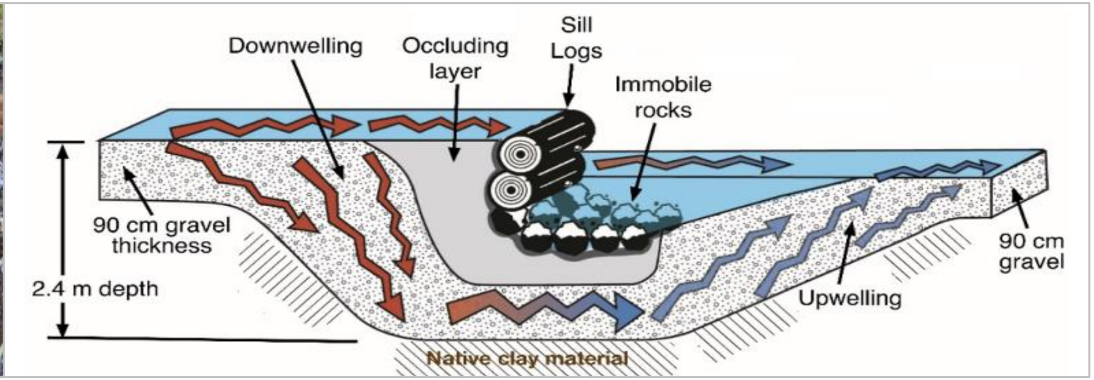
Design principles for maximizing water quality performance of stream restoration via the hyporheic zone



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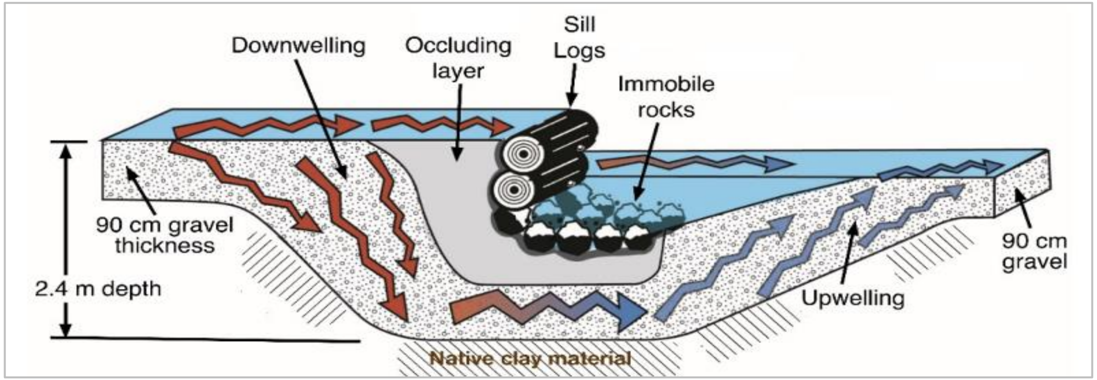
Natural Resources Program

College of Forestry

What about water quality?

- Often a secondary goal of stream restoration, which rarely influences design.

- Minor and inexpensive adjustments to designs can dramatically improve performance.



Bad News

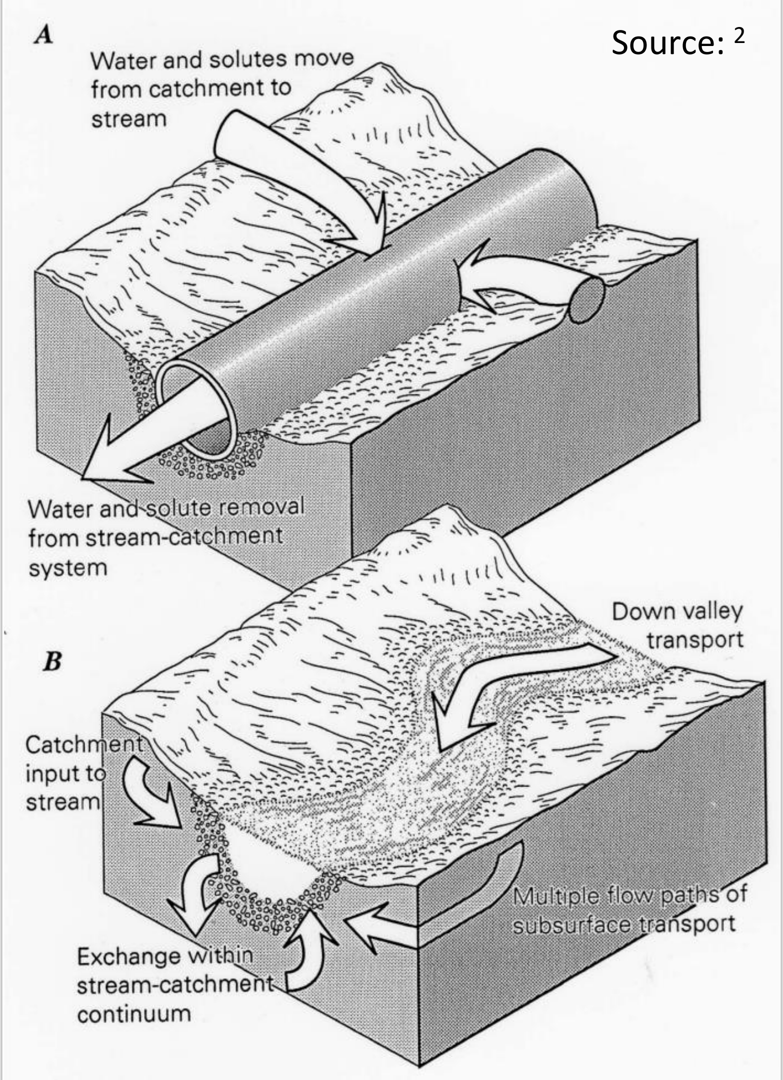
Nearly half of US stream miles are in poor biological condition.[1]

Good News

"The stream is not a pipe"[2]

