

# Comparative assessment of the performance of grassed swales and bioswales in reducing stormwater pollution from highway runoff

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2024 Chesapeake Bay Trust Pooled Monitoring Forum  
June 16, 2024

# Background

- Stormwater and the Chesapeake Bay restoration
- Traditional stormwater management practices (“routing” problem)
  - Gutters
  - Storm drains
  - Storm sewers
- Stormwater management practices for low impact development or green infrastructure
  - Retention and detention basins
  - Rain gardens
  - Vegetated swales
  - Bio-retentive swales (aka “bioswales”)



Gutter, curb opening inlet, and grated storm drain



Concrete-lined sewer (channel)



Bioswale in highway median



Detention basin

# Swales

- What are swales and what are their functions?

- Engineered ditches used to convey stormwater while allowing for both abstraction (permanent storage or loss) and detention (transient storage)
- Abstraction primarily by infiltration into the soil and evapotranspiration → *runoff reduction*
- Detention enhanced by channel roughness (grassy vegetation, check dams) → *stormflow attenuation*
- *Reductions in pollutant concentrations & loads*



Grassed swale along roadway

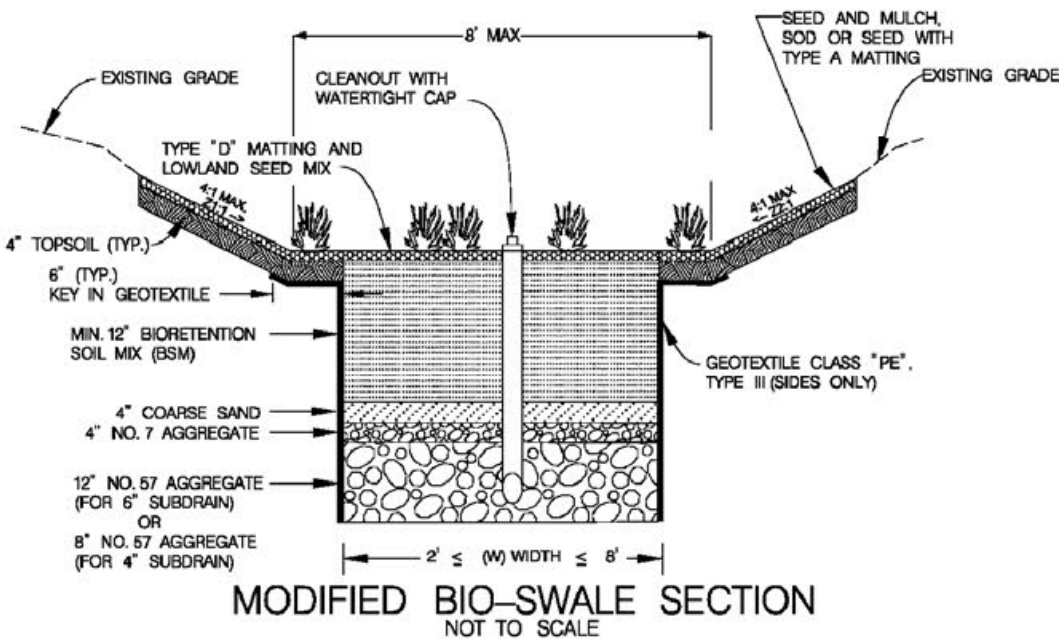
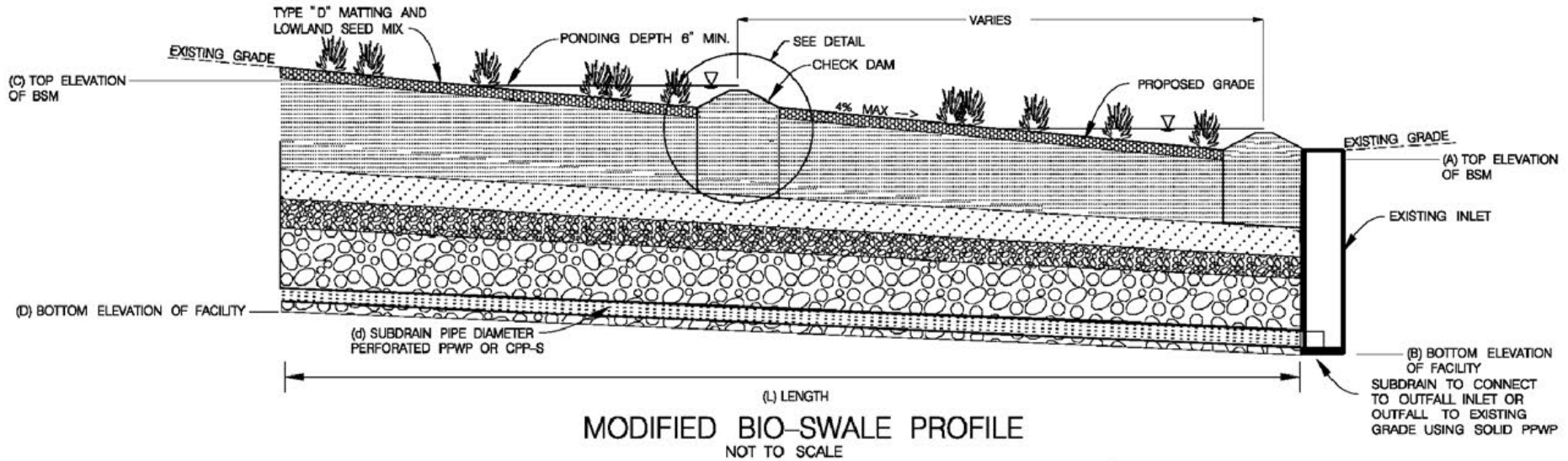
- What is a bioswale?

- Swale in which native soil is replaced with “bio-retentive soil” (engineered to enhance soil infiltration and pollutant retention)
- Underdrains often used to maximize infiltration
- Bioswale construction and retrofitting widely used by MDOT-SHA to address NPDES MS4 permitting issues (i.e., reduce pollution to “maximum extent practicable”)



Bioswale in highway median (with stormwater monitoring equipment)

# SHA Bioswales



Bioswale under construction (US Rte. 15 near Frederick)

# Comparative Assessment of Swale Performance

- Objective: Assess the effectiveness of bioswales in achieving three stormwater management objectives through multi-site, paired, field-scale comparisons of stormflow responses (and of nearby grassed swales serving as controls)
- Study Sites: Pairs of highway swale “mini-catchments” instrumented in Maryland: Washington County, (Dual Highway near Hagerstown: discontinued after 2016), Howard County (US Rte. 40 in Ellicott City), and Frederick County (US Rte. 15 near Lewistown)
  - No pre-treatment calibration data!
  - Paired swales have similar watershed areas, slopes, and imperviousness
  - Bioswale performance assessed relative to a grassed swale control



# Comparative Assessment of Swale Performance

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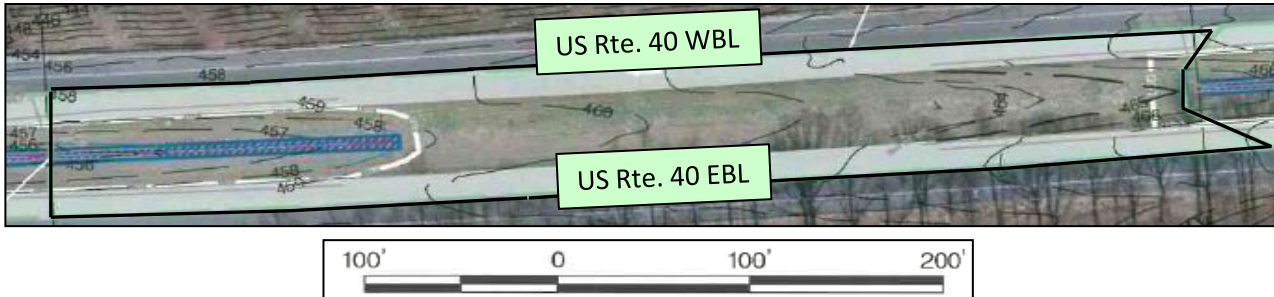
- Methodology

