Optimizing Stormwater Management to Protect Streams from Erosion

Sustainable Streams LLC
Science · Service · Solutions

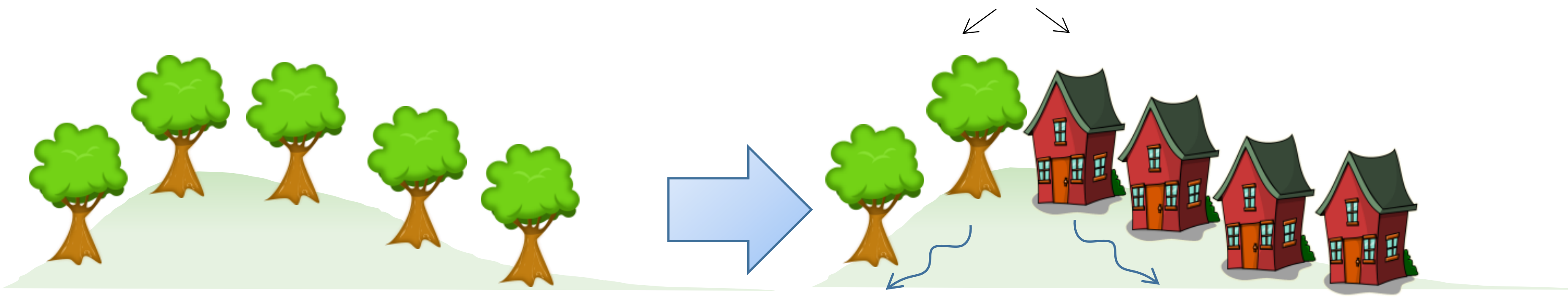
Dr. Bob Hawley, PE

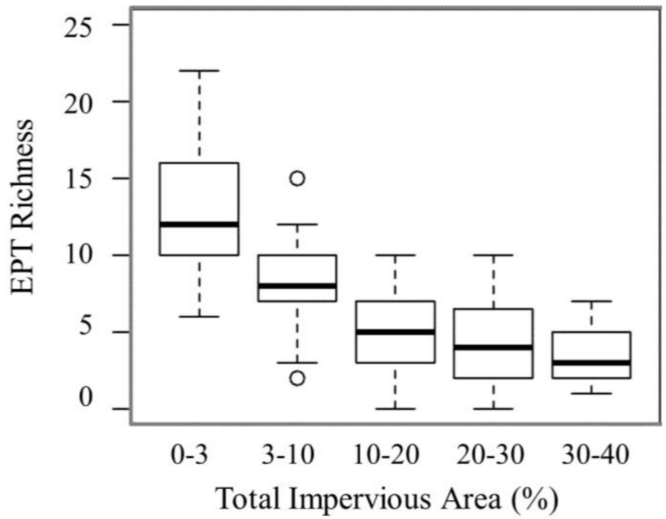
Central Ohio SW & EC Expo, 2/26/16

Survey

How Many of You Work in Watersheds with Streams Impaired by Stormwater?

Pre-developed **Post-developed**





Adapted from Hawley et al.
(In revision, Freshwater Science)

The Urban Stream Syndrome

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

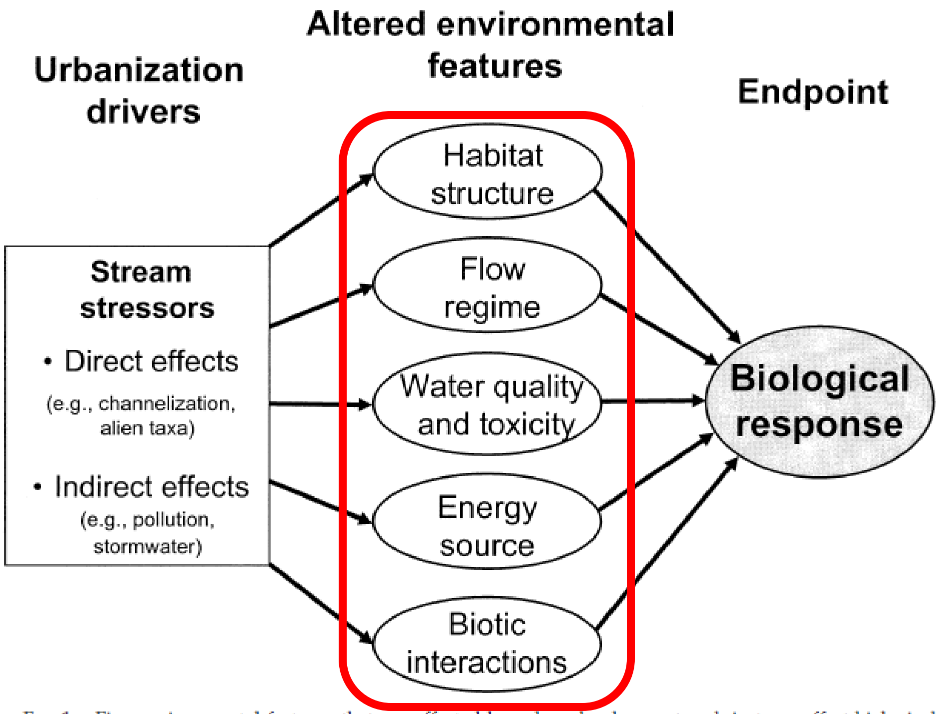


FIG. 1. Five environmental features that are affected by urban development and, in turn, affect biological conditions in urban streams (from Booth et al. 2004, reprinted with permission of the American Water Resources Association; modified from Karr 1991, Karr and Yoder 2004).

Stream Function Pyramid

(Adapted from Harmon et al., 2012)

Biological

Physicochemical

Geomorphology

Hydraulics

Hydrologic

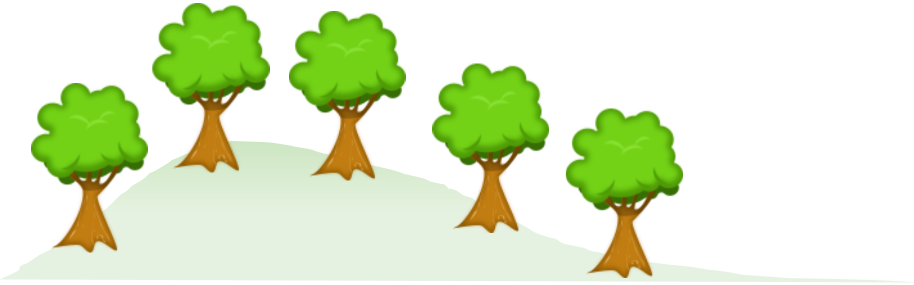
Stormwater Management

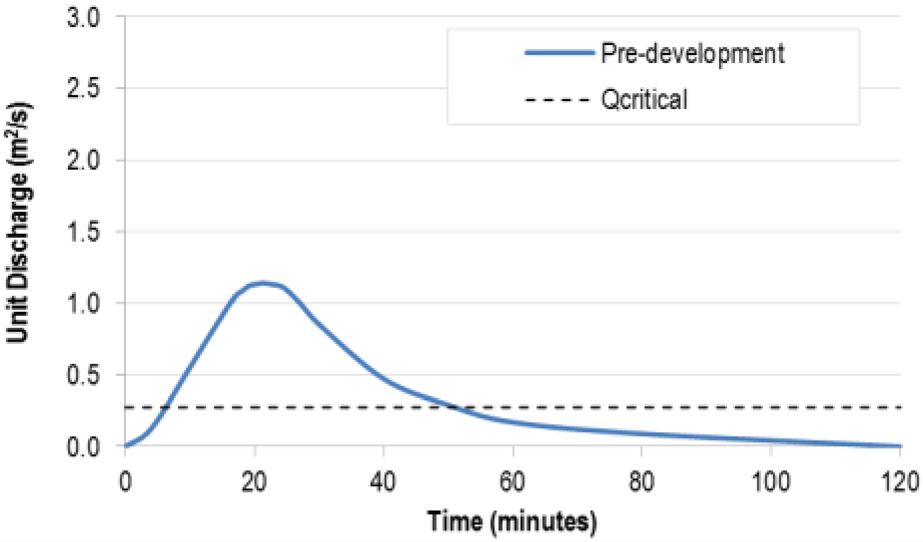
Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream

CHRISTOPHER J. WALSH[1]

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

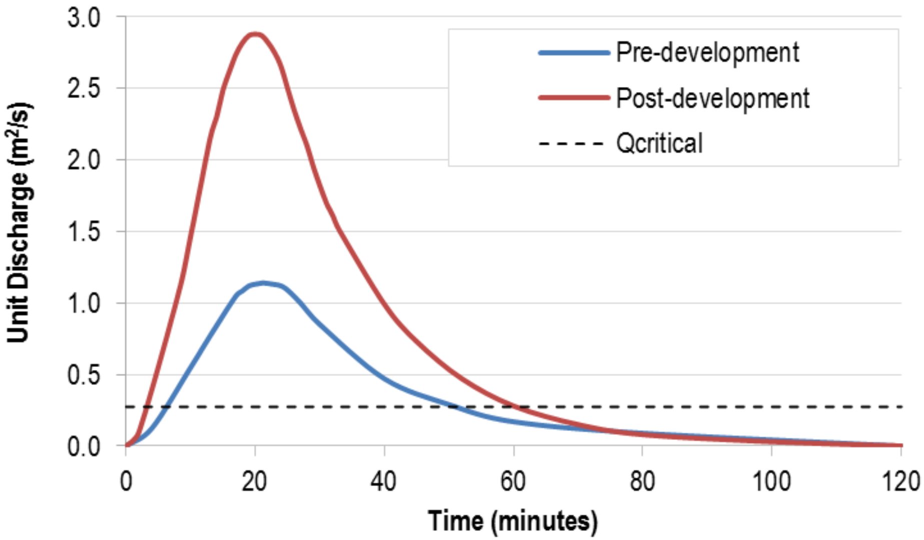
History of Stormwater Management





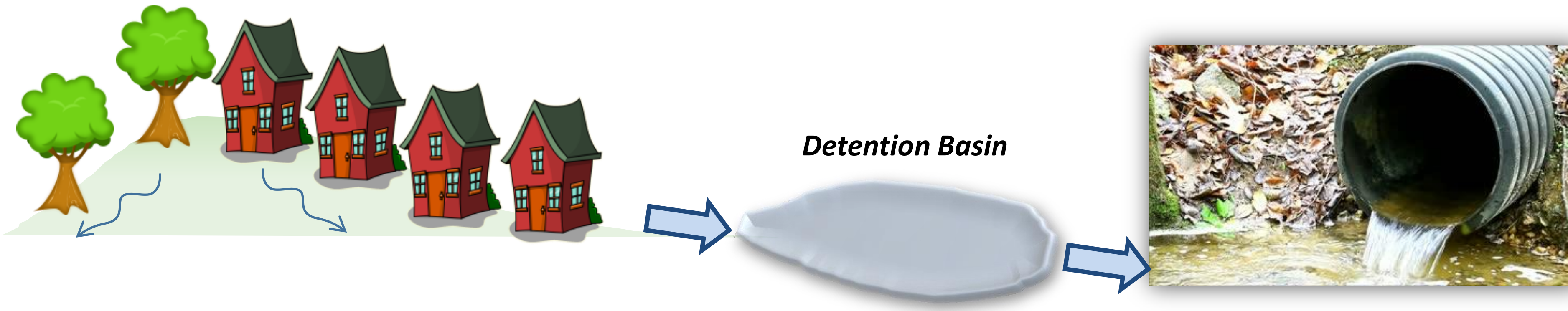
Analysis of the 2-yr, 2-hr storm from Fort Collins, CO by Bledsoe (2002), Journal of Water Resources Planning and Management

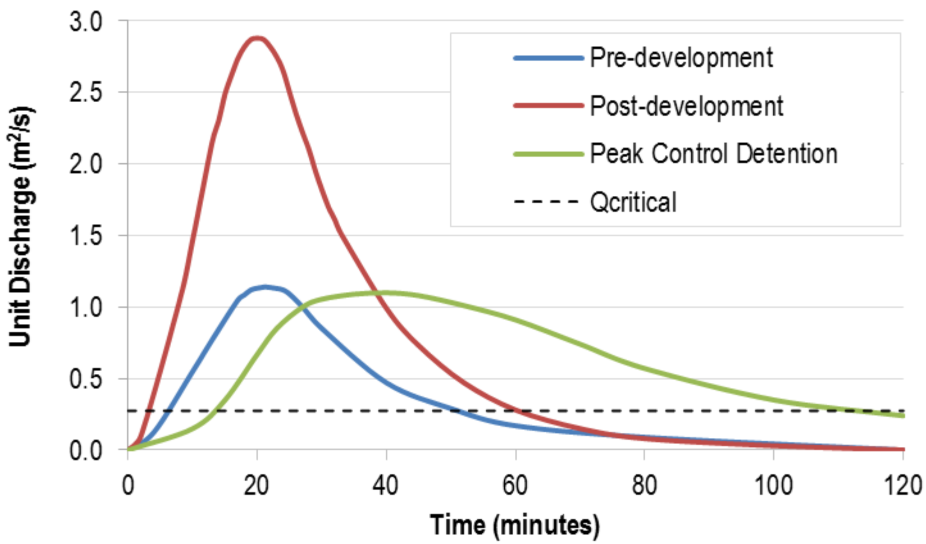
~Pre-1950



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

~1980-2000





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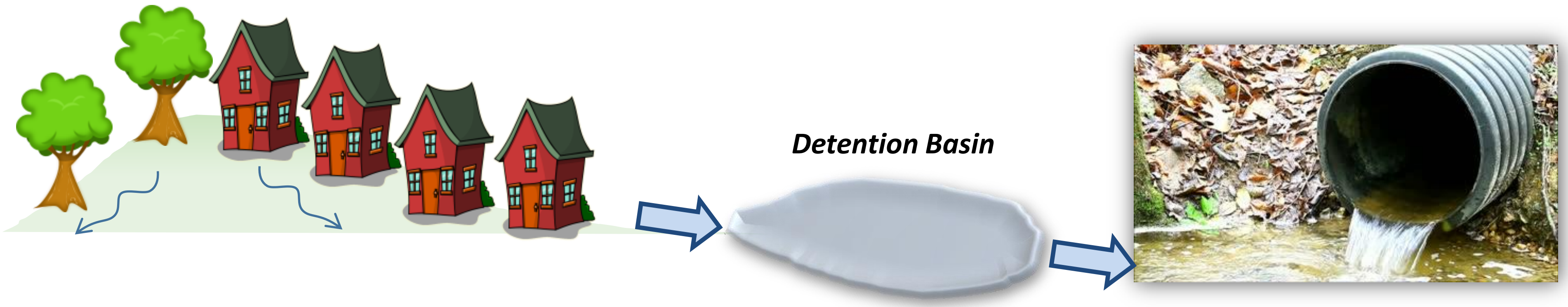
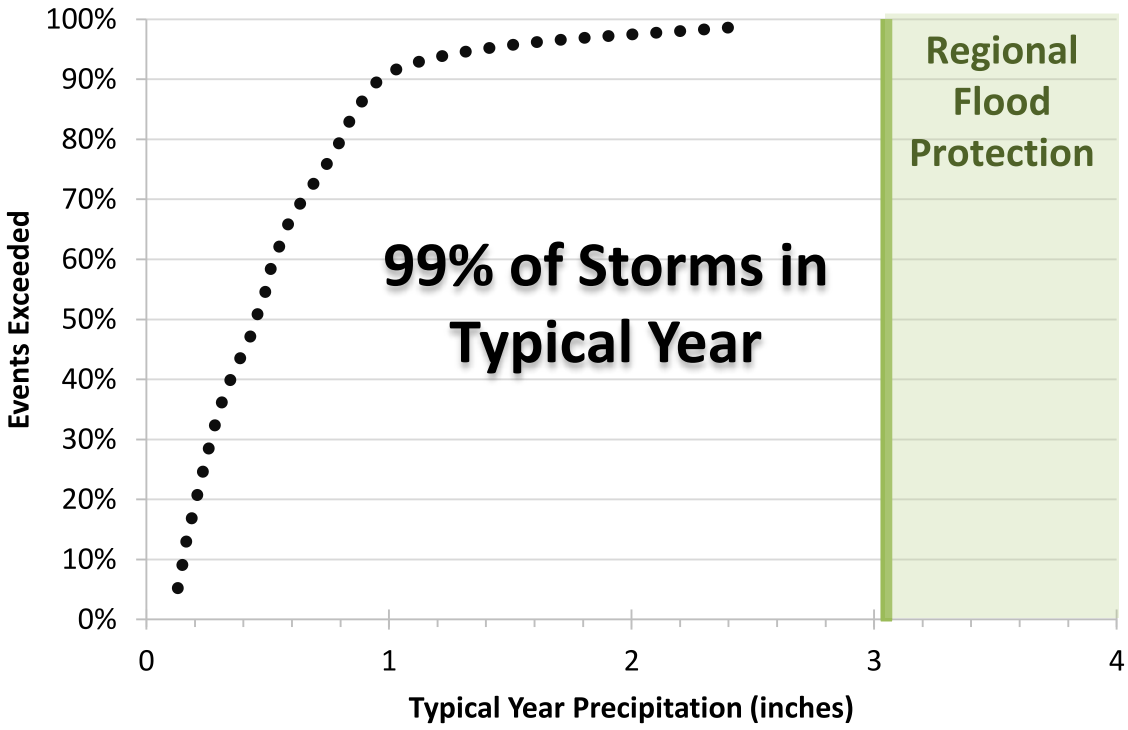
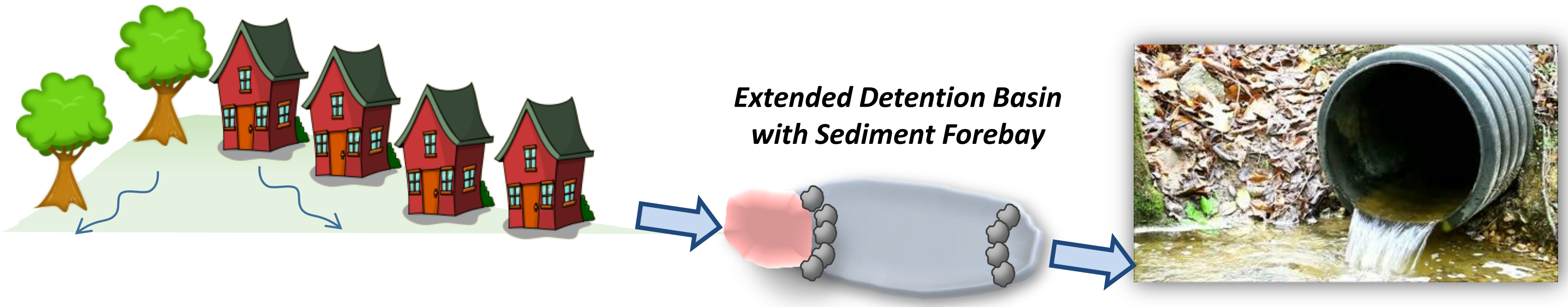


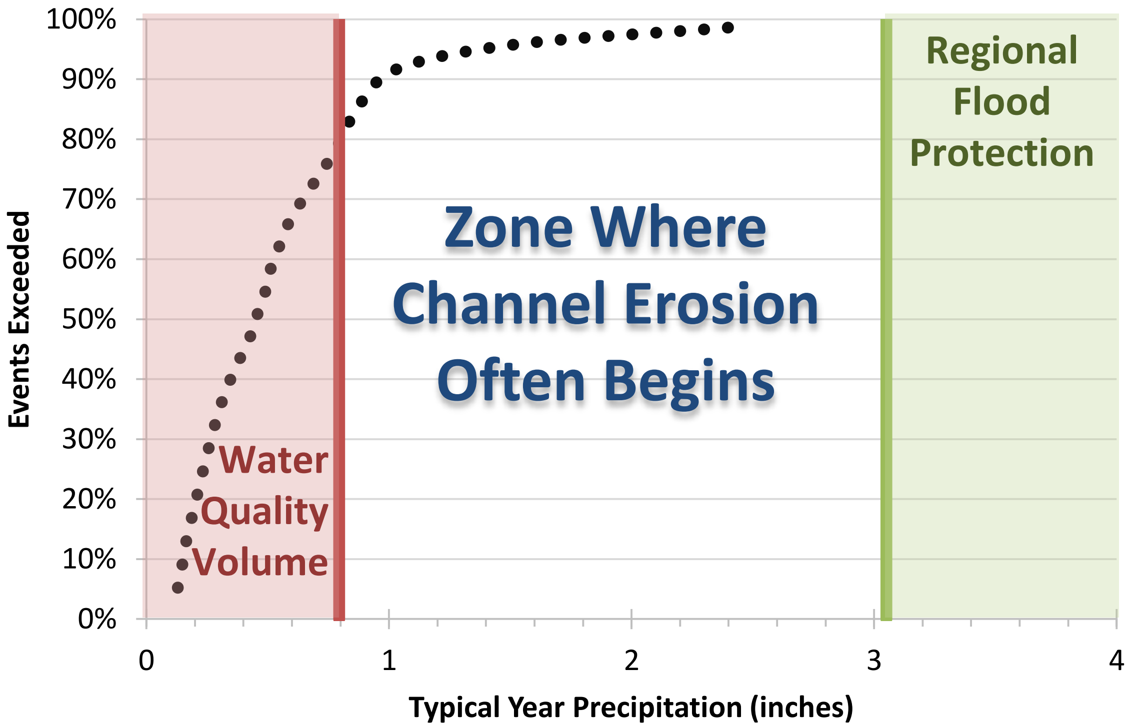


Adapted from Hawley (2012)




~2000-2015

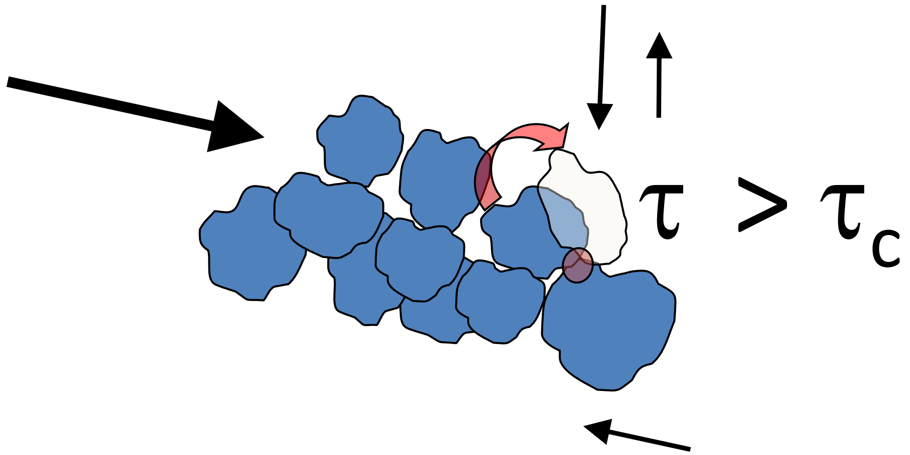




Adapted from Hawley (2012)

Introduction of $Q_{critical}$

The Critical Flow for Stream Bed Erosion

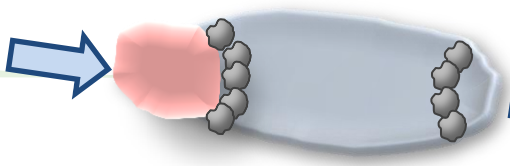


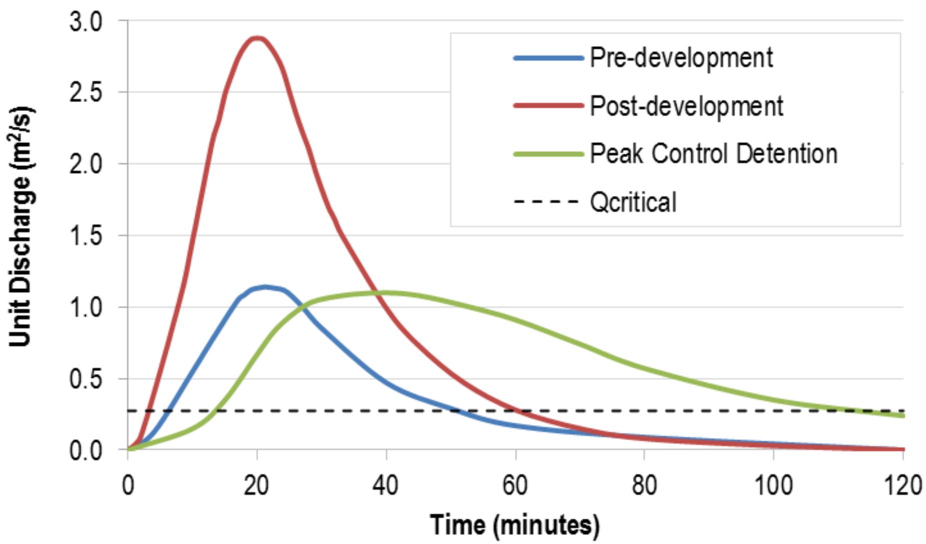
Bed Material Transport & Incipient Motion

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

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

~2000-2015





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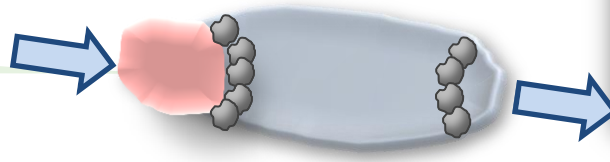
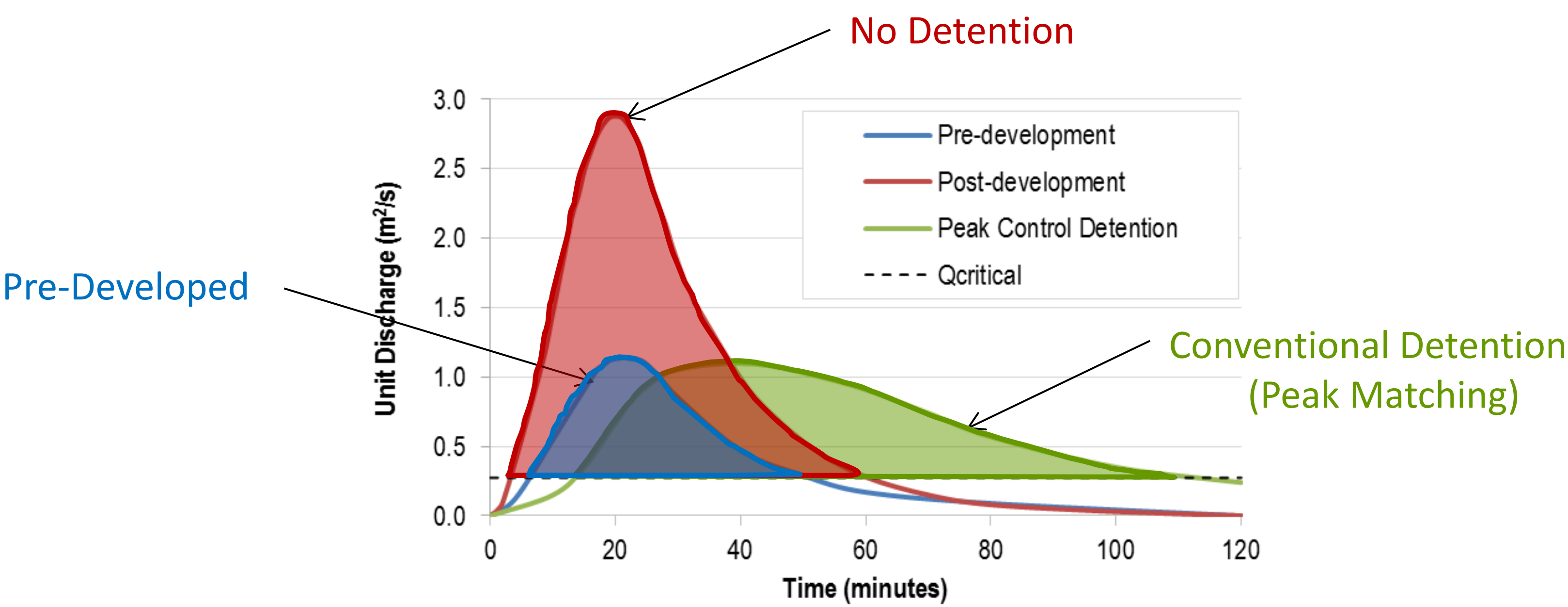
~2000-2015

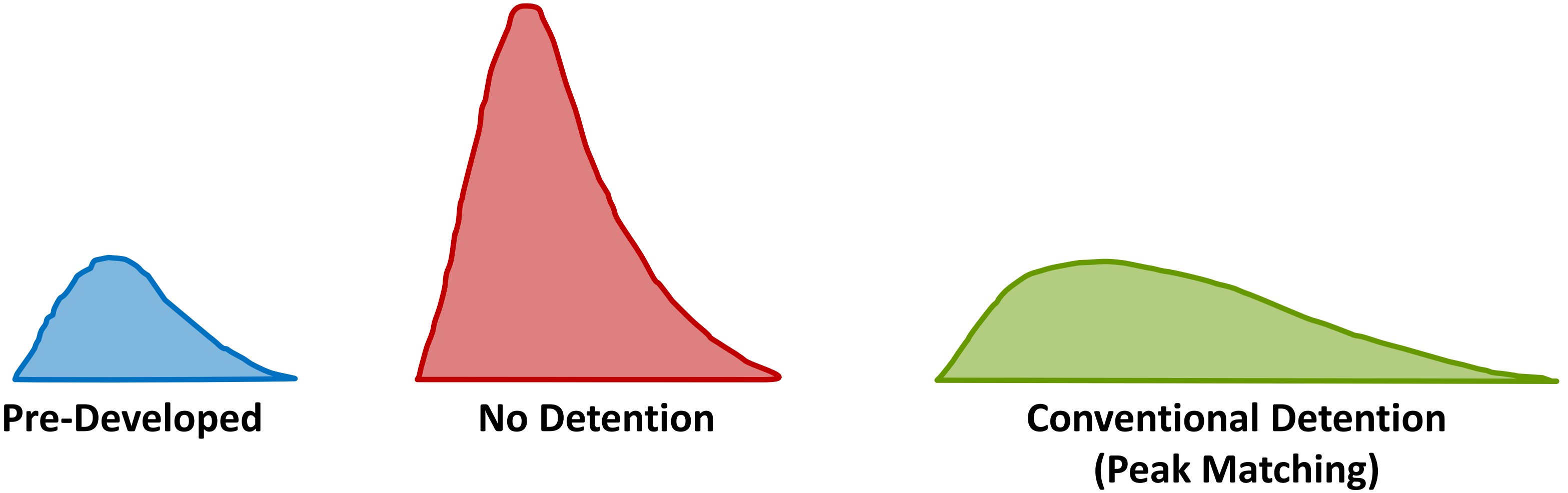
Extended Detention Basin with Sediment Forebay



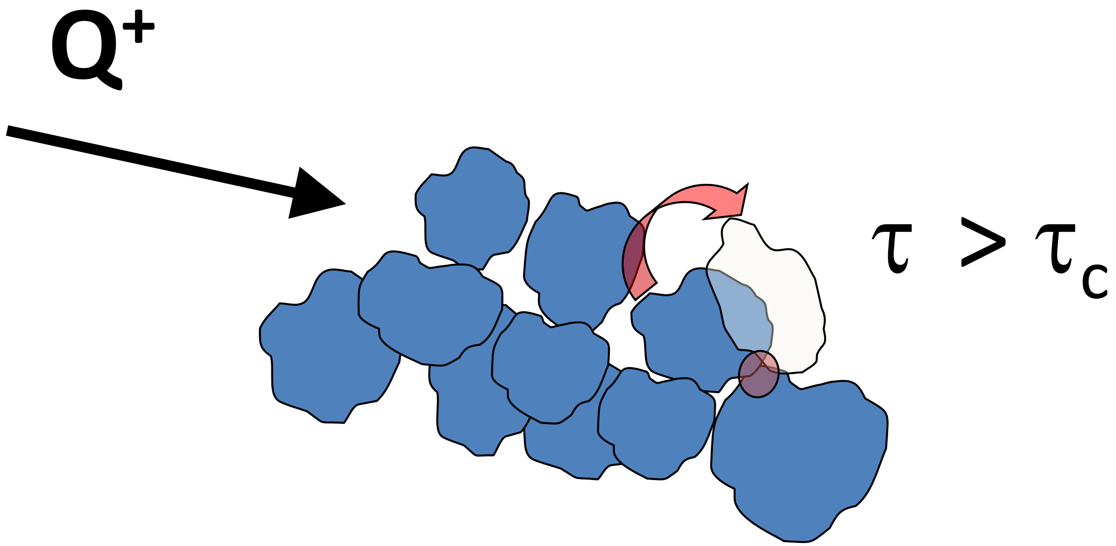


Analysis of the 2-yr, 2-hr storm from Fort Collins, CO by Bledsoe (2002), Journal of Water Resources Planning and Management

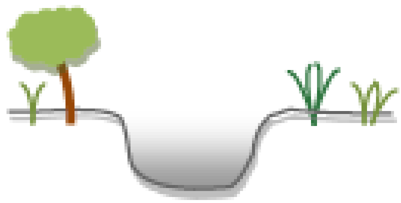
Conventional Detention = ***More Erosion*** than Pre-Developed Conditions



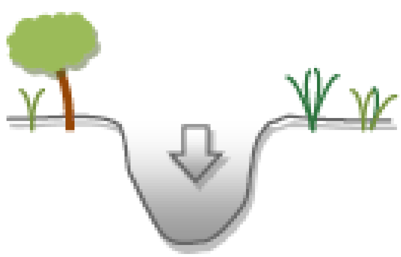
Longer Durations of Flows > $Q_{critical}$
Increased Transport of Stream Bed Material



Increased Bed Erosion → Incision (Downcutting)

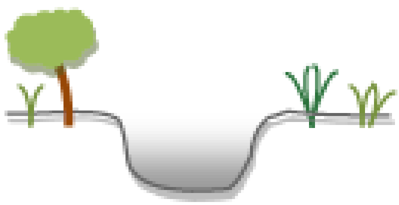


Stage1 – Equilibrium

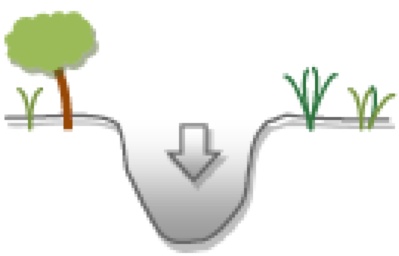


Stage 2– Incision

Incision → Taller Banks → Bank Failure



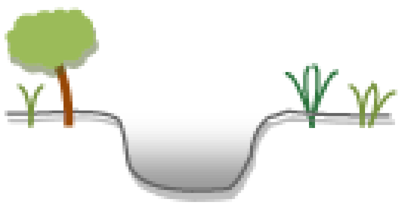
Stage1 – Equilibrium



Stage 2– Incision

Stage 3 – Widening

Bank Failure → Widening



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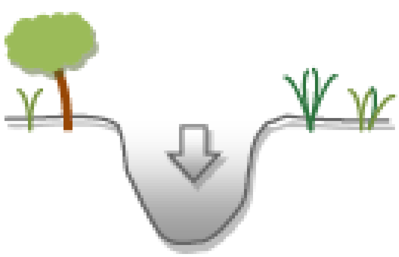
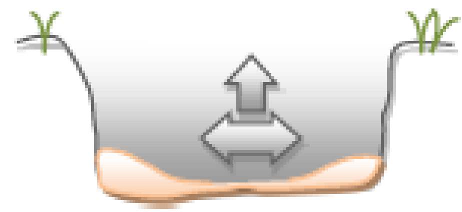