Recipient vs. Reactor

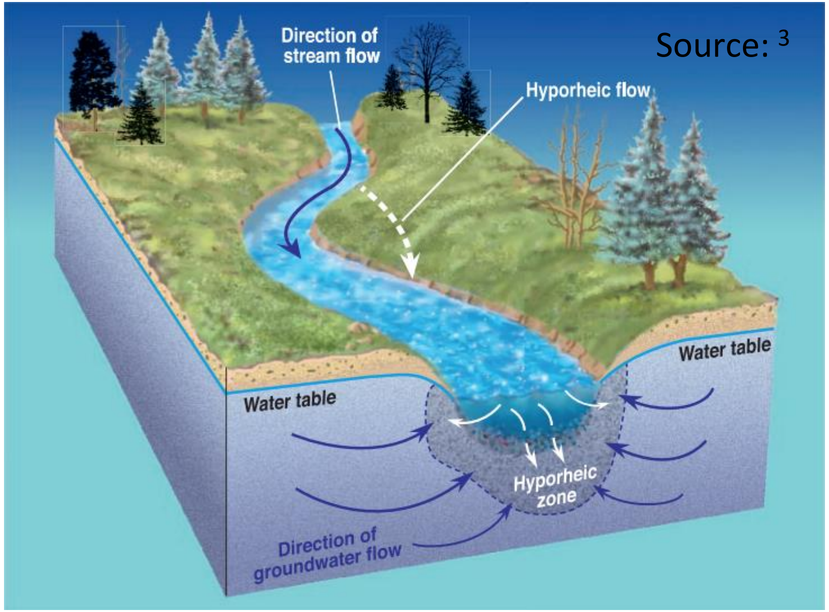
Nonpoint Source → Point Source



Hyporheic Zone – Streambed Sediments

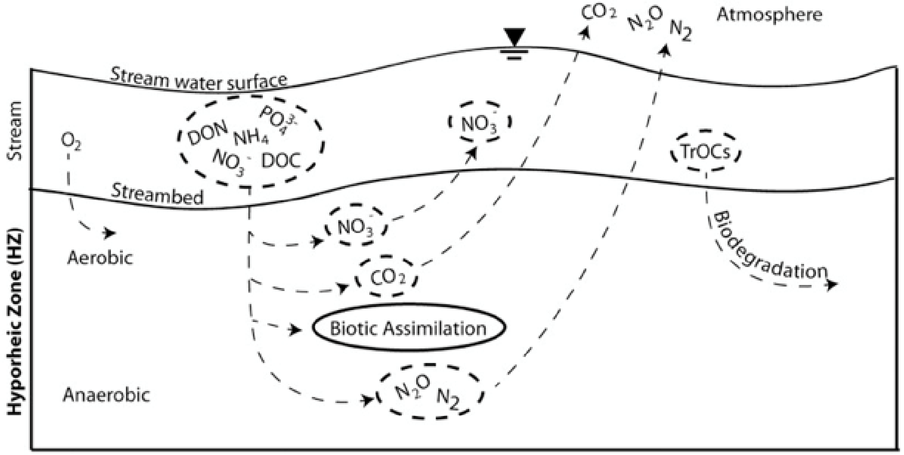
Natural biofilter – a river's liver

- Groundwater-stream mixing
- Slow water velocities
- Diverse microbial ecologies
- Can attenuate many different **dissolved contaminants**



Optimal water quality performance depends on:

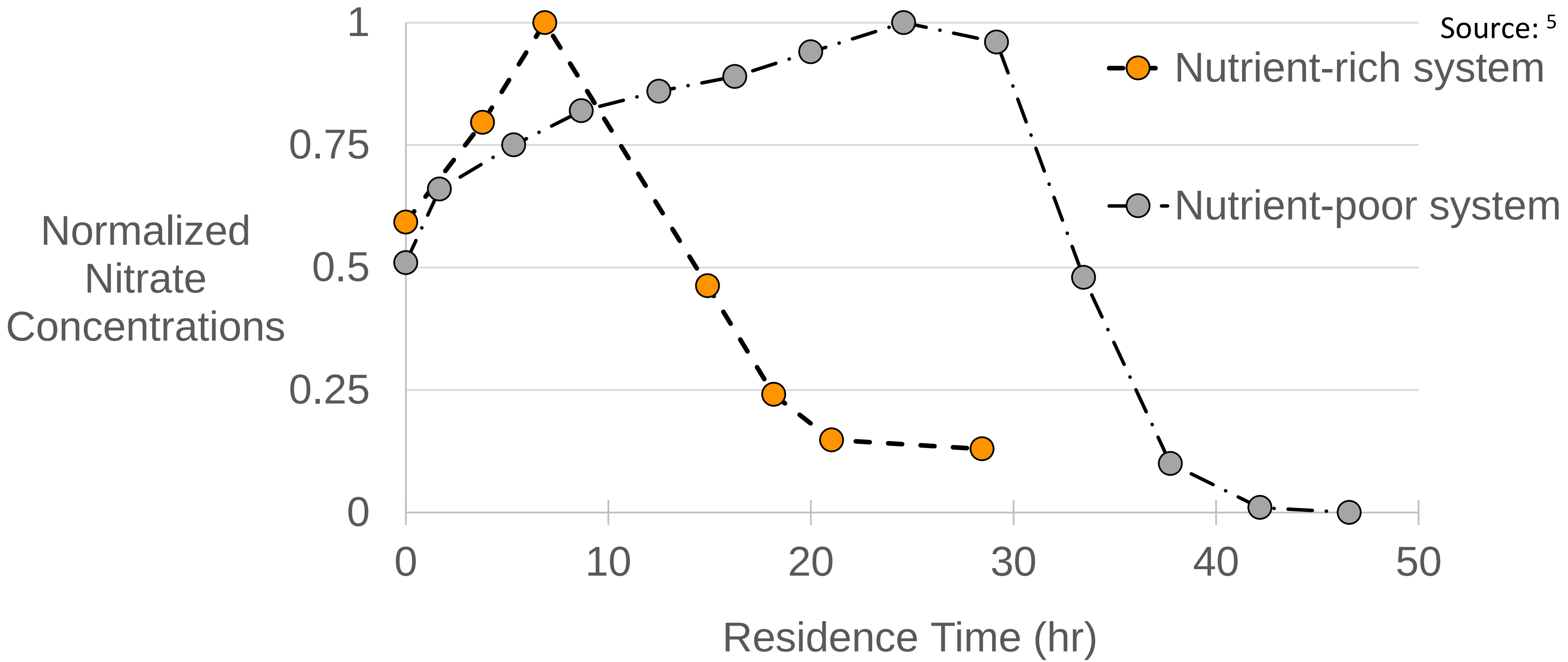
1. **Flux**: The amount of stream water passing through the hyporheic zone
2. **Residence time**: how long the water spends in the hyporheic zone



Source: [4]

Unfortunately, many structures only deliver one or the other.

Example: Residence Time and Nitrate



Example: Thornton Creek in Seattle, WA

What should be built for *water quality*?

Motivating Questions

1) What kind of hyporheic zone should we build?

