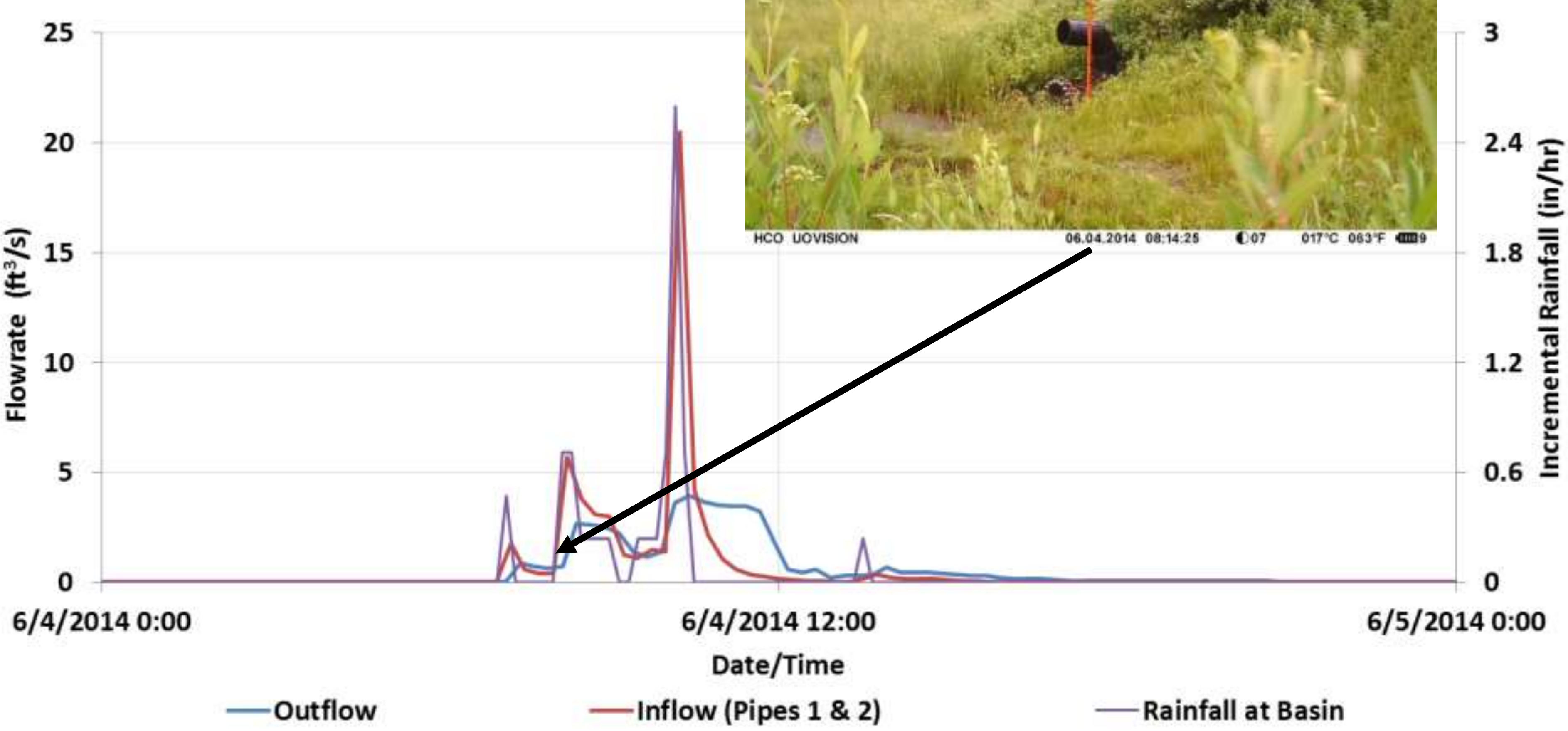
Adapted from Hawley et al. (In review)