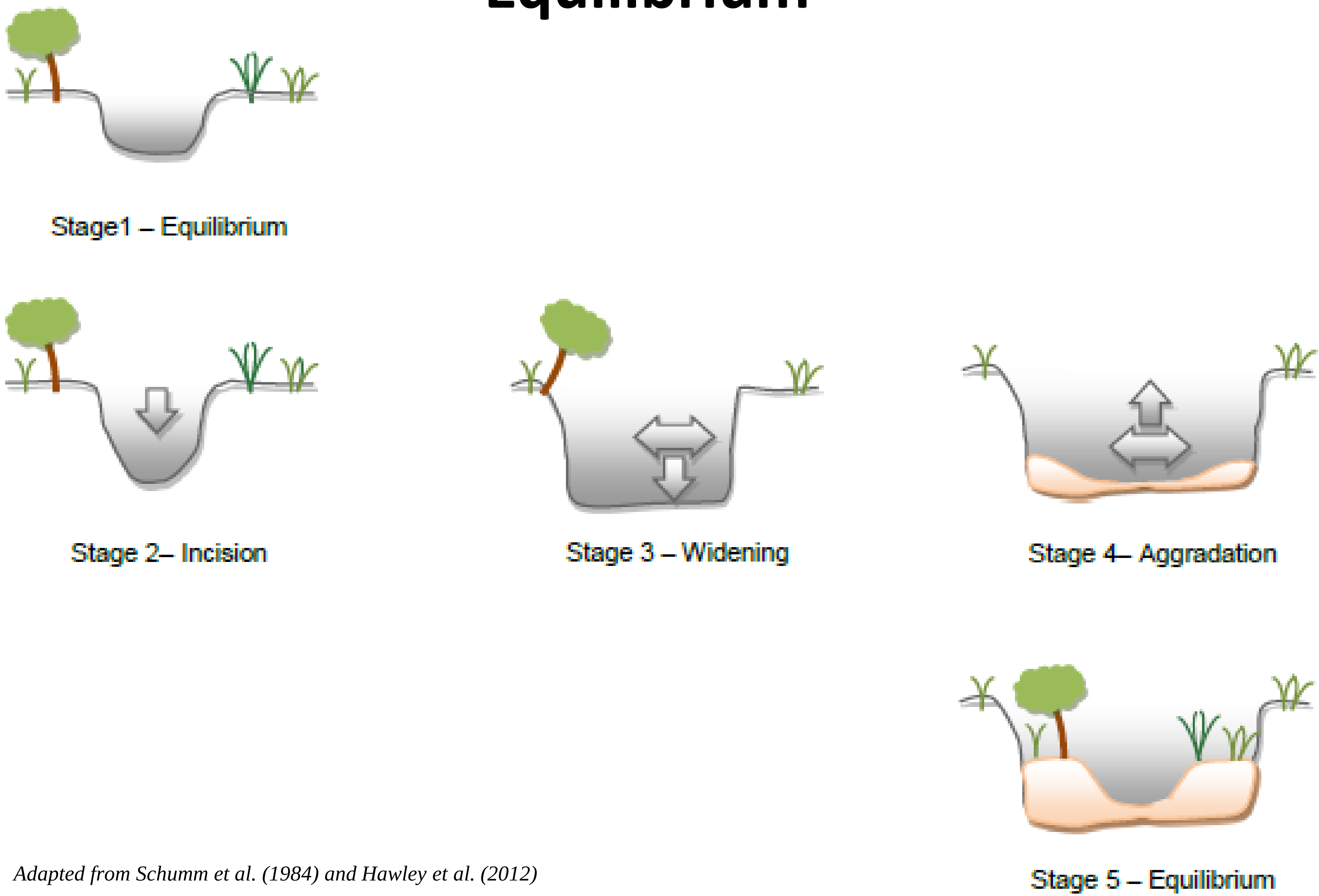
Stage 2– Incision

Stage 3 – Widening



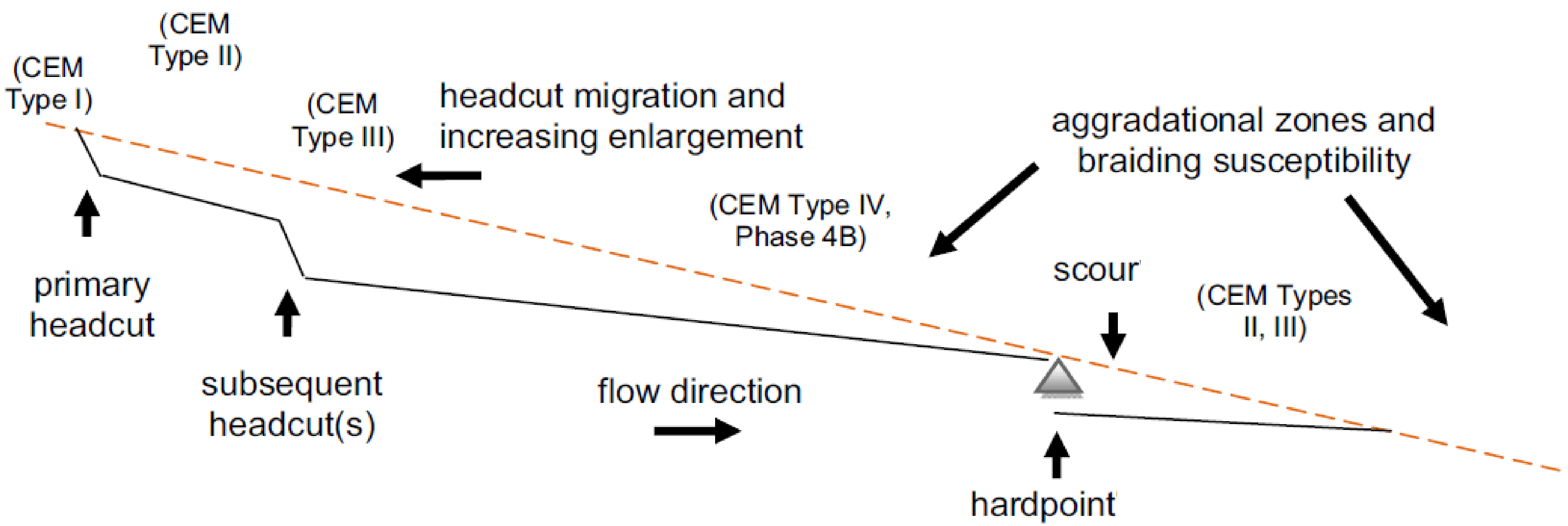
Stage 4– Aggradation

→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

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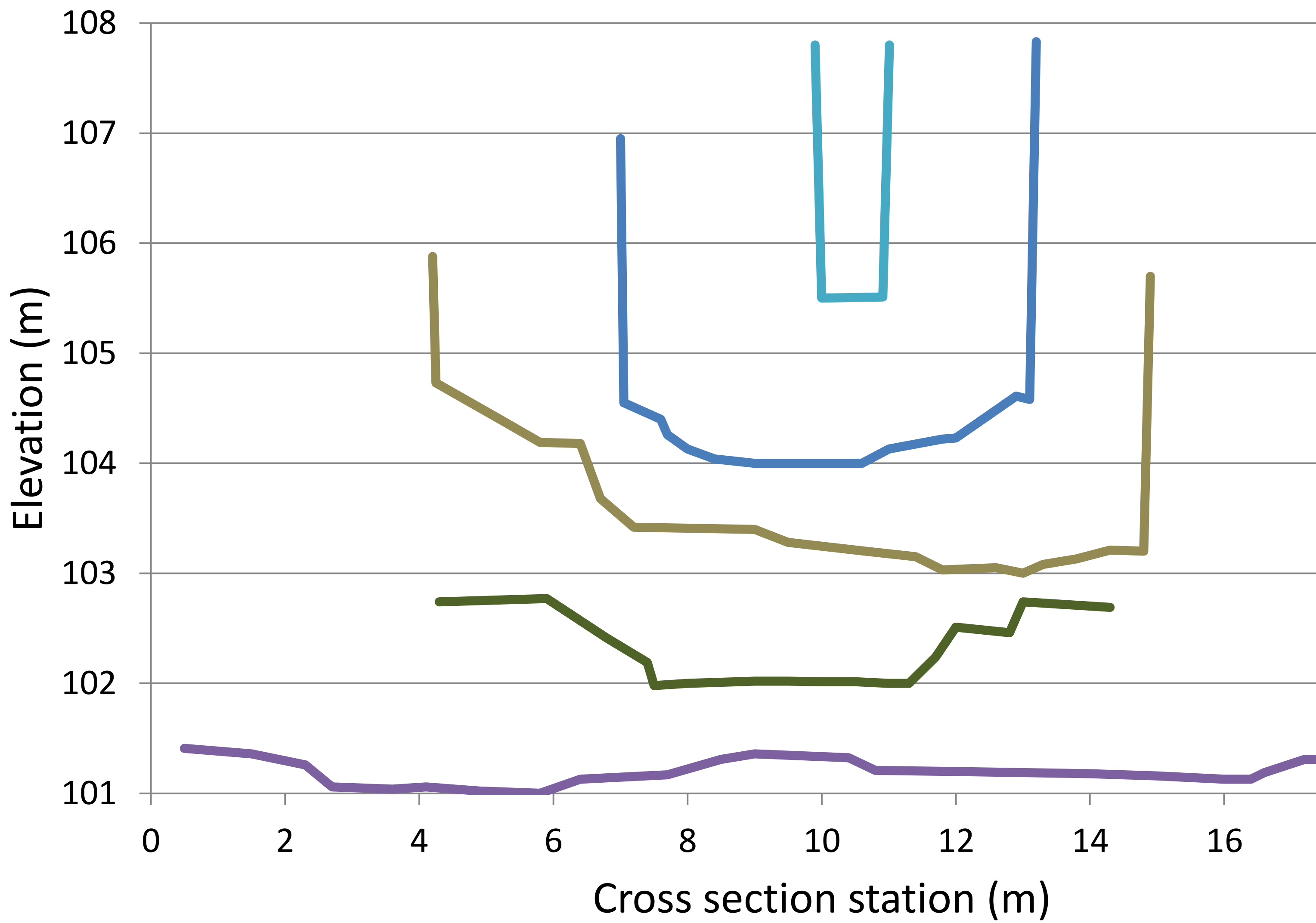
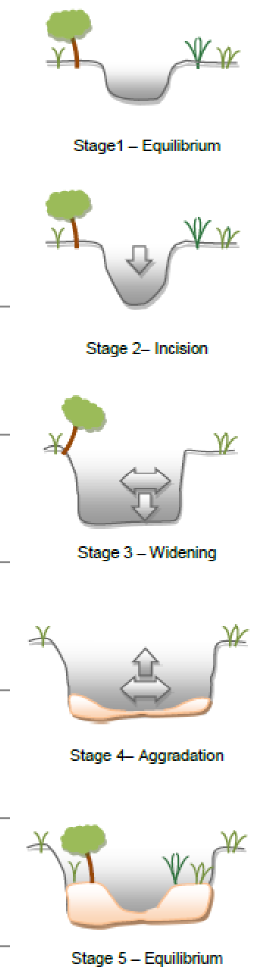
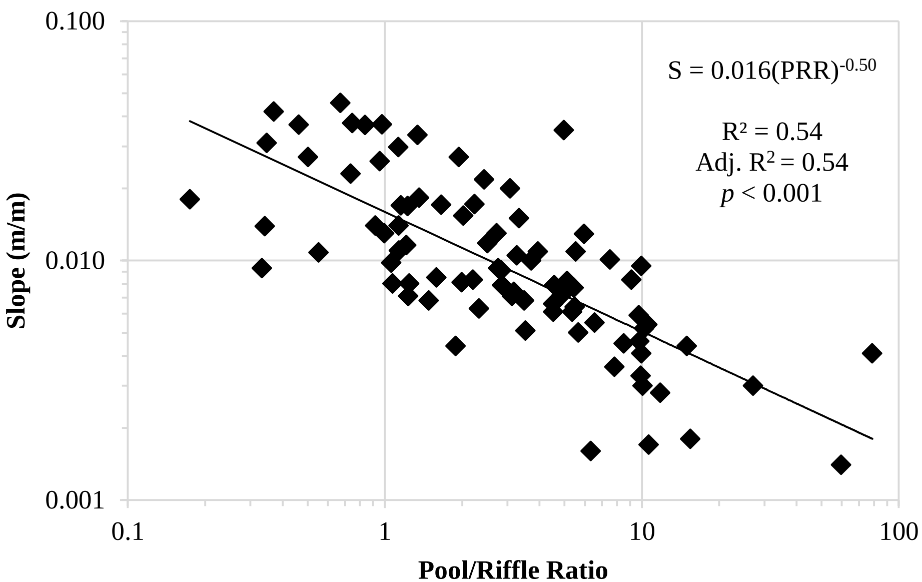




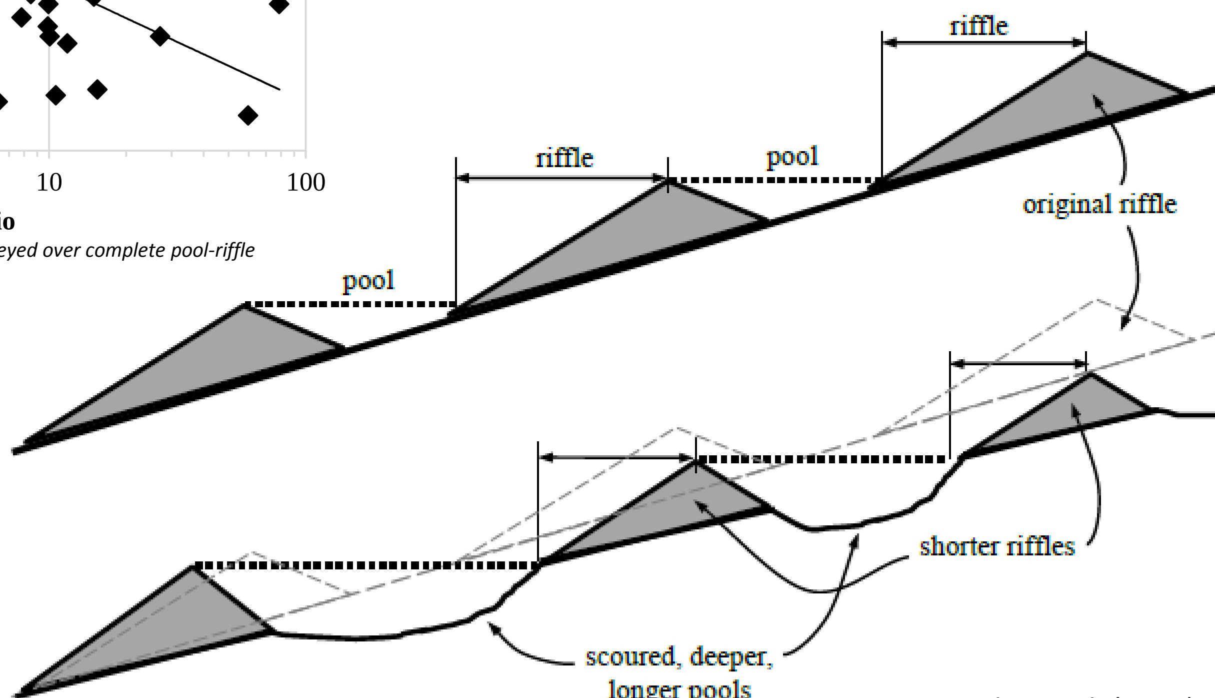
Channel Evolution Sequence in Response to Increased Flows from Urbanization, Adapted from Schumm et al. (1984) and Hawley et al. (2012)

Adapted from Hawley and Bledsoe (2013)

Headcutting → Flatter Slopes → Shorter Riffles & Longer Pools



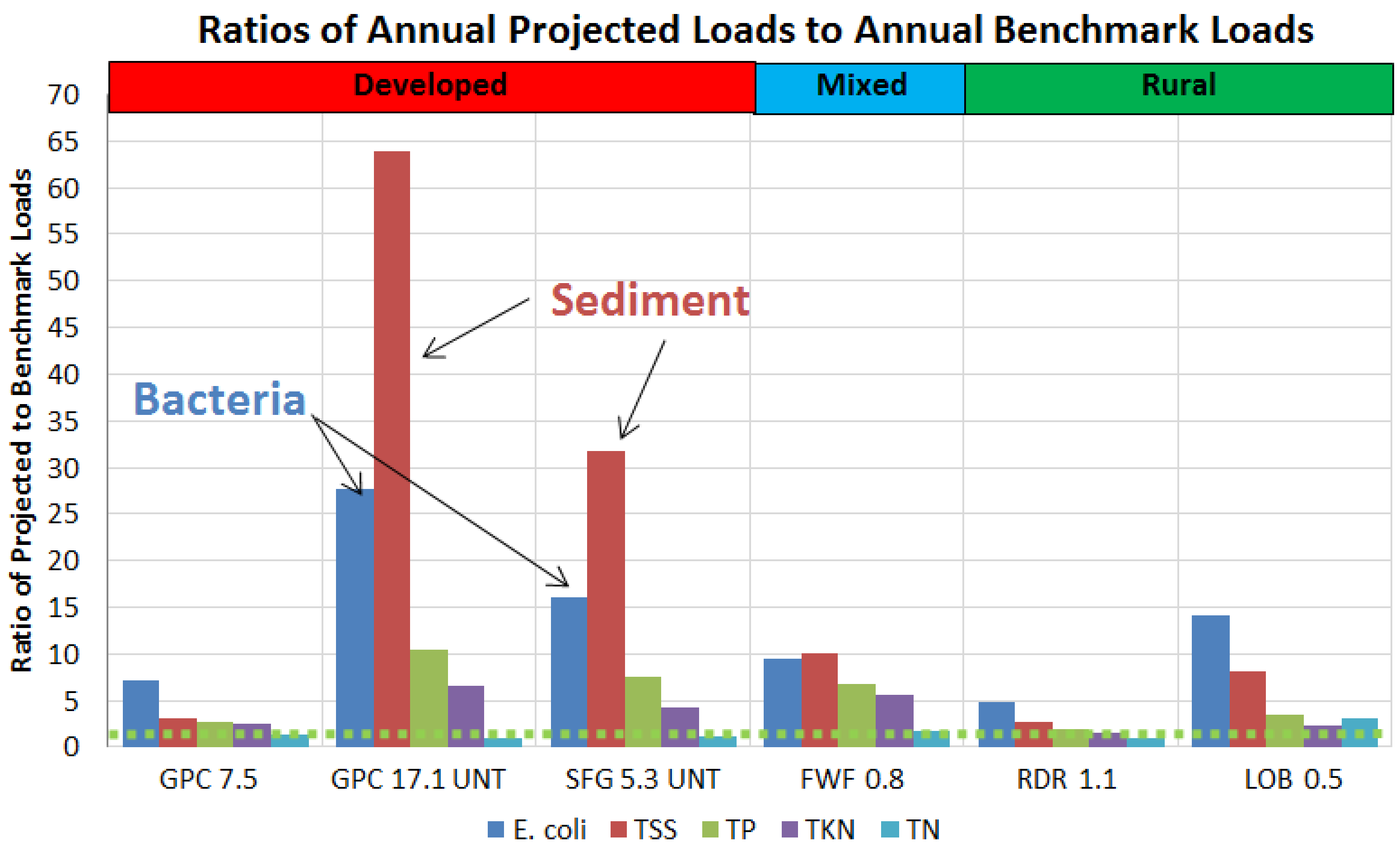
n = 86. Figure and trend includes all profile data surveyed over complete pool-riffle reaches.



Hawley et al. (2013)

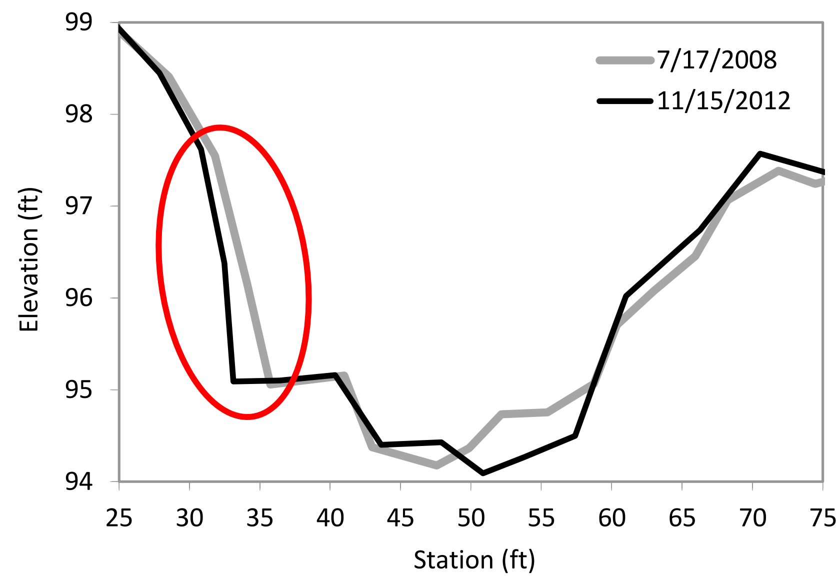
Bank Instability → Fine Sediment Loads
Sediment Is a Leading Impairment of U.S. Waterways

Gunpowder Creek Watershed Case Study (Northern Kentucky, USA)



SFG 5.3 - DS
28% impervious

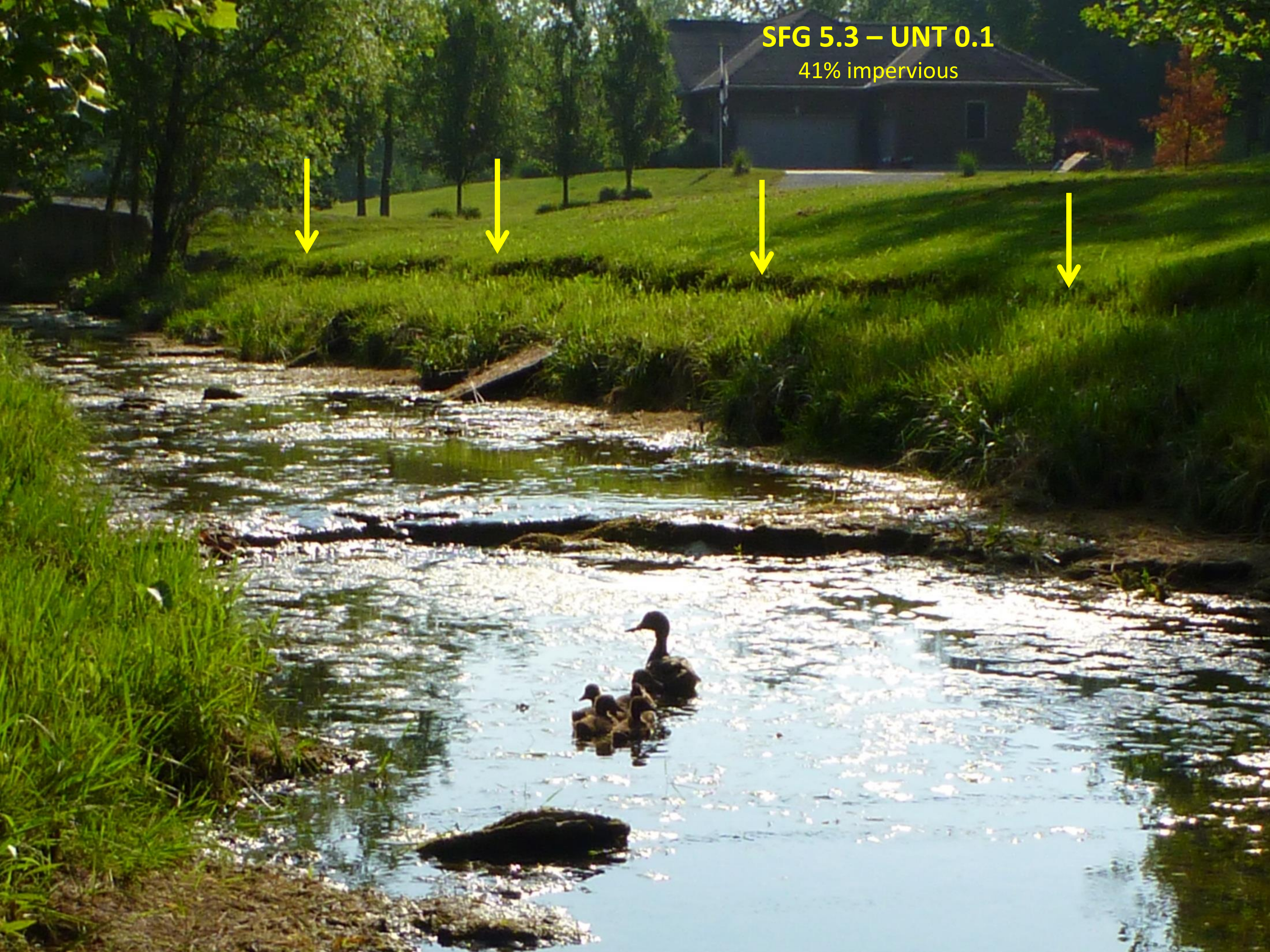
Bank Erosion and Tree Loss



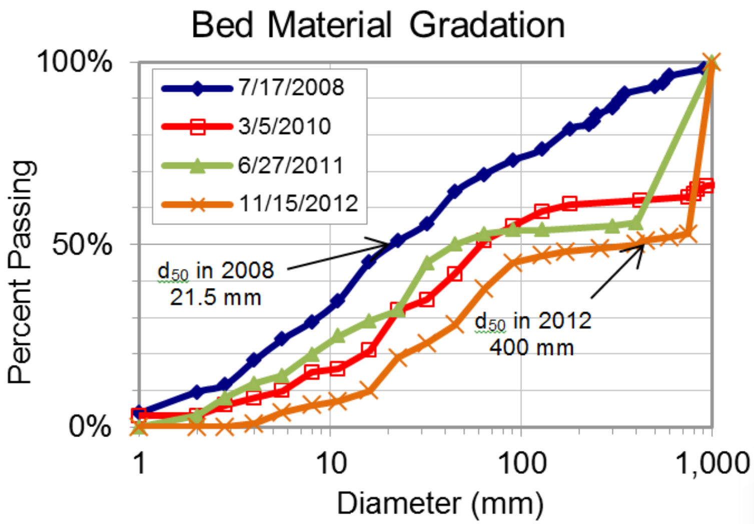
Monitoring Confirms Bank Erosion as a Dominant Source of TSS

Site Name	Projected TSS Yield Due to Bank Erosion (lb/mi²yr)	Projected TSS Yield From Water Column Samples (lb/mi²yr)	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.

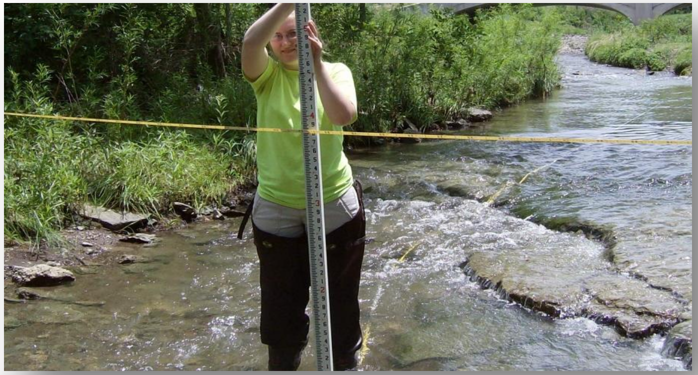

SFG 5.3 – UNT 0.1
41% impervious

Bed Coarsening and Habitat Homogenization



SFG 5.3 – DS

29% impervious



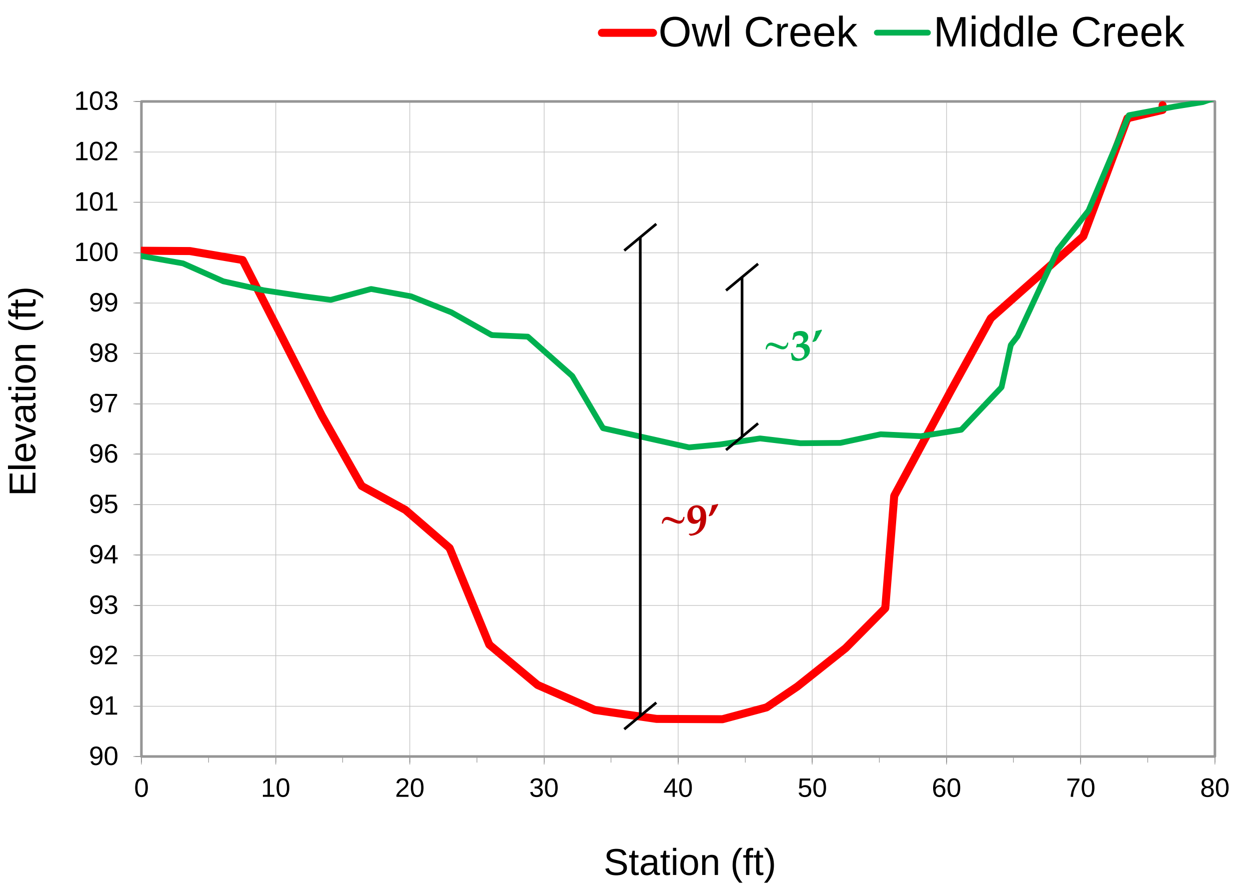
More homogenous habitat

Conventional Storm Water Designs → Unstable Streams

Middle Creek (3.3 mi^2)
0.6% Impervious

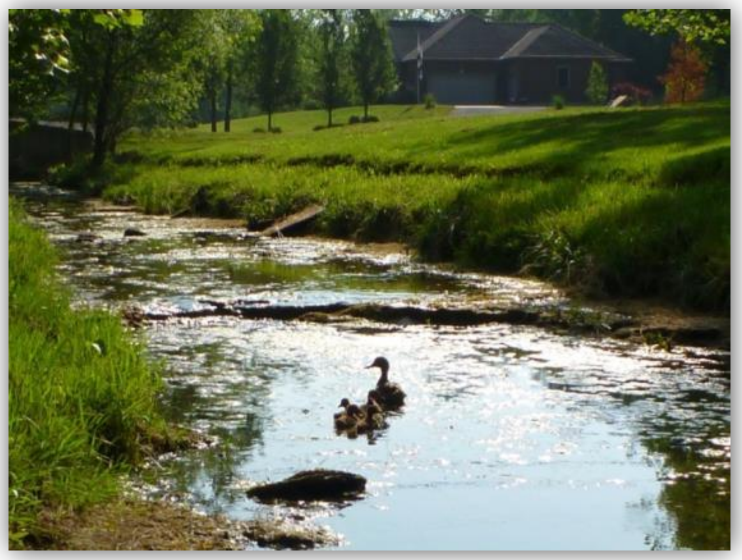
Owl Creek (3.7 mi^2)
9% Impervious

Conventional Storm Water Designs → Unstable Streams

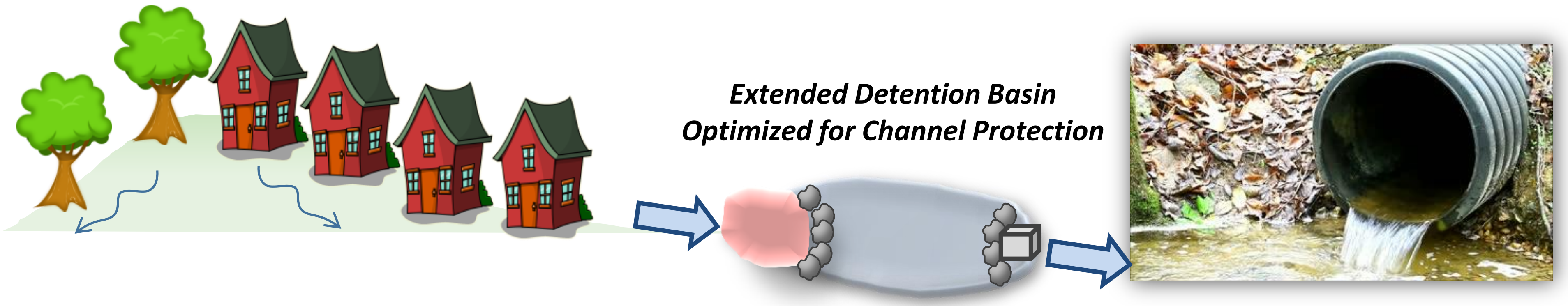


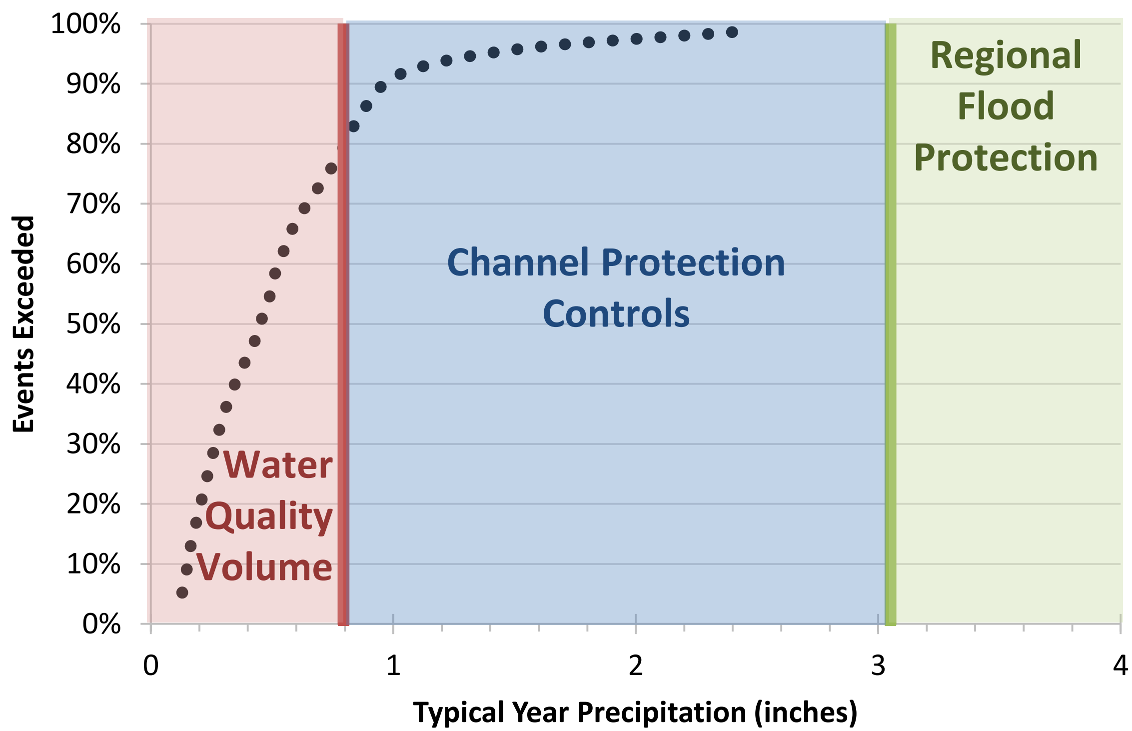
Unstable Streams
Impact Resources and Waste $$$

- Aquatic habitat
- Water quality
- Private property
- Infrastructure



Future of Stormwater Management





Adapted from Hawley (2012)

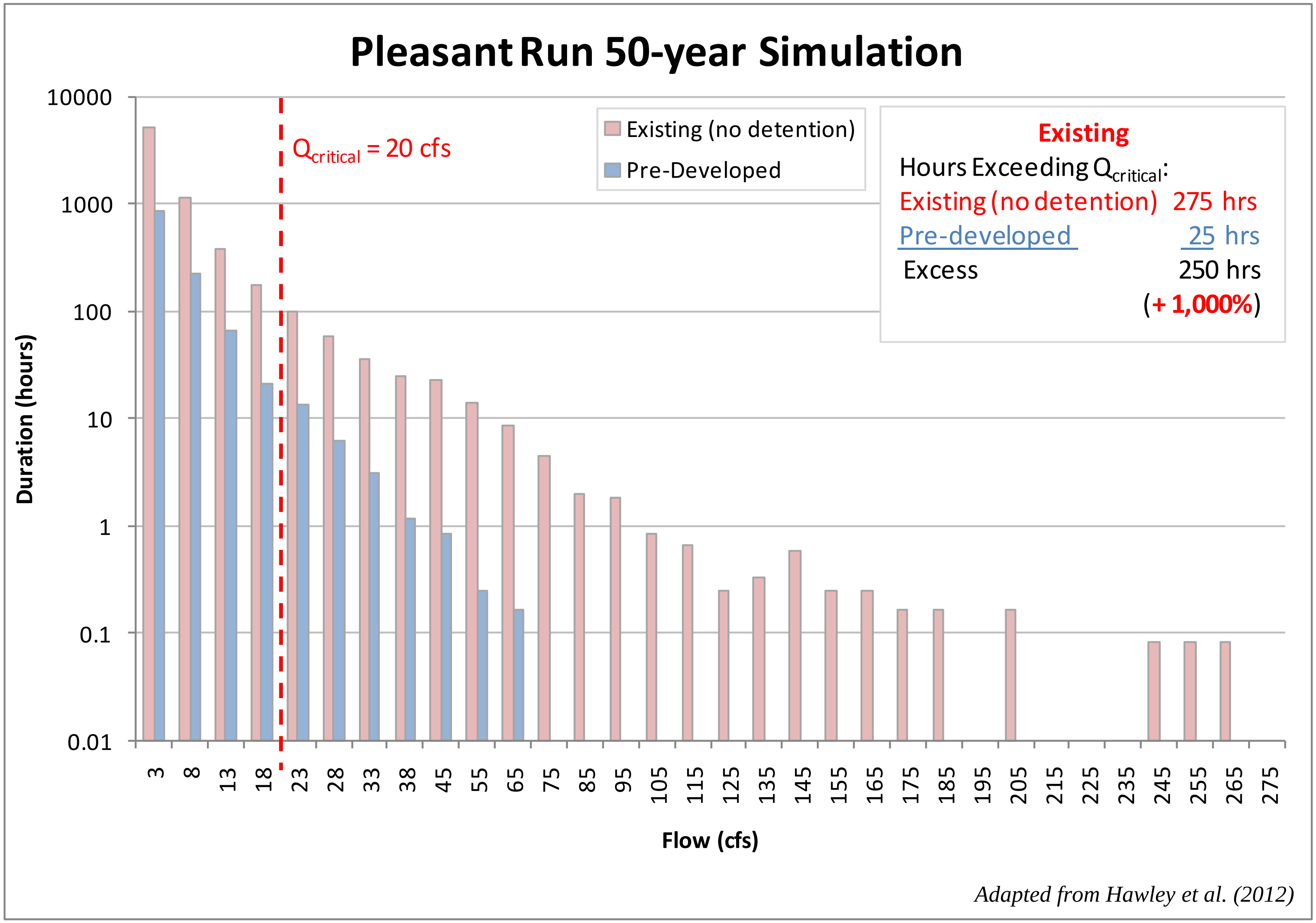
Channel Protection Controls Optimized to Prevent Excess Erosion