- Chemical and physical (steady-state soil infiltration capacity,  $I_{ss}$ ) characterization of swale soils (from previous SHA-sponsored project):
  - $I_{ss}$  of biosoil ~ 5X-10X higher than other highway median soils
- Continuous rainfall monitoring (tipping bucket gages, 15-min data)
- Continuous gaging of both overland (all swales) and underdrain (bioswales only) runoff (5-min data)
- Automated sequential sampling across multiple stormflow-producing events (3-seasons: March – October)
- Laboratory analyses of dissolved and suspended constituents: 25 constituents including N, P, TSM, trace metals
- Computation and statistical comparison of paired event runoff depths, runoff ratios, peak runoff rates, and annualized discharge-weighted event mean concentrations (EMC's) and event loads (EL's)
- **NEW for 2023!:** Synoptic swale stormwater sampling to assess spatial variability in water quality and representativeness

# Study Sites

## Delta bioswale at Ellicott City, MD

- Mini-catchment area = 1.07 acres
- Imperviousness = 45%
- Bioretention area = 0.039 acres



## Kappa grassed swale at Ellicott City, MD

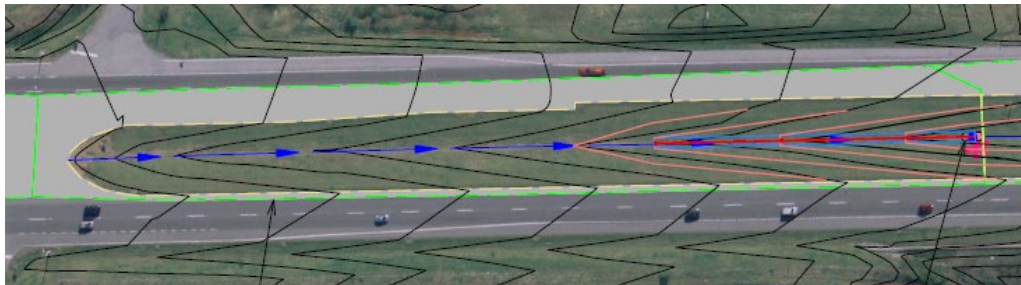
- Mini-catchment area = 1.10 acres
- Imperviousness = 57%
- Bioretention area = 0.0 acres

# Study Sites (cont.)



## Omega bioswale at Ellicott City, MD

- Mini-catchment area = 1.20 acres
- Imperviousness = 45%
- Bioretention area = 0.044 acres



## Epsilon bioswale at Lewistown, MD

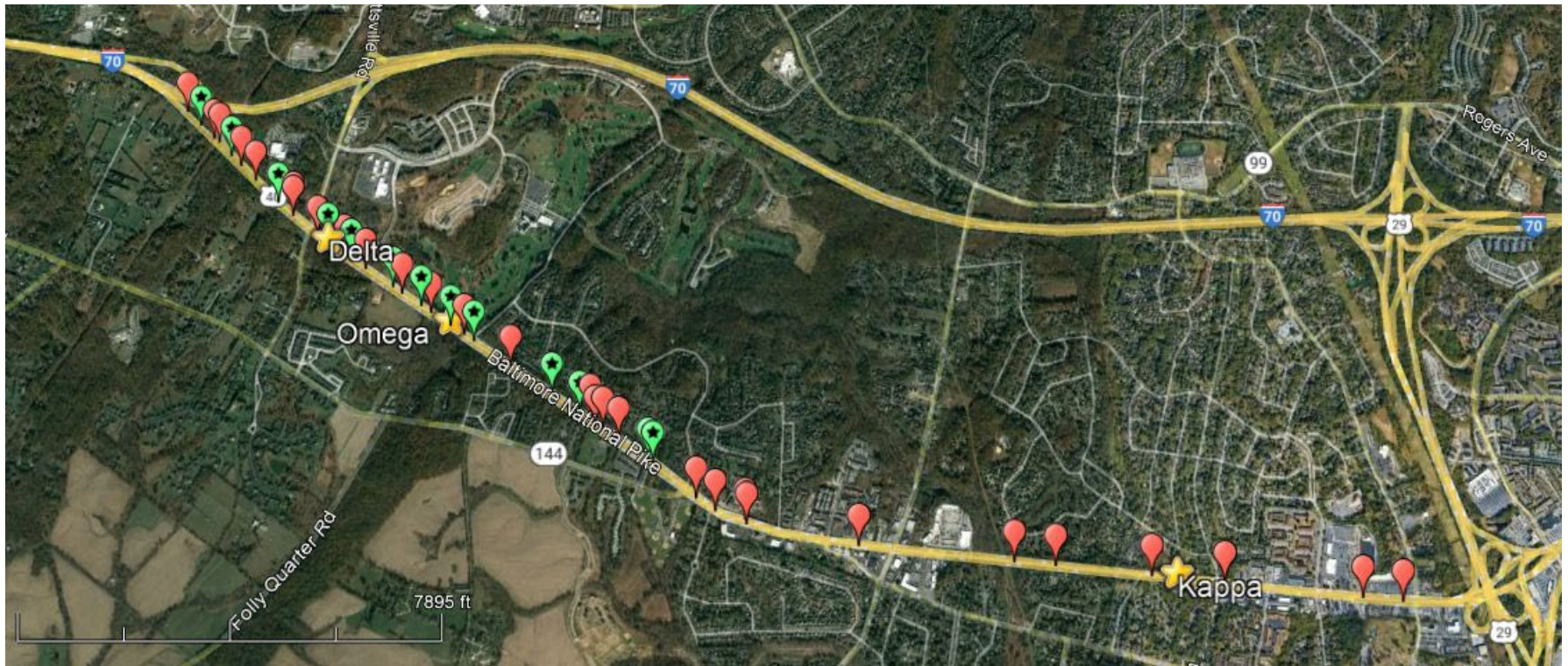
- Mini-catchment area = 1.63 acres
- Imperviousness = 38%
- Bioretention area = 0.048 acres



## Zeta grassed swale at Lewistown, MD

- Mini-catchment area = 1.43 acres
- Imperviousness = 24%
- Bioretention area = 0.0 acres