Post-retrofit



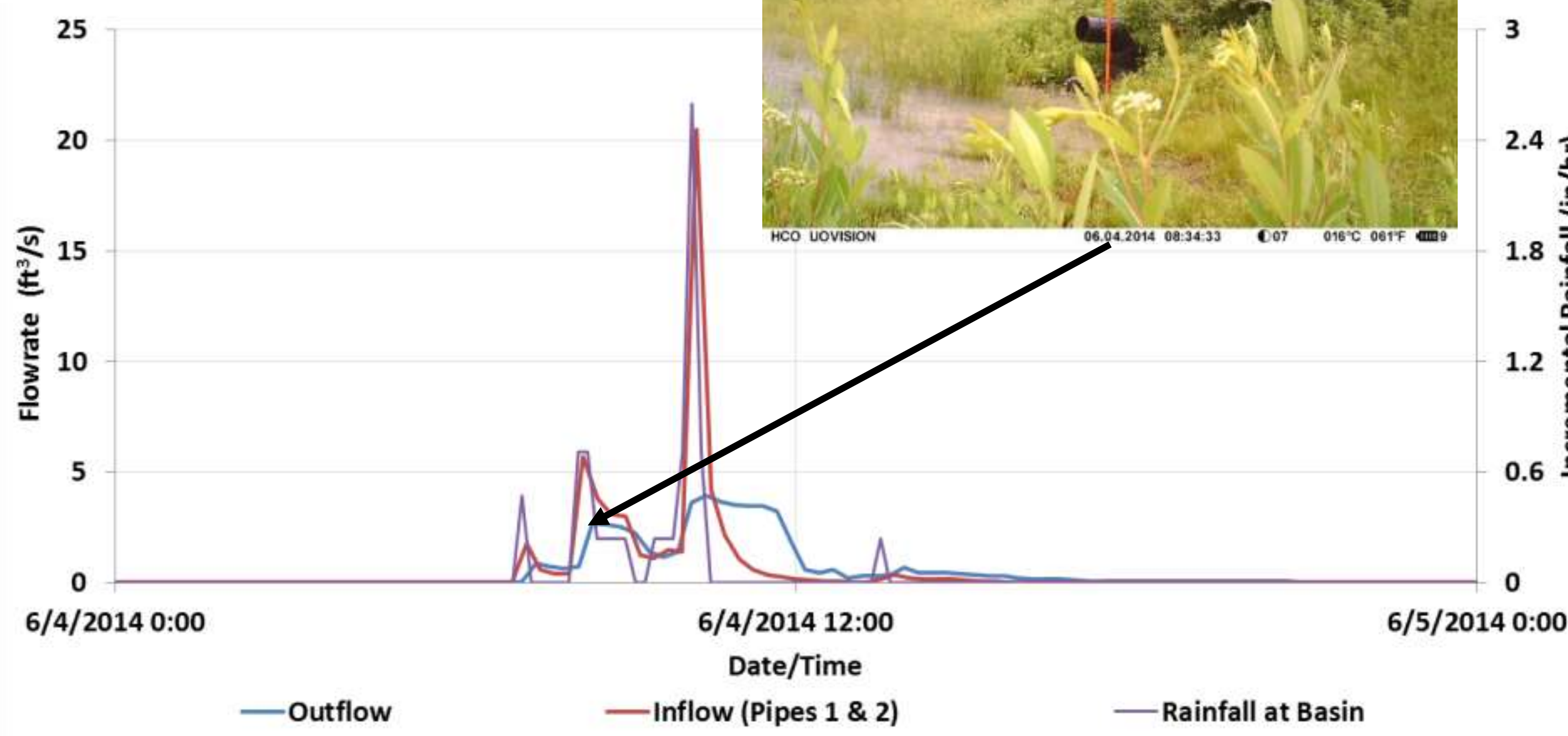
Adapted from Hawley et al. (In review)

Post-retrofit



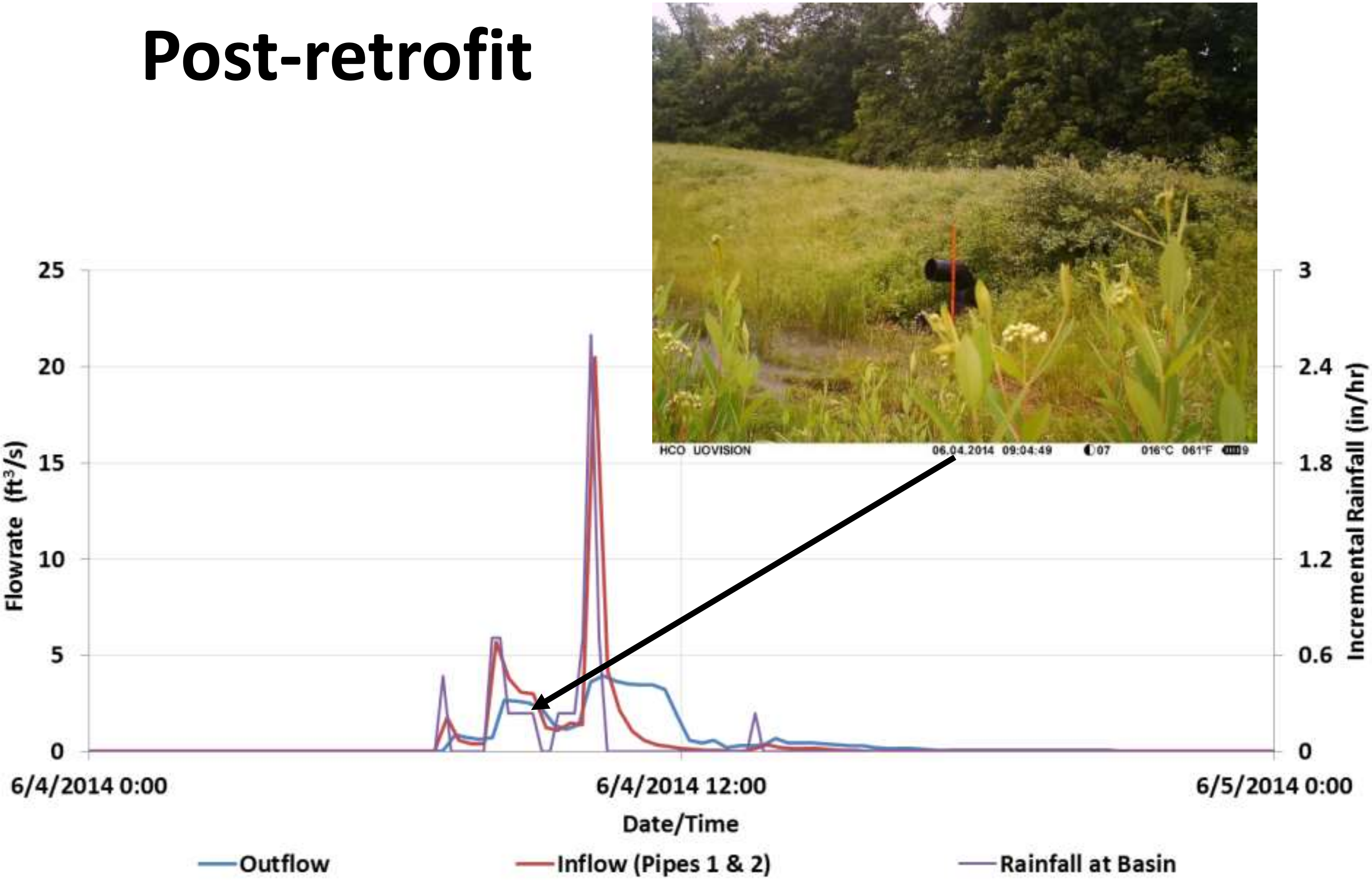
Adapted from Hawley et al. (In review)