0.45 inches in 2 hours

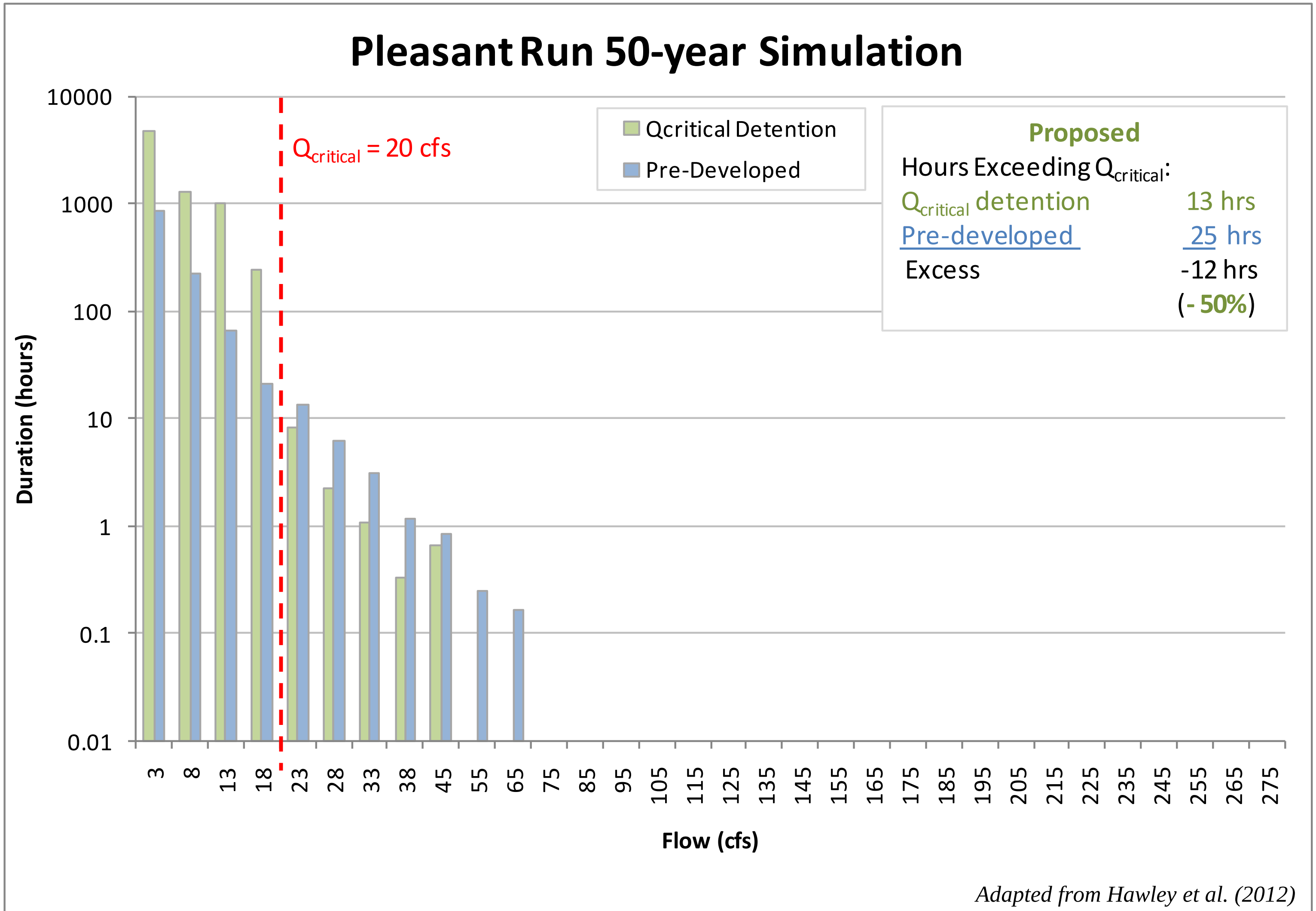
Unnamed Tributary

0.16 square miles (~100 acres), 26% Impervious

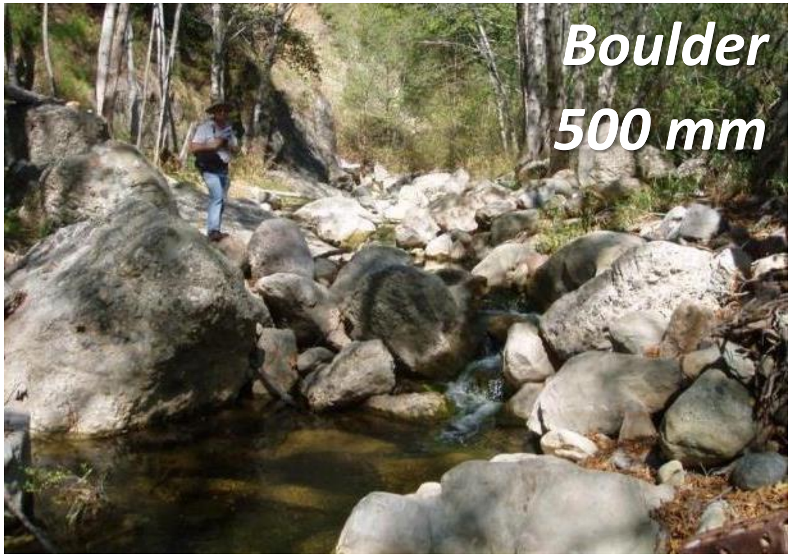
$Q_{critical}$ Design Target = "Safe Release Rate"

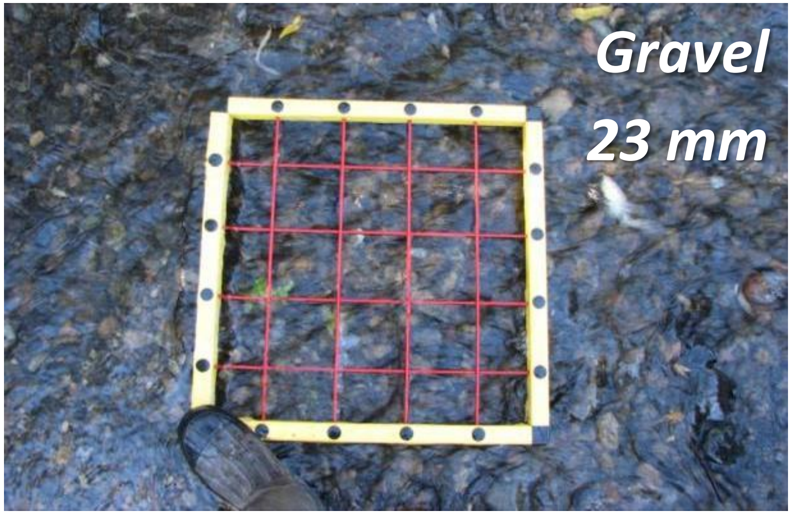


If Excess Volume Is Released Below $Q_{critical}$ →No Excess Erosion or Biological Disturbance

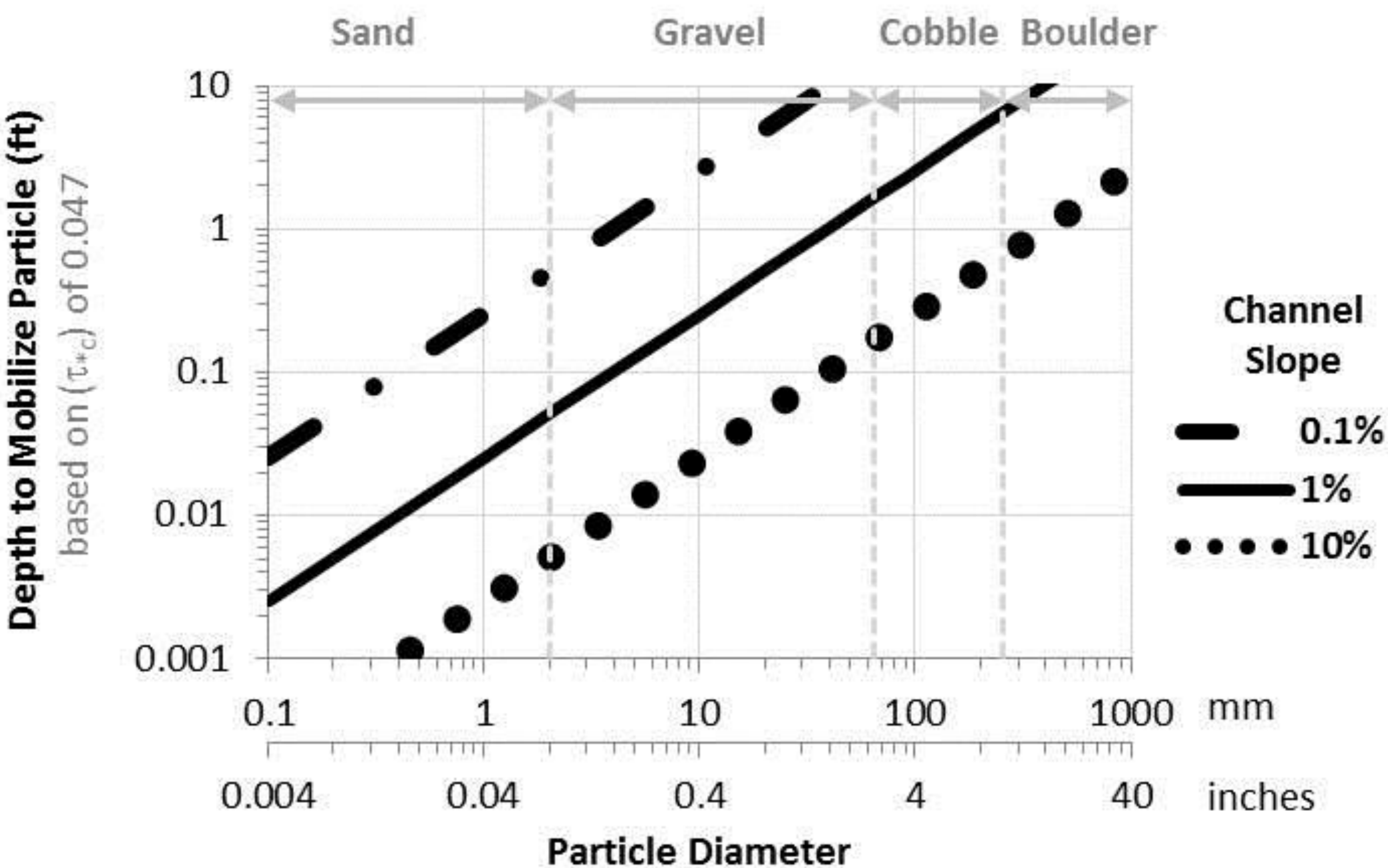


$Q_{critical}$ Varies by Stream Resistance





Resistance Increases with Particle Size and Decreases with Slope



Adapted from Hawley and Vietz (In Press, Freshwater Science)

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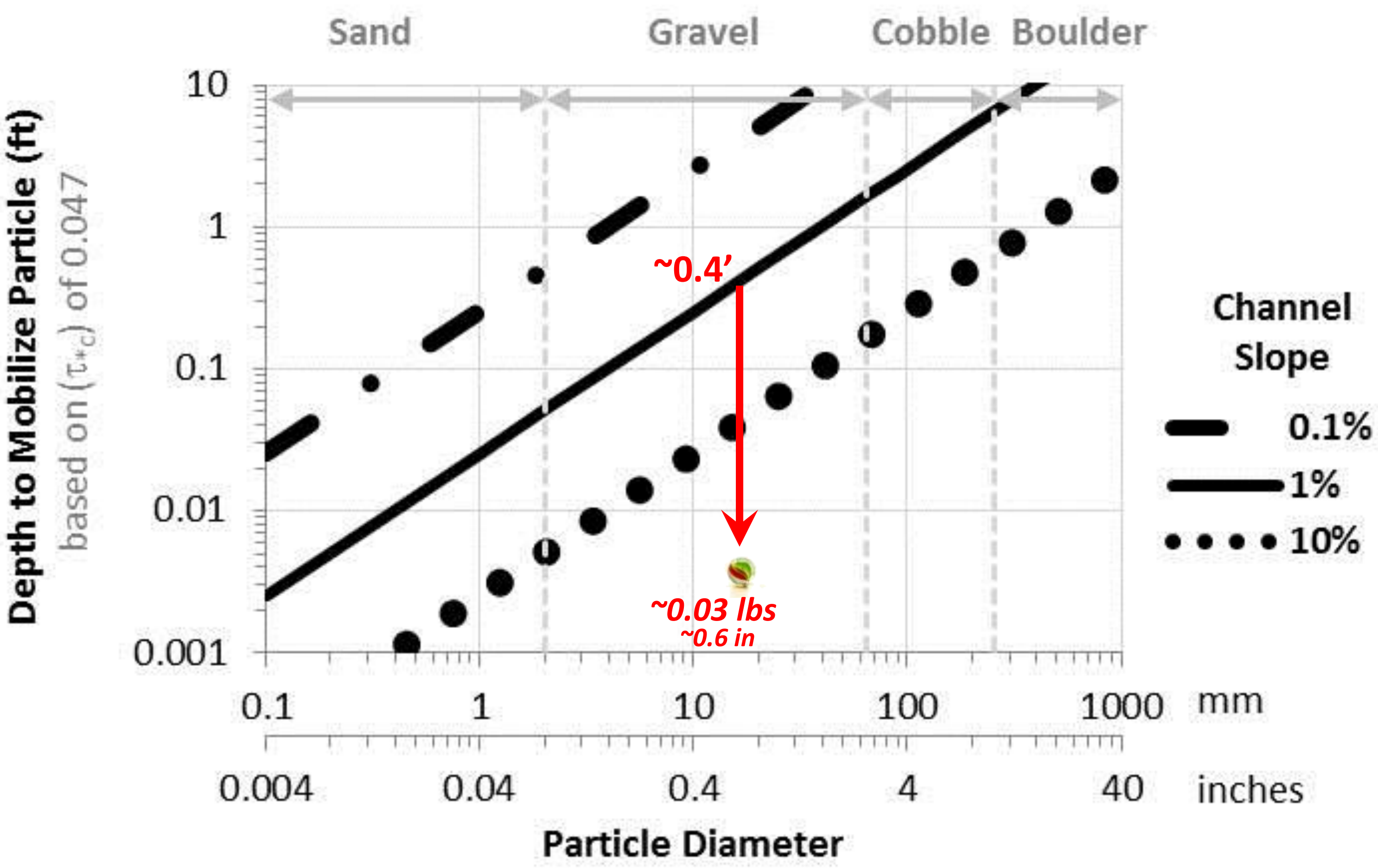

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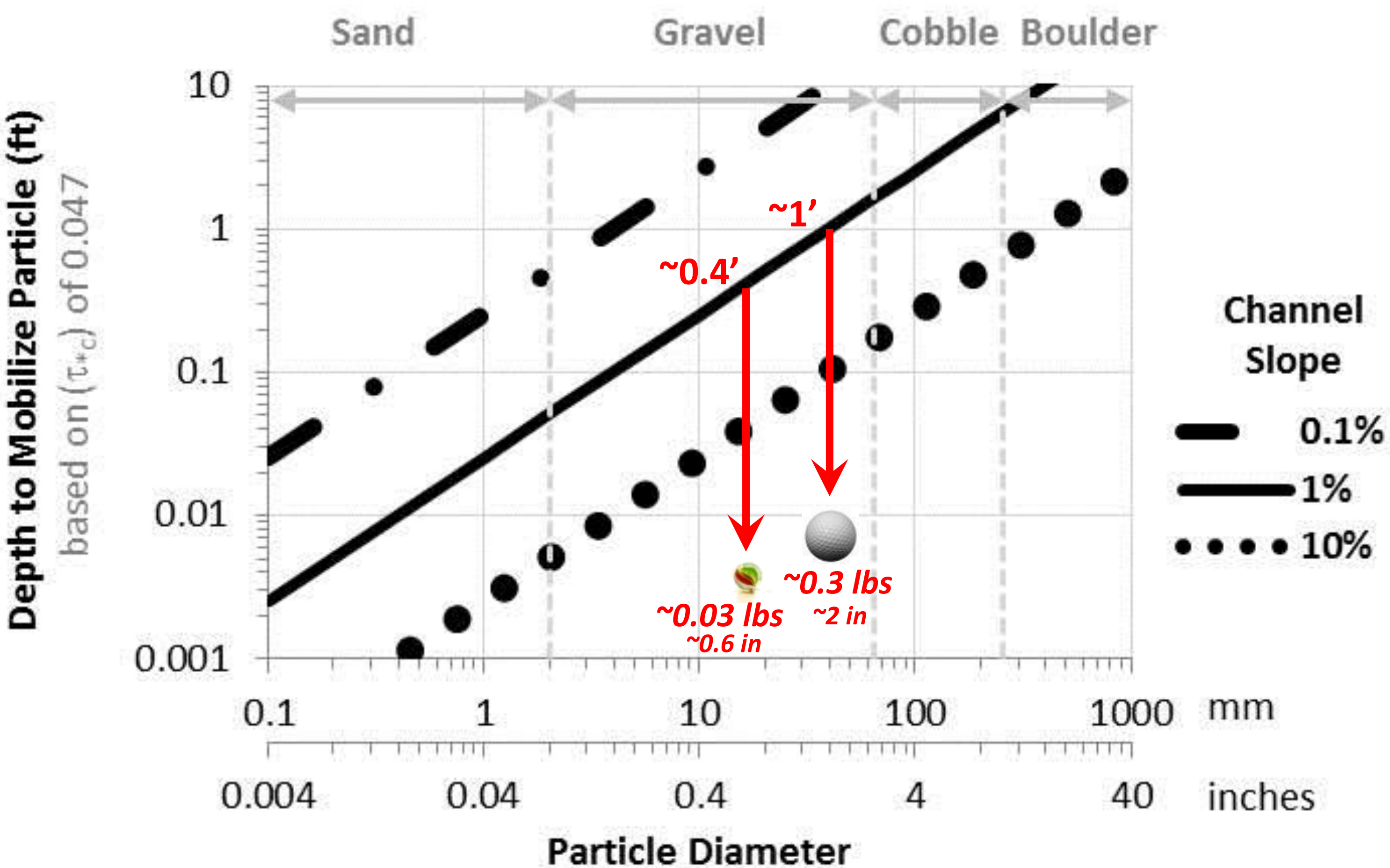

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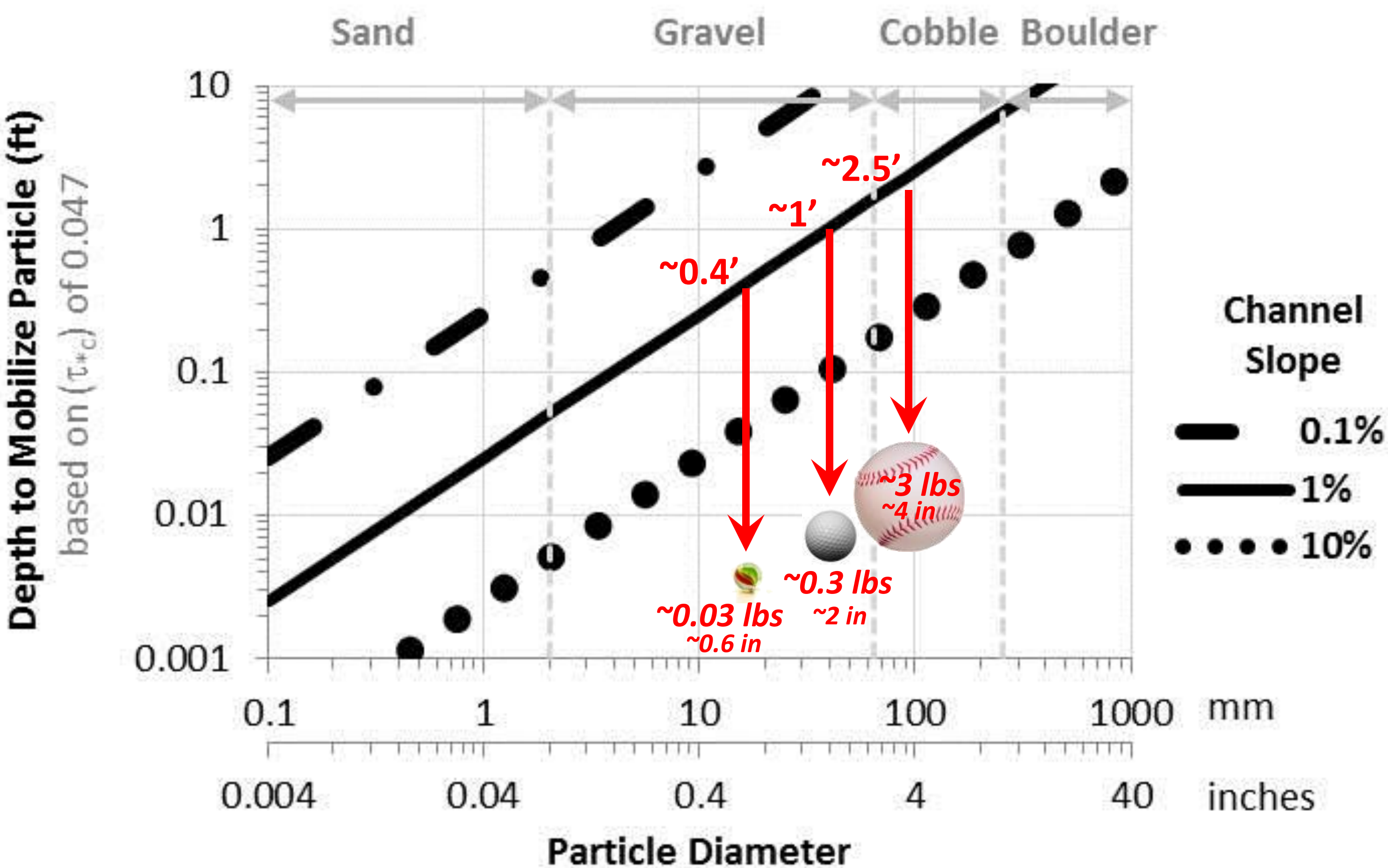

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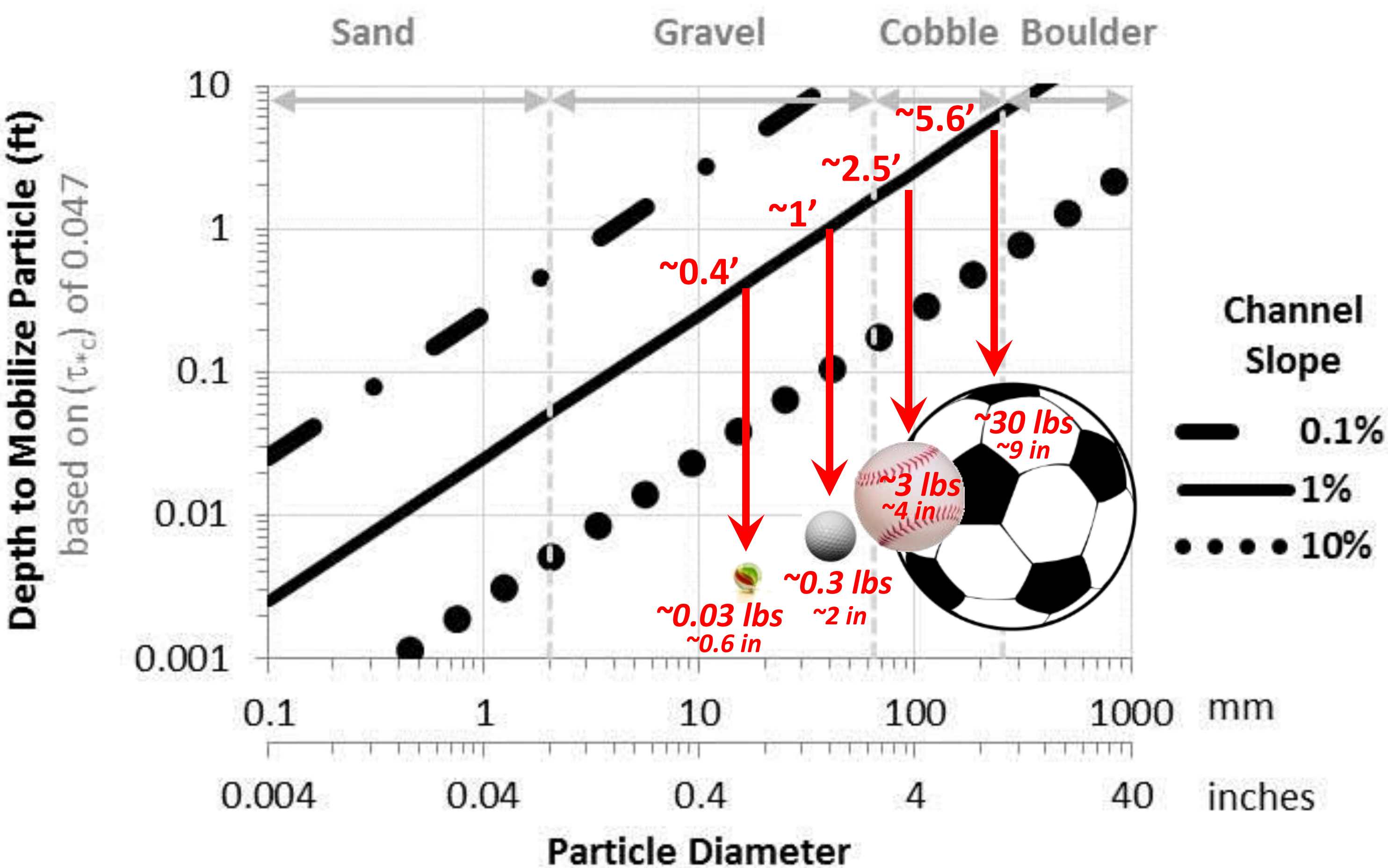
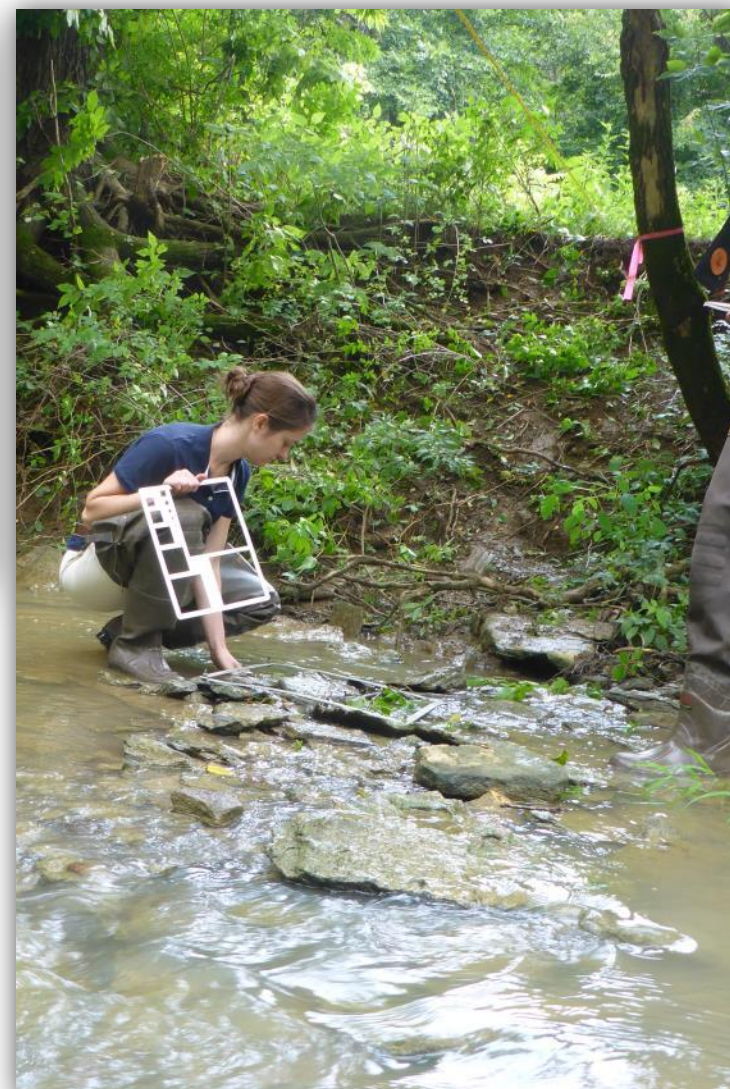
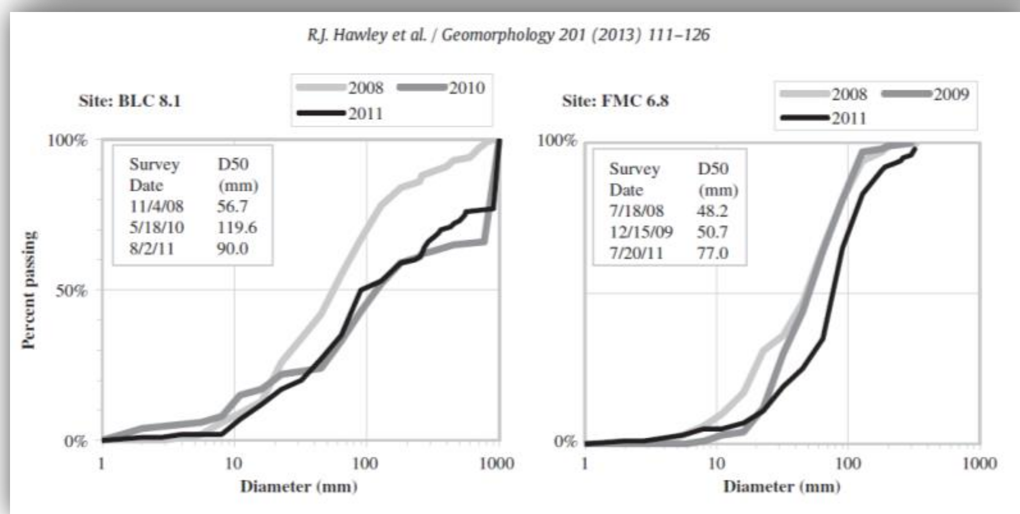


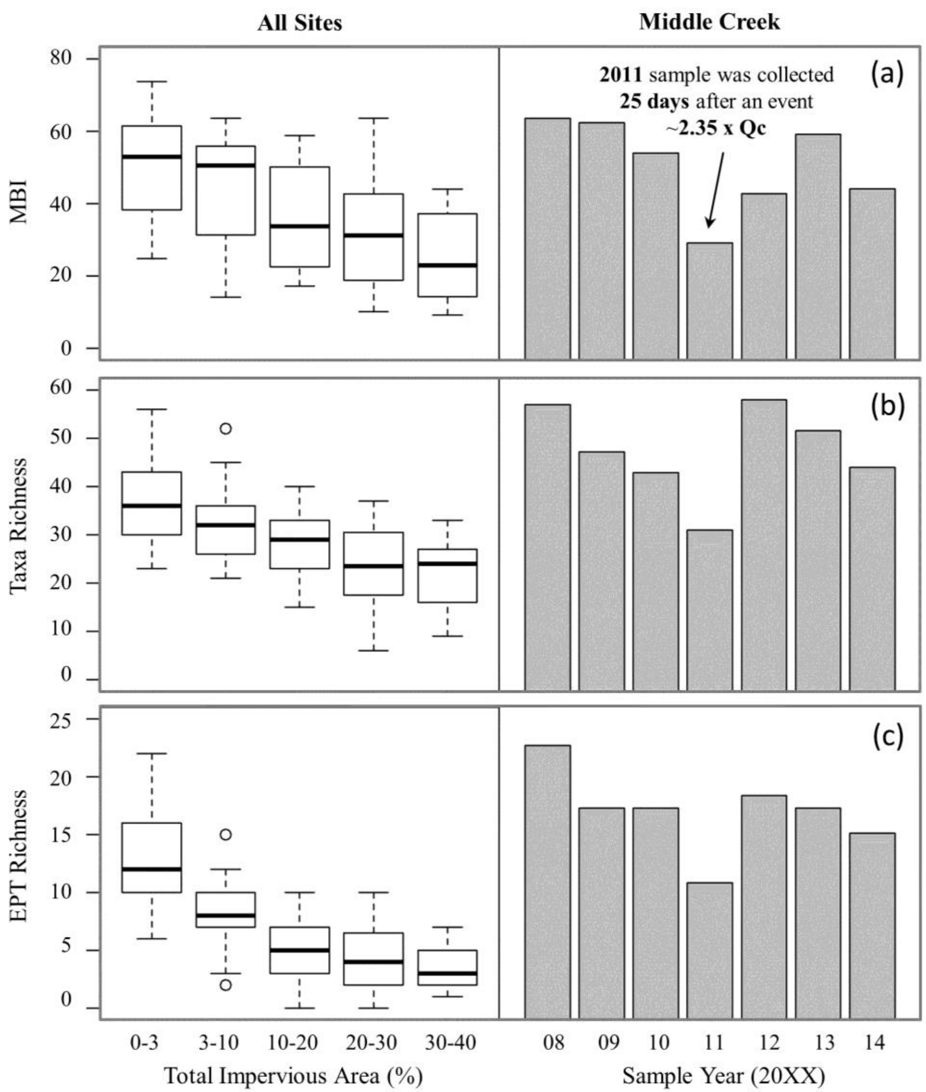
Adapted from Hawley and Vietz (In Press, Freshwater Science)

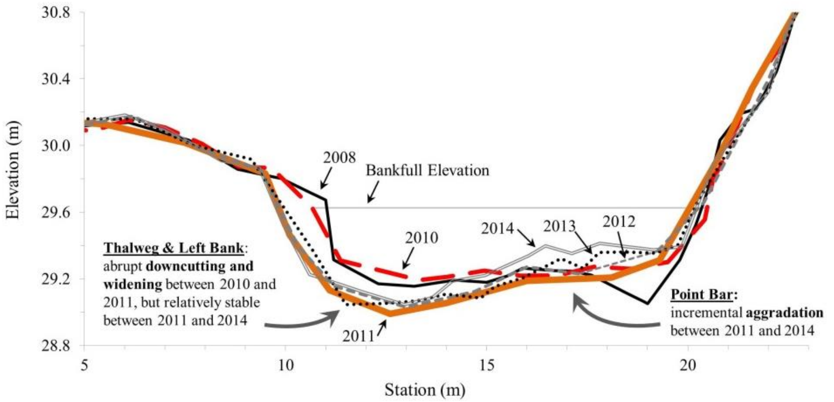
$Q_{critical}$ Needs to Be Calibrated to Stream/Region





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





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(In revision, Freshwater Science)

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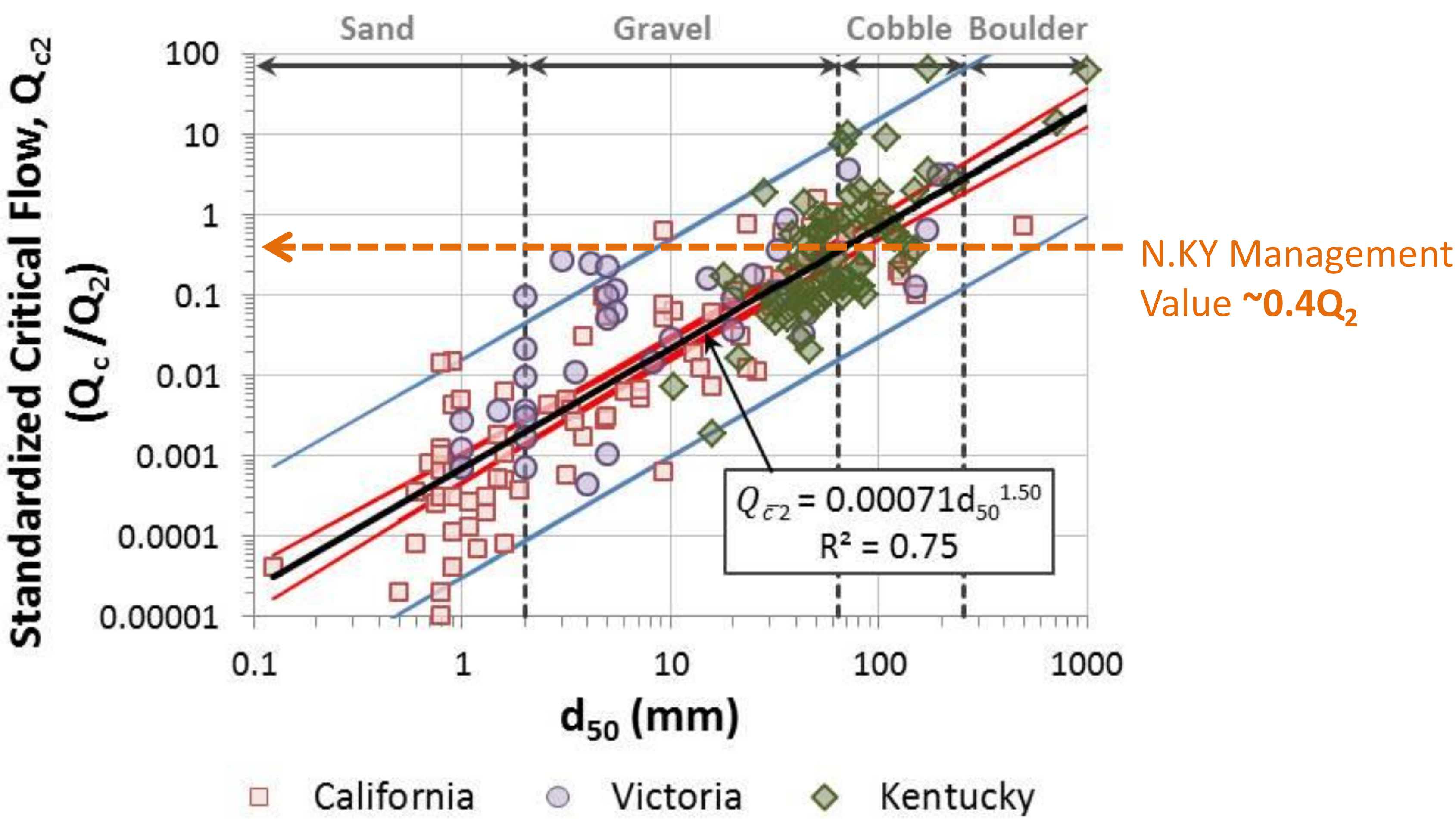


Adapted from Hawley and Vietz (In Press, Freshwater Science)

