STAC 2023

# Water quality effects of stream restoration in the Chesapeake Bay watershed: benefits, trade-offs, and unintended consequences

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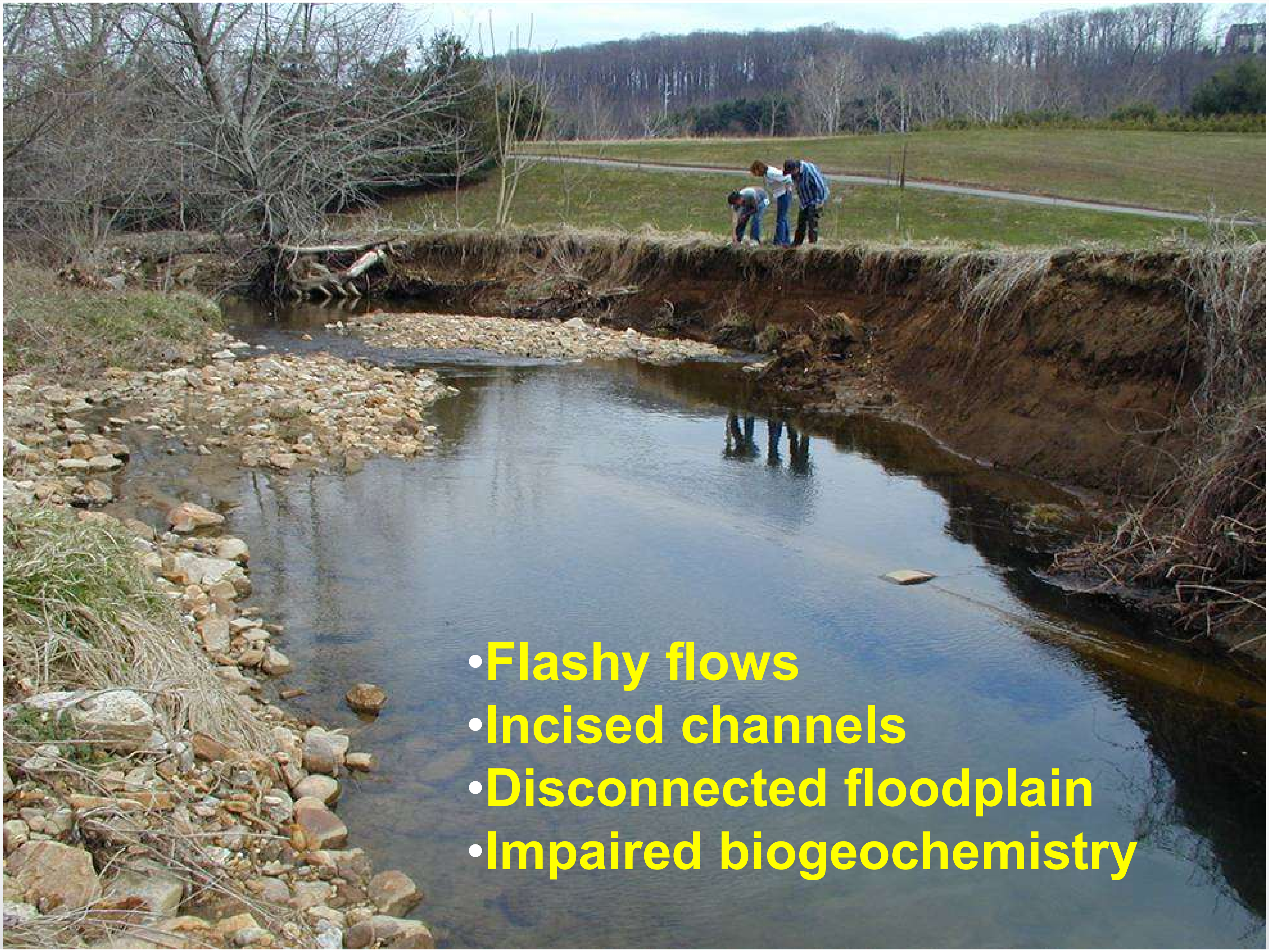
# Chesapeake Bay

**<u>Pollutants</u>**

**Nitrogen**
**Phosphorus**
**Metals**
**Sediment**
**Salt**

# Urban Stream Syndrome



# Stream Restoration Evolution by Objective

- Protection → property and infrastructure
- Water Quality → sediments, N, P, etc
- Biological uplift → bugs and fish

# Research Objectives

- Examine effect of restoration on water quality
- Elucidate the efficacy of restoration approaches
- Search for mechanistic patterns
  - Mayer, Kaushal, et al team: 50 pubs in 20 yrs

# Stream Functionality

## Example…Denitrification

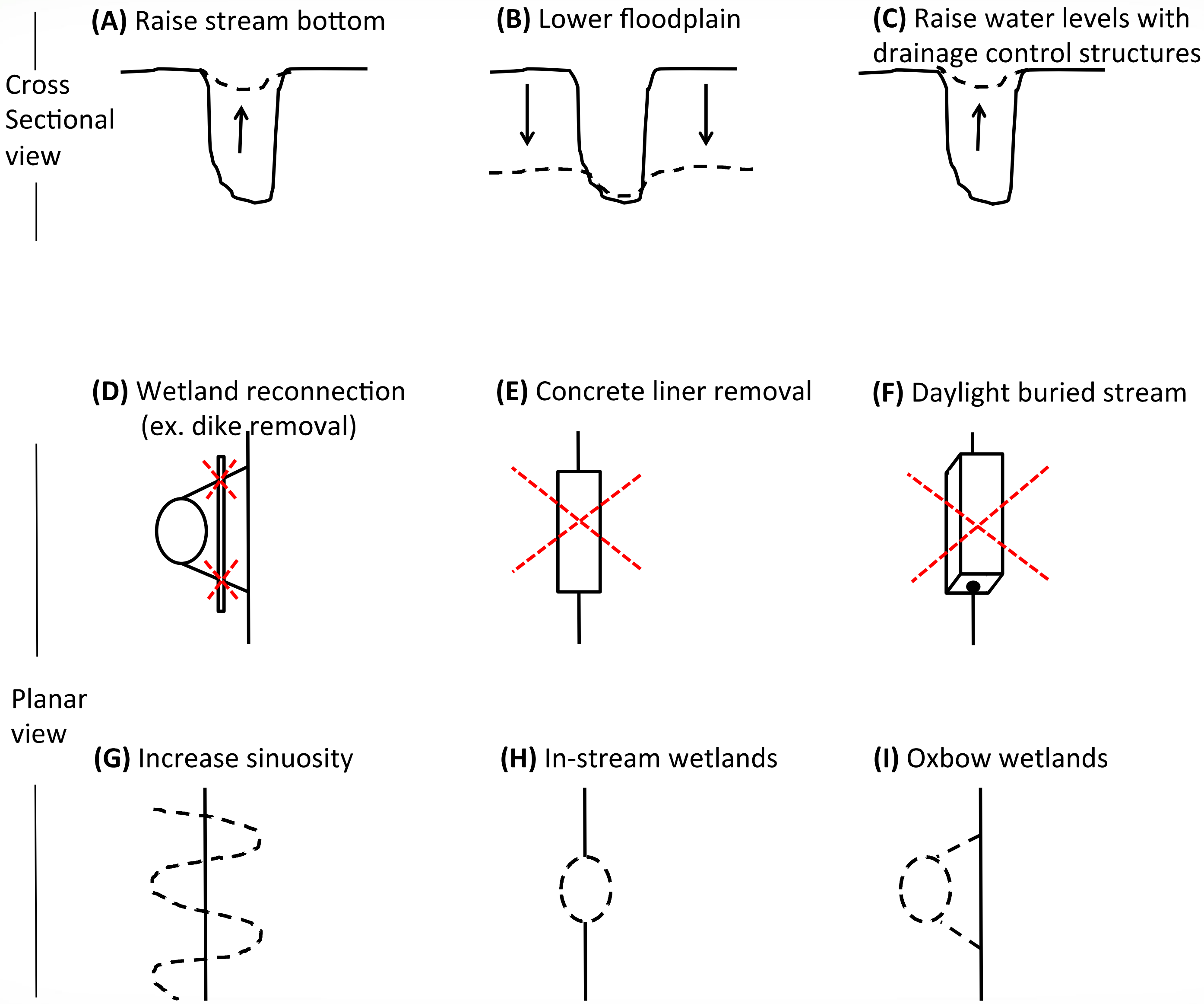
$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

>Anaerobic - reduced subsurface DO?

>Heterotrophic - inputs of organic C?

>Microbes, C, N mix - stream–floodplain reconnection?

# Restoration Typologies




Newcomer Johnson et al 2016

# Stream Restoration is Diverse

- Natural Channel Design
- Regenerative Stormwater Conveyance
- Legacy Sediment Removal
- Stream Daylighting

