Integrated Stream and Wetland Design: A Watershed Approach to Restoring Ecosystem Functions and Services on the Landscape.

Curtis J. Richardson, Neal Flanagan, & Mengchi Ho

Duke University Wetland Center, Durham, NC, USA

NICHOLAS SCHOOL OF THE ENVIRONMENT
DUKE UNIVERSITY

Why Restore Streams and Wetlands on the Landscape ?

- Degradation of Streams and Wetlands
- Loss of Ecosystem Functions
- Current Conditions
  - Incised channel
  - Tree falls
  - Erosion
  - Non-native species invasions
  - Loss of landscape diversity
  - Poor water quality

Channel Incision

Erosion & Sediment Loss

Stormwater Concerns & Water Quality Functions

Novel

Stream Wetland Assessment Management Park

- **Developed on Duke University Campus & Designed by Grad Students in Restoration Class Projects over 10 plus years (Provides Teaching, Research & Ecosystem Services)**
- **University Supported Projects become Model for Region**
  - **(Training Classes for University, Community and Gov't)**
- **Supported by City, State, Federal & Univ. Funding ($5M)**
- **Nutrient N and P Credits Developed and "Sold"**
- **Multiple Phases of Integrated Stream & Wetland Restoration in key areas of the Watershed with Targeted Restoration Approaches (Water use & Treatment)**
  - **Terraced Wetlands Approach (floodplain enhancement)**
  - **Off-line Wetland Treatment Cells (storm treatment)**
  - **Anabranching Wetlands (enhanced floodplain contact)**

- ***SWAMP*** **has provided a unique opportunity to evaluate and advance our understanding of restoration science.**

- **While the lessons learned at the monitoring & technical level are substantial, perhaps the best lessons are those at the watershed Level.**

One Approach Doesn't Fit All

SWAMP has used a variety of approaches to achieve its overall goals:

- Natural Channel Design (NCD)
- Anabranching Design
- Detention systems
- Wetland systems
- Stormwater BMP's

Data shows that different systems in series are often more effective than stand alone approaches.

One Approach Doesn't Fit All

- Natural Channel Design (NCD) is commonly promoted in NC as the preferred stream restoration design approach.

- But it is one tool in the tool box - there are others. The key question is when is each method appropriate to use.

Traditional Design Vs. Natural Channel Design

Stable Stream
"New Design Goal"

- A stable stream moves the sediment and water generated by its watershed while maintaining dimension, pattern, and profile, without aggrading or degrading

- The New "Design Goal"

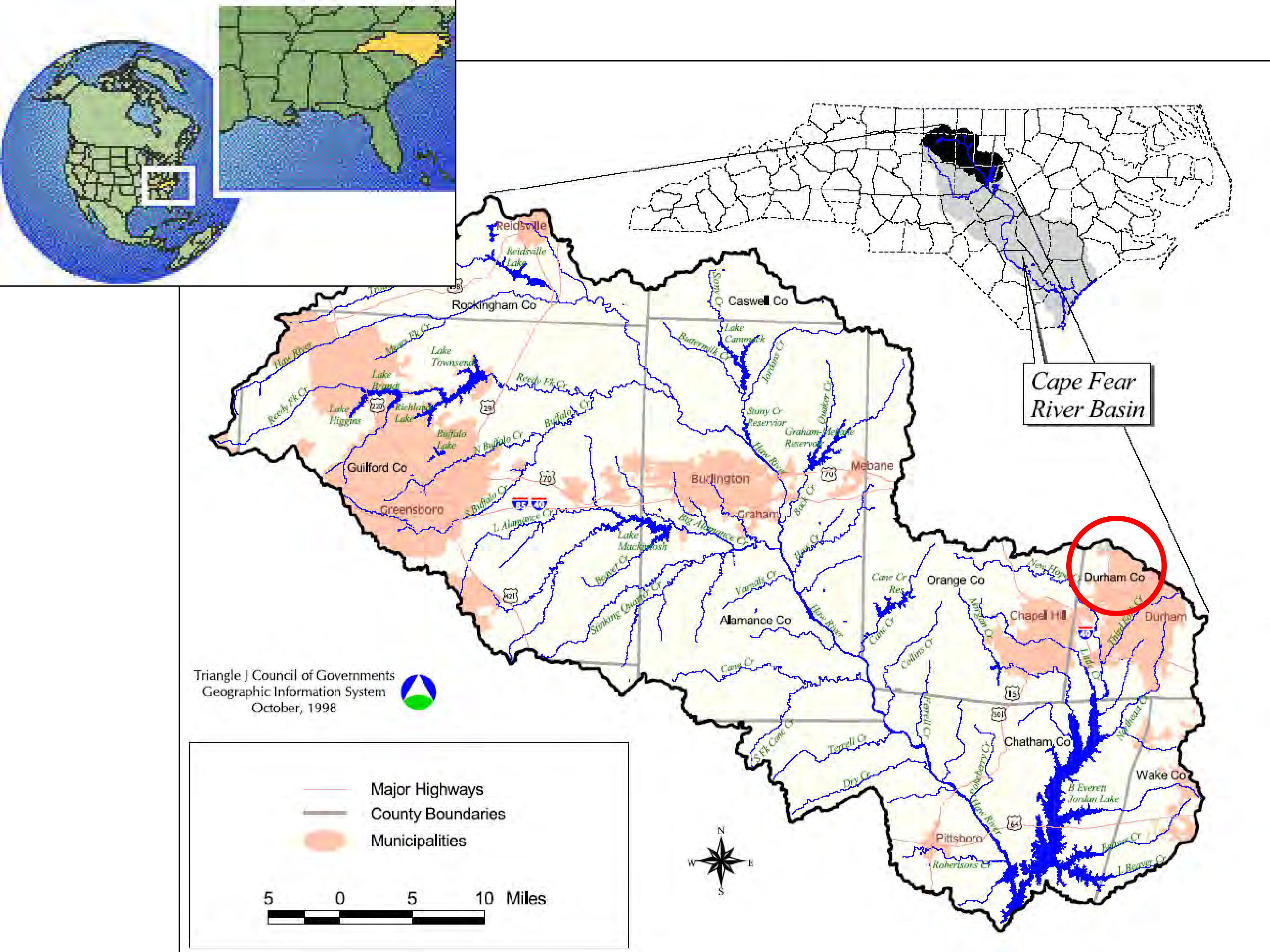
Functional Lift Pyramid

Ecology	Nutrient cycling, de-nitrification, organic processing, etc. Aquatic chemistry	Level 5
	Life cycles of aquatic insects, fish, amphibians, wildlife, etc). Aquatic and terrestrial life support.	Level 4
Geomorphology	Sediment transport, bedform diversity (riffle/pool sequence), channel stability. Creation of aquatic habitats.	Level 3
Hydraulics	**Floodplain connectivity**, shear stress, velocity. Water in the channel and on the floodplain.	Level 2
Hydrology	Rainfall/Runoff Relationships, Flow Duration, Channel Forming Discharge (Bankfull), etc. Water to the channel.	Level 1

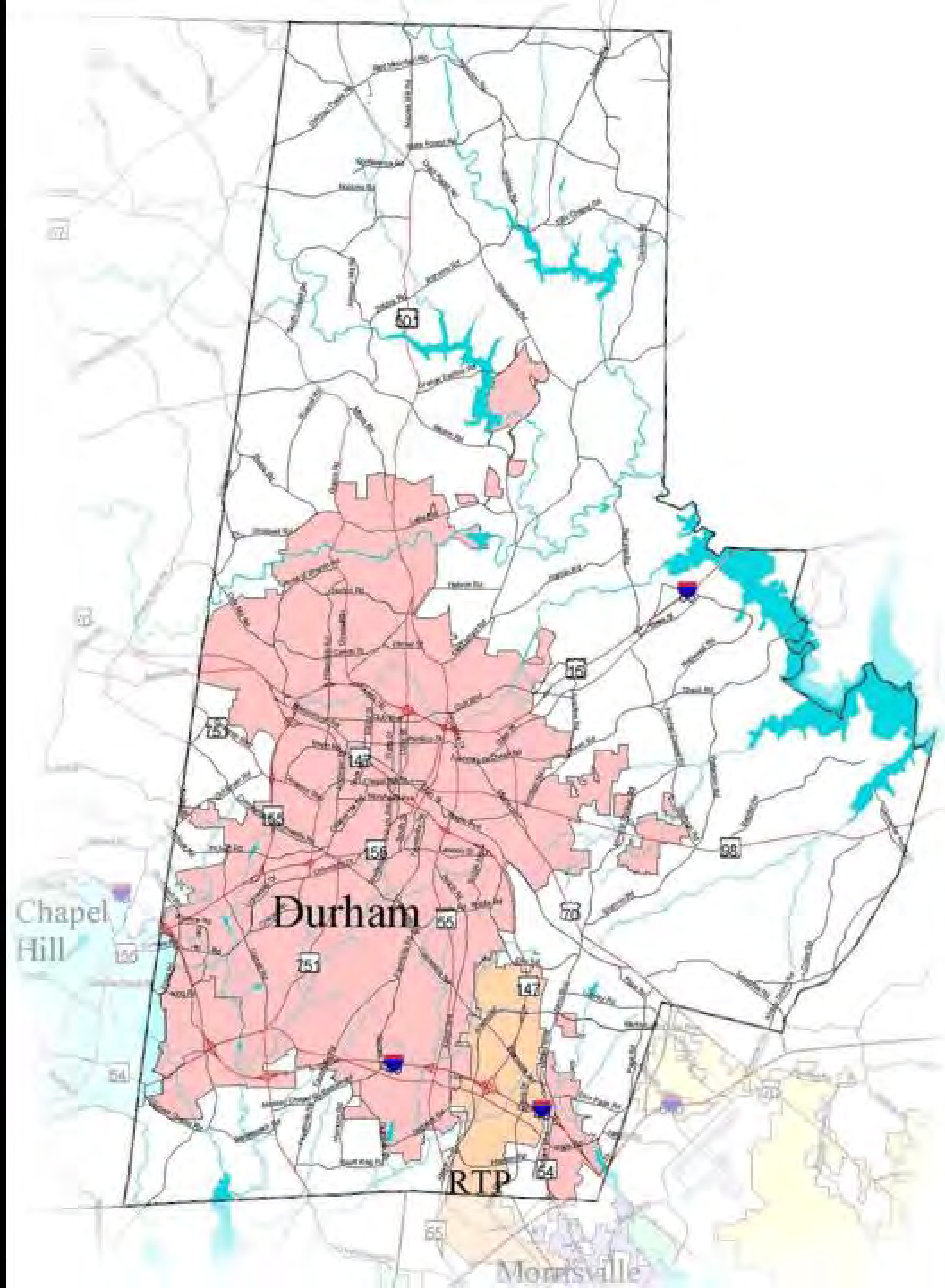
Harman, 2009

Ecological Goals of Restoration

- Restore connectivity between stream channel and floodplain
- Create functioning wetland
- Mitigate impacts of runoff from development
- Implement strategies for non-native species management

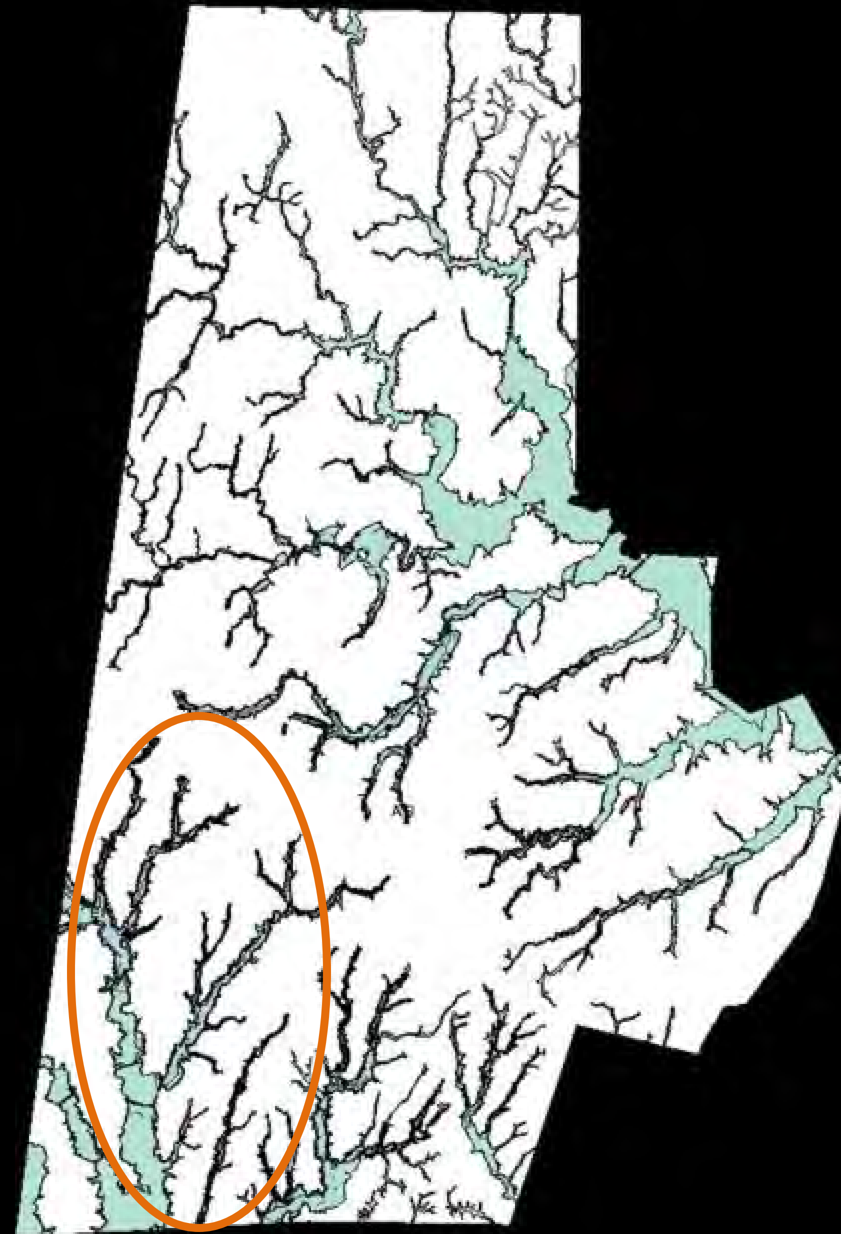


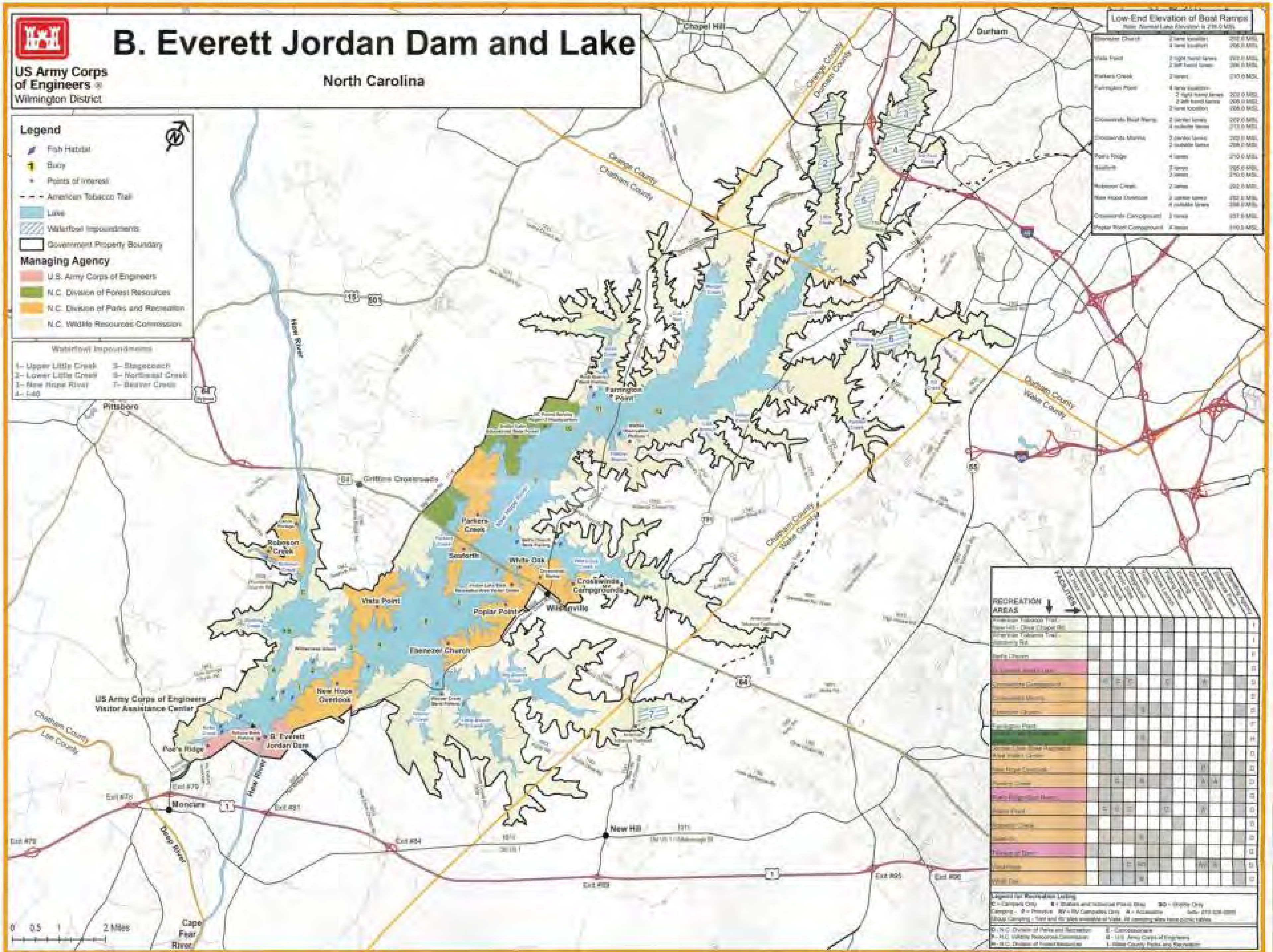
Cape Fear River Basin
Reidsville
Reidsville Lake
Rockingham Co
Caswell Co
Haw River
Reedy Fk Cr
Lake Brandt
Lake Townsend
Lake Higgins
Richland Lake
Buffalo Lake
Reedy Fk Cr
Buffalo Cr
N Buffalo Cr
S Buffalo Cr
Guilford Co
Greensboro
L Alamance Cr
Lake Mackintosh
Big Alamance Cr
Burlington
Graham
Mebane
Lake Cammack
Buttermilk Cr
Jordans Cr
Stony Cr Reservior
Graham-Mebane Reservoir
Quaker Cr
Back Cr
Haw Cr
Varnals Cr
Beaver Cr
Sinking Quarter Cr
Alamance Co
Cane Cr
Cane Cr Res
Orange Co
New Hope Cr
Durham Co
Durham
Chapel Hill
Morgan Cr
Collins Cr
Terrell Cr
Dry Cr
Chatham Co
B Everett Jordan Lake
Northeast Cr
Wake Co
Beaver Cr
L Beaver Cr
Pittsboro
Robertsons Cr
Haw River
Triangle J Council of Governments
Geographic Information System
October, 1998
Major Highways
County Boundaries
Municipalities
5 0 5 10 Miles
N
E
S
W



Durham
Chapel Hill
RTP
Morrisville
501
147
98
70
55
751
54

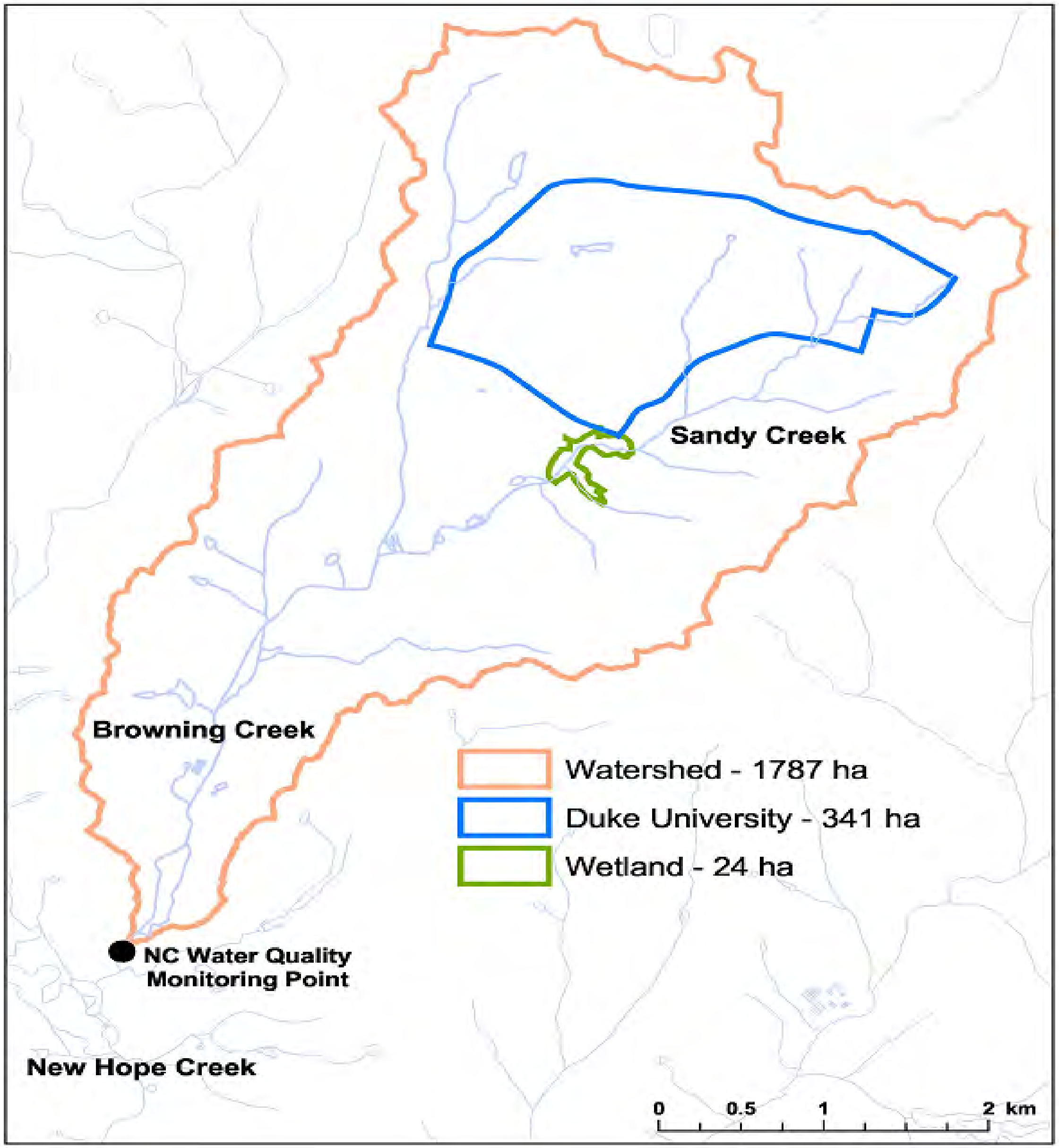

GENUINE
"BULL" DURHAM
GENUINE
DURHAM
Smoking Tobacco.
W. T. BLACKWELL & CO
Durham, N.C.
SMOKING
TOBACCO
STANDARD OF THE WORLD.

