SOLUTE TRACER STUDIES IN A RESTORED COASTAL PLAIN STREAM

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Art or Science?

<4%

<10%

- <10% of projects are assessed (Bernhardt et. al, 2005)
- Lack of data to determine success or failure (Pander and Geist, 2013; Bennett et al., 2011)
- Compared to nearby 'reference' streams in post-restoration period (Colangelo, 2014; Daniluk et. al, 2013; Howson et al., 2009)
- Only 4% of projects investigate pre-restoration status (Palmer et al., 2005)

Lack of baseline data from paucity of sound assessments

↓

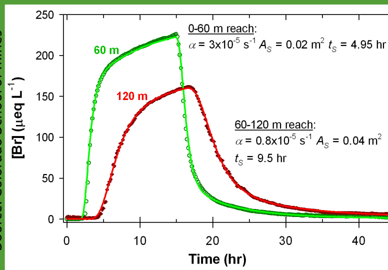
Do stream restorations have **measurable benefits**?

Source: USGS

Solution:
Assessment with Tracers?

- RAPID
- WATER QUALITY + HYDROLOGY
- LIMITED EQUIPMENT
- VARIOUS STREAM LENGTHS
- ONLY BASEFLOW
- DEPENDENT ON SEASON

Source: Colorado School of Mines



Source: USGS

What is a tracer study?

- Inject tracer
  - Continuously and constantly inject of a well-mixed solution
  - Pulse injection of solute
- Monitor downstream concentrations of solutes
- Utilize shape of breakthrough curves (BTCs) to characterize solute fate and transport

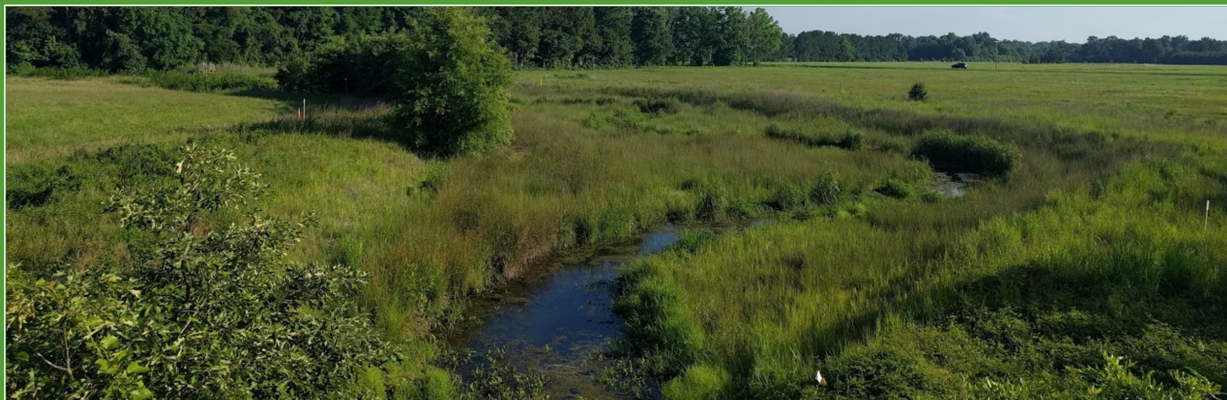
Study Objectives

Efficacy of Restoration

- Hydrologic processes
- In-stream NO_3^- uptake
- Retention time

Tracer Methodology

- Transient storage model (TSM) parameter optimization and outputs at various temporal resolutions
- IC-SC methods
- Novel techniques for NO_3^- during tracer studies



METHODS

Case Study: Priority 2 Mitigation Project

- Goldsboro, NC
  - Neuse River Basin
- Land uses: **cropland**, pasture, developed land, **forestry**, grassland, and forest
- 3 jurisdictional streams
  - 10,587 linear feet stream restored
  - 31.8 acres riparian buffer