# Stream Restoration is Diverse

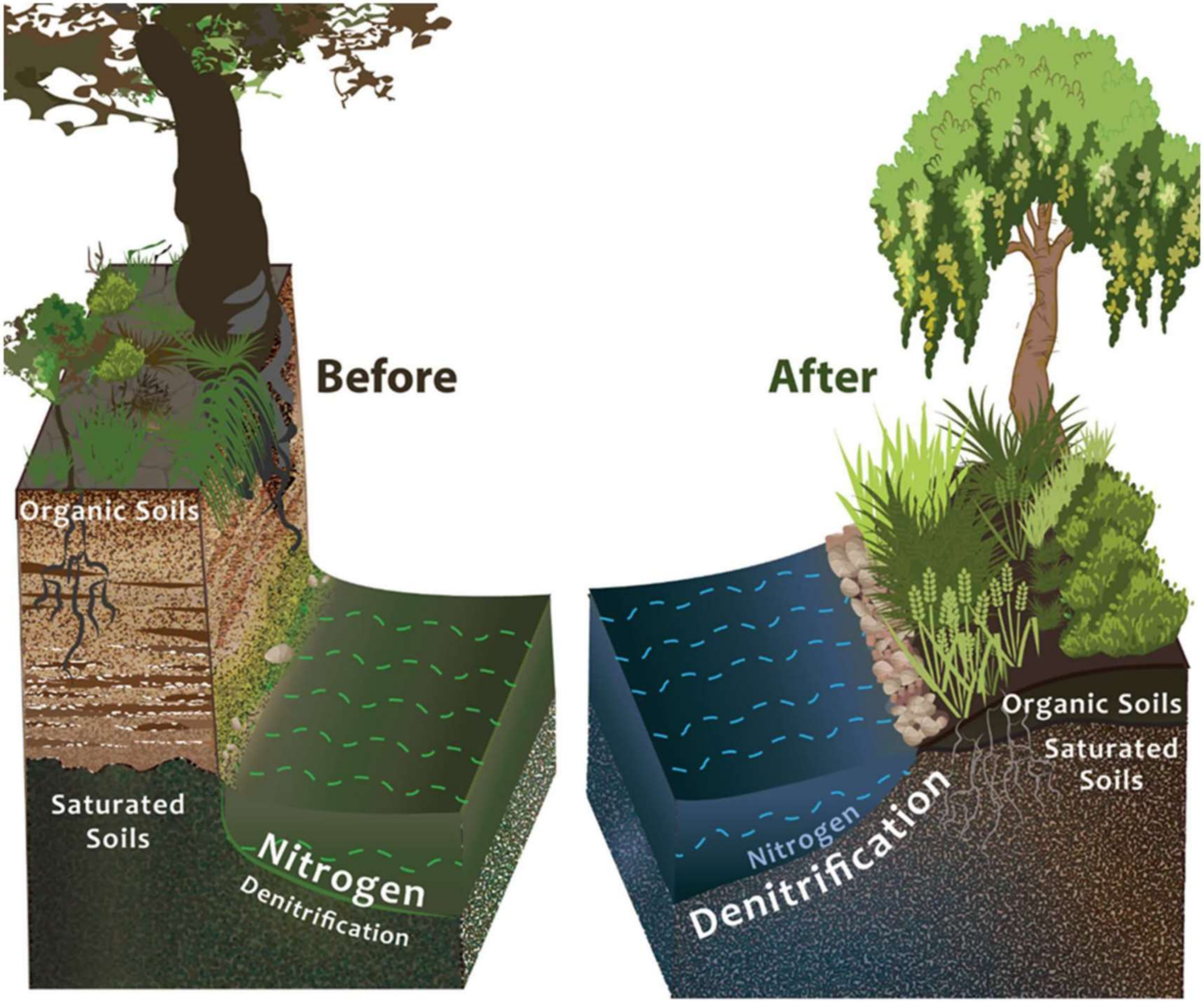
- Natural Channel Design

# Natural Channel Design: Minebank Run

**Pre-restoration**

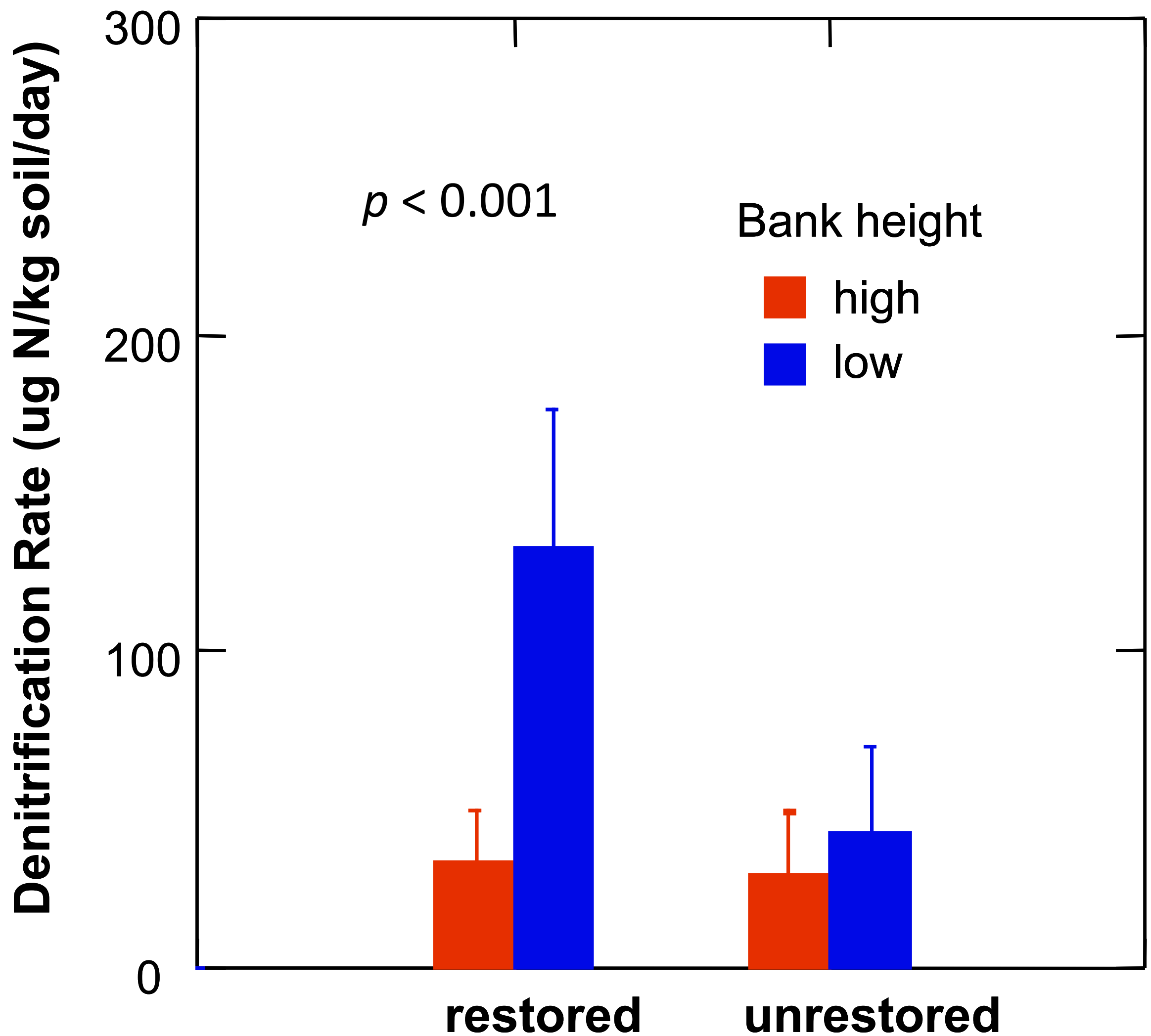
**Post-restoration**

# Reconnecting stream to floodplain



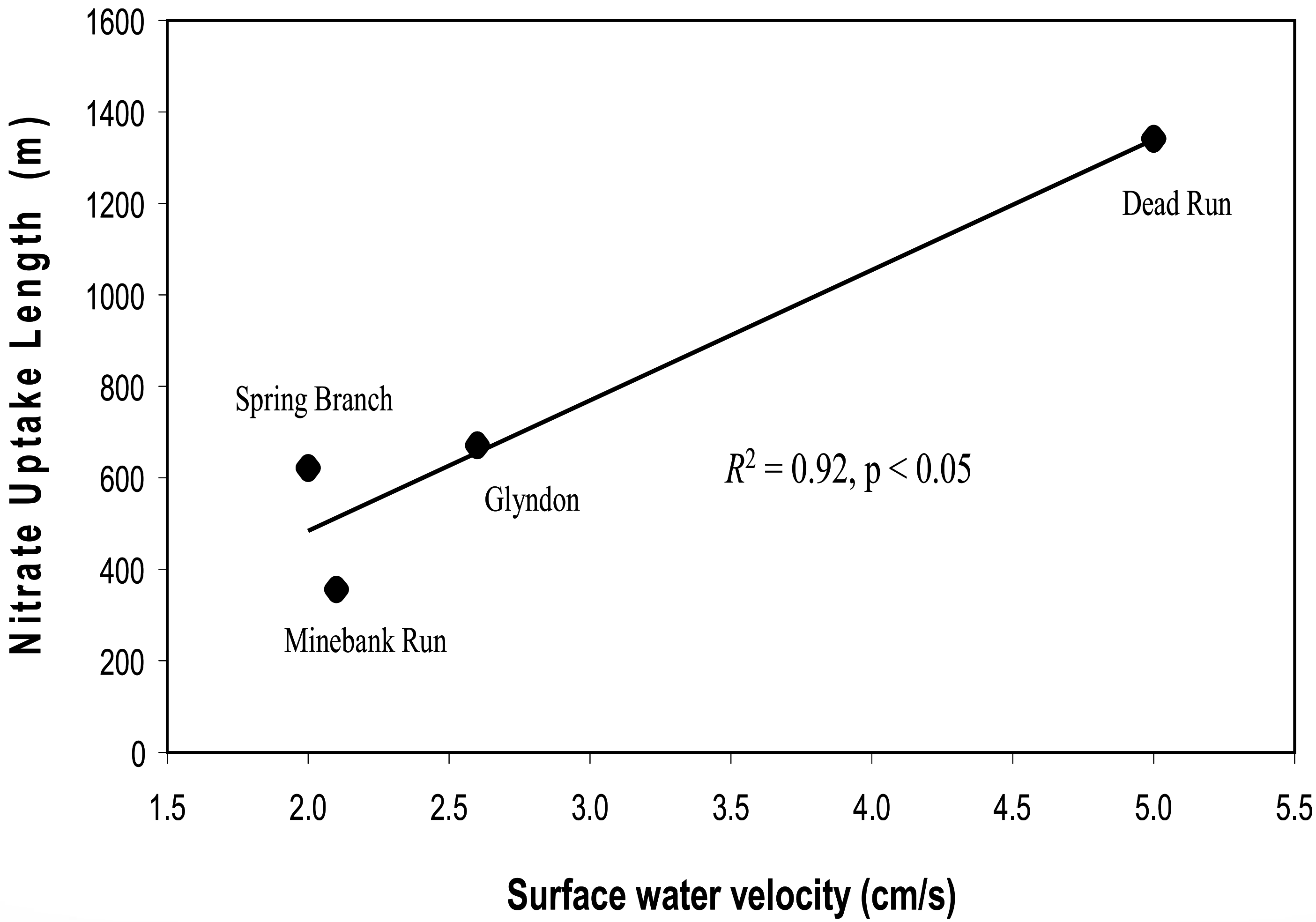

Mayer et al. 2022

# Restoration that reduces bank incision (low banks) improves denitrification rates



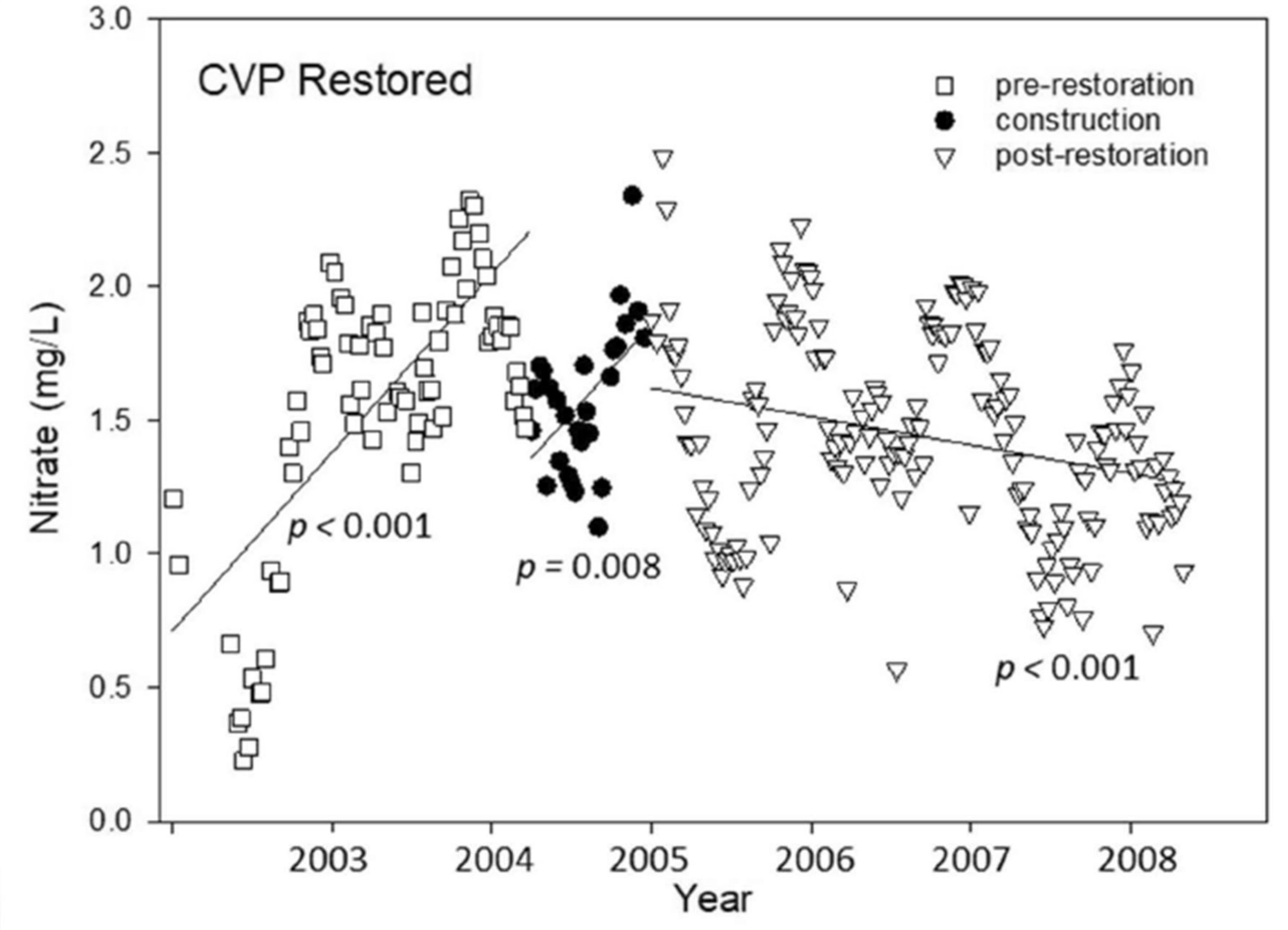

Kaushal et al. 2008

# Reducing stream velocity improves N uptake by increasing hyporheic exchange



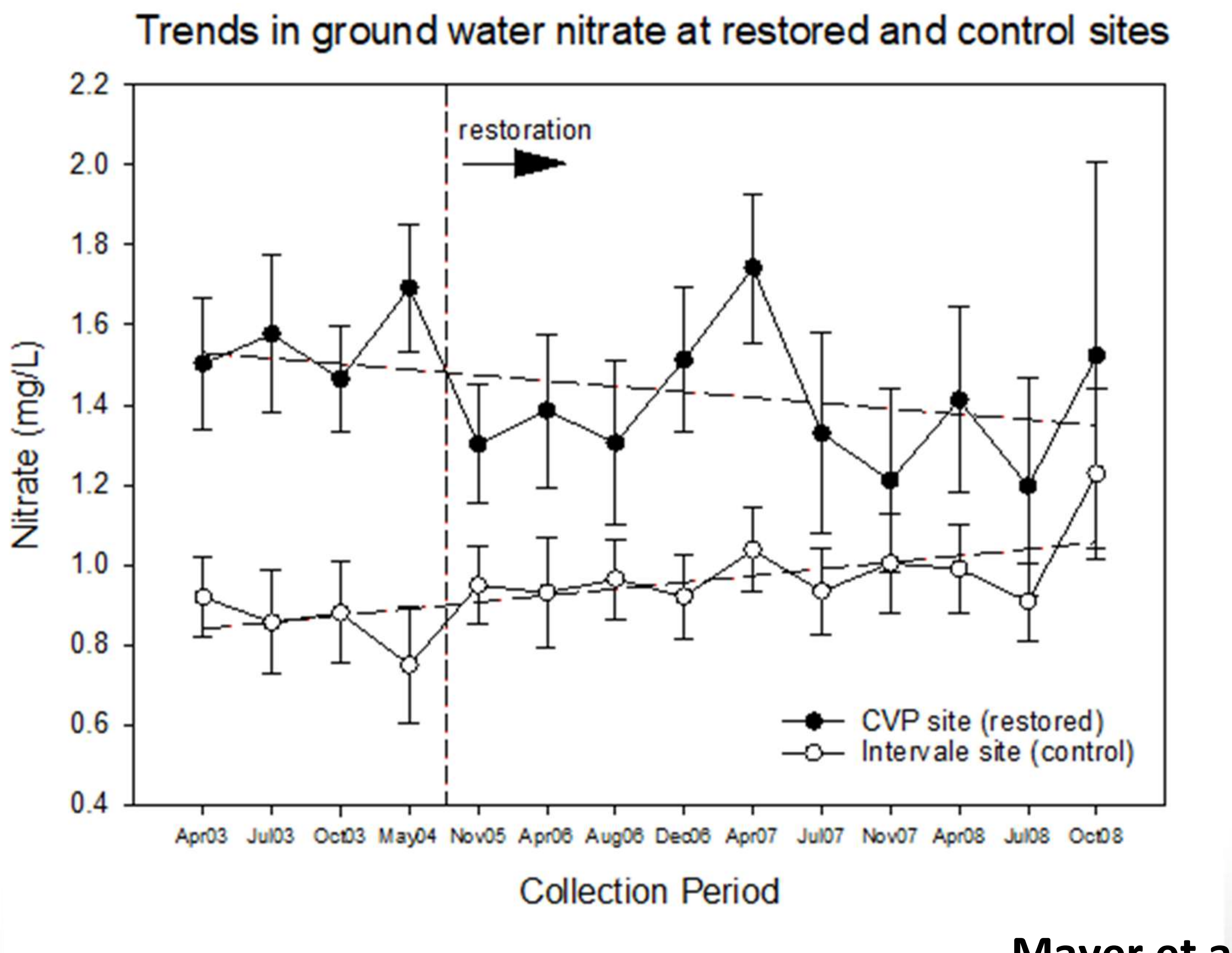

**Klocker et al. 2009**

# Surface water nitrate declined at Minebank Run after restoration (~49%)



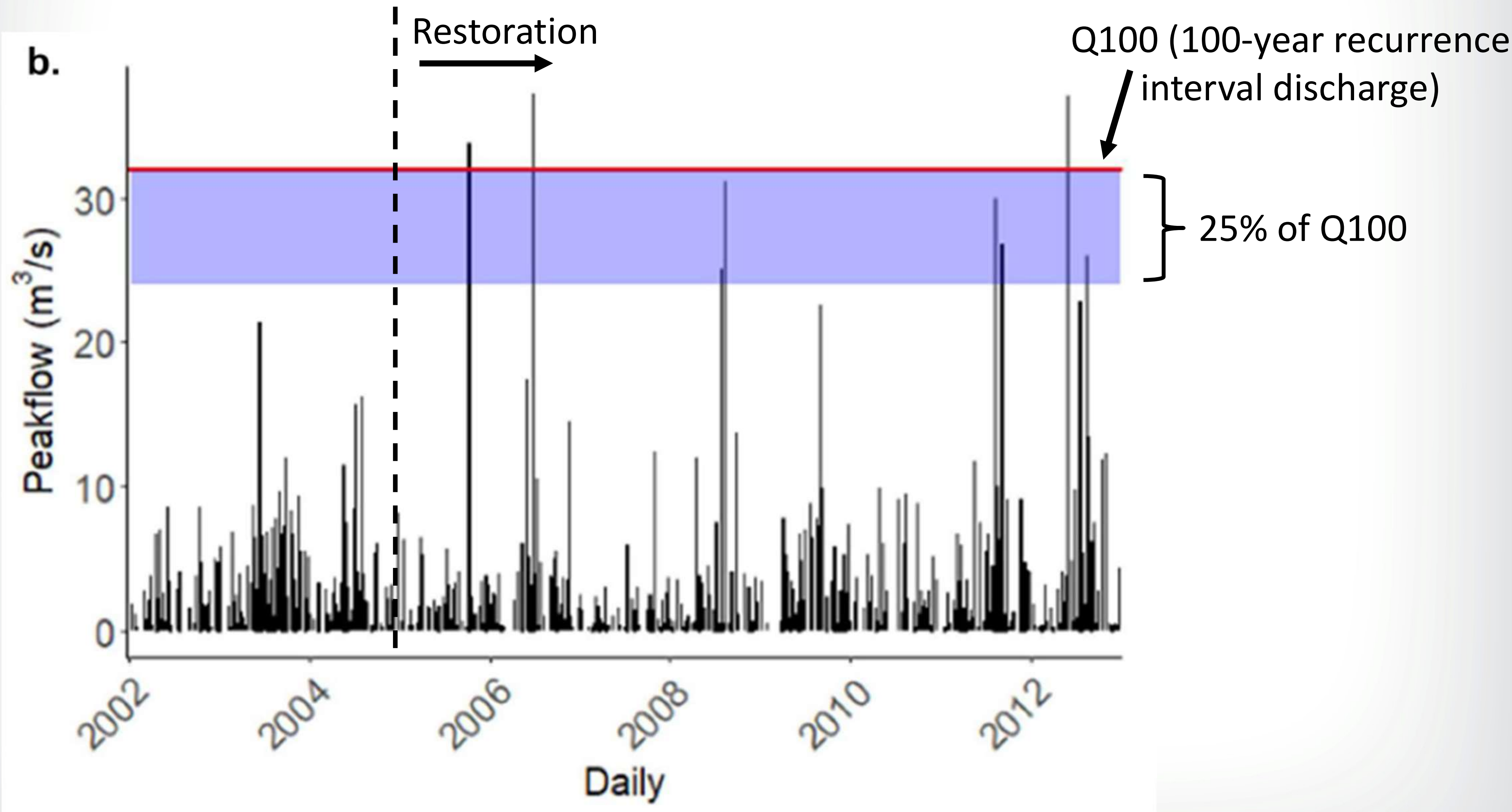

Mayer et al. 2022

