The Importance of Headwater Forest Wetlands in North Carolina Water Quality and Biotic Communities

NC Division of Water Quality
Rick Savage – rick.savage@ncdenr.gov
Ginny Baker – virginia.baker@ncdenr.gov

Headwater Wetlands

- Definition – Typically small bowl-shaped wetlands that grade into 1st order streams.
- Location - Upper reaches of watersheds in the Coastal Plain, Piedmont, and Mountain regions of NC.
- Importance – Protects downstream aquatic resources by acting as a natural filtering system for water quality.

Spring Garden

Batchelor

Nahunta

Kelly Rd

Study Objectives

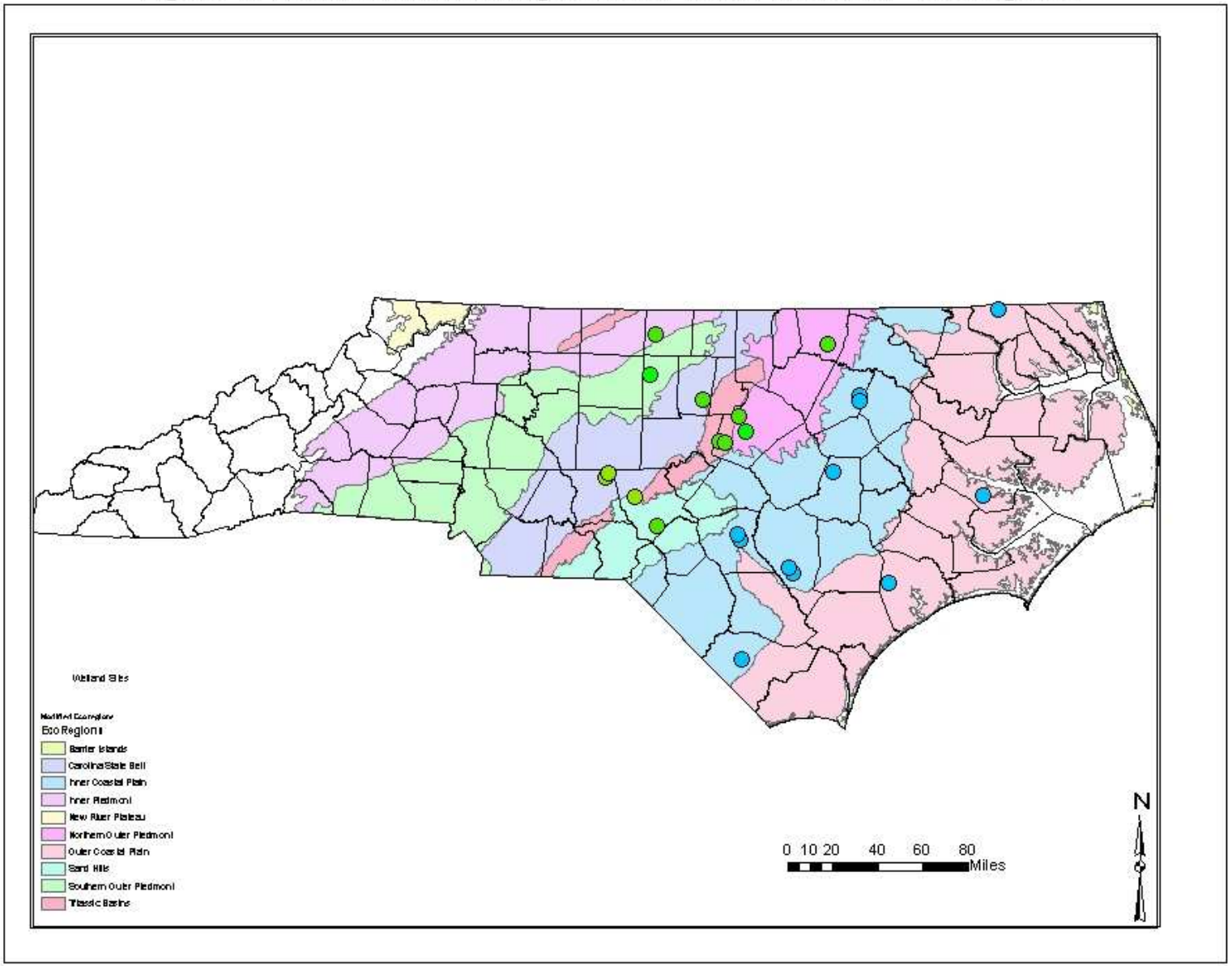
- Design and implement a wetland monitoring program for NC which assesses the change of wetland quality and function along a disturbance gradient.

