NC STATE UNIVERSITY

Monitoring Stormwater Control Measures: Ouch's and All-Right's!

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STAC Workshop, Fairfax, VA

www.bae.ncsu.edu/stormwater

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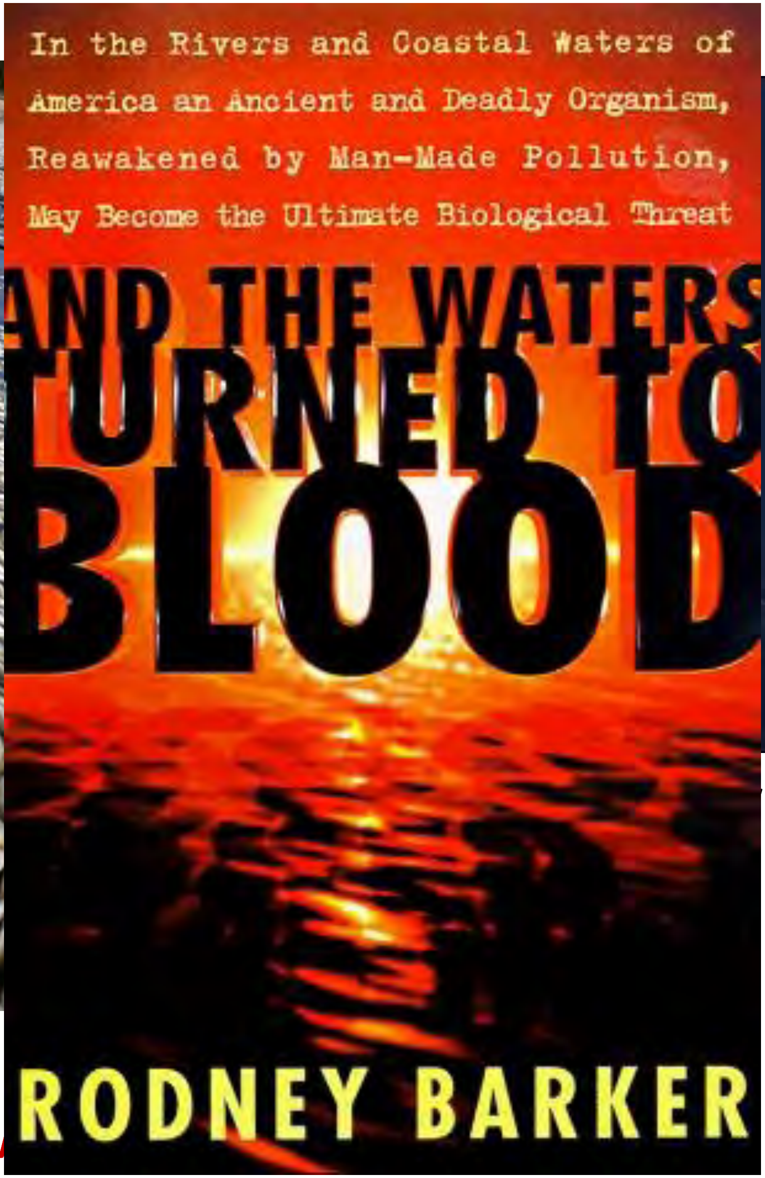
ENGINEERING

Turn Back Time 18 Years Ago



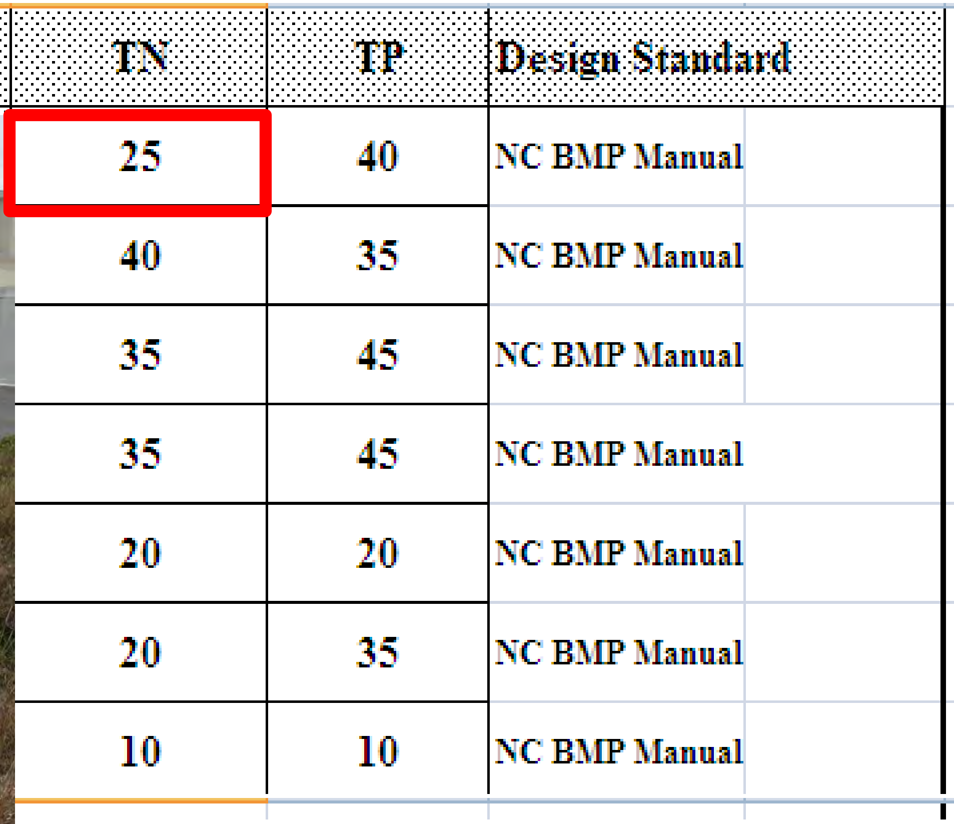
inchester Sun

State of North Carolina’s Reaction

- Require Designers to Use Stormwater Control Measures (called Best Management Practices, or BMPs)
  - Remove Nitrogen & Phosphorus
- Assigned Performance Rates based upon, shall we say, educated guesses.

So, 10 lb N into a wet pond…

- Would yield 7.5 lb Out.



TN	TP	Design Standard
25	40	NC BMP Manual
40	35	NC BMP Manual
35	45	NC BMP Manual
35	45	NC BMP Manual
20	20	NC BMP Manual
20	35	NC BMP Manual
10	10	NC BMP Manual

Why **Knowing** How Well an SCM works is Important…

Bioretention

Permeable Pavement

Green Roofs

Rainwater

Many Opportunities for a University

- Verifying/ Refining “Percent Removal” rates?
- Understanding Hydrology
- Improving Design, Construction & Maintenance Standards for better performance
- Defining Other Metrics for Evaluation

‘Consequence’ of Data

Close Examination of 4 Permeable Pavement Types (Collins et al. 2008)

Kinston, NC

- Pervious Concrete
- CGP – filled with sand
- PICP filled with pea gravel – 13% voids
- PICP filled with pea gravel – 7% voids
- Compared to Asphalt

A ‘crazy’ monitoring set-up

Percent Runoff Reduction Relative to Rainfall

Pavement Type	Mean	Median	Minimum
Standard Asphalt	34.6%	29.4%	~0%
Pervious Concrete	99.9%	99.9%	99.0%
PICP – Type 1	99.3%	99.4%	97.8%
PICP – Type 2	99.5%	99.7%	96.9%
Concrete Grid Pavement (Sand)	98.2%	98.7%	91.1%

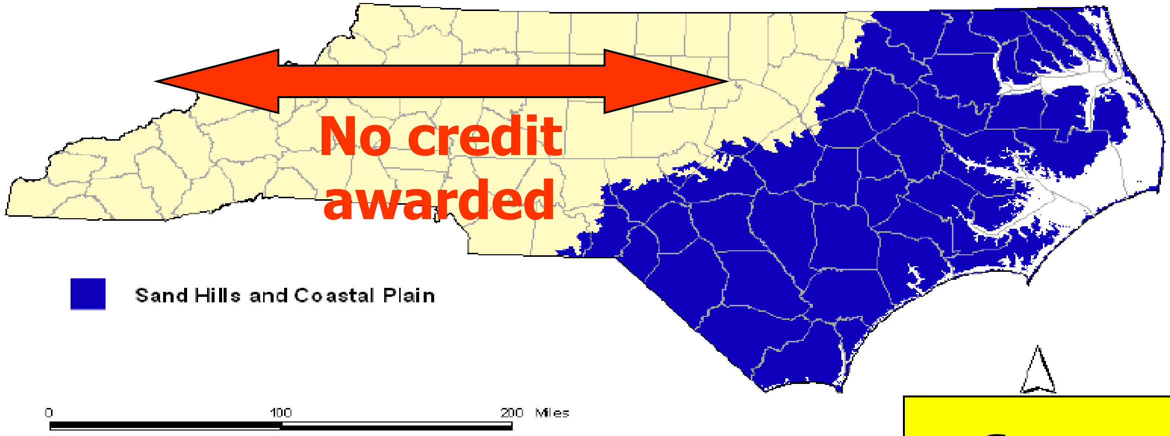
From Collins et al., 2008

Similar Results found in Washington State (Brattebo and Booth, 2003)

#1: Statewide Use and Credit

Before:

Credit awarded



No credit awarded

+ 0.52 in/hr soil infiltration

After: Credit awarded state-wide but design allowances must be made for differing soil permeabilities.

#2: More BUA Credit Awarded

Before: Permeable pavement received a BUA credit as 60% or 40% pervious depending on the type of pavement and the depth of the aggregate.

After: Permeable pavement will receive BUA credit based on the soils, not the location of the pavement.

Why?
This is a more accurate way to estimate the effectiveness of permeable pavement.

Pollutant Removal Credits

Infiltrating systems:

85%	TSS
30%	Total Nitrogen
35%	Total Phosphorus

Why?

The research data supports pollutant removal credit.