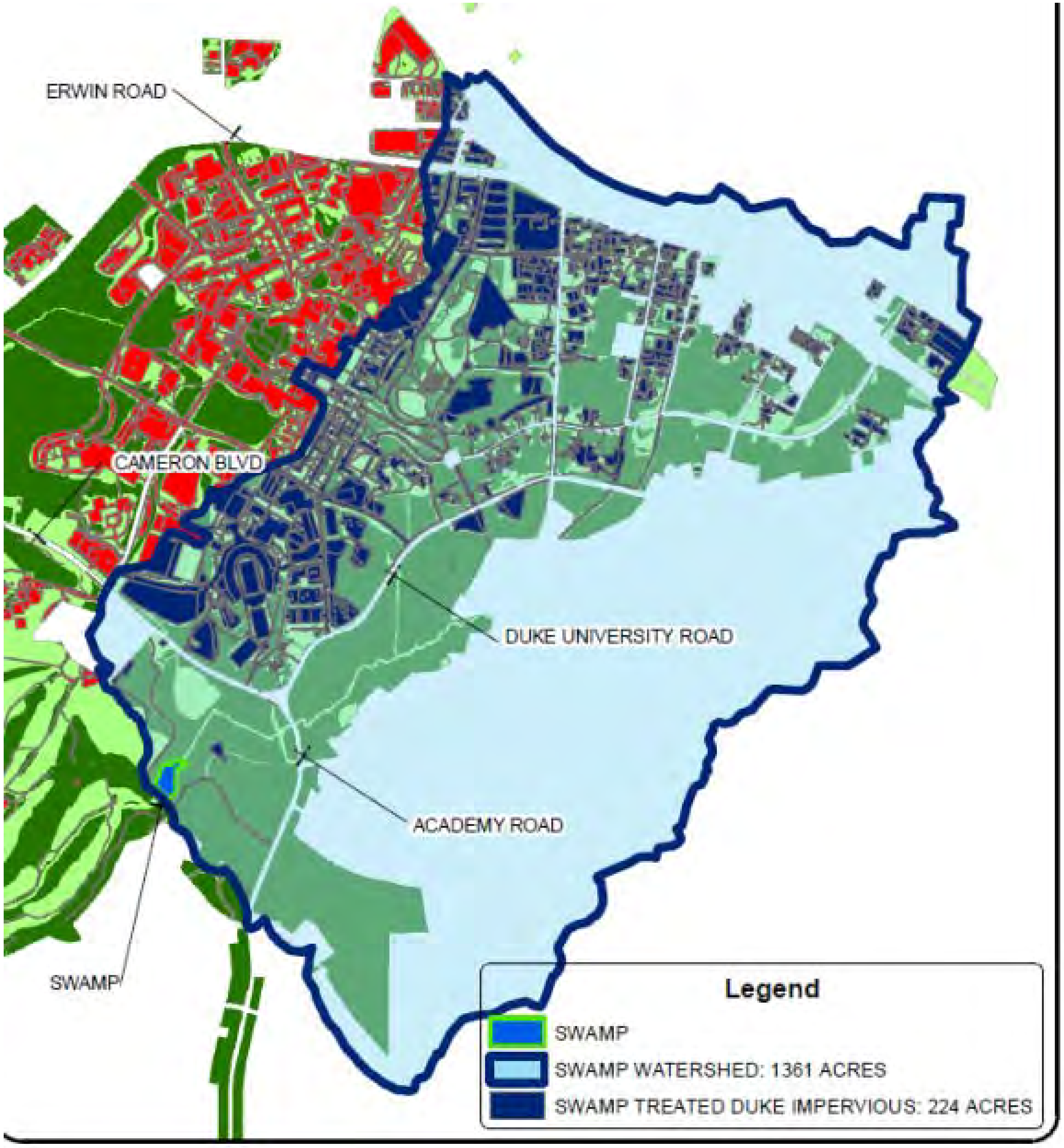


B. Everett Jordan Dam and Lake
US Army Corps of Engineers
Wilmington District
North Carolina
Legend
Fish Habitat
Buoy
Points of Interest
American Tobacco Trail
Lake
Waterfowl Impoundments
Government Property Boundary
Managing Agency
U.S. Army Corps of Engineers
N.C. Division of Forest Resources
N.C. Division of Parks and Recreation
N.C. Wildlife Resources Commission
Waterfowl Impoundments
1- Upper Little Creek
2- Lower Little Creek
3- New Hope River
4- I-40
5- Stagecoach
6- Northeast Creek
7- Beaver Creek
Low-End Elevation of Boat Ramps
Chapel Hill
Durham
Orange County
Durham County
Chatham County
Wake County
Lee County
Pittsboro
Griffins Crossroads
New River
Haw River
Deep River
Cape Fear River
Robeson Creek
Parkers Creek
Seaforth
Farrington Point
White Oak
Crosswinds Campgrounds
Wilsonville
Vista Point
Poplar Point
Ebenezer Church
New Hope Overlook
US Army Corps of Engineers Visitor Assistance Center
B. Everett Jordan Dam
Poe's Ridge
Moncure
New Hill
Exit #79
Exit #78
Exit #81
Exit #84
Exit #89
Exit #95
Exit #96
RECREATION AREAS
FACILITIES
0 0.5 1 2 Miles

Duke University Sandy Creek Watershed



SWAMP Treatment Boundaries



Nutrient Inputs

- Fertilizers
  - Playing fields
  - Residential Lawns
- Sewer Overflow

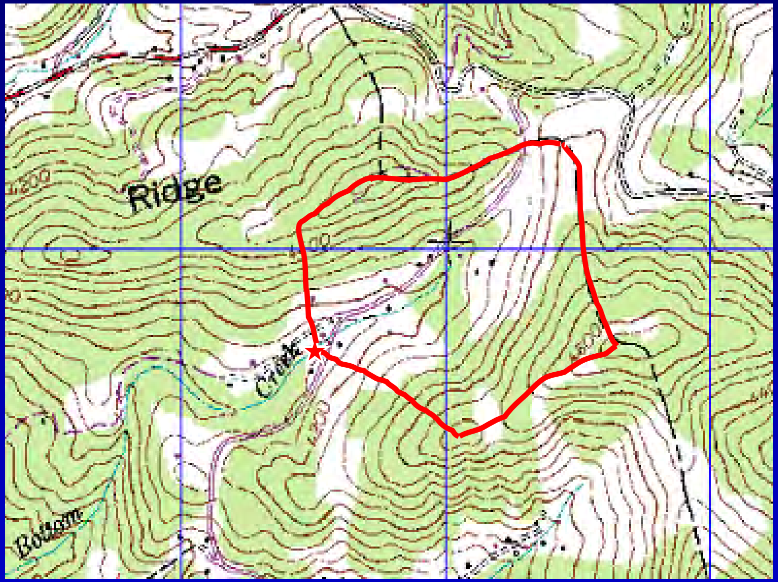
- Urban Runoff
  - Petroleum products
  - Metals

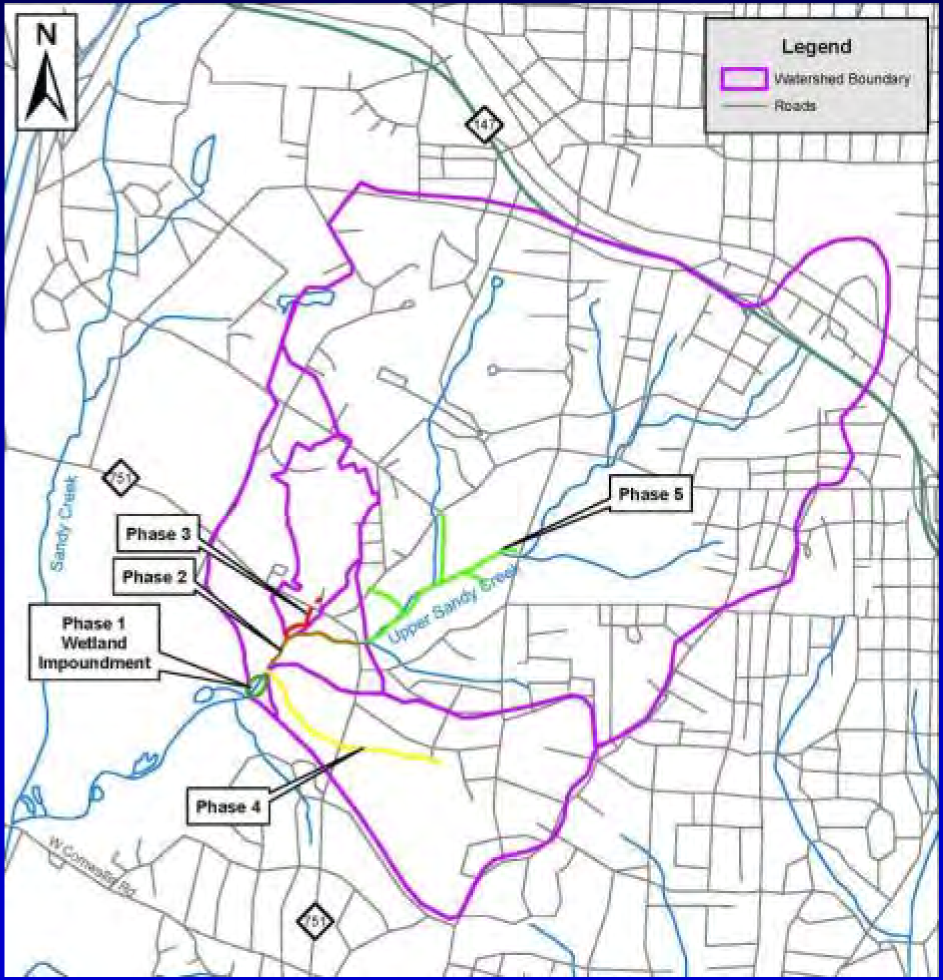
Restoration Design Sequence

- Watershed Assessment and Feasibility
- Existing Condition Survey
- Bankfull Verification
- Design Criteria Selection
- Design
- Permitting
- Construction
- Evaluation