- To characterize physical, chemical, and biological features of headwater wetlands.

- To determine whether headwater wetlands effectively improve water quality and how watershed development affects water quality.

- Develop Indices of Biotic Integrity (IBIs) specific for NC- A summary index composed of multiple biological indicators called metrics.

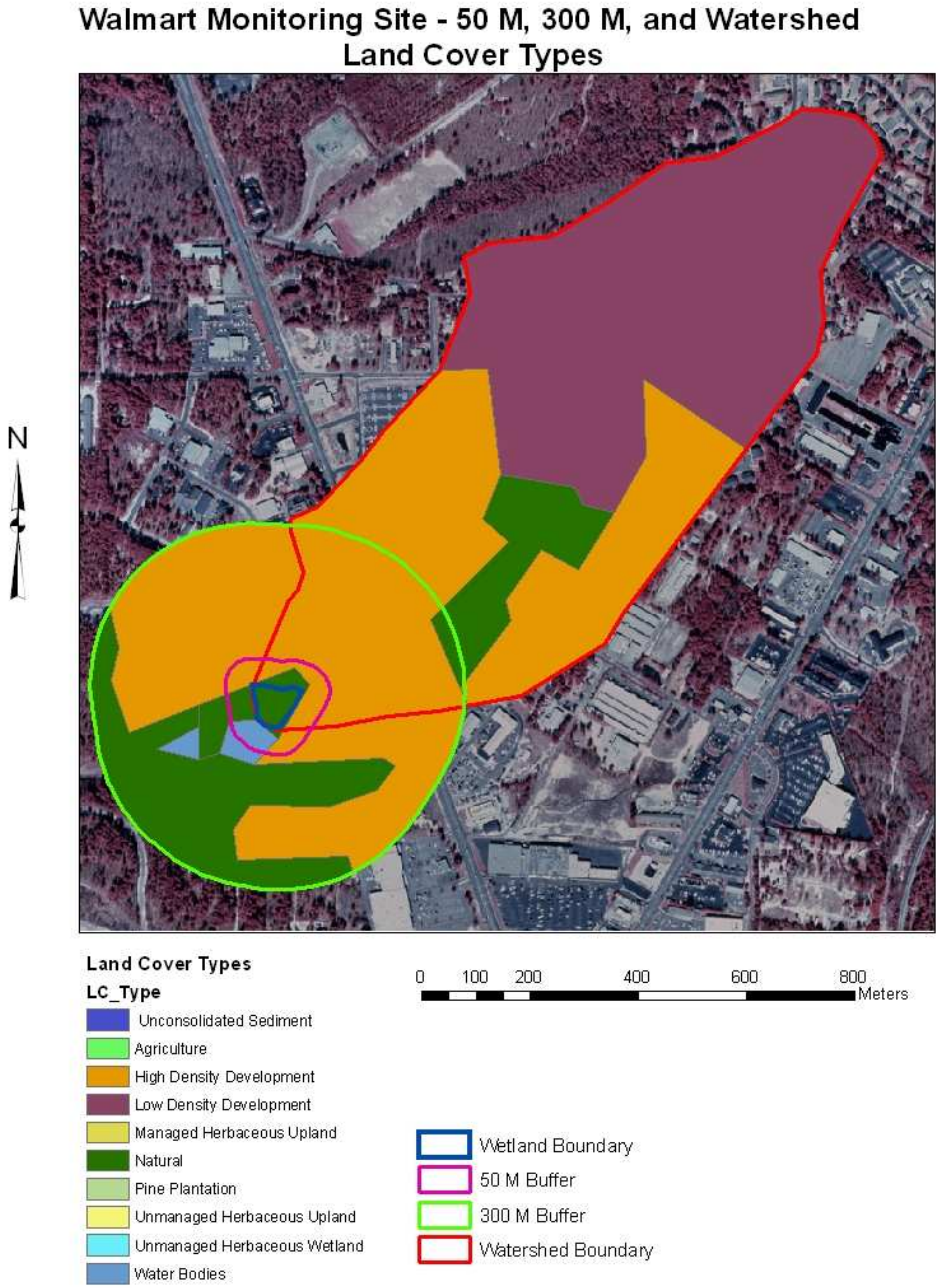
Figure 1 Wetland Monitoring Sites in North Carolina Ecoregions