Pre-Restoration

Tracer Study 1: March 2015

Cut New, Lower Floodplain →

Created Meandering Channel →

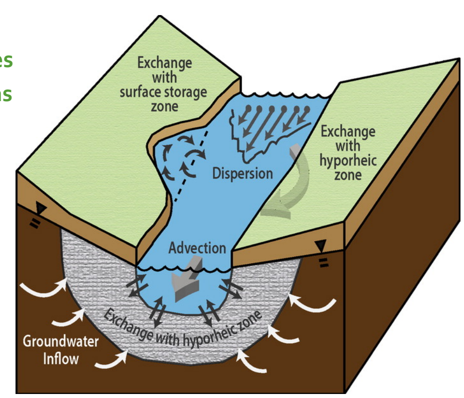
Reduced Channel Cross-Section →

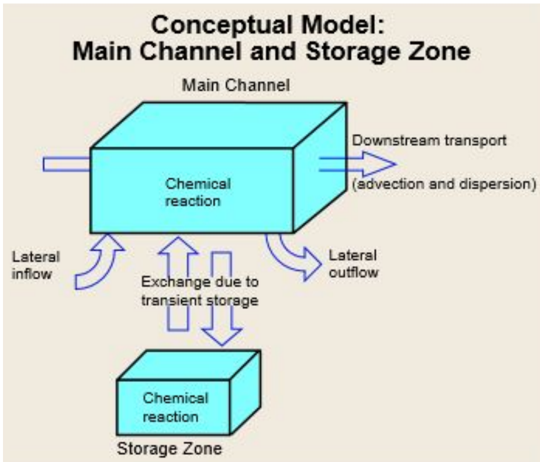
Converted tributaries to wetlands →

Post-Restoration

Tracer Study 2: June 2017

- Continuous injection of highly concentrated solution for 20 hours to raise background concentration by 1-3 mg/L
  - Conservative tracer: Bromide (5 kg)
  - Non-conservative tracer: Nitrate (10 kg)
- Used transient storage model (TSM)
  - Eddies
  - Pools
  - Hyporheic zones
  - Backwater areas

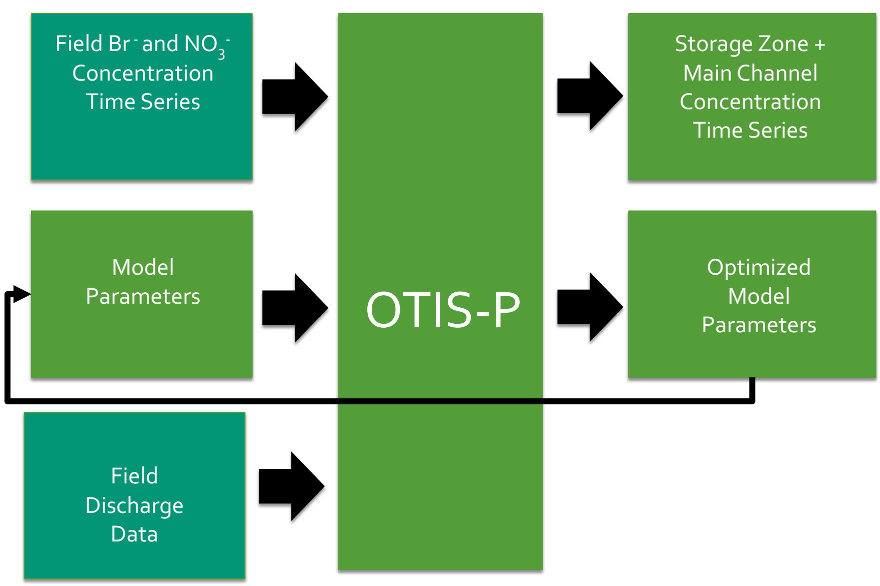




USGS OTIS-P Model

- Non-linear transient storage model
  - Hydrologic Transport
    - Advection
    - Dispersion
    - Lateral Inflow
    - Transient Storage
  - Chemical Transformation
    - First Order Decay
    - ~~Sorption~~

OTIS-P Structure



Field Data Collection

Continuous, in-situ sensors + less frequent discrete samples

Why?

- Reduce cost of analysis
- Increase reliability of BTCs
- Enhance model parameterization
- Simplify data collection

How?

1. Ion-Concentration-Specific-Conductivity (IC-SC) relationships
   - Bromide
   - Specific Conductivity
2. Linear calibration between S::CAN and discrete samples
   - Nitrate

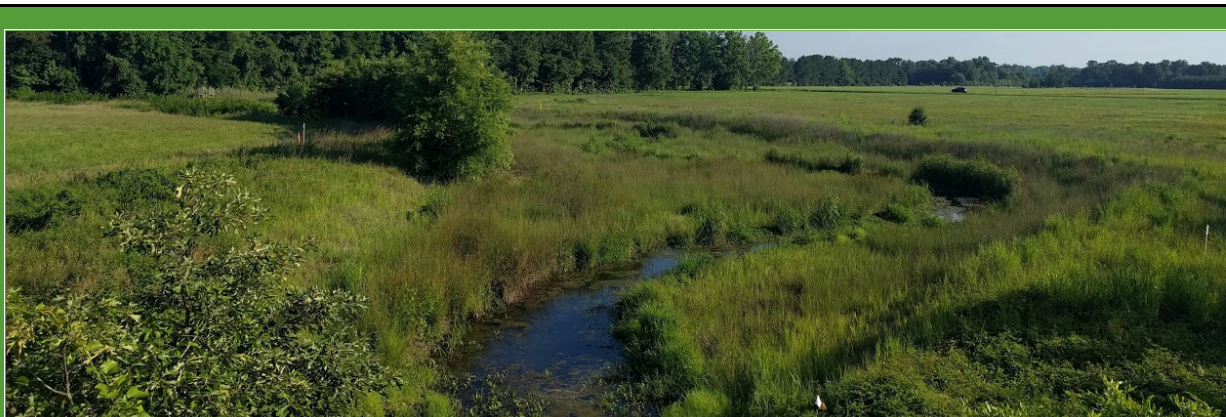
Sensor		Parameter(s) Measured	Measurement Interval
S::CAN spectro::lyser™ spectrophotometer		NO_3^-	Pre: 4 min Post: 2 min
SonTek-IQ® acoustic doppler		Stage Velocity	Pre: 15 min Post: 15 min
Eureka Manta 2™ water quality sonde		Specific Conductivity	Pre: 5 min Post: 2 min
YSI® OMS-600 conductivity probe		Specific Conductivity	Pre: 2 min Post: 2min