Post-retrofit



Adapted from Hawley et al. (In review)

Post-retrofit



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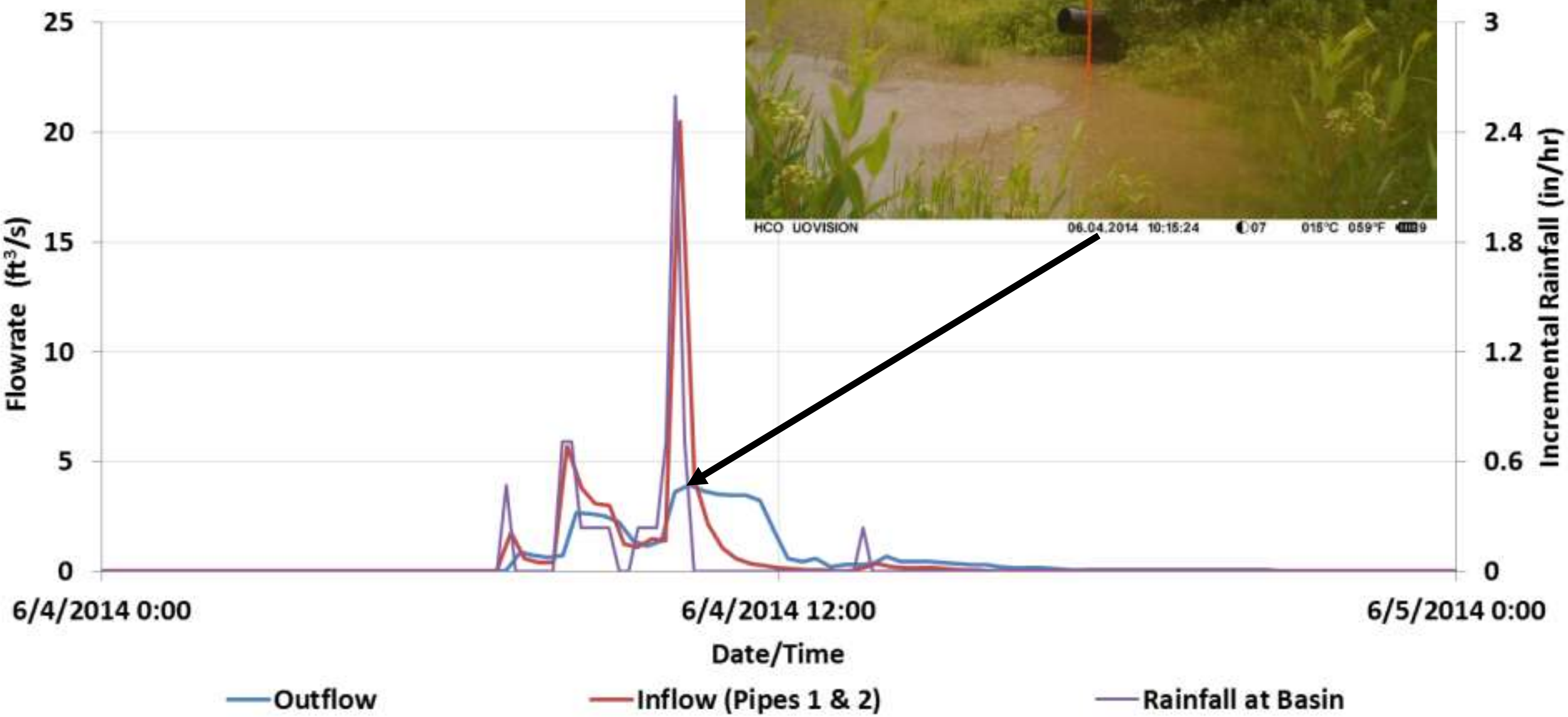
Post-retrofit