Detention systems (explained in a minute):

70%	TSS with an impermeable liner
85%	TSS with no liner
10%	Total Nitrogen
10%	Total Phosphorus

Current Stormwater Regulations

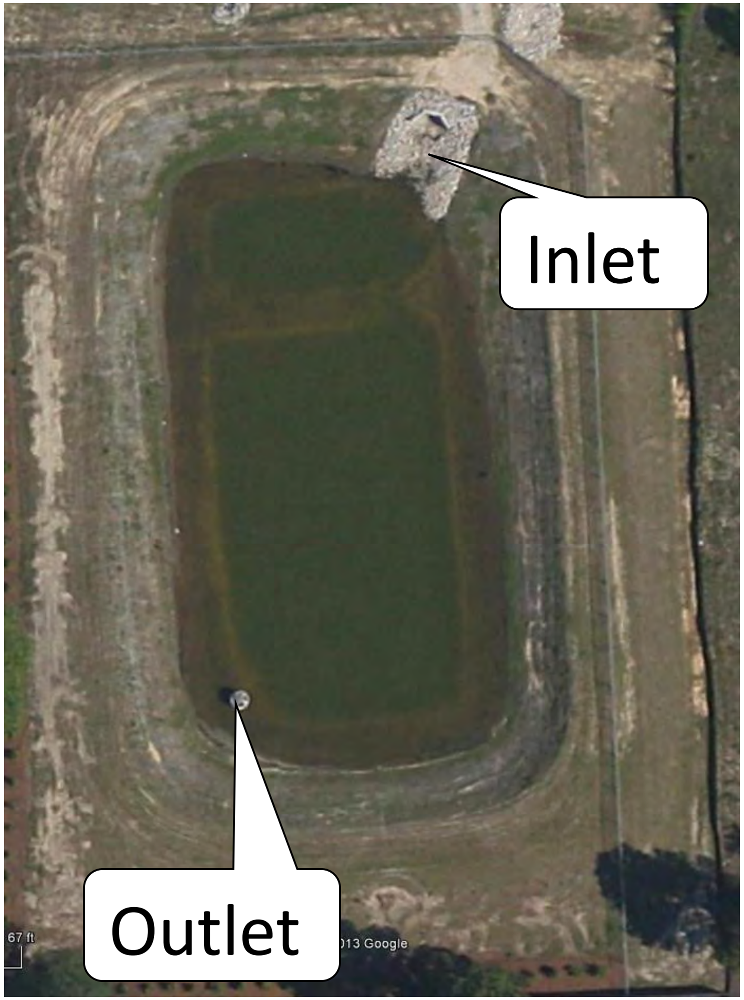
Image from USGS

Falls Lake Watershed

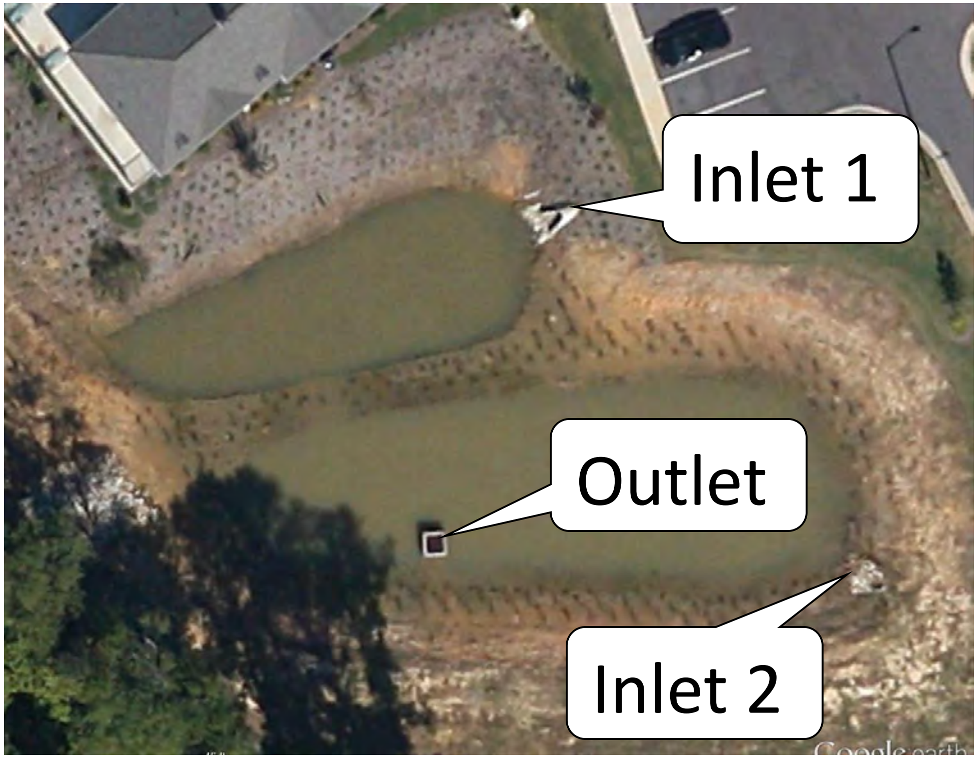
- Nutrient management strategy: new development
  - ✓ Control & treat first flush (first 25 mm of rainfall)
  - ✓ No peak flow increase at 1-yr, 24-hr storm
  - ✓ Nitrogen: 2.5 kg/ha-yr (TMDL)
  - ✓ Phosphorus: 0.35 kg/ha-yr (TMDL)

Single SCM Monitoring, e.g., Infiltrating Wet Pond

Bingham Station



Raeford Crossing Apartments



Images from Google Earth

Water Budget

$$V_i + \sum_{i=1}^{n} (V_{in} + P - V_{out} - E - F)_i = \mathrm{V}_\mathrm{f}$$

$\mathrm{V_i}$ = Initial volume
$\mathrm{V_{in}}$ = Inflow volume
P = Rainfall on pond
$\mathrm{V_{Out}}$ = Outflow volume
E = Evaporation
F = Infiltration
$\mathrm{V_f}$ = Final volume

Methods

- Influent/Effluent Flow Rates and Volumes - ISCO 6712 Automated samplers with Area Velocity Meter or compound weirs
- Rainfall and Intensity – manual and tipping bucket rain gauge
- Evaporation - ET gage atmometer model E with #30 turfgrass reference ET cover (Allen et al., 1998)
- Storage Volume - Hobo U20 - water level logger

Water Quality

- Flow-proportional, composite samples using ISCO samplers
- Nutrients (TKN, TAN, NO_x, TN, OrthoP, and TP) and Total Suspended Solids (TSS)

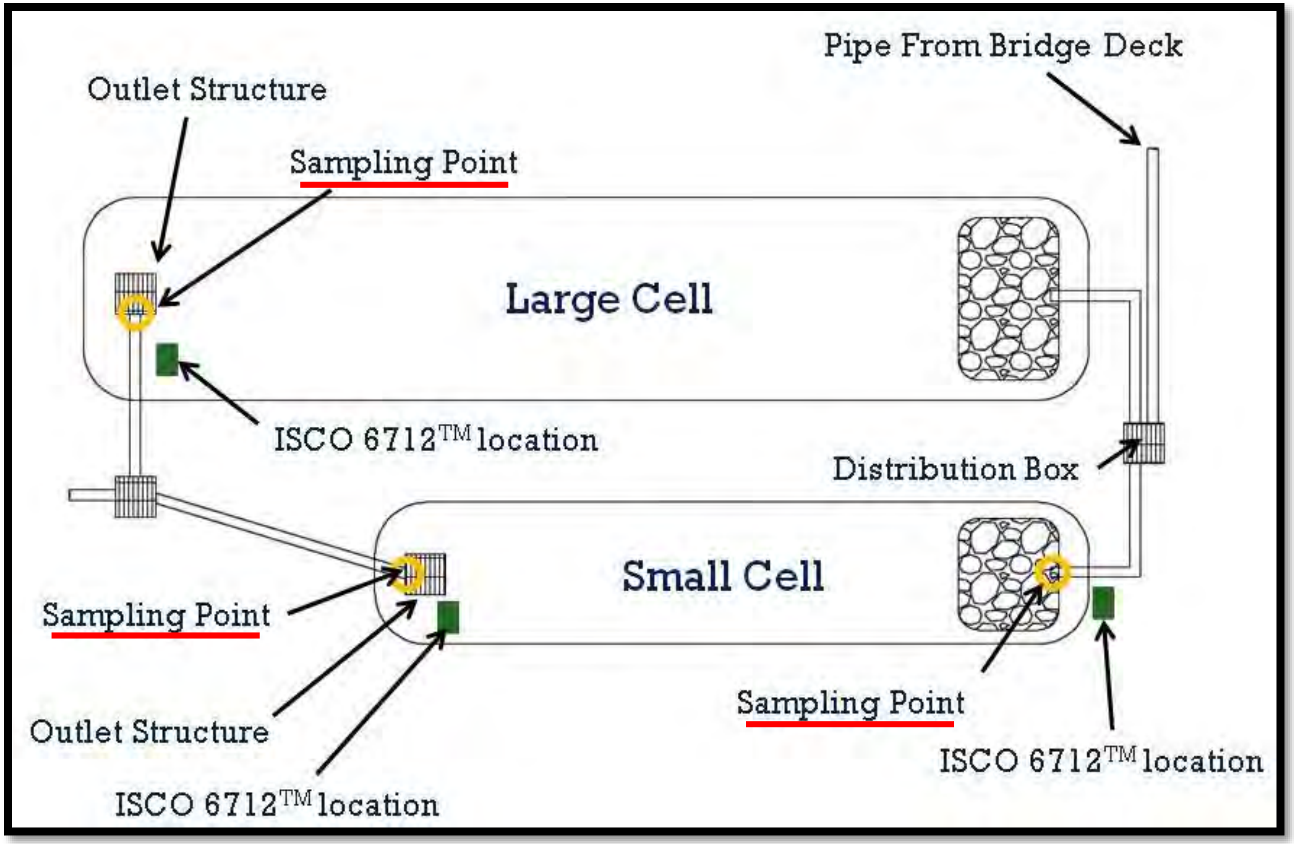
Monitoring Bioretention

Bioretention Cells

- Contributing drainage area:
  - 0.4 ha (0.98 ac)
- Centipede grass sod

- Large Cell SA: 188 m^2 (2020 ft^2)
  - Captured 2.5 cm (1 in) event
- Small Cell SA: 101 m^2 (1090 ft^2)
  - Captured 0.8 cm (0.3 in) event

Sampling Locations



Swale

- Contributing drainage area:
  - 0.46 ha (1.13 acres)
- 2% centerline slope
- Centerline length: 37 m (120 ft)
- 8:1 side slope
- V-shaped geometry