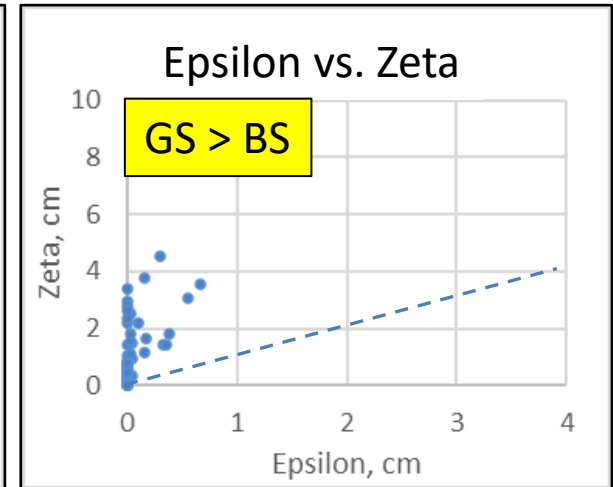
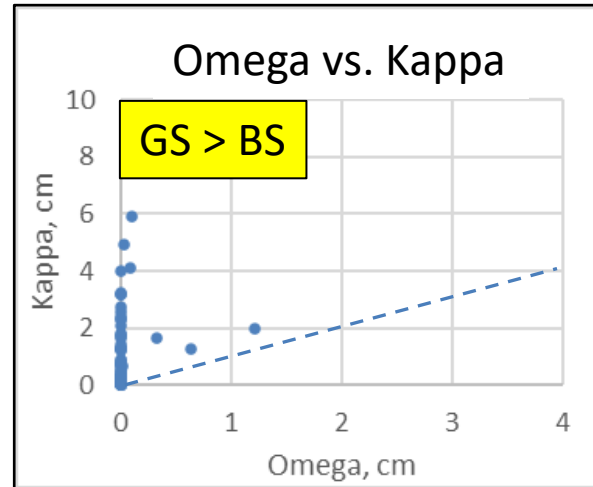
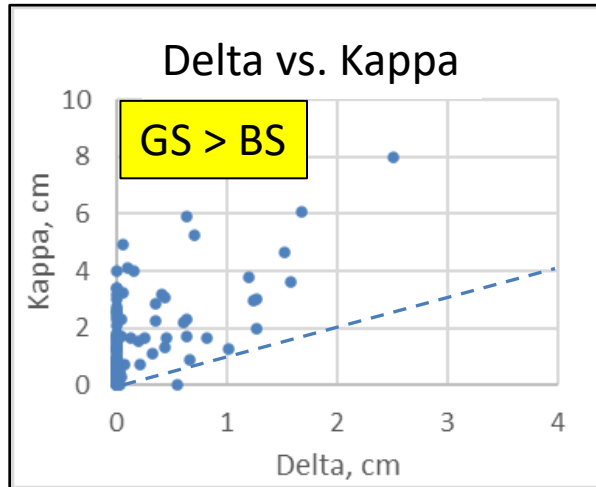
# Study Sites (cont.): “synoptic”\* stations



“Population” of highway swales (bioswales = ●; grassed swales = ●) on US Rte. 40 in Howard County (between I-70 US Rte. 29 interchange); 3 instrumented swales also shown

\*the word is used here in the same way as it is used in the field of meteorology: “of, or relating to, data obtained nearly simultaneously over a large area of the atmosphere”

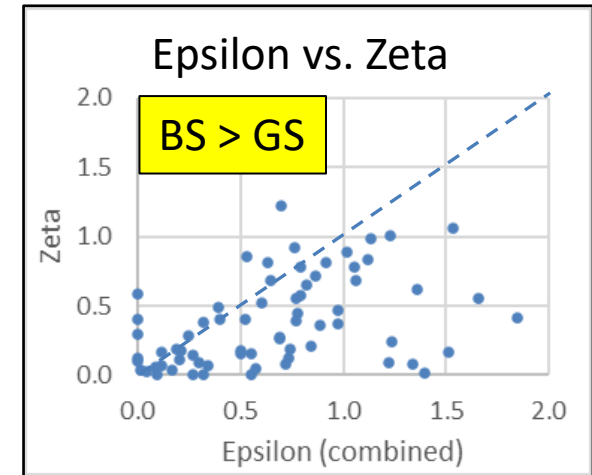
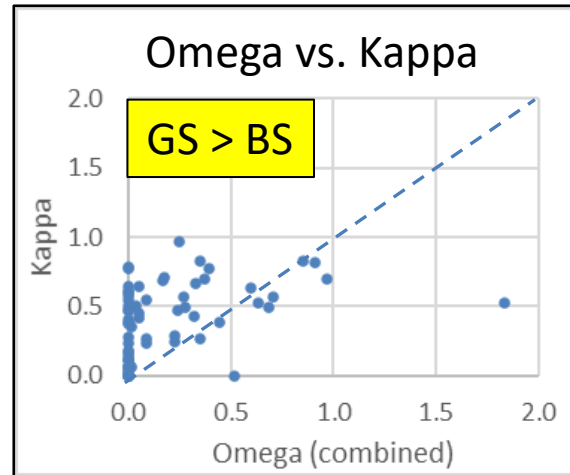
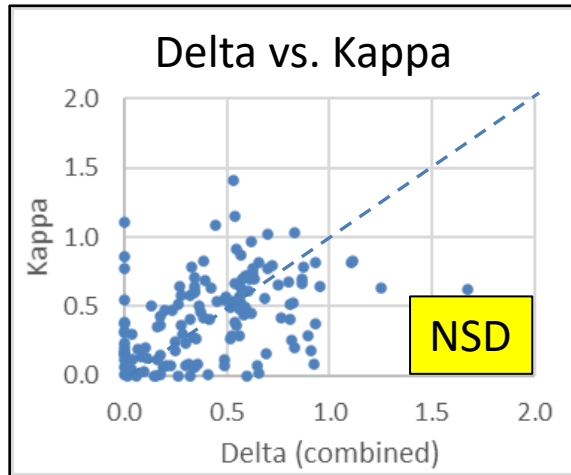
# Overland Runoff Reduction



	Overland Runoff					
Years (no. events)	2017-2023 (142)		2020-2023 (69)		2019-2023 (69)	
Swale	Delta	Kappa	Omega	Kappa	Epsilon	Zeta
Runoff (cm)	22.7	173.3	2.4	64.8	9.1	80.3

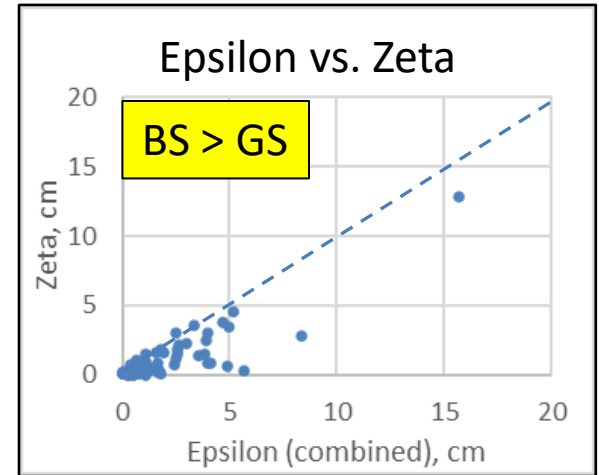
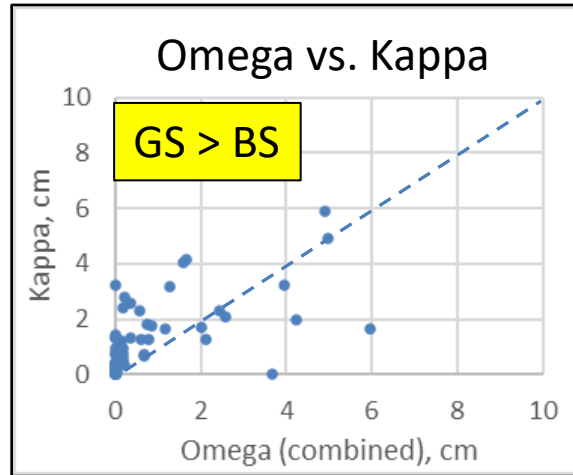
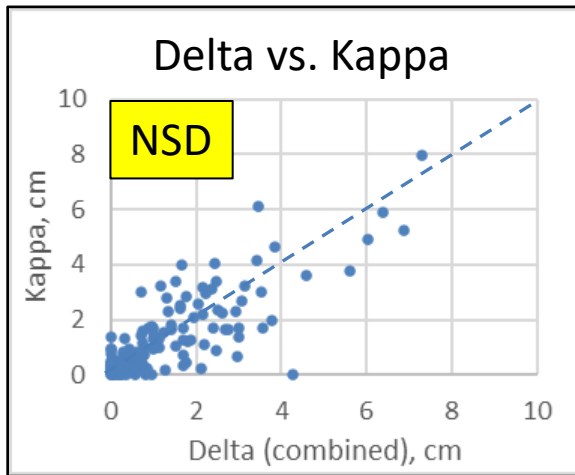
- Aggregated **overland runoff** from the bioswale mini-catchments was reduced by 87% to 96% relative to the grassed swale controls
- Dramatic reductions in **overland runoff** were attributed to soil infiltration in the bioretention areas