Watershed Assessment

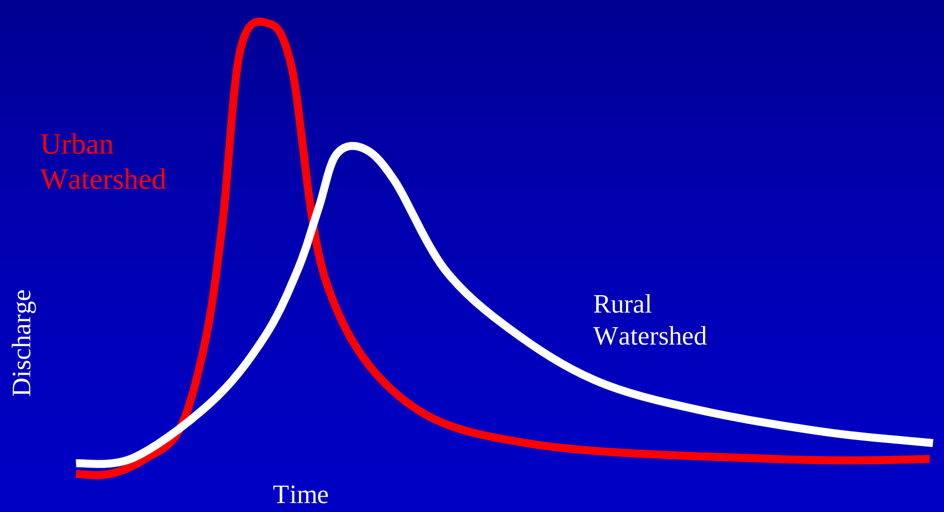
- Determine the drainage area

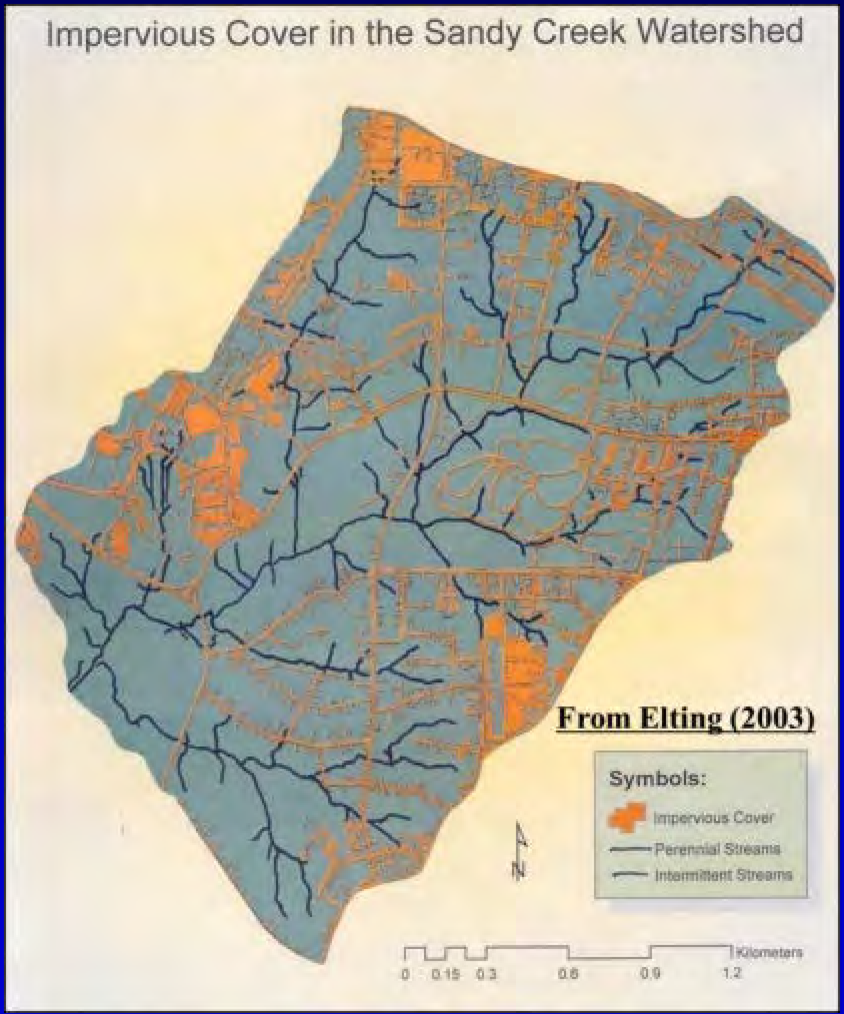


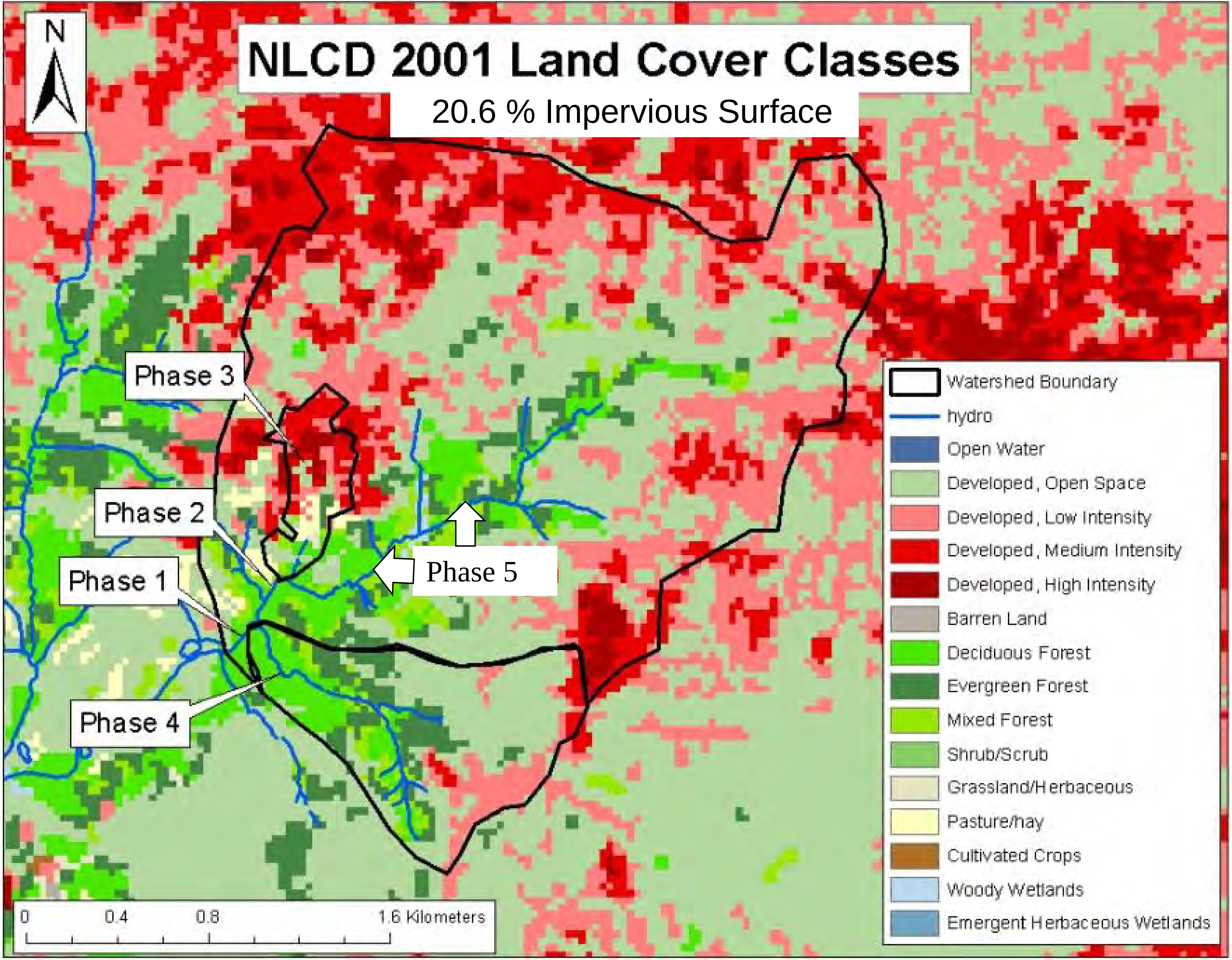


Watershed Assessment

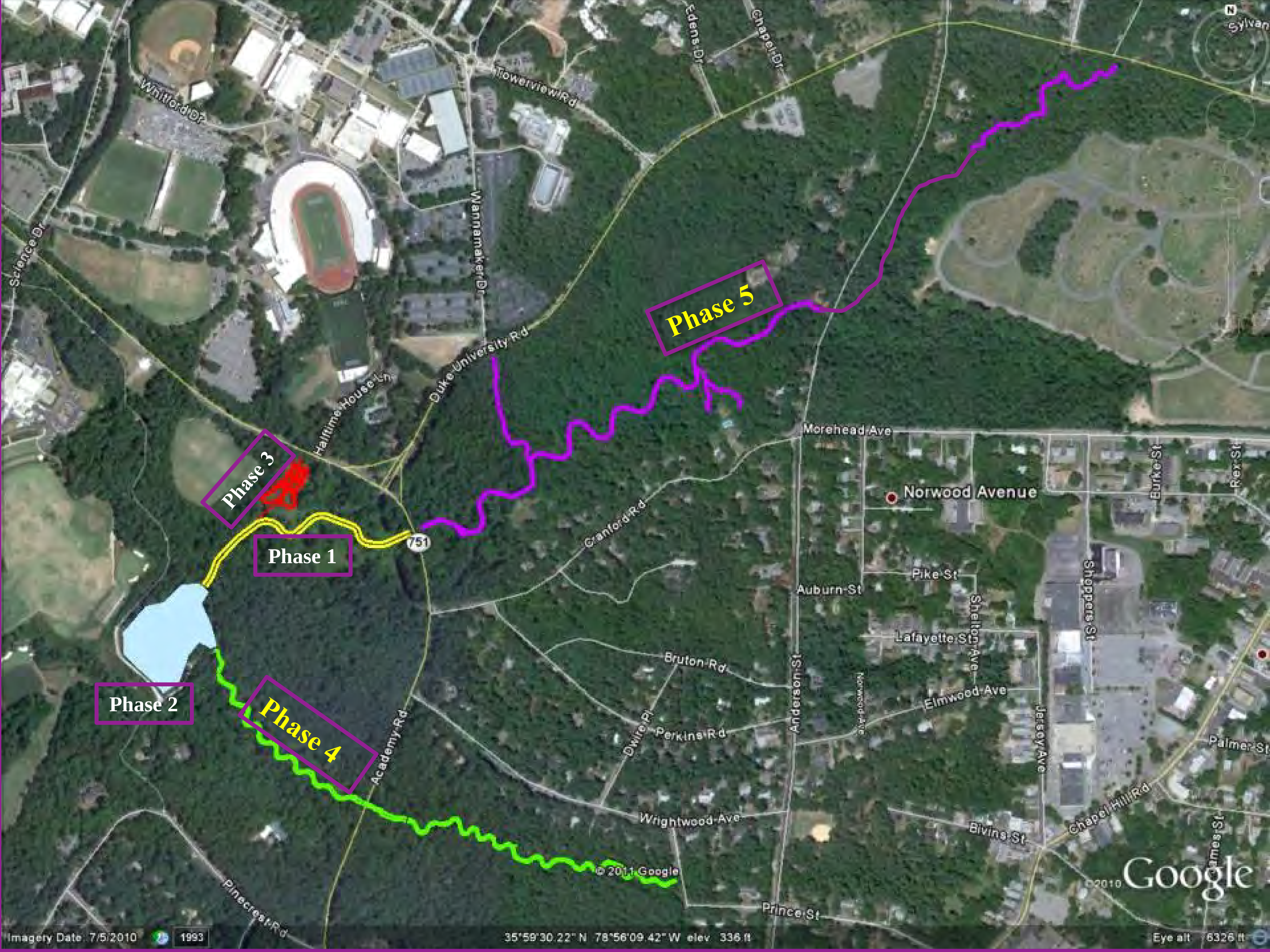
Determine the percent impervious cover for the watershed.

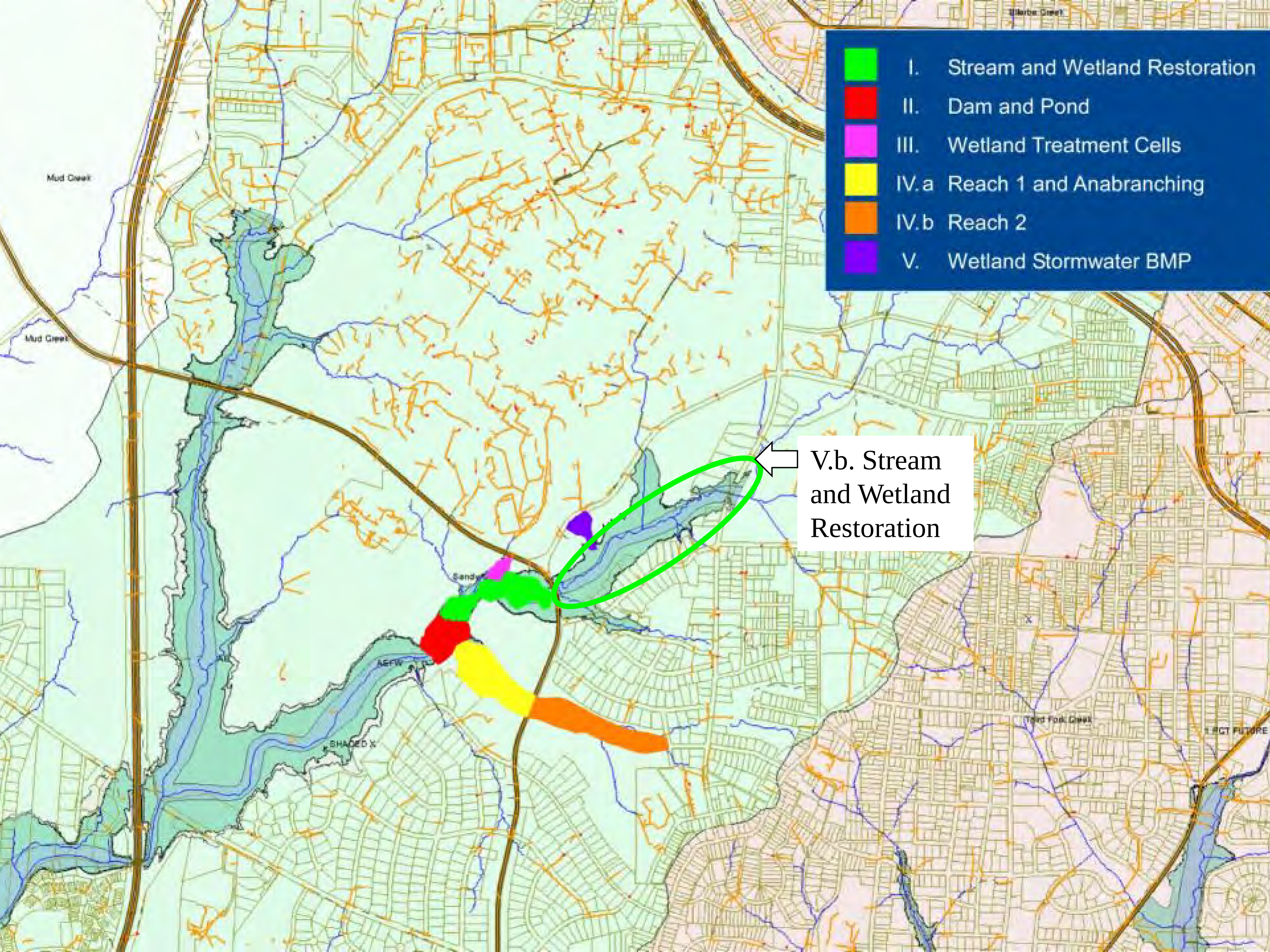




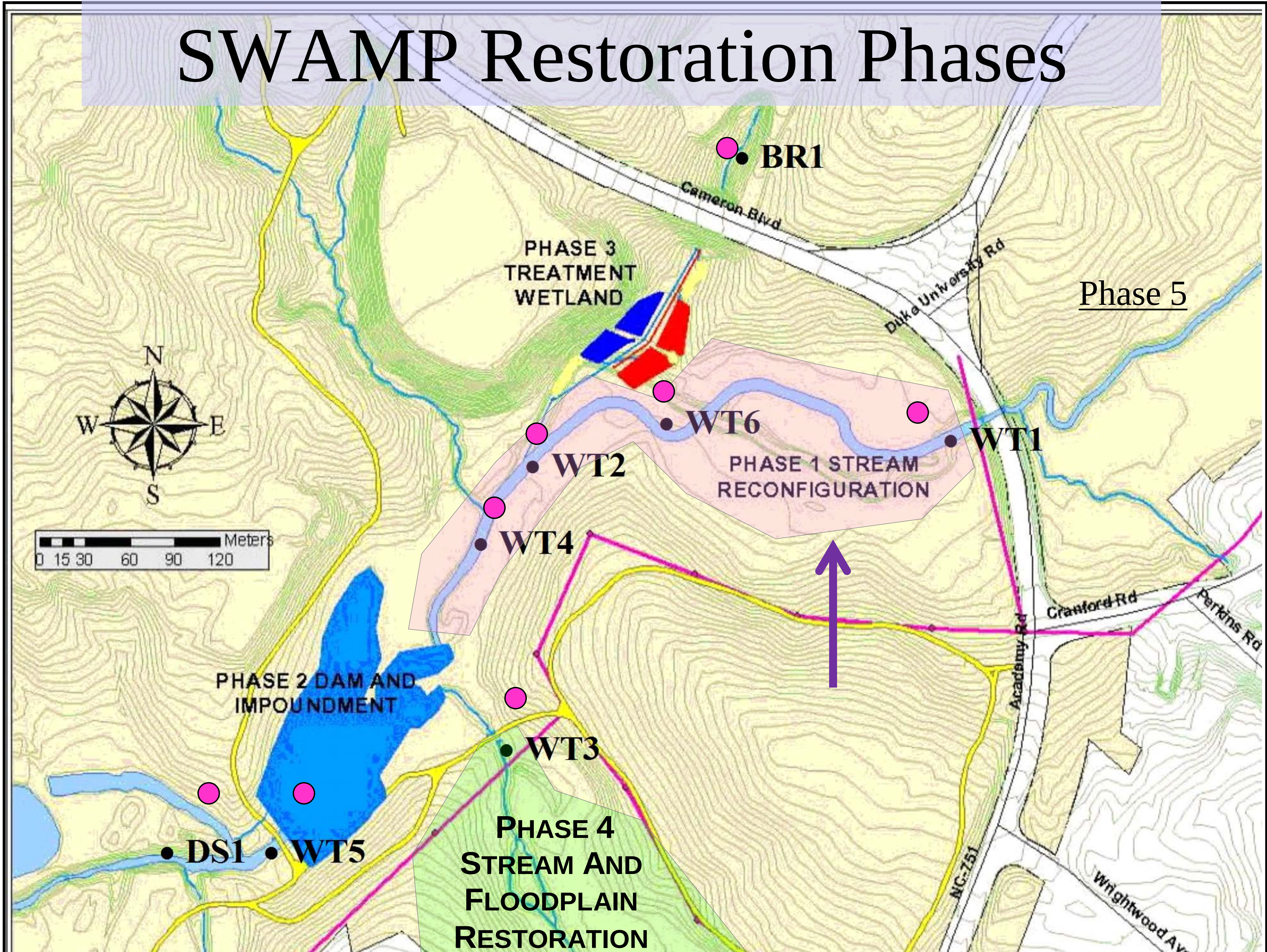


NLCD 2001 Land Cover Classes
20.6 % Impervious Surface
N
Phase 3
Phase 2
Phase 1
Phase 4
Phase 5
Watershed Boundary
hydro
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
0
0.4
0.8
1.6 Kilometers

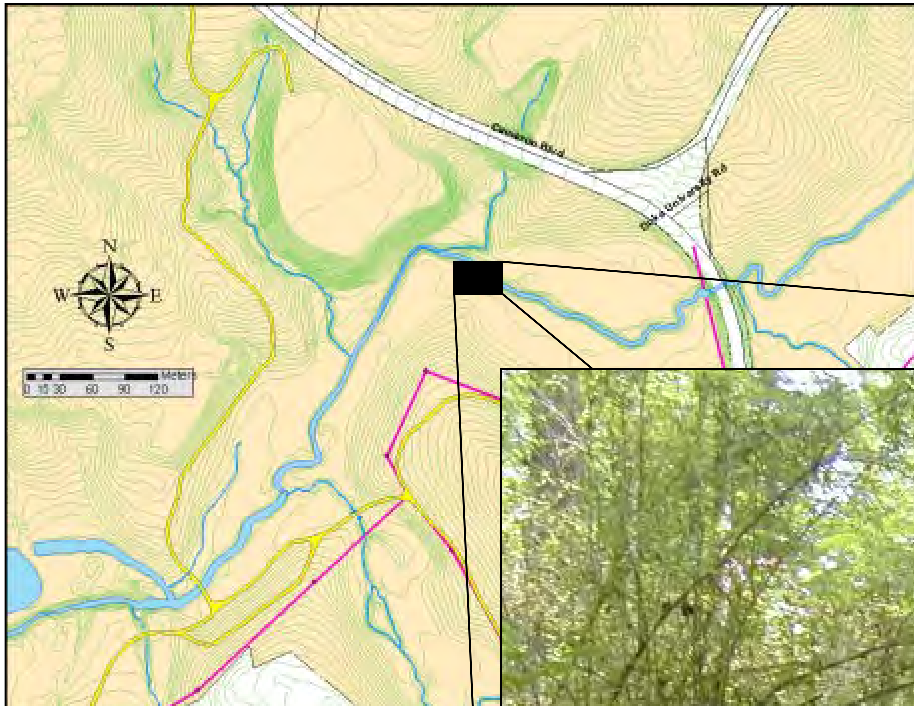

Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Towerview Rd
Wannamaker Dr
Duke University Rd
Halftime House Ln
Whitford Dr
Science Dr
Edens Dr
Chapel Dr
Morehead Ave
Norwood Avenue
Cranford Rd
Auburn St
Pike St
Lafayette St
Shelton Ave
Bruton Rd
Elmwood Ave
Perkins Rd
Dwire Pl
Academy Rd
Anderson St
Jersey Ave
Shoppers St
Wrightwood Ave
Bivins St
Chapel Hill Rd
Palmer St
Burke St
Rex St
Prince St
Pinecrest Rd
751
© 2011 Google
©2010 Google
Imagery Date: 7/5/2010
1993
35°59'30.22" N 78°56'09.42" W elev 336 ft
Eye alt 6326 ft


I. Stream and Wetland Restoration
II. Dam and Pond
III. Wetland Treatment Cells
IV.a Reach 1 and Anabranching
IV.b Reach 2
V. Wetland Stormwater BMP
V.b. Stream and Wetland Restoration
Mud Creek
Mud Creek

SWAMP Restoration Phases



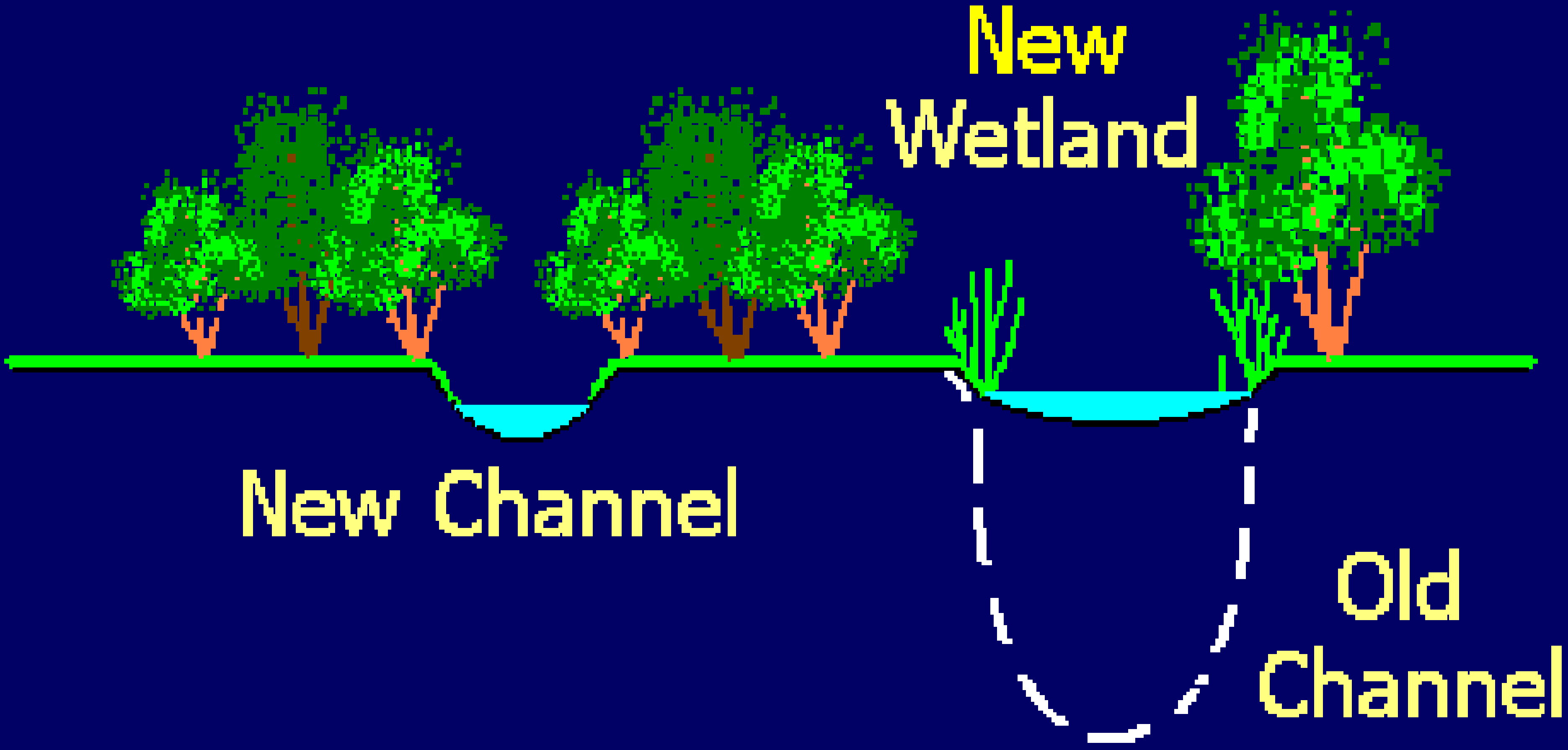

2003



Phase 1: PRECONSTRUCTION STREAM CHANNEL

DUWC SITE
WT-6
19 May 2003

Priority 1



Hydrologic Design Criteria

Will Harman & Buck Engineering

- **Utilize Reference Reach & Natural Channel design Approach**
  - Duke Wetland Center Modifications
- **Determine Stabilization Needs**
  - **Vegetation (native species)**
  - Root wads (natural design)
  - Cross vanes (engineering design)
- **Raised Stream Bed**
  - Stream Bank Depth = 1.5 meters (59 inches)
    - Lower Bound Storm Depth
    - Bankfull flooding frequency design
      1.67/yr rate of return (modified)
    - Create pools, riffles and contours