Optimized N.KY Facilities Can Meet $Q_{critical}$ Target without Becoming Larger

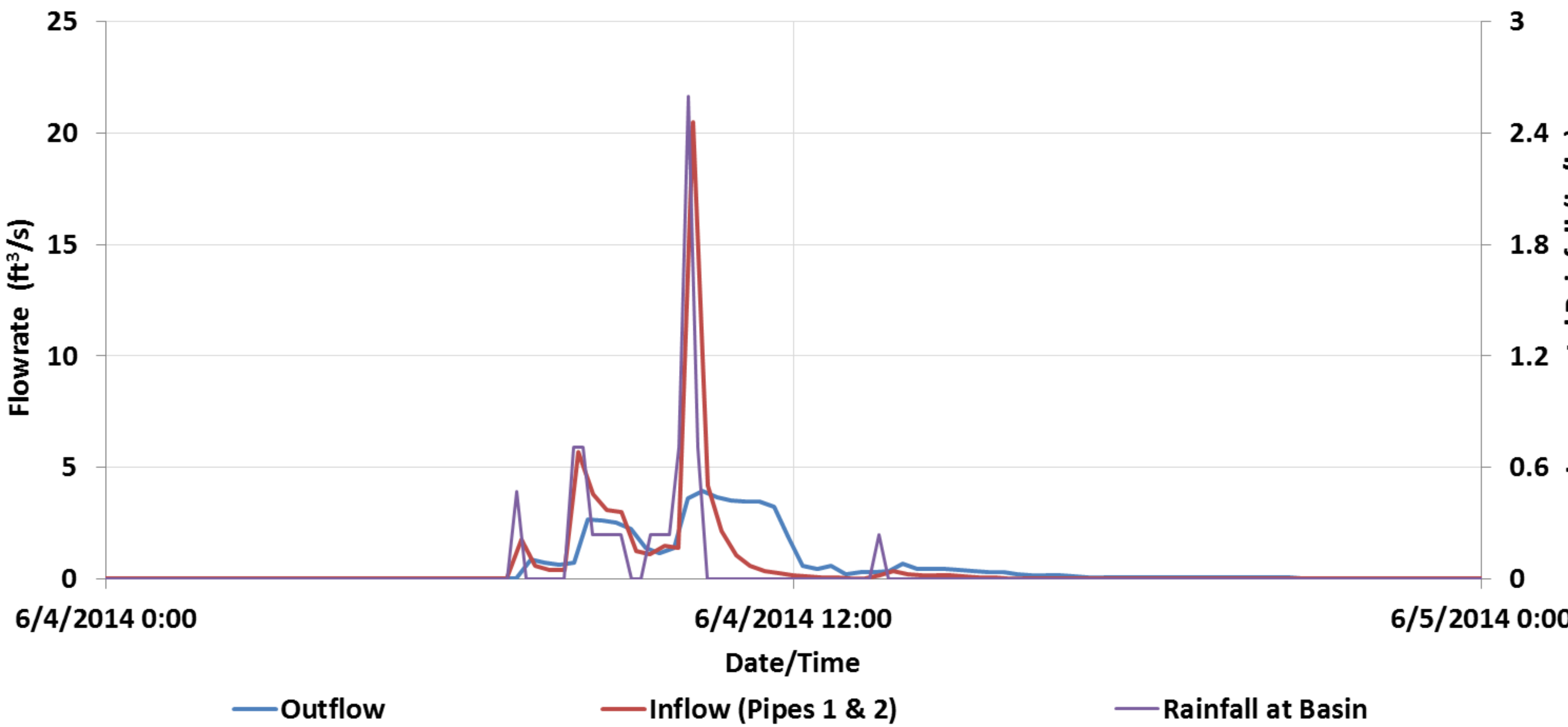
Detention Type	Cumulative Hours > $Q_{critical}$	Cumulative Tons of Sediment Transport
	% Difference from Reference	% Difference from Reference
No Control	903%	1145%
Flood Control Detention	516%	290%
Bioretention with Flood Control and Water Quality	120%	197%
Bioretention with Flood Control, Water Quality, and $Q_{critical}$ Control	32%	-11%

Adapted from Hawley et al. (In prep)

$Q_{critical}$ = Simple Solution for Most Developments in N.KY

(*Facilities Draining ≤ 100 acres*)

Release 2-yr Storm < $Q_{critical}$



Adapted from Hawley et al. (In review)

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
  - $Q_{critical} = 0.4*Q_2$
  - $Q_{critical} = 0.4*17.89cfs = 7.16$ 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**

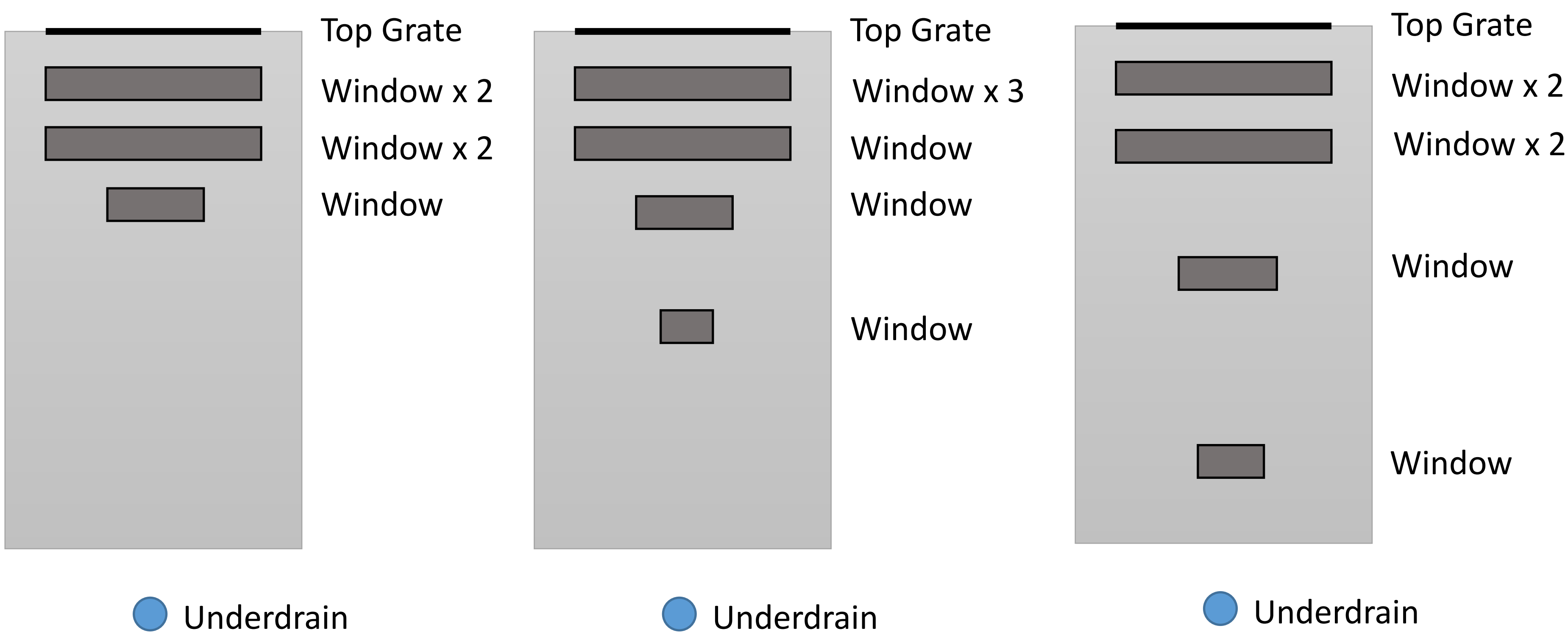
Good Optimization to Meet $Q_{critical}$

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

Bioretention Basin

Optimization of Outlet Control Structure

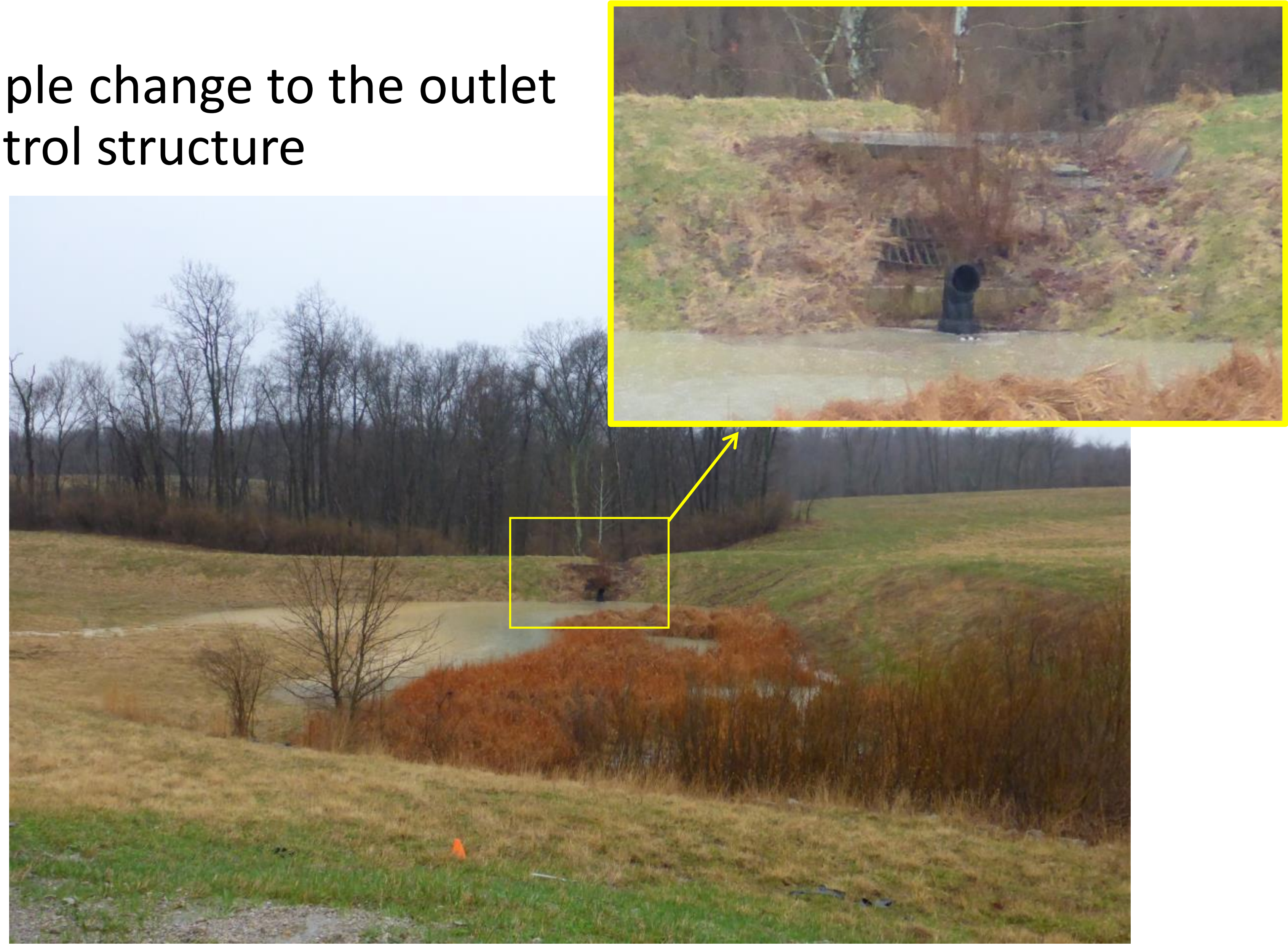
Non-Optimized ***Multiple Iterations*** ***…*** ***Optimized***



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)

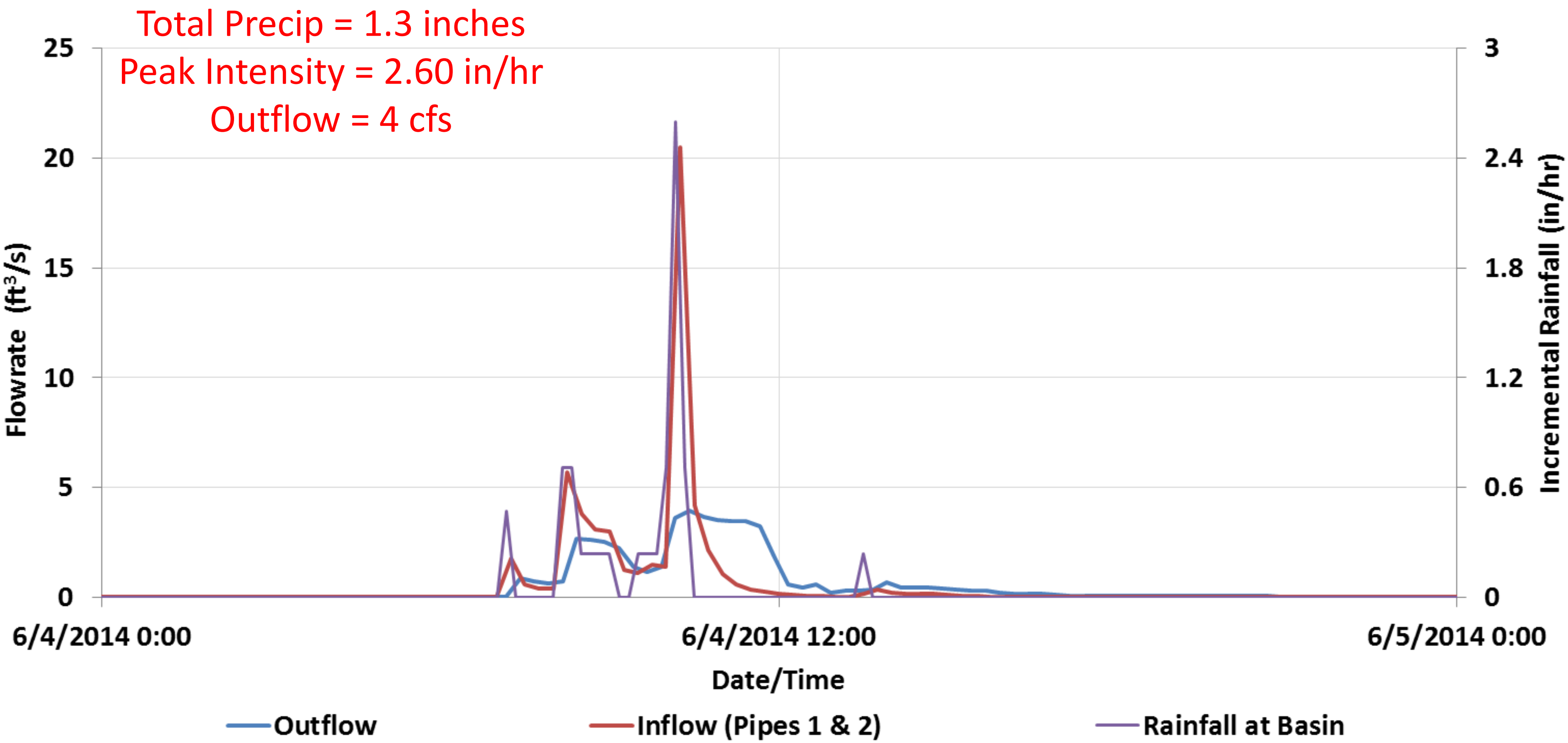
Post-retrofit outflow:

All design storms < pre-retrofit outflow

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

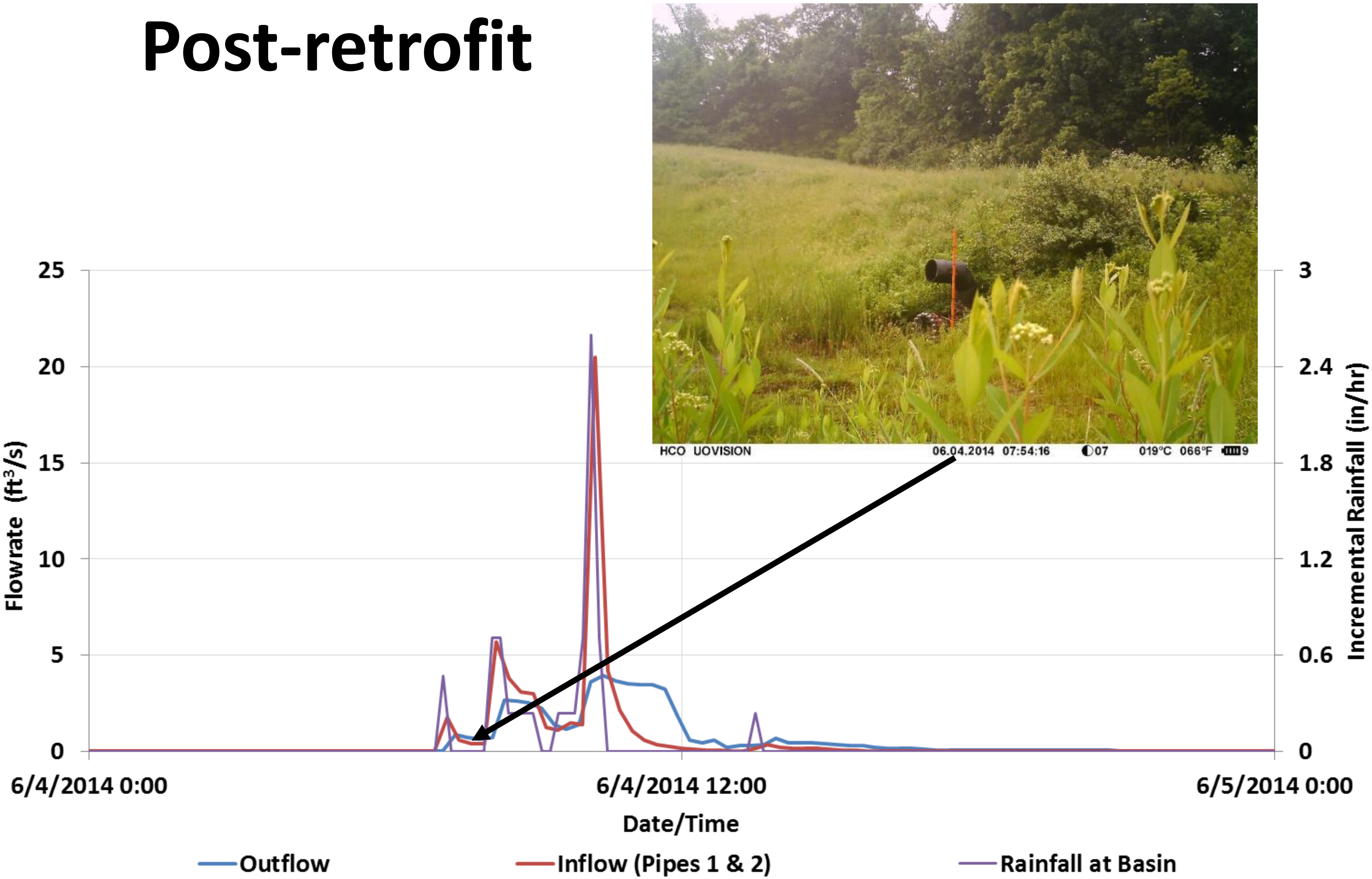
Detention Basin Retrofit

Post-installation Monitoring



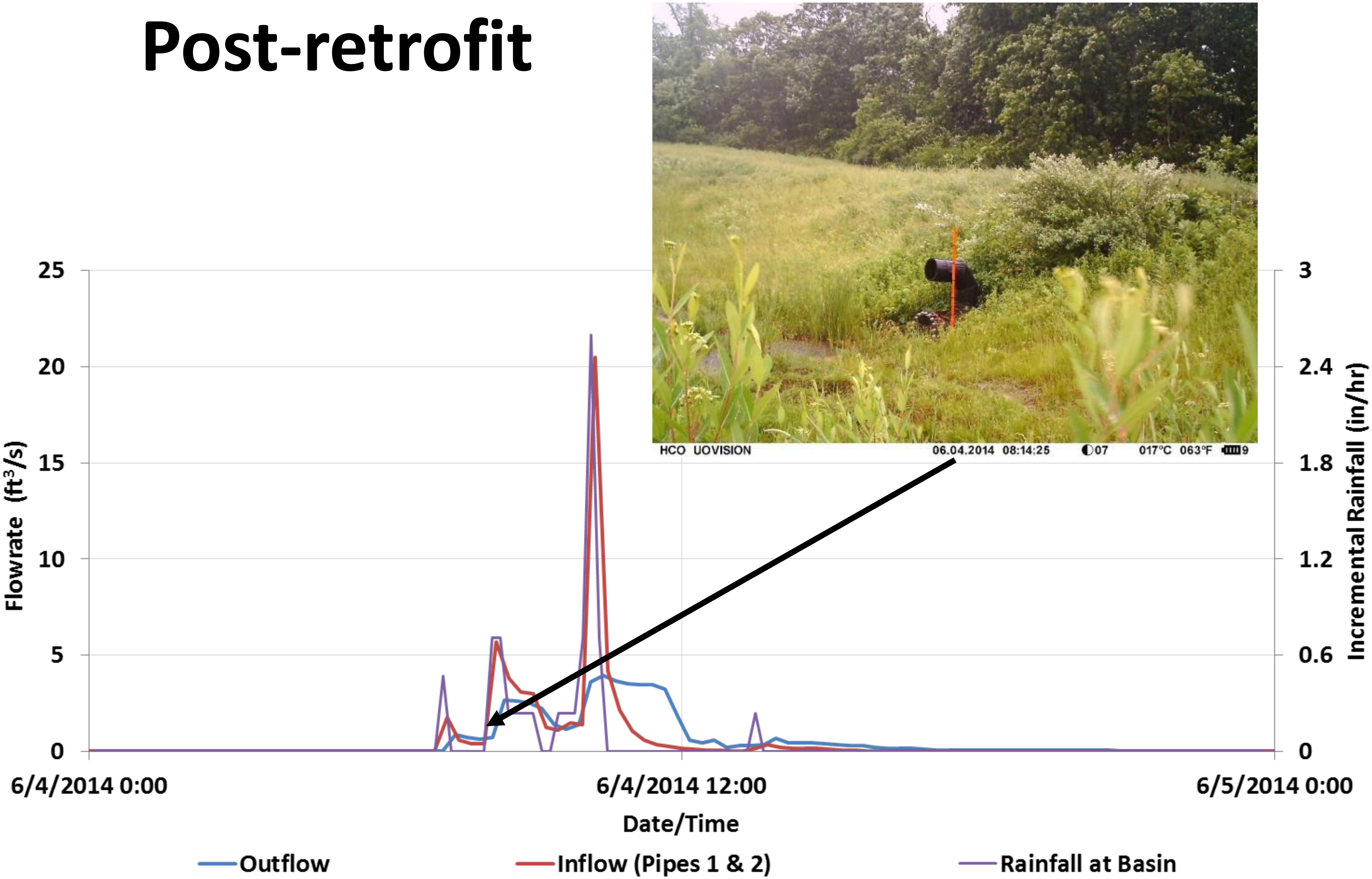
Adapted from Hawley et al. (In review)

Post-retrofit



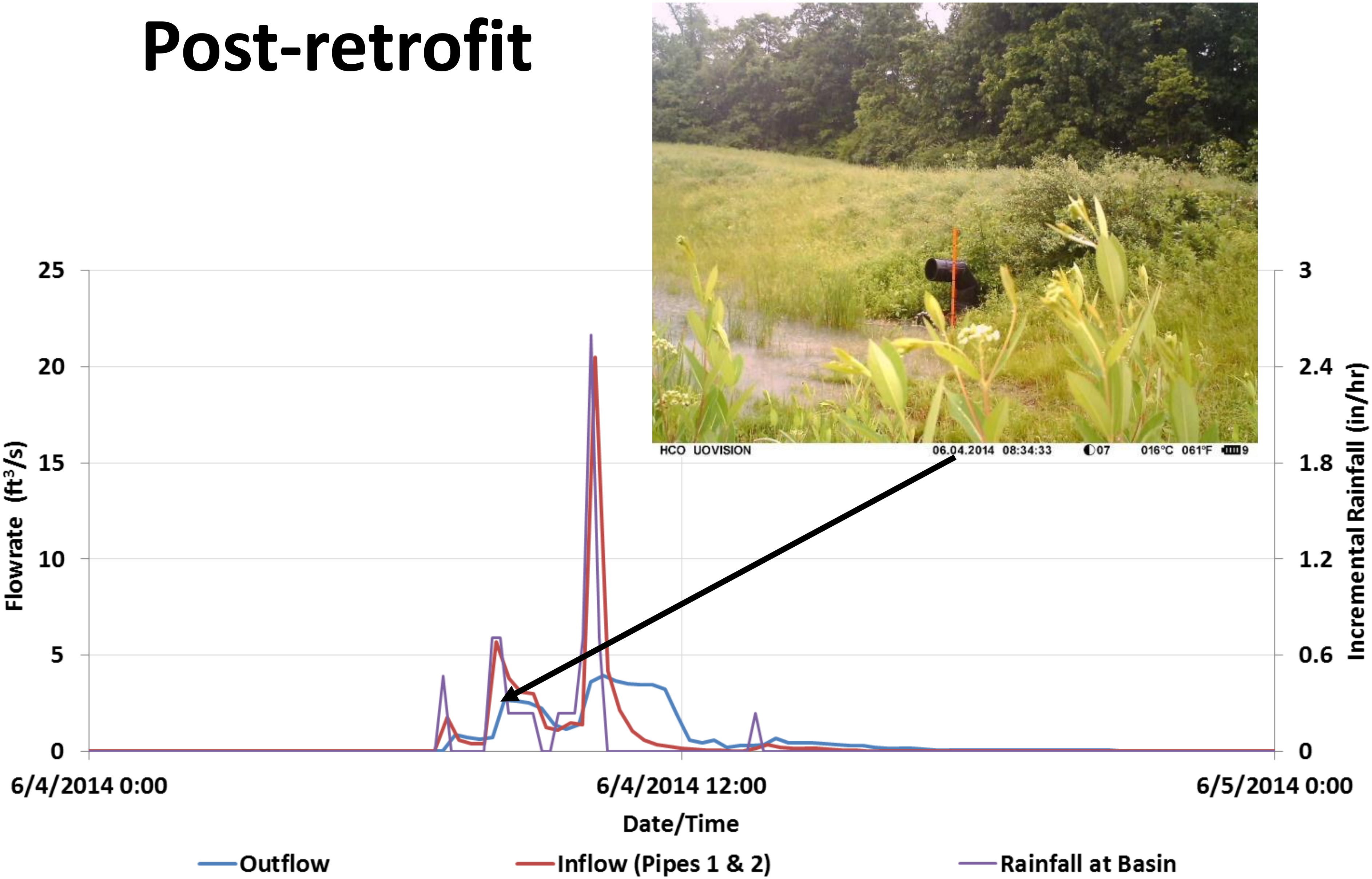
Adapted from Hawley et al. (In review)

Post-retrofit



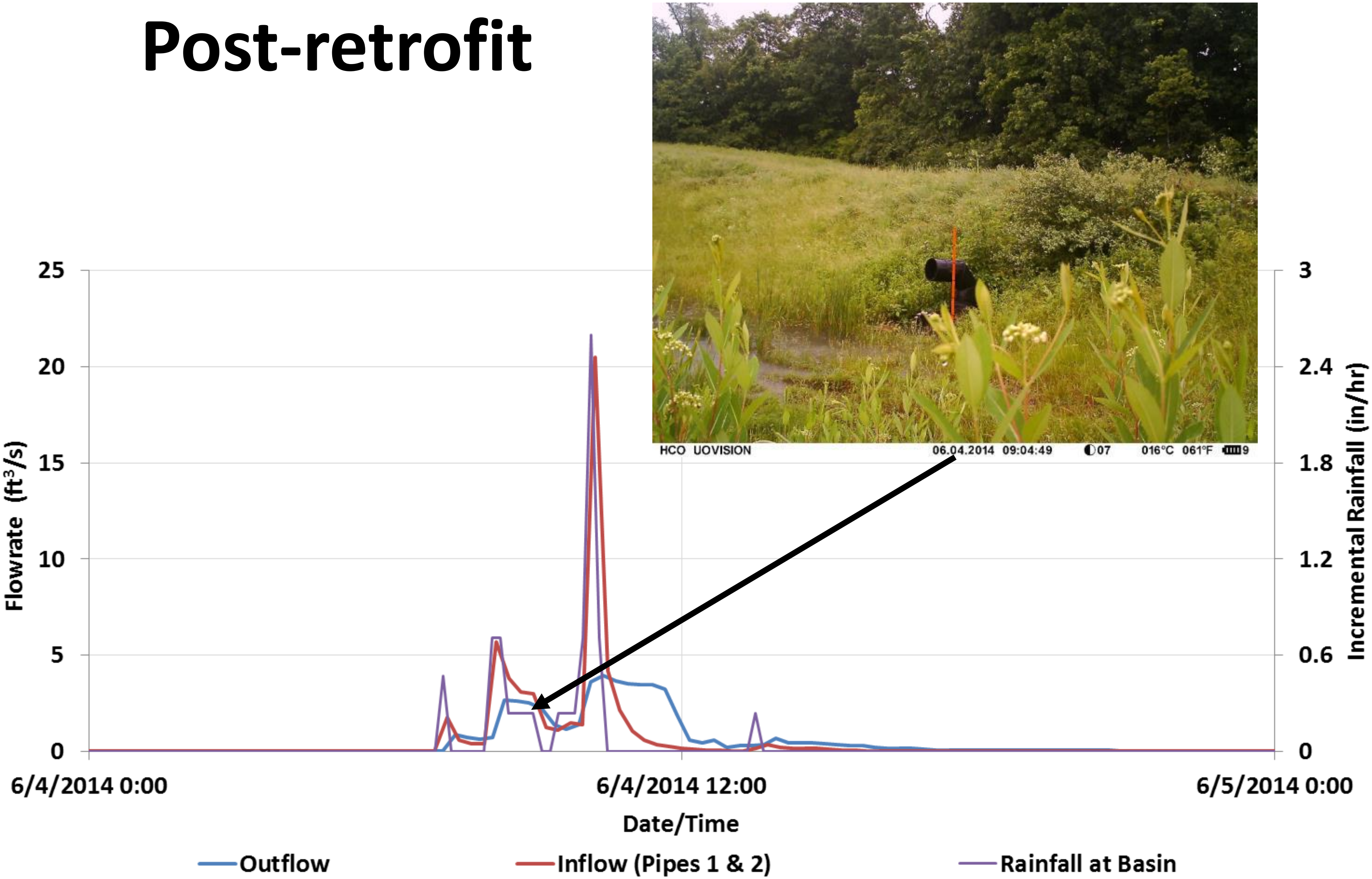
Adapted from Hawley et al. (In review)

Post-retrofit



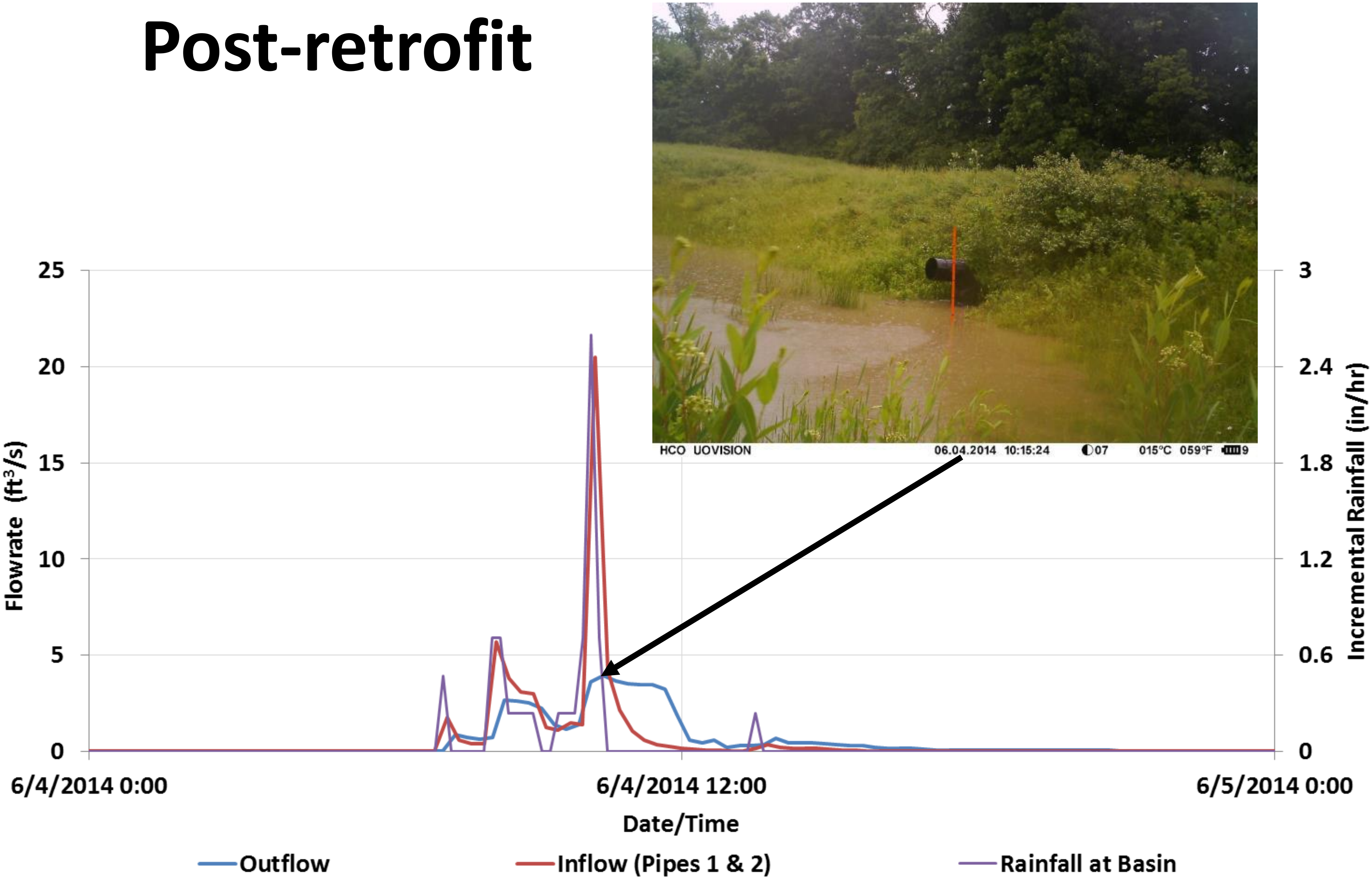
Adapted from Hawley et al. (In review)

Post-retrofit



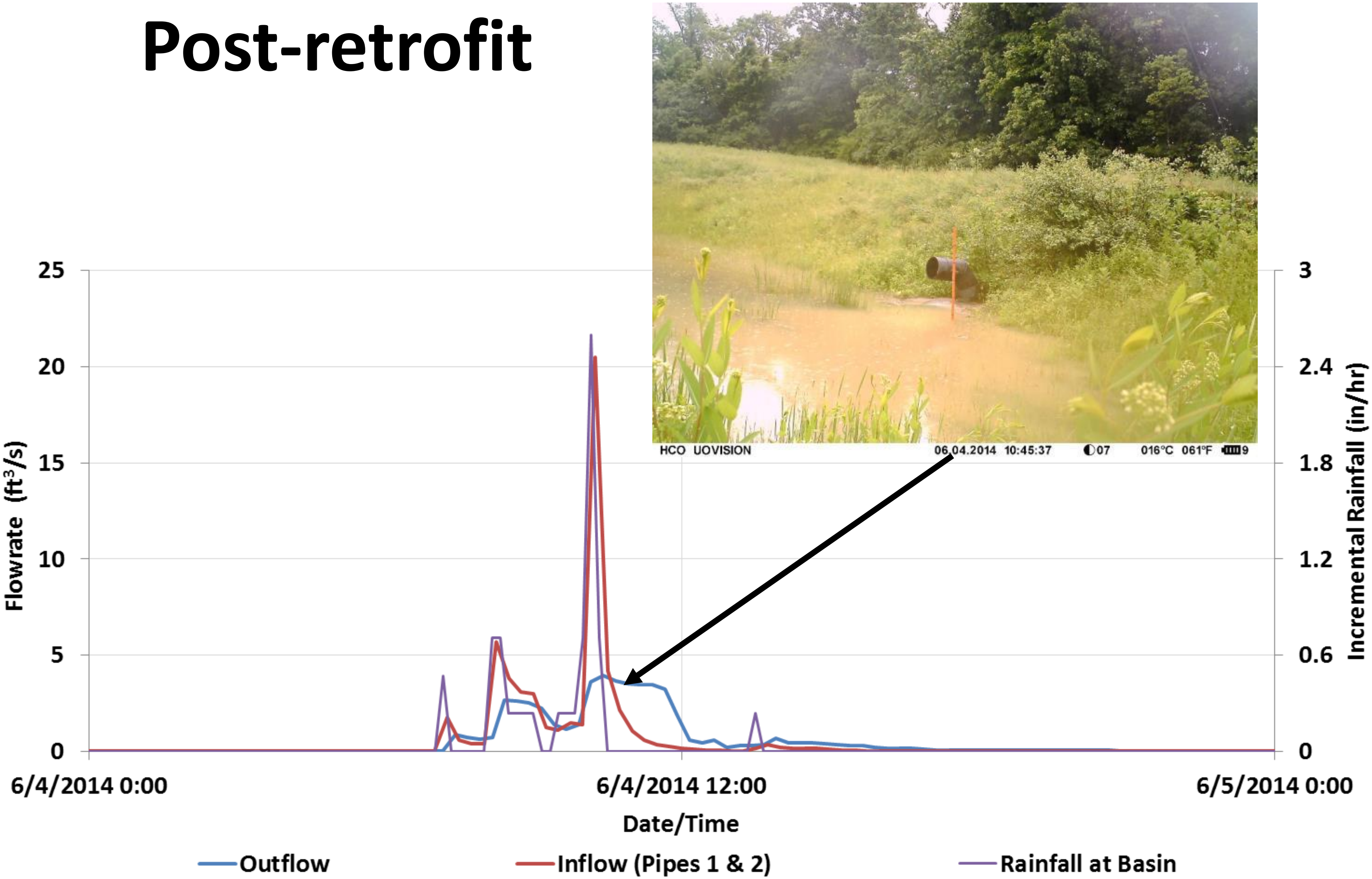
Adapted from Hawley et al. (In review)