# Storm Runoff:Rainfall Ratios

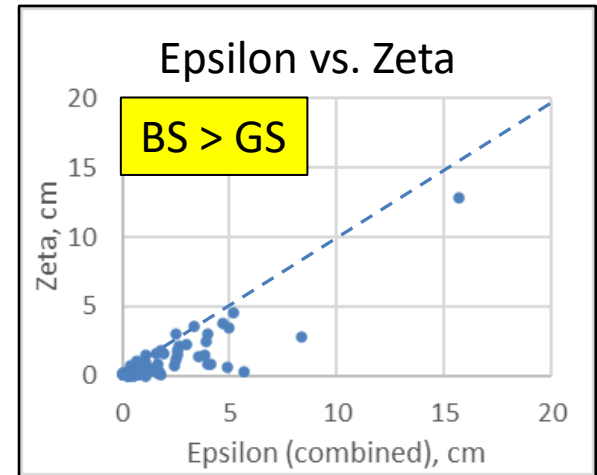
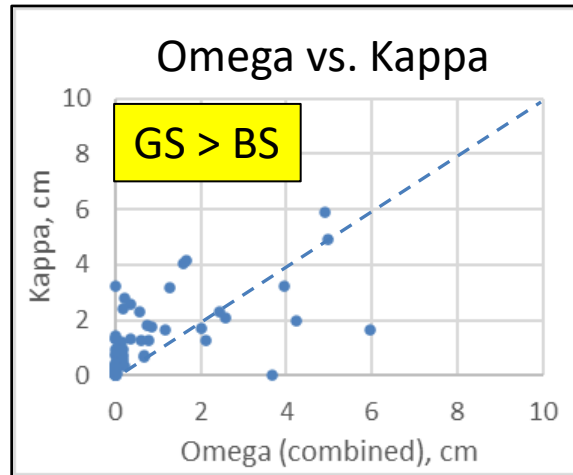
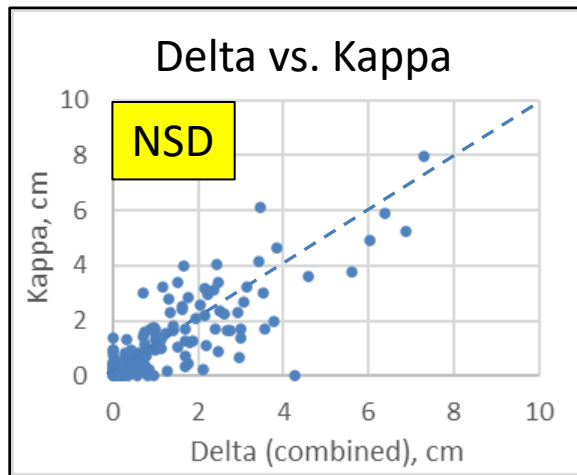


- Mixed results for ***storm runoff:rainfall ratios***
- All bioswales show an appreciable no. of events with ***storm runoff:rainfall = 0***
- Preponderance of values  $> 1$  at Epsilon suggests: 1) likely underestimation of mini-catchment area; or 2) systematic underdrain gaging errors

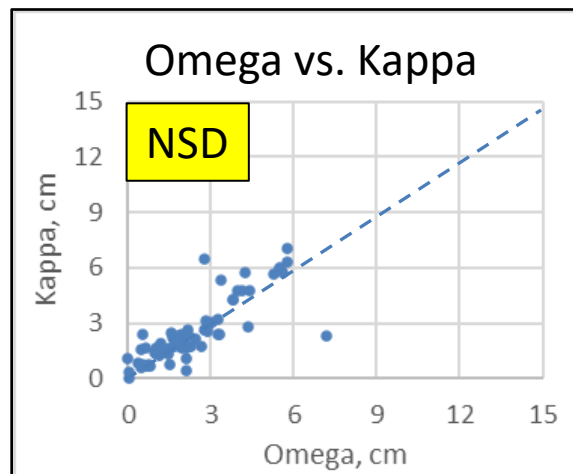
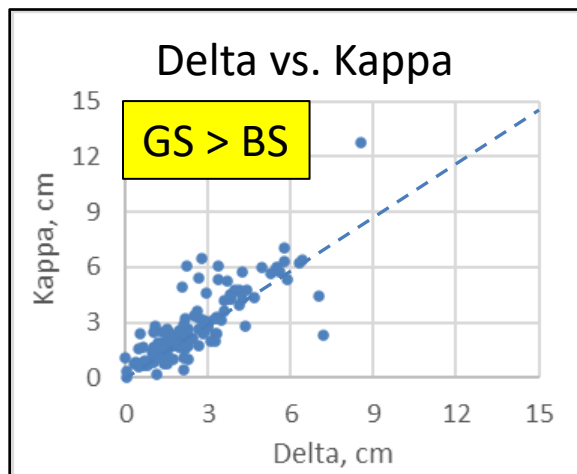
# Total Runoff Reduction



# Total Runoff Reduction



# Event Rainfall

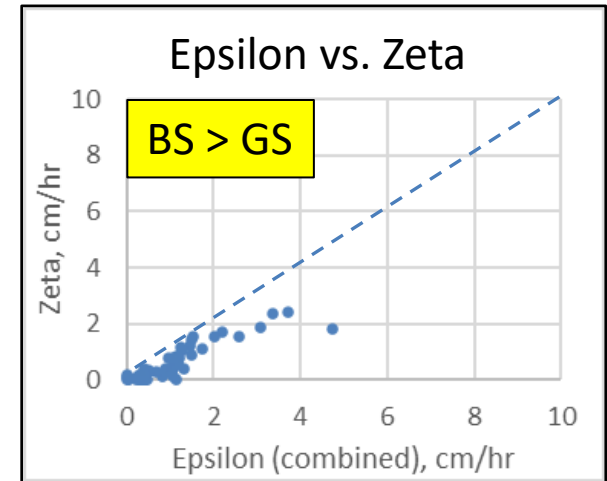
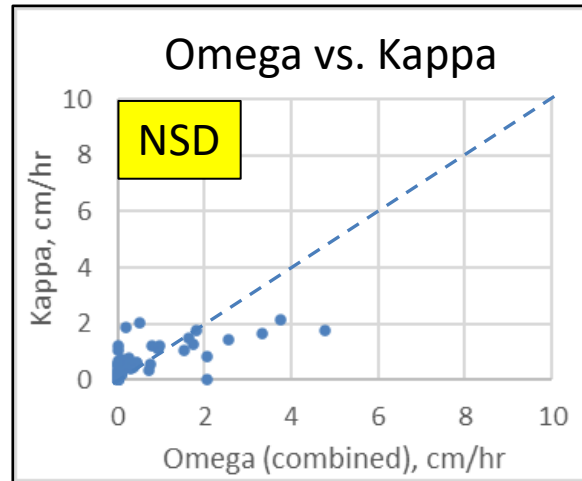
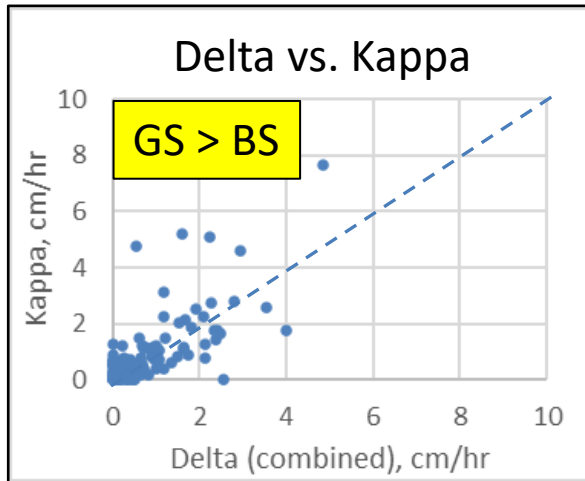