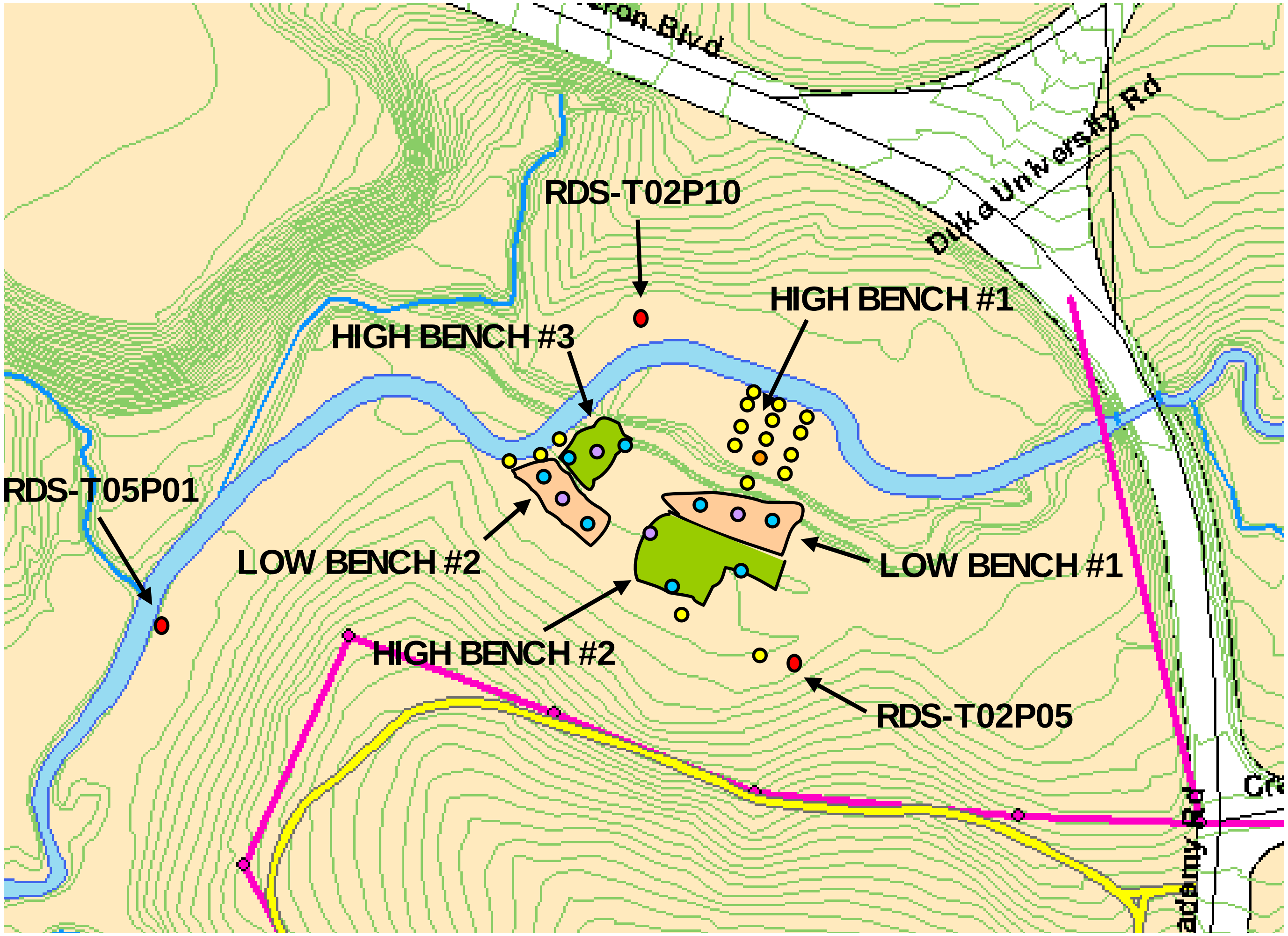
New Channel Configuration 2005

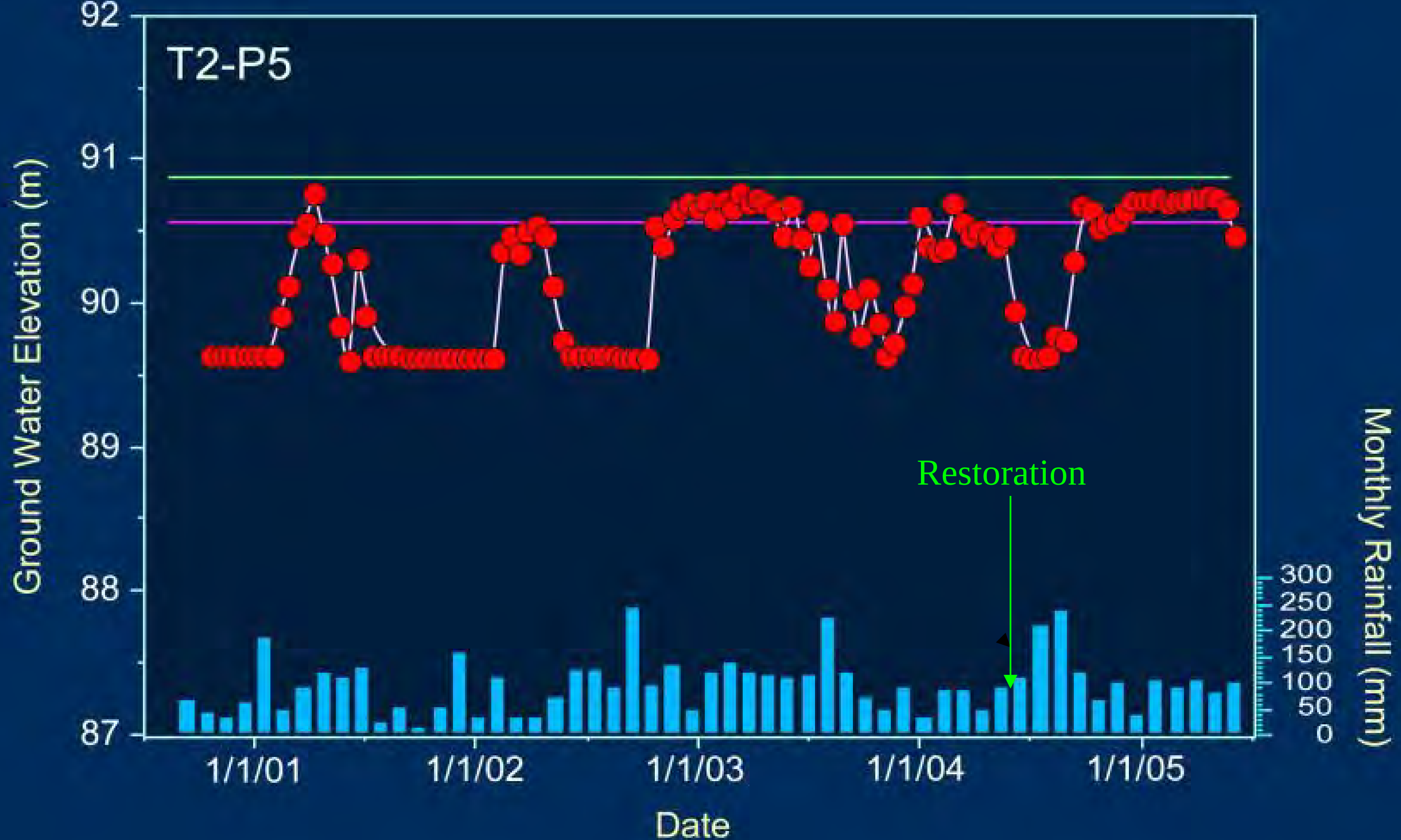

June 2007

JUNE 2010

Wetland Groundwater Hydrology Restored ?

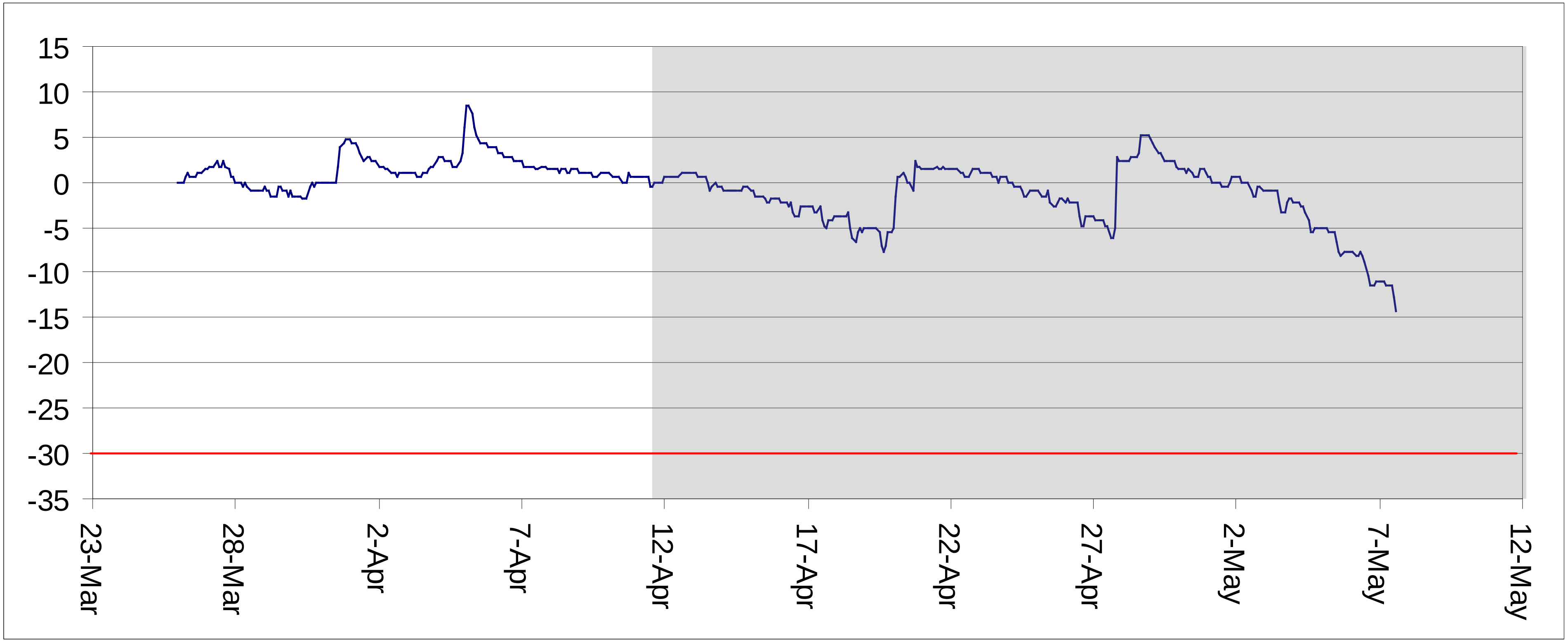
Low and high Marsh Hydroperiod Study





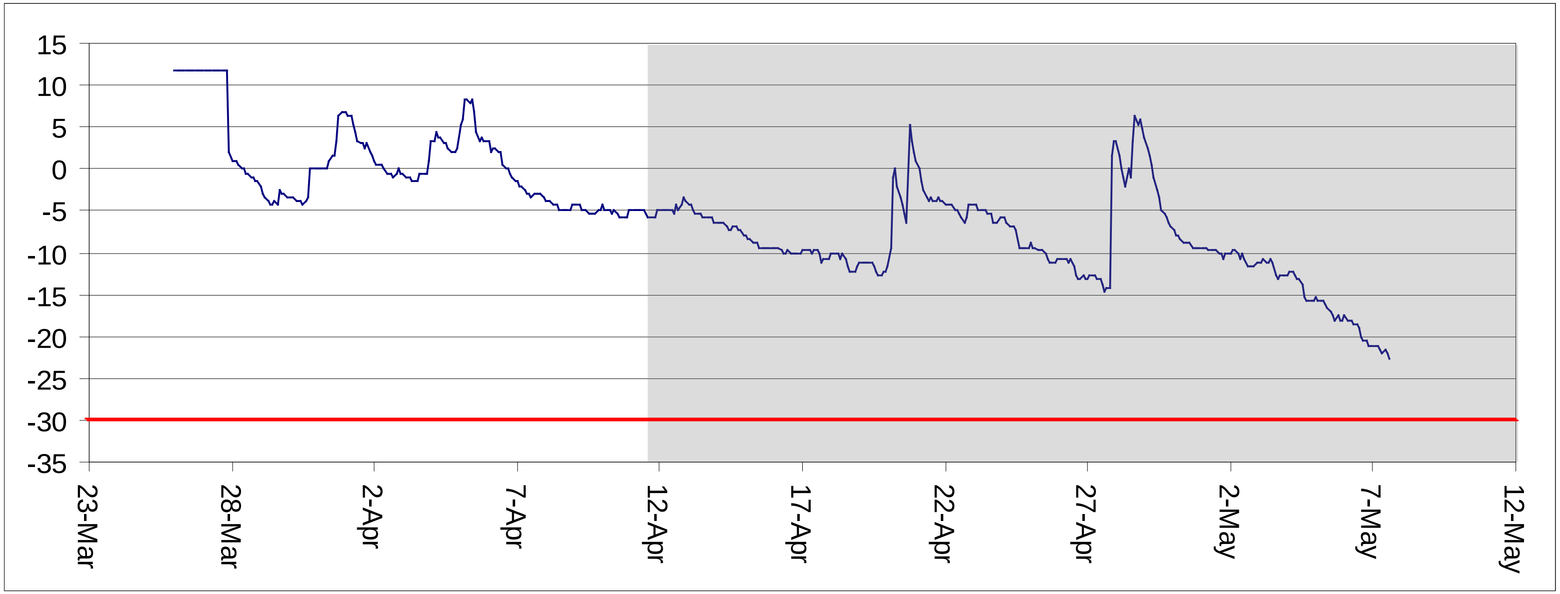
T2-P5
Ground Water Elevation (m)
92
91
90
89
88
87
Monthly Rainfall (mm)
300
250
200
150
100
50
0
1/1/01
1/1/02
1/1/03
1/1/04
1/1/05
Date
Restoration

High bench (HB2)= High marsh



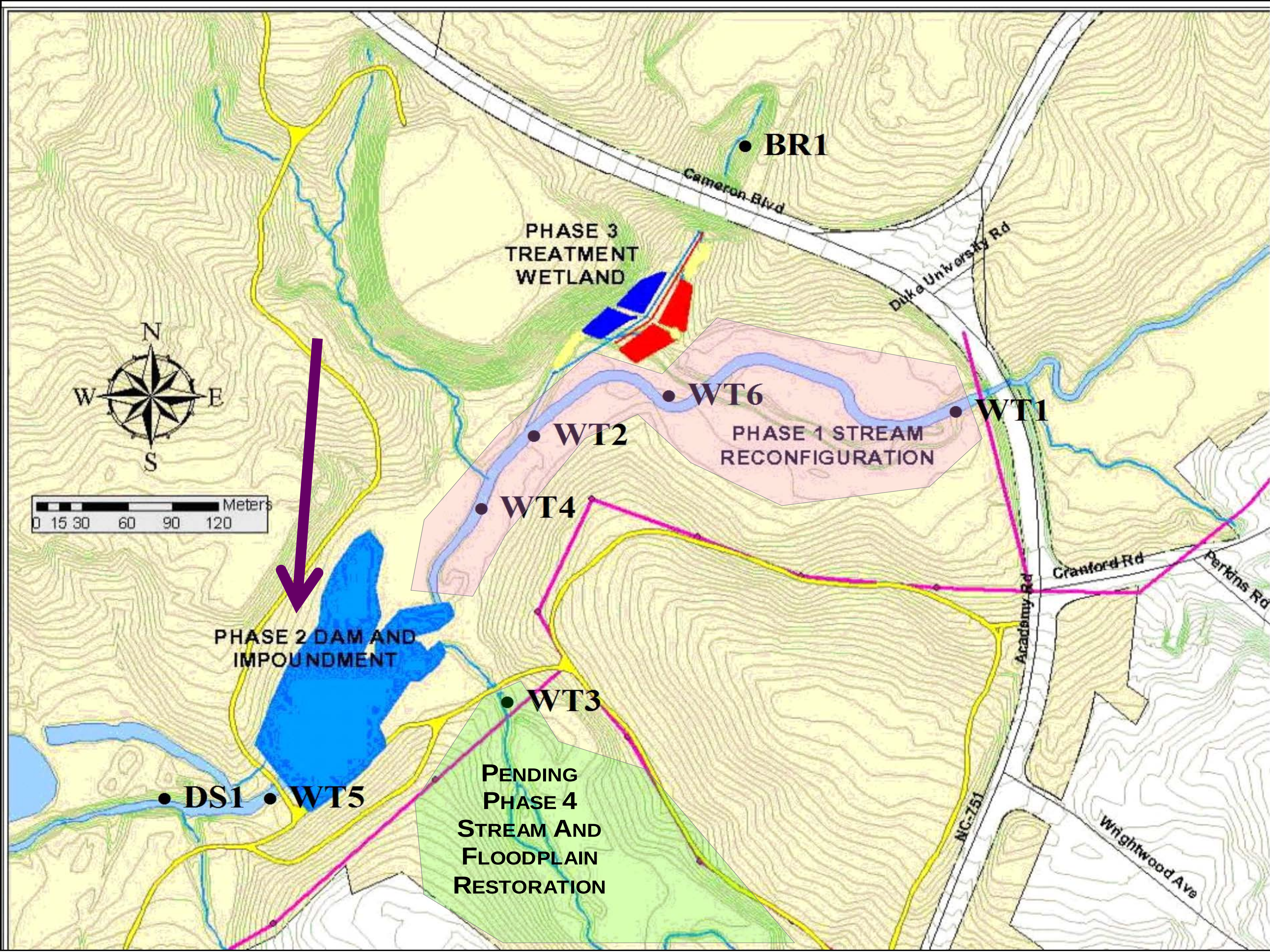
(2008)

Low bench (LB2)= Low Marsh



(2008)


High Marsh
Low Marsh

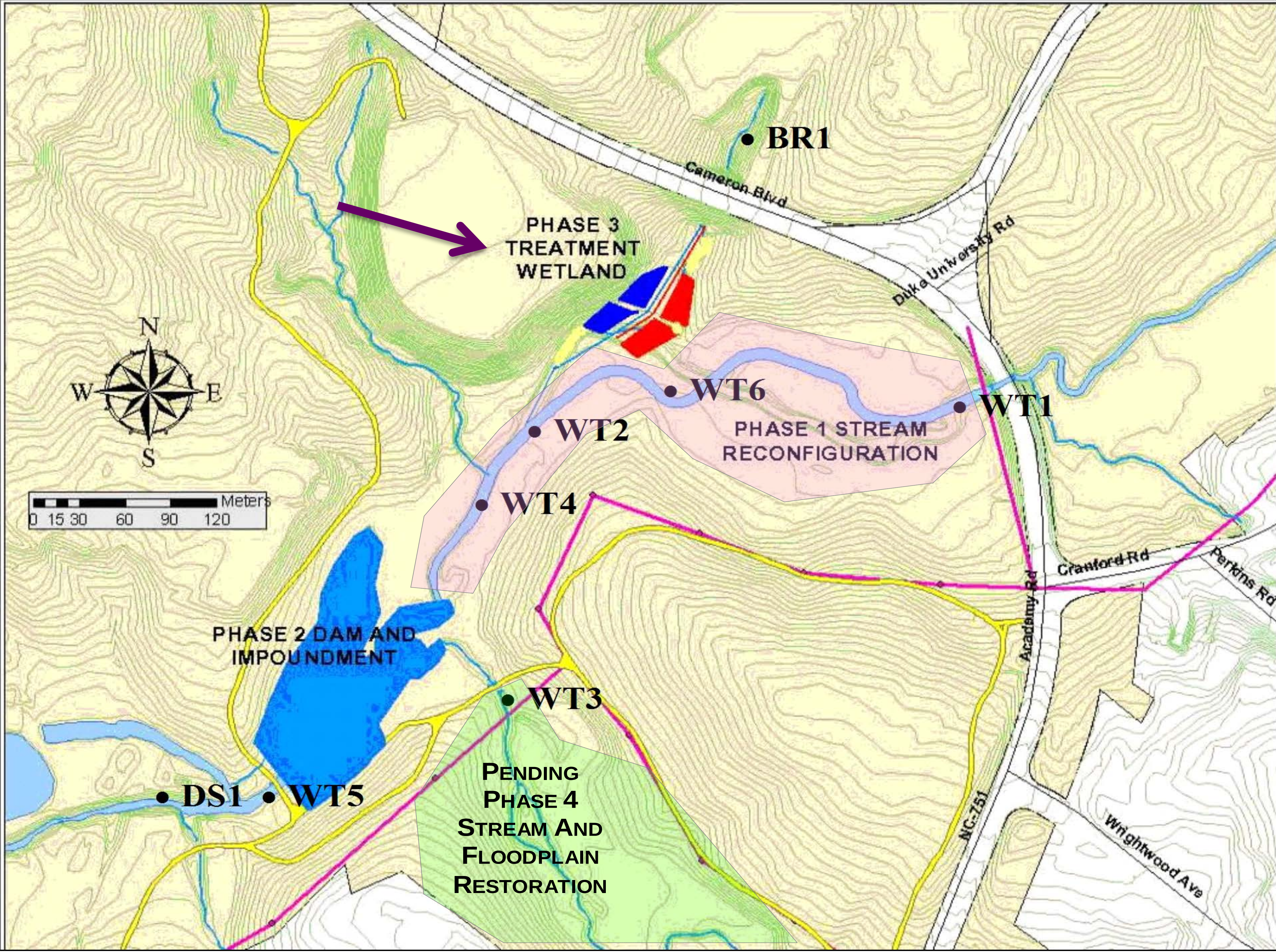

BR1
Cameron Blvd
PHASE 3
TREATMENT
WETLAND
Duke University Rd
WT6
WT1
WT2
PHASE 1 STREAM
RECONFIGURATION
N
W
E
S
Meters
0 15 30 60 90 120
WT4
Cranford Rd
Perkins Rd
Academy Rd
PHASE 2 DAM AND
IMPOUNDMENT
WT3
PENDING
PHASE 4
STREAM AND
FLOODPLAIN
RESTORATION
DS1
WT5
NC-751
Wrightwood Ave