Wetland Monitoring Methods

- Level I - Use of remote sensing techniques and / or GIS mapping.
- Level II – Rapid on the ground wetland assessments.
- Level III – Intensive, long-term, on the ground survey methods (biological, chemical, and physical monitoring).

Level I - GIS Analysis Disturbance Measurement and Development Index (LDI)



Level II- Rapid Assessment Method ORAM

Ohio Rapid Assessment Method (ORAM) v. 5.0

1. Wetland Area
2. Upland buffers and surrounding land-use
3. Hydrology
4. Habitat Alteration and Development
5. Plant Communities, Interspersion, microtopograpy

Level III Intensive Monitoring Methods

- Physical and Chemical Attributes
  - Water Quality
  - Hydrology
  - Soils
- Biotic Communities
  - Amphibians
  - Macroinvertebrates
  - Plants

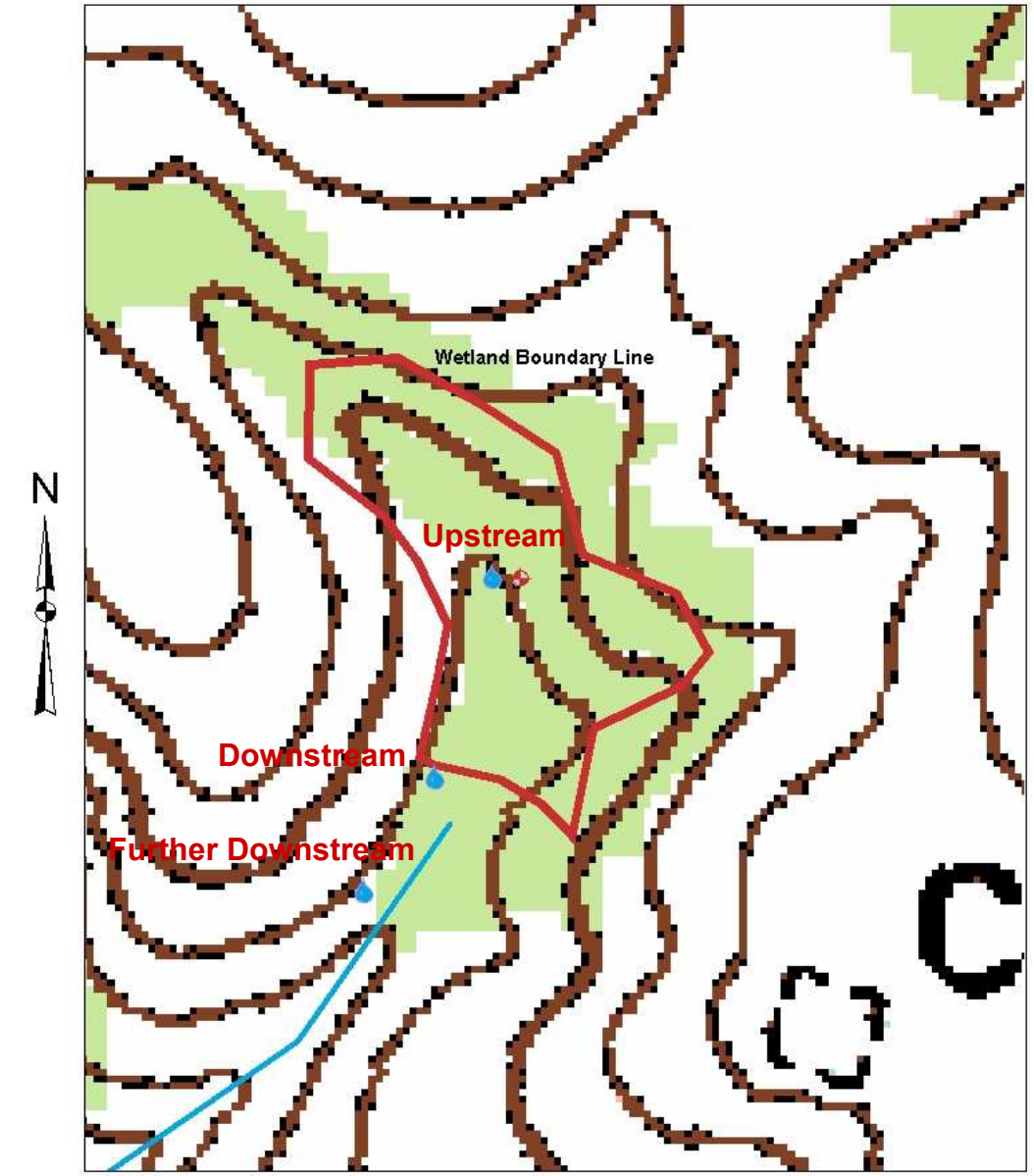
Physical and Chemical Surveys

Water Quality

Hydrology

Soils

Hog Farm Upper



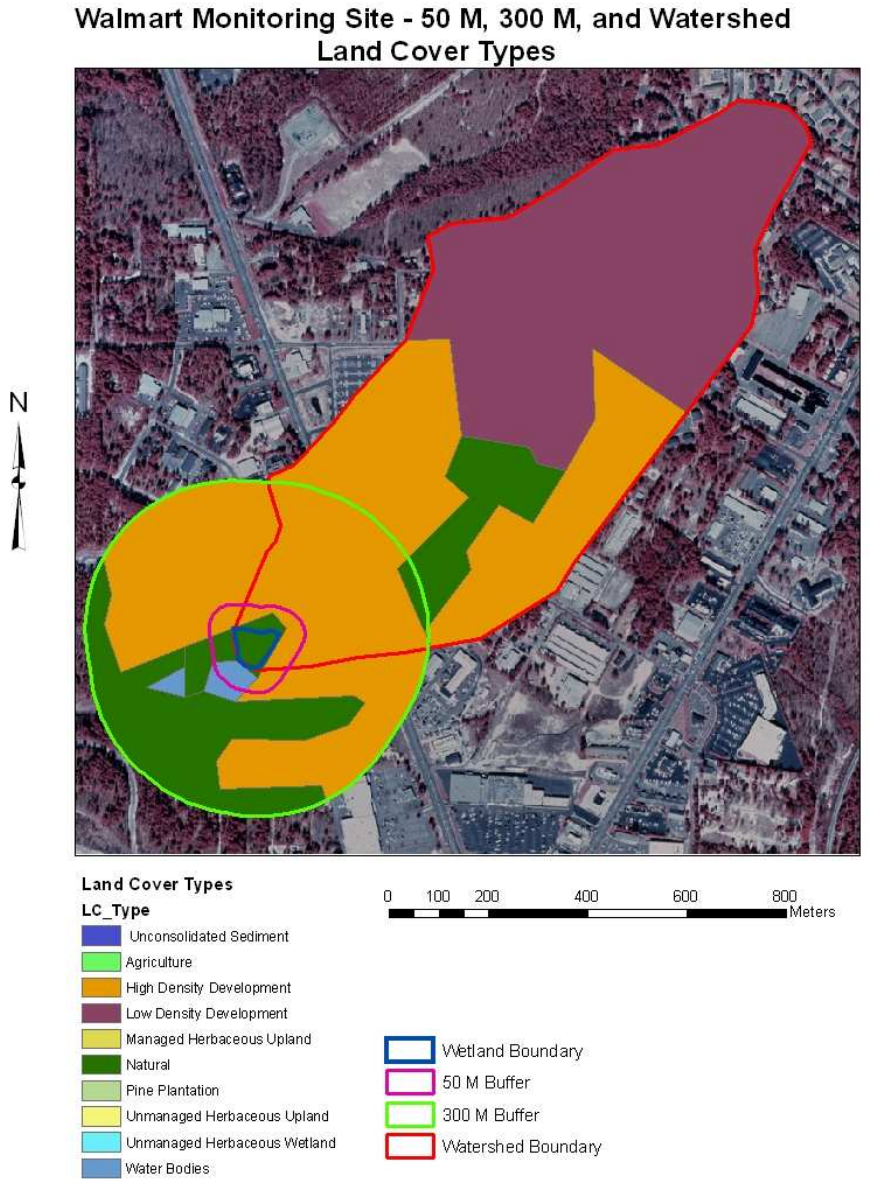
Watershed Affect on Headwater Wetland Water Quality