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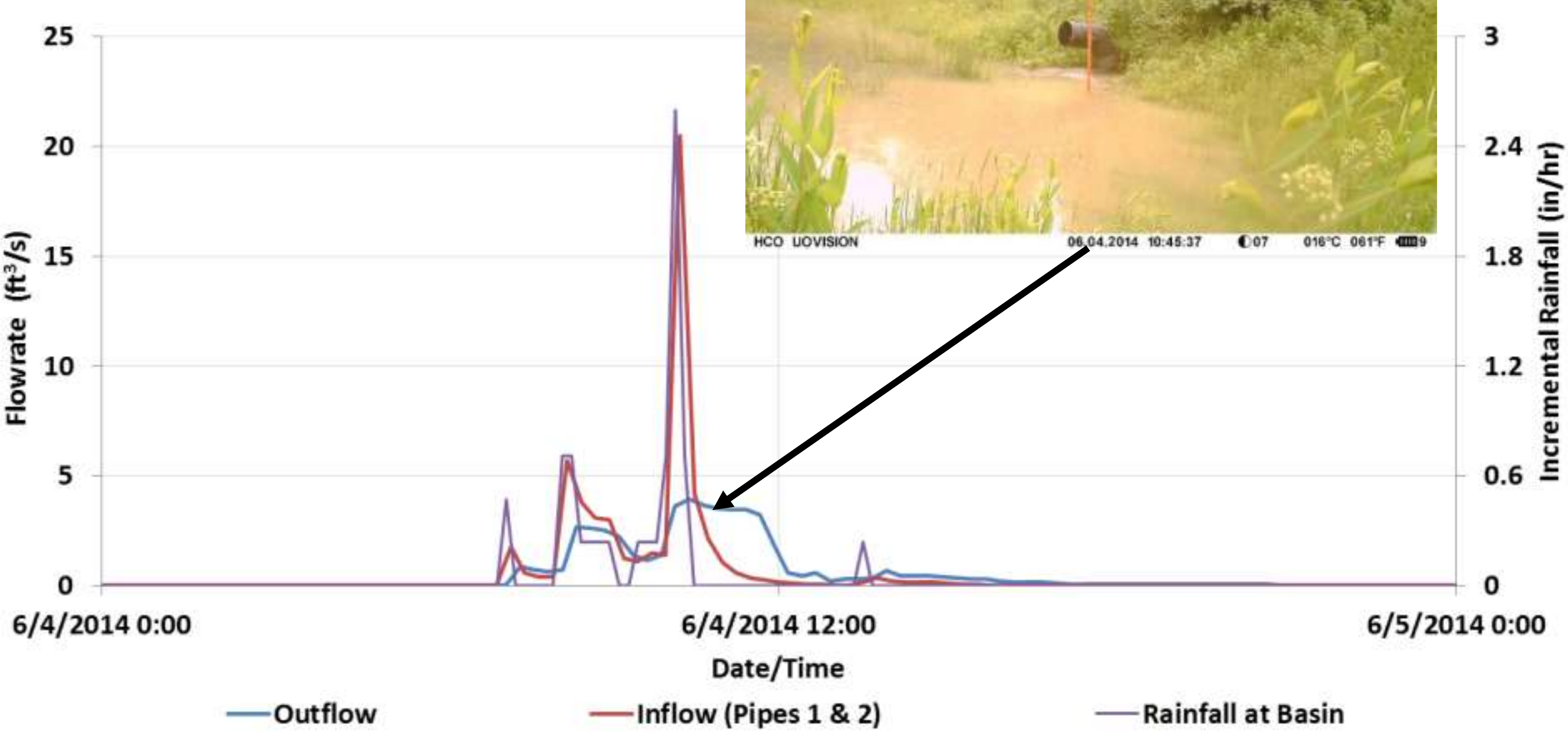
Post-retrofit



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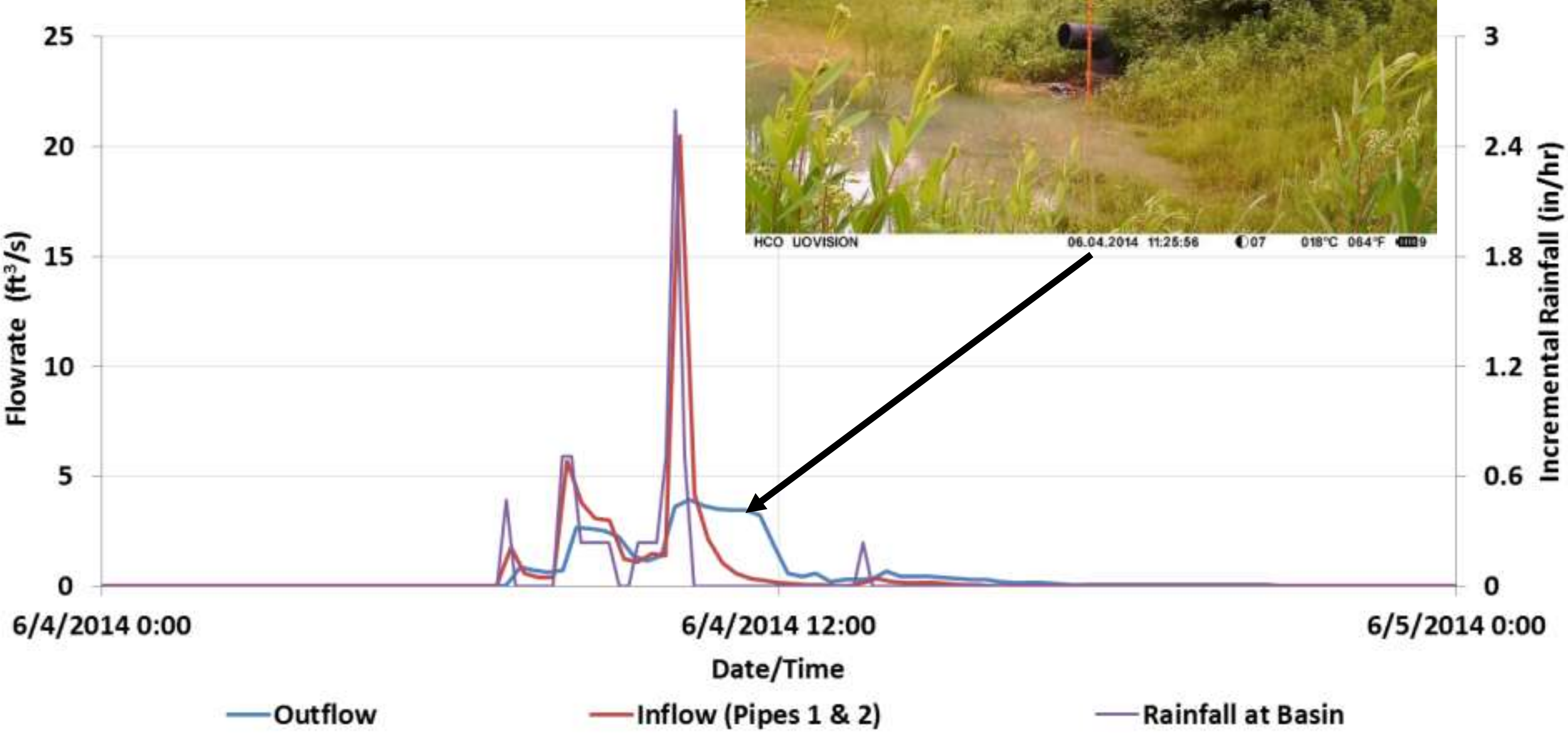
Post-retrofit