November 2007


March 2005

June, 2007


2012



BR1
Cameron Blvd
PHASE 3
TREATMENT
WETLAND
Duke University Rd
N
W
E
S
Meters
0 15 30 60 90 120
WT6
WT1
WT2
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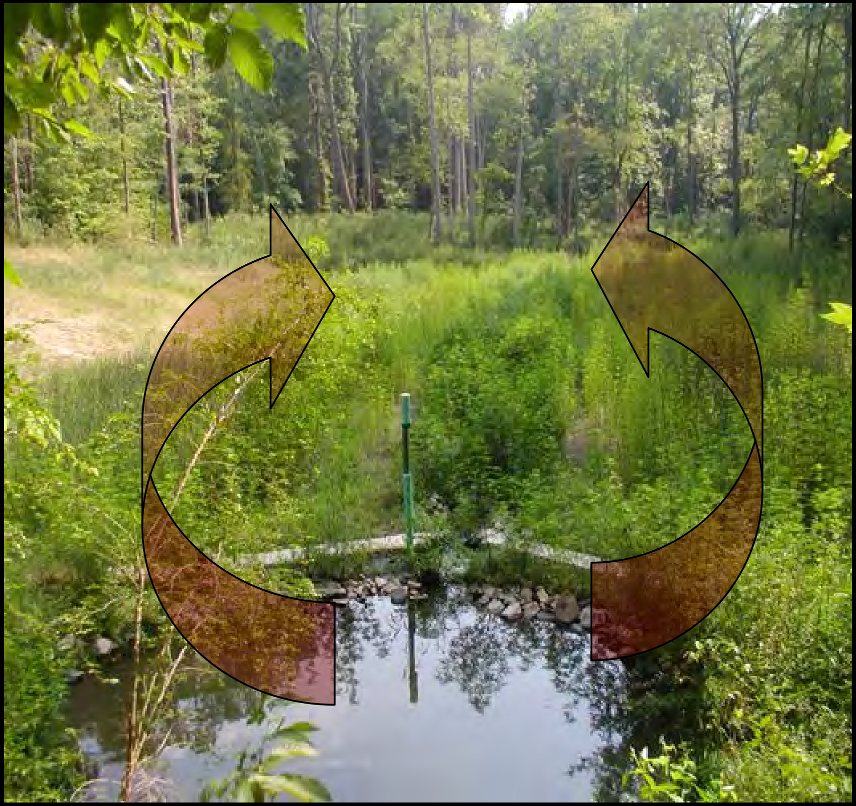
RECONFIGURATION
WT4
Cranford Rd
Perkins Rd
Academy Rd
PHASE 2 DAM AND
IMPOUNDMENT
WT3
PENDING
PHASE 4
STREAM AND
FLOODPLAIN
RESTORATION
NC-751
Wrightwood Ave
DS1
WT5

Phase III constructed wetland 2007

Storm water diverter / Weir




Phase IV, Reach I, Prior to Restoration


Phase IV, Reach I, After Restoration

Phase IV, Reach 2

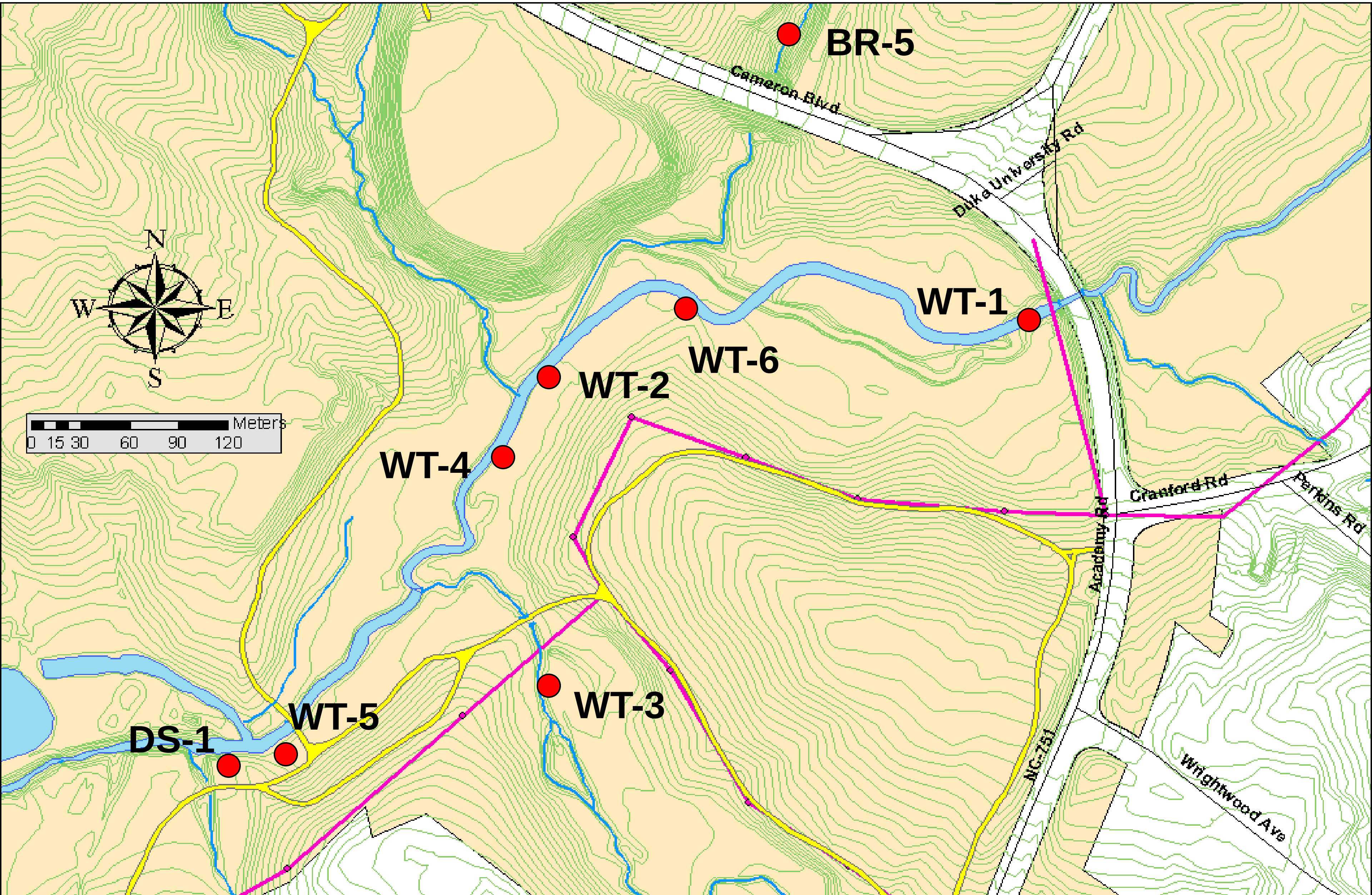
Phase V: Storm Water Wetland Treatment (Preconstruction)

Phase V: Storm Water Wetland Treatment, August 2012

Phase V: Stormwater Wetland Treatment, April 2013

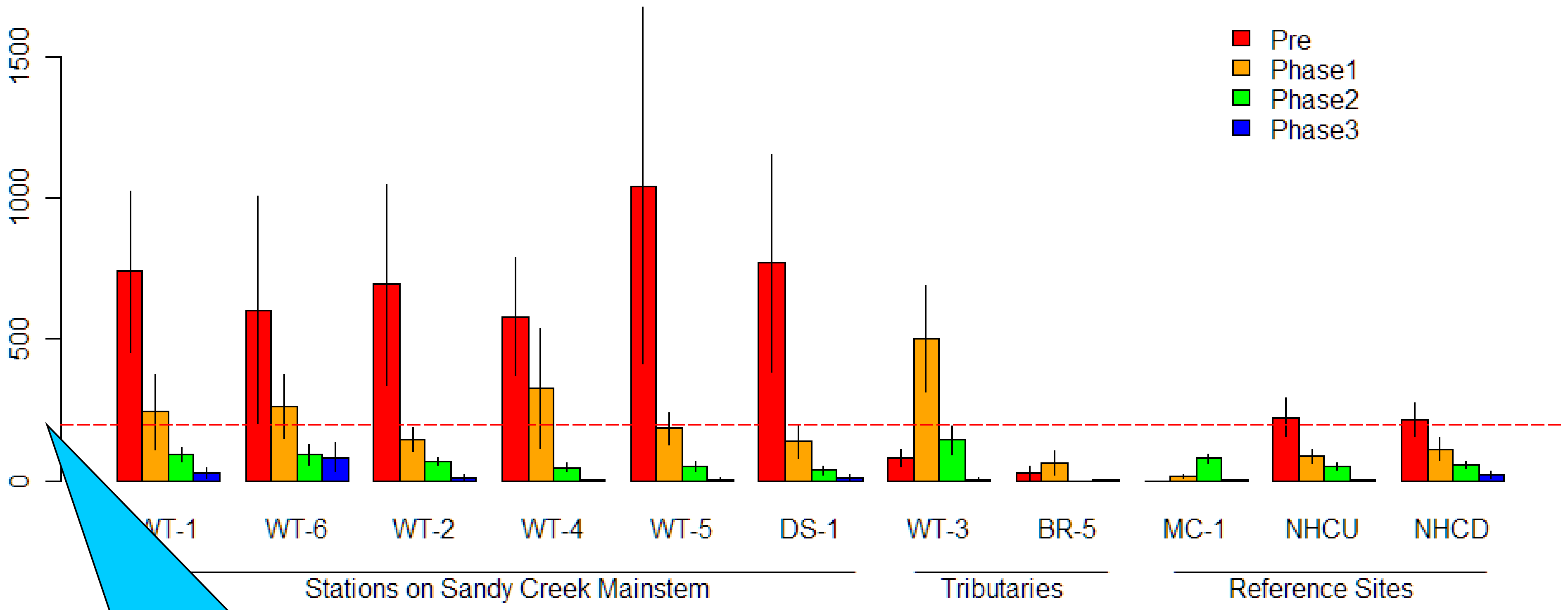
Does Phased Stream and Integrated Wetland Restoration Result in Improved Water Quality and Nutrient/sediment Retention ?

Water Quality Monitoring Stations



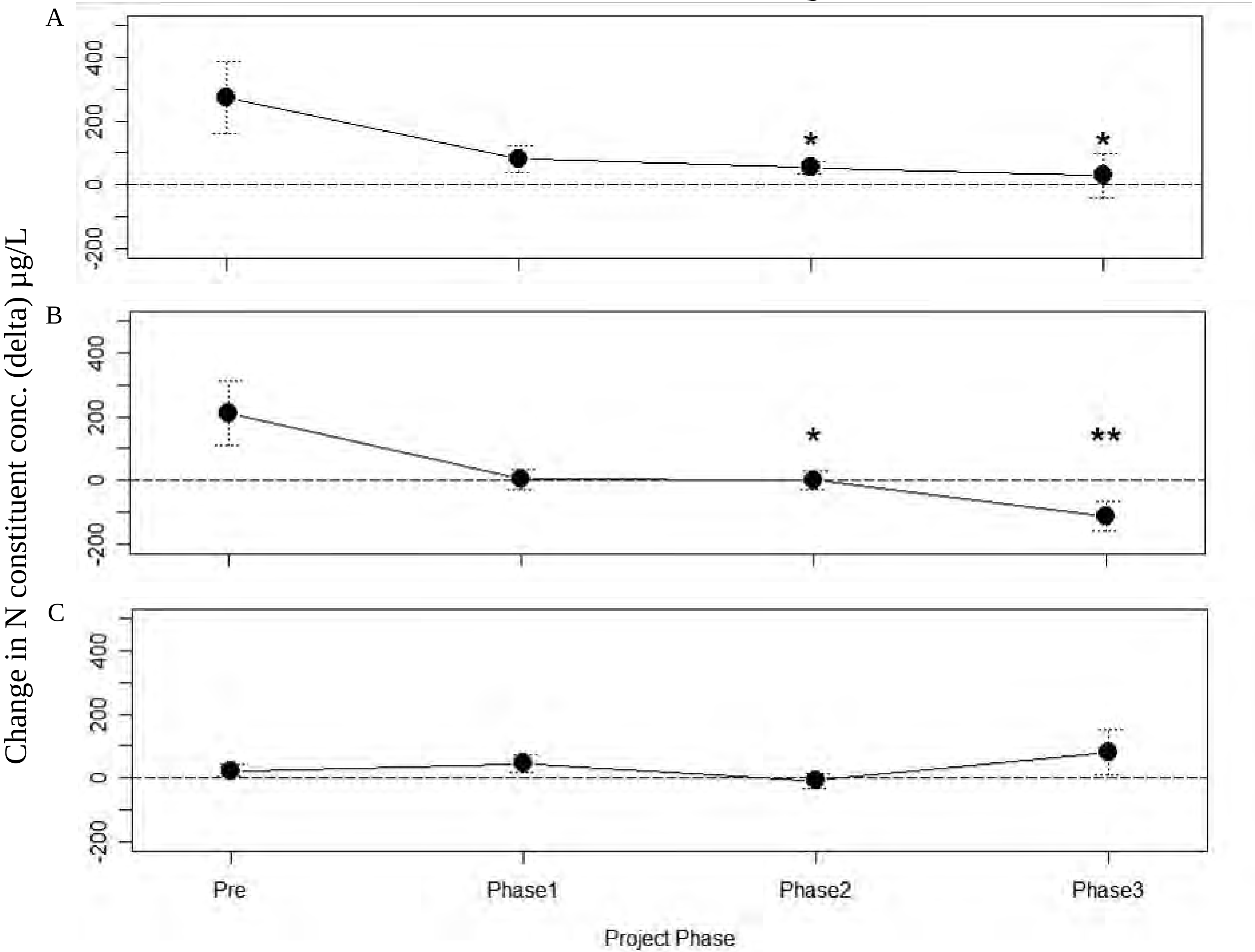
Richardson, C.J. et. al., 2011. *Ecological Engineering* 37:25-39.

Fecal Coliforms



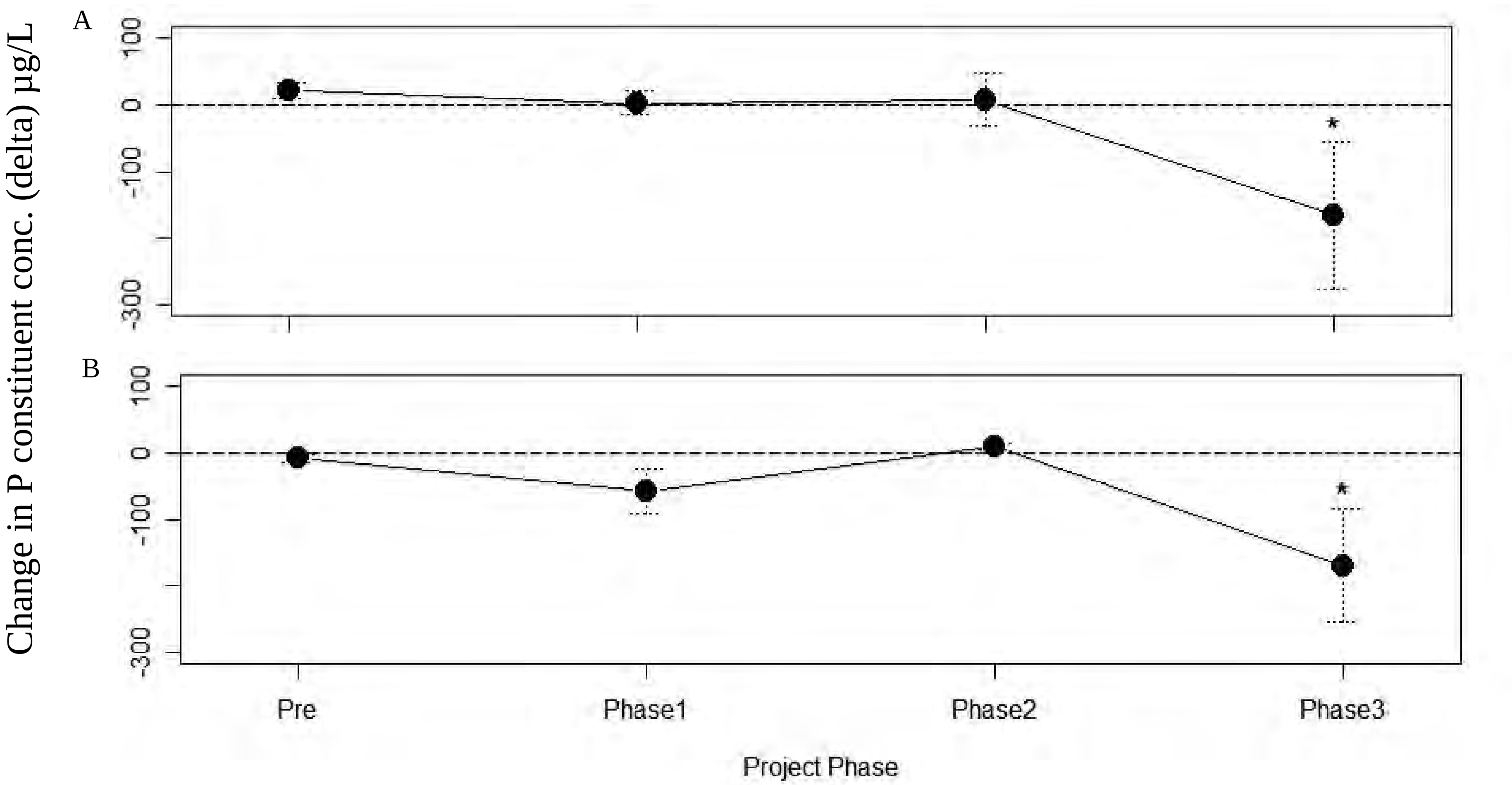
State of North Carolina ambient criteria

Paired Sites Analysis - N



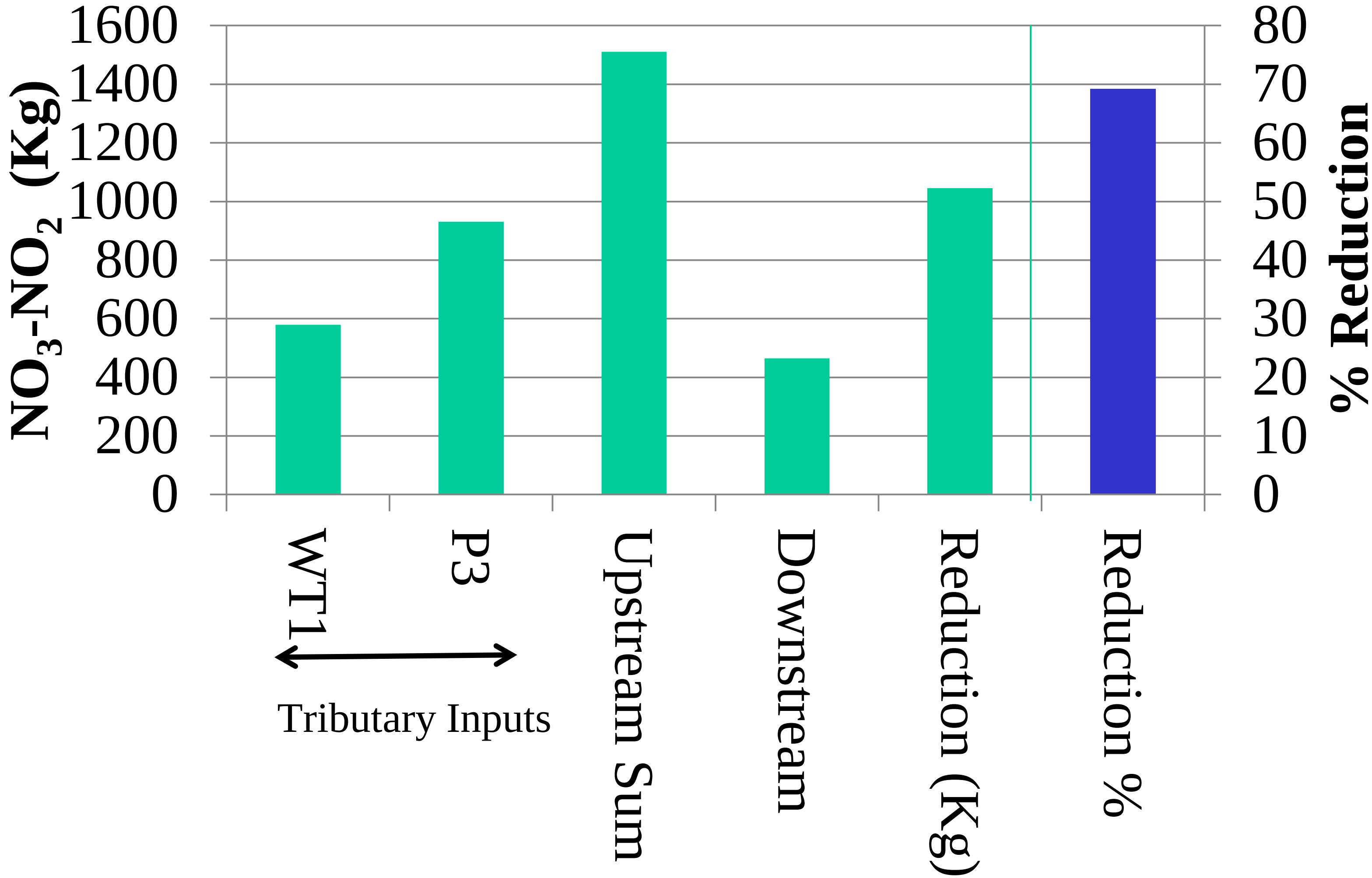
A. total nitrogen, B. (NO3- + NO2-)-N, C. NH4+ -N_