$$LUI_{Total} = \sum \%Lui * LUIi$$

- LUI_{Total} = LUI Ranking for landscape unit ***i***
- $\%Lu_i$= percent of the total area of influence in the land use ***i***
- land use i LUI_i=landscape development intensity coefficient for land use

Headwater Wetland Landcover Type and LUI Coefficient Values

Land Cover Type Coefficient (LUI_i)	*LUI*
Natural Areas	1
Water Bodies	1
Unmanaged Herbaceous Upland	2
Unmanaged Herbaceous Wetland	2
Managed Herbaceous Wetland	2
Cultivated	4
Unconsolidated Sediment	4
Low Intensity Development	5
High Intensity Development	8
High Intensity Development	8



To Determine the Watershed affect on Headwater Wetland Water Quality

Results

- Significant correlation between Watershed LUI scores and magnesium, Nitrite + Nitrate, and Fecal Caliform (p-value<0.05) for all water quality samples (surface and pore water) and surface water quality samples.

Conclusion

- There is a direct correlation between the headwater wetland water quality and the condition of the surrounding watershed.

Headwater Wetland
Water Quality – with ORAM as disturbance gradient

Analysis Method

- Ohio Rapid Assessment Method (ORAM v. 5.0, Ohio EPA 2001) was used to calculate a disturbance score for each site. ORAM assesses a site's size, 50m-buffer condition, hydrology, habitat, and plant community quality and interspersion, and microtopography.
- Correlation Analysis was run for each site's ORAM score against each site's 19 different water quality parameter results.

Results

- Significant correlation ($p<0.05$) between ORAM scores and calcium, magnesium, N+N, Special Conductivity, and Zinc for all water quality samples (surface and pore water and surface only).
- Significant correlation ($p<0.05$) between ORAM scores and ammonia, fecal coliform, and zinc for surface water quality samples only.

Water Quality Station Comparisons to Determine Headwater Wetland Filtering Capacity

- Water Quality Sampling Stations
  - UP - Upstream
  - DN - Downstream (located 200 feet down stream from Upstream water quality station)
  - FD - Further Downstream - (located another 200 feet down stream from Downstream water quality station, 5 sites in Coastal Plain only, sampled last 2 quarters)
- Water Quality Station Comparisons
  - UP-DN – Upstream compared to Downstream
  - UP-FD – Upstream compared to Further Downstream
  - DN-FD – Downstream compared to Further Downstream

Regional Sample Station Location Comparison by Site of Water Quality Parameter Means

All Water Quality Results

Station Comparisons	Piedmont	Coastal Plain			
	UP-DN	UP-DN	UP-FD	DN-FD	Total Stations
Improvement	130	117	73	66	**386**
No Improvement	94	88	17	24	**223**
Total Stations	224	205	90	90	**609**
Chi Square Results	**P=0.016**	**P=0.04**	**P<0.0001**	**P<0.0001**	

Surface Water Quality Results

Station Comparisons	Piedmont	Coastal Plain			
	UP-DN	UP-DN	UP-FD	DN-FD	Total Stations
Improvement	104	104	55	66	**329**
No Improvement	91	101	35	24	**251**
Total Stations	195	205	90	90	**580**
Chi Square Results			**P=0.03**	**P<0.0001**	

Blue - Water Quality **Improved**

Red - Water Quality showed **No Improvement** (stayed the same or became worse)

Headwater Water Quality
Individual Site Analysis

- 21 of 23 sites showed statistically significant improvement on at least one water quality measure
- 10 of 23 sites showed statistically significant improvement on at two or more water quality measure
- Only 2 sites had statistically significant results showing water quality measures degrading