Water Quality Sampling

- Flow proportional, composite water quality
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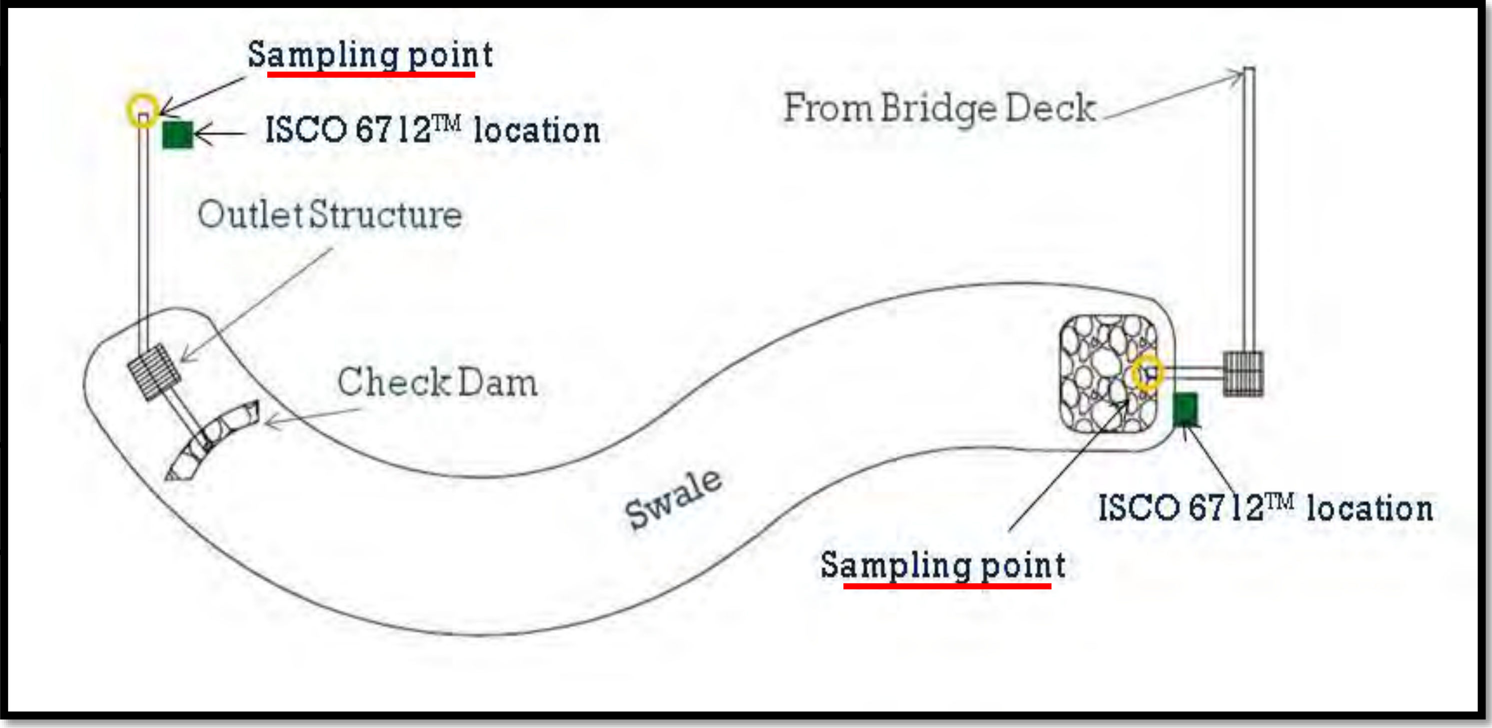
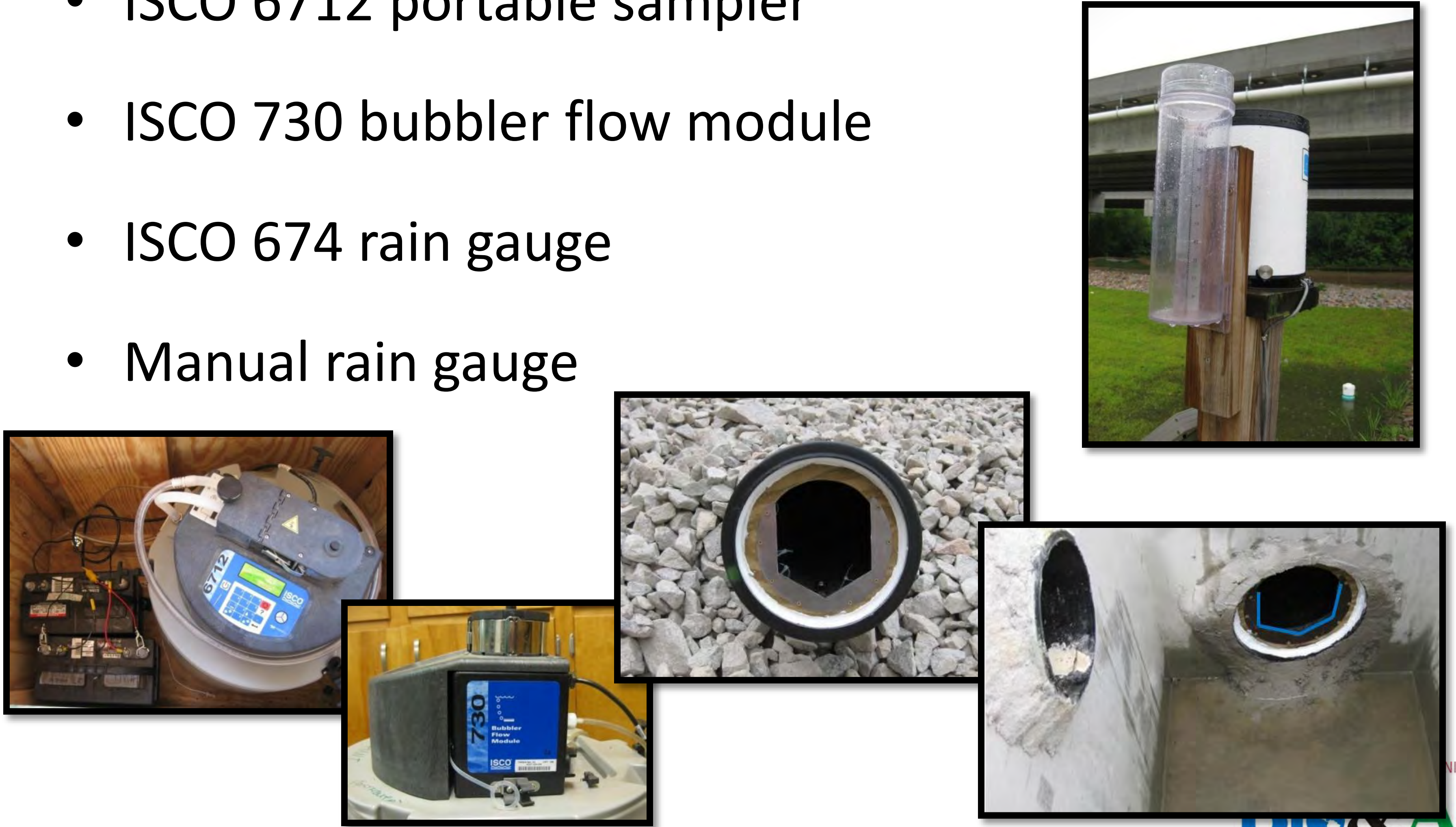
  SC
- W
  -
  -



Monitoring Equipment

- ISCO 6712 portable sampler
- ISCO 730 bubbler flow module
- ISCO 674 rain gauge
- Manual rain gauge



Monitoring Challenges

- Accuracy-related issues associated with hydrology:
  - Turbulent flow
  - Backwater cond
  - Pressurized flow

Bioretention

Swale

→ Inaccurate wate

Monitoring Challenges

- Result:
  - Bioretention inflow volumes calculated using the Initial Abstraction method (Pandit and Heck, 2009)
  - Bioretention influent peak flowrates calculated using Rational Method (Haan et al., 1994)
  - Swale hydrologic data:
    - mostly unreliable
    - assumed inflow=outflow

We had to survey the Bridge!

Verifying Inflow

Objective

LID vs. Traditional Development

- **Hydrology** (Runoff volume, runoff coefficient, lag times, peak flow)
- **Water quality** (nutrient concentrations, nutrient loadings)
- Compare values to Falls Lake standards