Post-retrofit



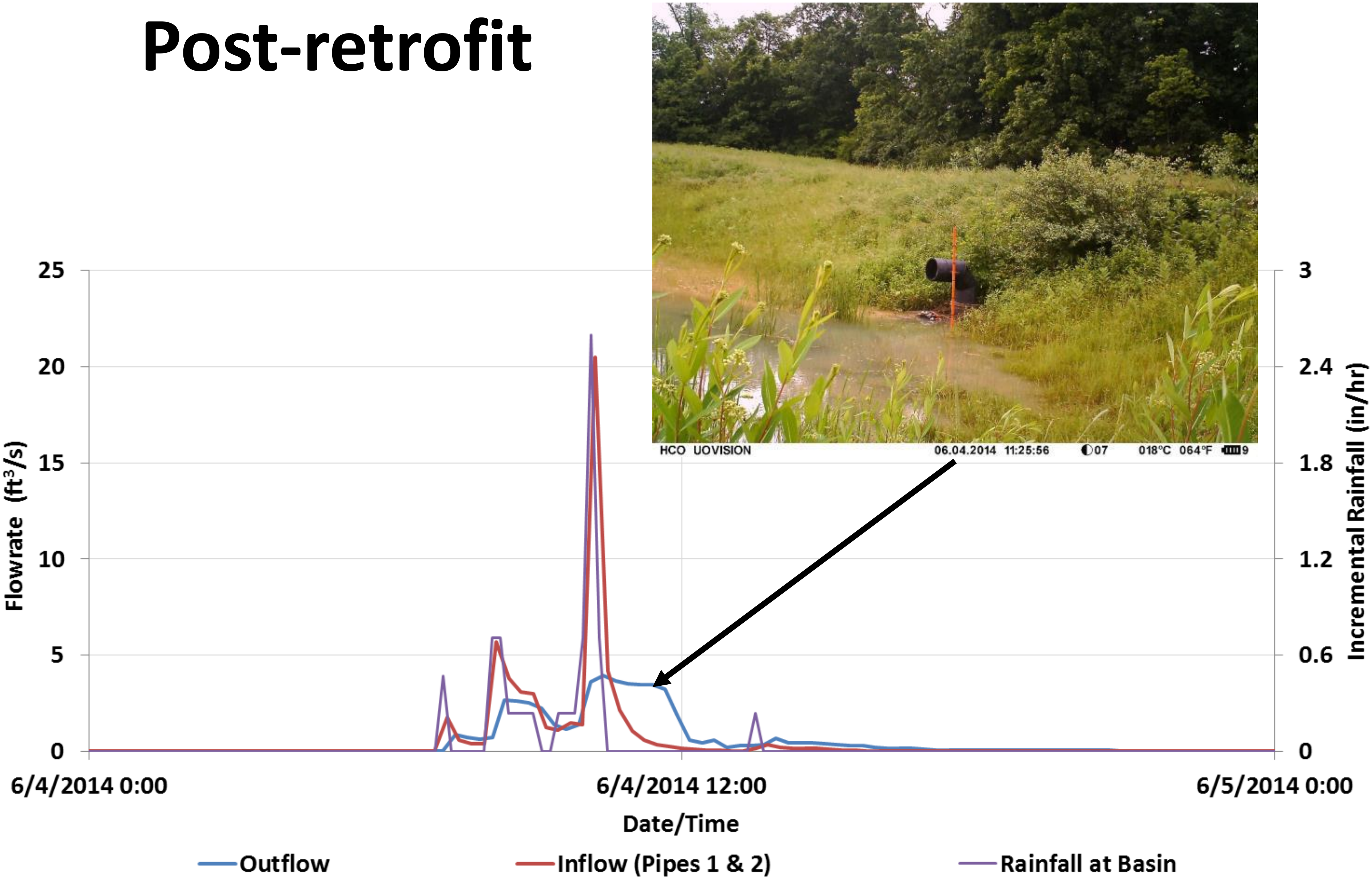
Adapted from Hawley et al. (In review)

Post-retrofit



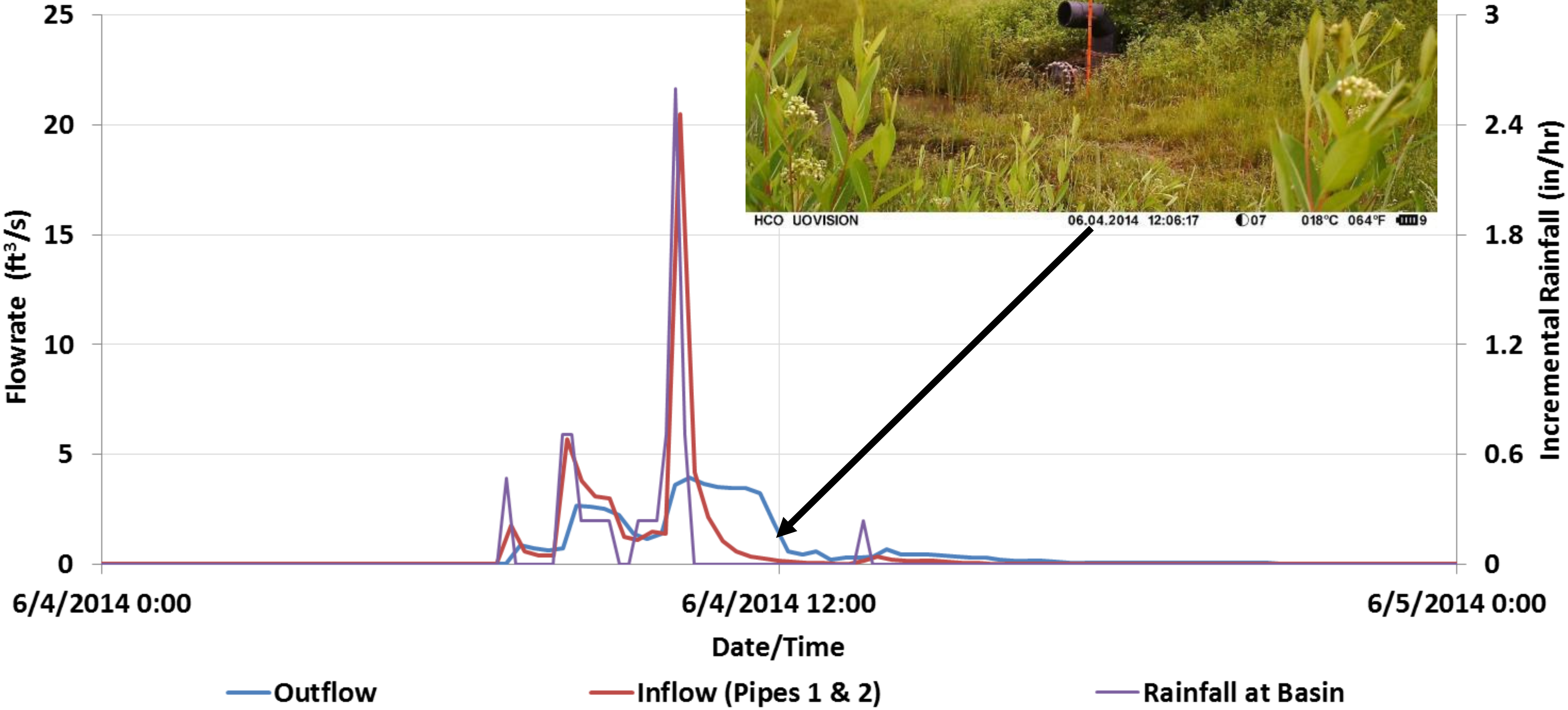
Adapted from Hawley et al. (In review)

Post-retrofit



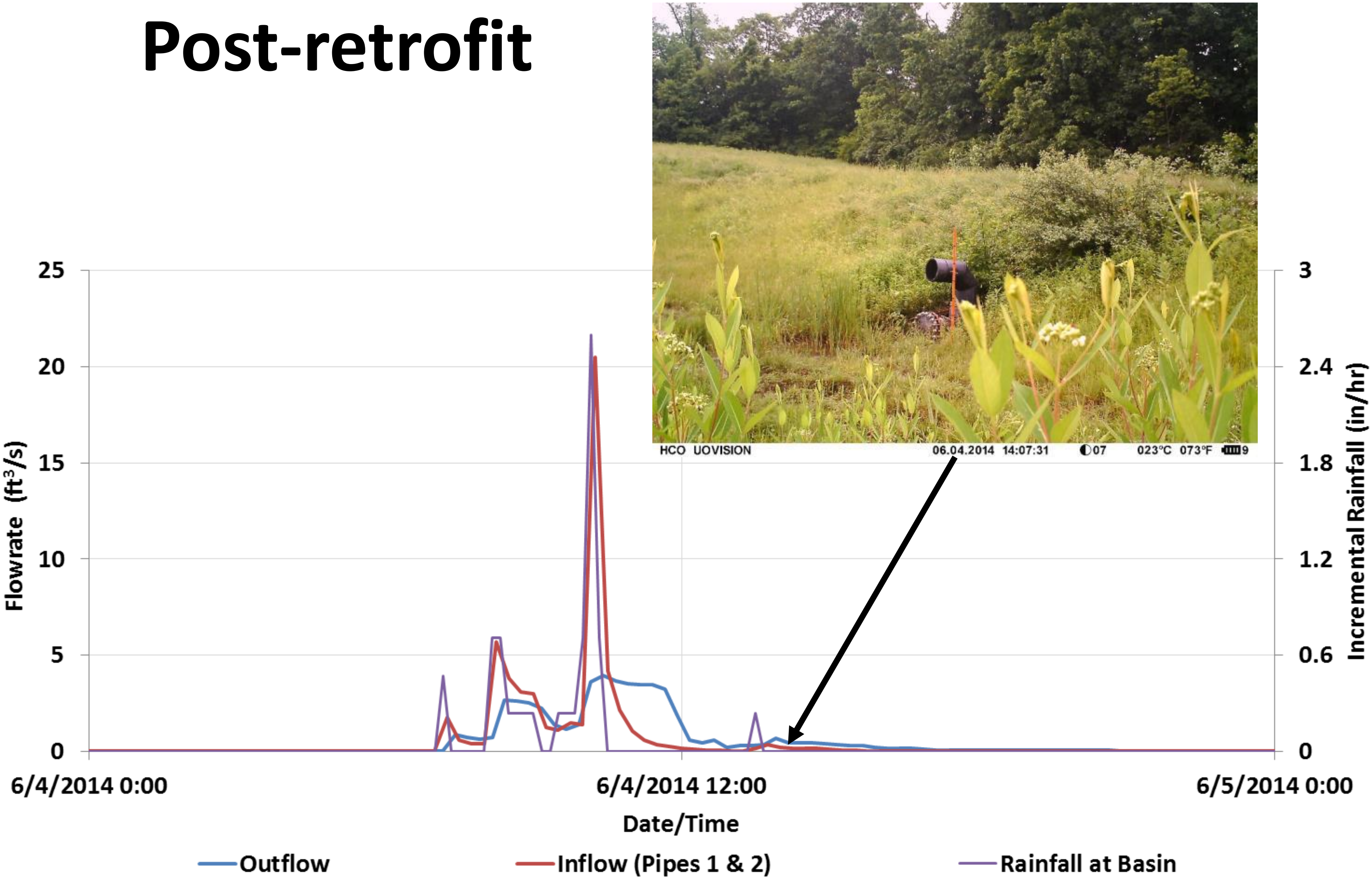
Adapted from Hawley et al. (In review)

Post-retrofit



Adapted from Hawley et al. (In review)

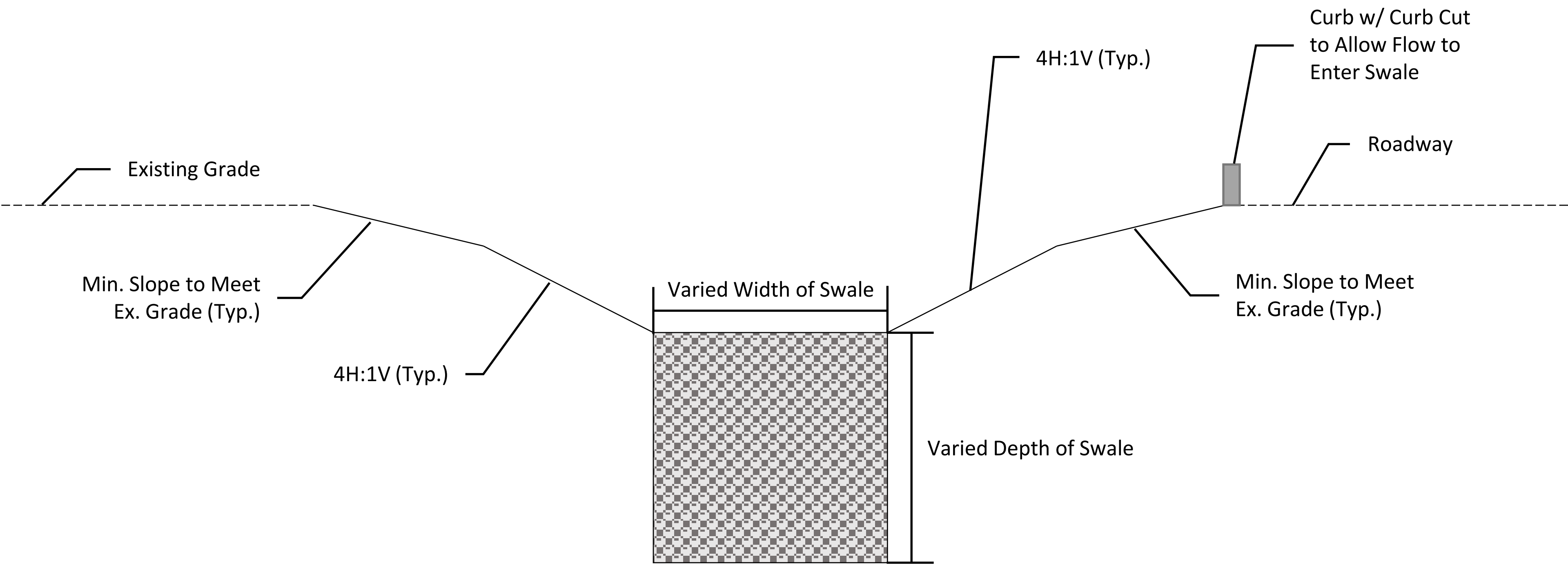
Post-retrofit



Adapted from Hawley et al. (In review)

Example 3
Enhanced Swale

Enhanced Swale Cross Section

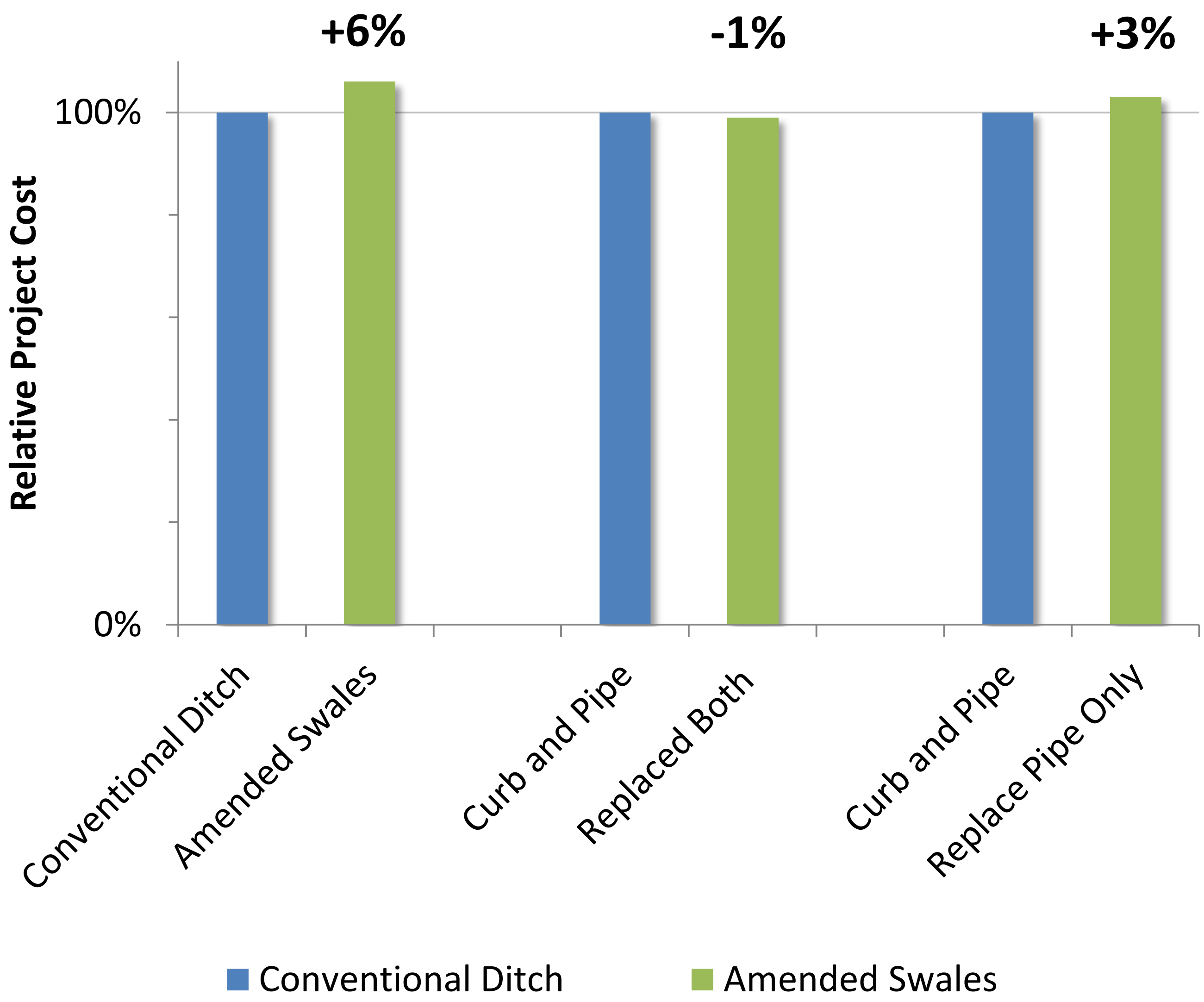


Adapted from: Illinois Department of Transportation

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



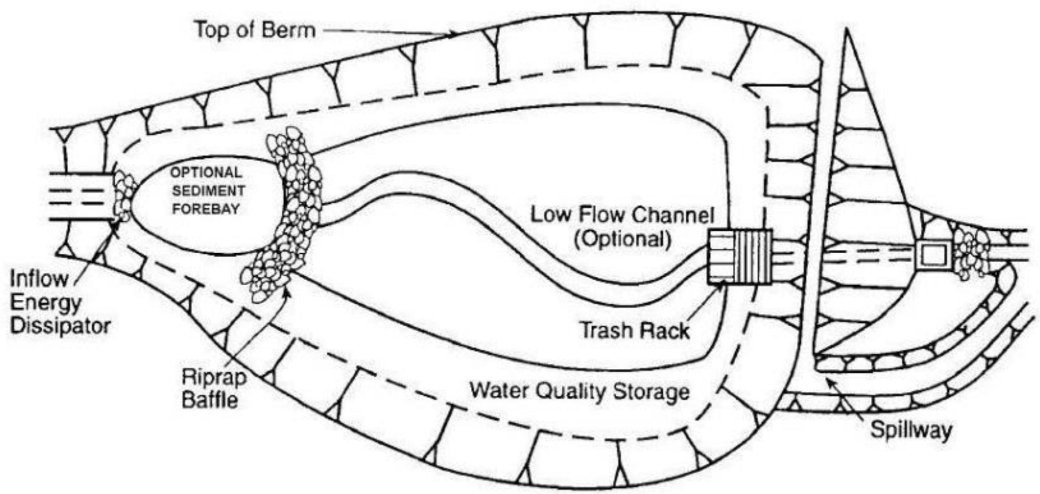
Example: Enhanced Swale Preliminary Results

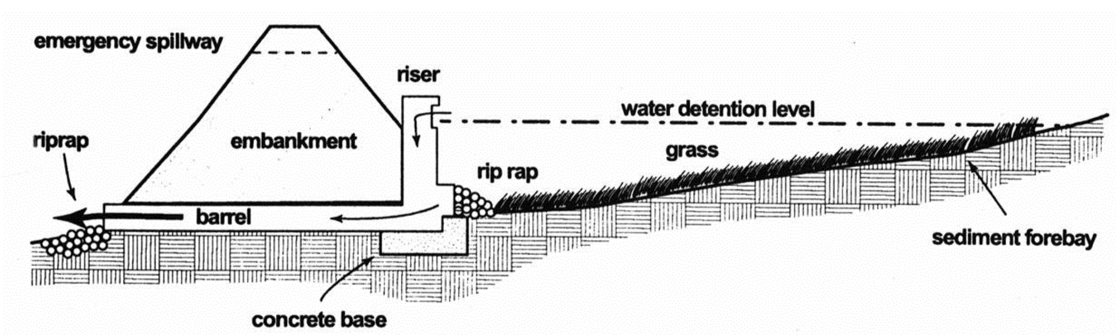
Swale/ Roadway	Drainage Area *acres*	Pre Q_2 *cfs*	$Q_{critical}$ (44% Q_2) *cfs*	Post Q_2 *cfs*	Post Q_2 Control *cfs*	Swale Length *ft*	Bottom Width *ft*	Gravel Depth *ft*	Gravel Volume *CY*
Veterans Way									
1	0.35	0.81	0.36	1.10	0.31	213	14	2	70.7
2	0.46	0.84	0.37	1.48	0.33	132	14.25	5	111.84
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

Resources

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Sustainable Streams LLC

Science | Service | Solutions

Resources and Links

Peer-reviewed Journal Articles on Hydromodification:

Hawley, R.J. and B.P. Bledsoe. 2011. How do flow peaks and durations change in suburbanizing semi-arid watersheds? A southern California case study. *Journal of Hydrology* 405 (1-2), 69-82. Read article »

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., Bledsoe, B.P., Stein, E.D., and B.E. Haines. 2012. Channel evolution model of semiarid stream response to urban-induced hydromodification. *Journal of the American Water Resources Association.*, 48(4): 722-744. 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 »

Peer-reviewed Journal Articles on Hydromodification Management Approaches and Case Studies

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 »

Hawley, R.J., Wooten, M.S., Vatter, B.C., Onderak, E., Lachniet, M.J., Schade, T., Grant, G., Groh, B., and J. DelVerne. 2012. Integr stormwater controls designed for channel protection, water quality, and inflow/infiltration mitigation in two pilot watersheds to restore natural flow regime in urban streams. *Watershed Science Bulletin.* 3(1), 25-37. Read article »

Technical Reports and Tools for Monitoring, Screening, and Managing Hydromodofication:

Bledsoe, B.P., **Hawley, R.J.**, Stein, E.D. and D.B. Booth. 2010. Hydromodification Screening Tools: Technical Basis for Development Regionally Calibrated Probabilistic Channel Susceptibility Assessment. Southern California Coastal Water Research Project (SCCWR Technical Report 607. Costa Mesa, CA. July, 2010. 42 pp. Download article (PDF) »

Featured article

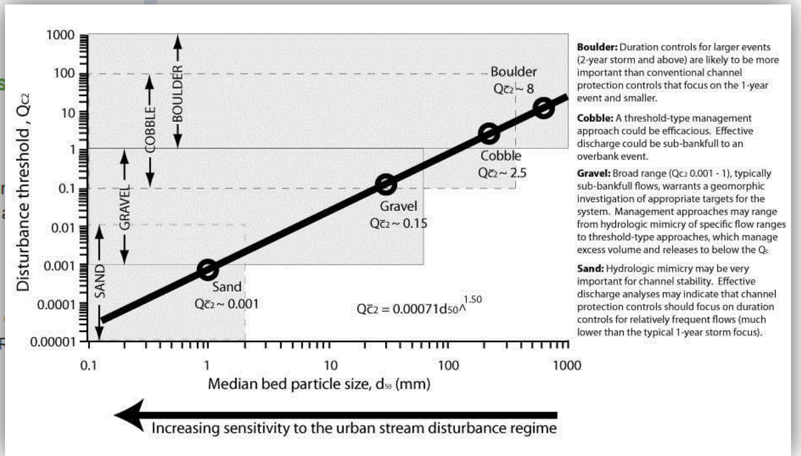
Two recent papers on the effects of hydromodification from different settings published in the *Journal of Hydrology* and *Geomorphology*.

Available online:

Channel Enlargement in Southern California »

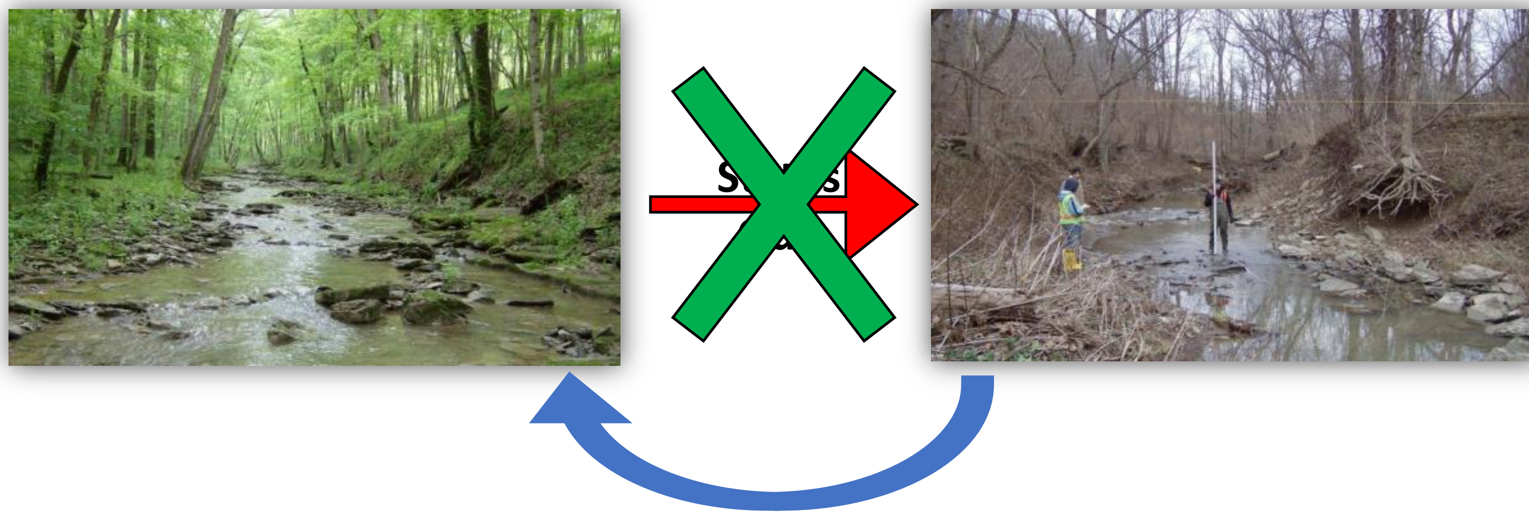
Riffle Shortening in Northern Kentucky »

Matt Wooten
Aquatic Biologist, SD1
859-578-6887
mwooten@sd1.org



Adapted from Hawley and Vietz (In Press, Freshwater Science)

Find an Appropriate Approach for Your Community

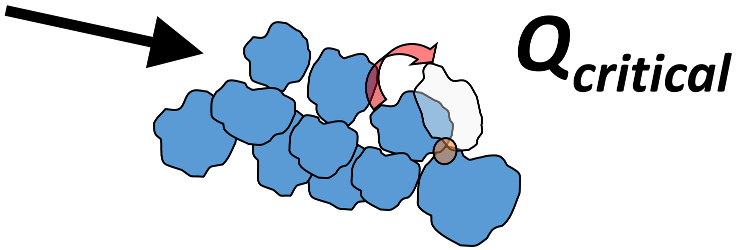


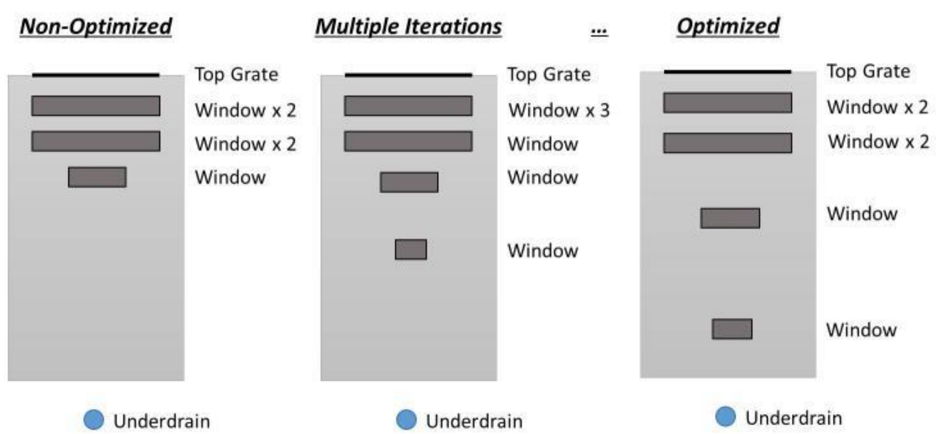
1. **Prevent Future Problems:**
   - Optimize Post Construction Rules & Regs to Protect Your Streams

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

1. The $Q_{critical}$ Design Offers A Practical Approach to Rules & Regs in N.KY

- $Q_{critical}$ Design Target ~40% of Pre-developed Q_2
- Releasing 2-year storm below $Q_{critical}$ Achieves
  - ✓ Similar Basin Sizes
  - ✓ Similar Design Process
  - ✓ Long-term Stability



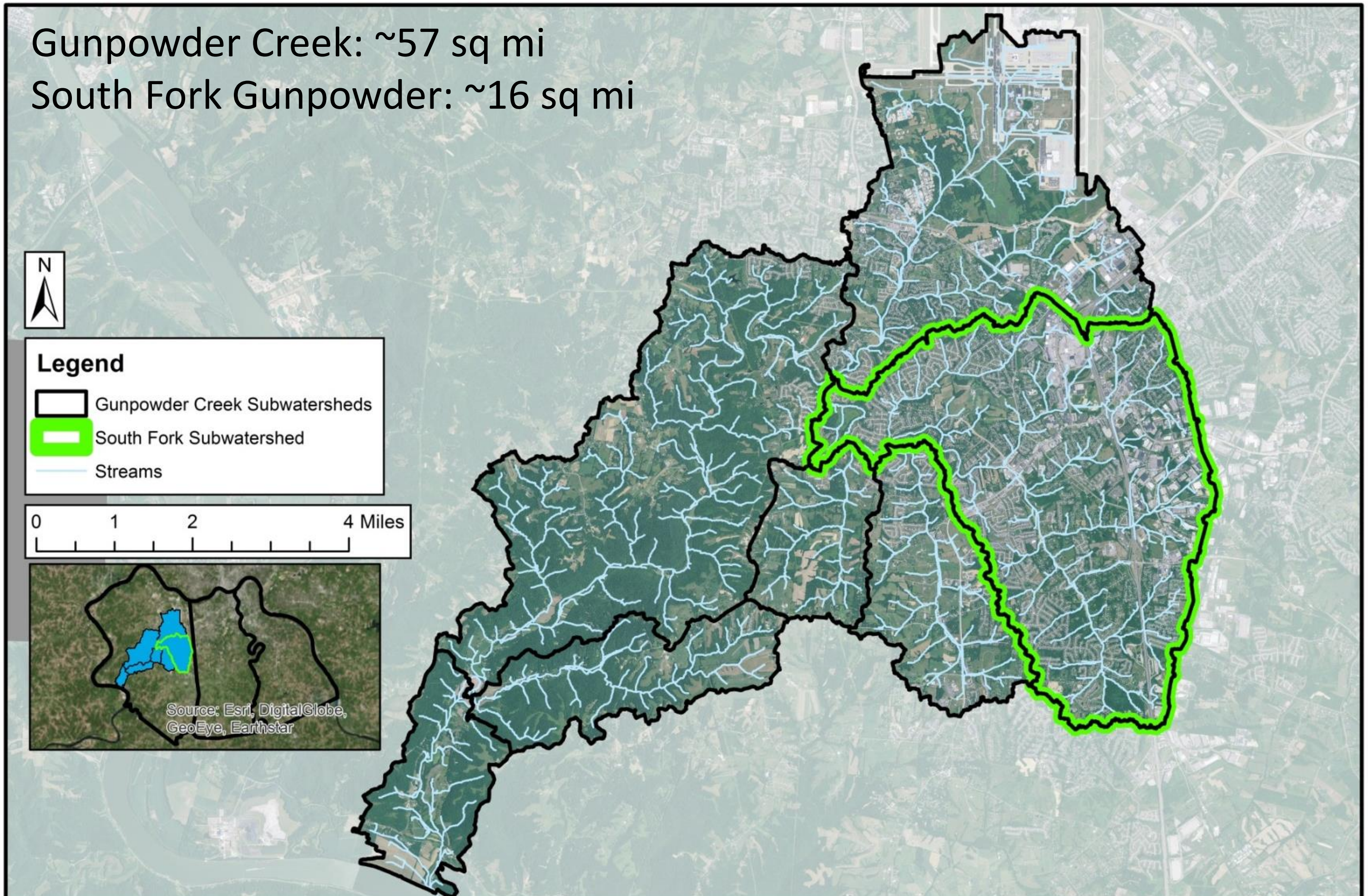


2. Retrofitting Existing Detention Basins Offers A Cost-effective Approach to Mitigate Existing Impacts

Strategy	Cost per Acre Treated	Notes
Distributed GI	~$50,000	King Co. (2013) pilot study
Stream Restoration	~$5,000	Equivalent of ~$200-300 per foot
New Detention	~$3,000	Hawley et al., 2012
Retrofit Detention	**~$500**	"Kraken" (EPA, Patent Pending) $10,000 installed by Site Supply

Adapted from Hawley et al. (In Review)

Watershed Planning Case Study
Combines Retrofits with Bankfull Wetlands



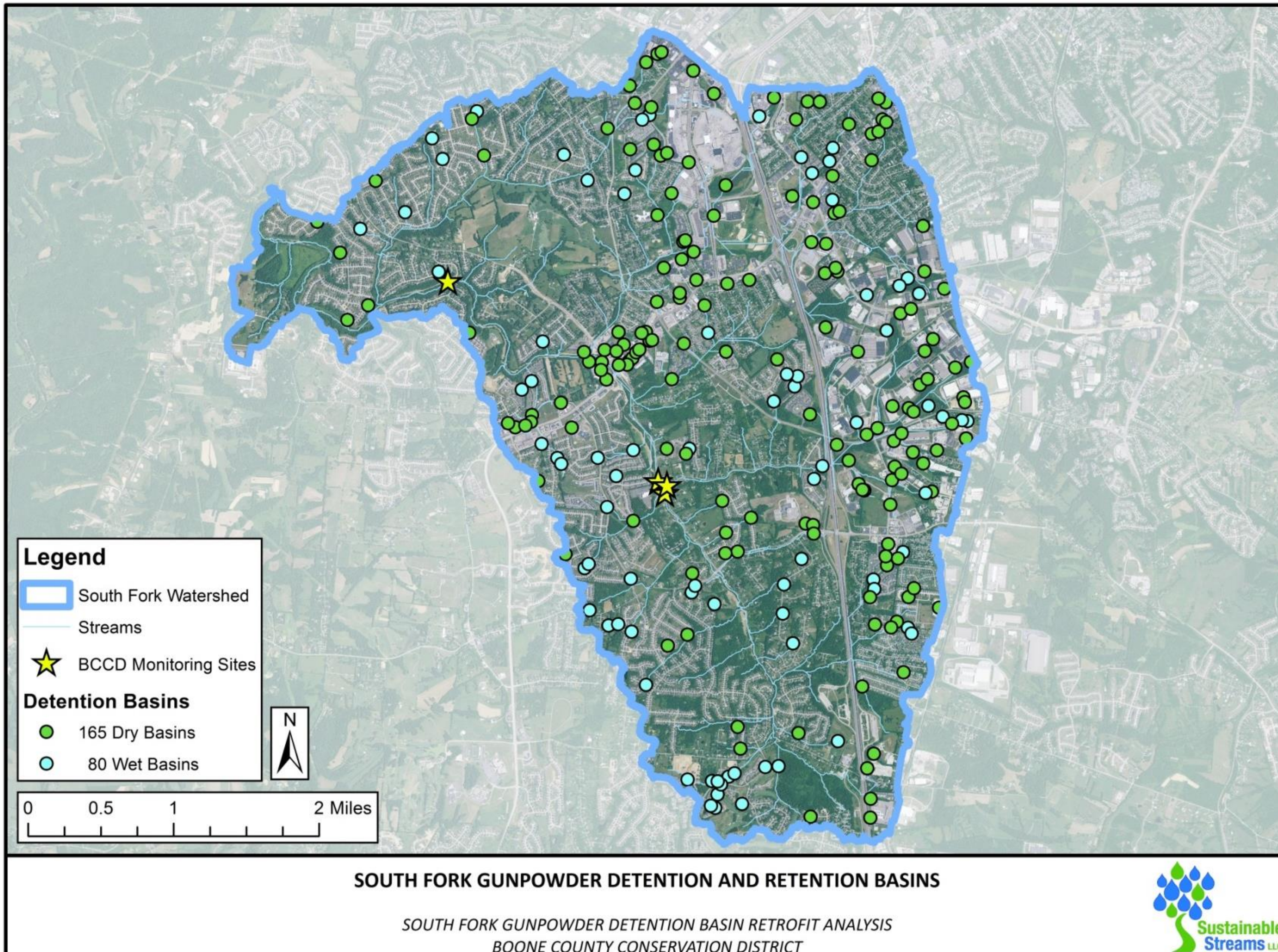
SOUTH FORK GUNPOWDER SUBWATERSHED

SOUTH FORK GUNPOWDER DETENTION BASIN RETROFIT ANALYSIS
BOONE COUNTY CONSERVATION DISTRICT

Sustainable Streams LLC

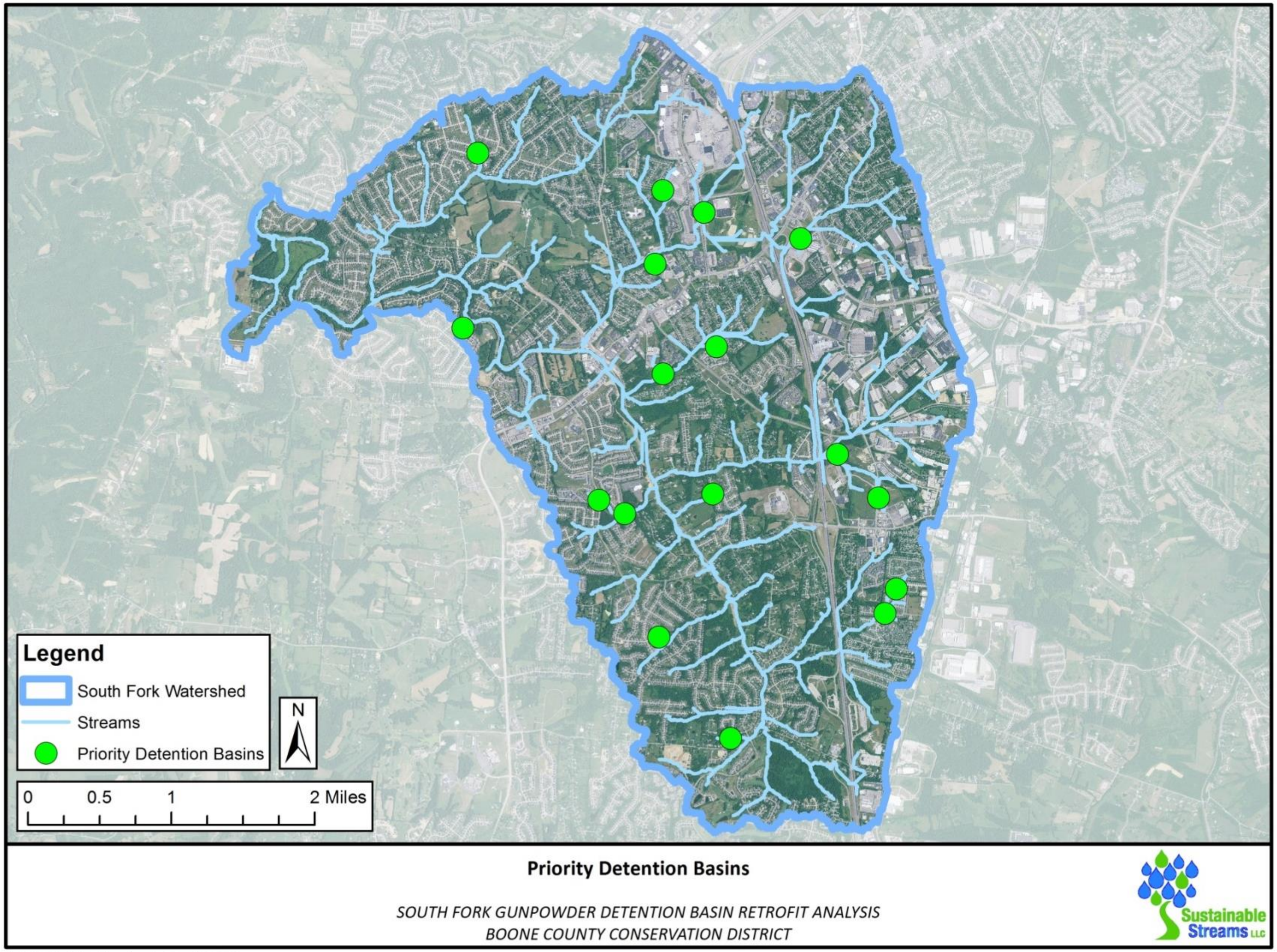
Last Updated On: Thursday, October 08, 2015