Water Quality Parameter Station Comparisons for Individual Sites

Site Name	Parameter	Wilcoxon / Kruskal-Wallis P-Value	Significant Station Comparison
Batchelor	Specific Conductivity	0.009	**UP-DN**
Battle Park	Ammonia	0.0833	**UP-DN**
Battle Park	Dissolved Oxygen (%)	0.0833	**UP-DN**
Battle Park	Dissolved Oxygen (mg/L)	0.0833	**UP-DN**
Black Ankle Powerline	Dissolved Oxygen (%)	0.0495	**UP-DN**
Black Ankle Powerline	Dissolved Oxygen (mg/L)	0.0495	**UP-DN**
Boddie Noell	Dissolved Oxygen (%)	0.0641	**UP-DN**
Boddie Noell	Dissolved Oxygen (mg/L)	0.0641	**UP-DN**
Boddie Noell	Lead	0.0491	**UP-DN**
Boddie Noell	Zinc	0.0603	**UP-DN**
Cox	TKN	0.0642	UP-DN & **DN-FD**
Duke Forest	TKN	0.0833	**UP-DN**
East Fayetteville North	Copper	0.0979	UP-DN & **DN-FD**
East Fayetteville North	pH	0.0995	**UP-DN**
East Fayetteville North	Specific Conductivity	0.0244	**DN-FD**
East Fayetteville South	Magnesium	0.0635	**UP-DN**
East Fayetteville South	pH	0.0861	**UP-DN**
East of Mason	Fecal Coliform	0.0339	UP-DN
Fire Tower	Calcium	0.0731	**UP-DN**
Fire Tower	Copper	0.0021	**UP-DN**
Fire Tower	Dissolved Oxygen (%)	0.0027	**UP-DN**
Fire Tower	Dissolved Oxygen (mg/L)	0.0027	**UP-DN**
Fire Tower	Lead	0.0074	**UP-DN**
Fire Tower	Magnesium	0.0758	**UP-DN**
Fire Tower	pH	0.0026	**UP-DN**
Fire Tower	Phosphorus	0.0037	**UP-DN**
Fire Tower	TKN	0.0065	**UP-DN**
Fire Tower	TOC	0.0039	**UP-DN**
Fire Tower	Total Suspended Residue	0.0603	**UP-DN**
Fire Tower	Zinc	0.0401	**UP-DN**