# Groundwater nitrate declined at Minebank Run after restoration (~17%)



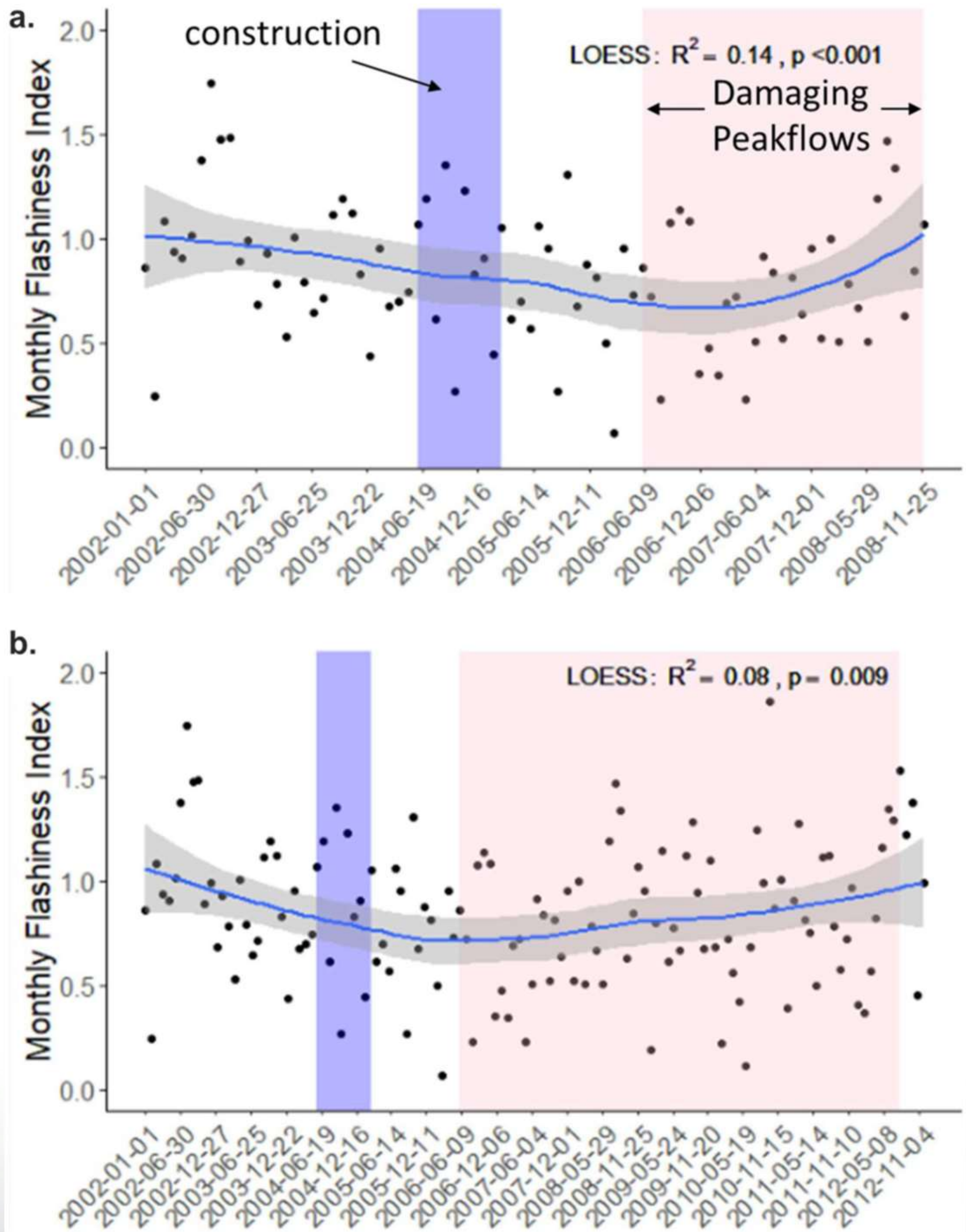

Mayer et al. 2022

# Daily peakflow at Minebank Run was highly variable and became extreme – climate change?



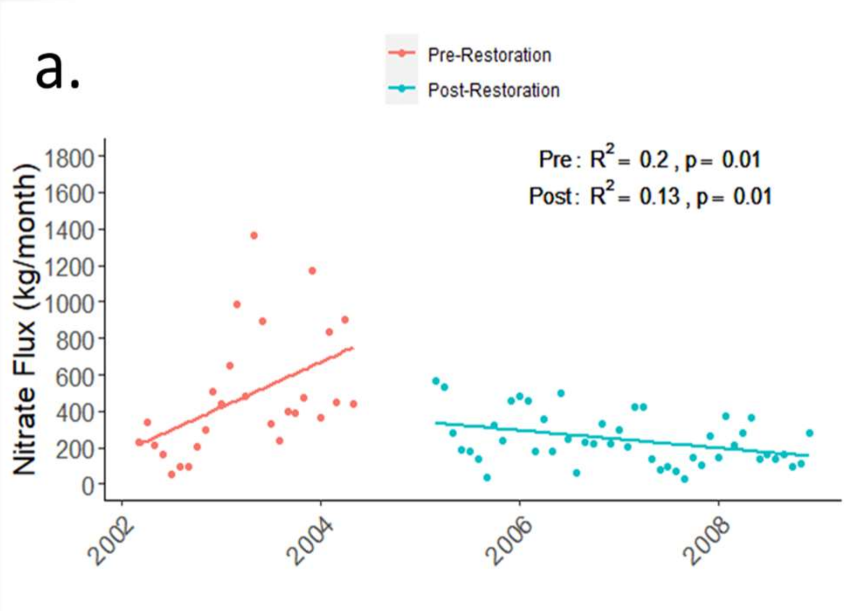

Mayer et al. 2022

# Damaging peakflows were observed after the restoration

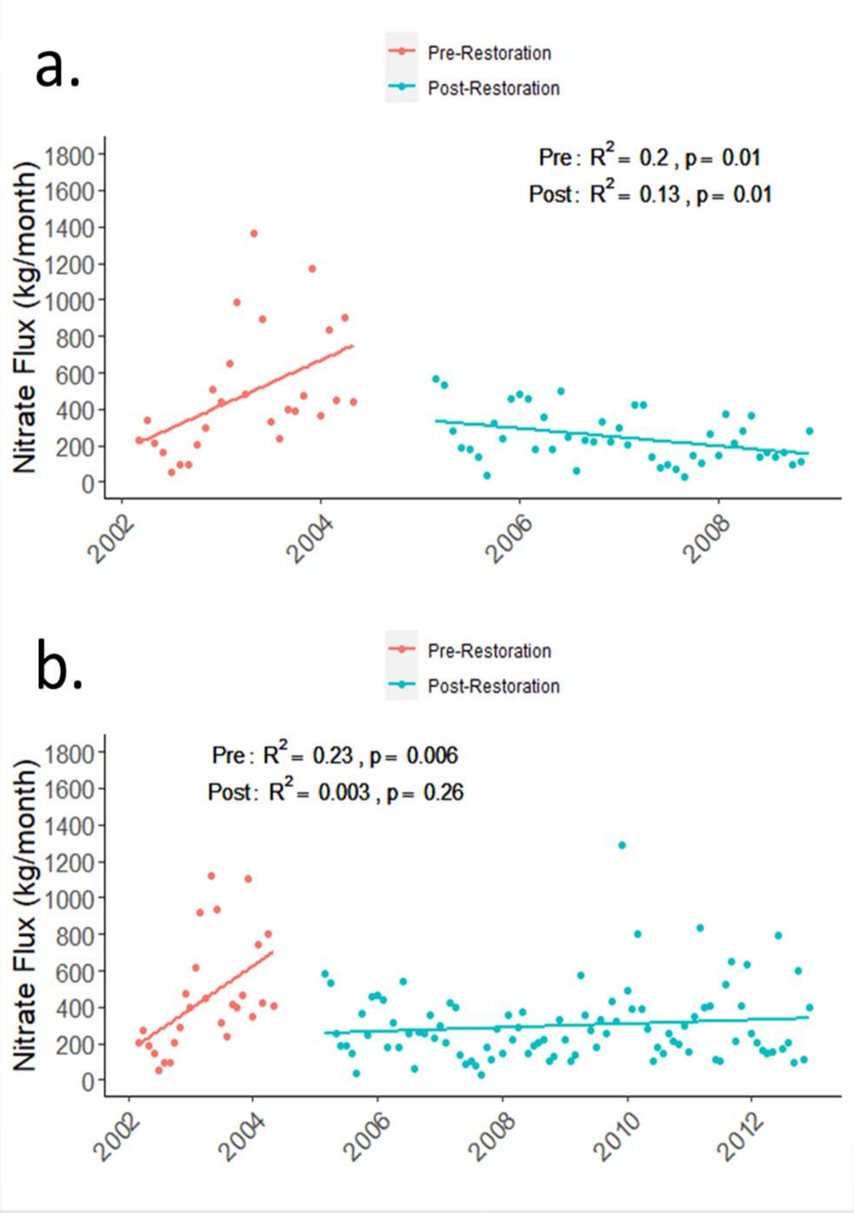



**Mayer et al. 2022**

# Reduced Nitrate Flux Post-restoration



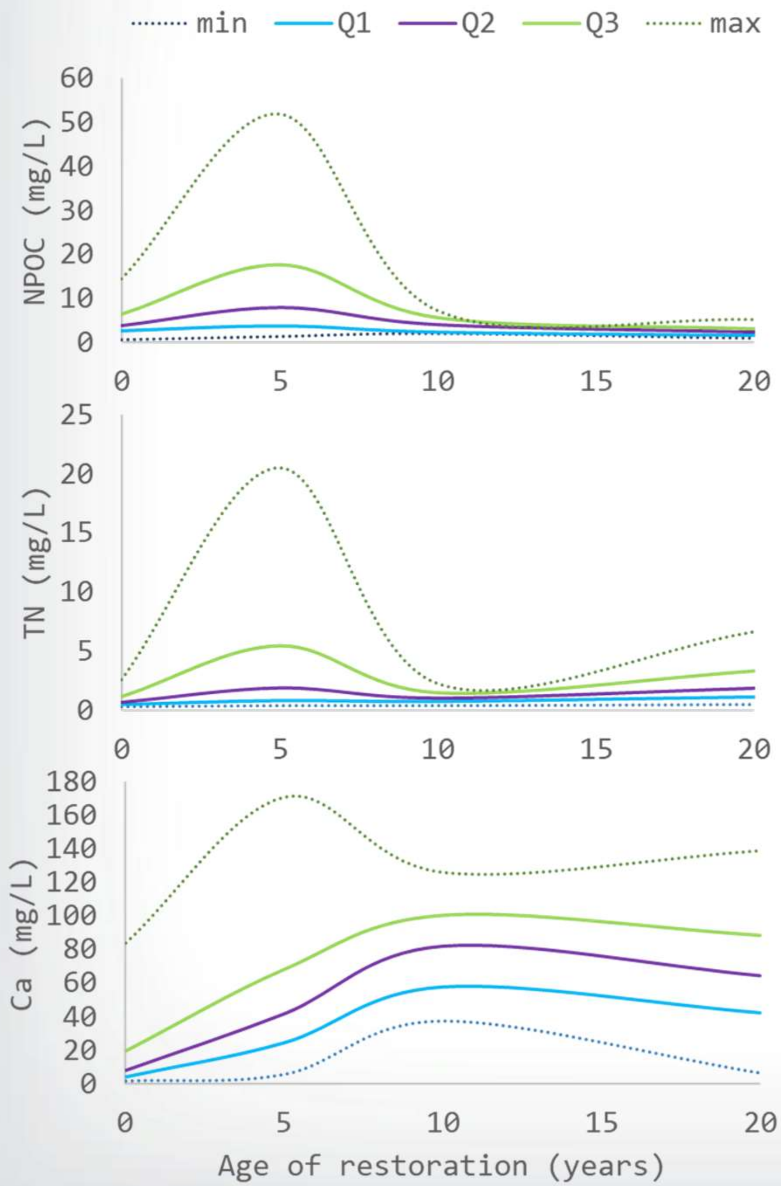

# Efficacy of the restoration was reduced over time due to chronic degredation from stormwater runoff






Mayer et al. 2022

# Unintended release of nutrients due to tree removal



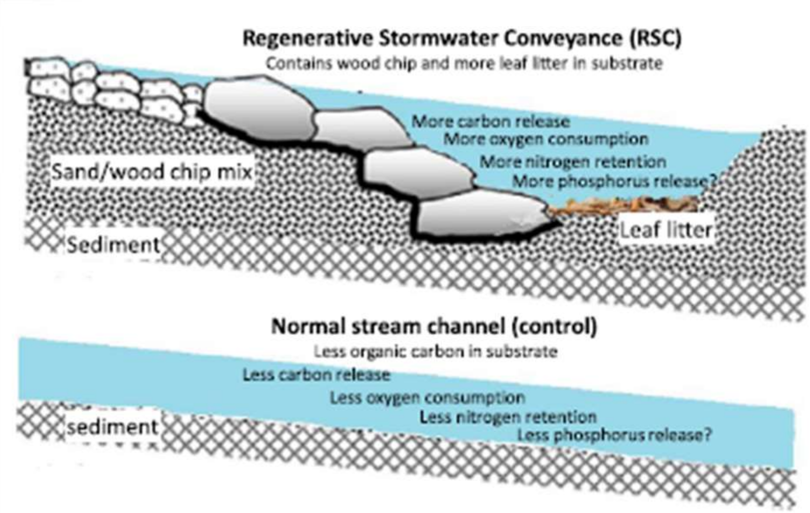

1) **Loss of macronutrients: C and N**
2) **Loss of micronutrients: Ca, S, etc**
3) **Greatest loss in most recent restorations**