245 Existing Detention Basins Provide ~460 ac-ft of storage



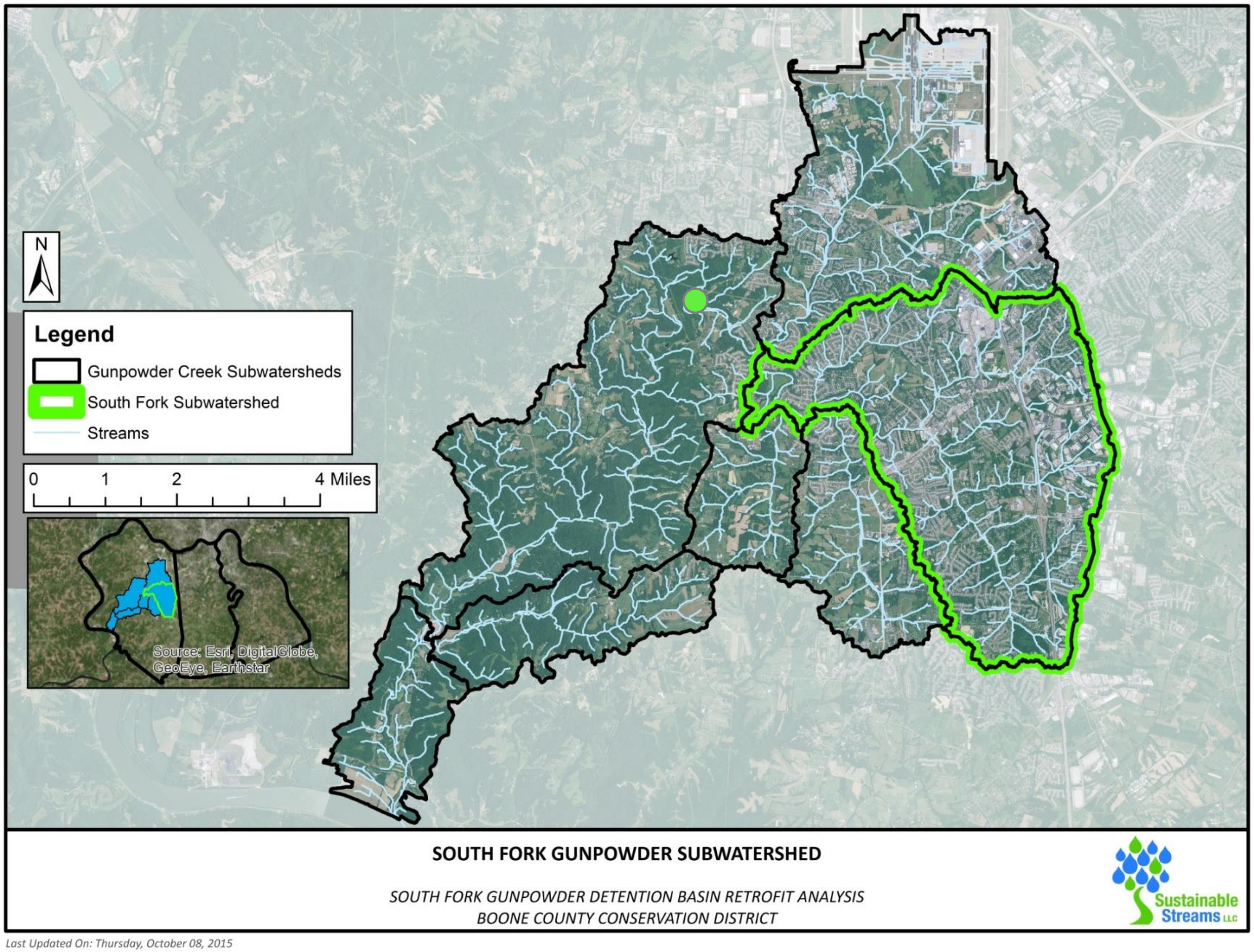
Last Updated On: Thursday, October 08, 2015

17 Prioritized Basins for Retrofitting Can Optimize 94 ac-ft of storage (>20%)

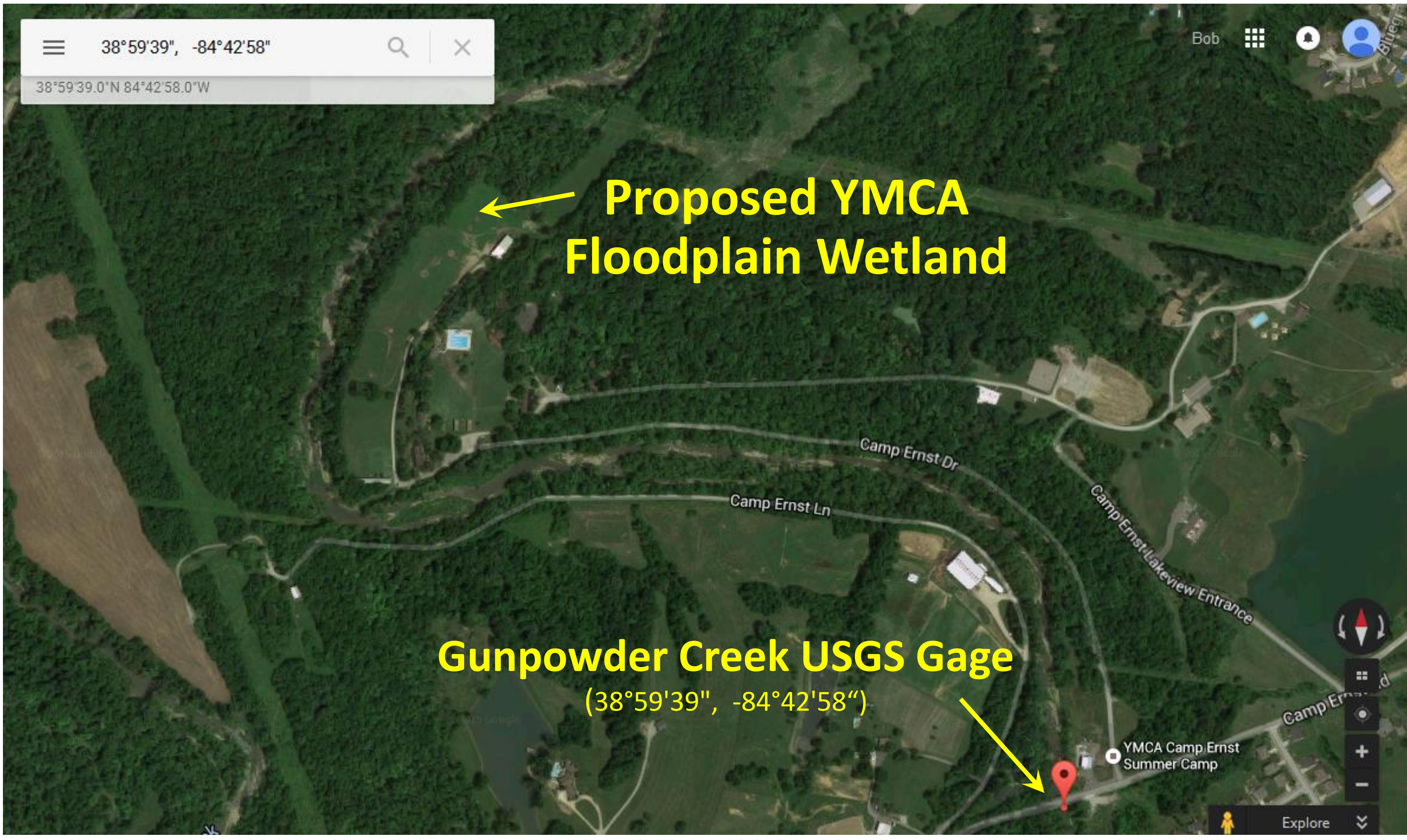


Last Updated On: Thursday, October 08, 2015

Strategic Opportunities for New Storage Using Bankfull Wetlands

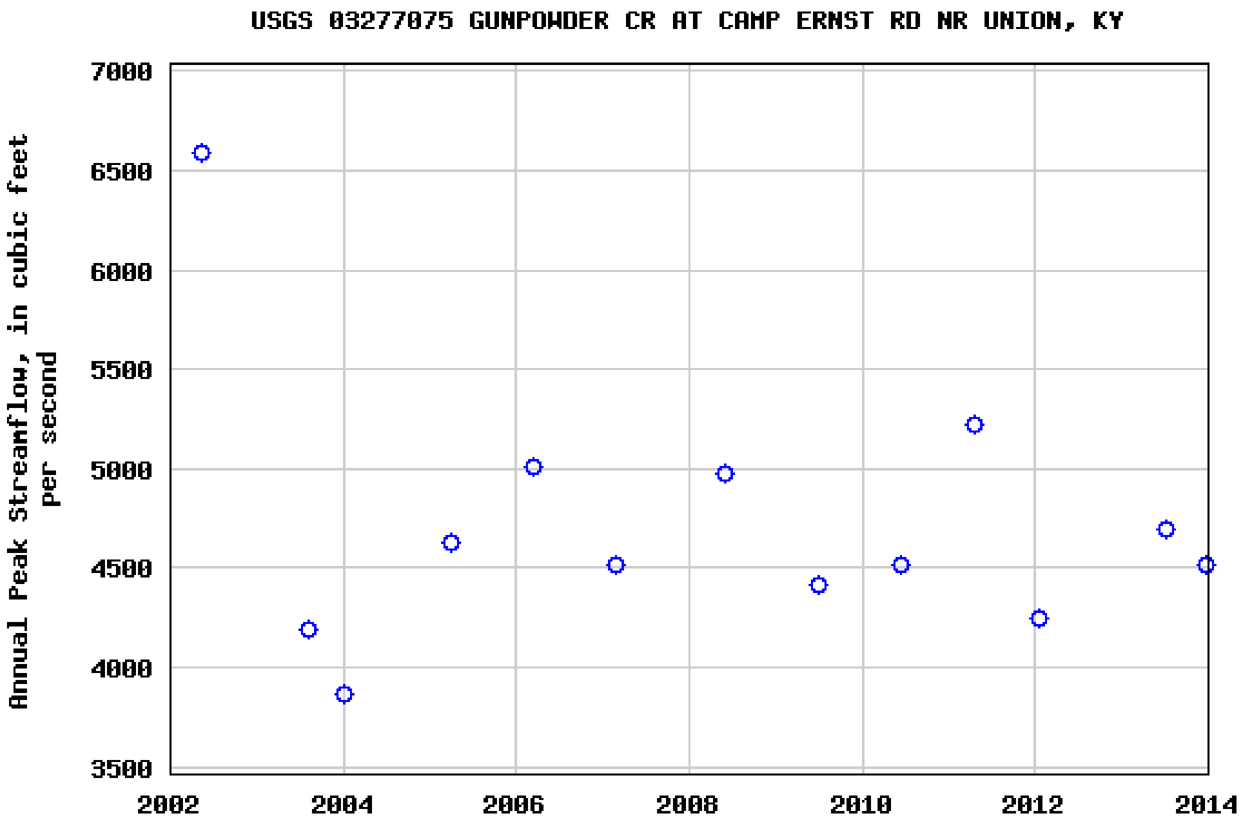


Proposed Bankfull Wetlands Increases Habitat and Reduces $Q_{critical}$ Flows



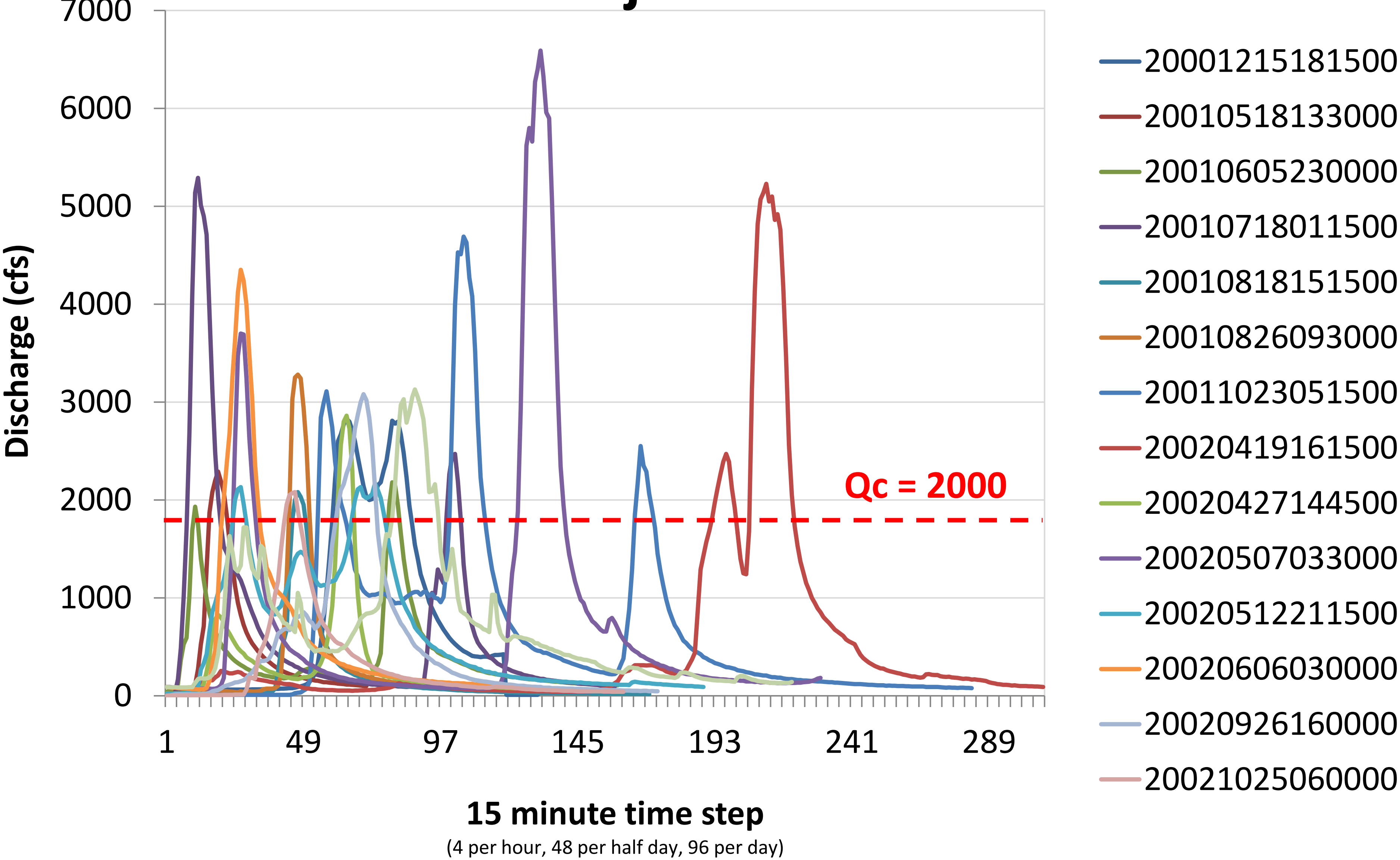
Creates Storage in a Previously Disconnected Floodplain

Qc estimated as 2000 cfs
Gunpowder Creek Exceeds Qc Every Year

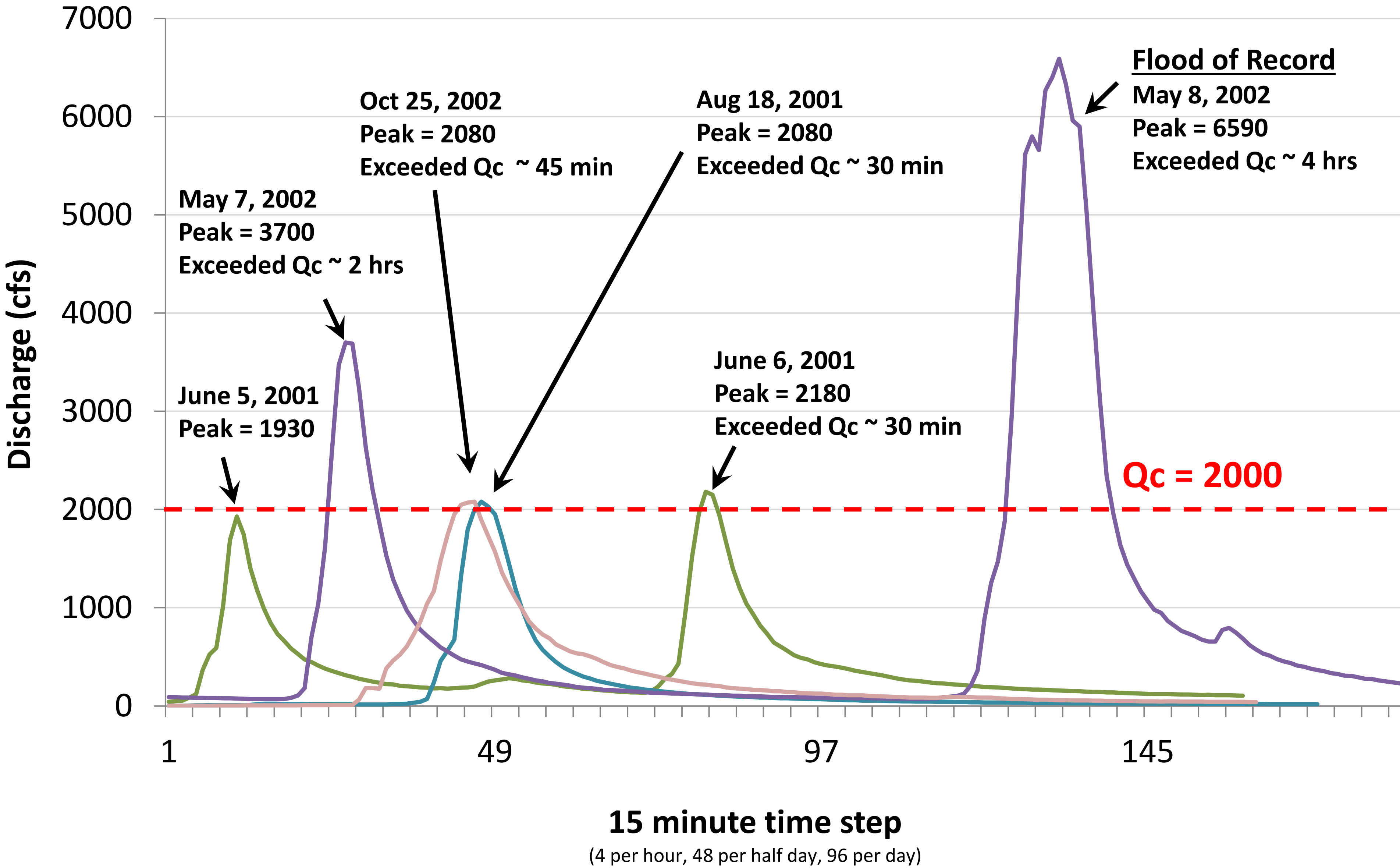


http://nwis.waterdata.usgs.gov/usa/nwis/peak/?site_no=03277075

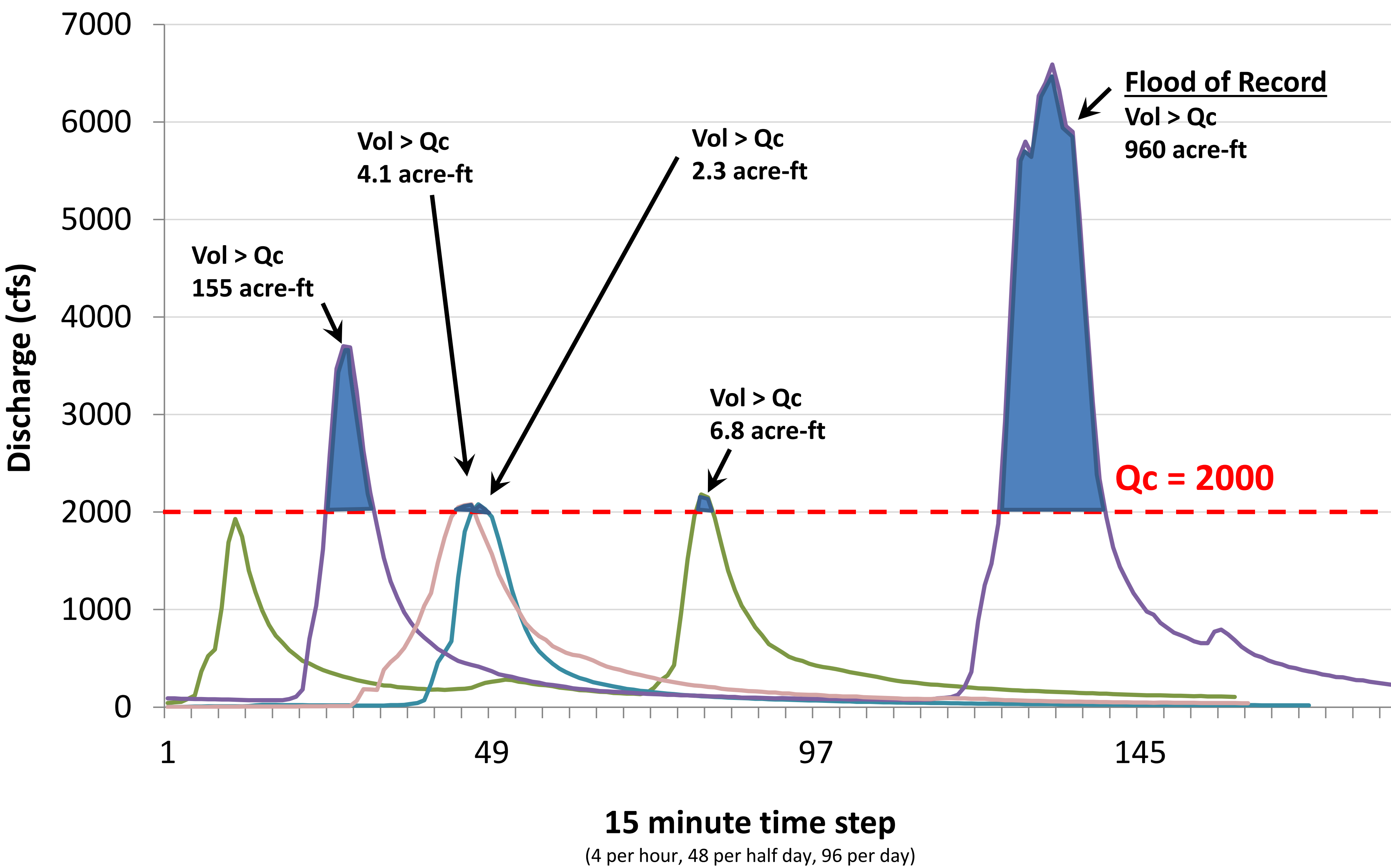
2001-2002 ~ 13 Events Exceeded Qc
Some for up to ~ 12 hours
Others for just ~30 minutes



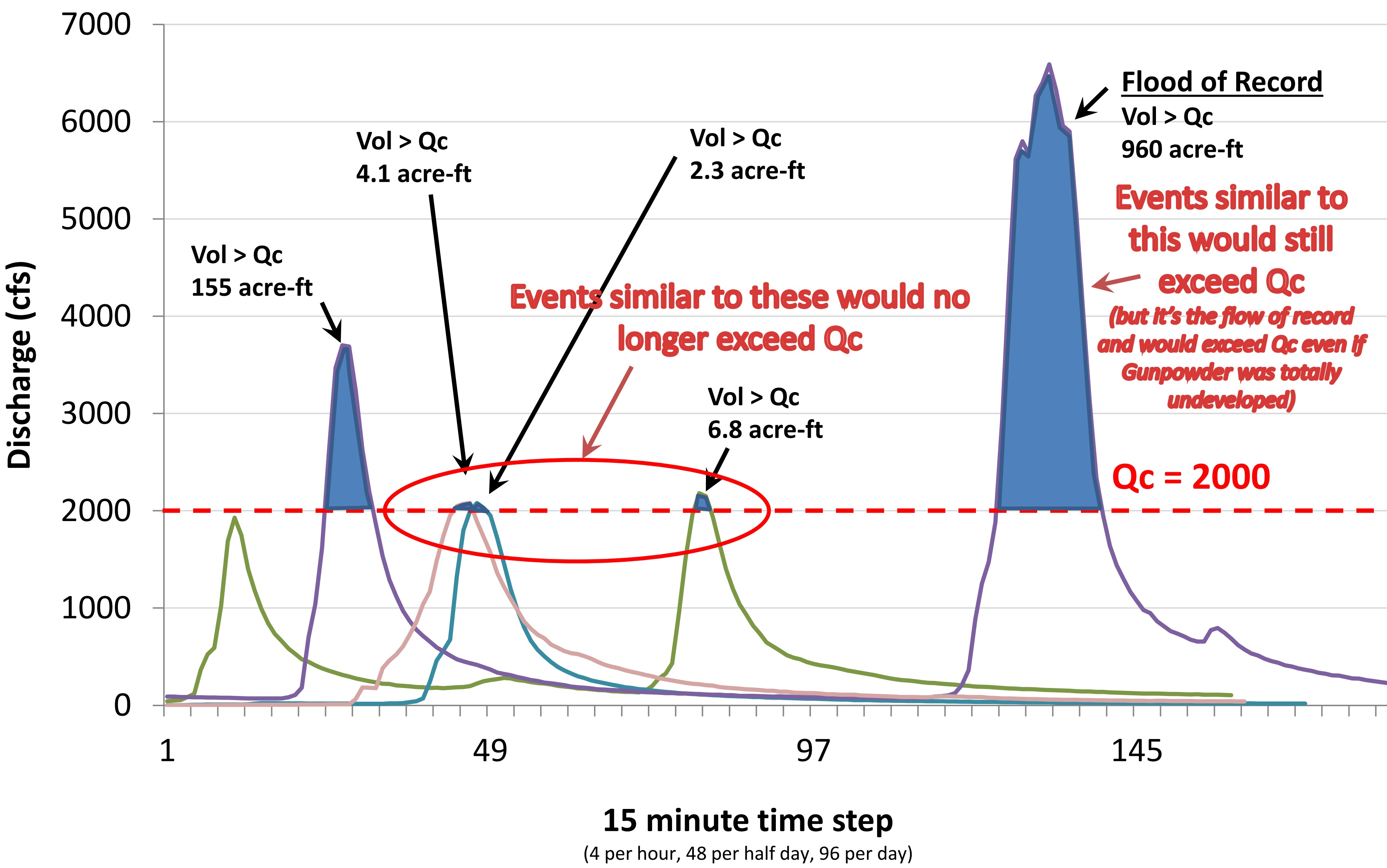
2001-2002
3 Out of the 13 Events Barely Exceed Qc

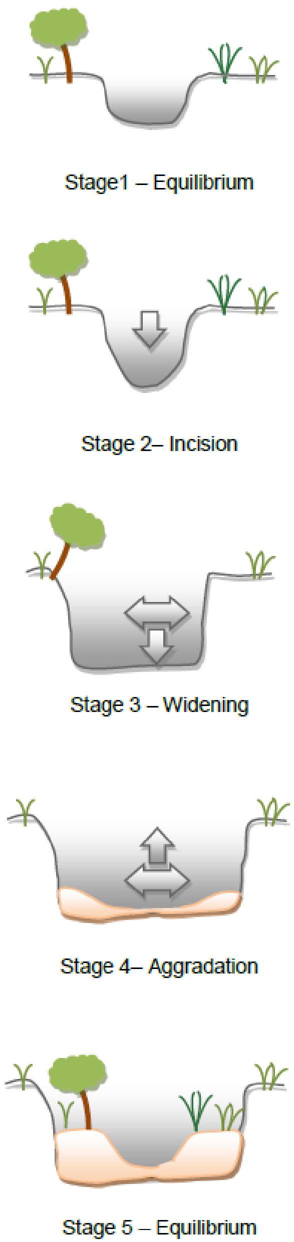


2001-2002
3 Out of the 13 Events Barely Exceed Qc



YMCA Bankfull Wetlands Will Store ~ 5-7 acre-ft above Qc



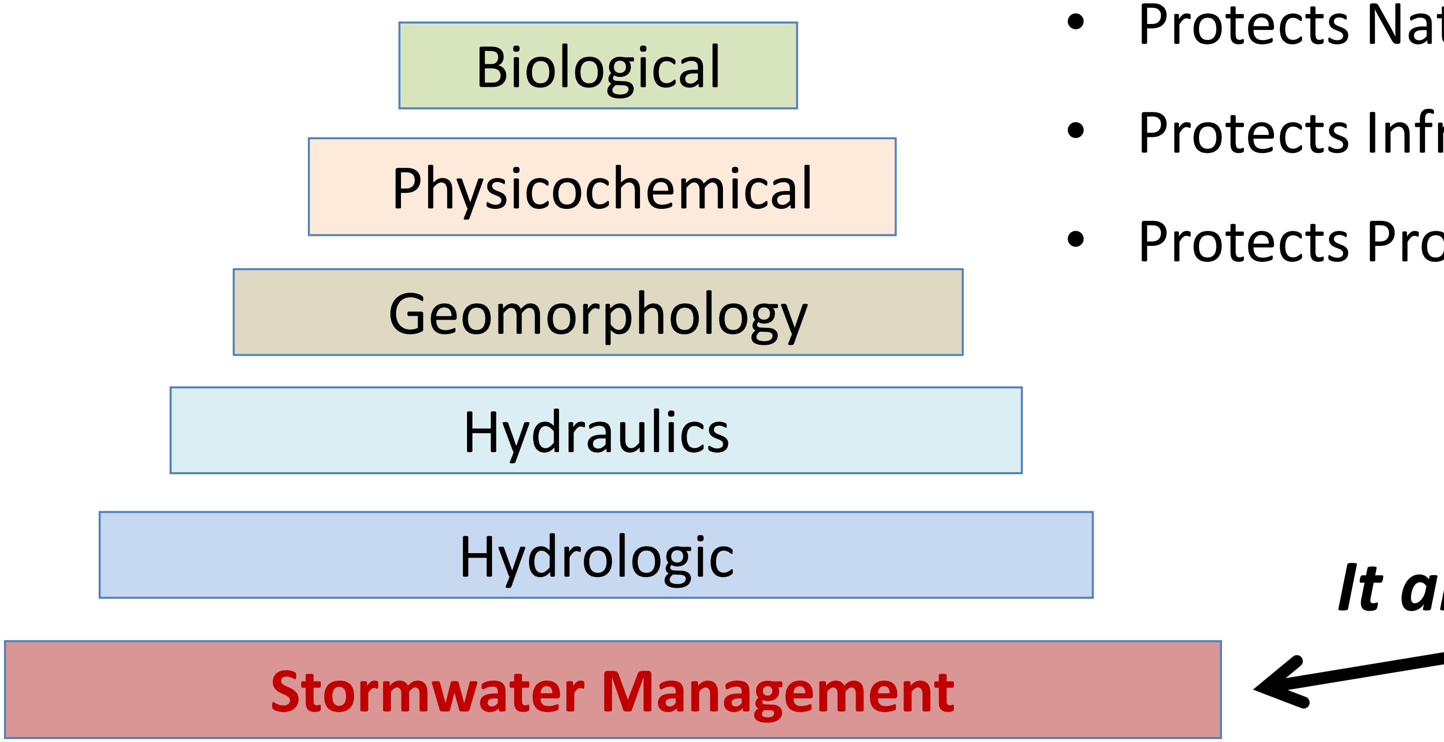


Channel Evolution Sequence in Response to Increased Flows from Urbanization, Adapted from Schumm et al. (1984) and Hawley et al. (2012)

Conclusion

Successfully Managing Stream Stability:

- Protects Natural Resources
- Protects Infrastructure
- Protects Property



It all starts here

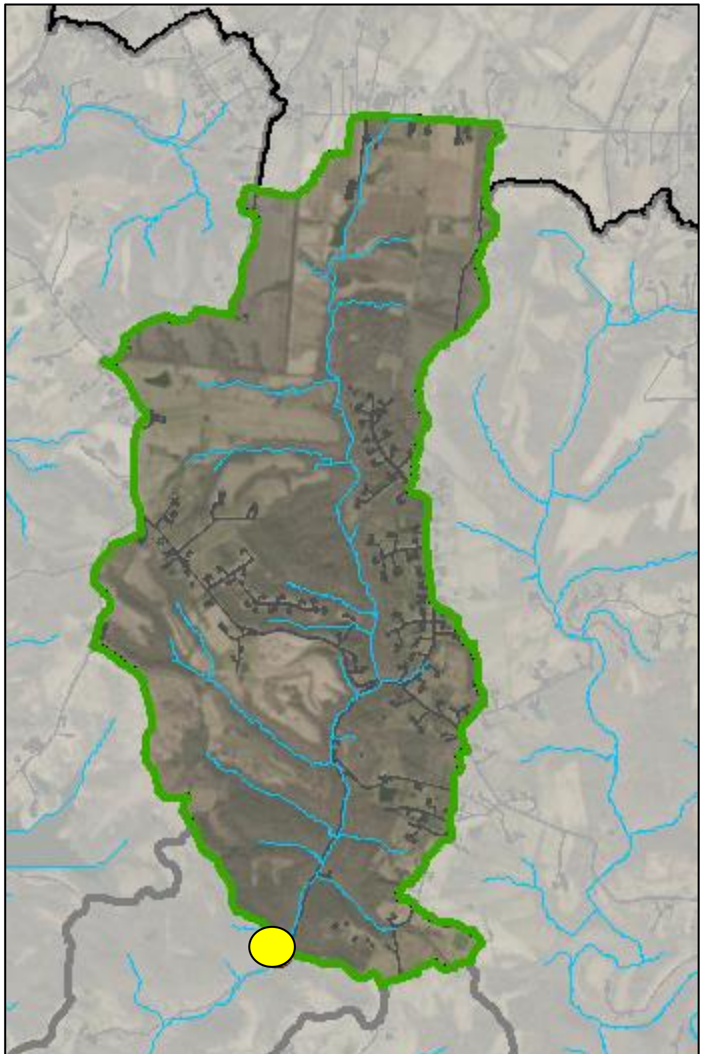
Thank You!