Paired Sites Analysis – P



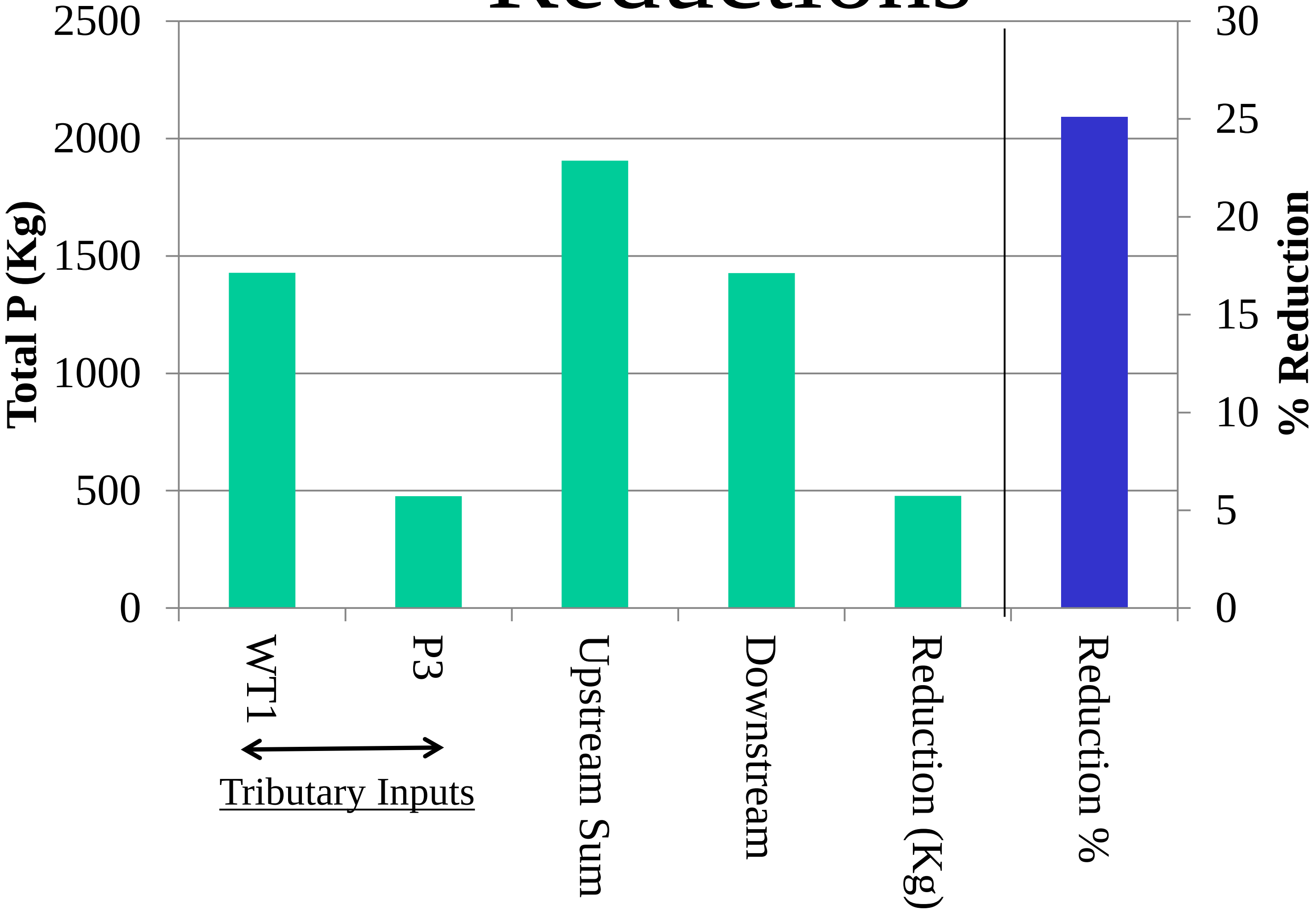
A. total phosphorus, B. Soluble Reactive Phosphorus.

Annual Load and Reduction Nox



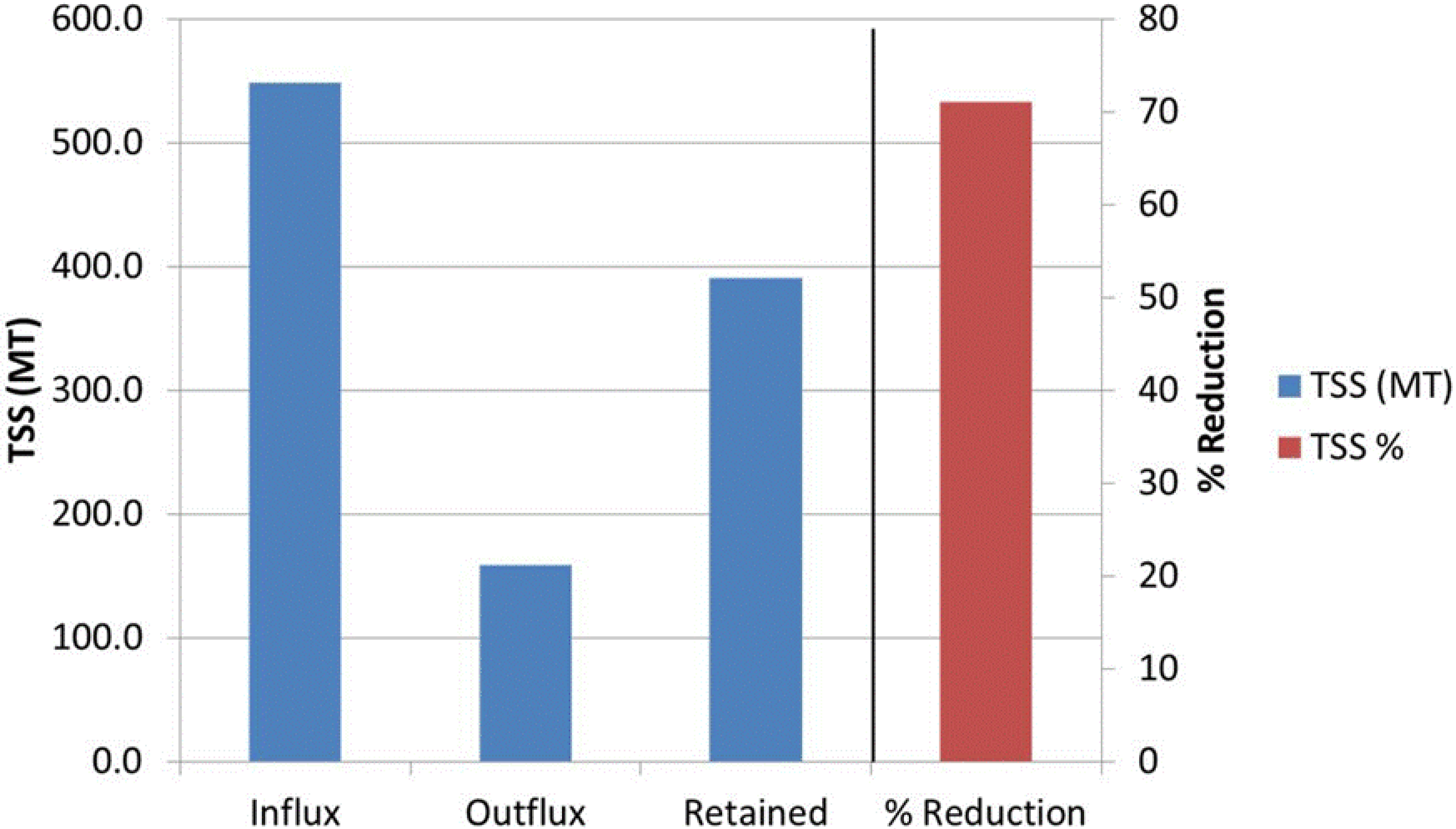
Richardson, C.J. et. al., 2011. *Ecological Engineering* 37:25-39.

Annual Total Phosphorus Reductions



Richardson, C.J. et. al., 2011. *Ecological Engineering* 37:25-39.

TSS Reduction



STORMS FLOWS

Table 1 Summary of catchment area of study catchments in SWAMP and USGS Station 0209722970 Sandy Creek at Cornwallis Rd.

Site	Annual Discharge m^3	Area Ha.	Area Adj. Discharge (mm)	Trib. % of WT5	Discharge Coefficient
SWAMP					
P3D Tributary	210,649	25.9	813*	10.4	0.760*
AN1 Tributary	300,636	83.0	362	14.9	0.315
WT1 Inflow	1,510,216	418.2	361	74.7	0.314
WT5 Outflow	2,021,501	527.1	383	100	0.333
USGS 0209722970	4,368,491	1210.0	361	-	0.314
WT5 as % USGS	46.3	43.6			

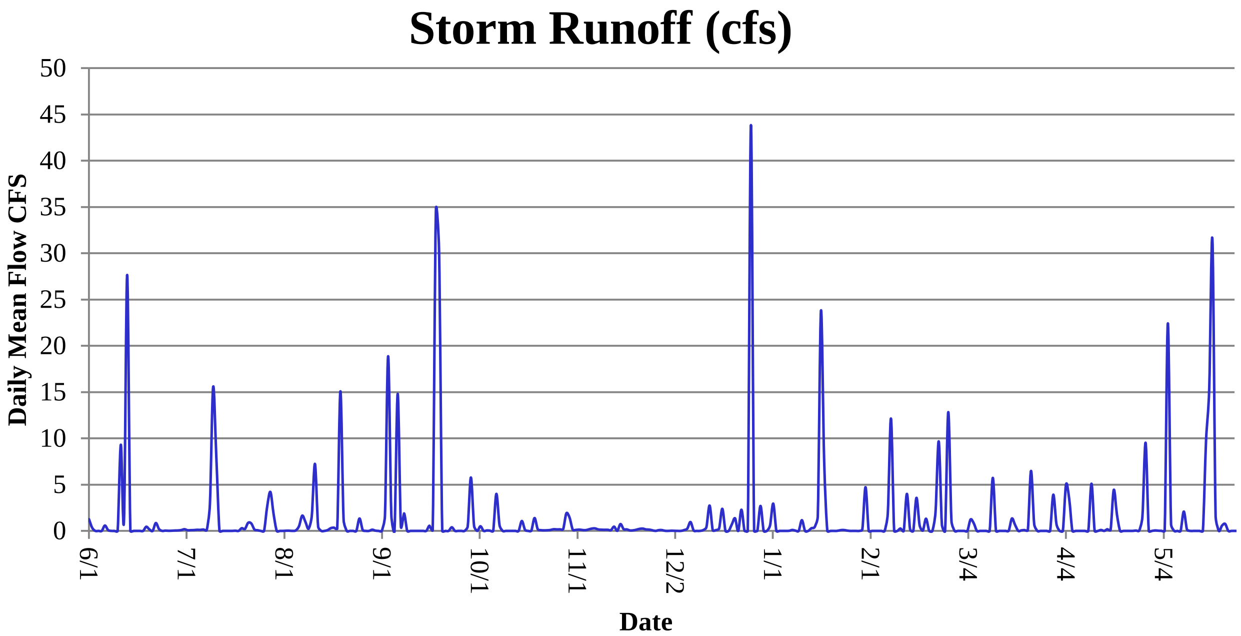
Precipitation 6/1/2012-5/31/2013 = 1151 mm

* Catchment of P3D has significant irrigation of athletic fields that contributes to baseflow