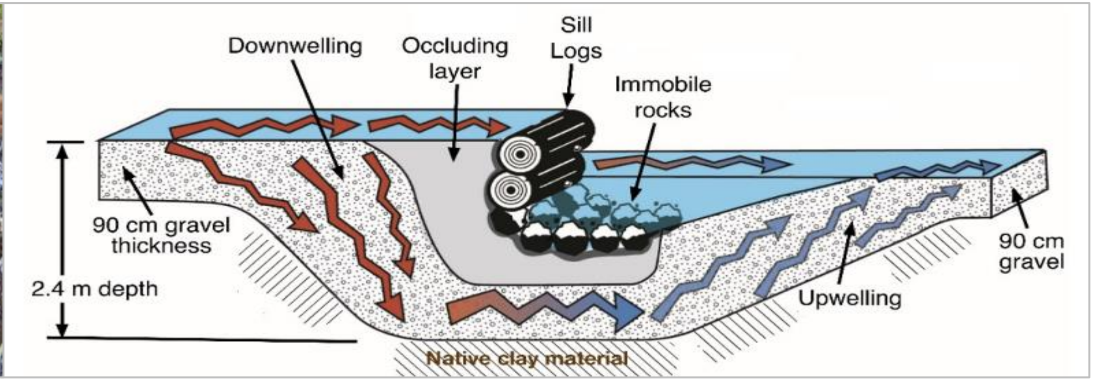
- Selection tools may be inadequate
- Academics are unhelpful: “It depends.”

2) Perhaps how a structure is built could be more important than what kind of structure it is?

- How can any given structure be adjusted to provide the proper biogeochemical conditions for pollutant removal?

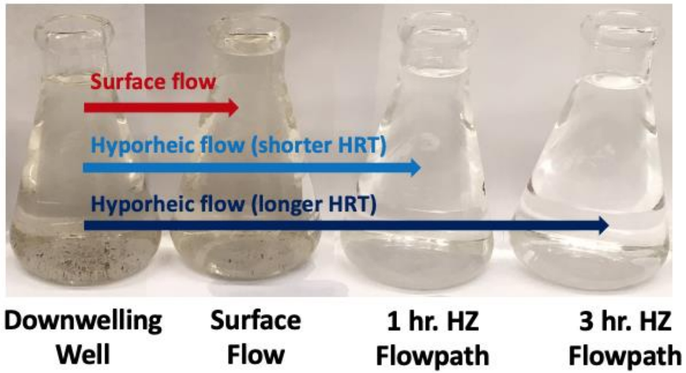
Example: Thornton Creek in Seattle, WA

- State-of-the art design by Hrachovec, Bakke, and Lynch.
- Over-excavation increases cross-sectional area (flux)
- Impermeable layer increases flowpath length (residence time)



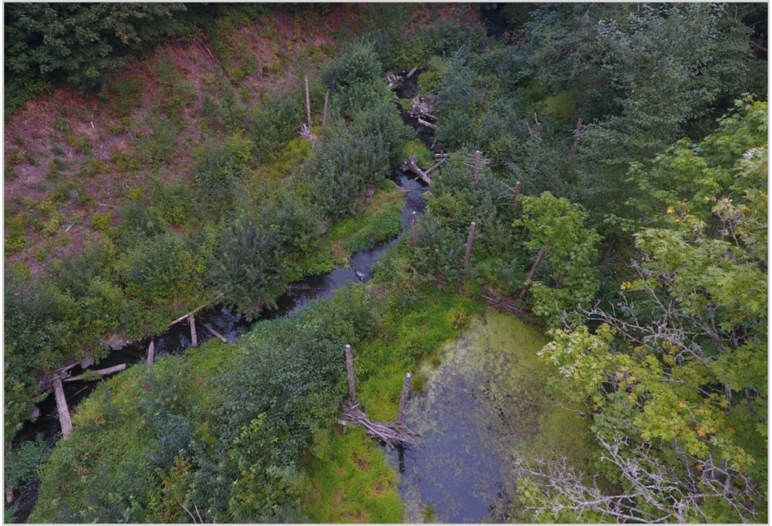
Monitoring summary

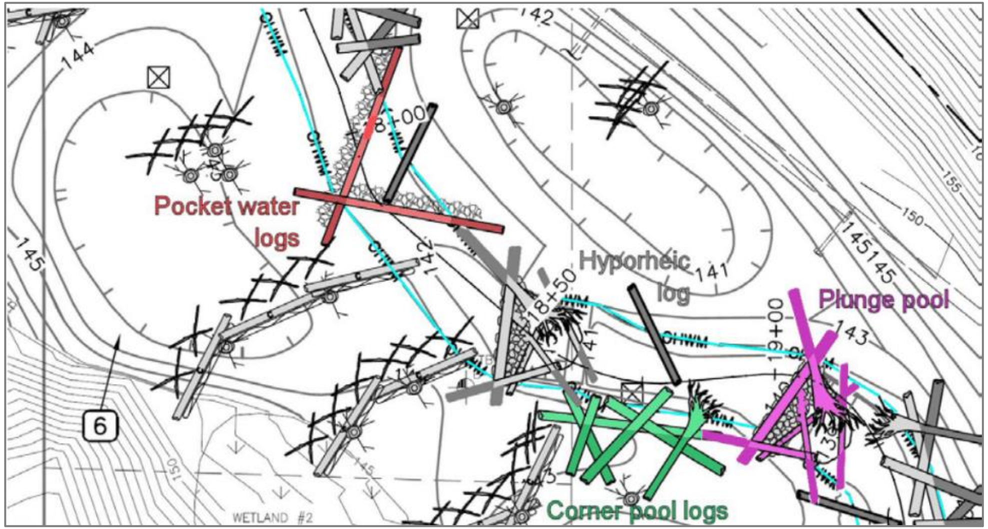
- 89x higher flux than non-restored reach[6]
- Residence times were minutes-to-hours instead of seconds-to-minutes
- Hundred of stormwater compounds were removed by >50%[7]
- Increased macroinvertebrate density and richness[8]



Example: Thornton Creek in Seattle, WA

This is a carefully engineered structure within a complex, messy, and very dynamic system.