Site Layout

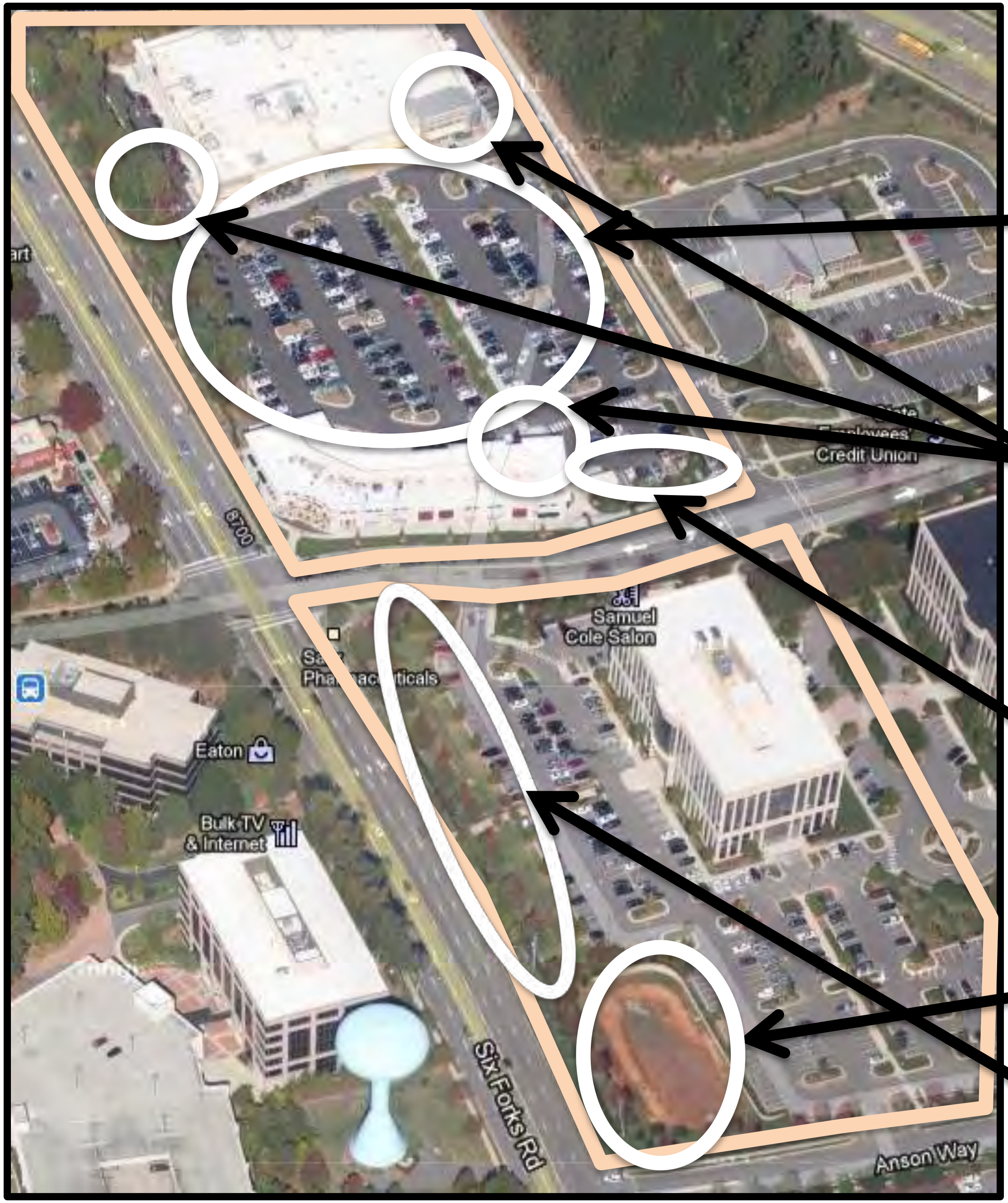
LID Site

- 2.5 hectares
- 84% DCIA

Traditional Site

- 2.8 hectares
- 61% DCIA

Site Layout



Underground detention/infiltration system

Cisterns
- Toilet flushing
- Irrigation

Bioretention/swale pretreatment

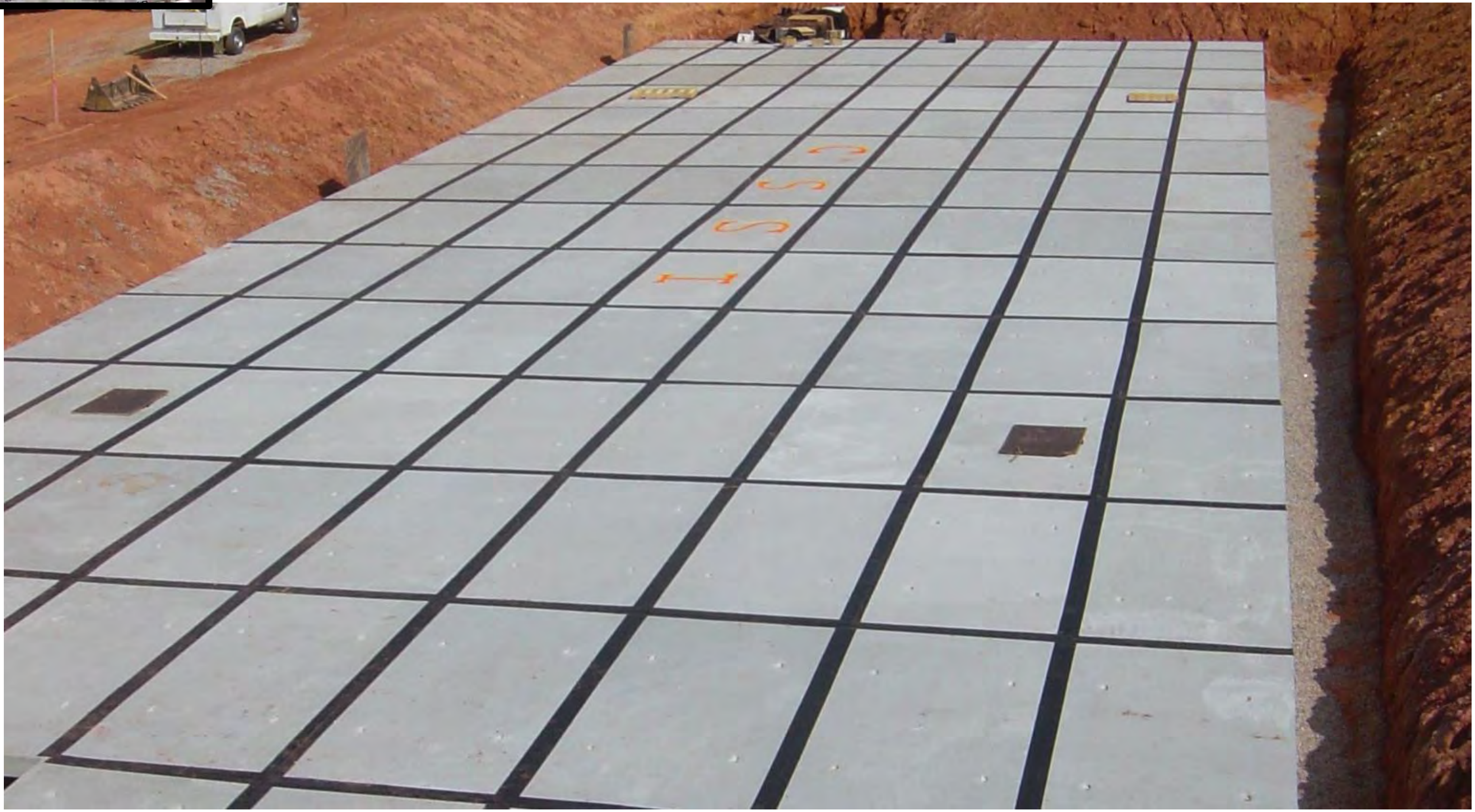
Dry Detention

Pretreatment swales

LID: Pretreatment

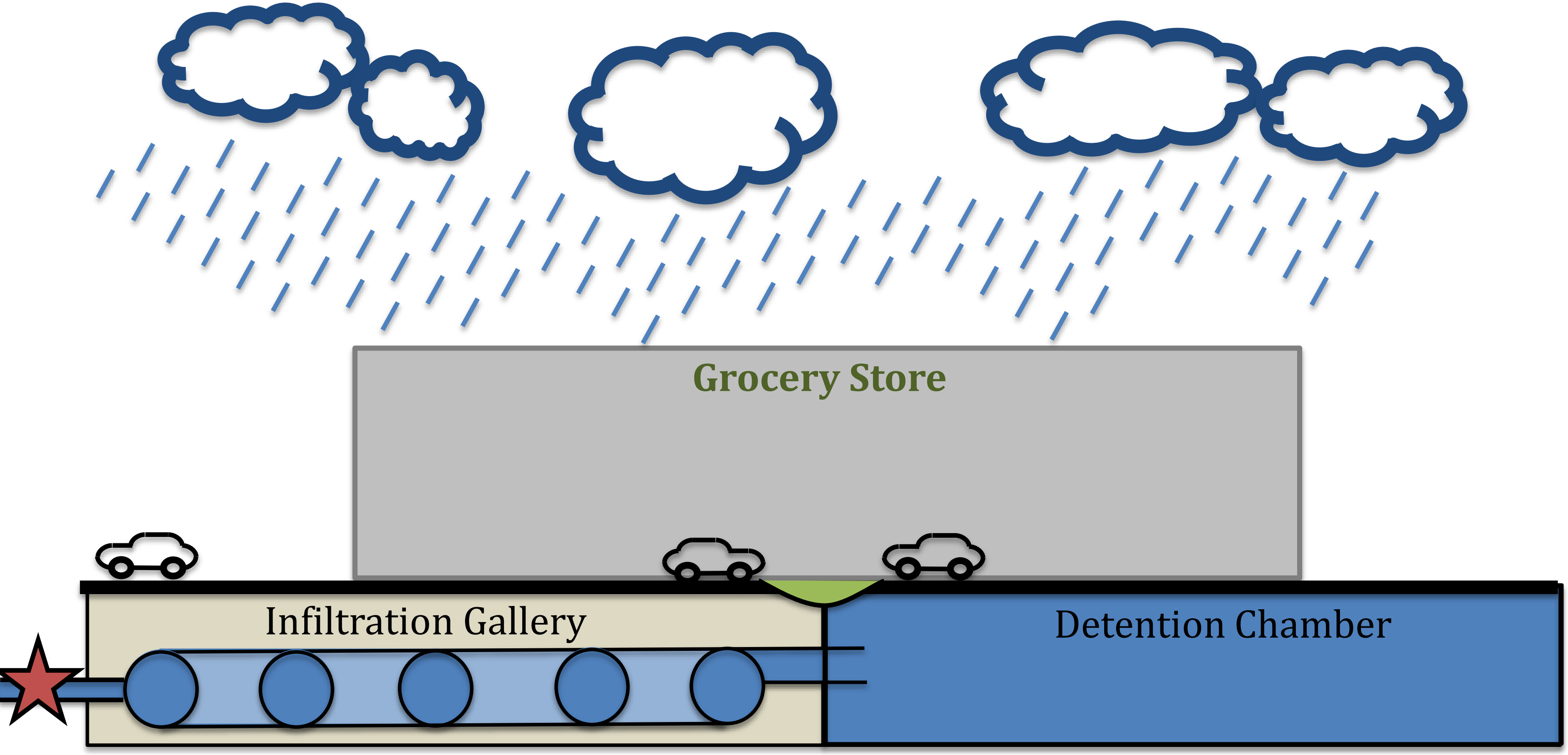
Underground Detention

Underground Detention



Underground Infiltration

LID Site



(not to scale)

Traditional Site: Pretreatment

Traditional Site: Perimeter Swale

Traditional Site: Dry Pond

LID Monitoring

Water Quantity

- Weir, AV meter, ISCO 6712

Water Quality

- Nitrogen
  - TN, TKN, NH_4-N, NO_{2+3}-N
- Phosphorus
  - TP, PO_4^{3-}
- Total Suspended Solids (TSS)