**Wood et al. 2022**

# Stream Restoration is Diverse

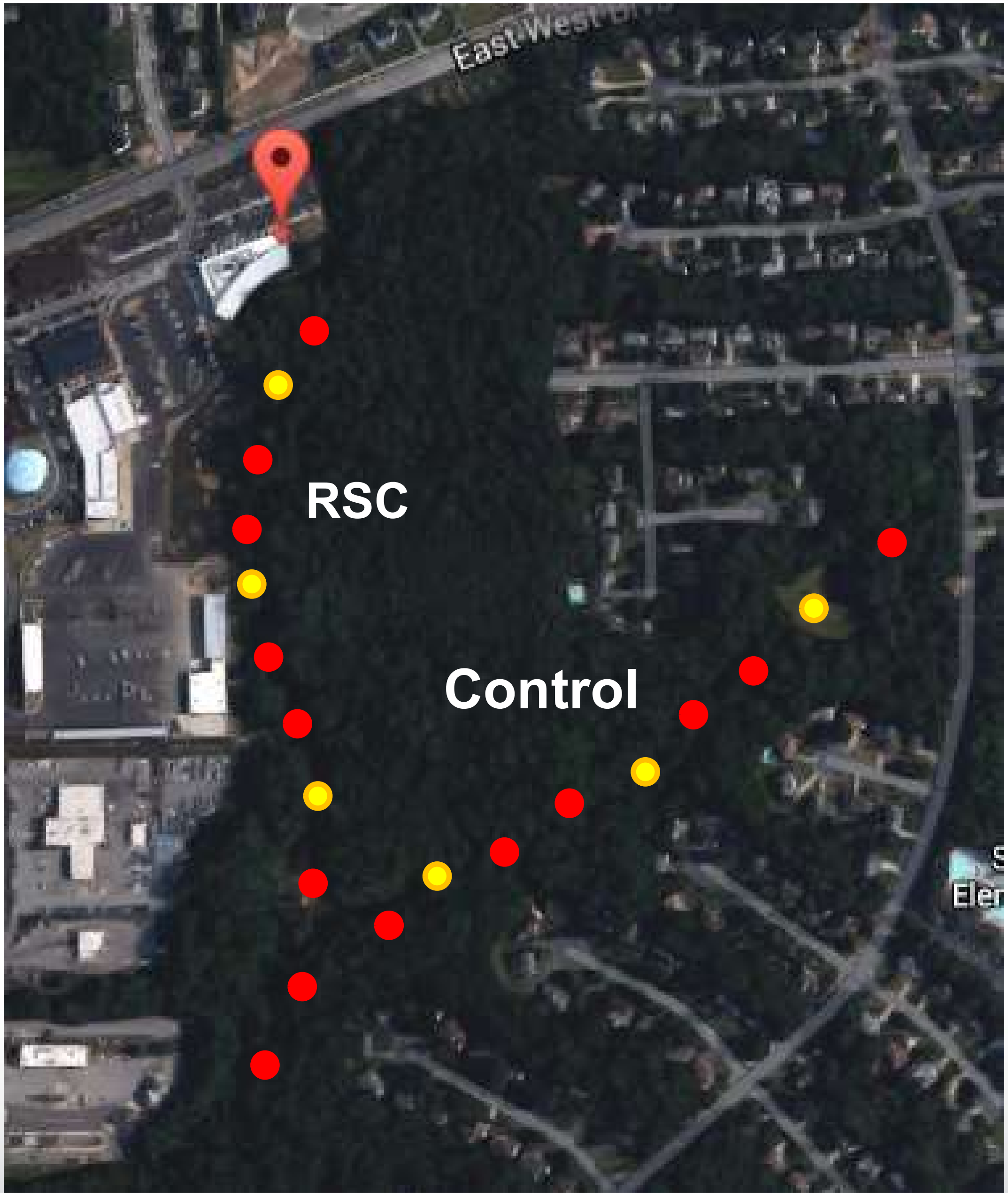
- **Regenerative Stormwater Conveyance**

# RSCs in Practice






# Field Studies




Duan et al 2019

# Part II: Lab simulation experiments

Organic carbon

Wood chips – recalcitrant C

Leaf litter – labile C

Sands

silicate sands (low Fe, Ca）

Carbonate sands (High Ca）

Fe-containing sands

Duan et al 2019

# RSC water quality outcomes

- Reduction in N, sediments and TDS, DO, and particulate P
- Increase in soluble P, Fe, Mn
- hydrology, carbon, DO, and temp affect metal mobilization
  - Nitrate retention of 16-37%
  - DOC released, 18-54%

  - -59% vs -23% in total nitrogen (TN),
  - -54% vs -28% in total phosphorus (TP),
  - -76% vs -40% in total suspended solids (TSS)

Duan et al 2019; Brown et al 2010, Koryto et al. 2017; Williams et al. 2016
Williams et al. 2023; Willams and Filoso 2023

# Trade-offs and unintended consequences

**Reduced water velocity**
**vs**
**Fe flocculant**

**TDN retention**
**vs**
**SRP release &**
**Riparian flooding**

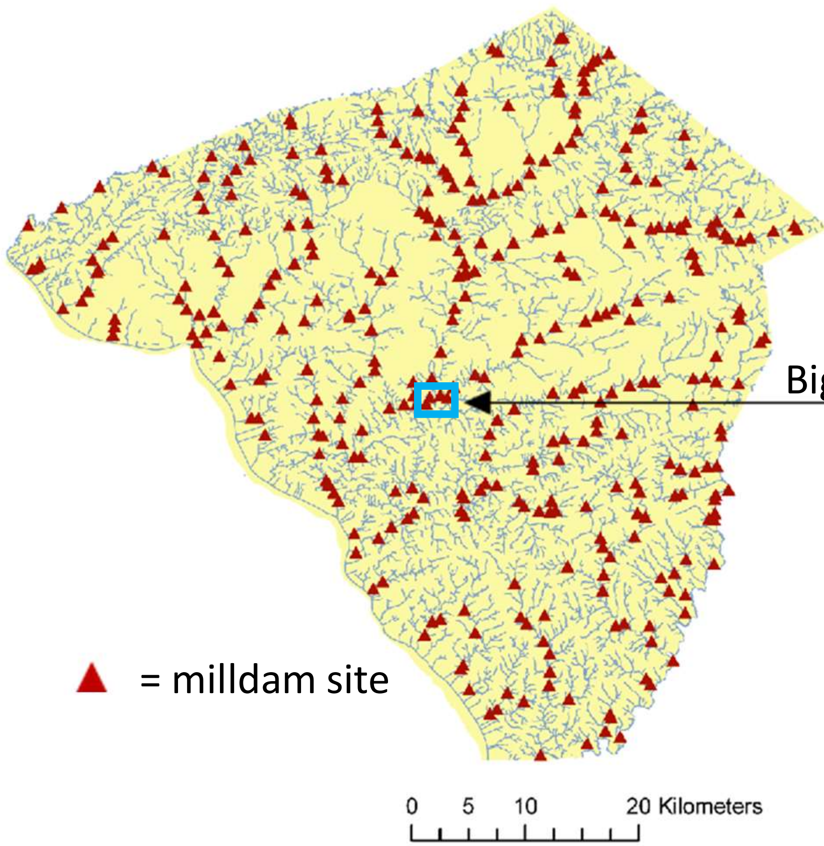
# Stream Restoration is Diverse

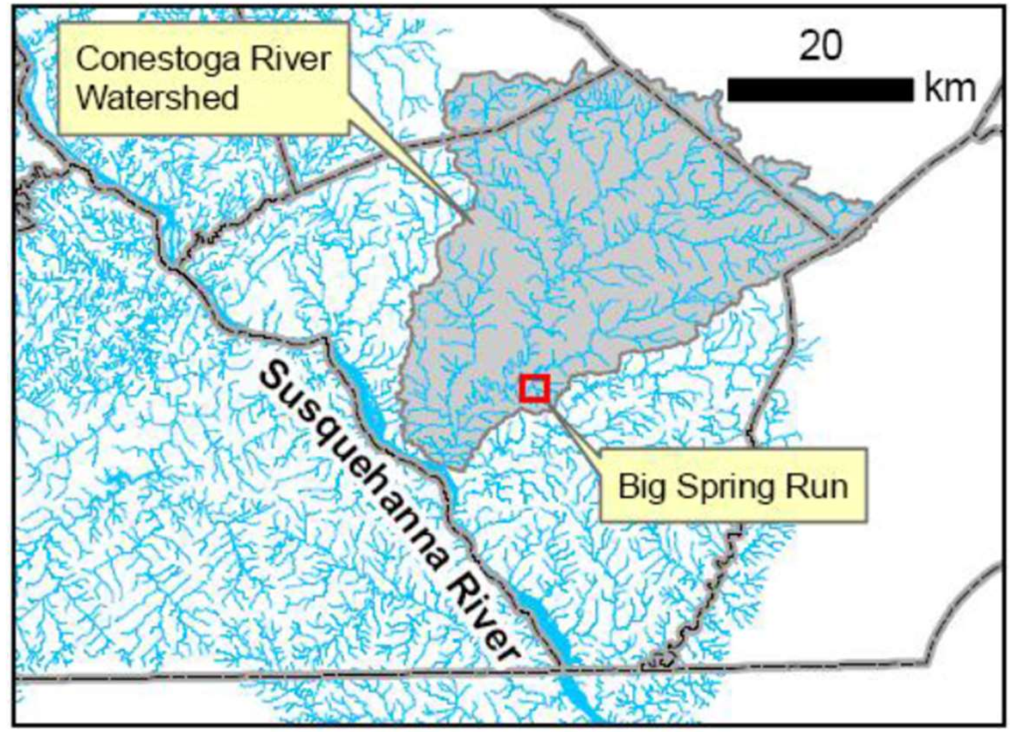
- **Legacy Sediment Removal**

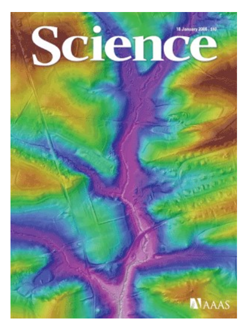
# 18th century energy technology

# Walter and Merritts showed us that streams in the Chesapeake Bay watershed have been degraded for centuries

## LOCATION OF 383 HISTORIC MILL DAMS, LANCASTER COUNTY, PA



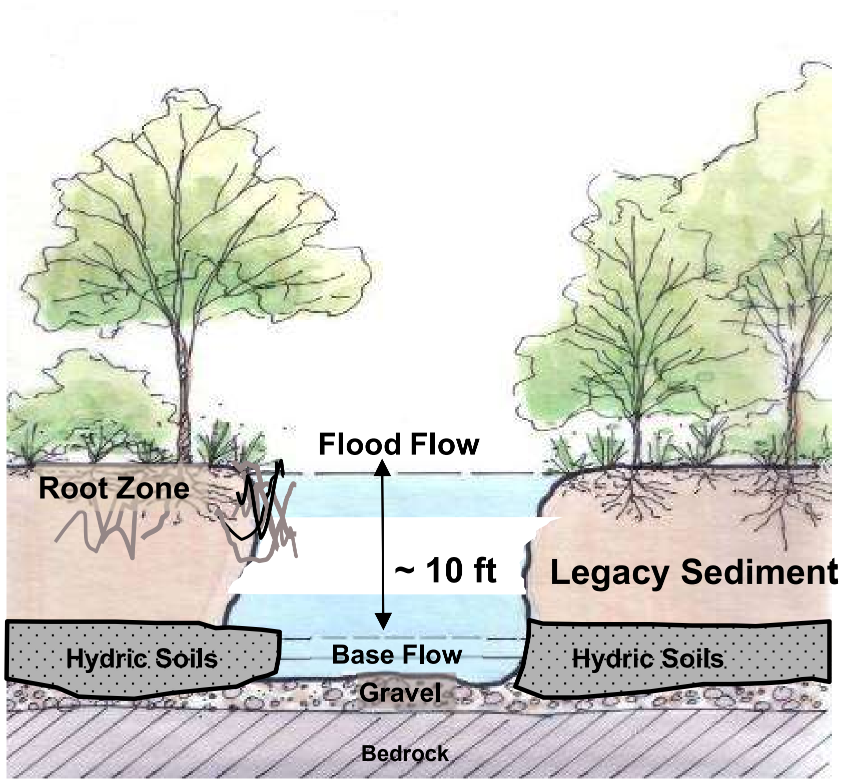

Walter and Merritts 2008 Natural Streams and the Legacy of Water-Powered Mills. Science 319:299-304

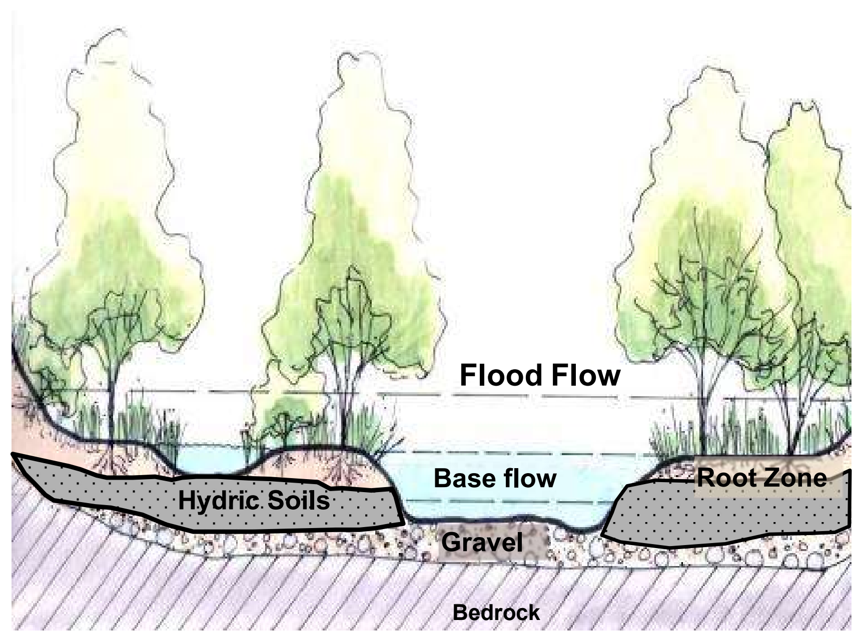
**Roughly 1 mill every 2.4 km of stream length in Lancaster County**

# Reconnecting stream to floodplain

## Before Restoration

## After Restoration



# Big Spring Run Restoration – Oct 2011


# Restoration via legacy sediment removal

**Pre-restoration**

9/13/2011

**Post-restoration**

07/27/2012

**Incised channel, erosion** → **No incision, reduced erosion**

# Big Spring Run

# Increased residence time

## Big Spring Run, Lancaster County PA

Courtesy Telemonitor, Inc.