# Total Runoff Reduction

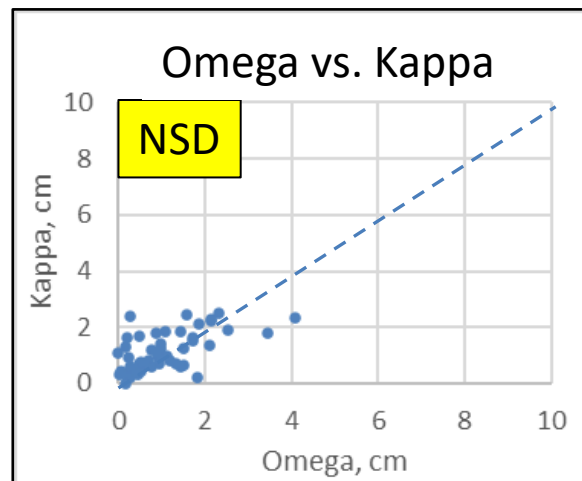
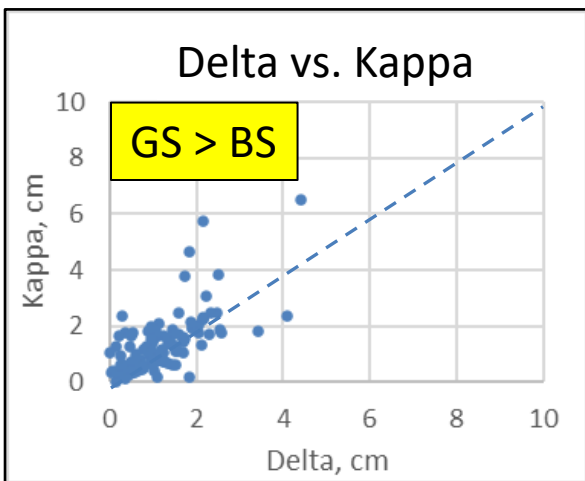
	Seasonal (Mar. – Oct.) Averages					
Swale	Delta	Kappa	Omega	Kappa	Epsilon	Zeta
Runoff (cm)	26.2	24.8	14.1	18.5	27.8	16.1
Underdrain runoff (cm)	23.0	-	13.4	-	26.6	-
Rainfall (cm)	49.8	56.6	45.0	48.5	34.9	34.9
Runoff: Rainfall	0.53	0.44	0.31	0.38	0.80	0.46

- ***Underdrain runoff*** was dominant (87–96% of total runoff) at all bioswales
- Greater variability in ***total runoff*** from bioswales than from grassed swales
  - *Omega*: 1) lower runoff than *Delta* (drier study period); and 2) only bioswale to show runoff reduction relative to grass swale
  - *Epsilon*: much higher runoff than either *Delta* or *Omega* (underestimation of catchment area or gaging errors?)
- Underestimation of catchment area has no effect on computed EMC's

# Peak Runoff

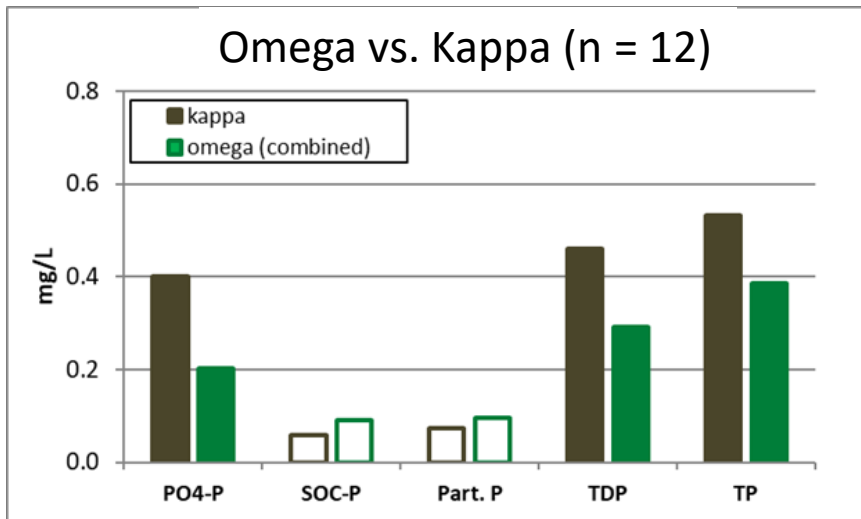
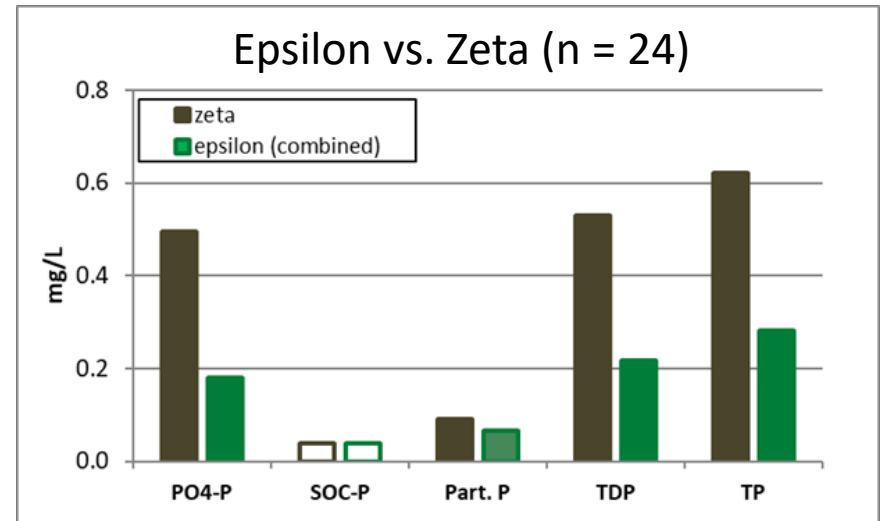
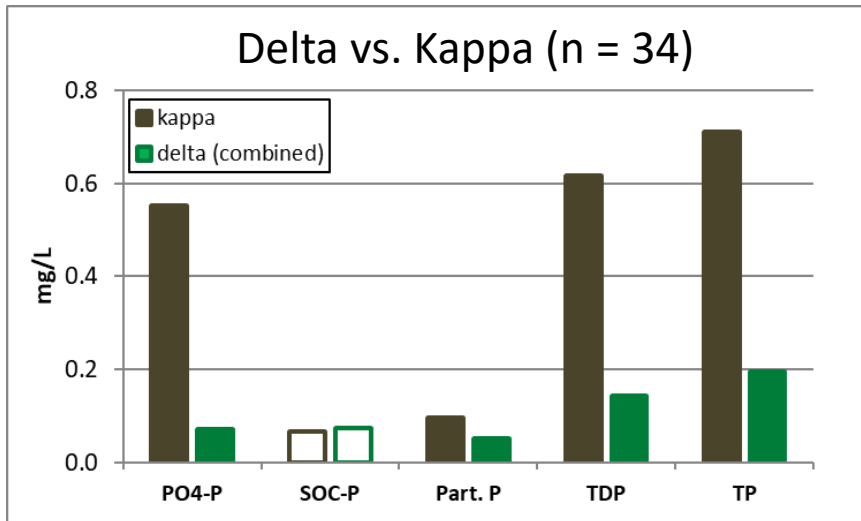