Dry Detention Monitoring

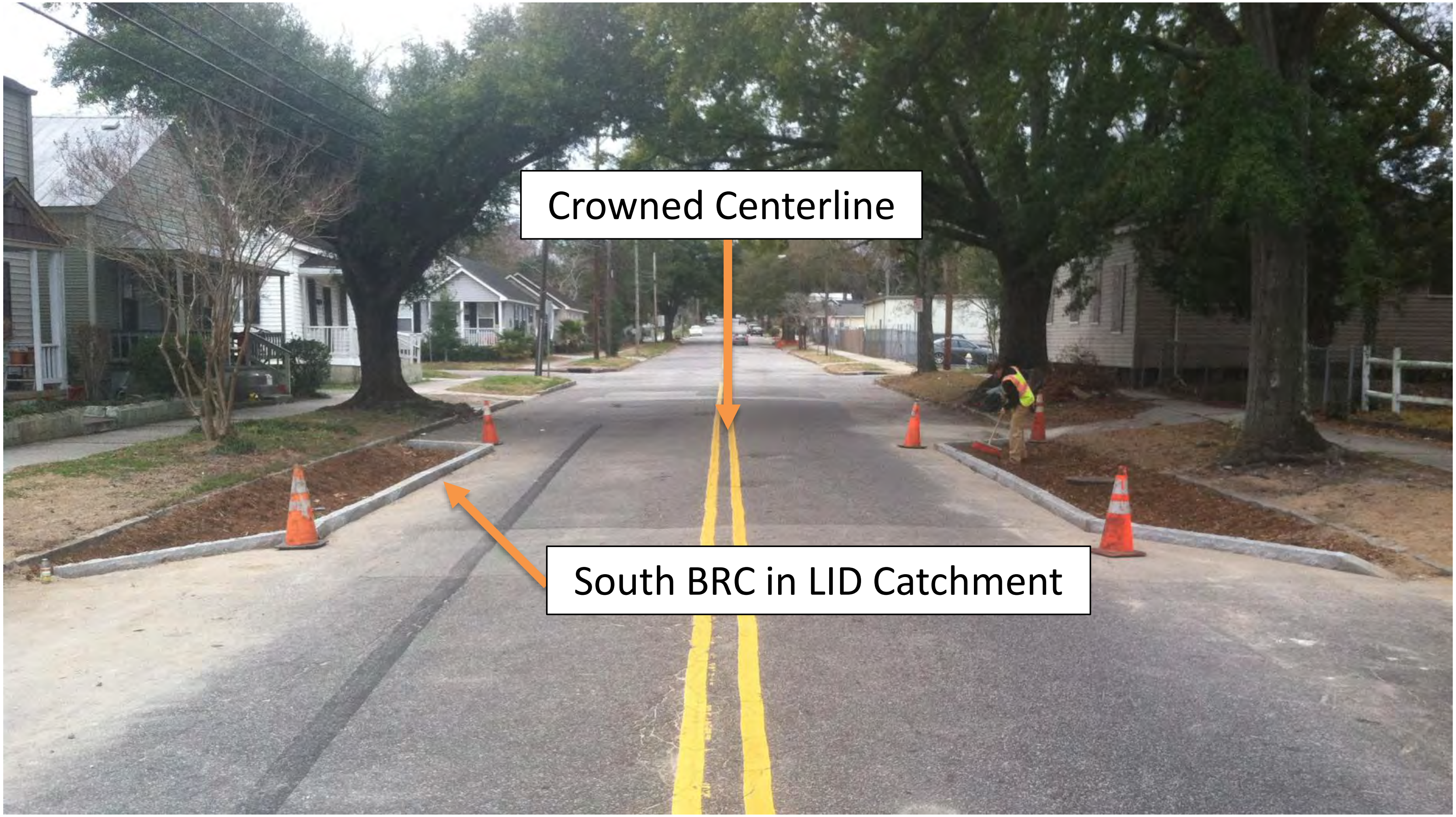
Materials and Methods

New Hanover County Orthophoto

Drainage Area Properties

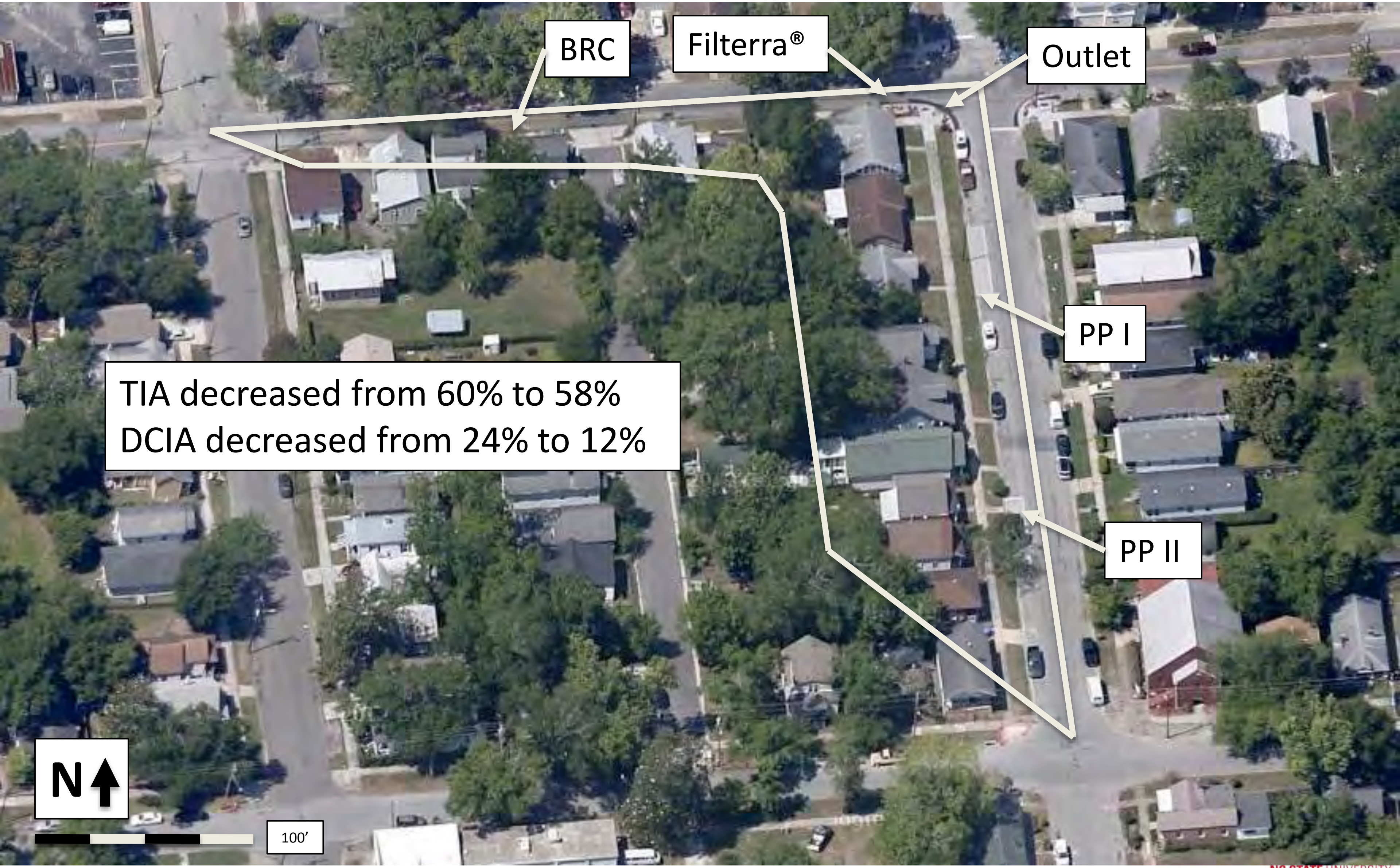
Parameter	Catchment	
	LID	Control
Drainage Area (m^2) (%)	5,300 (0.53 ha)	3,480 (0.35 ha)
Total Impervious Area (TIA)	3,180 (60%) ←	2,088 (60%) ←
Street Surface (DCIA)	1,278 (24%) ←	557 (16%) ←
Rooftop	1,378 (26%)	1218 (35%)
Sidewalk	530 (10%)	313 (9%)
Open Space	2,120 (40%)	1,392 (40%)
Slope	0.5%	0.7%
Soil Series	Baymeade Urban	Leon Urban
USDA Soil Class	PSA: 98% → Sand	PSA: 95% → Sand
Receiving Water Body	Burnt Mill Creek: 303 (d) List, toxicity and sedimentation	
River Basin	Cape Fear	

SCMs: Construction: BRCs



SCMs: Permeable Pavement

SCMs: Filterra® Unit



TIA decreased from 60% to 58%
DCIA decreased from 24% to 12%

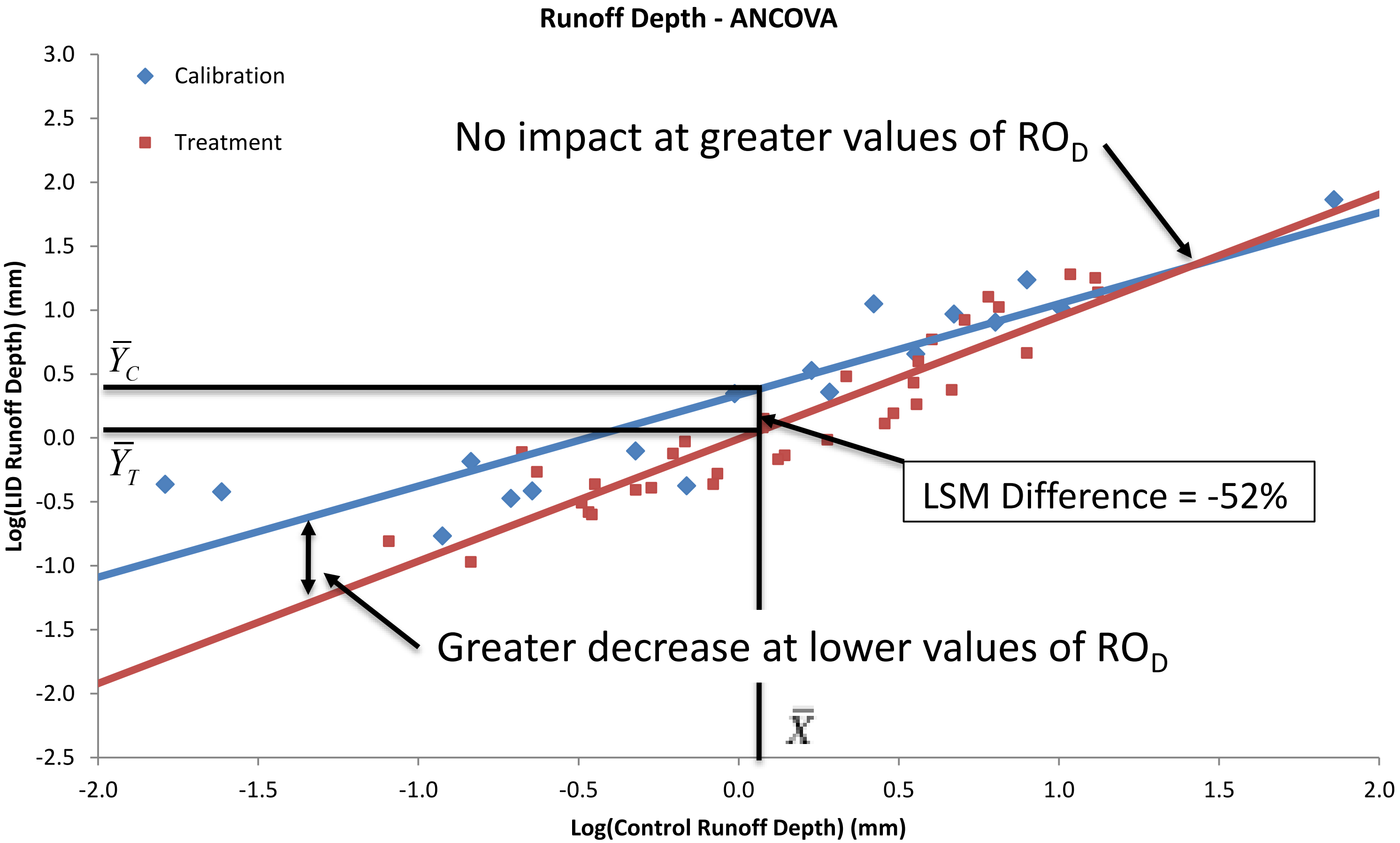
Photo Credit: Google Earth

Monitoring Design

- Paired watershed study[1,2]
  - Two watersheds, two monitoring periods
  - Analysis of covariance (ANCOVA)
  - Least Squared Means (LSM)
  - Quantify change
- Data Collection
  - V-notch weirs and weir boxes
  - Record stage: Q_P, T_L, RO_D and C_R
  - Flow-weighted water quality samples collected: TSS, TKN, TAN, $NO_{2\text{-}3}$-N, TP, O-PO_4^{3-}, Cu, Pb, Zn