Temporary Monitoring Stations

- Specific Conductivity
- Br^- Discrete Samples

Permanent Monitoring Stations

- Specific Conductivity
- NO_3^- sensor
- Discharge
- NO_3^- and Br^- discrete samples



RESULTS & DISCUSSION

Retention Time

Pre-Restoration

Reach	$(\frac{hr}{m})$
2	0.0072
3	0.0046
4	0.0028

Post-Restoration

Reach	Main $(\frac{hr}{m})$
1	0.0035
2	0.0087
3	0.0054
4	0.0033
5	0.0016

Different Phases of Recovery = Different Hydraulic Resistance

Sinuosity ≈ 1

Sinuosity ≈ 1.3

Similar Retention/Length * Longer Length = + Hydraulic Retention

Transient Storage

Pre-Restoration

Reach	$\frac{Storage\ Zone}{Main\ Channel}$
2	0.77
3	0.43
4	0.35

Post-Restoration

Reach	$\frac{Storage\ Zone}{Main\ Channel}$
1	5.35
2	0.82
3	1.07
4	2.50
5	3.66

Increase in A_s/A after Restoration

Post-Restoration: + Variation in As/A Flow Diversity = + Flow Diversity

Reach	Storage Zone / Main Channel
1	5.35

Exchange with Adjacent Wetland

Gravel Riffles and Runs

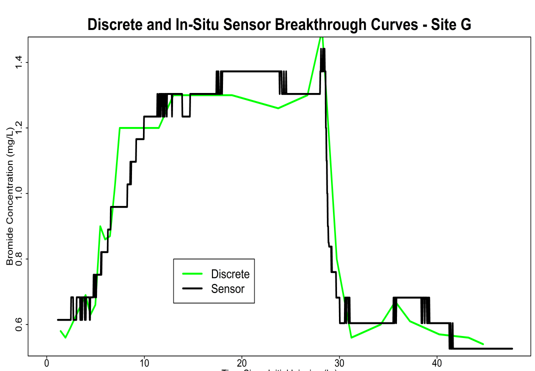
Reach	Storage Zone / Main Channel
4	2.50
5	3.66