**September 18, 2012 @ 3:30 PM**

**Post-Restoration**

# Increased residence time

**Big Spring Run, Lancaster County PA**

Courtesy Telemonitor, Inc.

**September 18, 2012 @ 5:00 PM**

**Post-Restoration**

# Increased residence time

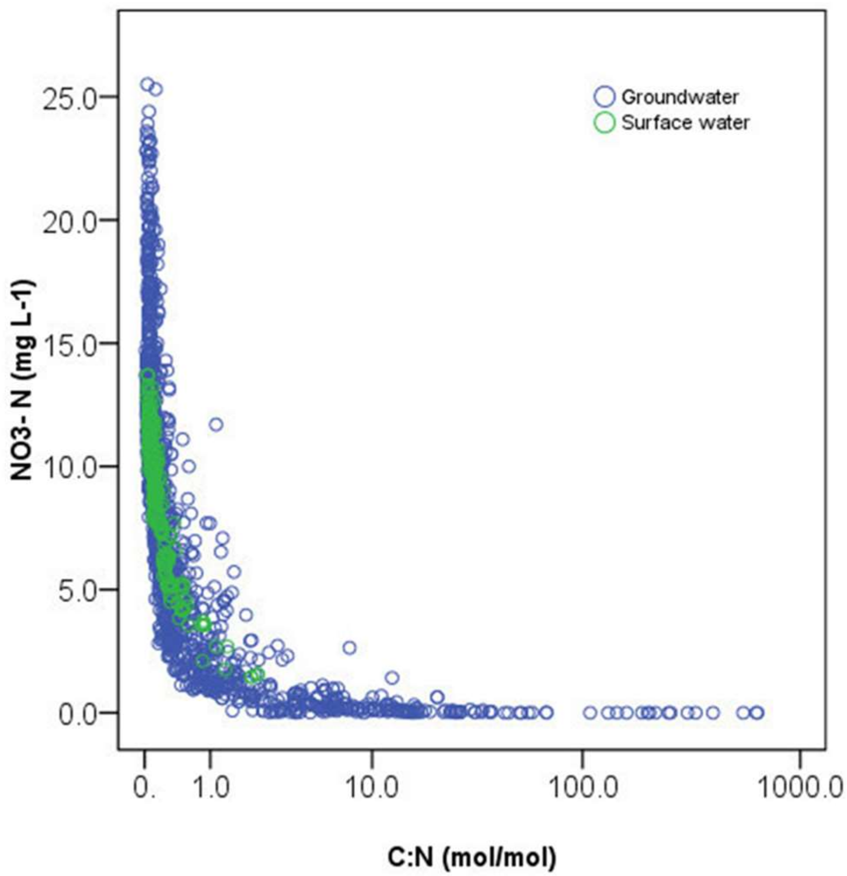
**Big Spring Run, Lancaster County PA**

Courtesy Telemonitor, Inc.

**September 20, 2012 @ 10:00 AM**

**Post-Restoration**

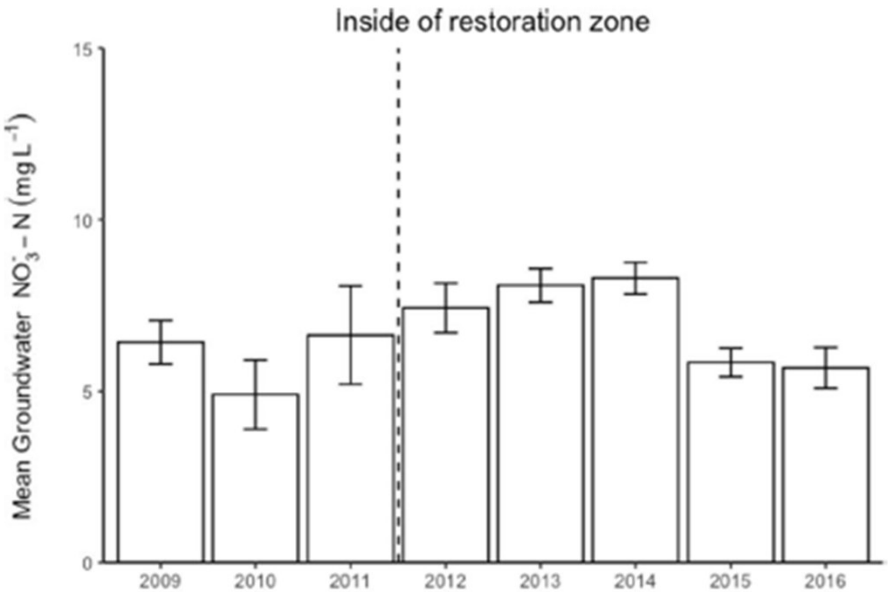
# High C:N at Big Spring Run was a good indicator of denitrification and GW-SW connectivity

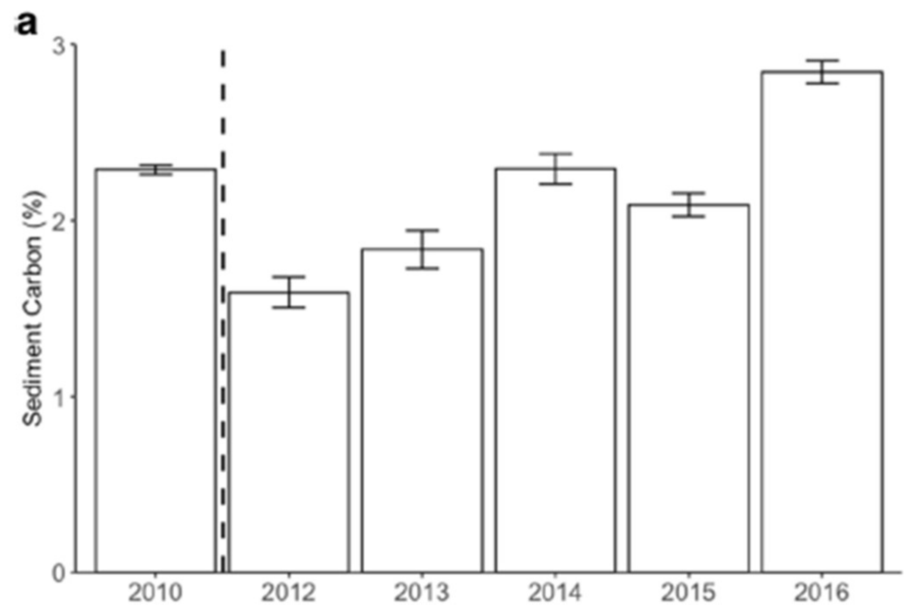


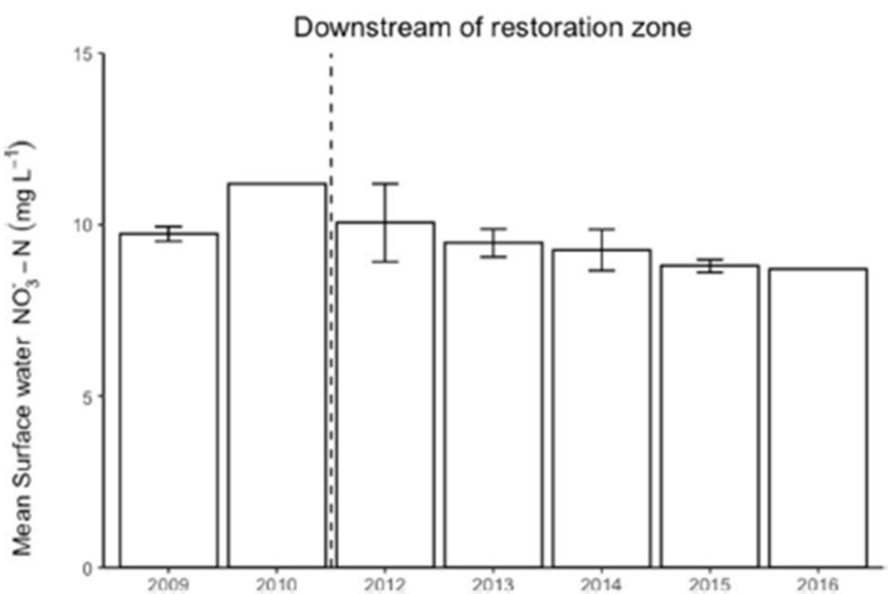

Forshay et al. 2022

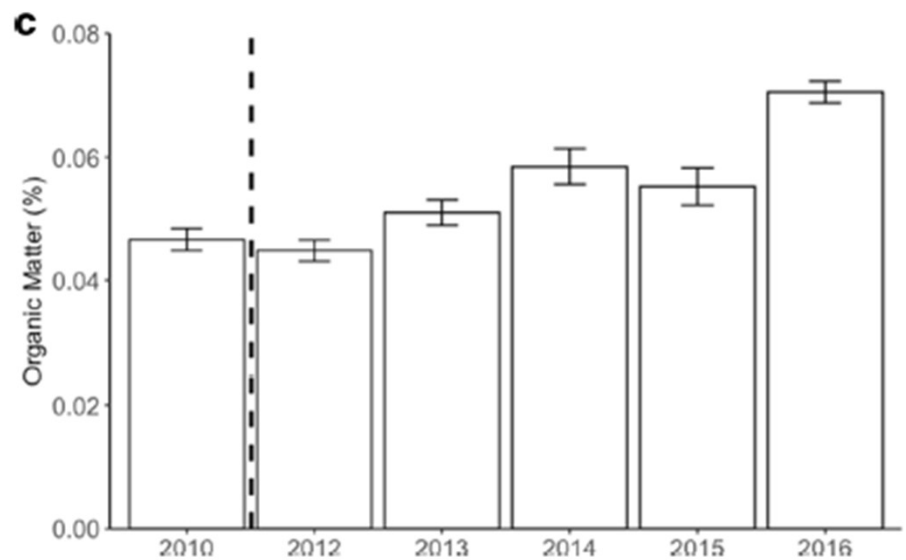
# Nitrate retention improved as organic matter accumulated to support higher rates of denitrification