Photo by Mark Jacobs (Boone County Conservation District)

Sustainable Streams LLC

Science · Service · Solutions

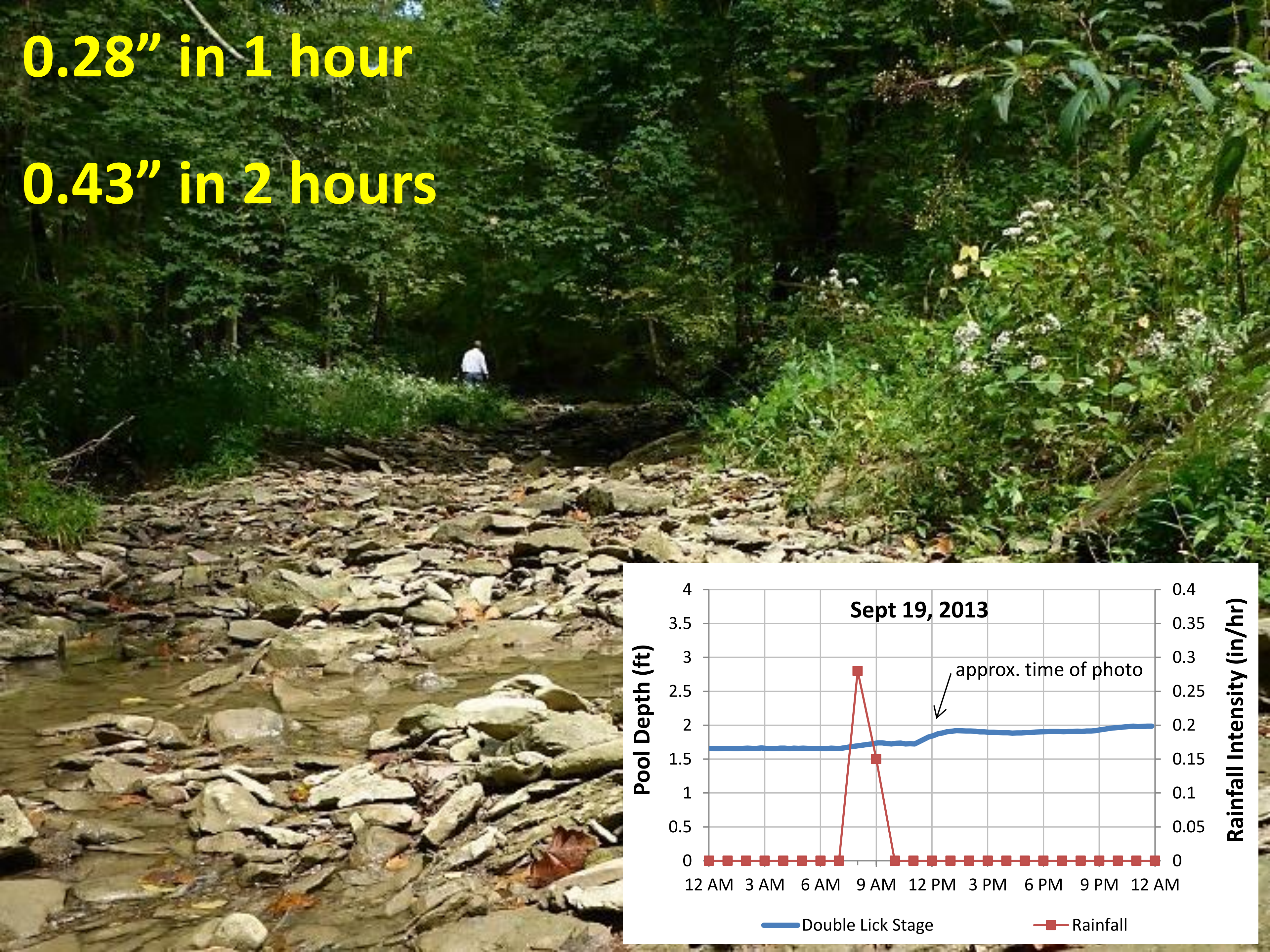
Stream Flow in Undeveloped Watershed



Double Lick Creek

1.8 square miles, 3% impervious

Outstanding State Resource Water


0.28” in 1 hour
0.43” in 2 hours
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

Stream Flow Downstream of Conventional Development

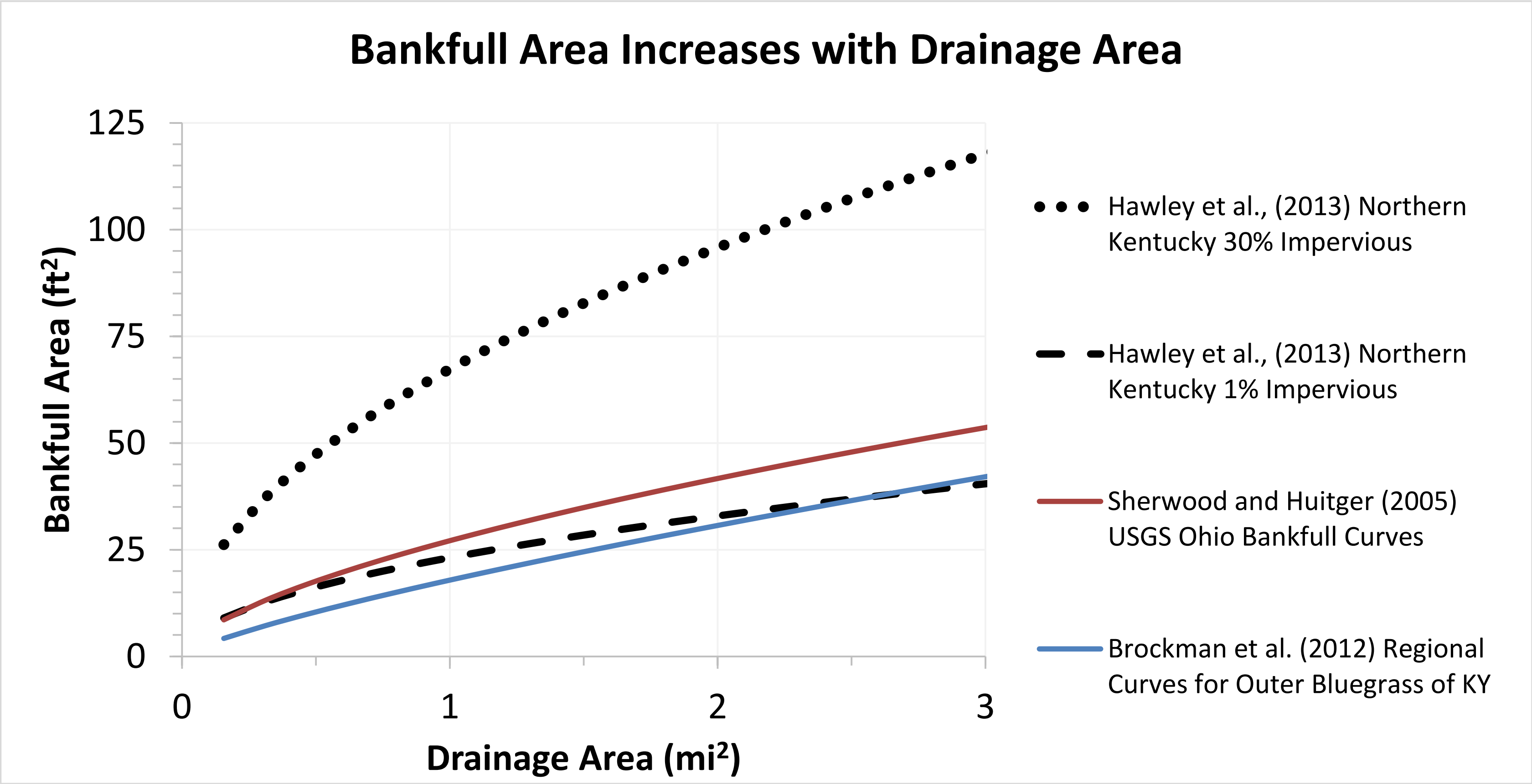
Sand Run

2.2 square miles, 29% impervious


Sand Run
08/28/2008 11:14


0.3” in 1 hour
06/10/2009 08:26

More Water = Larger Channels
More Storm Water = Larger Urban Streams



Adapted from Smith et al. (Forthcoming, Freshwater Science)

Reach Scale Stream Restoration

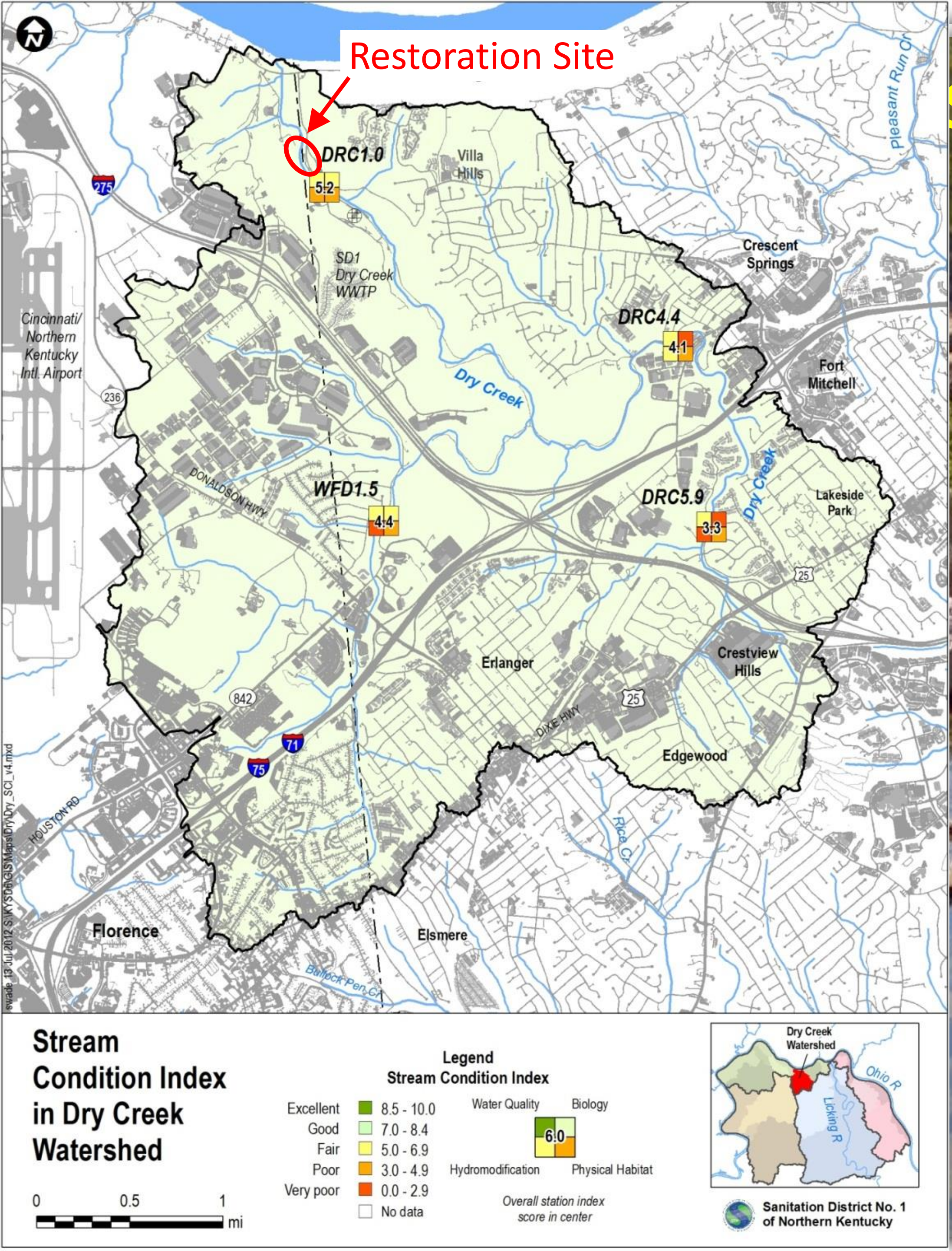
Biological

Water Quality

Physical/Habitat

Stream Flow

Land Use and Management


Restoration Site
DRC1.0
5.2
Villa Hills
SD1 Dry Creek WWTP
Crescent Springs
DRC4.4
4.1
Fort Mitchell
Dry Creek
Cincinnati/ Northern Kentucky Intl. Airport
WFD1.5
4.4
DRC5.9
3.3
Dry Creek
Lakeside Park
DONALDSON HWY
Erlanger
Crestview Hills
DIXIE HWY
Edgewood
HOUSTON RD
Florence
Elsmere
Bullock Pen Cr
Rice Cr
Pleasant Run Cr
275
236
842
71
75
25
Stream Condition Index in Dry Creek Watershed
Legend
Stream Condition Index
Excellent 8.5 - 10.0
Good 7.0 - 8.4
Fair 5.0 - 6.9
Poor 3.0 - 4.9
Very poor 0.0 - 2.9
No data
Water Quality
Biology
6.0
Hydromodification
Physical Habitat
Overall station index score in center
0 0.5 1 mi
Dry Creek Watershed
Ohio R
Licking R
Sanitation District No. 1 of Northern Kentucky


$2,000 per foot

Reach Scale Projects Typically Show Limited Biological Improvement

Freshwater Biology (2009), **55** (Suppl. 1), 1–18 doi:10.1111/j.1365-2427.2009.02372.x

River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice?

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2 out of 78 projects (2.5%) showed significant increases in biodiversity

The Urban Flow Regime is often suspected for the Lack of Biological Success

INVITED FEATURE

Ecological Applications
Vol. 21, No. 6

Ecological Applications, 21(6), 2011, pp. 1932–1949

Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems

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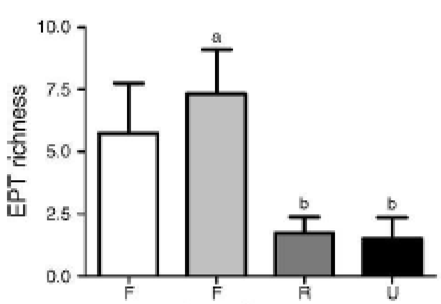
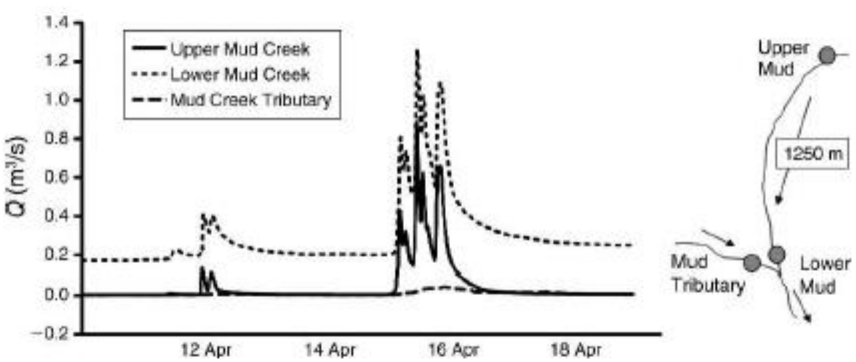
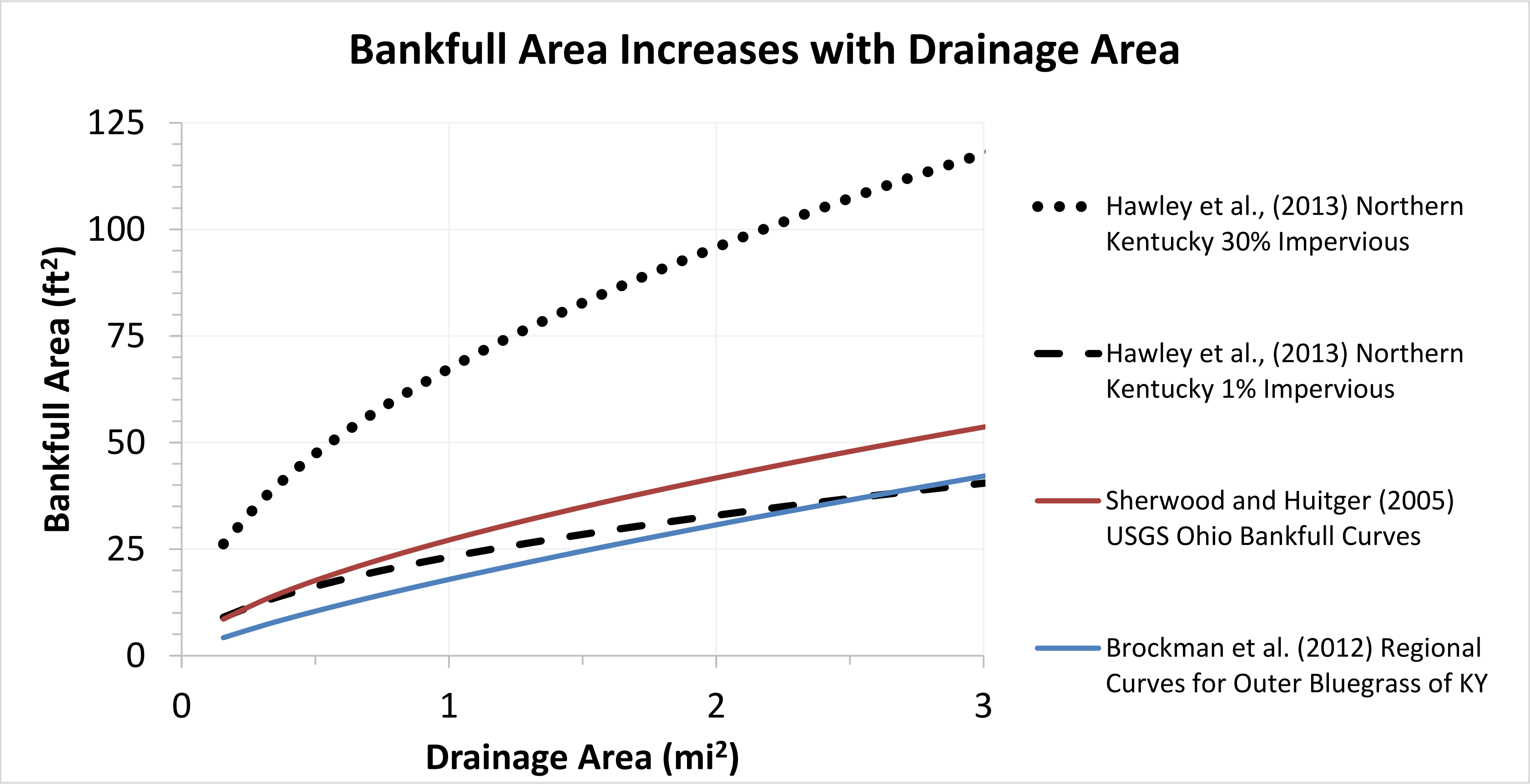


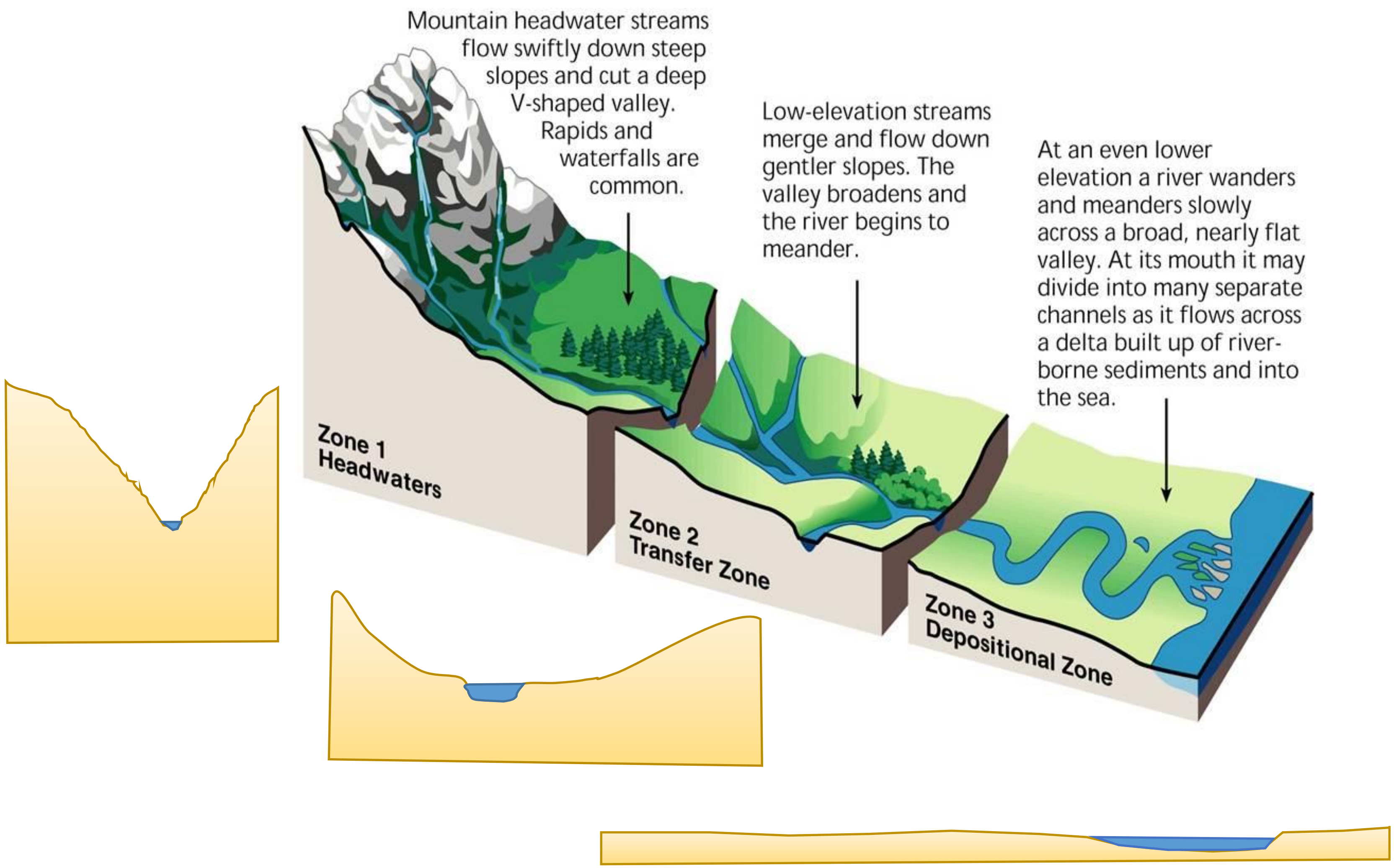


More Water = Larger Channels
More Stormwater = Larger Urban Streams

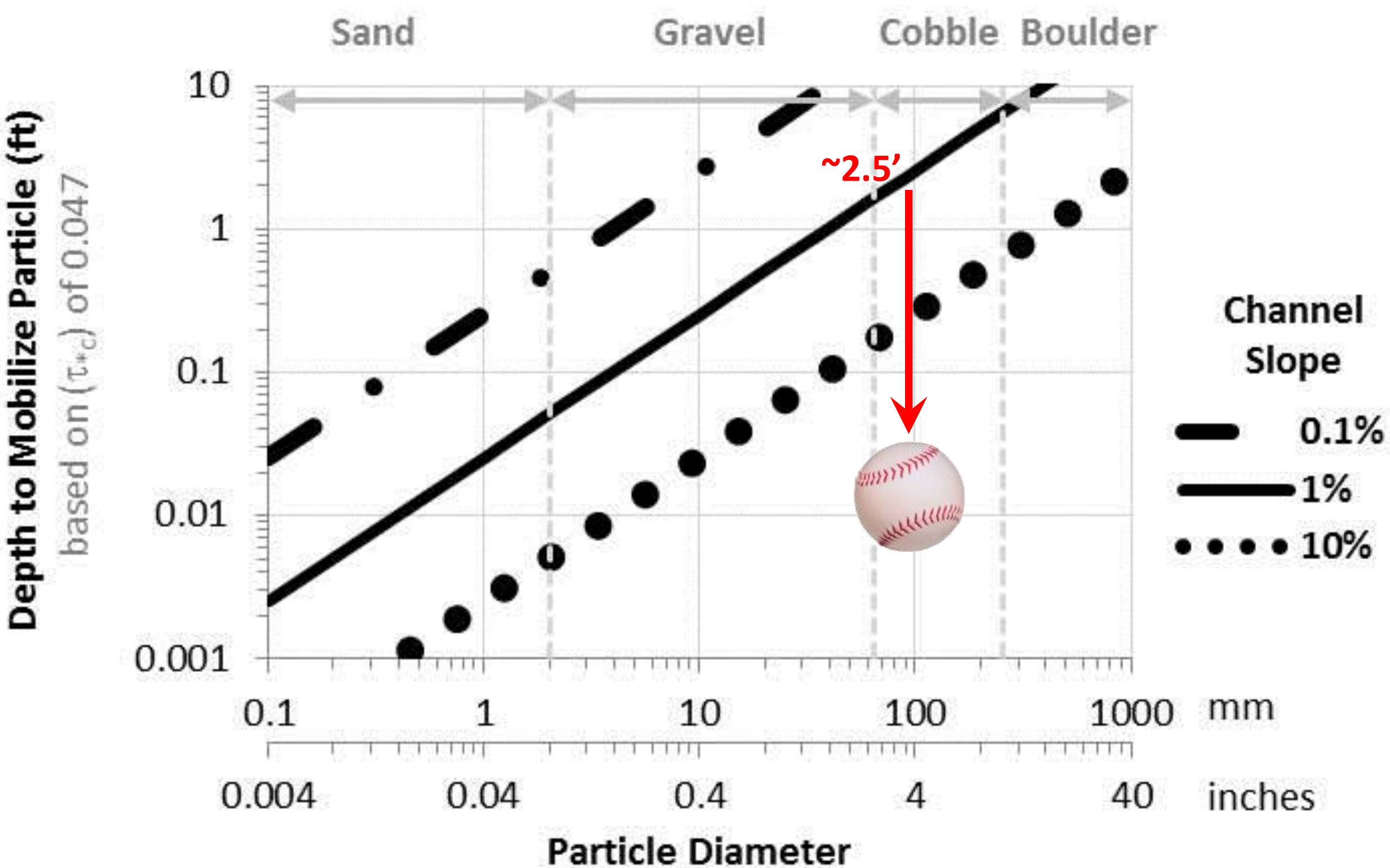


Adapted from Smith et al. (Forthcoming, Freshwater Science)

$Q_{critical}$ Also Depends on Channel & Valley Form

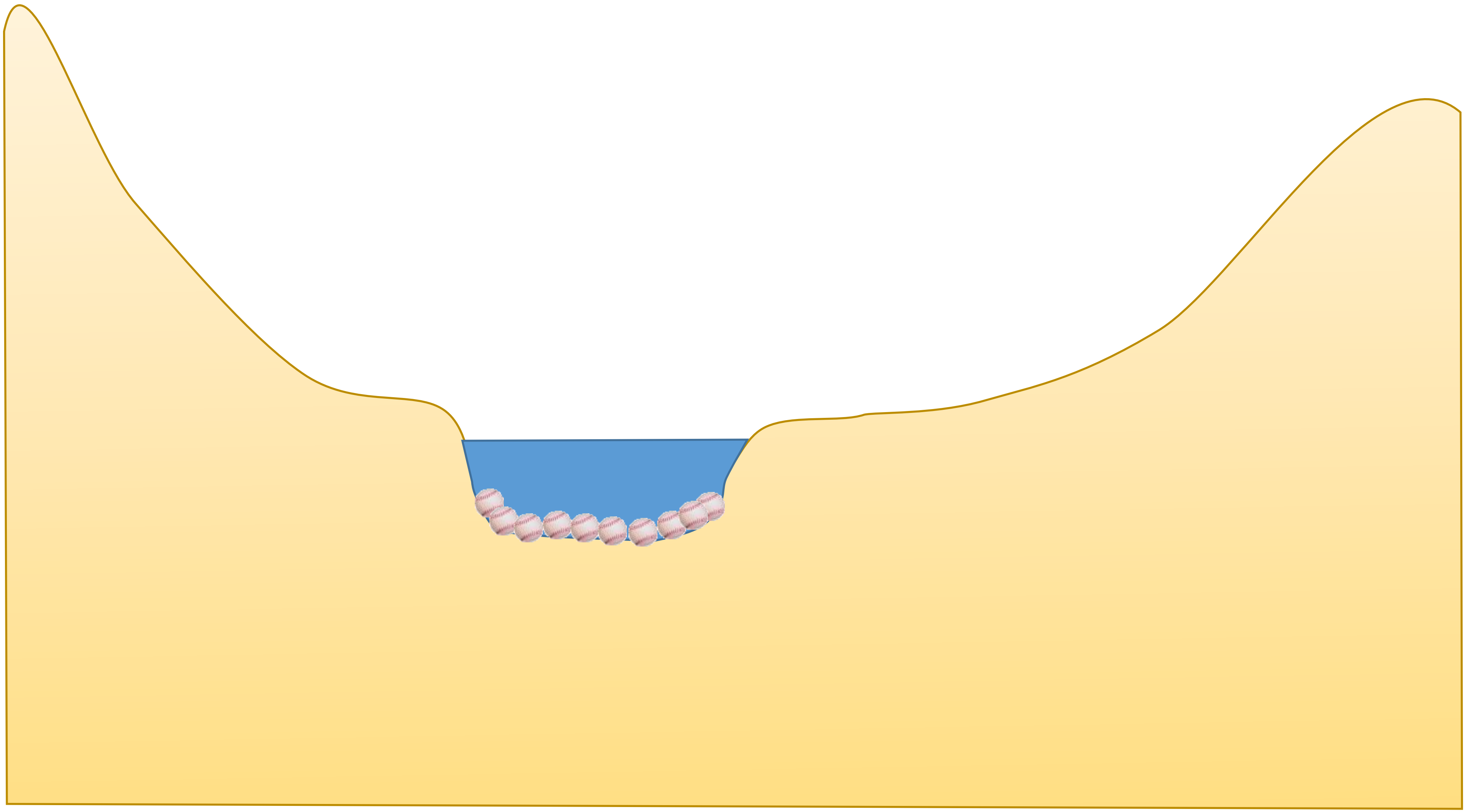


Softball Example:
On 1% Slope, Required Depth to Mobilize Is 2.5’



Adapted from Hawley and Vietz (Forthcoming, Freshwater Science)

Softball Example:
If Water Depth > 2.5’ Bed Erosion Occurs



Softball Example:
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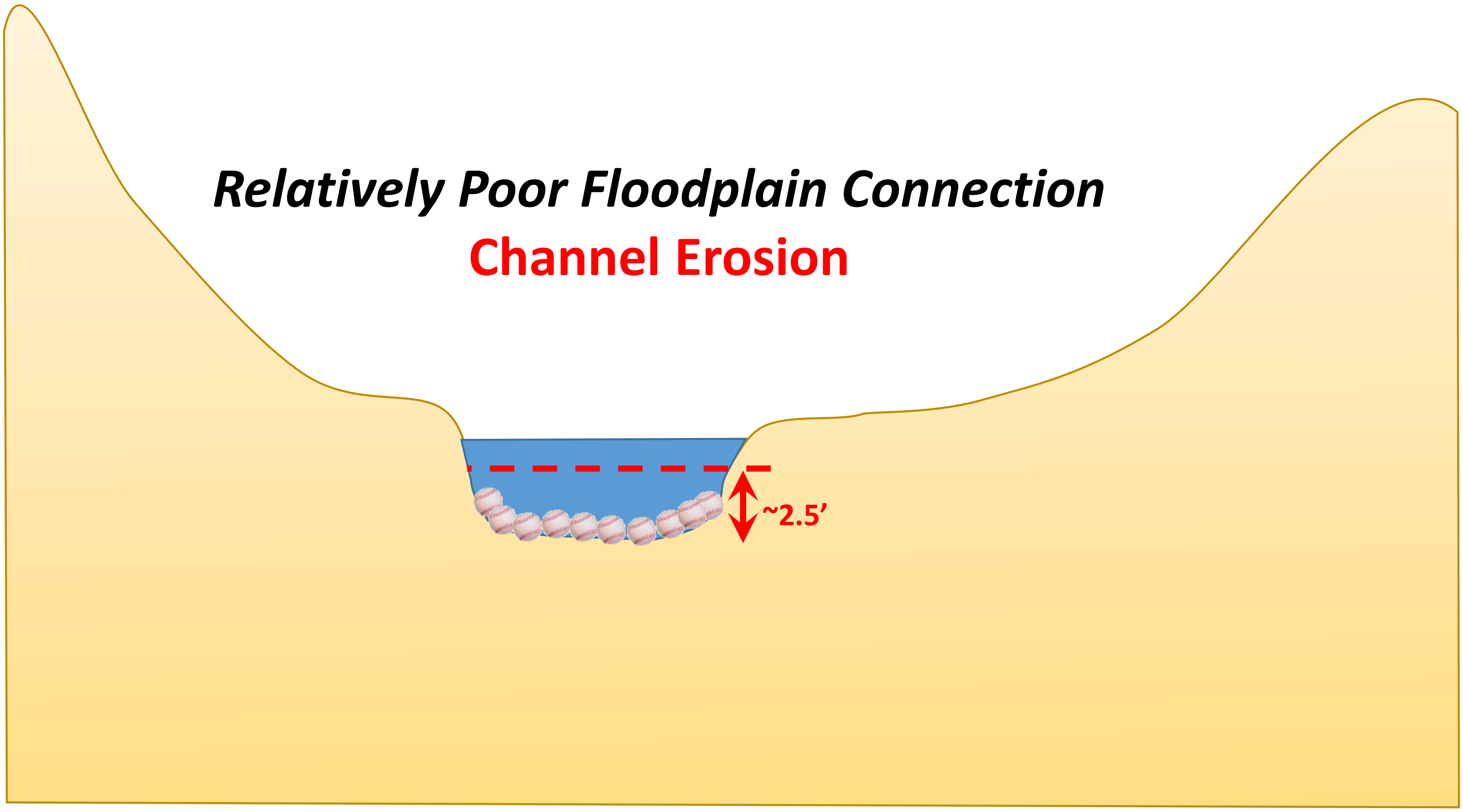
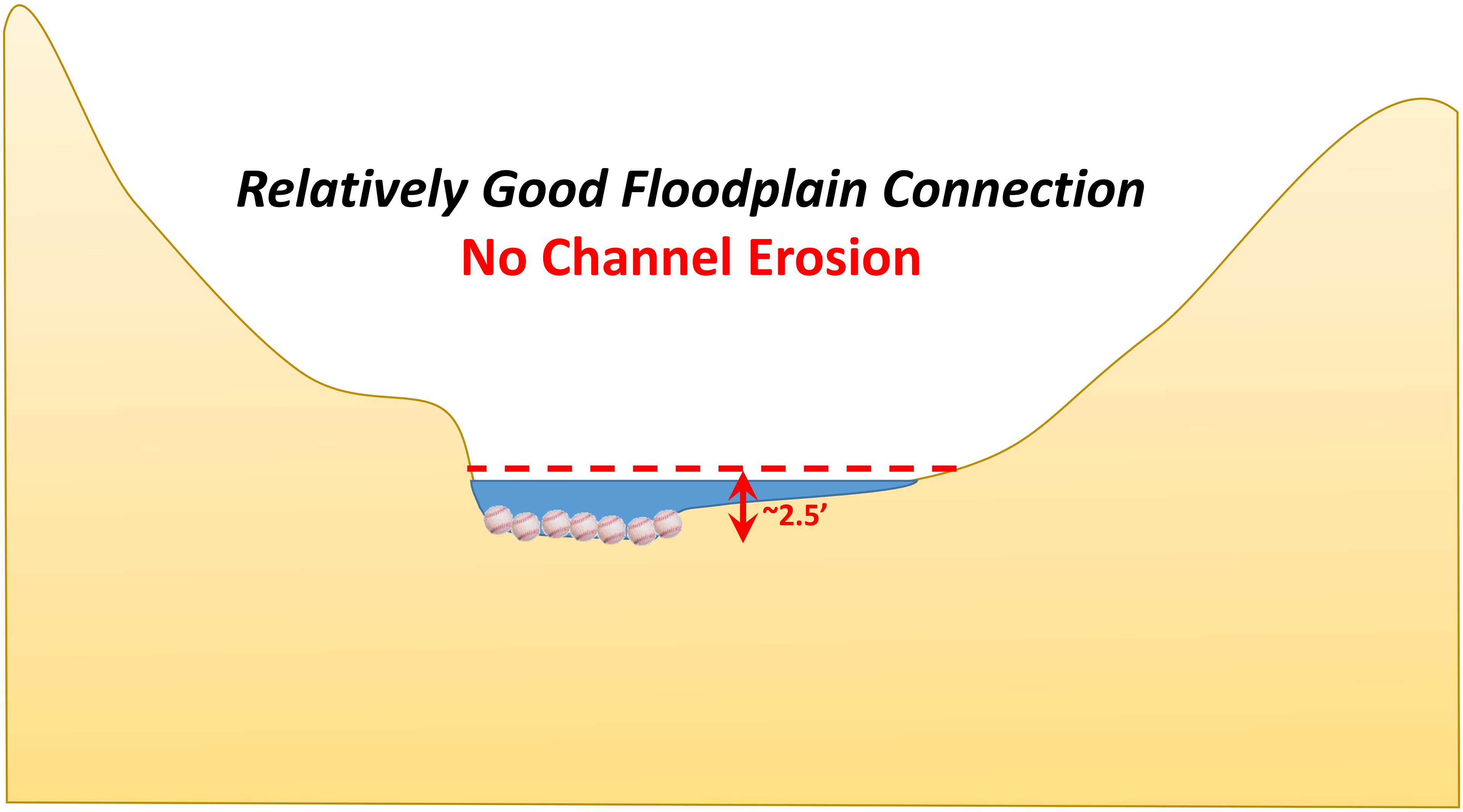
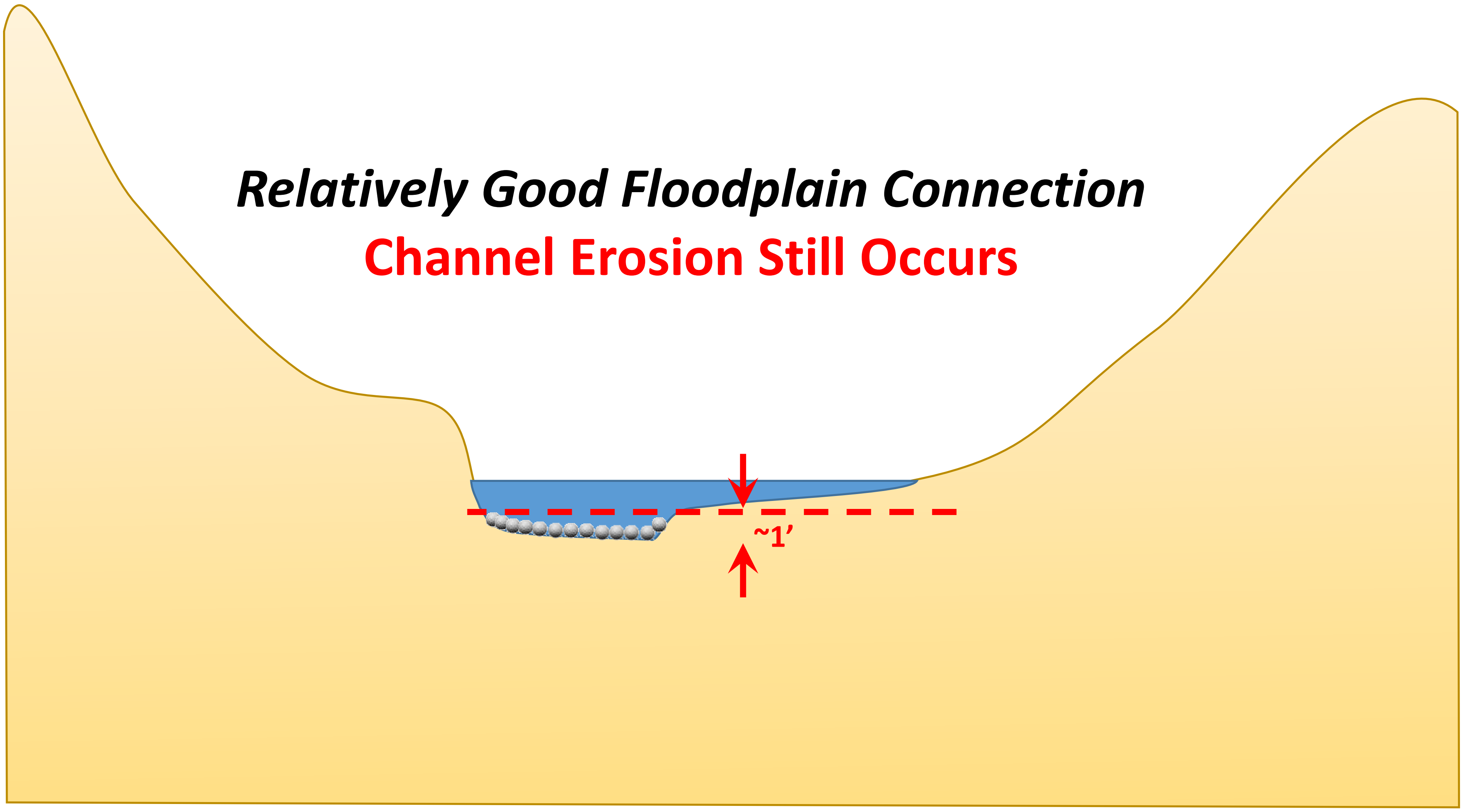