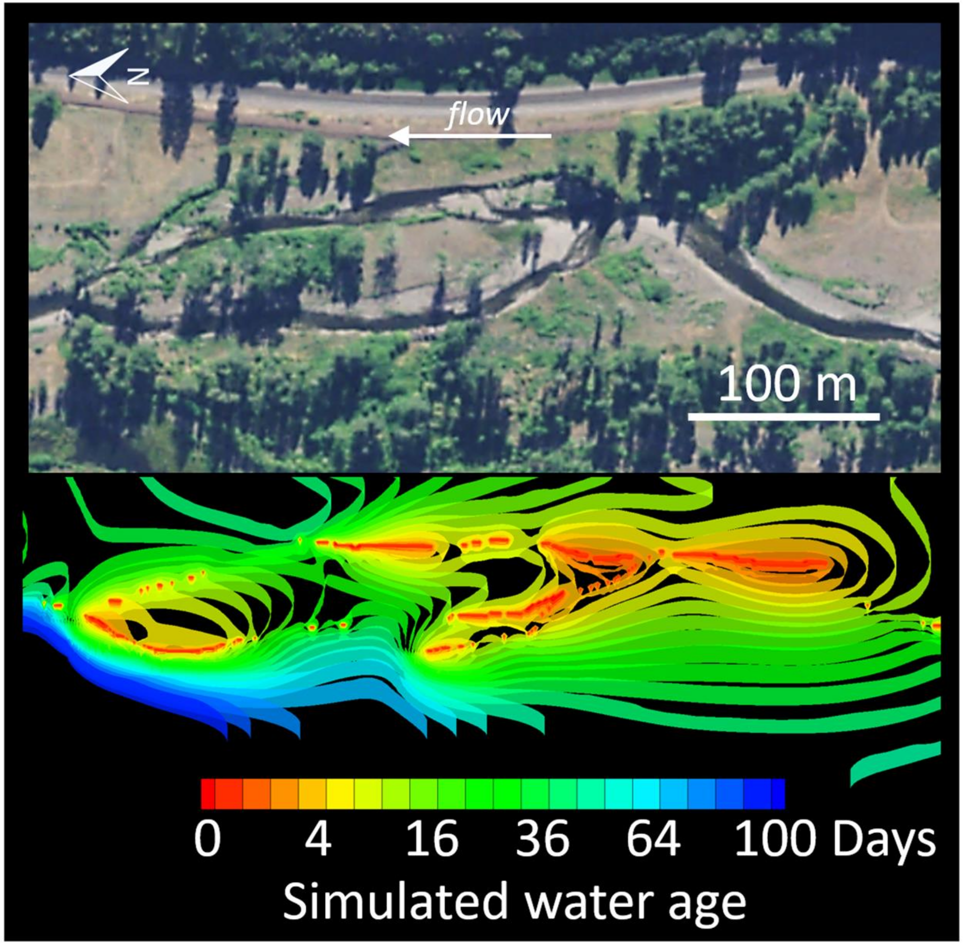


Source: [9]

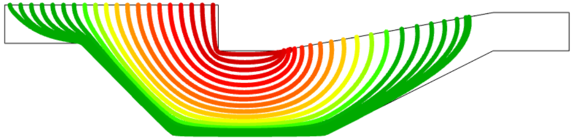
Complex, messy systems are great

… until you have to measure performance

We used dye to trace flowpaths and sample influent/effluent.



Can the Thornton Creek structures be improved?



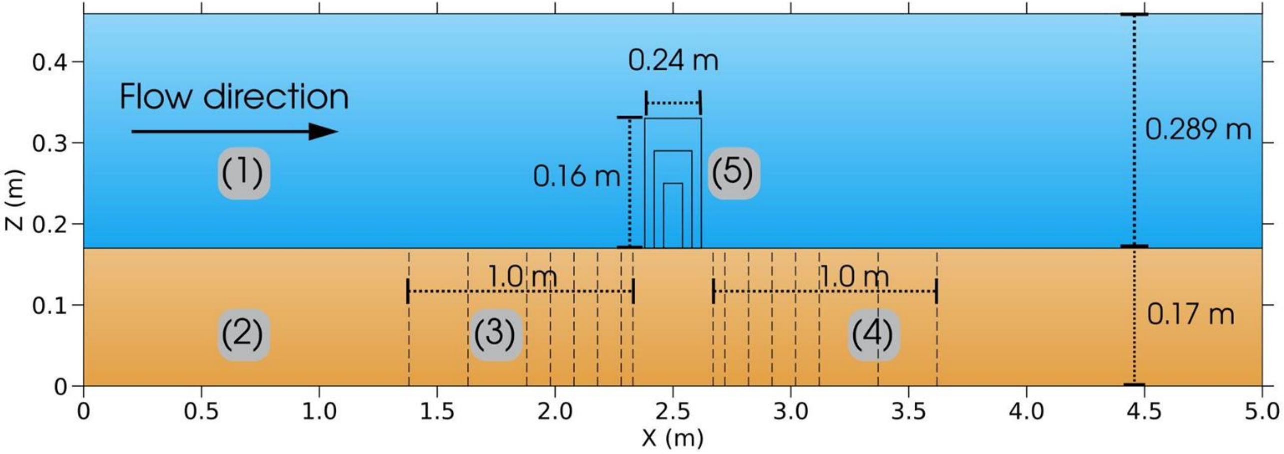
1) Maximize flows of ideal residence time (e.g., 1-3 hours)

2) Simplify monitoring

3) Improve seasonal consistency

Lessons from flumes and numerical models

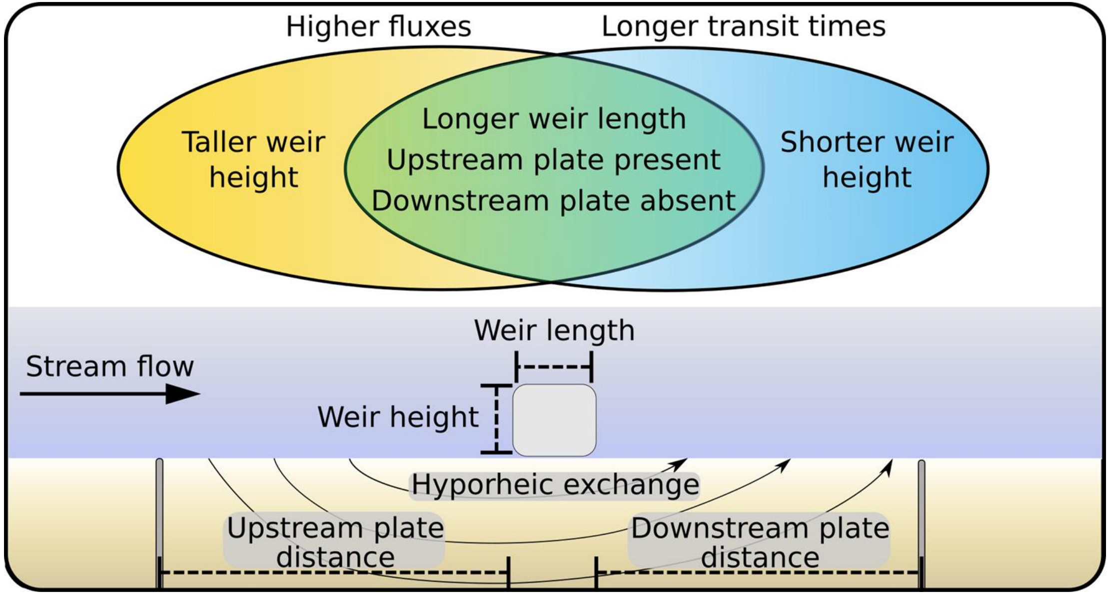
There is no one-size-fits-all solution, but many design “levers” to pull