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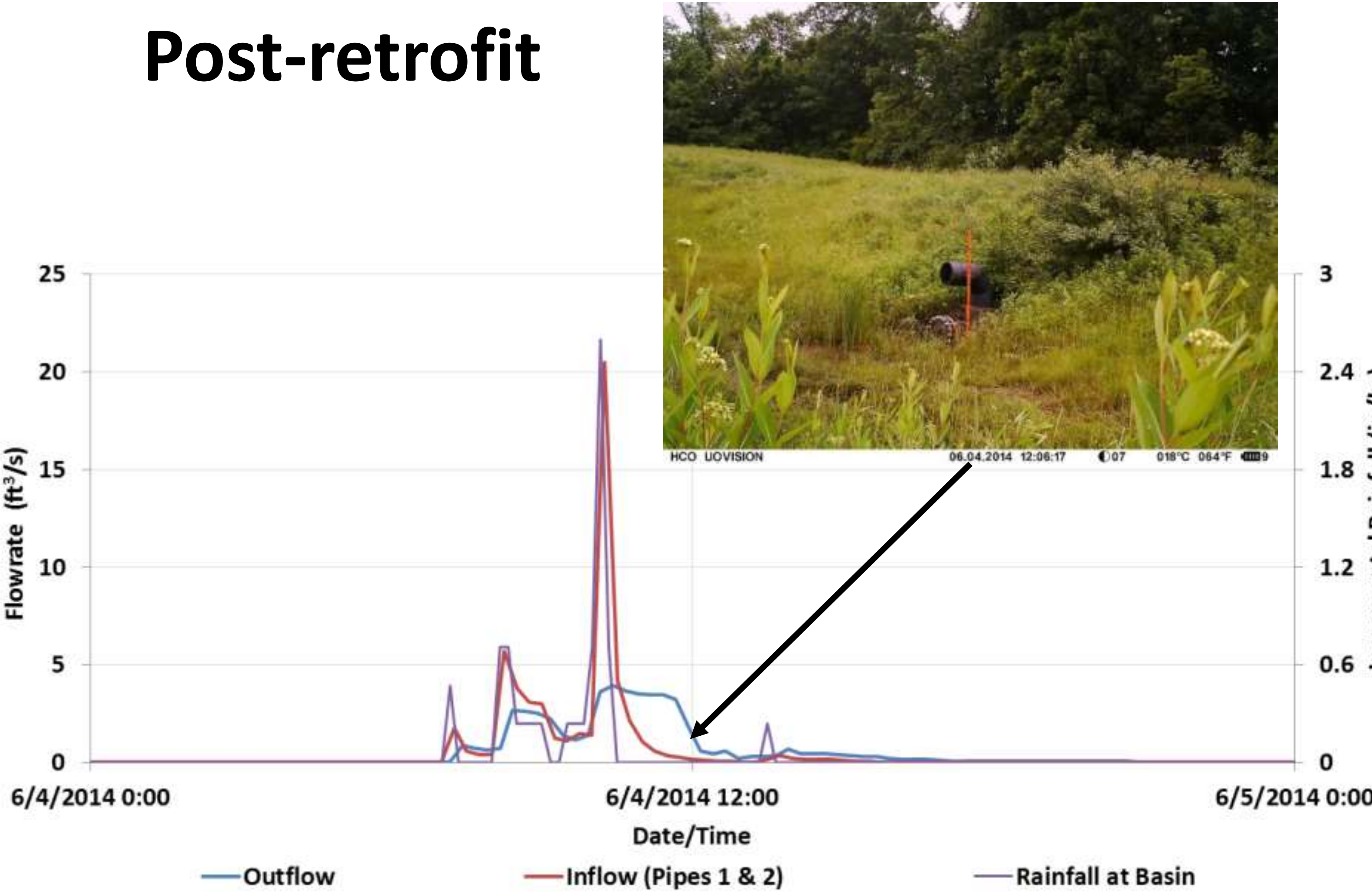