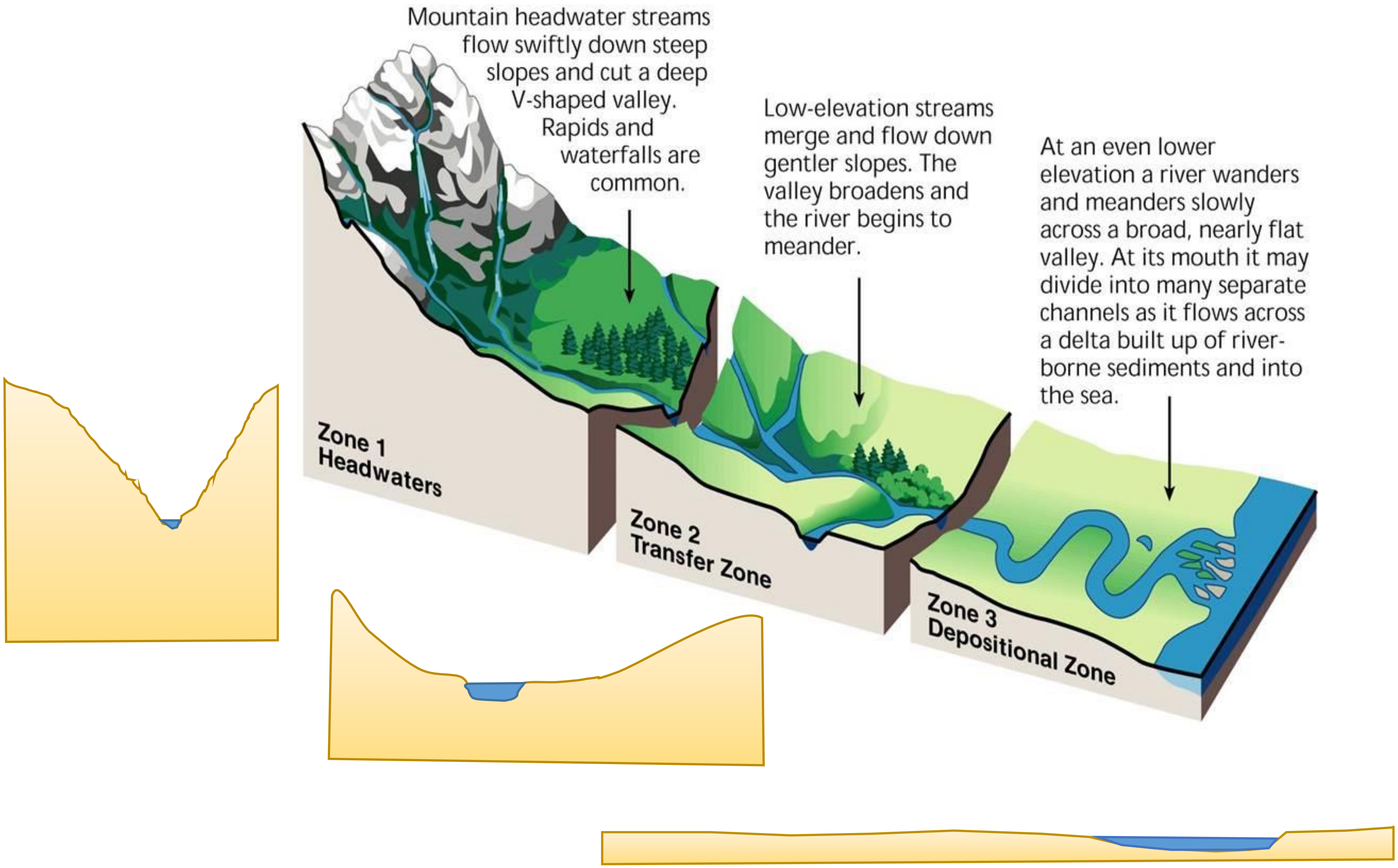
Softball Example:
If Water Depth > 2.5’ Bed Erosion Occurs



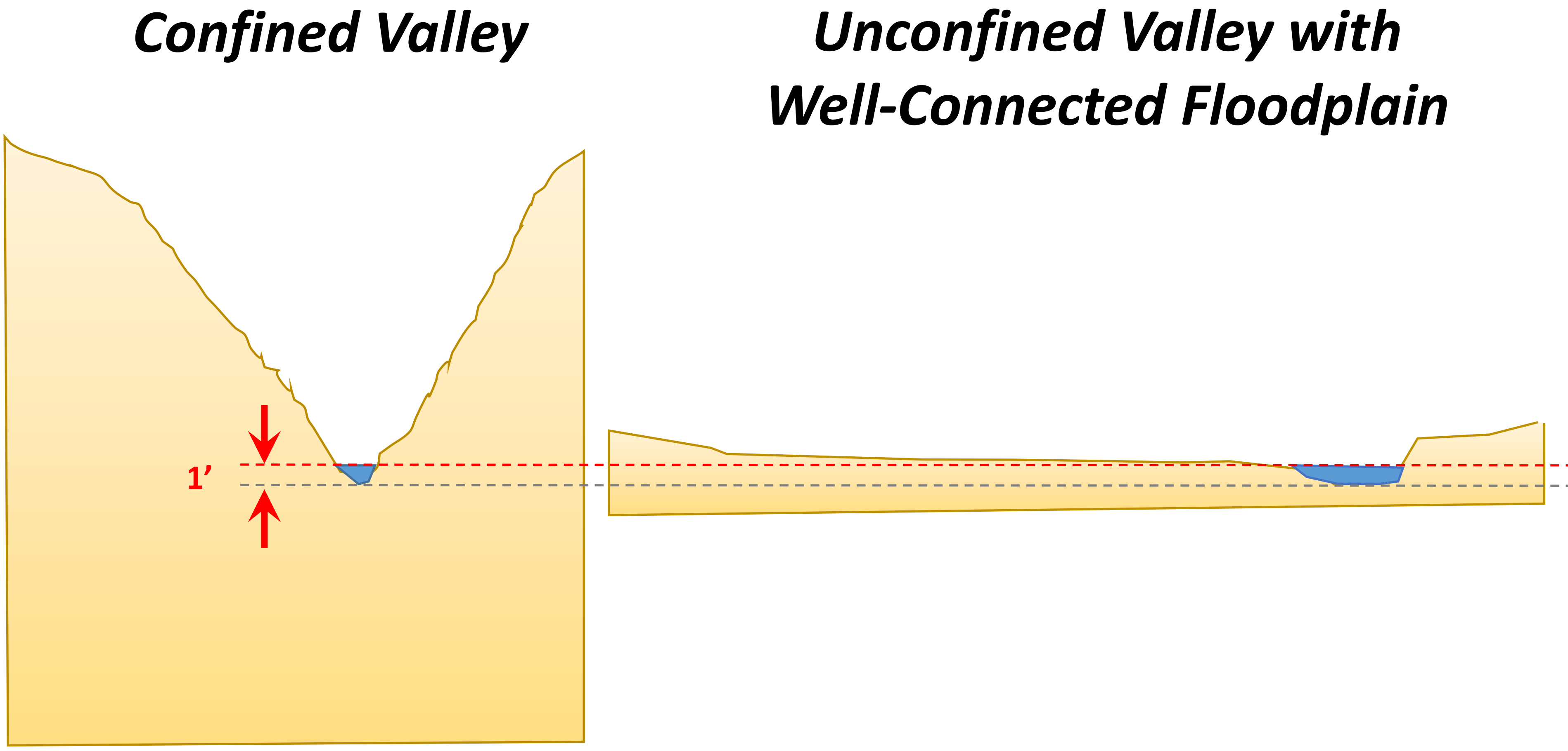
Golf Ball Example:
On 1% Slope, Required Depth to Mobilize Is 1’



Floodplain Connectivity also Affects How Erosive A Flow Can Be



Confined vs. Unconfined Example:
Low Flow



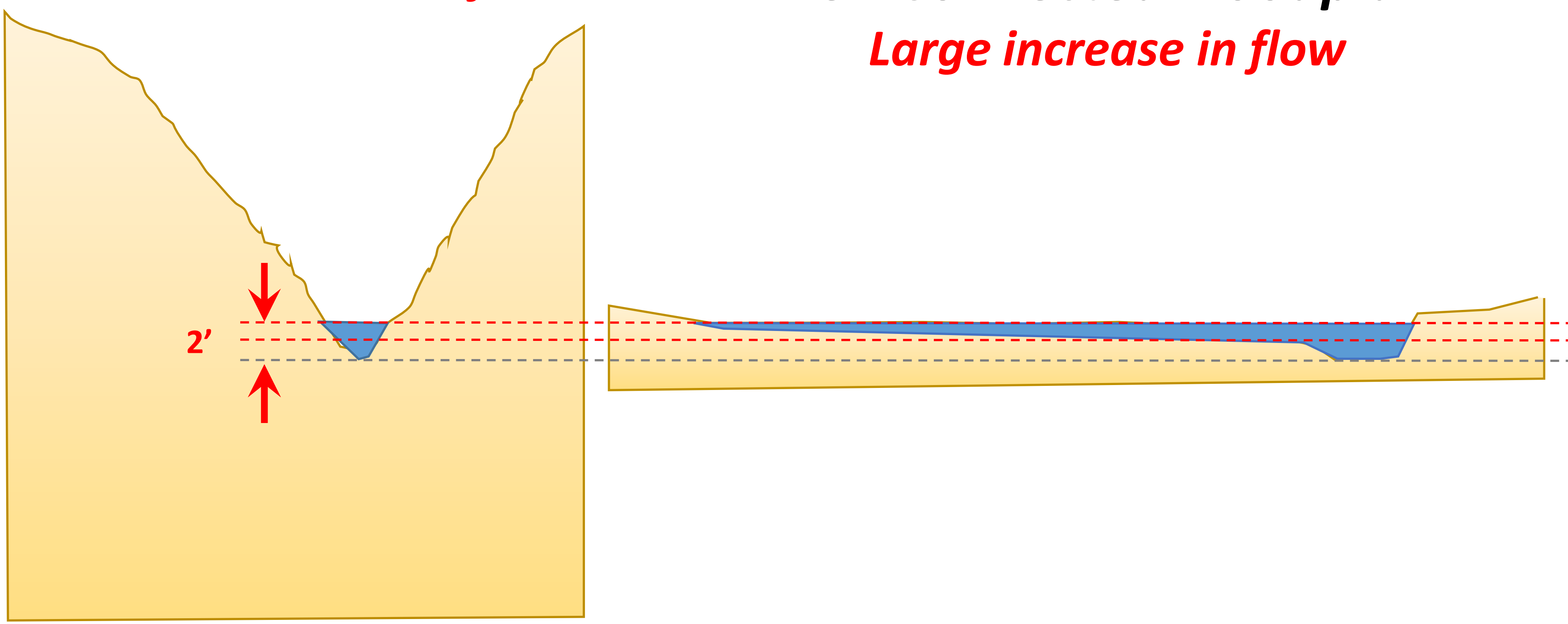
Confined vs. Unconfined Example:
1’ Increase in Depth

Confined Valley

Small increase in flow

Unconfined Valley with Well-Connected Floodplain

Large increase in flow



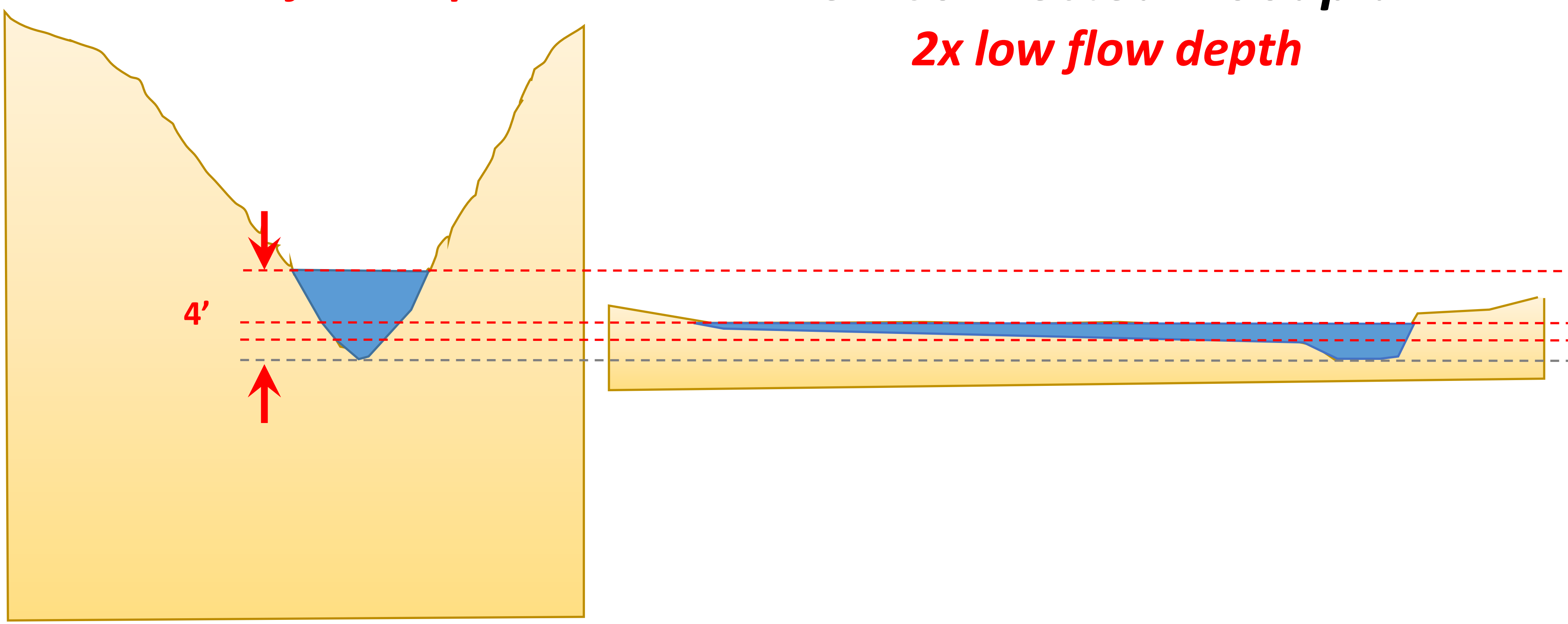
Confined vs. Unconfined Example:
Required Depth to Convey Same Flow On Same Slope

Confined Valley

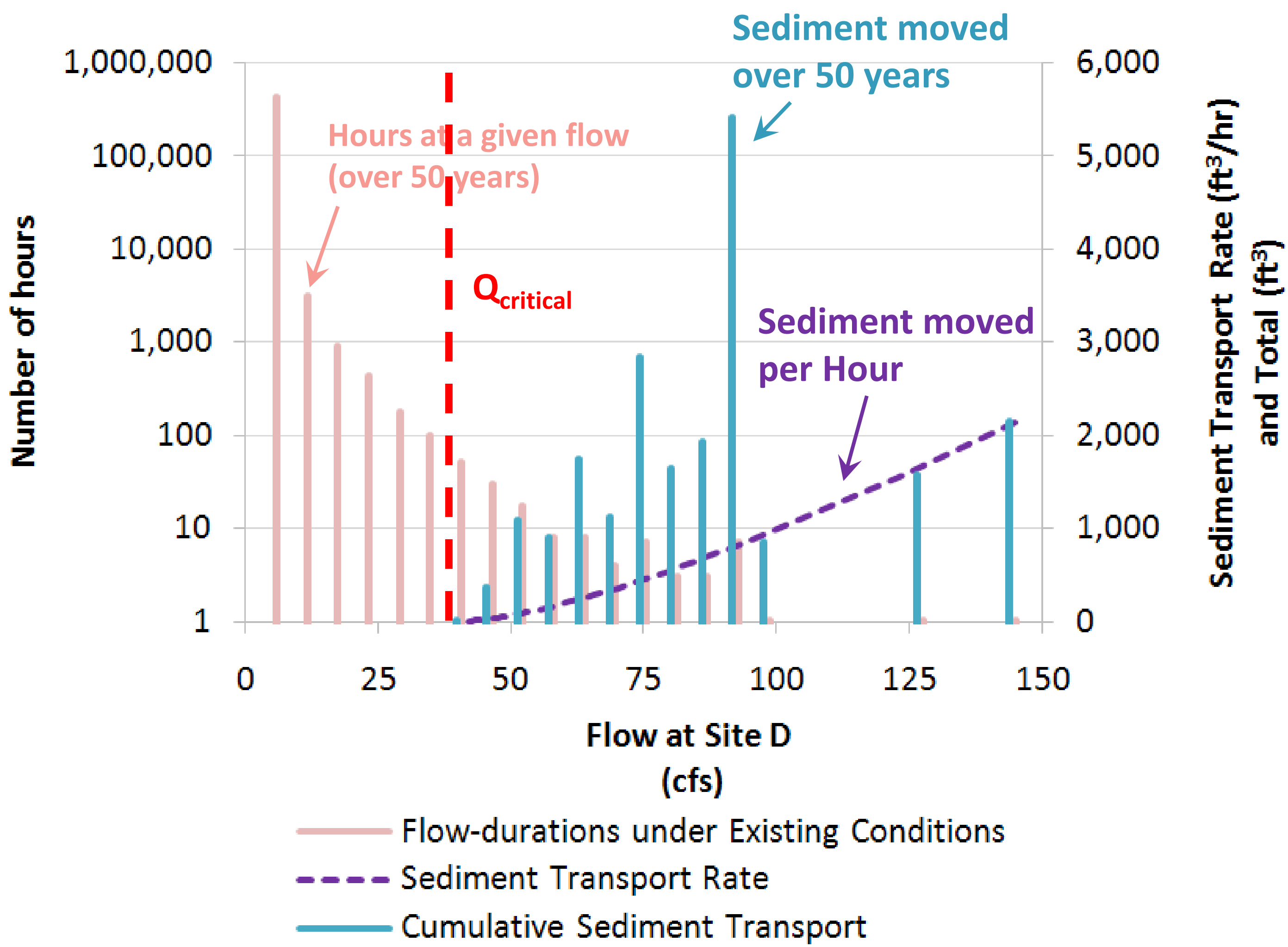
4x low flow depth

Unconfined Valley with Well-Connected Floodplain

2x low flow depth

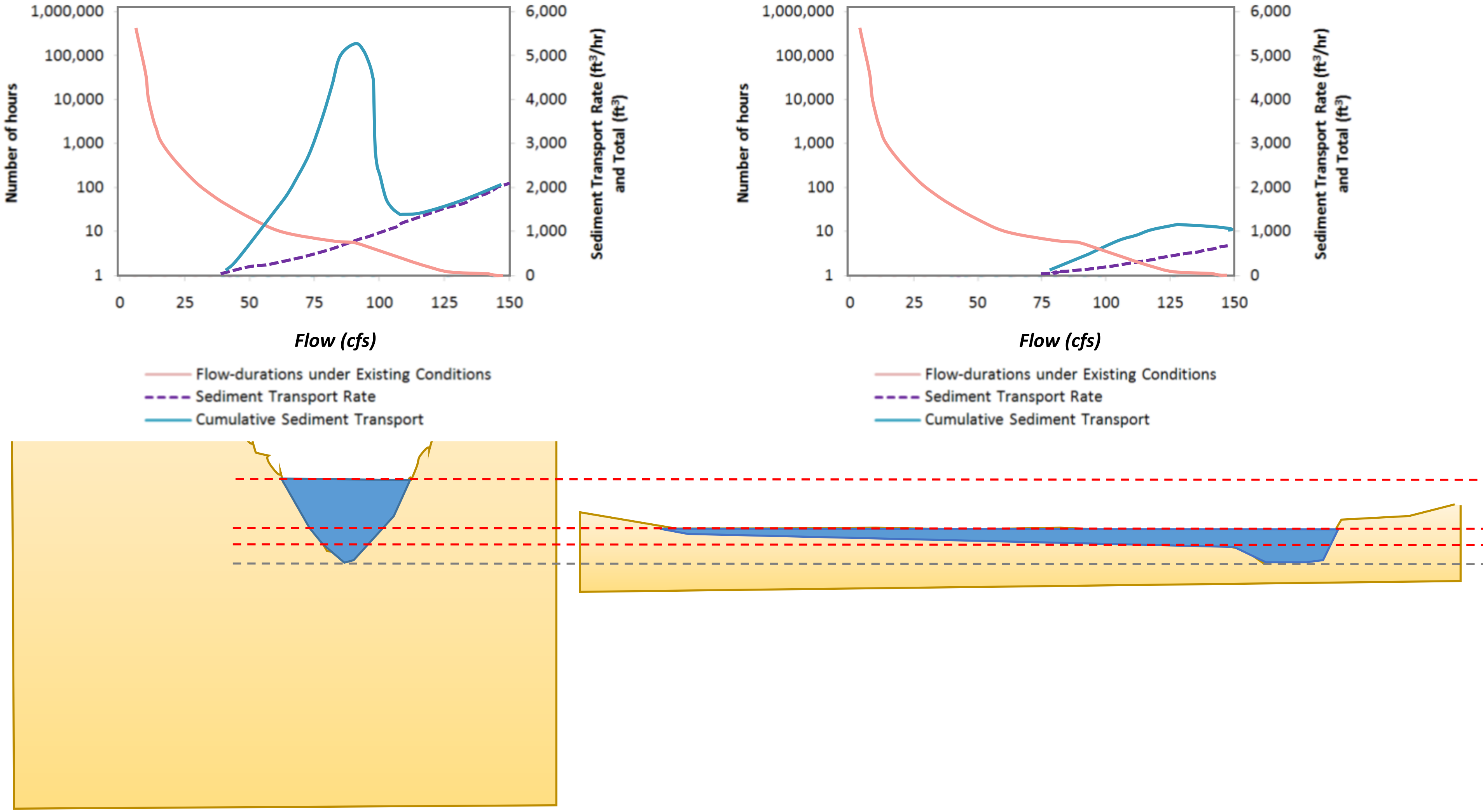


Above $Q_{critical}$, Sediment Transport Continues to Increase with Deeper Flows



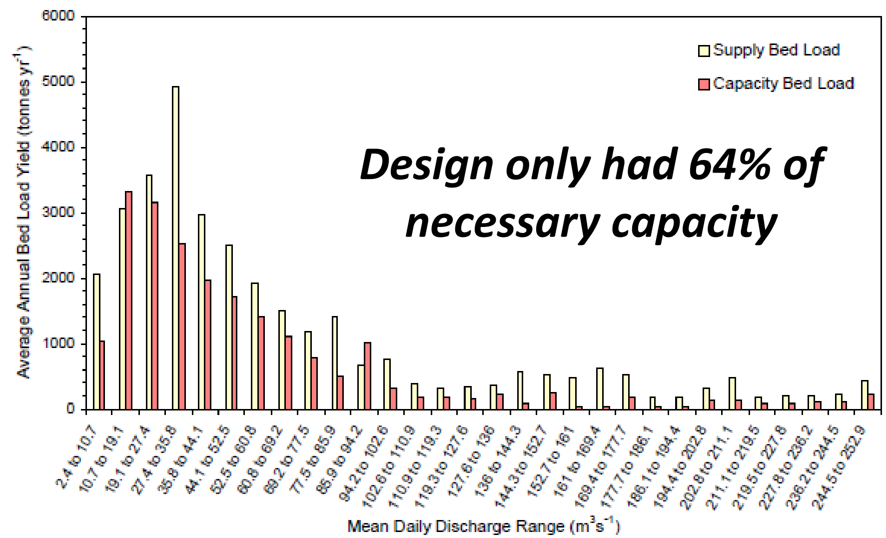
Adapted from Hawley et al. (2012)

Confined vs. Unconfined Example: Sediment Transport Potential



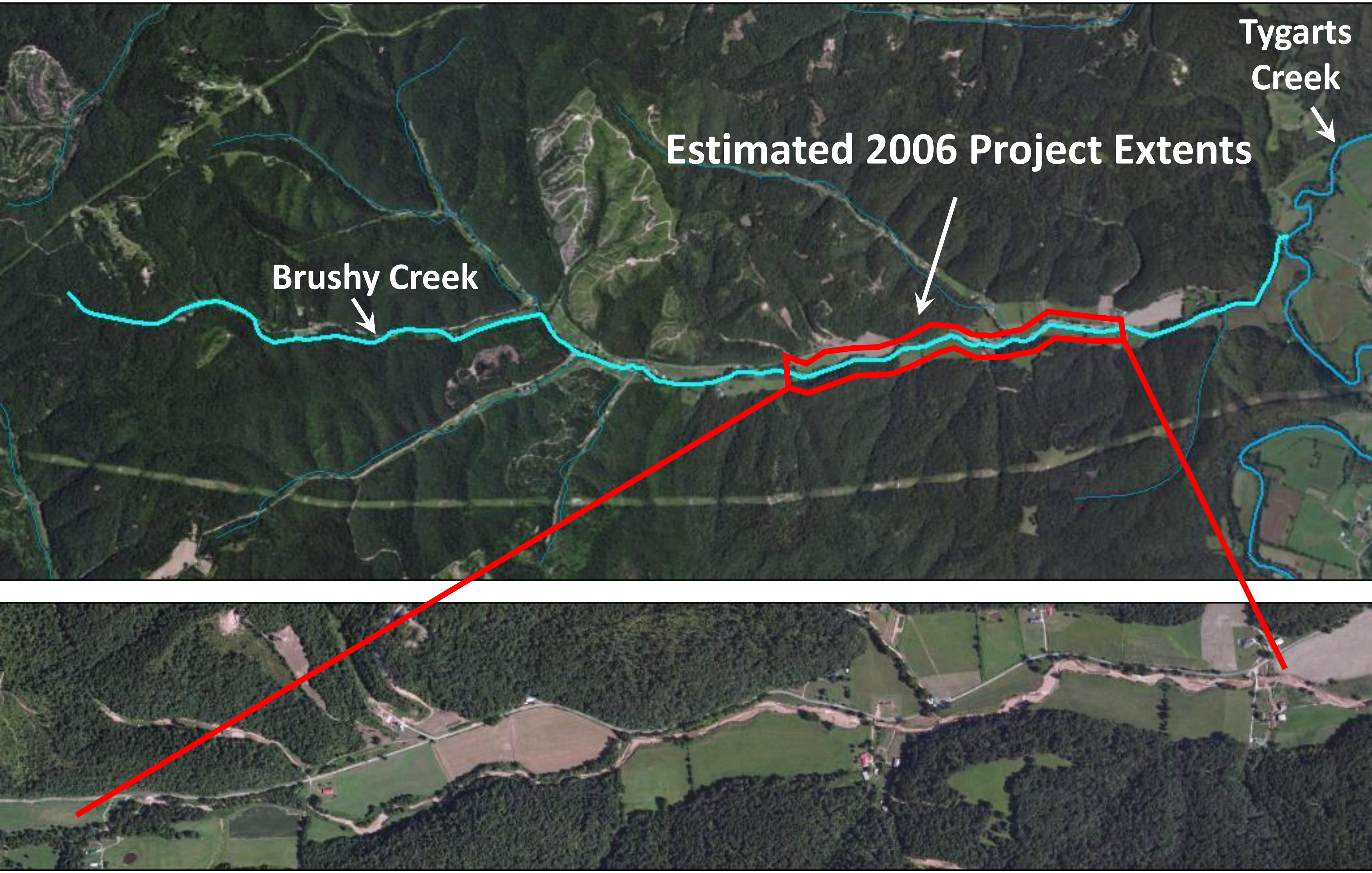
Matching Long-term Sediment Transport Is Critical For Geomorphic Equilibrium

- **Insufficient transport capacity**
  - → ***Aggradation***



Soar & Thorne, 2001

Similar Failures Evident with Regional Projects



Similar Failures Evident with Regional Projects

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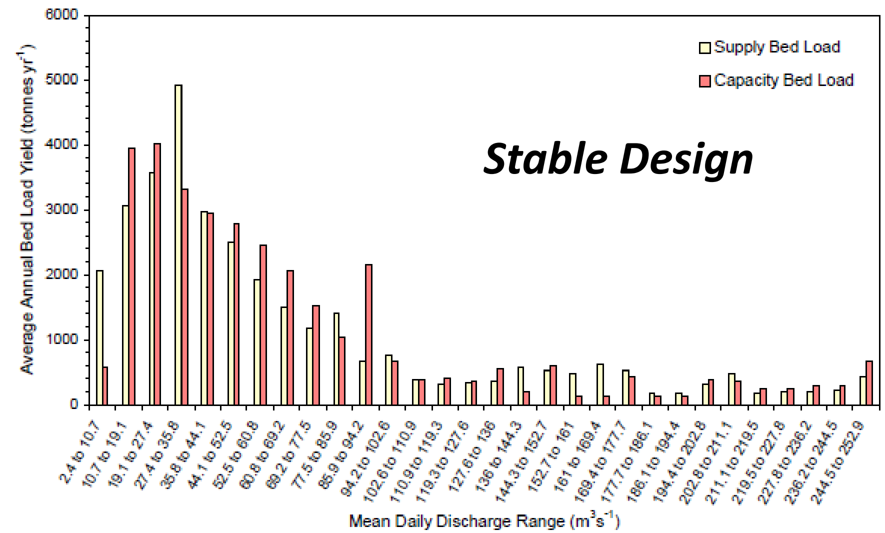
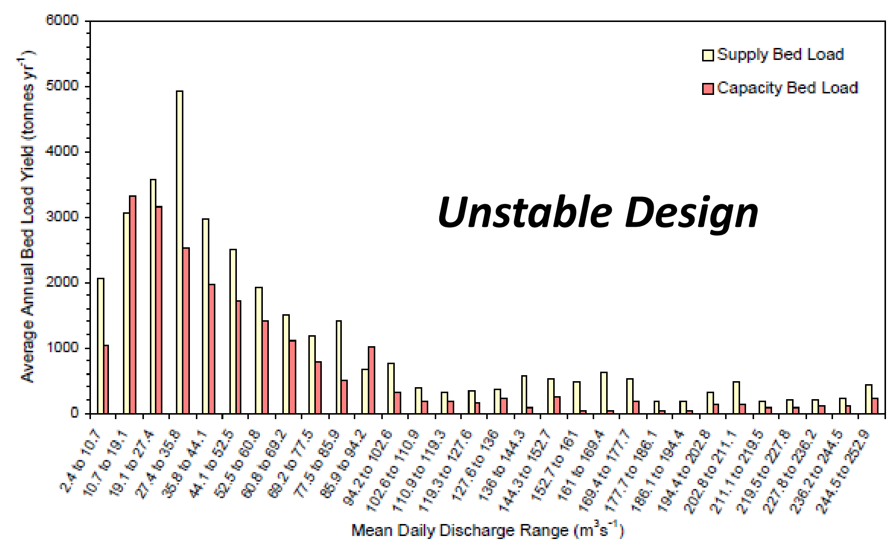
Sedimentation Transport Continuity Should Be A Critical Design Factor

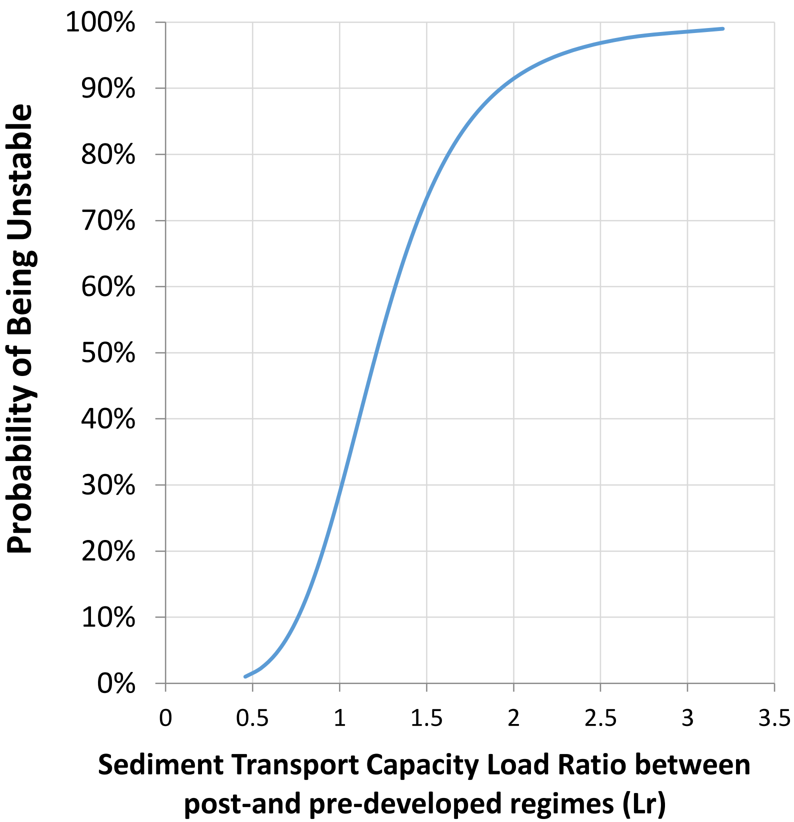
- **Stream Restoration**
- **Stormwater Management**

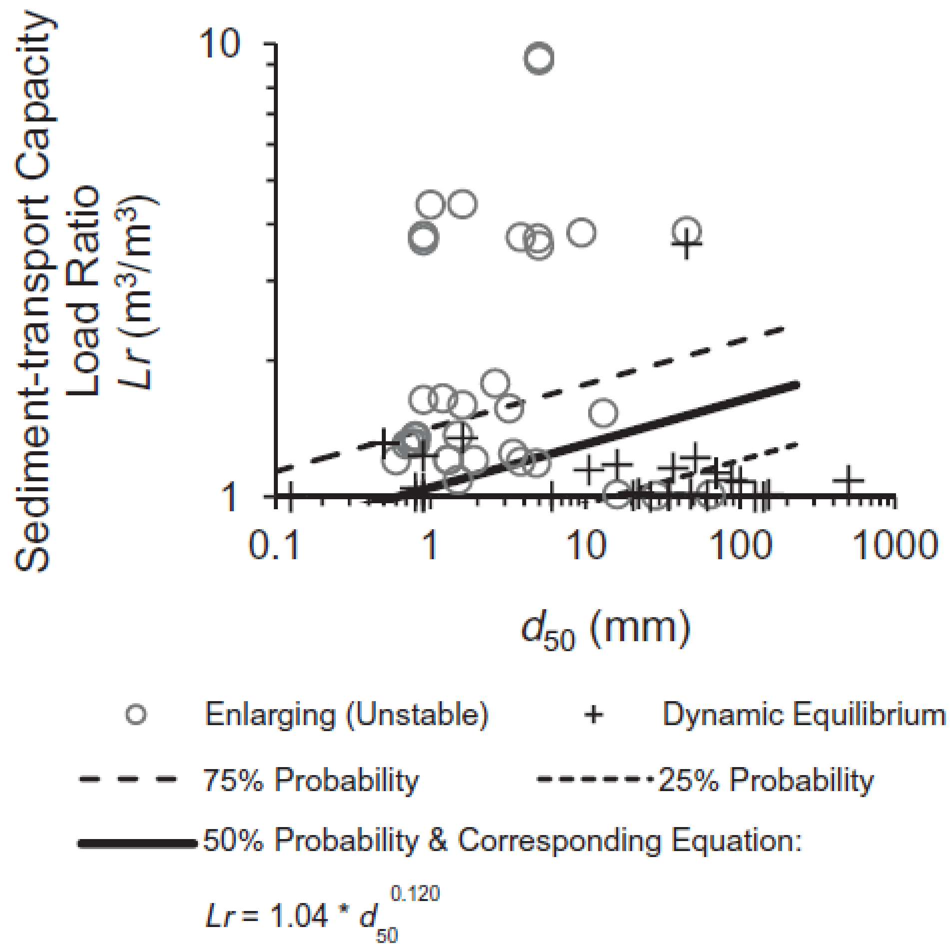




Soar & Thorne, 2001

Stormwater Designs that Fail to Match Pre-developed Sediment Loads→Stream Instability





Adapted from Hawley and Bledsoe (2013)