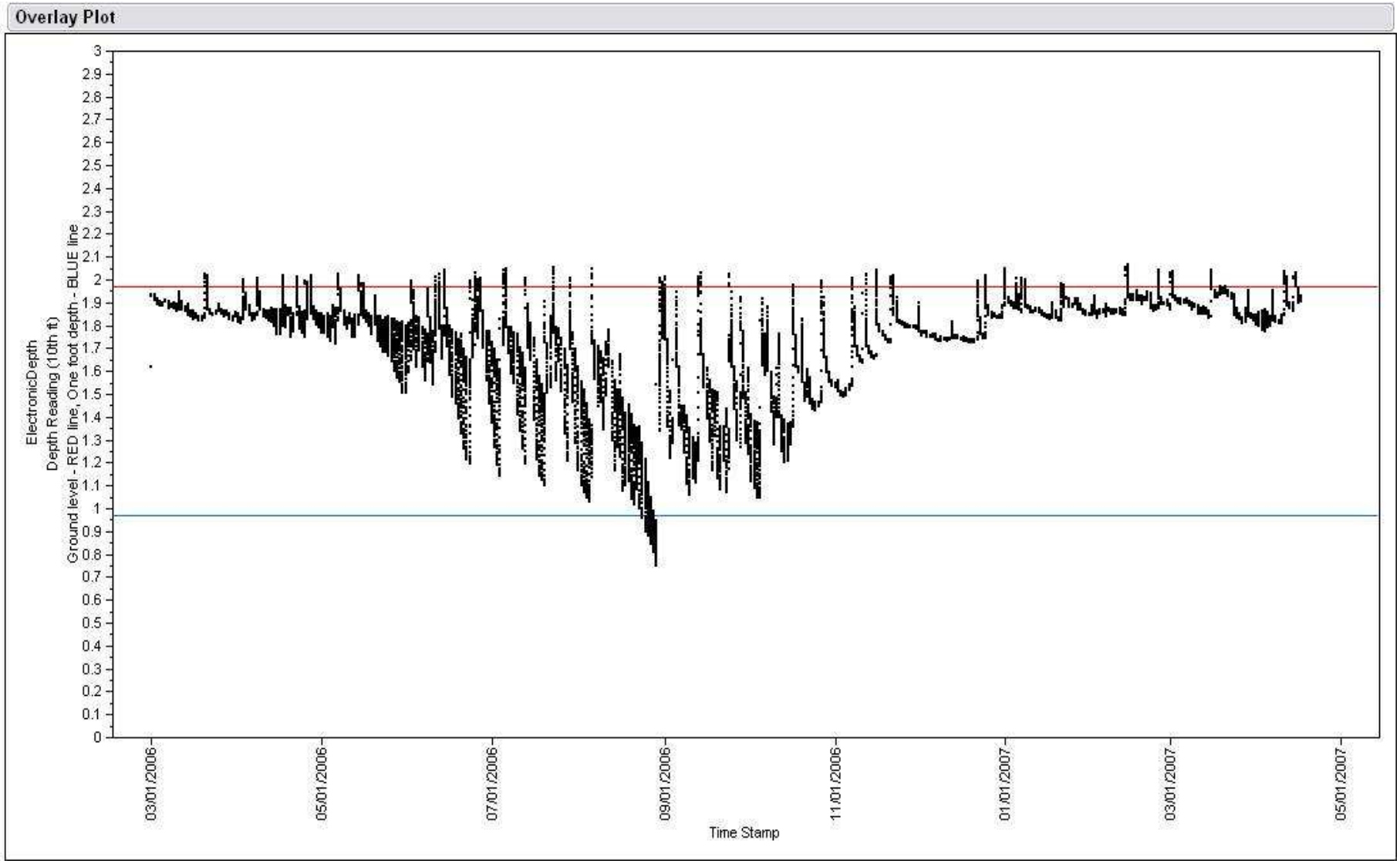
Hog Farm Lower	DOC	0.0641	UP-DN
Hog Farm Lower	Phosphorus	0.0679	UP-DN
Hog Farm Lower	Specific Conductivity	0.0176	UP-DN
Hog Farm Lower	TKN	0.0174	UP-DN
Hog Farm Lower	TOC	0.0176	UP-DN
Hog Farm Upper	Dissolved Oxygen (%)	0.0041	**UP-FD**
Hog Farm Upper	Dissolved Oxygen (mg/L)	0.0099	**UP-FD**
Hog Farm Upper	Magnesium	0.0802	**UP-FD**
Hog Farm Upper	Phosphorus	0.0266	**UP-FD**
Hog Farm Upper	TKN	0.0873	**UP-DN**
Hog Farm Upper	TOC	0.0069	**UP-FD**
Nahunta	Zinc	0.0459	**UP-DN**
PCS	Ammonia	0.0289	**DN-FD**
PCS	Copper	0.0871	**DN-FD**
PCS	Lead	0.0477	**DN-FD**
PCS	TKN	0.0414	**DN-FD**
PCS	TOC	0.049	**DN-FD**
PCS	Zinc	0.0287	**DN-FD**
Pete Harris	Calcium	0.0833	UP-DN
Pete Harris	Magnesium	0.0833	UP-DN
Spring Garden	DOC	0.0833	UP-DN
Umstead	Water, Temperature	0.0209	**UP-DN**
Walmart	Ammonia	0.0086	**UP-DN**
Walmart	Calcium	0.0143	**UP-DN**
Walmart	Copper	0.0027	**UP-DN**
Walmart	Dissolved Oxygen (%)	0.05	**UP-DN**
Walmart	Lead	0.0028	**UP-DN**
Walmart	Magnesium	0.0143	**UP-DN**
Walmart	Phosphorus	0.0082	**UP-DN**
Walmart	Specific Conductivity	0.0176	**UP-DN**
Walmart	TKN	0.0088	**UP-DN**
Walmart	TOC	0.0061	**UP-DN**
Walmart	Zinc	0.0041	**UP-DN**