# Maximum hourly rainfall



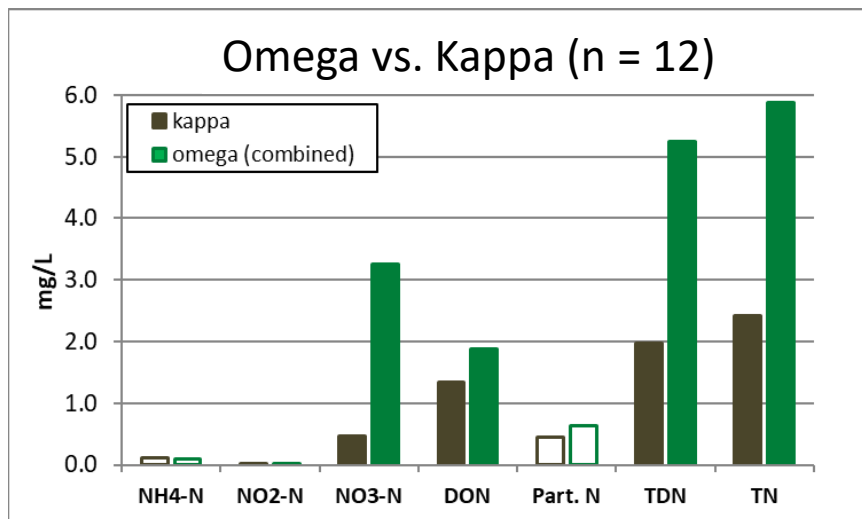
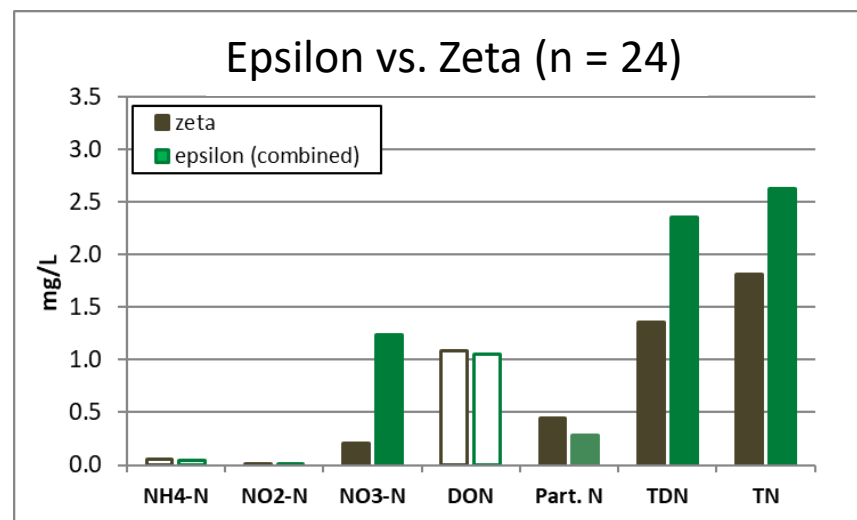
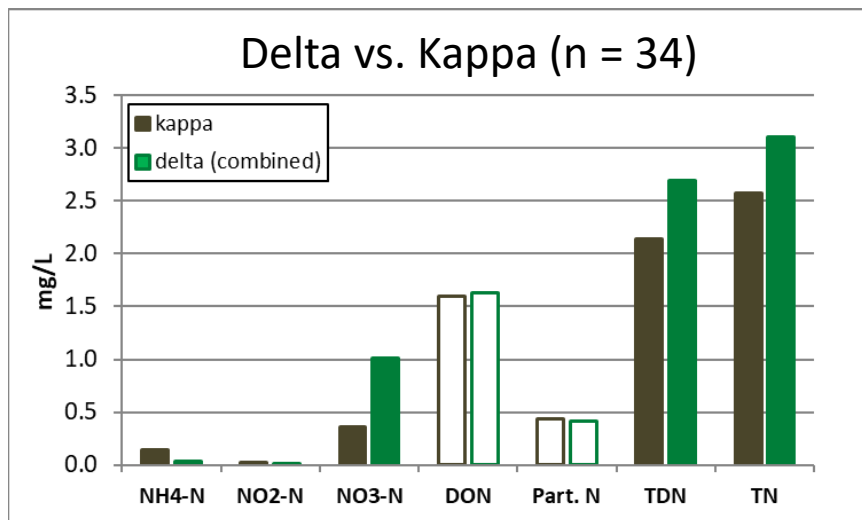
- Mixed results for **peak runoff**
- For the Delta bioswale, lower peak runoff is explained by lower maximum hourly rainfall

# Event Mean Concentrations (EMC's): *P*



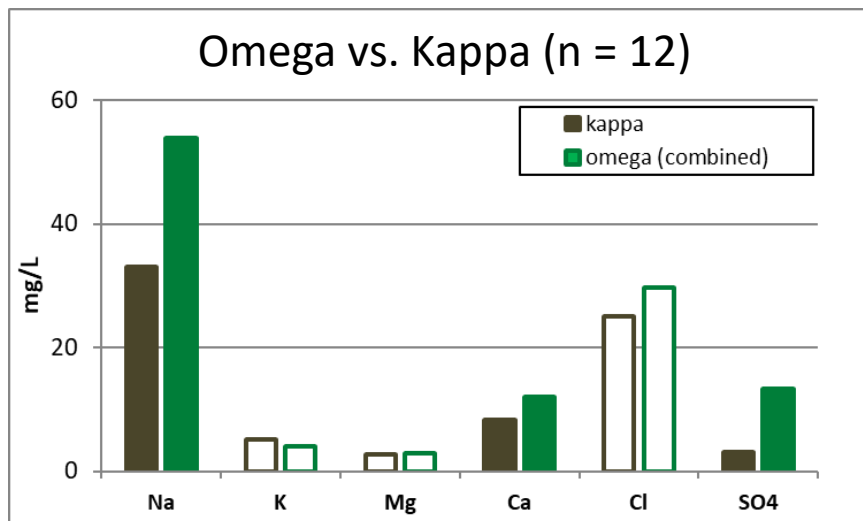
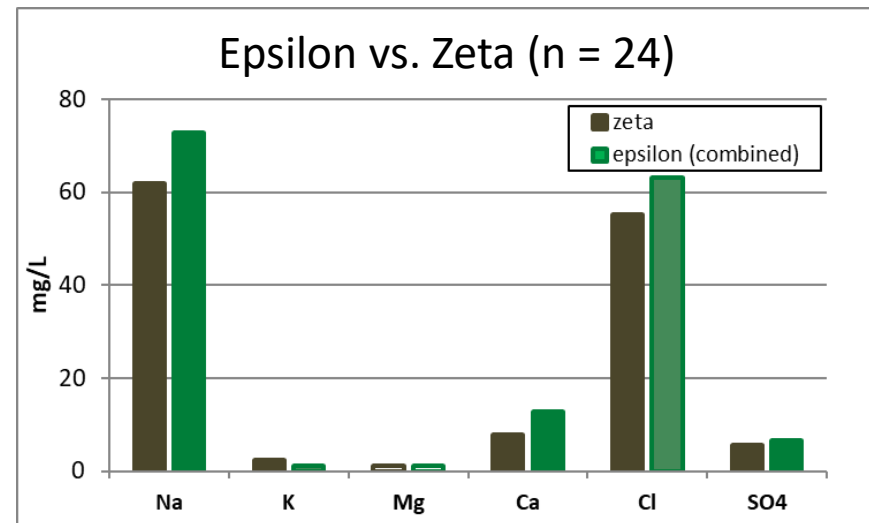
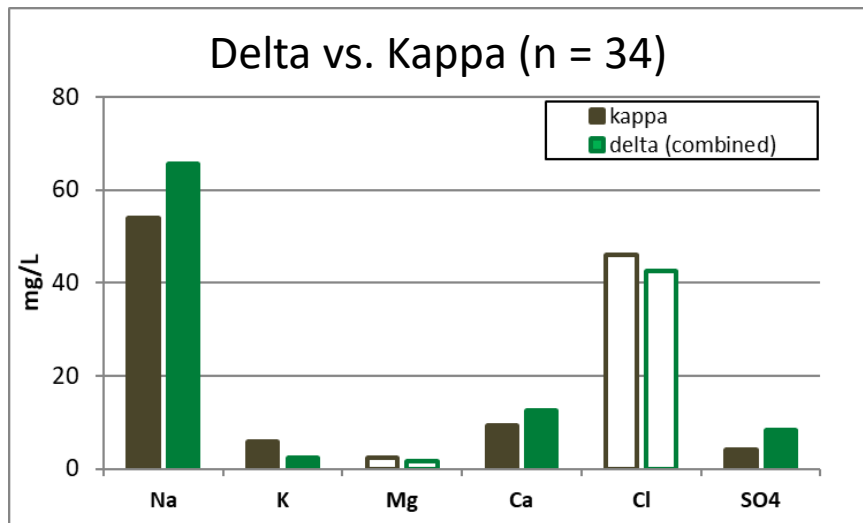
- $\text{PO}_4\text{-P}$  was the dominant form of P in runoff from all five swales
- Significant reductions in  $\text{PO}_4\text{-P}$  EMC's (50% - 87%) at bioswales: sorption onto Fe- and Al-oxides
- Reductions in TDP (37% - 77%) and TP (26% - 72%) EMC's