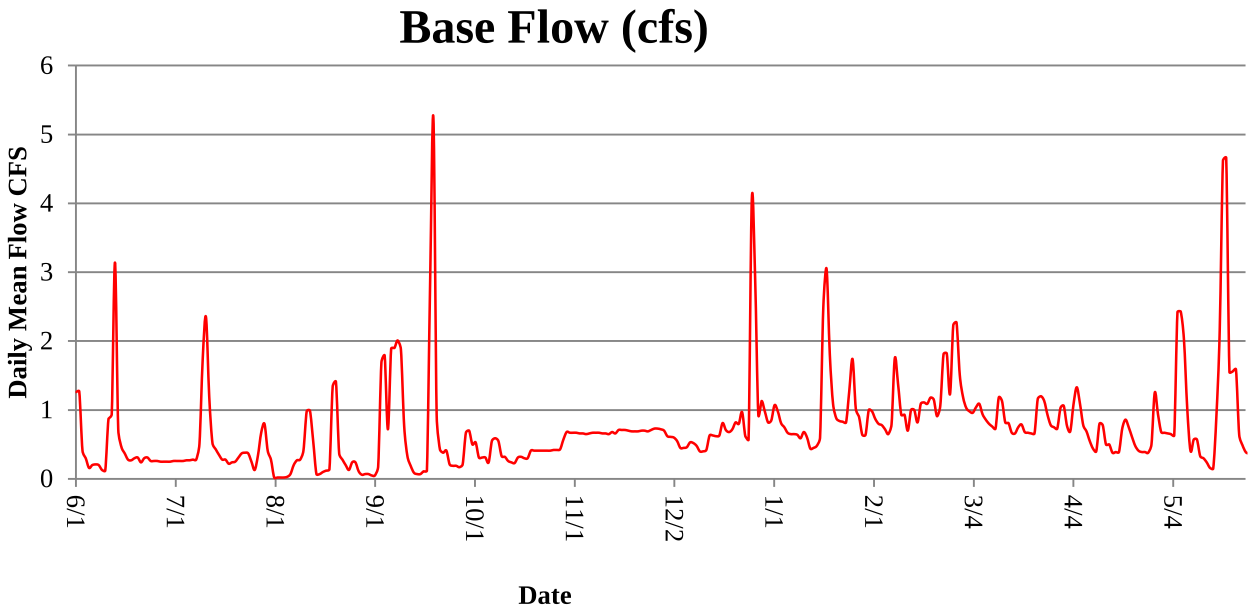
Annual Nutrient Budgets

2012 -2015

Baseflow – Stormflow Separation

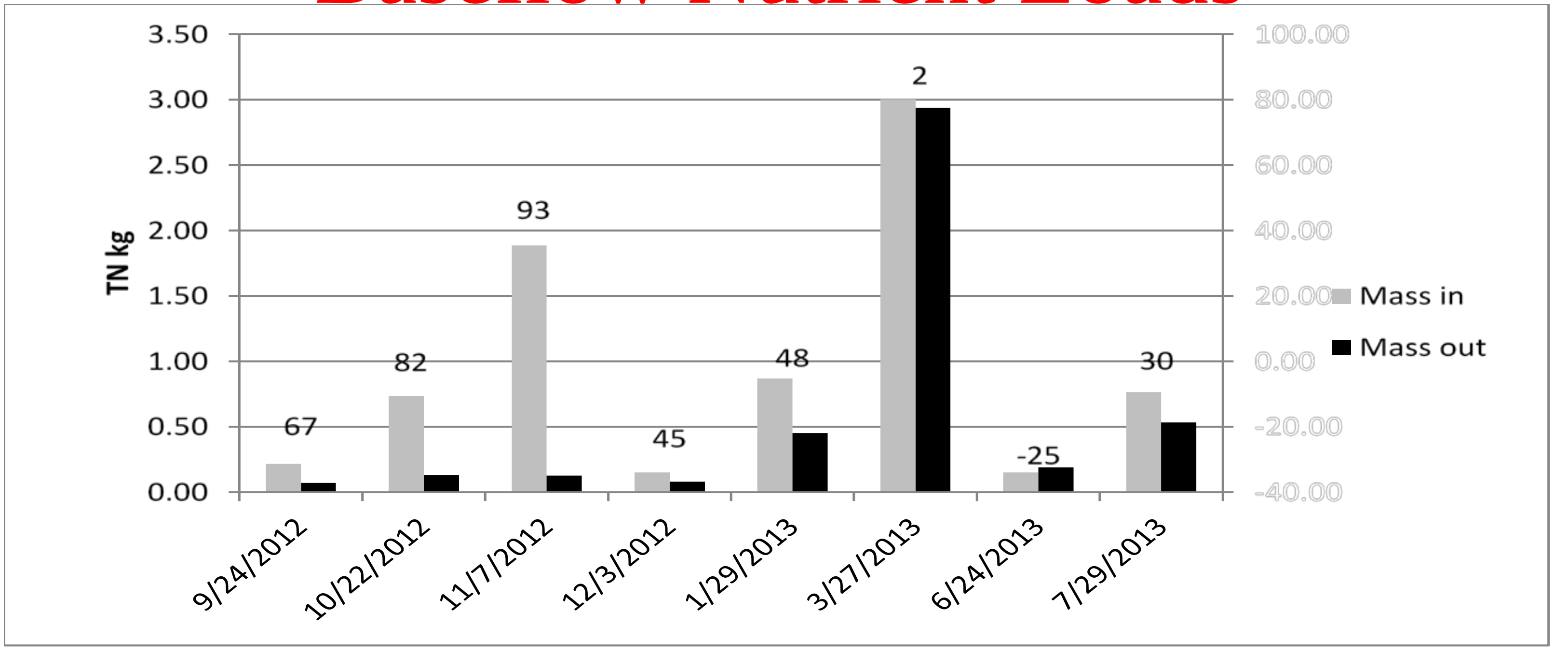


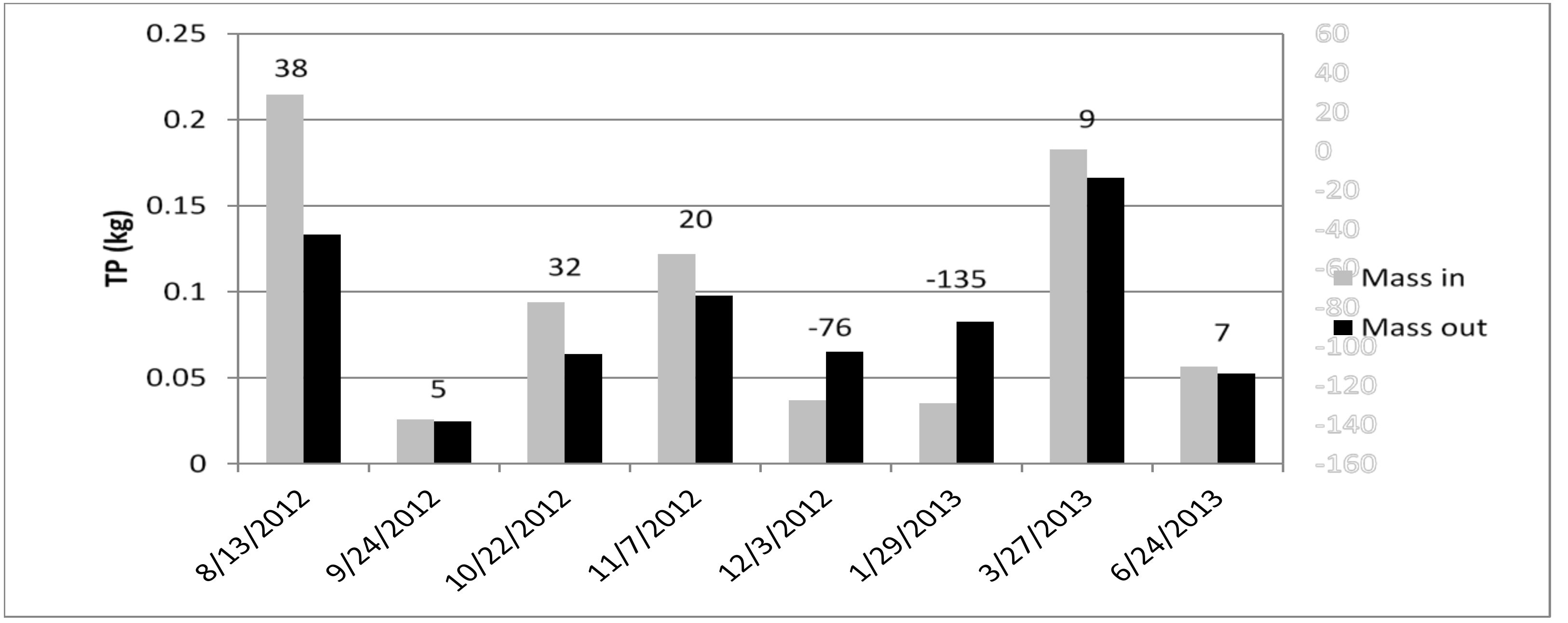
65%



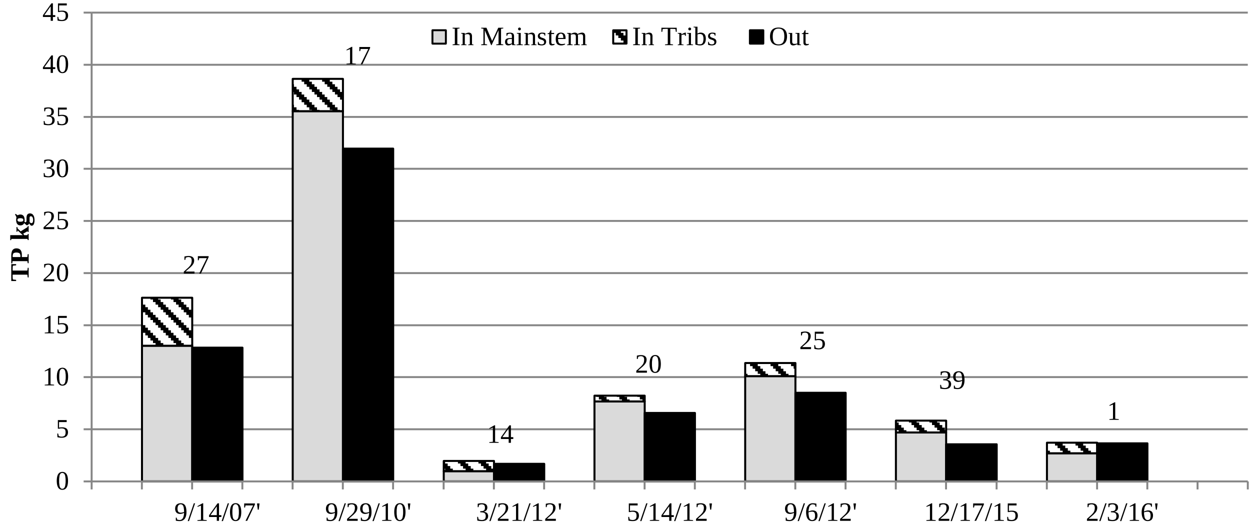
35%

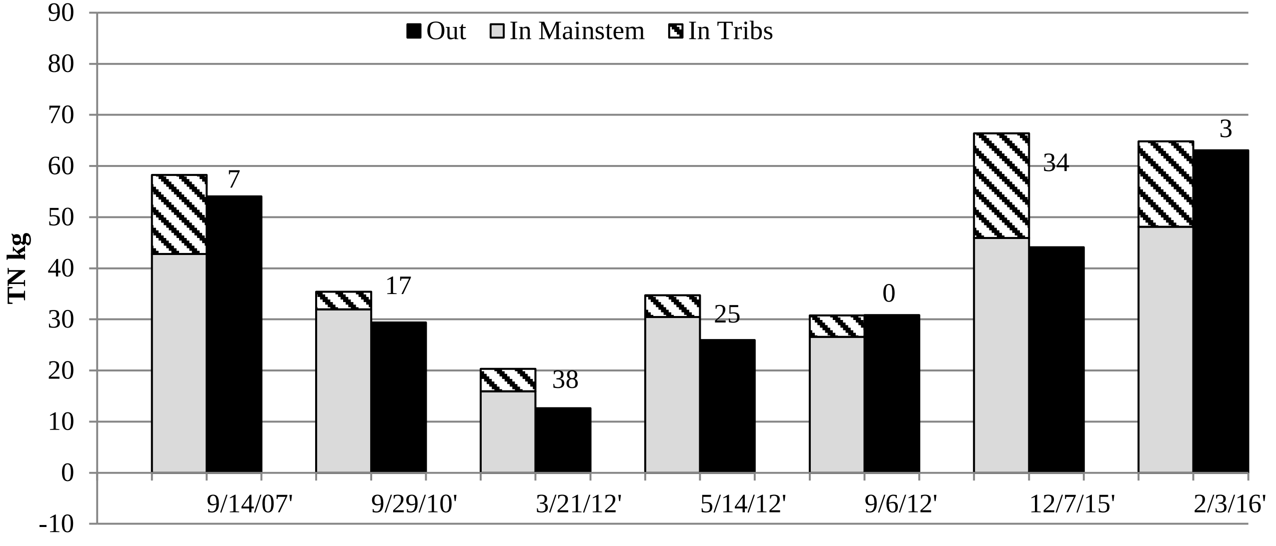
Baseflow Nutrient Loads





Storm Nutrient Loads

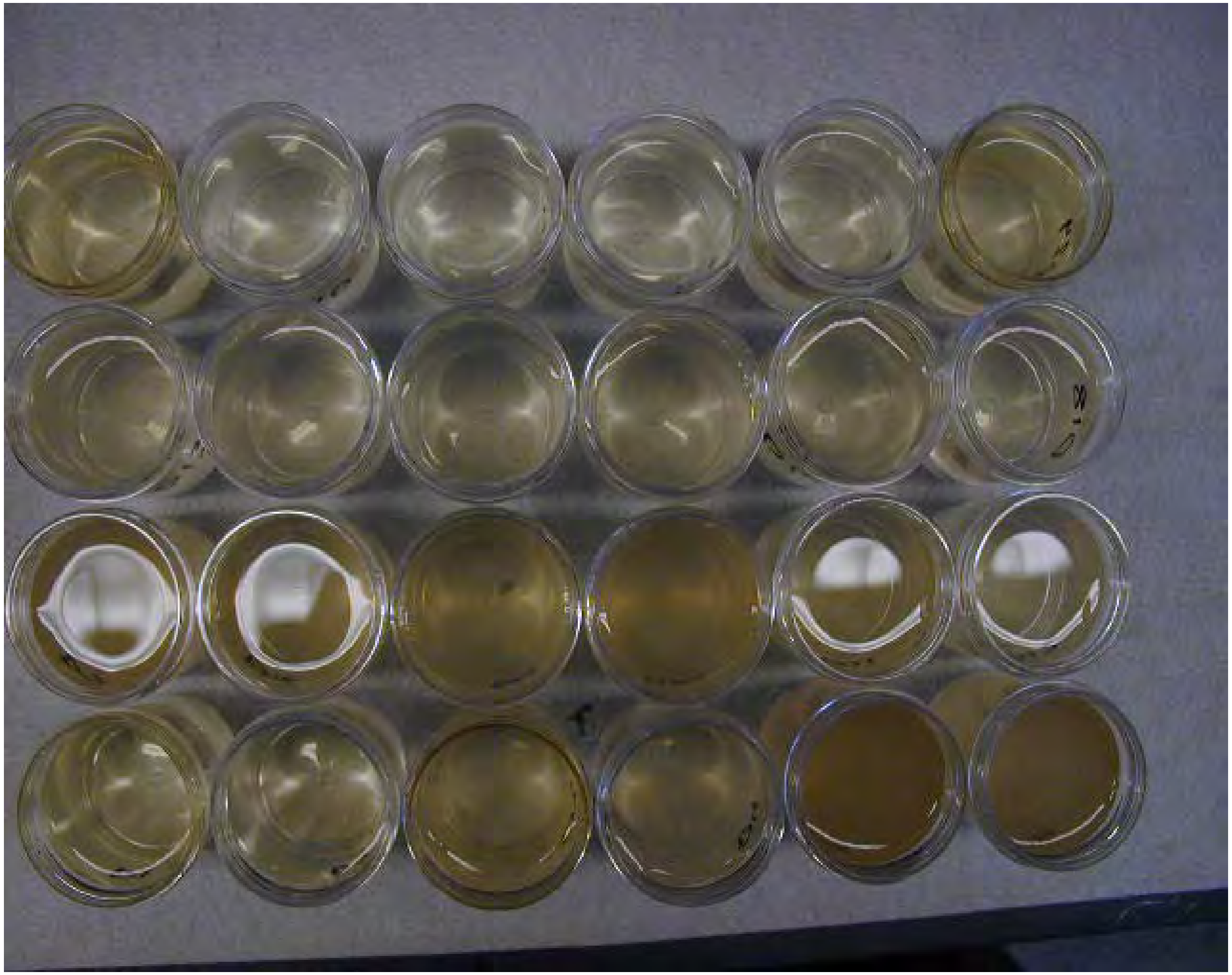




A summary of annual nutrient retention in SWAMP 2011-12. Mass fluxes into and out of SWAMP and the product of stormflow and baseflow EMC's multiplied by annual hydraulic flux during stormflow and baseflow.

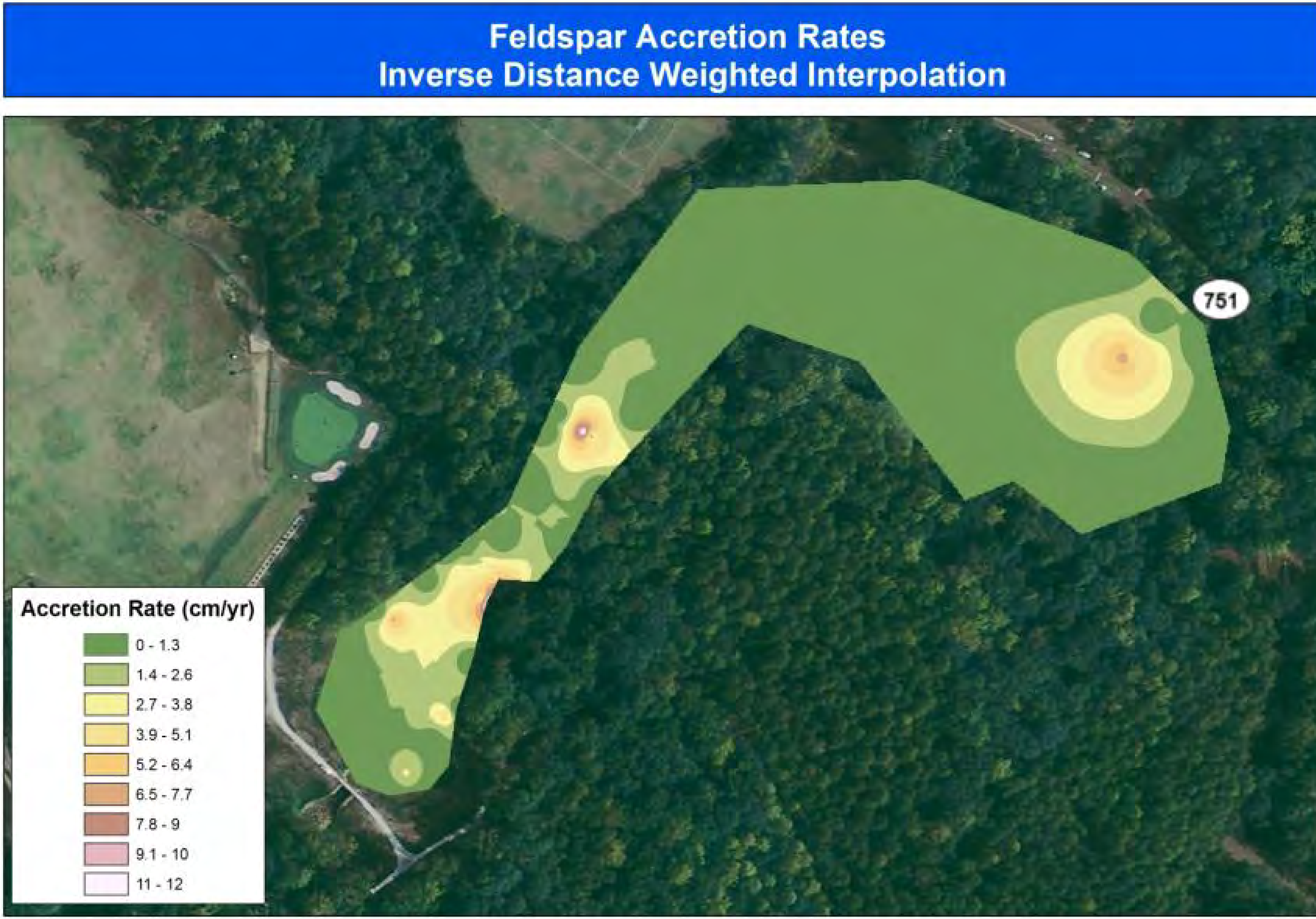
	Disharge	**EMC Conc. ug/l**		**Mass Flux (Kg)**		Retention	
TN	m3/yr	IN	OUT	IN	OUT	Kg/yr	%
storm	1,345,082	616.8	506.0	829.6	680.6	149.0	18.0
base	676,419	641.3	370.7	433.8	250.7	183.0	42.2
Overall	2,021,501	625.0	460.7	1263.4	931.4	332.1	26.3
TP							
storm	1,345,082	230.7	184.0	310.3	247.5	62.8	20.2
base	676,419	64.8	59.7	43.8	40.4	3.5	7.9
Overall	2,021,501	175.2	142.4	354.1	287.9	66.2	18.7

Out



In

Sandy Creek stream Storm water samples collected upstream and downstream in SWAMP



Rates of sediment accretion in SWAMP averaged over 2006-2010

(Richardson et al. 2011)

Sediment Storage in SWAMP

Site	Accretion rate (cm/yr)	Bulk Density (ug/cm^3)	Metric tons of Storage per Year
Lake	1.8	0.67	89
Riparian Floodplain	1.1	0.89	399

Total SWAMP storage 488 MT/year

SWAMP storage since 2006 = 1952 MT

Lessons From First 4 Phases

Water Quality significantly Improved

- Significant decreases in fecal coliform, Nitrate, TN, TP, TSS after 3 phases restored
- Preliminary storm mass balance calculations indicate (NO_3- NO_2)-N loads were reduced by 64% and TP by 28%
- Total annual N (26%) and P load stream reductions (20%) after 4 phases.
- 488 MT of sediments retained Annually, mostly stored in the floodplain wetlands

Conclusions To-Date

- **TN mass removal (kg) is ~ equal for both storm and baseflow**
- **TP removal occurs primarily during storms (sediment P)**
- **TP Removal Rates have decreased slightly since 2011**
  - **Particularly in baseflow samples**
  - **Internal loading from sediment?**
  - **Likely new nutrient sources from new construction in the watershed**
    - **New athletic field drainage, five new buildings on campus**
- **After ten years, SWAMP continues to remove both TN (30%) and TP (20%)**
- **Next Phase:**
  - **Track down increased sources internal/eternal nutrient loads in the aging SWAMP complex**
  - **Test new approach to increase nutrient removal: ANABRANCHING**

Anabranching

(How to Work Like a Beaver)

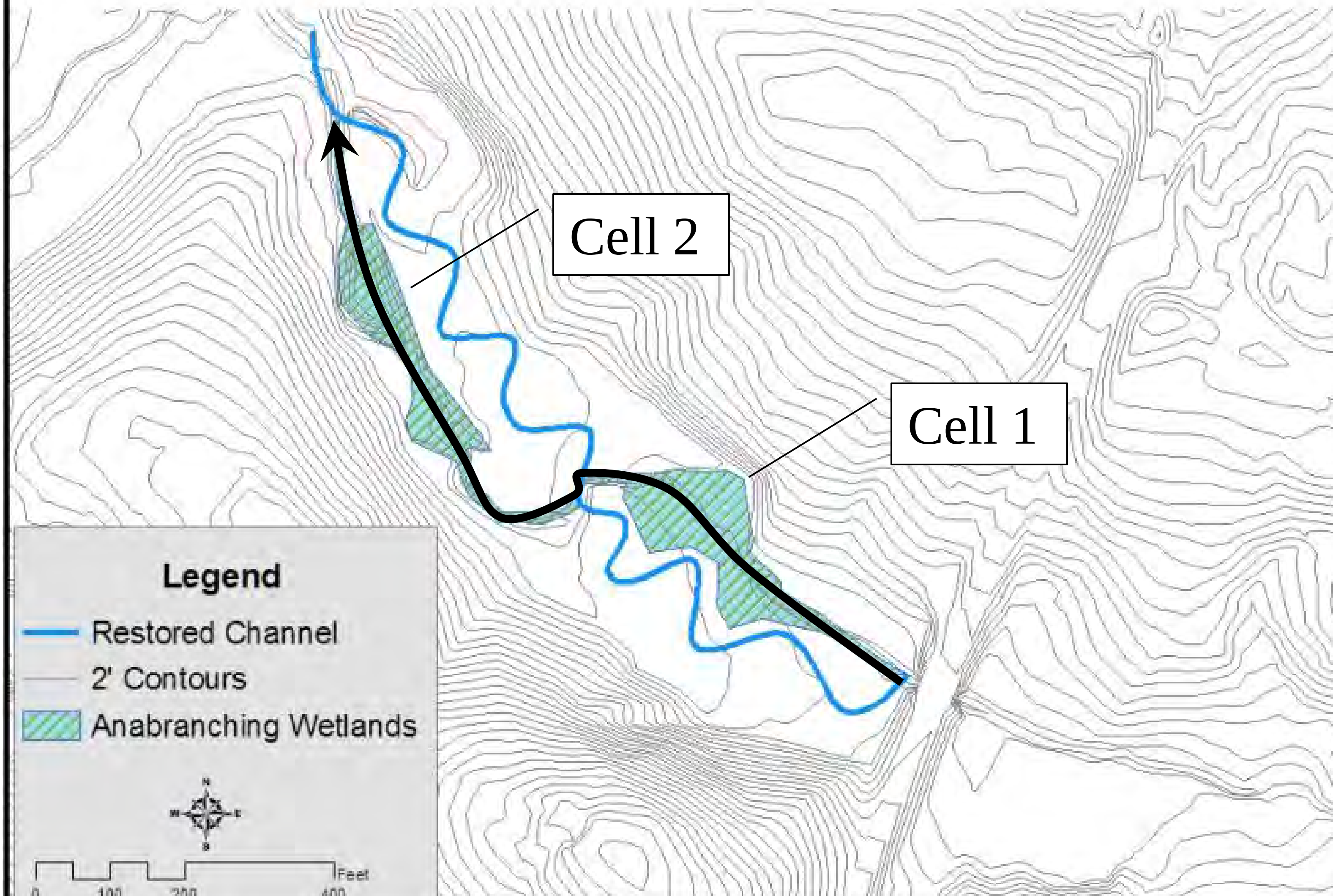
R C Walter, D J Merritts Science 2008;319:299-304

PRESETTLEMENT CONDITIONS

- **forested wetland networks of small streams and low, vegetated islands within the flood zone, In Europe and USA**
- **small, shallow (<1-m) anabranching and chain-of-pool streams with frequent overbank flow**
- **extensive alteration by beaver dams.**

(Walter and Merritts, 2008)