[1]Clausen and Spooner, 1993; [2]Grabow et al., 1999

Results: Runoff Depth (RO_D)



No impact at greater values of RO_D

LSM Difference = -52%

Greater decrease at lower values of RO_D

Results: Water Quality

Nutrient and sediment concentration summary (mg/L)

Station	Dur. (yr)	n[a]	TKN	TAN	$NO_{2,3}$-N	TSS	$O\text{-}PO_4^{3-}$	TP
Control	1.14	25						
Mean			1.92	0.20	0.25	53	0.23	0.44
Median			1.14	0.06	0.14	42	0.10	0.22
LID-Calibration	0.47	9						
Mean			1.52	0.07	0.30			
Median			1.35	0.04	→ 0.26	54	0.11	0.21
LID-Treatment	0.67	16						
Mean			0.66	0.04	0.18	11	0.12	0.21
Median			0.45	0.03	→ 0.07	7	0.10	0.17
LSM Difference			**-62%***	**0%**	**0%**	**-82%[T]***	**-54%[S]***	**-38%***

Control median $NO_{2,3}$-N conc. decreased from 0.36 to 0.12 mg/L

*Statistically significant change

[T] Paired t-test

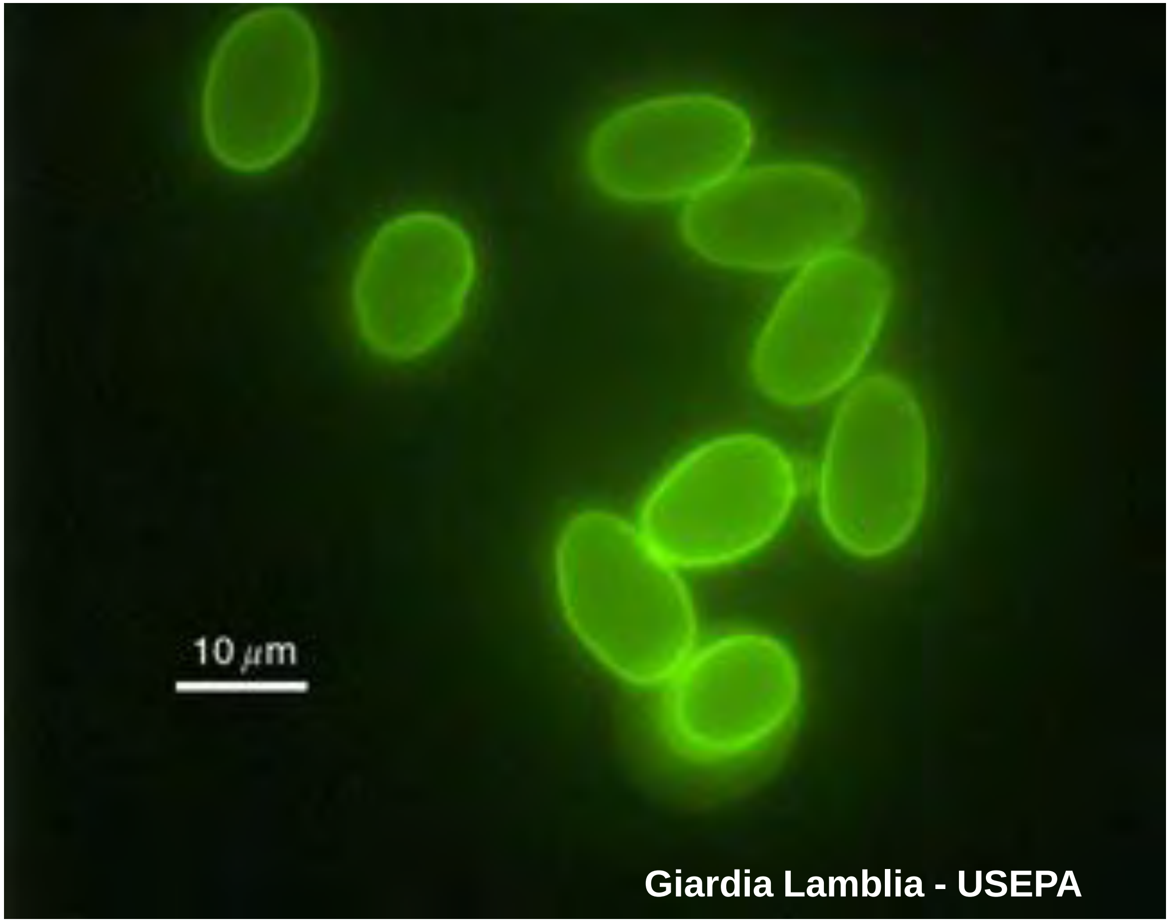
[S] Sign test


STOP

Monitoring Design Considerations

- Pretreatment at the inlet is ***<u>very</u>*** important
  - Trashguards, catch basin inserts, grates, linear radial screens
  - Maintenance is important to prevent bypass