**Forshay et al. 2022**

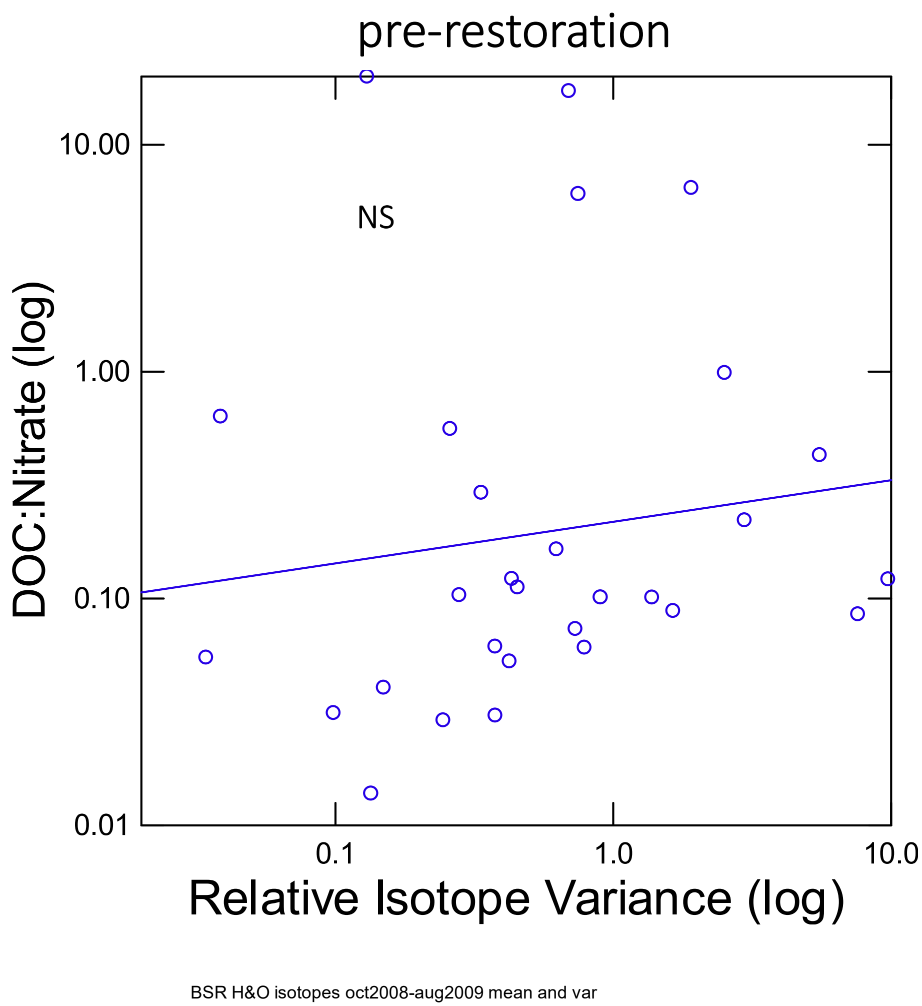


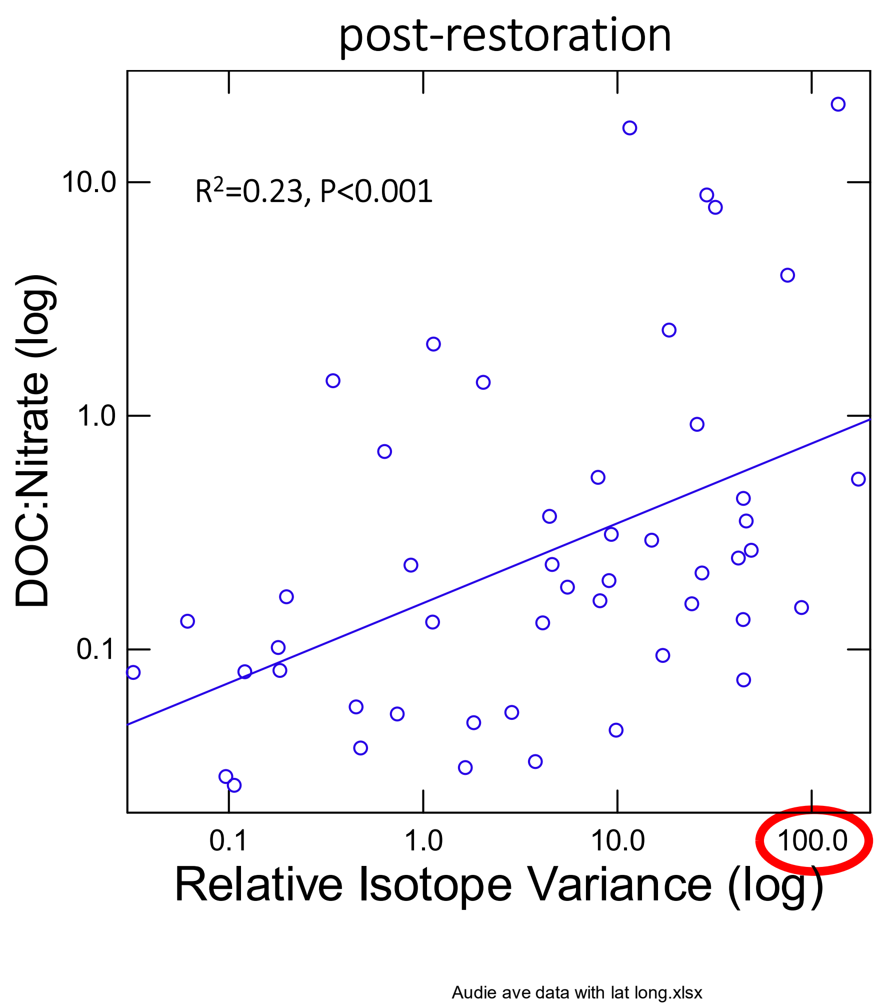



# C:N is related to groundwater residence after restoration at Big Spring Run suggesting improved floodplain reconnection and supply of DOC to denitrifiers




**Mayer et al. unpublished**

# Stream Restoration is Diverse

- **Stream Daylighting**

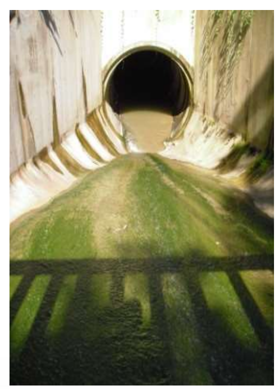
# Buried Streams


# Buried vs Exposed Streams


CINCINNATI

720m

430m



300m

BALTIMORE

127m

61m

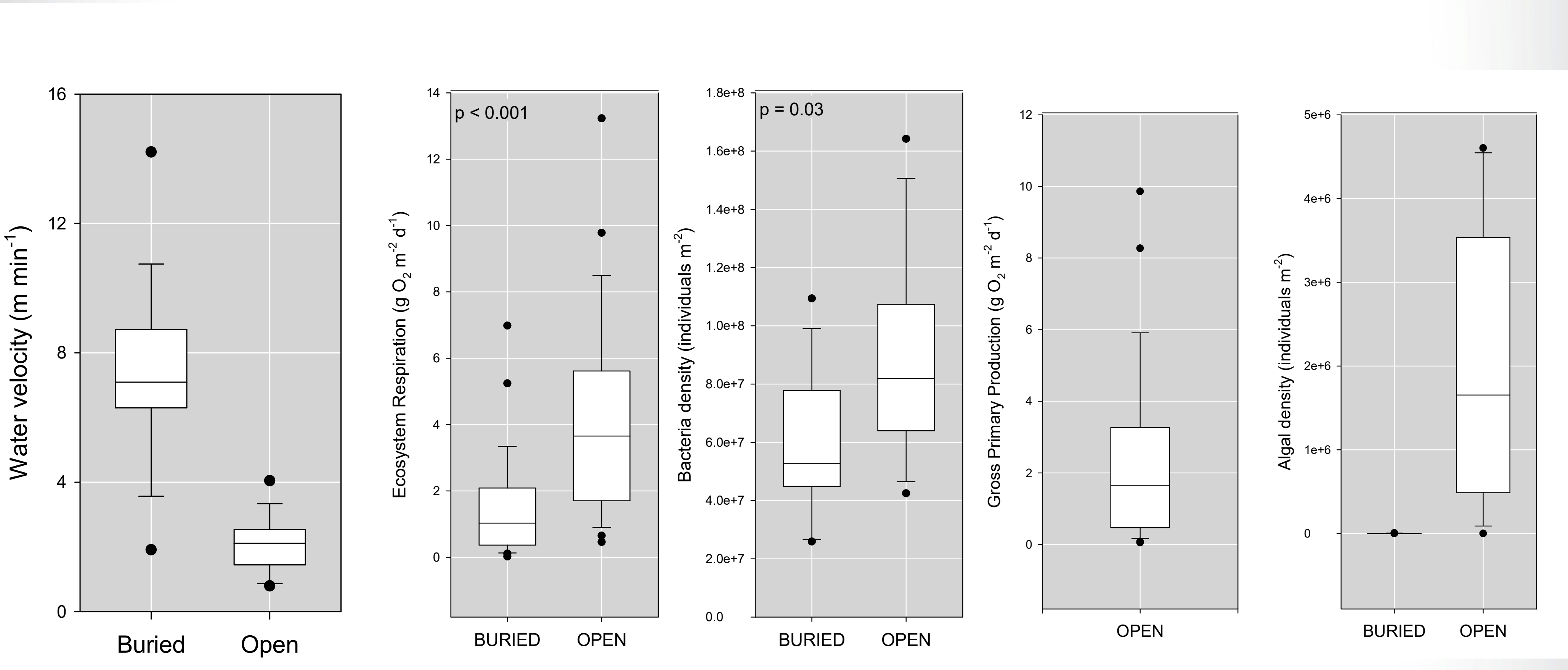
79m



**Beaulieu et al. 2014; Pennino et al. 2014; Beaulieu et al. 2015**

# Stream burial increases water velocity and reduces all ecosystem processes

**Nitrate travels 18x farther downstream in buried than in open streams before being removed from the water column**




**Beaulieu et al. 2014**
**Pennino et al. 2014**
**Beaulieu et al. 2015**

# Nutrient Meta-Analysis

*water*

MDPI

*Review*

## Nutrient Retention in Restored Streams and Rivers: A Global Review and Synthesis

**Tammy Newcomer Johnson [1,2,*], Sujay S. Kaushal [2], Paul M. Mayer [3], Rose M. Smith [2] and Gwen M. Sivirichi [4]**

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[3] US Environmental Protection Agency, National Health and Environmental Effects Research Lab, Western Ecology Division, Corvallis, OR 97333, USA; mayer.paul@epa.gov

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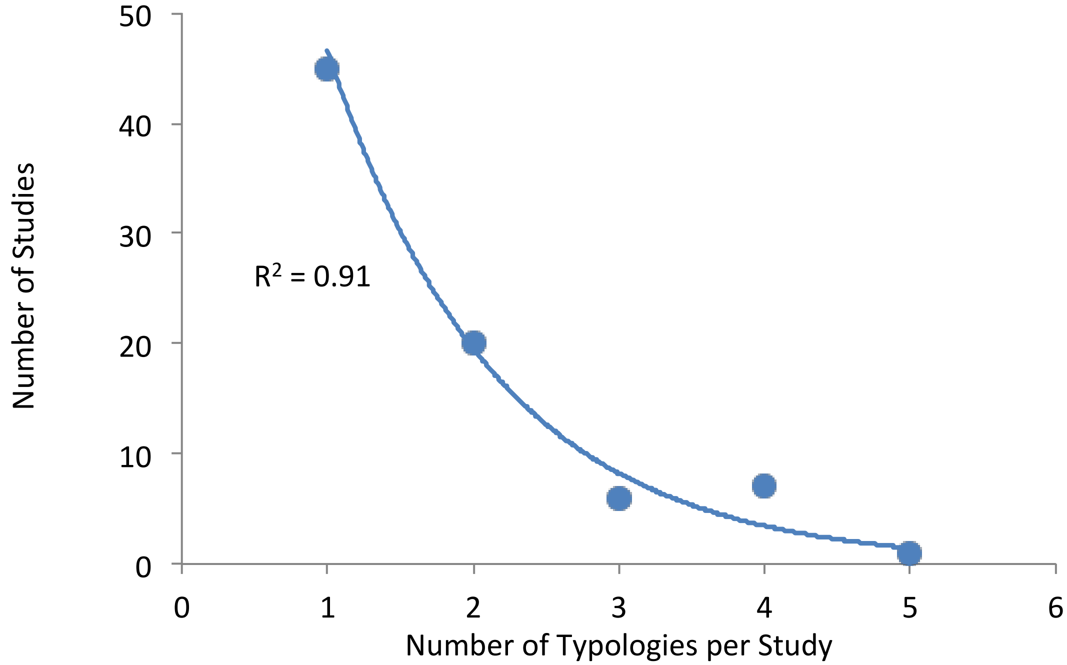
* Correspondence: newcomer-johnson.tammy@epa.gov; Tel.: +1-410-227-6982