# Event Mean Concentrations (EMC's): *N*



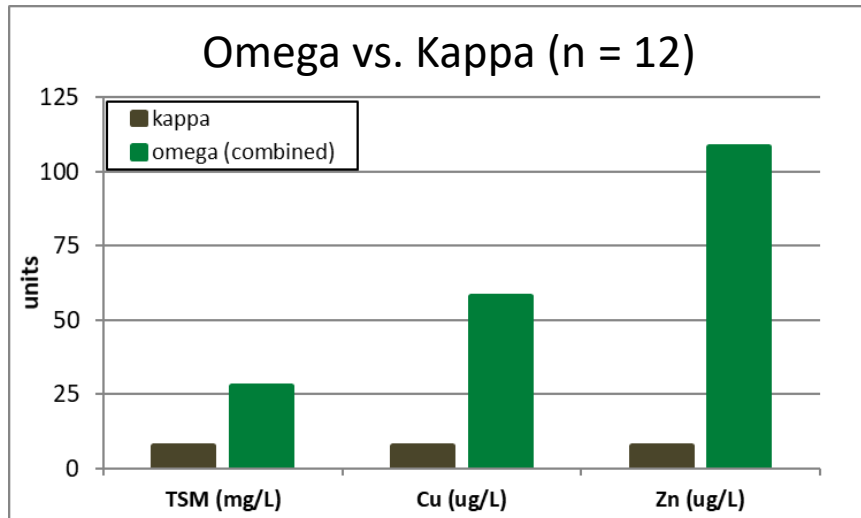
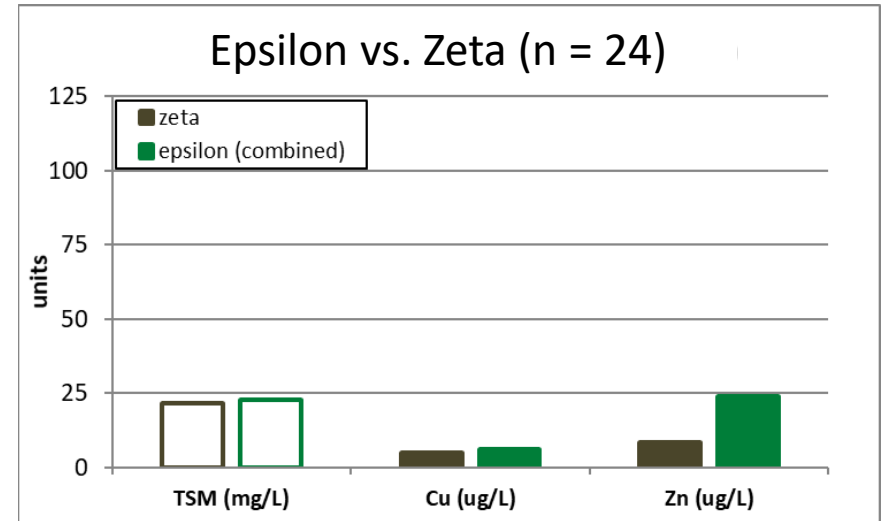
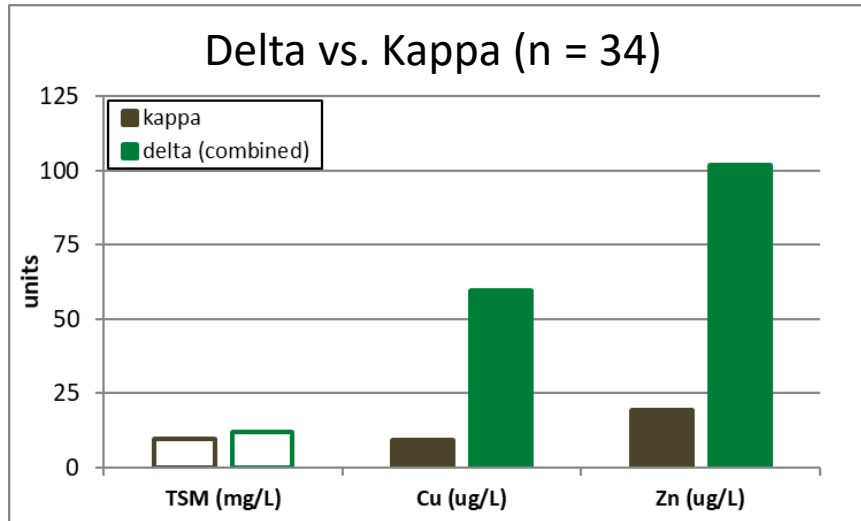
- Bioswales are a significant **source** of NO<sub>3</sub>-N, TDN, and TN
- NO<sub>3</sub>-N EMC's in bioswale runoff were higher by factors of 3 – 7
- Source: nitrification and flushing from biosoils
- Omega > Delta N EMC's: less flushing?