Bacteria Pollution



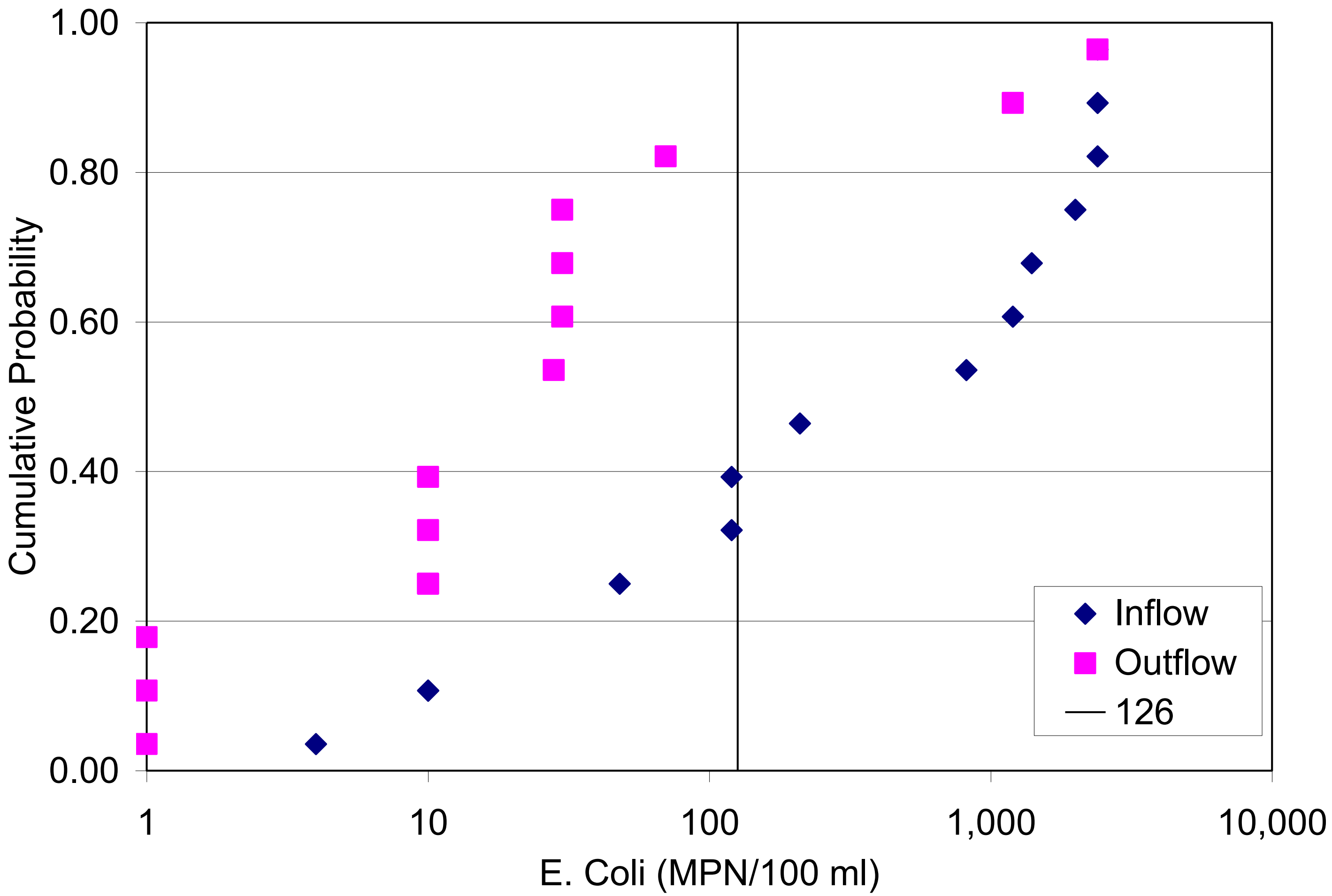
Giardia Lamblia - USEPA

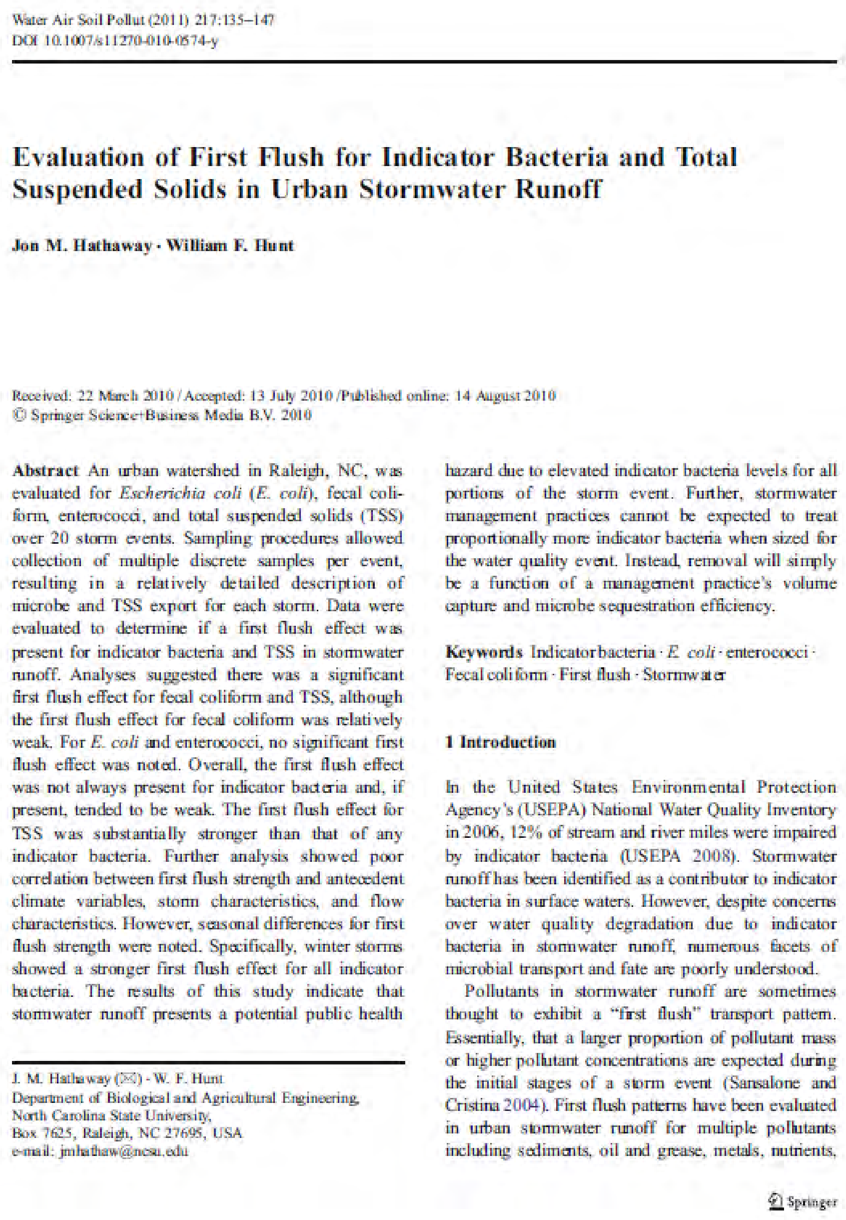
Hal Marshal (Bioretention)

Watershed = 0.4 ha

CN = 98

Cumulative Probability Plots – Bioretention





Water Air Soil Pollut (2011) 217:135–147
DOI 10.1007/s11270-010-0574-y

Evaluation of First Flush for Indicator Bacteria and Total Suspended Solids in Urban Stormwater Runoff

Jon M. Hathaway · William F. Hunt

Received: 22 March 2010 / Accepted: 13 July 2010 /Published online: 14 August 2010

Abstract An urban watershed in Raleigh, NC, was evaluated for *Escherichia coli* (*E. coli*), fecal coliform, enterococci, and total suspended solids (TSS) over 20 storm events. Sampling procedures allowed collection of multiple discrete samples per event, resulting in a relatively detailed description of microbe and TSS export for each storm. Data were evaluated to determine if a first flush effect was present for indicator bacteria and TSS in stormwater runoff. Analyses suggested there was a significant first flush effect for fecal coliform and TSS, although the first flush effect for fecal coliform was relatively weak. For *E. coli* and enterococci, no significant first flush effect was noted. Overall, the first flush effect was not always present for indicator bacteria and, if present, tended to be weak. The first flush effect for TSS was substantially stronger than that of any indicator bacteria. Further analysis showed poor correlation between first flush strength and antecedent climate variables, storm characteristics, and flow characteristics. However, seasonal differences for first flush strength were noted. Specifically, winter storms showed a stronger first flush effect for all indicator bacteria. The results of this study indicate that stormwater runoff presents a potential public health hazard due to elevated indicator bacteria levels for all portions of the storm event. Further, stormwater management practices cannot be expected to treat proportionally more indicator bacteria when sized for the water quality event. Instead, removal will simply be a function of a management practice's volume capture and microbe sequestration efficiency.

Keywords Indicator bacteria · *E. coli* · enterococci · Fecal coliform · First flush · Stormwater

1 Introduction

In the United States Environmental Protection Agency's (USEPA) National Water Quality Inventory in 2006, 12% of stream and river miles were impaired by indicator bacteria (USEPA 2008). Stormwater runoff has been identified as a contributor to indicator bacteria in surface waters. However, despite concerns over water quality degradation due to indicator bacteria in stormwater runoff, numerous facets of microbial transport and fate are poorly understood.

Pollutants in stormwater runoff are sometimes thought to exhibit a "first flush" transport pattern. Essentially, that a larger proportion of pollutant mass or higher pollutant concentrations are expected during the initial stages of a storm event (Sansalone and Cristina 2004). First flush patterns have been evaluated in urban stormwater runoff for multiple pollutants including sediments, oil and grease, metals, nutrients,

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Indicator Bacteria Performance of Storm Water Control Measures in Wilmington, North Carolina

J. M. Hathaway[1] and W. F. Hunt, M.ASCE[2]

Abstract: Indicator bacteria are a common source of impairment in surface waters in the United States. Urban storm water runoff has been identified as a contributor to elevated indicator bacteria concentrations. Six storm water control measures (SCMs) were monitored in Wilmington, North Carolina, for *E. coli* and enterococci. Monitored SCMs included two storm water wet ponds, two bioretention cells, and two storm water wetlands. Sandier watersheds in Wilmington potentially lead to differences in SCM performance for indicator bacteria compared to SCMs implemented in clayey watersheds. Results showed *E. coli* and enterococci concentration reductions between 70 and 98% for the two wet ponds and a bioretention cell with a 60-cm-deep fill media. Other SCMs showed poor removal of indicator bacteria, in some cases negative, with storm water wetlands performing the poorest overall for the three SCM types. Further analysis showed that SCMs with high concentration reductions tended to have geometric mean effluent concentrations lower than the U.S. EPA's target surface-water concentration for *E. coli*. Conversely, no SCM had a geometric mean effluent enterococci concentration lower than the U.S. EPA target value. SCM geometric mean effluent concentrations were typically higher during North Carolina's swimming season between the beginning of April and the end of October, although no statistically significant relationship could be found ($p < 0.05$). Despite a lack of statistically significant relationships, the potential for higher effluent indicator bacteria concentrations from SCMs during the peak recreational season may have implications for both public health and watershed management and should be further evaluated by the scientific community. **DOI: 10.1061/(ASCE)IR.1943-4774.0000378.** © *2012 American Society of Civil Engineers.*

CE Database subject headings: Stormwater management; Best management practice; Bacteria; Water pollution; North Carolina.

Author keywords: Storm water; Best management practice (BMP); Indicator bacteria; Fecal coliform; *E. coli*; Enterococci; Storm water control measure (SCM).

Introduction

Surface waters in the United States are commonly placed on the U.S. EPA's 303(d) list because of impairment by pathogens (indicator bacteria) (U.S. EPA 2008). Subsequently, indicator bacteria total maximum daily loads (TMDLs) have been established for numerous surface waters. Storm water runoff has been identified as a contributor to indicator bacteria pollution, with indicator bacteria concentrations in urban runoff commonly exceeding U.S. EPA standards for surface waters (Hathaway et al. 2009; Krometis et al. 2009).

Typically, storm water runoff mitigation involves the use of storm water control measures [SCMs—also known as best management practices (BMPs)]. SCMs have been shown to effectively reduce numerous types of pollutants, yet their ability to remove indicator bacteria and pathogens is still under evaluation. Studies have indicated variable performance of SCMs for indicator bacteria from storm to storm and on the basis of SCM type (Hathaway et al. 2009; Krometis et al. 2009; Passeport et al. 2009; Li and Davis 2009; Birch et al. 2004; Davies and Bavor 2000; Mallin et al. 2002). Evaluations of indicator bacteria removal in SCMs have typically been performed on data sets with less than 10 samples. Other than Hathaway et al. (2009), studies with more than 10 data points have collected samples at a predetermined time interval (e.g., monthly, biweekly), and thus did not isolate SCM performance during storm flow.

Indicator bacteria are of particular concern in coastal areas, where human exposure can occur during recreational activities or during the consumption of shellfish (U.S. EPA 2001). Such human health concerns have economic implications for the tourism and commercial fishing industries. Despite the need for microbial controls in coastal areas, few evaluations have been performed for storm water wetlands, wet ponds, and bioretention areas in watersheds with similar characteristics to those of watersheds in the coastal southeastern United States. In particular, limited data are present with regard to SCM removal and sequestration of enterococci, which is recommended for use as an indicator species in coastal areas and potentially has different survival characteristics than other indicator bacteria species in the environment (U.S. EPA 2001). Only two field studies could be found in scientific literature where either a storm water wetland or bioretention area was monitored for enterococci sequestration and removal (Davies and Bavor 2000; Jones et al. 2008)

Coastal areas in the southeastern United States are characterized by sandy soils. This may lead to differences in SCM microbe removal efficiency. For instance, the percentage of incoming microbes attached to sediment may vary from that in clayey watersheds because microbes predominately attach to smaller particles (Davies and Bavor 2000). Krometis et al. (2009) proposed that

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[2] Associate Professor and Extension Specialist, Dept. of Biological and Agricultural Engineering, North Carolina State Univ., Raleigh, NC 27695.

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Entire Journal Articles Based on GRAB SAMPLES

So… a better? way

Residual Pathogens?