Reach 4 & 5 → Sandy Substrate

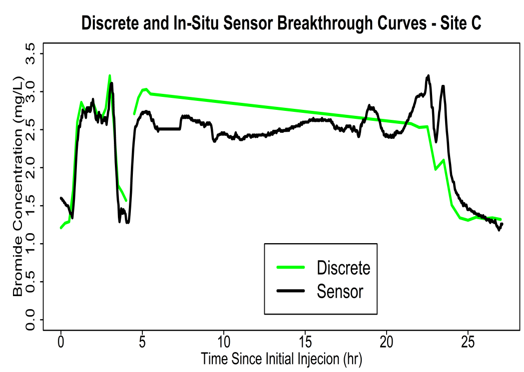
METHODOLOGIES

IC-SC Methods

Pre-Restoration

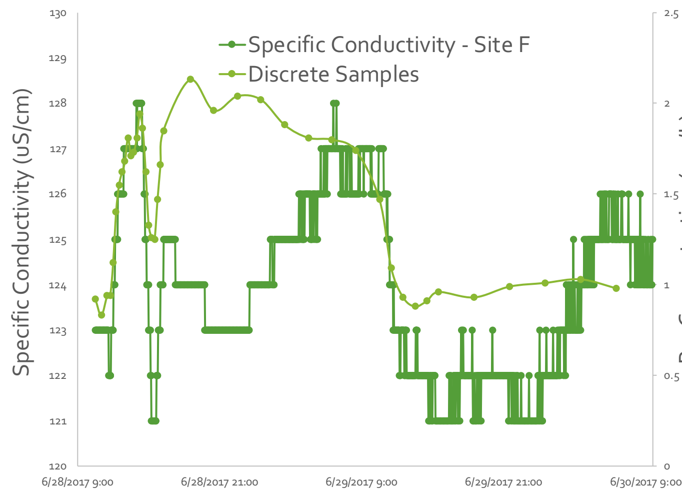


Post-Restoration

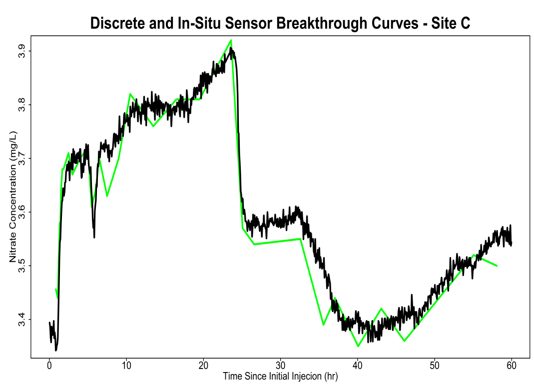


Issues with IC-SC

- Must have nearly constant flow
  - Excludes late spring and summer
  - Inconsistent with highest biological activity
- Need long-term records of flow and conductivity at all stations
  - No longer a rapid assessment
- Need >30 samples per reach across 36 hours
  - Expensive analytical costs + equipment
- Sensitive to influx of other salts
  - Tributaries
  - Different riparian land use
    - Forest v. Ag



Short-term NO_3^- Calibration



- NO_3^--sensor data consistently matched laboratory results
- Only requires 10 to 15 discrete samples were required for a strong sensor **linear** calibration
- Sensors were highly sensitive to changes in NO_3^- concentration

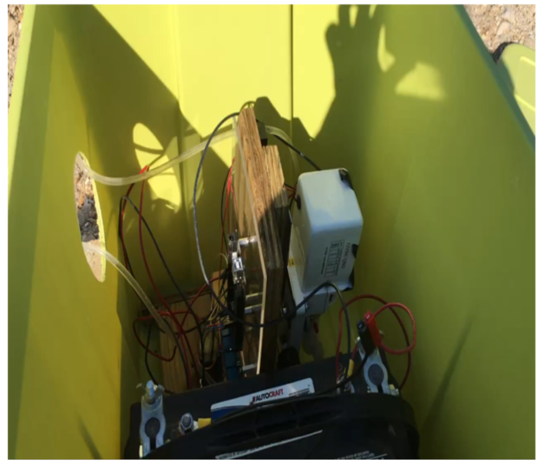
CONCLUSIONS

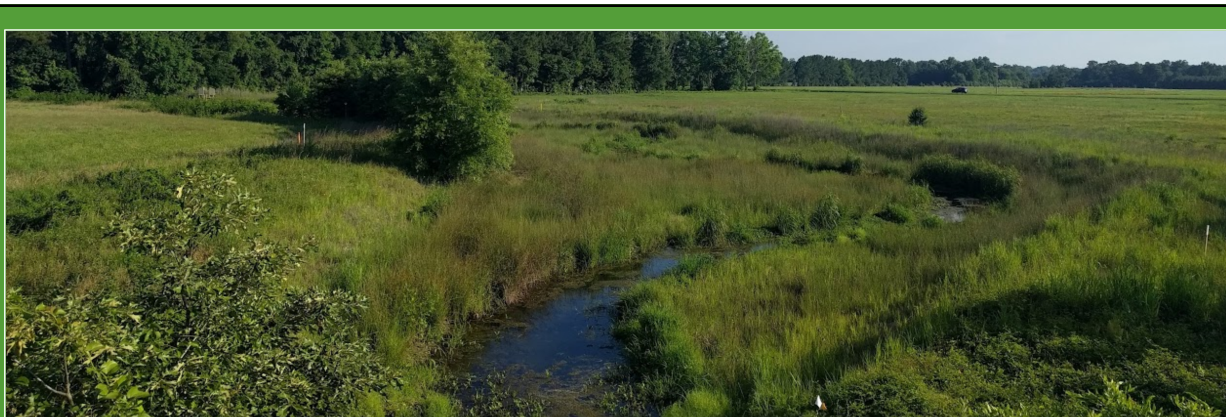
Pre-Restoration v. Post-Restoration

- Similar retention/length, but increased sinuosity suggests higher retention in post-restoration
- Lower retention/length in newer portions of the restored stream
- Consistently higher ratio of transient storage to main channel in restored stream
- Increased flow diversity in restored stream

Tracers for Evaluating Stream Restorations

- Evaluate well beyond 1 year after restoration implementation
- Avoid IC-SC methods for streams that have complex hydrology and mixed land use if long-term flow and conductivity data is not available
- Avoid IC-SC during warmer months if high-resolution discharge data is unavailable at all sampling points
- **Focus resources on high quality, frequent discrete samples, rather than specific conductivity**
- Use NO_3^- sensors (if available) to collect high quality concentration time series with minimal calibration required





THANK YOU!

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