Phase IV Restoration Layout

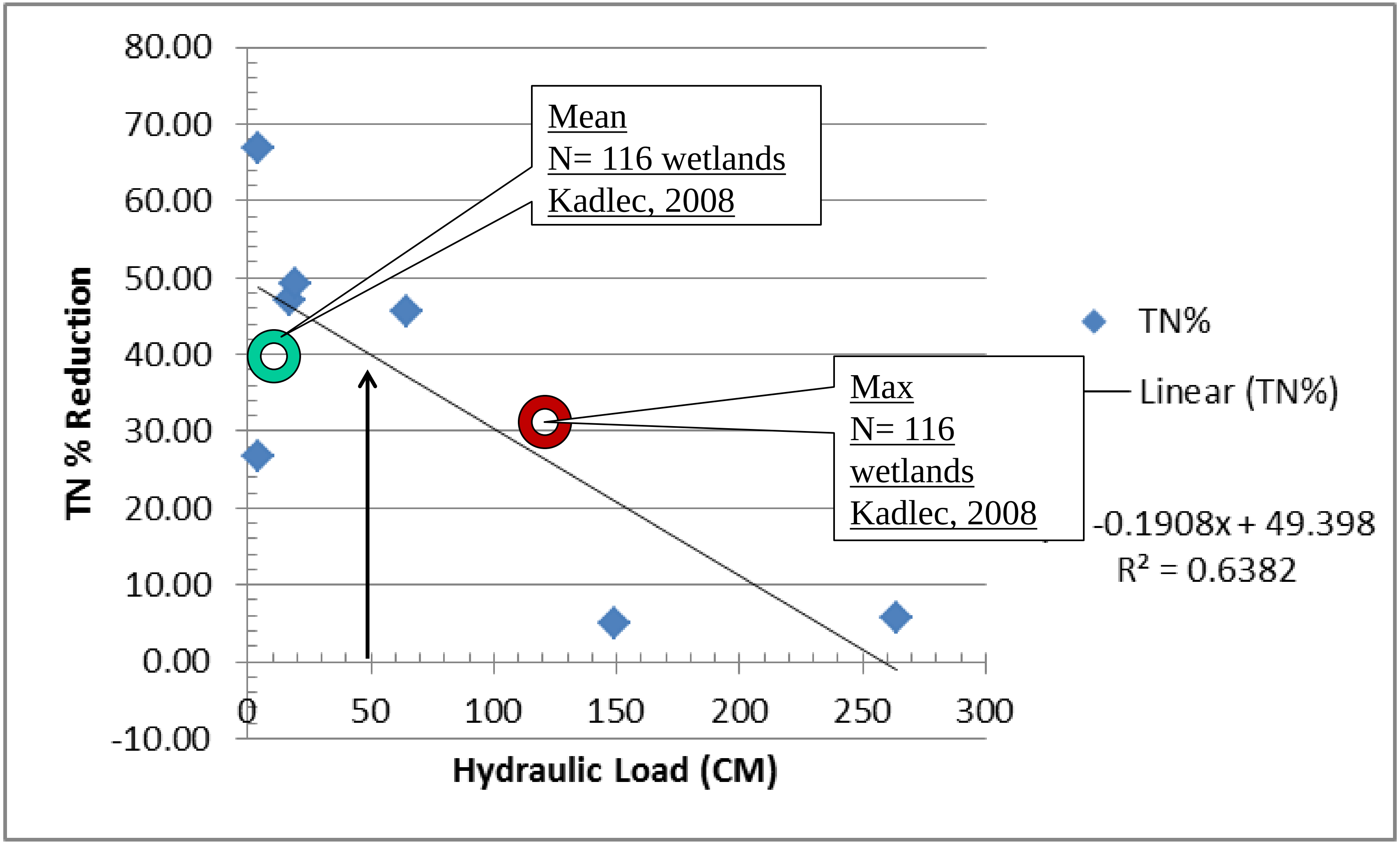


BEFORE-AFTER

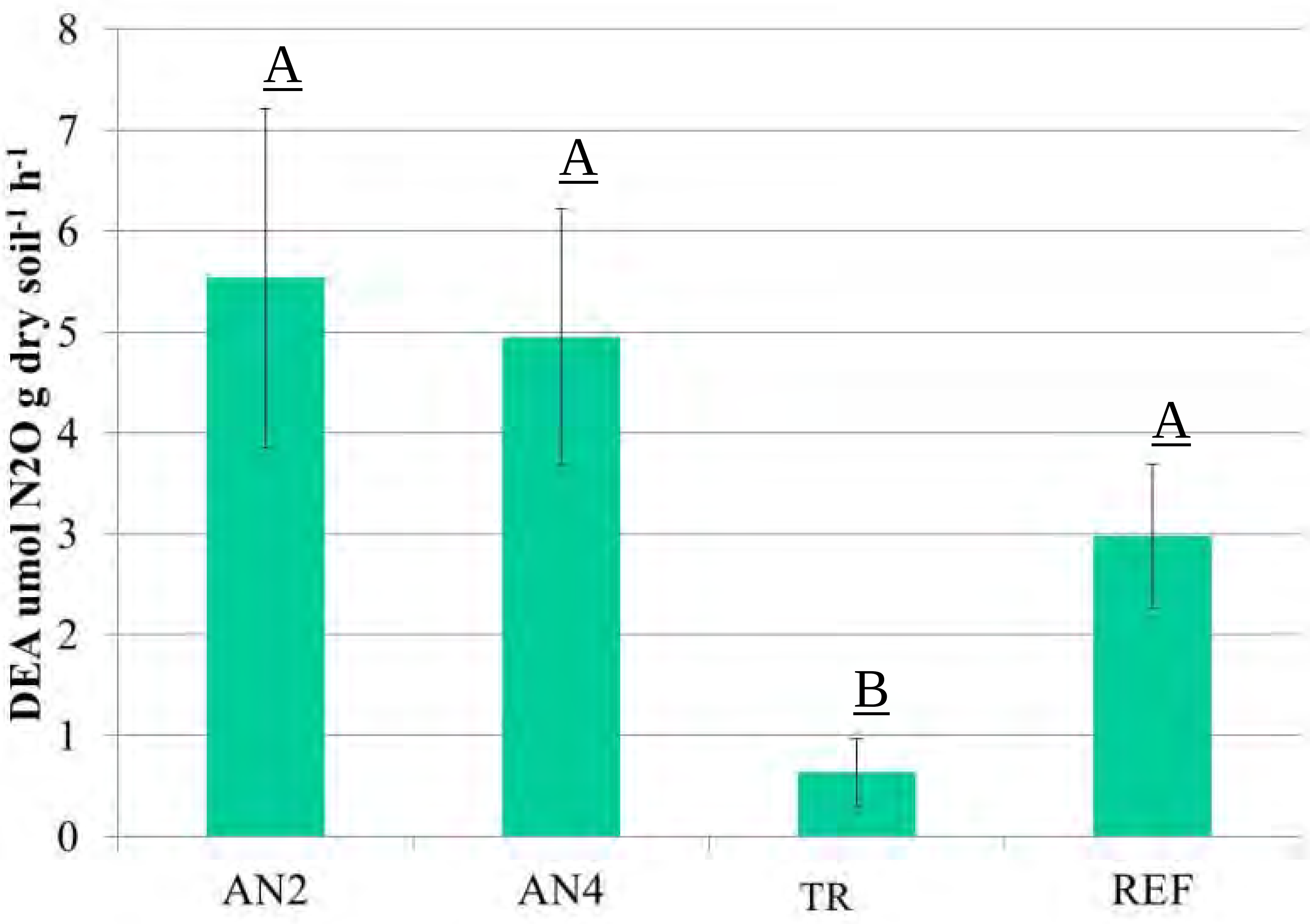
ANABRANCH RESULTS

Water Quality Functions

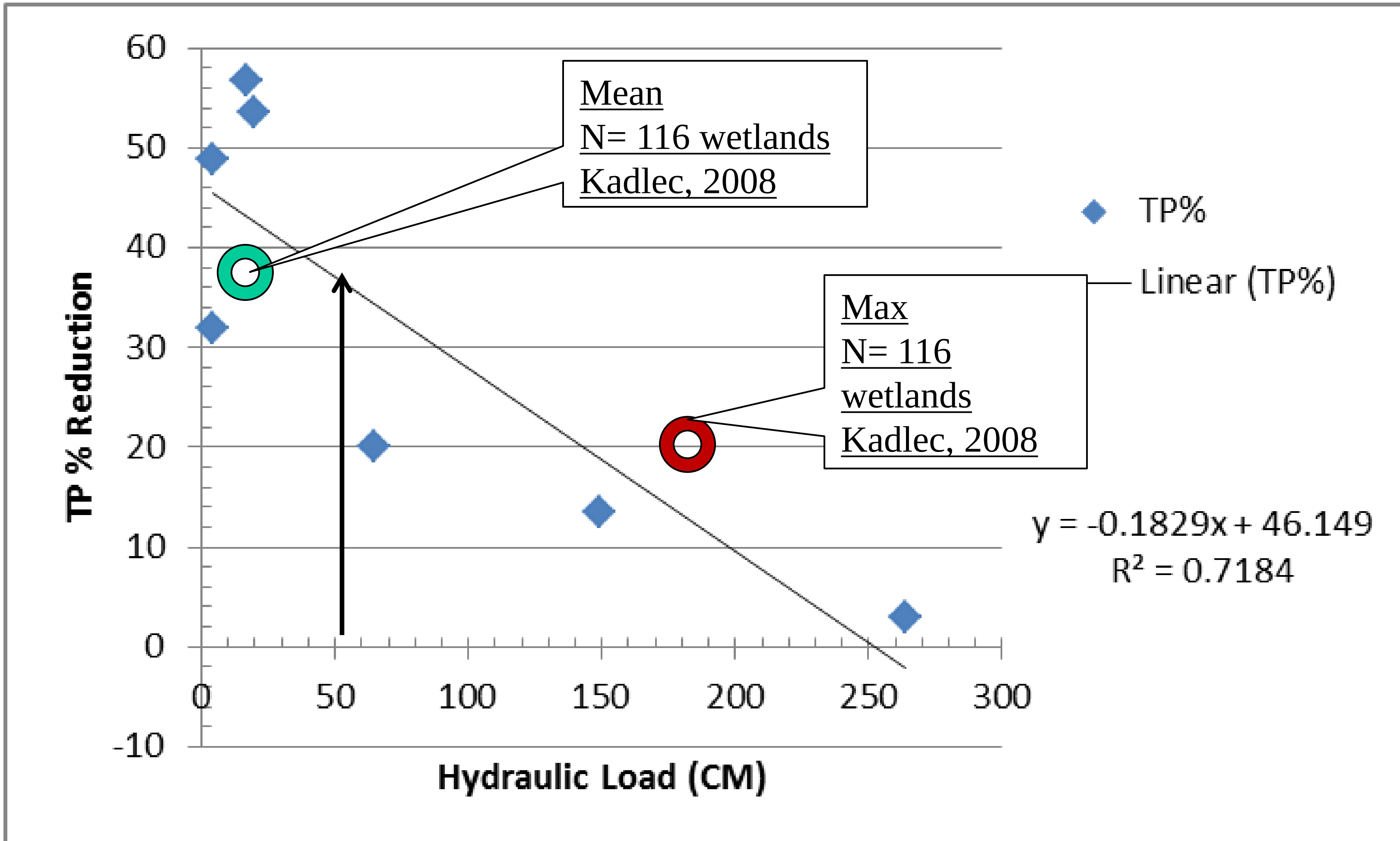
Storm Hydraulic Load v. TN Removal



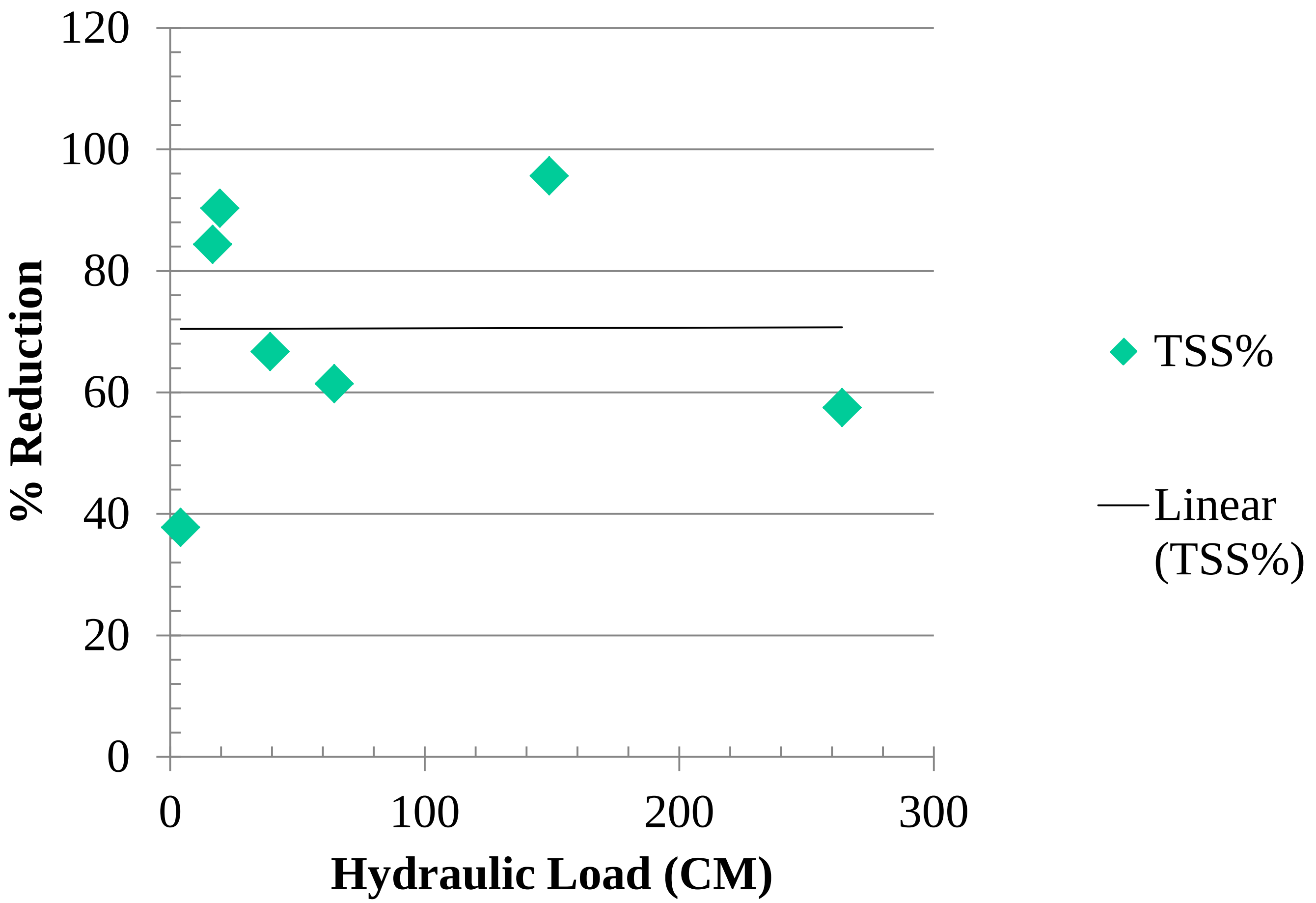
DENITRIFICATION



Hydraulic load v. TP Removal



Wetland Hydraulic Load v. TSS Removal



CONCLUSIONS

- Anabranch wetlands key to increased nutrient reductions
- Systems can reliably achieve 40% reductions in TN and TP under moderate storm loads
- Performance comparable to other constructed surface flow wetlands, nutrient reduction values exceed standard stream restoration approaches, especially in storm events
- Denitrification Potential
    - rates near those of reference wetlands
    - exceeds traditional restoration approaches.

Take Away Message

- **Stream-wetlands complexes (anabranch) are not unnatural systems**
  - **They were a common pre-settlement riparian condition across temperate Europe and North America,**
  - **They are no longer common because of past human impacts and current riparian management to inhibit reestablishment.**
- **Provide high levels of ecosystem functions and services,**
  - **Water quality, habitat (birds, amphibians).**
- **Anabranch wetlands are another approach to restoration.**

Does Restoration increase Vegetation & Animal Diversity ?


Rose-breasted Grosbeak
(*Pheucticus ludovicianus*)
Red-shouldered Hawk
(*Buteo lineatus*)
Birds of SWAMP
118 species
photos by Scott Winton
Northern Flicker
(*Colaptes auratus*)
American Bittern
(*Botaurus lentiginosus*)
Common Yellowthroat
(*Geothlypis trichas*)
Great Blue Heron
(*Ardea herodias*)
Solitary Sandpiper
(*Tringa solitaria*)
Green Heron
(*Butorides virescens*)
Birdwatchers
(*Homo sapiens*)

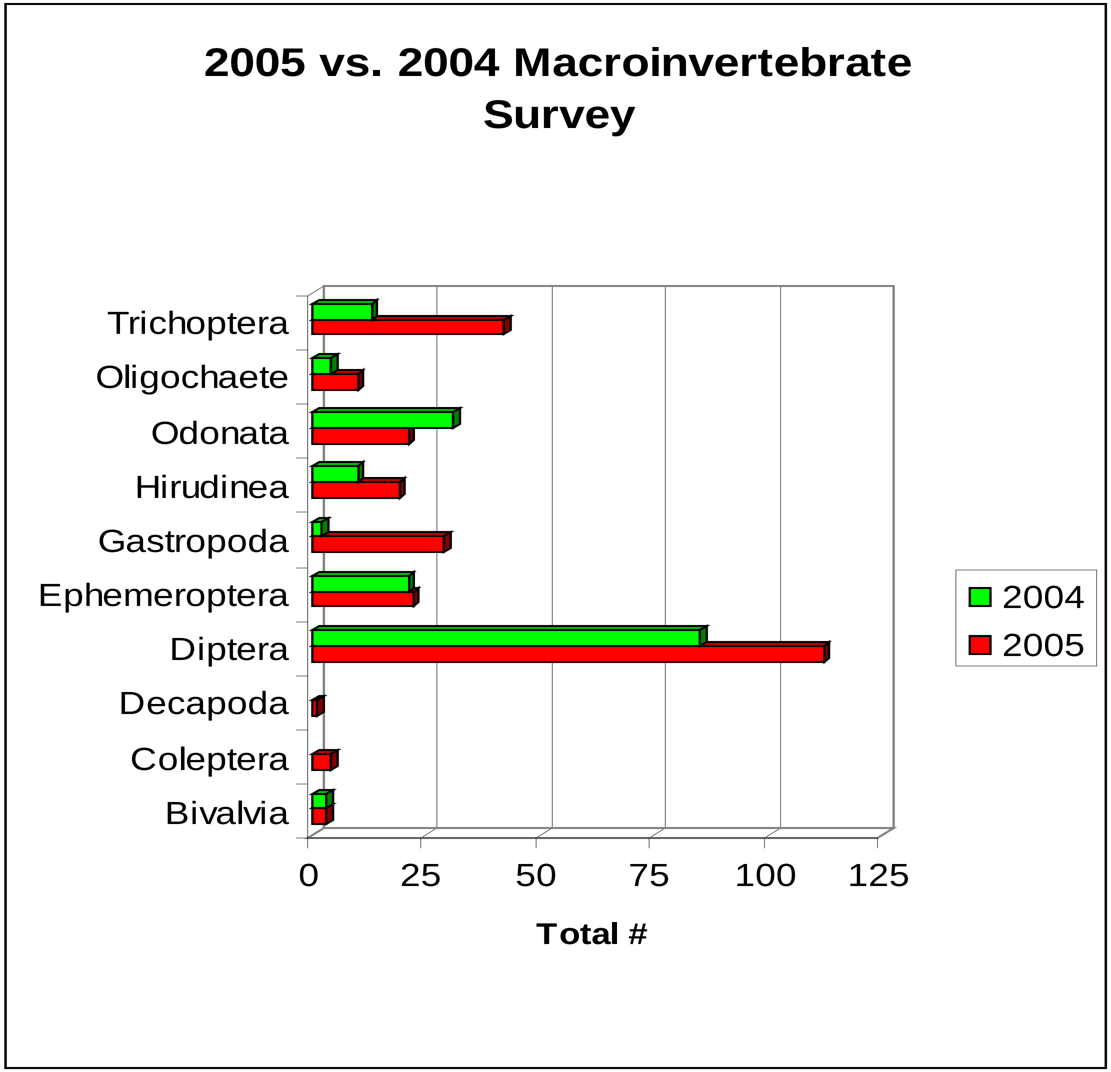
Does Stream Restoration and Improved Water Quality Improve Stream Habitat for Macroinvertebrates ?

Kick Net Sampling

(Jean Still)

A Macroinvertebrate Survey of Sandy Creek in Durham County, NC: A Comparative Study of Post-Restoration and Pre-Restoration Surveys

Water Quality Effects on Macroinvertebrates



2001: 34 Taxa

2005: 89 Taxa

2015: 104 Taxa

(Roberts, 2005)

Macroinvertebrate Feeding Groups

	Gathering Collectors	Filtering Collectors	Predators	Shredders	Scrapers
WT-1	22	30	32	13	4
WT-A	9	34	31	22	8
WT-5	20	1	13	21	3
MC	41	22	29	8	10
PRE	6	4	23	5	4

(Still, 2009)

A Decade + of Restoration Lessons (2003-2015)

- Integrated Stream and Wetland Approaches Needed within the Watershed to Improve Water Quality, Sediment Retention, Wetland Habitat & Ecosystem Services
- No Major Water Improvements Until Multiple Phases of the Restoration Completed in the Watershed
- Runoff and Water Treatment Problems in the Watershed Required Novel Restoration Approaches
- Restoring Floodplain Anabranching Significantly Reduced Stormwater Runoff, Improved Water Quality & Increased Wetland Ecosystem Services

SWAMP Projects

Funded by

The Clean Water Management Trust Fund
NC Ecosystem Enhancement Program
Durham soil and Water Conservation District
EPA 319 Program
NSF
Duke University Wetland Center
Duke Forest
Duke Facilities
USDA

Questions ?

www.env.duke.edu/wetland