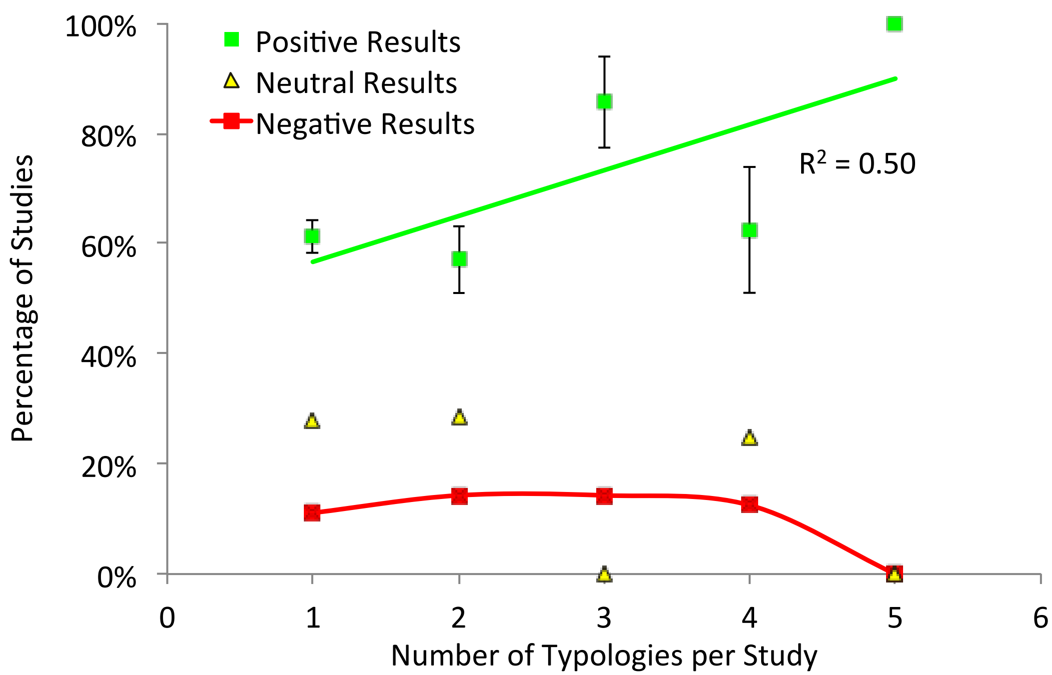
Academic Editor: Athanasios Loukas

Received: 27 November 2015; Accepted: date 29 February 2016; Published: date

**Abstract:** Excess nitrogen (N) and phosphorus (P) from human activities have contributed to

# Applications of multiple methods




**79 studies**

**240 exp additions of ammonium nitrate and srp**

**62% positive**

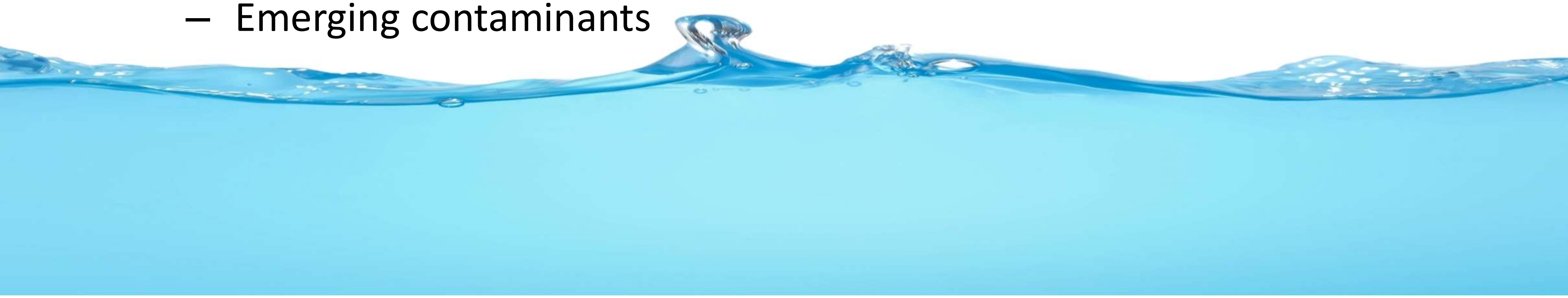
**26% neutral**

**12% negative**

**Newcomer Johnson et al. 2016**

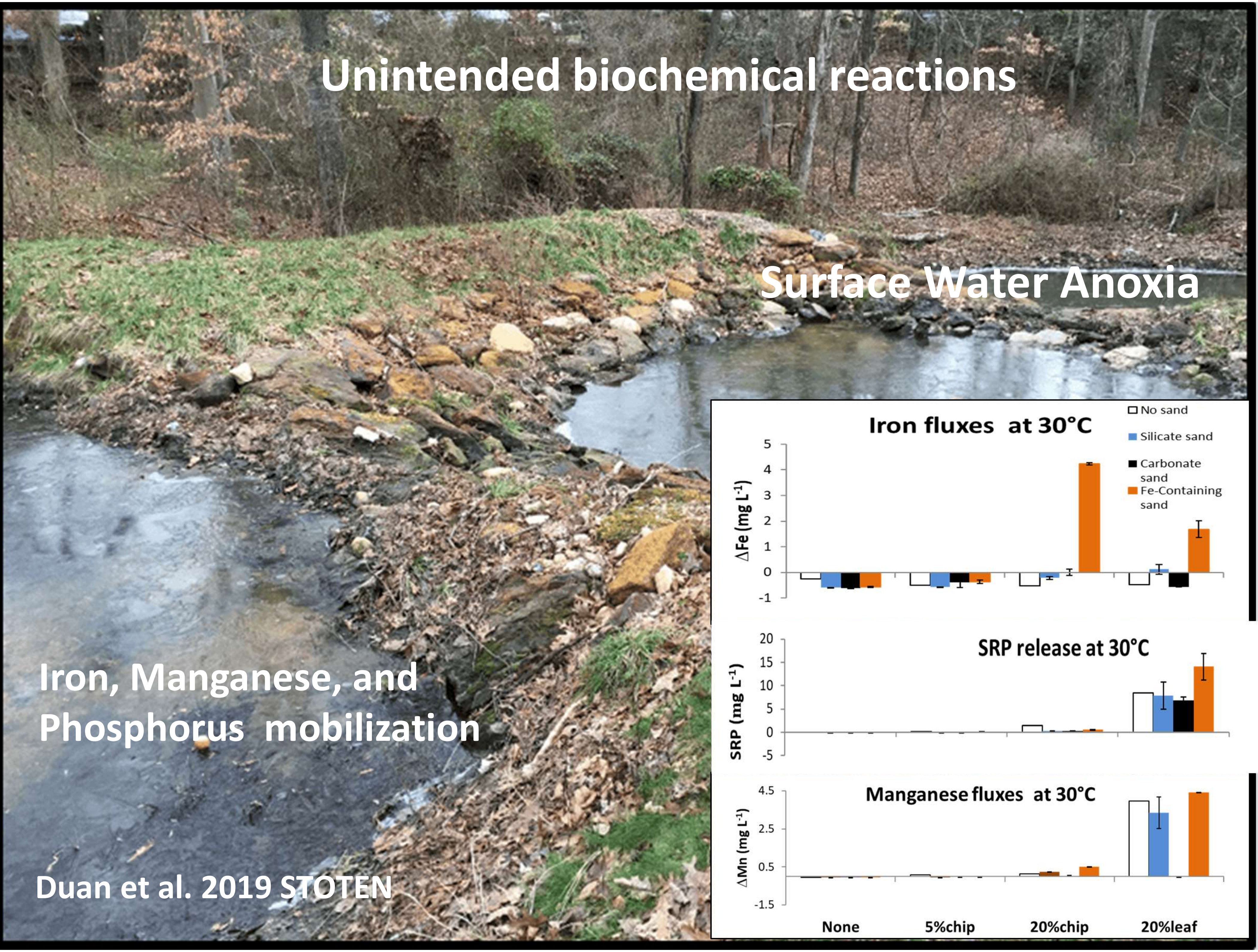
# Key Points

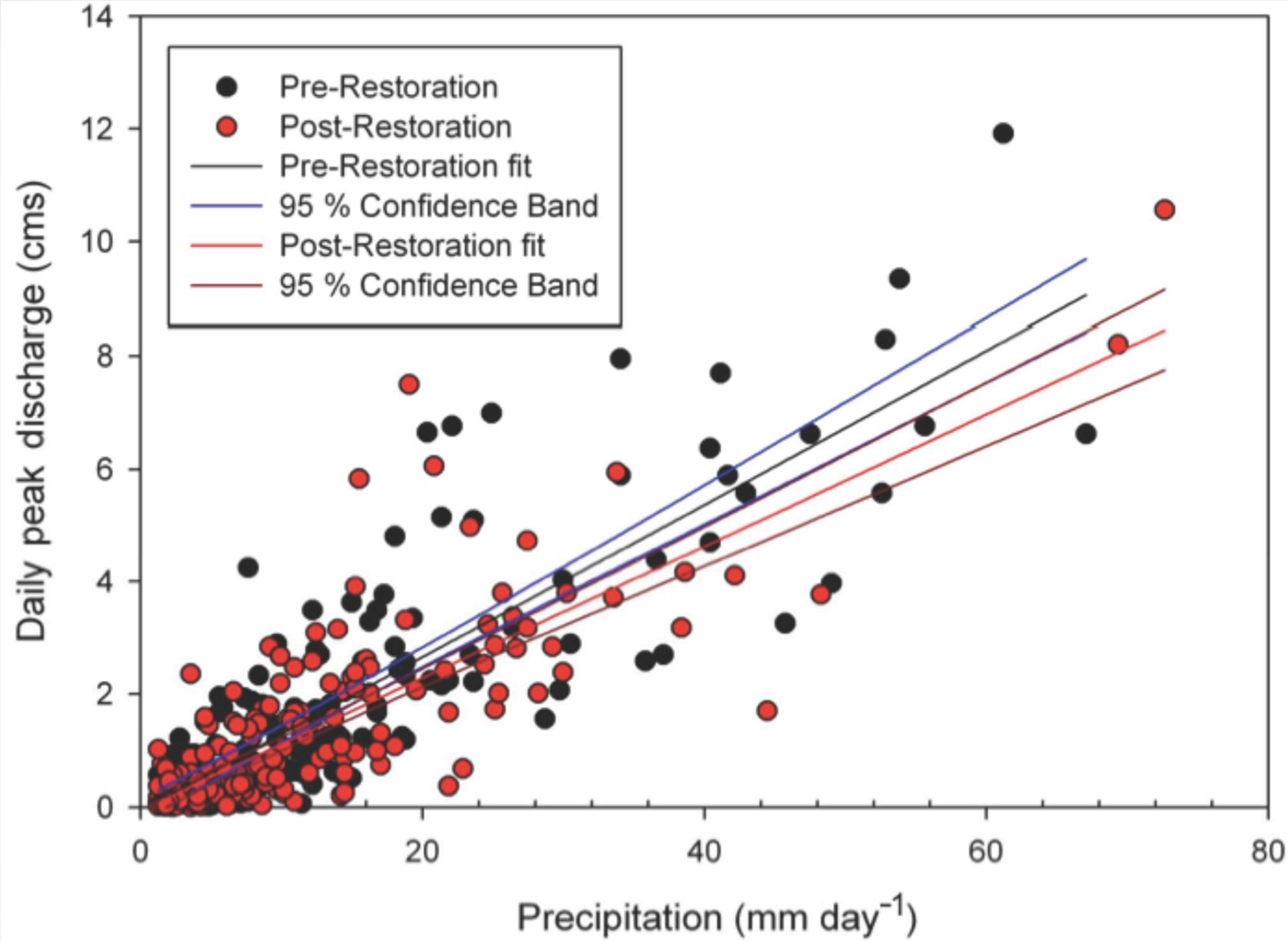
- **Many stream restoration approaches can improve water quality**
  - Within limits
  - Often, there are trade-offs
  - Application of multiple methods may improve outcomes
- **There are key drivers of water quality improvement**
  - size of the restoration
  - hydrologic connectivity and residence time
  - water velocity and flashiness
  - carbon availability
- **Other contaminants can reduce the benefits of restoration**
  - Salts
  - Metals
  - Emerging contaminants



# Questions?

?


Unintended biochemical reactions
Surface Water Anoxia
Iron, Manganese, and Phosphorus mobilization
Duan et al. 2019 STOTEN
Iron fluxes at 30°C
No sand
Silicate sand
Carbonate sand
Fe-Containing sand
ΔFe (mg L-1)
5
4
3
2
1
0
-1
SRP release at 30°C
SRP (mg L-1)
20
15
10
5
0
-5
Manganese fluxes at 30°C
ΔMn (mg L-1)
4.5
2.5
0.5
-1.5
None
5%chip
20%chip
20%leaf


Pre-Restoration
Post-Restoration
Pre-Restoration fit
95 % Confidence Band
Post-Restoration fit
95 % Confidence Band
Daily peak discharge (cms)
Precipitation (mm day$^{-1}$)
0
2
4
6
8
10
12
14
0
20
40
60
80

# Nitrogen Studies

| Study | Reference | WATERSHED | FEATURE | *N* | UNRESTORED | RESTORED | REFERENCE | METRIC | UNITS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Kaushal et al. 2008 | Minebank Run | low bank | 3 | 4.2-60.7 | | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 1 | Kaushal et al. 2008 | Minebank Run | high bank | 2 | 19.5-40.2 | | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 1 | Kaushal et al. 2008 | Minebank Run | low bank | 2 | | 108.6-156.2 | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 1 | Kaushal et al. 2008 | Minebank Run | high bank | 2 | | 26.1-41.1 | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 2 | Klocker et al. 2009 | Gwynns Falls | stream channel | 2 | 2.5-17.5 | | | $NO_3^-$ uptake (*U*) | mg m$^{-1}$s$^{-1}$ |
| 2 | Klocker et al. 2009 | Gunpowder Falls | stream channel | 2 | | 6.7-26.3 | | $NO_3^-$ uptake (*U*) | mg m$^{-1}$s$^{-1}$ |
| 3 | Sivirichi et al. 2011 | Gwynns Falls | stream channel | 2 | 327.1-629.2 release | | | change in TDN | mg m$^{-1}$d$^{-1}$ |
| 3 | Sivirichi et al. 2011 | Gunpowder Falls | stream channel | 2 | | 420.3-821.8 uptake | | change in TDN | mg m$^{-1}$d$^{-1}$ |
| 4 | Harrison etal 2011 | Stoney | constructed wetland | 3 | 147 ± 29 | | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 4 | Harrison etal 2011 | Minebank Run | oxbow wetland | 2 | | 100 ± 11 | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 4 | Harrison etal 2011 | Baismans Run | forested wetland | 2 | | | 106 ± 32 | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 5 | Harrison etal 2012 | Minebank Run and Dead Run | stream channel | 2 | 442 ± 98 | | | denitrification potential | ng N [g dry sediment]$^{-1}$ h$^{-1}$) |
| 5 | Harrison etal 2012 | Minebank Run | stream channel | 2 | | 391 ± 116 | | denitrification potential | ng N [g dry sediment]$^{-1}$ h$^{-1}$) |
| 5 | Harrison etal 2012 | Pond Branch and Baisman's Run | stream channel | 2 | | | 1439 ± 613 | denitrification potential | ng N [g dry sediment]$^{-1}$ h$^{-1}$) |
| 6 | Newcomer etal. 2012 | Scott's Level and Dead Run | stream channel | 2 | 30.1 ± 8.8 | | | denitrification potential | ng N [g dry sediment]$^{-1}$ h$^{-1}$) |
| 6 | Newcomer etal. 2012 | Minebank Run and Spring Branch | stream channel | 2 | | 36.0 ± 12.3 | | denitrification potential | ng N [g dry sediment]$^{-1}$ h$^{-1}$) |
| 6 | Newcomer etal. 2012 | Pond Branch and Baisman's Run | stream channel | 2 | | | 2.2 ± 1.0 | denitrification potential | ng N [g dry sediment]$^{-1}$ h$^{-1}$) |
| 7 | Newcomer-Johnson etal 2014 | Gwynns Run | floodplain | 4 | 43.3-490.8 | | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 7 | Newcomer-Johnson etal 2014 | Gwynns Run | stormwater pond | 4 | 200.2 -423.4 | | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 7 | Newcomer-Johnson etal 2014 | Spring Branch | floodplain | 4 | | 8.5-588.7 | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 7 | Newcomer-Johnson etal 2014 | Spring Branch | stormwater pond | 4 | | 33.5-341.5 | | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 7 | Newcomer-Johnson etal 2014 | Pond Branch | floodplain | 4 | | | 99.5-317.3 | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 7 | Newcomer-Johnson etal 2014 | Pond Branch | pond | 4 | | | 13.6-57.6 | denitrification | µg N kg soil$^{-1}$d$^{-1}$ |
| 8 | Newcomer-Johnson etal 2016 | multiple | multiple | 12,32,10 | 0.01–33.6 | 0.15–32 | 0.00–1.43 | $NO_3^-$ uptake (*U*) | µg m$^{-2}$s$^{-1}$ |

# Strategies Used to Increase Hydrologic Connectivity

| Strategies | Typologies Included from Figure 2 | Number of Results from 79 Studies | Positive Results (%) | Neutral Results (%) | Negative Results (%) |
|---|---|---|---|---|---|
| Floodplain Reconnection | ABCD | 62 | 60% | 28% | 12% |
| Streambed Reconnection | EF | 9 | 70% | 20% | 10% |
| Increased Stream Surface Area | G | 19 | 65% | 22% | 13% |
| Increased Wetland Surface Area | HI | 24 | 75% | 14% | 11% |
| Total | | 114 | **62%** | **26%** | **12%** |