Manuscript in revision at Environmental Science & Technology

Lessons from flume and model experiments

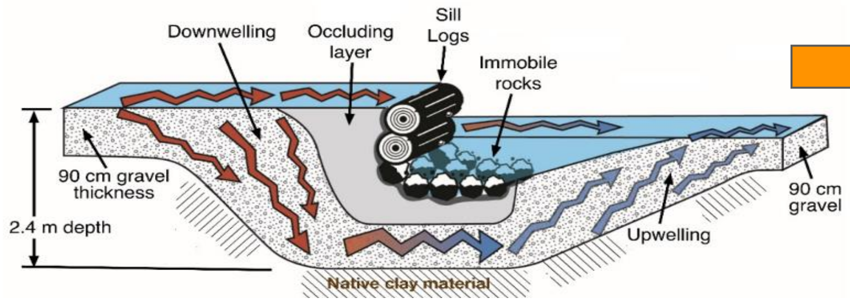
Adjusting flowpath length can optimize flux and residence time.



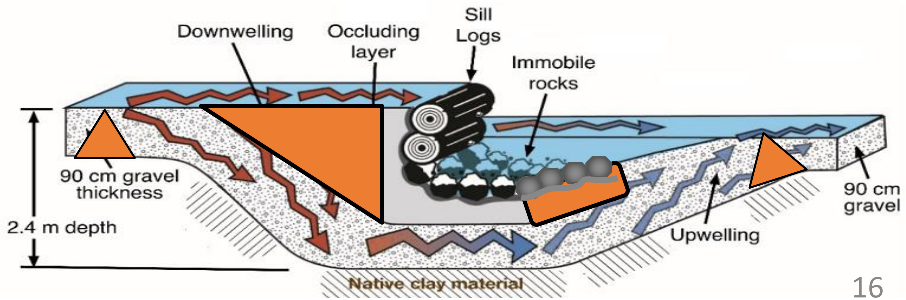
Applying design concepts to Thornton Creek

- Doubling cap length can increase residence time by 50%
- Increasing depth by 33% (120 cm vs 90 cm) keeps same flux
- Buried baffle walls can increase flux and uniformity
- Can also modify plunge pool height, sediment permeability

Original Structure



Lengthened cap, baffle walls



Proposed workflow for optimization

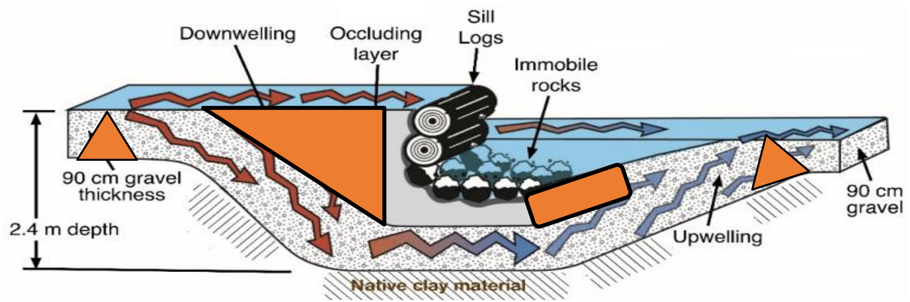
Part 1: What do you want?

1. Choose baseline **structure**
2. Choose **reaction** of interest and estimate reaction rate
3. Choose target **flux** (e.g., 0.5 cfs per structure)
4. Calculate ideal **residence time** (reaction rate^{-1})

Proposed workflow for optimization

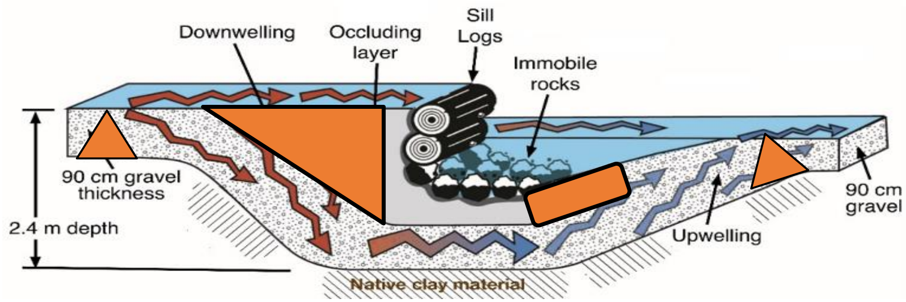
Part 2: How to achieve it?

5. Determine cap length to achieve residence time
6. Adjust hyporheic cross-sectional area to achieve flux
7. Consider adding plates and walls to make flowpath consistent



Applying design concepts to stream restoration

- Slight modifications can enhance water quality performance
- Flowpath length may be the most important factor
- Design with monitoring in mind
- We are pursuing field tests of these designs in several locations



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Thank you!

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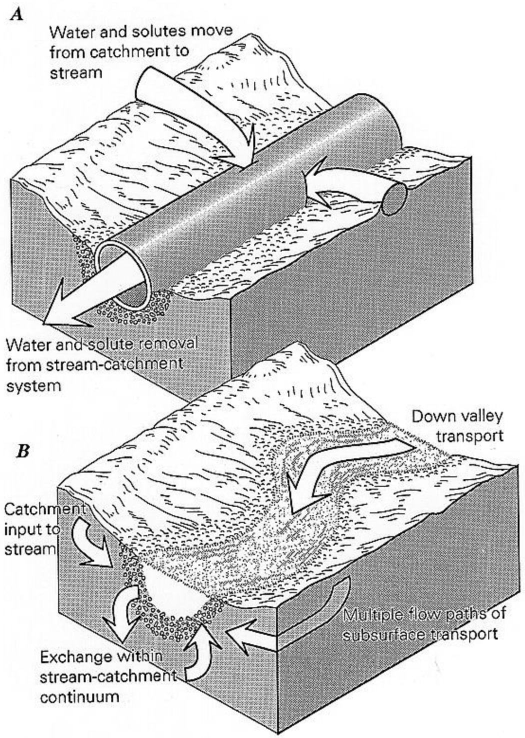