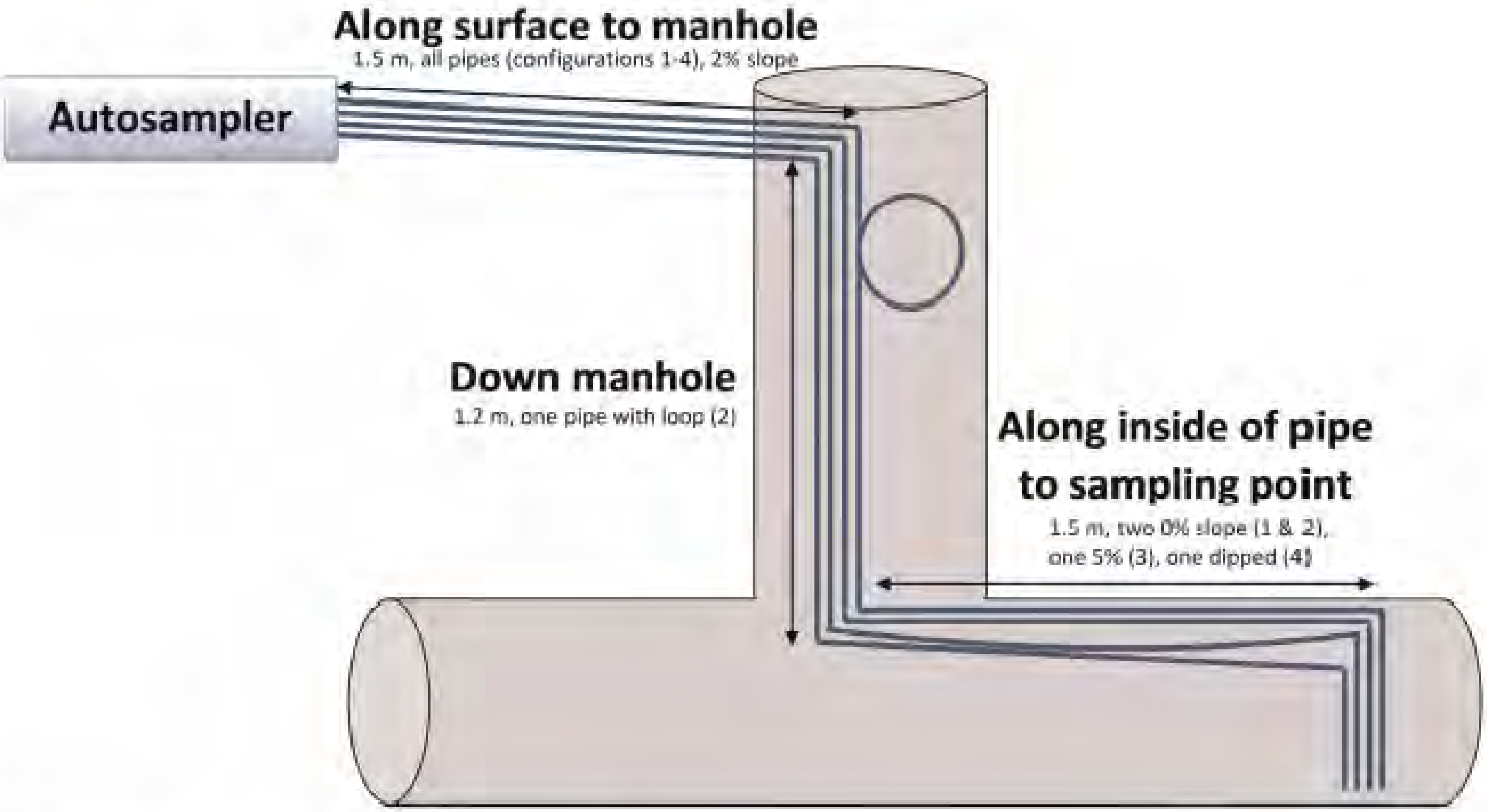


Figure 1 | Laboratory setup of sampling tubes experiment.

What fits through one of those sampling tubes?

Are there unaccounted for pollutants in 'this stuff?'

Preliminary Assessment Suggests “Yes”

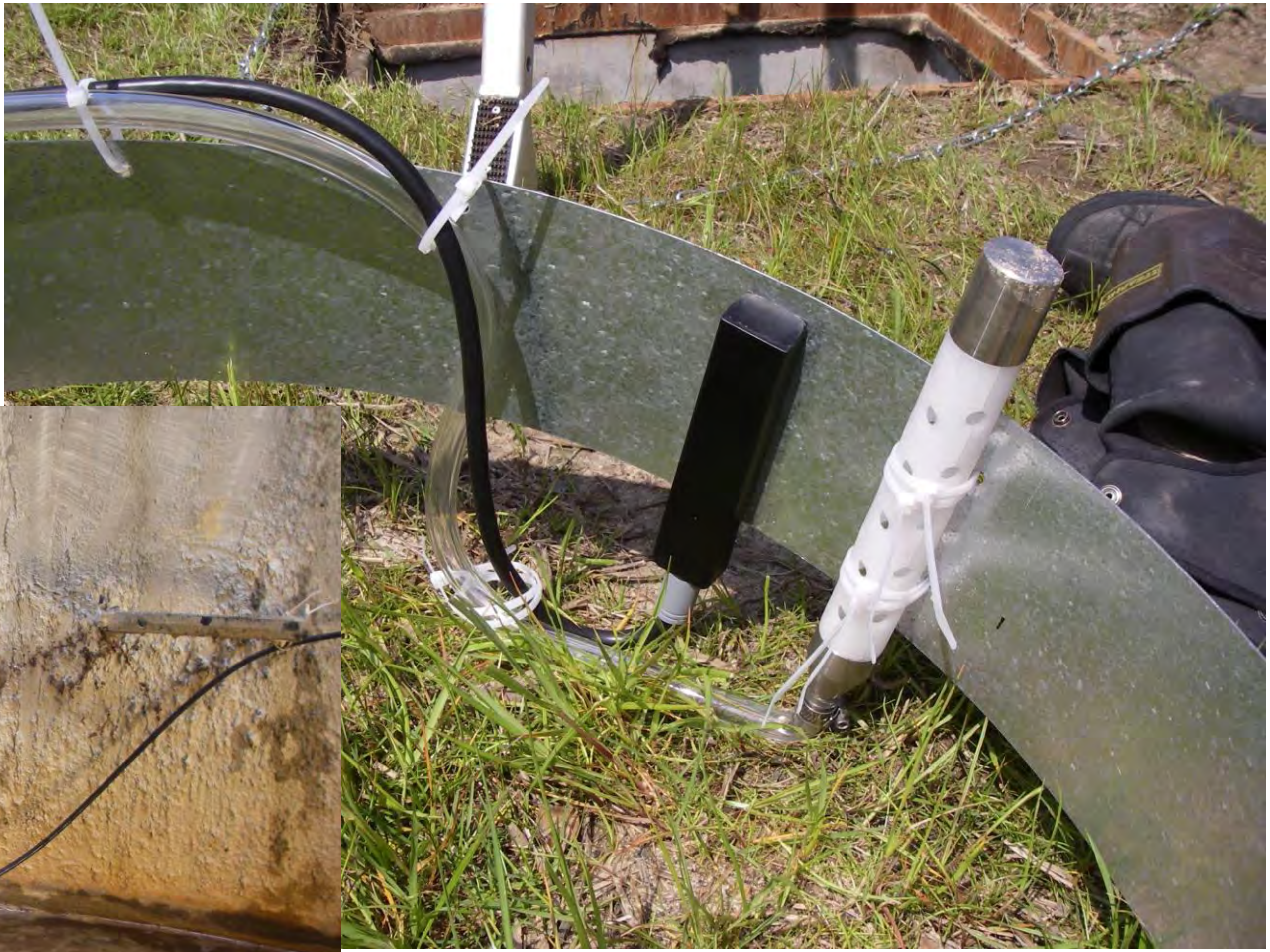
- 1-2 # of N / ac <u>may</u> be trapped in drop inlets
  - 10-20 # of N / Impermeable acre

Early On…

Calibration / Check Weirs

Look Fancy, but not entirely accurate…

How else are you going to monitor this application?



A substantial amount of field time is needed to Check Validity of data

Frequent site visits needed

Advantages of Pie Bottles….

Water Air Soil Pollut (2012) 223:5903–5915

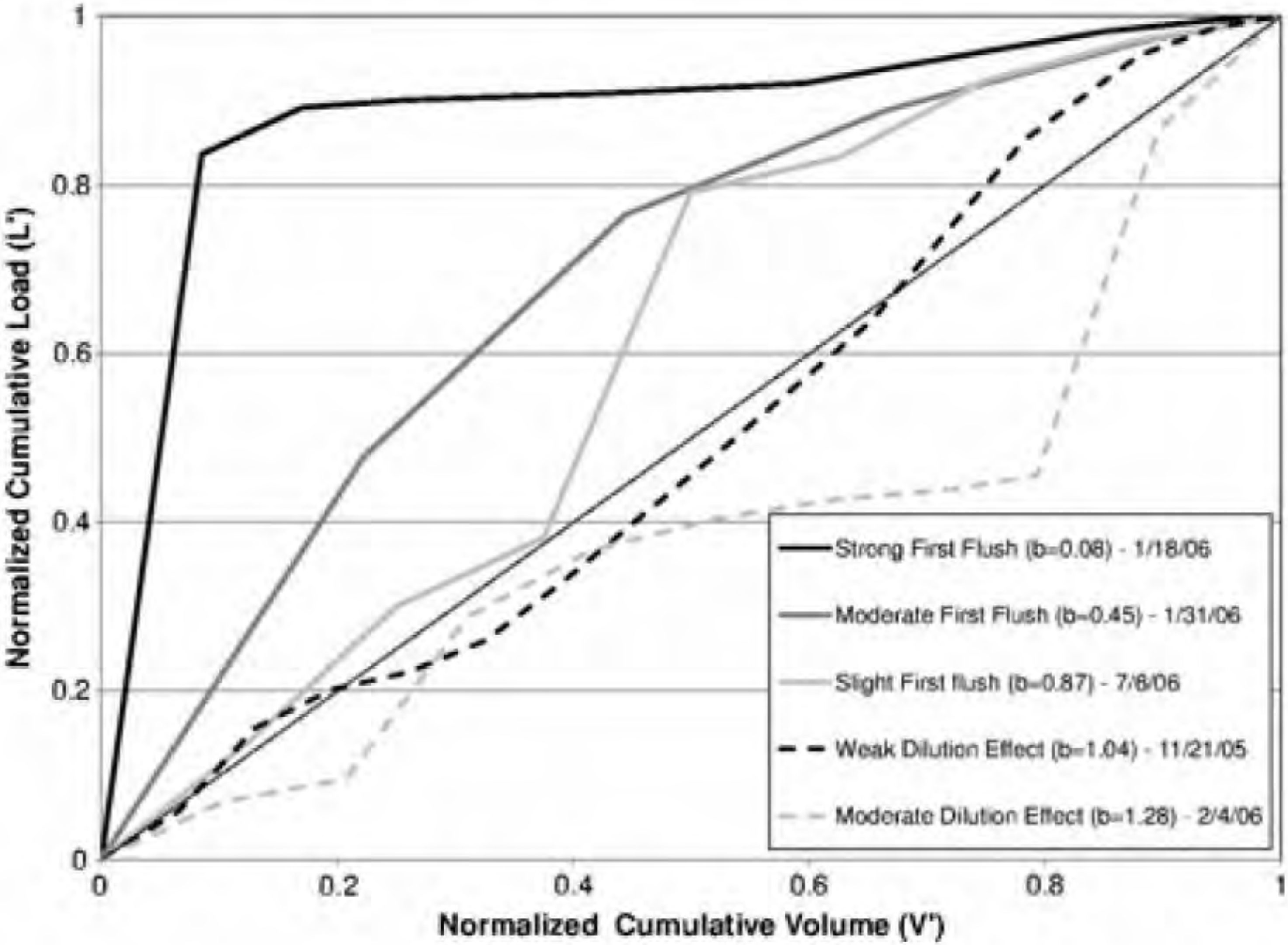


Fig. 3 Illustration of $L'V'$ curves and corresponding b-values

Disadvantage:

- Sample Analysis Costs go up by a factor of 5-10.
- The fraction of TOTAL project cost, however, increases from 3 - 10% to 15 – 35%.
- However, often a subset of composites is norm

Questions