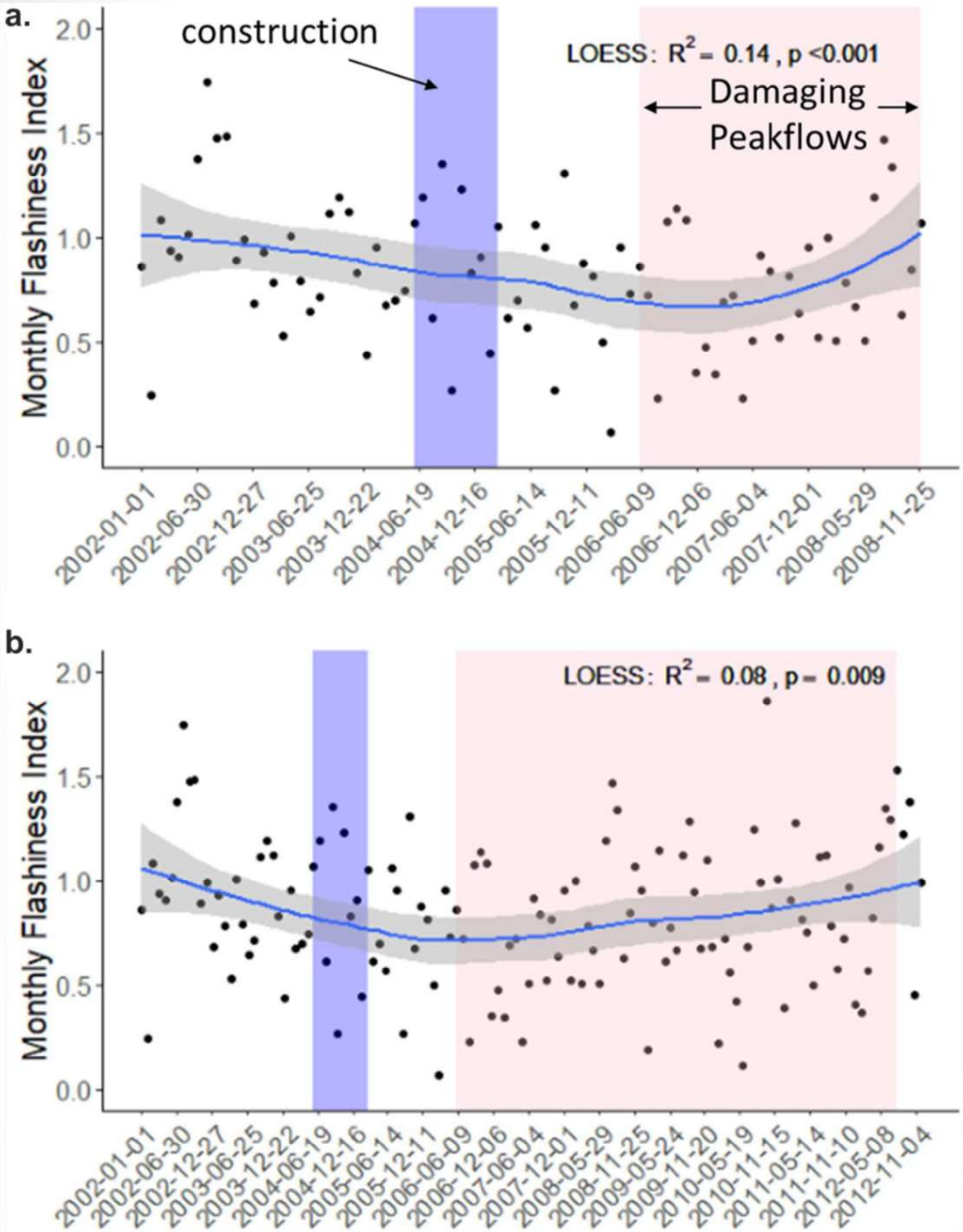
**Newcomer Johnson *et al*. (*2016)* Water**

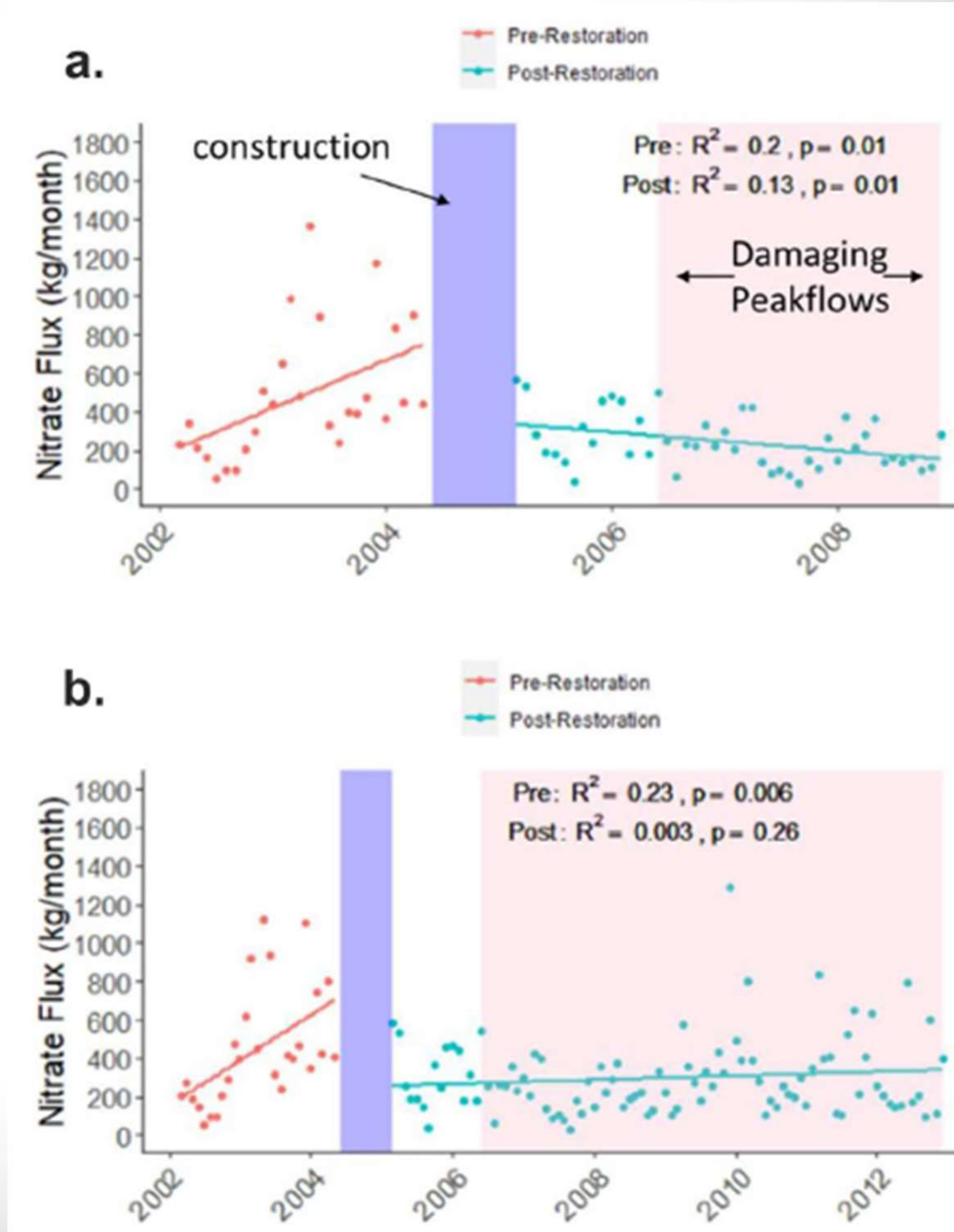
# (Some) unintended consequences of urban stream restoration

- Biochemical reactions due to restoration design
- Macro and micro-nutrient release after removal of riparian trees
- Salinity and Chemical Cocktail impacts on biogeochemistry
- Failure to Thrive & Low Efficacy

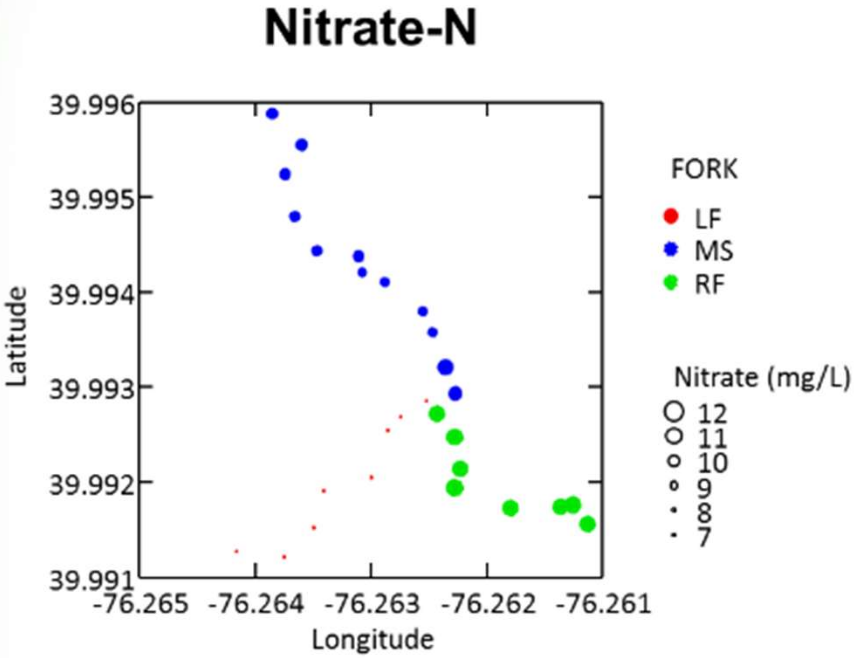
EPA at 50
Progress for a Stronger Future

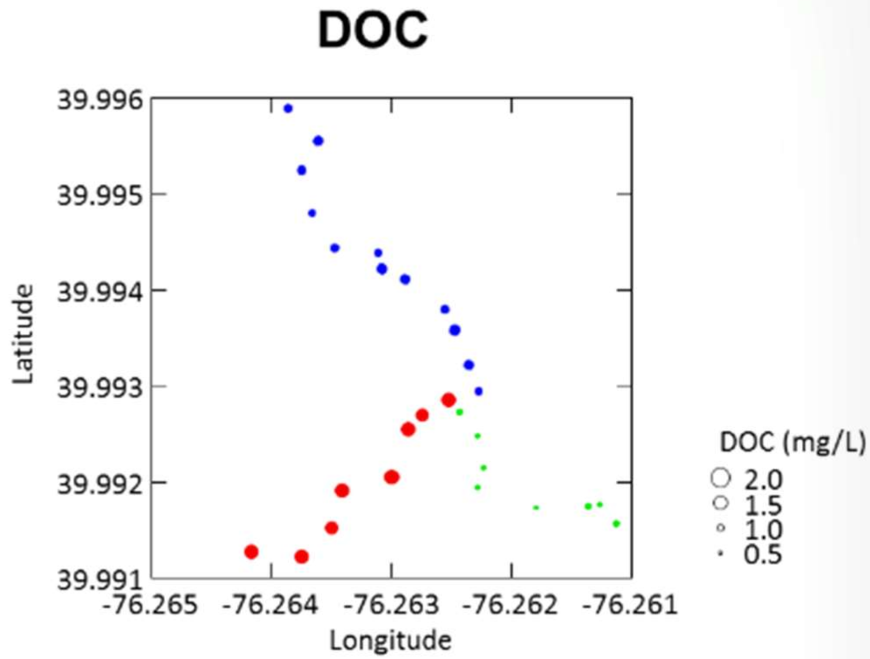
# Damaging peakflows degraded the restored reach and reduced nitrate attenuation

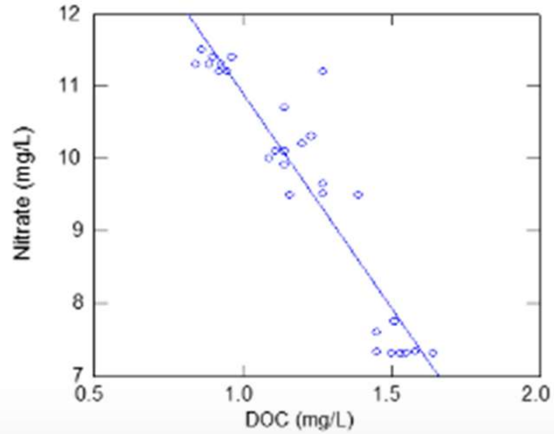


# Nitrate and DOC are Inversely Related



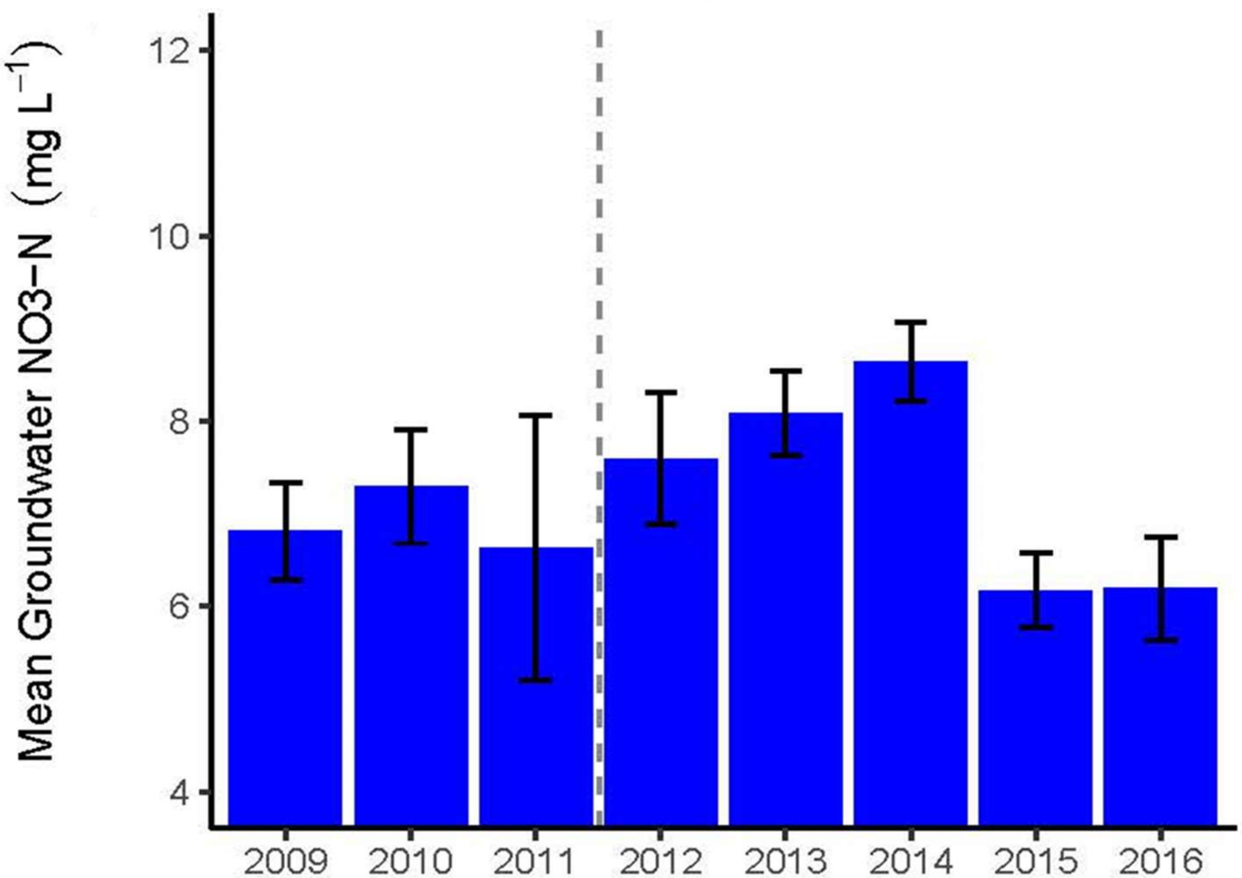




P<0.001
$R^2$=0.87

Source: Mayer unpublished

## NO3 retention improved after several years as organic matter accumulated to support higher rates of denitrification that transitioned from organic C limitation to NO3 limitation




**Forshay et al. 2022**

# Improving restoration outcomes

- **Avoid anoxia and metal mobilization**
  - Maintain flow
  - Choose construction materials wisely
- **Manage riparian zones**
  - Limit cutting trees
- **Reconnect floodplains**
  - Proper channel design
  - Remove legacy sediments (where feasible)
- **Manage road salt and other chemicals**
  - Stormwater management
  - Placement decisions