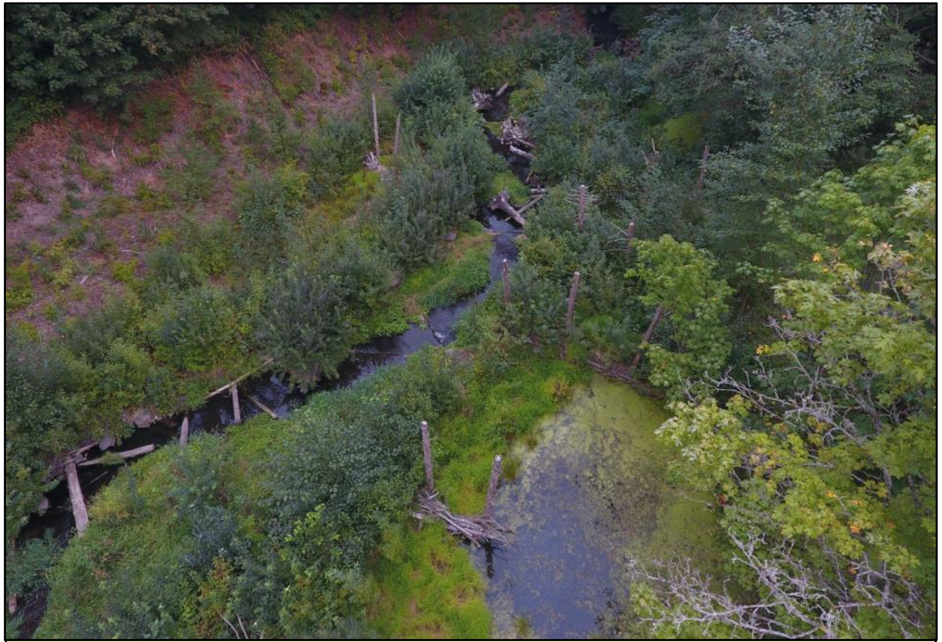

Ceci n’est pas une pipe.

References

1. U.S. Environmental Protection Agency. Office of Water and Office of Research and Development. National Rivers and Streams Assessment 2008-2009 Technical Report (EPA/841/R-16/008). Washington, DC. March 2016.
2. Bencala et al. (2011). Rethinking hyporheic flow and transient storage to advance understanding of stream-catchment connections. *Water Resources Research*, 47(3).
3. Alley et al. (2002). Flow and storage in groundwater systems. *Science*, 296(5575), 1985-1990.
4. Lawrence et al. (2013). Hyporheic zone in urban streams: A review and opportunities for enhancing water quality and improving aquatic habitat by active management. *Environmental Engineering Science*, 30(8), 480-501.
5. Zarnetske et al. (2011). Dynamics of nitrate production and removal as a function of residence time in the hyporheic zone. *Journal of Geophysical Research: Biogeosciences* 116.G1.
6. Bakke et al. (2020). Hyporheic process restoration: design and performance of an engineered streambed. *Water*, 12(2), 425.
7. Peter et al. (2019). Evaluating emerging organic contaminant removal in an engineered hyporheic zone using high resolution mass spectrometry. *Water Research*, 150, 140-152.
8. Morley et al. (2021). Invertebrate and microbial response to hyporheic restoration of an urban stream. *Water*, 13(4), 481.
9. Poole et al. (2022). Hyporheic hydraulic geometry: Conceptualizing relationships among hyporheic exchange, storage, and water age. *Plos One*, 17(1), e0262080.

Appendix Slides (if useful for Q&A)

Longer hyporheic residence time = better water quality

Across hundreds of stormwater compounds:

- 1-hr flowpath had 50% reduction (in total peak area)
- 3-hr flowpath had 85% reduction

ELSEVIER

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Evaluating emerging organic contaminant removal in an engineered hyporheic zone using high resolution mass spectrometry

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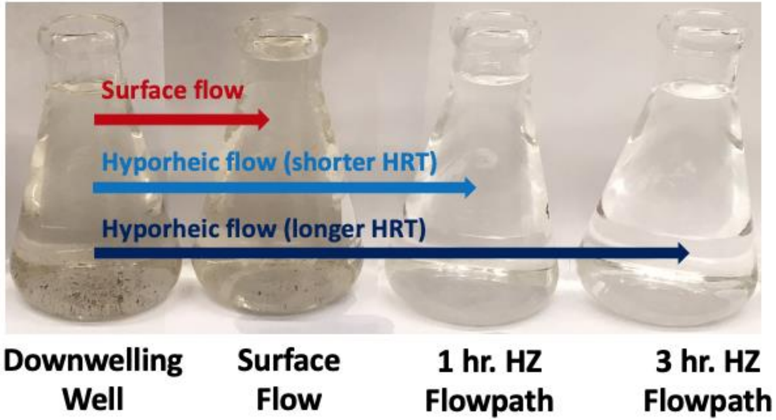


BMPs not effective for slow reactions

- Not enough flow and residence time simultaneously.
  – e.g., Azinheira et al. (2014); Hester et al. (2016)

- Hyporheic exchange localized, residence times too short.
  – e.g., Gordon et al. (2013)

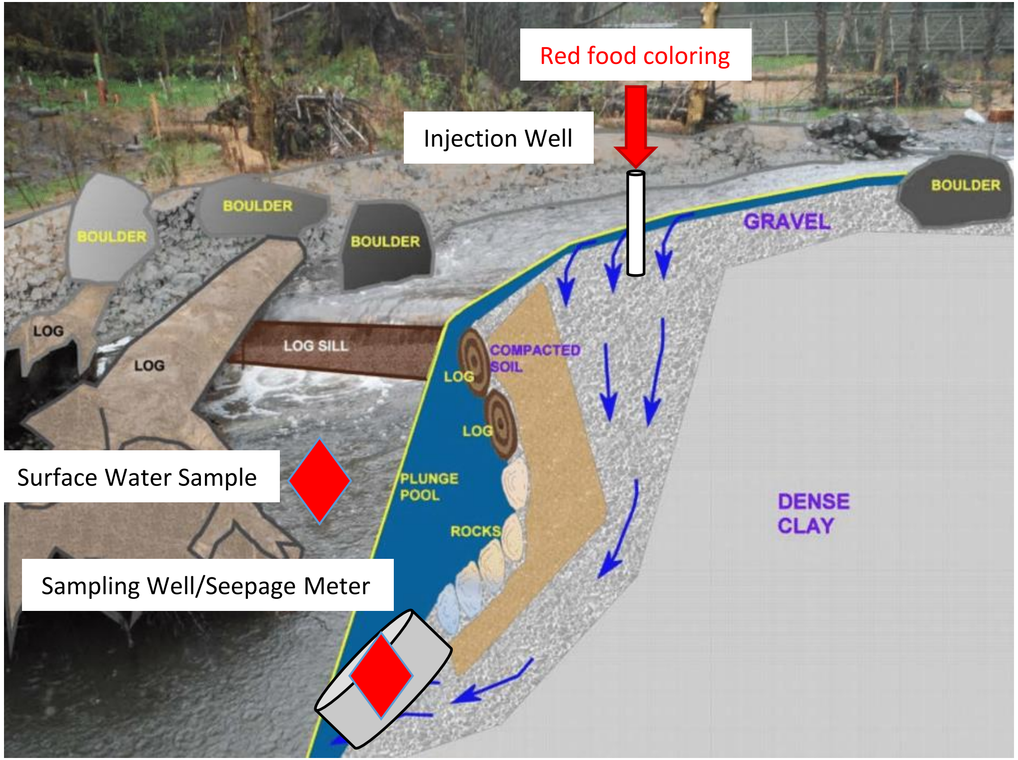
- No existing HZ BMP has been consistently effective at reach-scale.