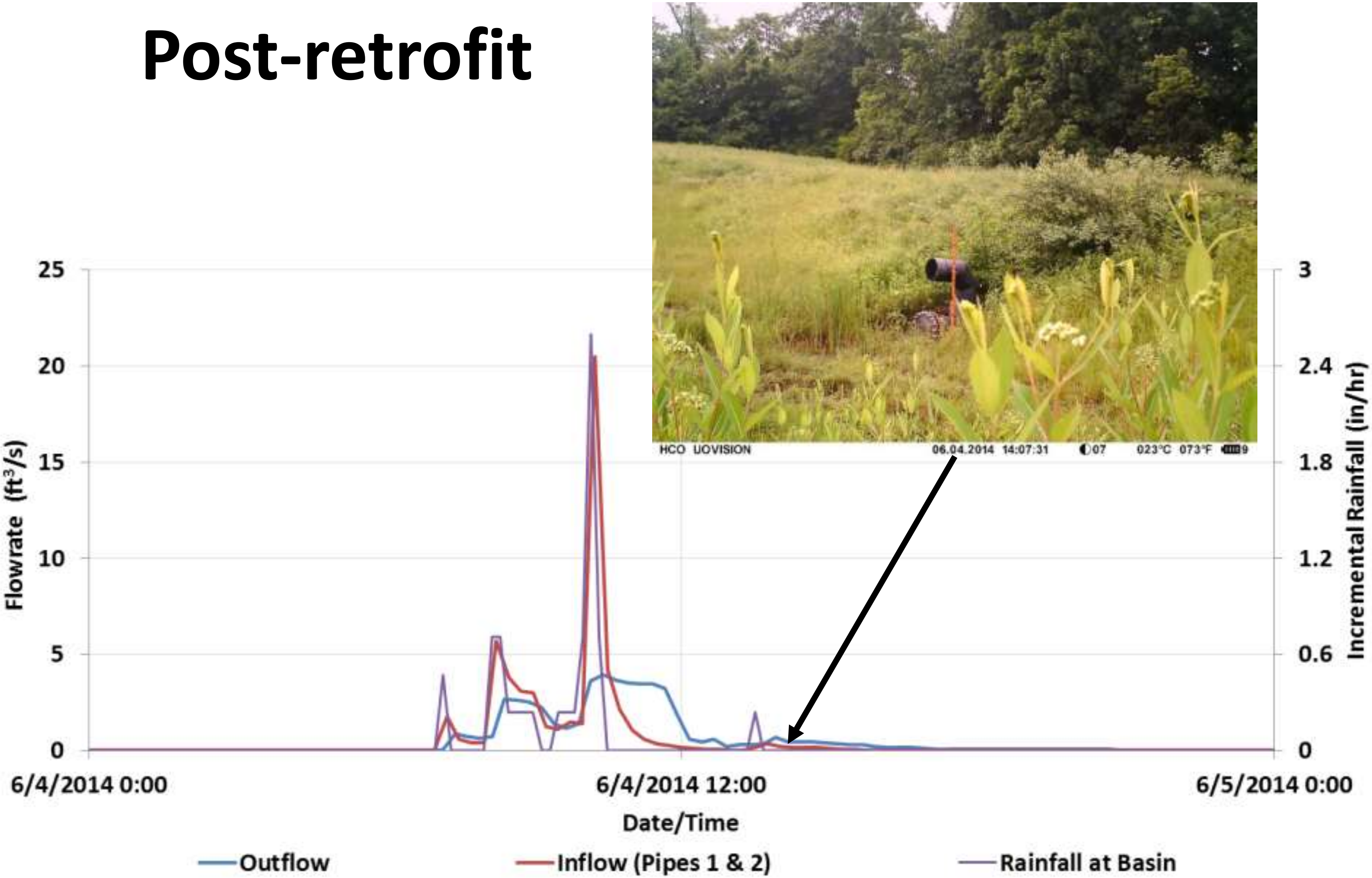
Post-retrofit