# Event Mean Concentrations (EMC's): *Major Ions*



- Based on higher EMC's, bioswales are **sources** of some major ions: Na, Ca, SO<sub>4</sub>
- Role of cation exchange and/or, enhanced mineral weathering in biosoils and/or underdrain materials (limestone gravels)

# Event Mean Concentrations (EMC's): *Other Pollutants*



- No evidence of any reduction in TSM concentrations by bioswales
- Possibly due to short-circuiting of bioretention areas through broken/modified clean-outs (“bio-passing”?)
- Enhanced ***leaching of trace metals*** from biosoils

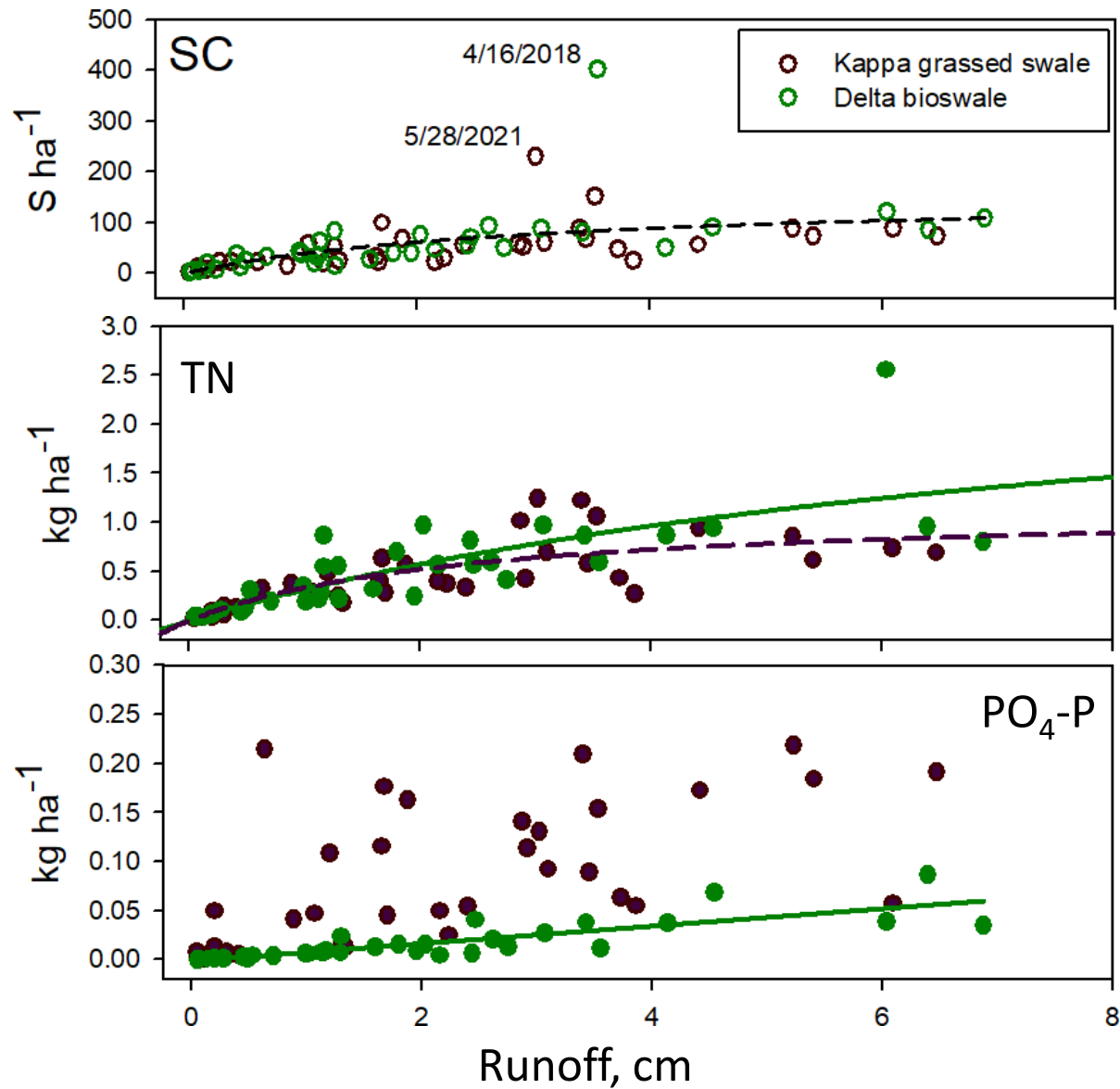
# Damage to/modification of underdrain clean-outs?



# “Synoptic” EMC’s: 4/28/23 event

Constituent	BS (n=7)	Delta	Omega	GS (n=12)	Kappa
Na	<b>39.0</b>	28.1	27.9	<b>27.5</b>	35.6
Mg	1.1	2.4	3.9	0.9	3.9
Ca	<b>10.7</b>	6.5	5.6	<b>7.3</b>	10.4
Cl	10.2	5.1	3.4	7.2	8.3
SO <sub>4</sub>	<b>7.2</b>	3.5	7.1	<b>1.8</b>	2.2
Cu	<b>29.6</b>	36.7	42.5	<b>6.2</b>	7.4
Zn	<b>35.0</b>	42.8	61.8	<b>8.6</b>	7.0
PO <sub>4</sub> -P	<b>0.14</b>	0.08	0.20	<b>0.23</b>	0.23
Part. P	0.05	0.05	0.16	0.07	0.08
TDP	0.19	0.13	0.29	0.26	0.26
TP	<b>0.24</b>	0.18	0.46	<b>0.34</b>	0.34
NO <sub>3</sub> -N	<b>0.82</b>	0.55	0.87	<b>0.01</b>	0.00
Part. N	<b>0.22</b>	0.21	0.71	<b>0.40</b>	0.39
TDN	<b>2.12</b>	1.78	2.83	<b>1.10</b>	1.02
TN	2.34	1.98	3.55	1.50	1.41

# Event Loads



# Summary

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- Paired mini-catchment design is able to quantify differences in hydrologic pathways and relative stormwater treatment effectiveness
- Major hydrologic differences are soil infiltration capacity, overland runoff, and underdrainage
- Greater abstraction and detention of highway stormwater runoff through biosoil infiltration—relative to the grassed swale control—was not achieved with the present bioswale design
- Major weakness is the hyper-efficient underdrain system
- Bioswales reduced P EMC's by 50%-90% relative to the grassed swales
- No reductions in either N or TSM were observed
- Evidence of trace metal leaching by percolating stormwater
- Synoptic stormwater sampling—while logistically tricky—can provide useful information for evaluating swale performance
- Is “bioretention” a misnomer?

# Acknowledgments

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- Funding
  - MDOT, State Highway Administration, Highway Hydraulics and Water Programs Divisions (2013-2022)
  - Chesapeake Bay Trust Restoration Research Program (2022-2025)
- Laboratory assistance
  - Katie Kline
  - Jim Garlitz
  - Nancy Castro
  - Joe Accord
  - Stephanie Siemek
  - Ev Demott
  - Briana Rice
  - Trevor Frissell
- Field support
  - Ian Smith
  - Briana Rice
  - Trevor Frissell

# Translation Slides

What are the take home points?  
What does this mean for me?

Translation Slides by Bel Martinez da Matta  
Maryland Department of the Environment  
Watershed Protection, Restoration, and Planning Program

# What does this mean for me?

- Bioswales are effective in enhancing infiltration compared to grass swales, but this not necessarily represent effective water quality treatment
- Lack of maintenance can highly impact BMP performance
- Multi-year studies are very important to capture the range of weather conditions in the region
- Less expensive and complex instrumentation does not necessarily mean less accurate/representative data.

# What does this mean for me?

## What do I take from this if I am a practitioner:

- BMP design considerations are important, since the material used can result in increased pollutant loads.
- Opportunity to think about redesigning bioswales to address the increased loads observed in the results.

## What do I take from this if I am a regulator:

- There is no one size fits all → best BMP type should take into consideration the main issue to be tackled within the catchment.
- More research is needed to understand the trade-offs of different BMP types to help inform guidance documents on recommended practices.