- No BMP optimizes flow and residence times.

Research Question: Do HDEs remove PSM-linked contaminants?

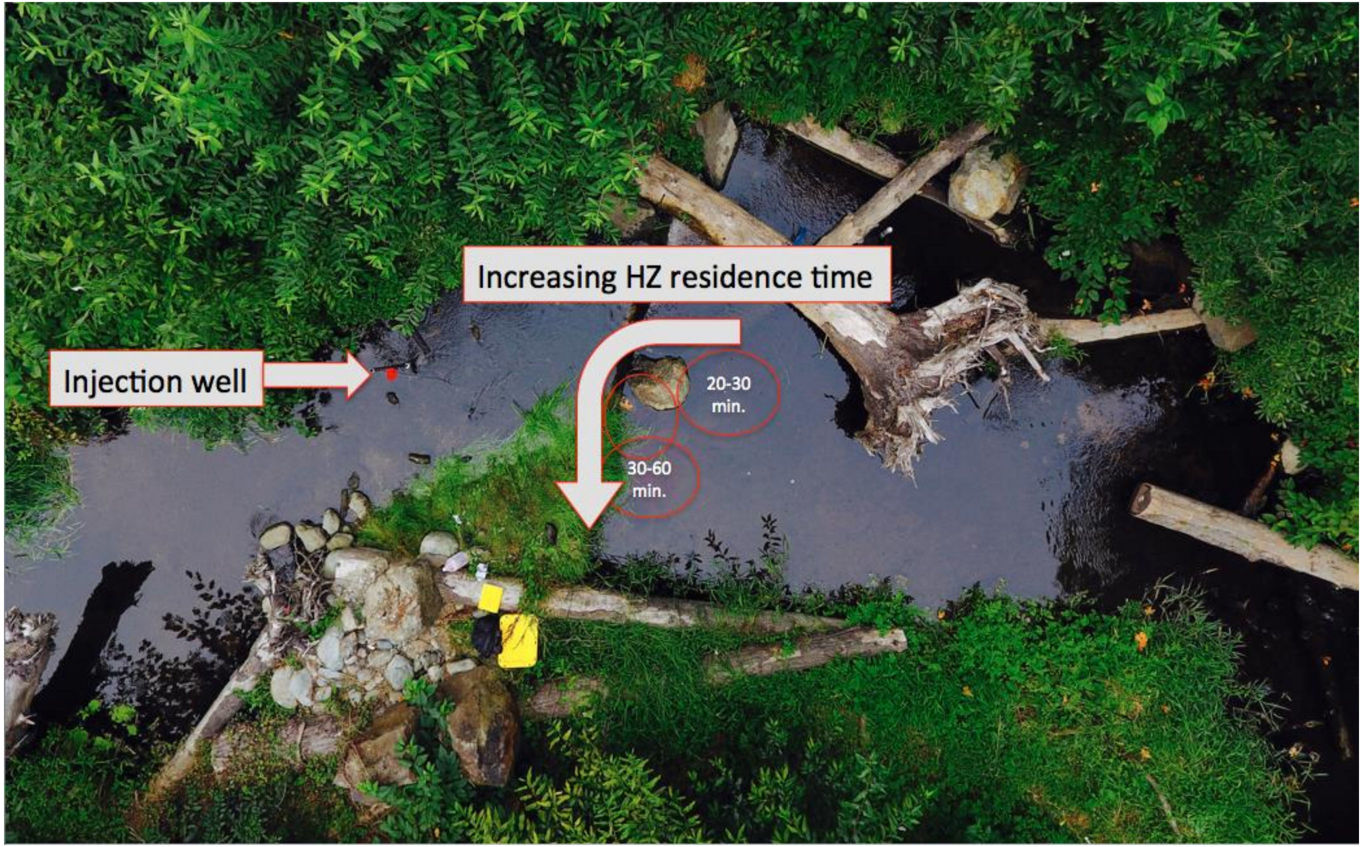
- How to capture hydrologically-paired samples?
  - "Influent" vs. "Effluent"
  - Particle tracing approach

- Multi-tracer approach
  1. Visual dye (estimate RT)
  2. Install sampling gear
  3. Collect samples with quantitative tracer
     a. Baseflow Sept 2017
     b. Storm Oct 2017
  4. Non-target analysis