Adapted from Hawley et al. (In review)

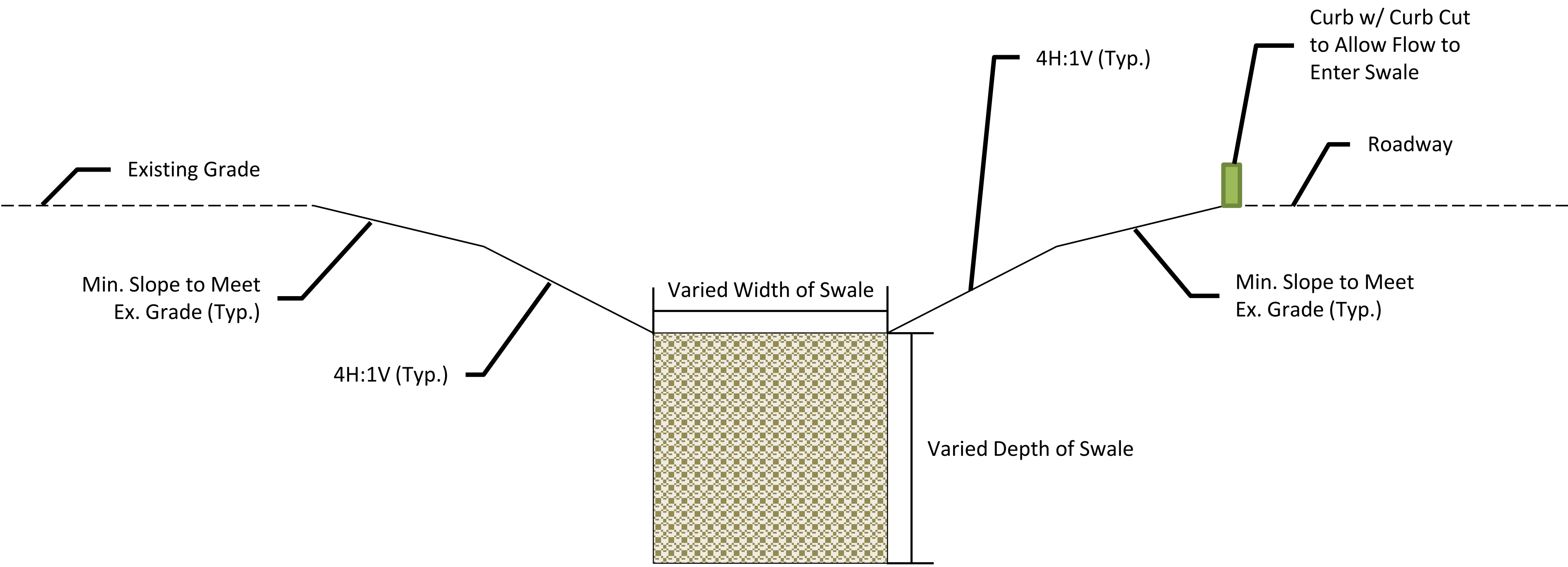
Post-retrofit



Adapted from Hawley et al. (In review)

Example 3
Enhanced Swale

Enhanced Swale Cross Section

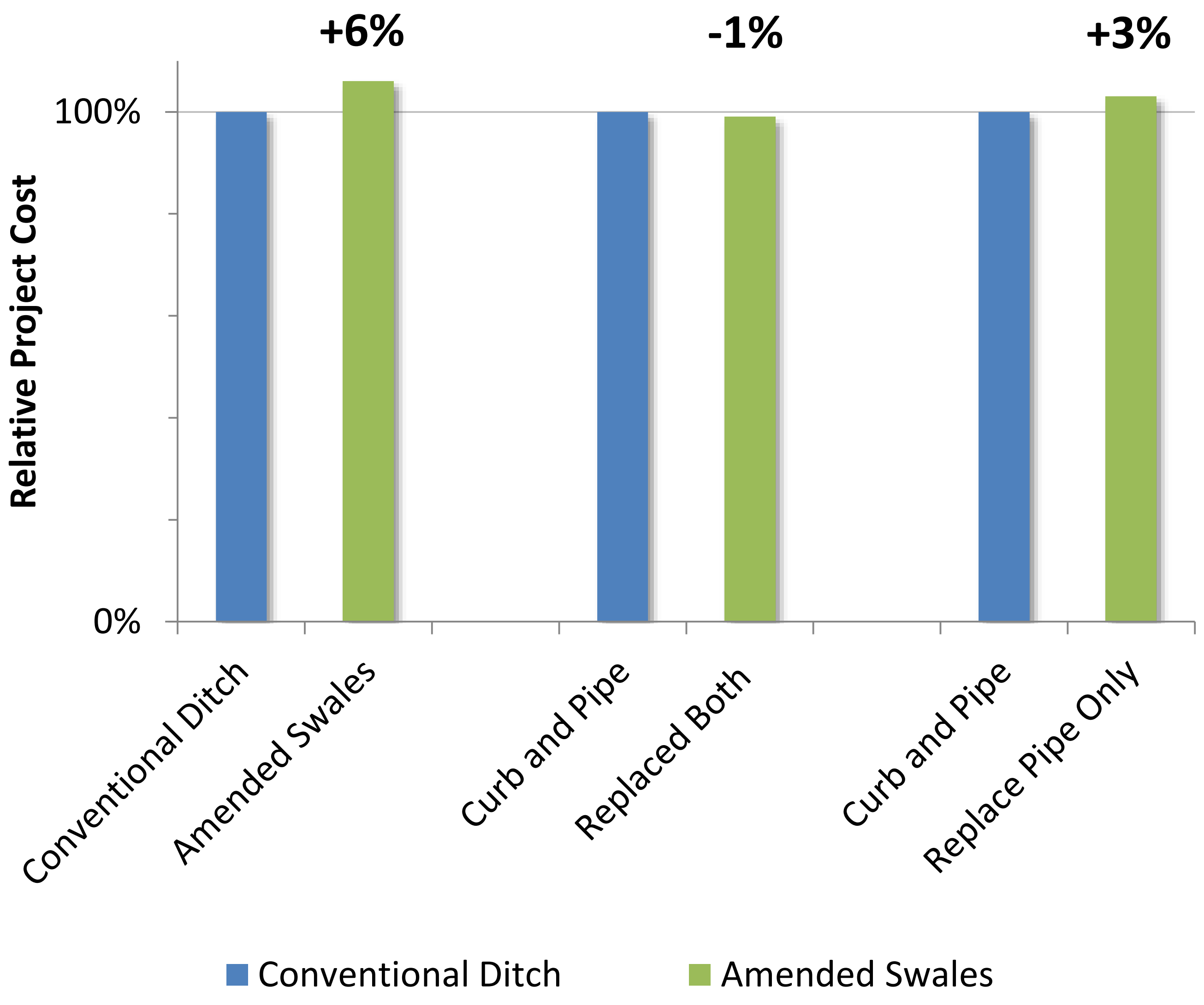


Adapted from: Illinois Department of Transportation

Enhanced Swale Components

- Gravel
  - Sized to resist erosion
    - Steep slopes: rip rap
    - Gentle slopes: gravels
- Other variations have included:
  - Topsoil
  - Vegetation
    - Turf grass or natives depending on preference