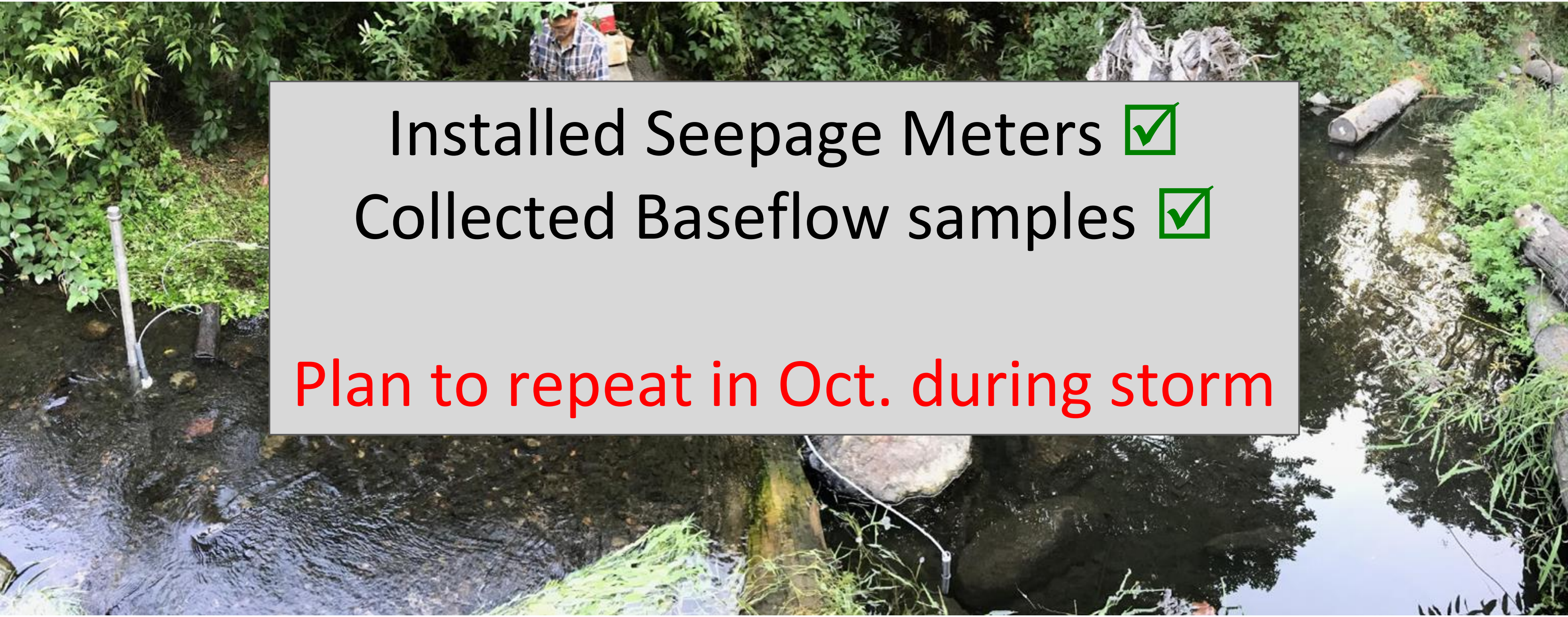


Example dye trace: Sept 2017

Example dye trace: Sept 2017



Example dye trace: Sept 2017

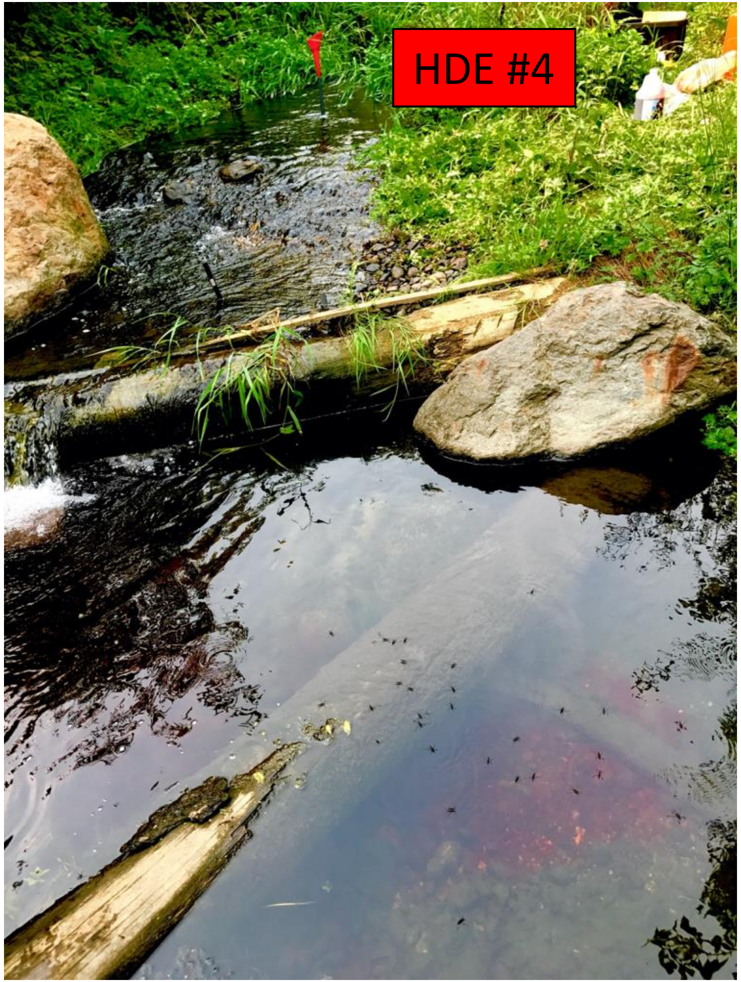


Installed Seepage Meters ☑

Collected Baseflow samples ☑

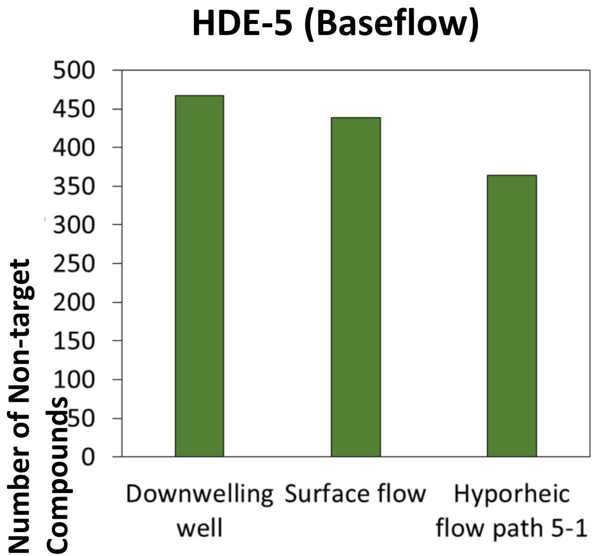
Plan to repeat in Oct. during storm

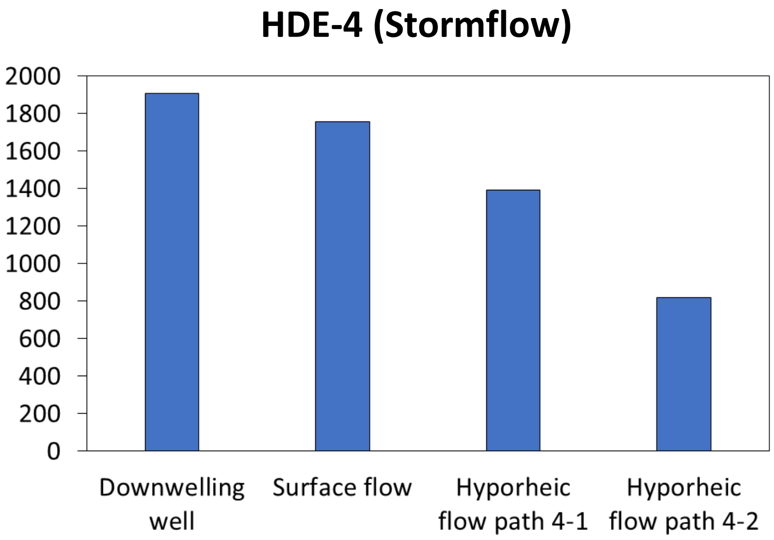
Shifting hyporheic flowpaths: Oct. 2017


HDE #4

Overall system performance: Total number of non-target compounds

- **Less contaminants detected in hyporheic water than surface water**
- **Longer residence time flowpath had fewer detections**





Baseflow

22/57 of PSM signature detected

Stormflow

50/57 of PSM signature detected

Combined surface and subsurface structures can optimize hyporheic removal of stream water pollutants.

In review at ES&T.