Preliminary Costs



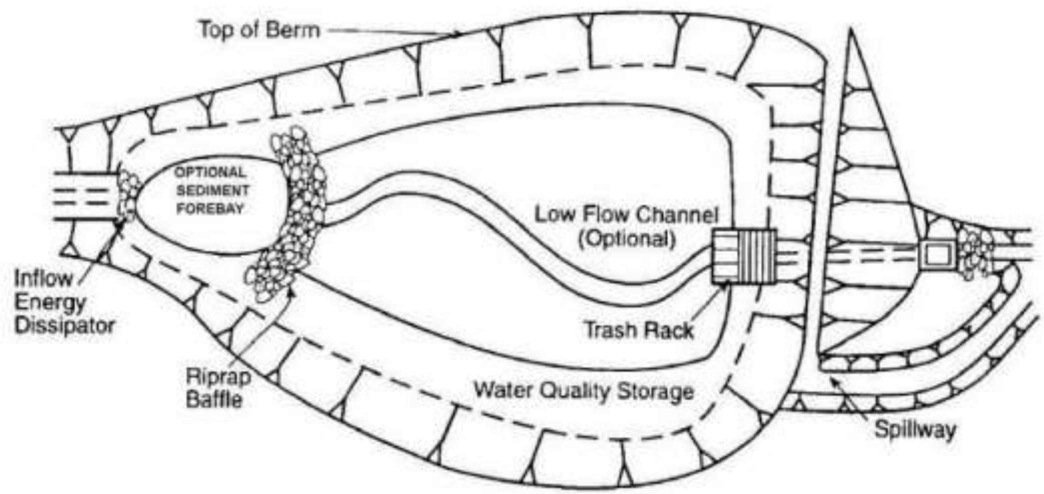
Example: Enhanced Swale Preliminary Results

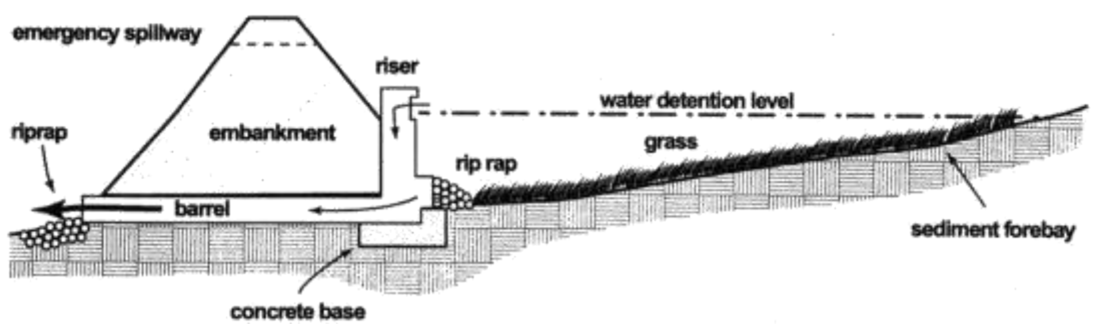
Swale/ Roadway	Drainage Area *acres*	Pre Q_2 *cfs*	$Q_{critical}$ (44% Q_2) *cfs*	Post Q_2 *cfs*	Post Q_2 Control *cfs*	Swale Length *ft*	Bottom Width *ft*	Gravel Depth *ft*	Gravel Volume *CY*
Veterans Way									
1	0.35	0.81	0.36	1.10	0.31	213	14	2	70.7
2	0.46	0.84	0.37	1.48	0.33	132	14.25	5	111.84
3	0.80	1.30	0.57	2.67	0.52	541	10	3.1	198.8
4	0.19	0.31	0.14	0.64	0.14	54	27	3	51.8
North Bend Road									
5	2.15	5.50	2.42	7.90	1.63	956	8.6	3.1	301.9
6	2.06	3.75	1.65	7.60	1.30	810	14	4.1	550.9
Burlington Pike									
7	2.11	4.91	2.16	8.22	1.66	451	15	6.25	501.4
8	1.74	4.26	1.87	6.79	1.46	376	15.25	5	339.6

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

Example 4
Extended Detention Basin

Extended Detention Basins





Example: Extended Detention

$Q_{critical}$ = 0.4 * 17.89 cfs = 7.16 cfs

Event	Method	Pre-development cfs	Post-development No Control cfs	Post-development Flood Control & WQ cfs	Post-development Flood, WQ, $Q_{critical}$ cfs
WQ Event	Rational	0.87	1.41	0.37	0.54
3-mo, 24-hr	SCS Type II	2.56	13.67	0.32	0.42
6-mo, 24-hr	SCS Type II	6.37	21.10	1.03	0.76
1-yr, 24-hr	SCS Type II	11.76	29.85	5.99	3.53
2-yr, 24-hr	SCS Type II	17.89	39.15	14.74	7.15
10-yr, 24-hr	SCS Type II	36.59	64.71	33.67	32.94
25-yr, 24-hr	SCS Type II	48.86	80.28	44.91	47.72
50-yr, 24-hr	SCS Type II	58.97	92.70	52.08	56.10
100-yr, 24-hr	SCS Type II	69.78	105.68	61.08	67.97

- Footprint Sizing:
  - Flood control and WQ only = 10,903 SF
  - Flood control, WQ, and $Q_{critical}$ = 10,903 SF
  - Additional Design Time for optimization: 45 minutes