Bold Blue = Improvement and Red = No Improvement

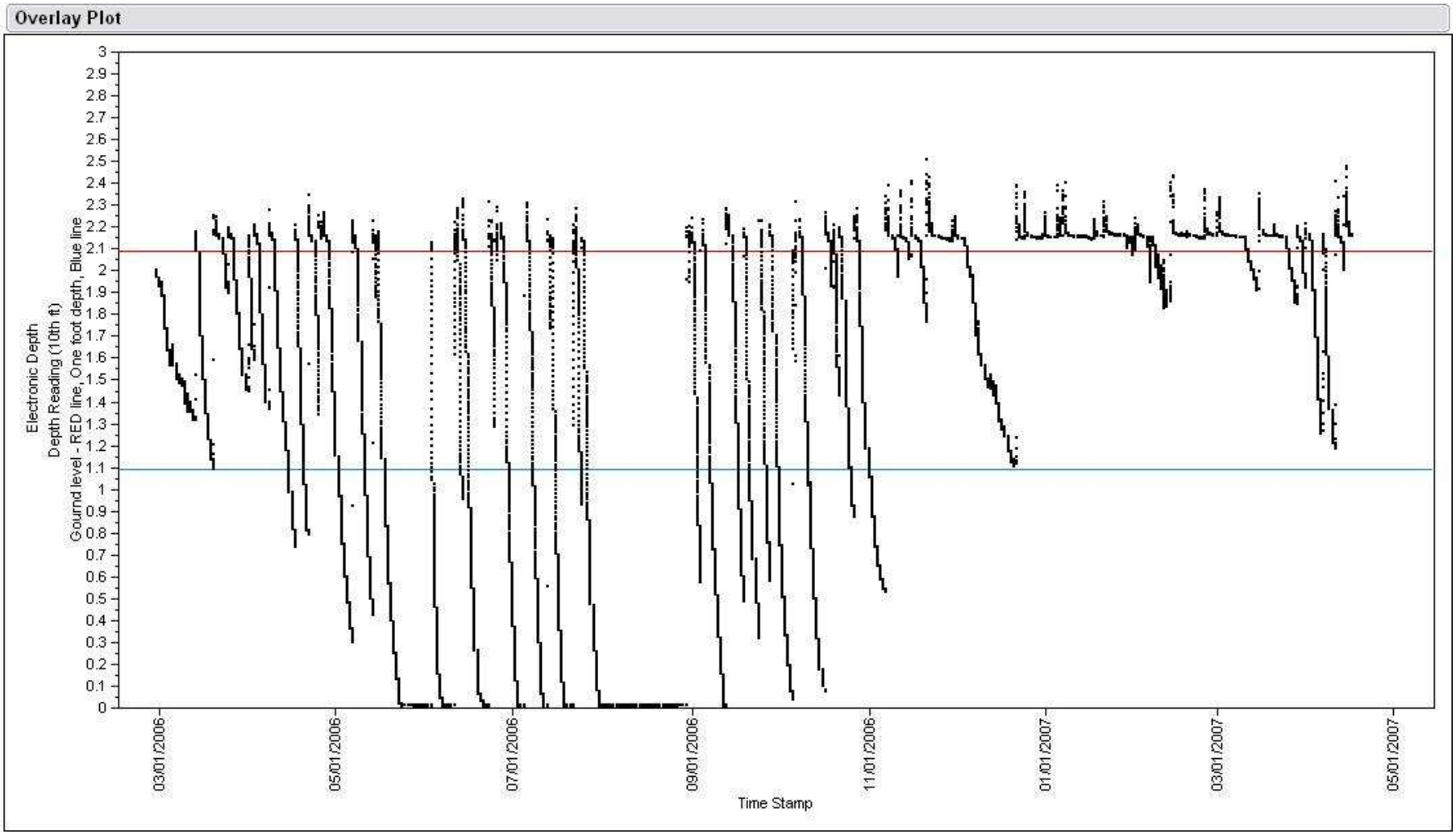
Headwater Hydrology Results

- Automated Transducers were installed on 12 headwater sites
- Six in the Piedmont and six in the Coastal Plain
- Data collected every 30 minutes for 18 months, including one complete growing season
- Headwater wetlands are within one foot of the surface for at least 47% of the growing season (mean of 75% on the Coastal Plain and 72% in the Piedmont)

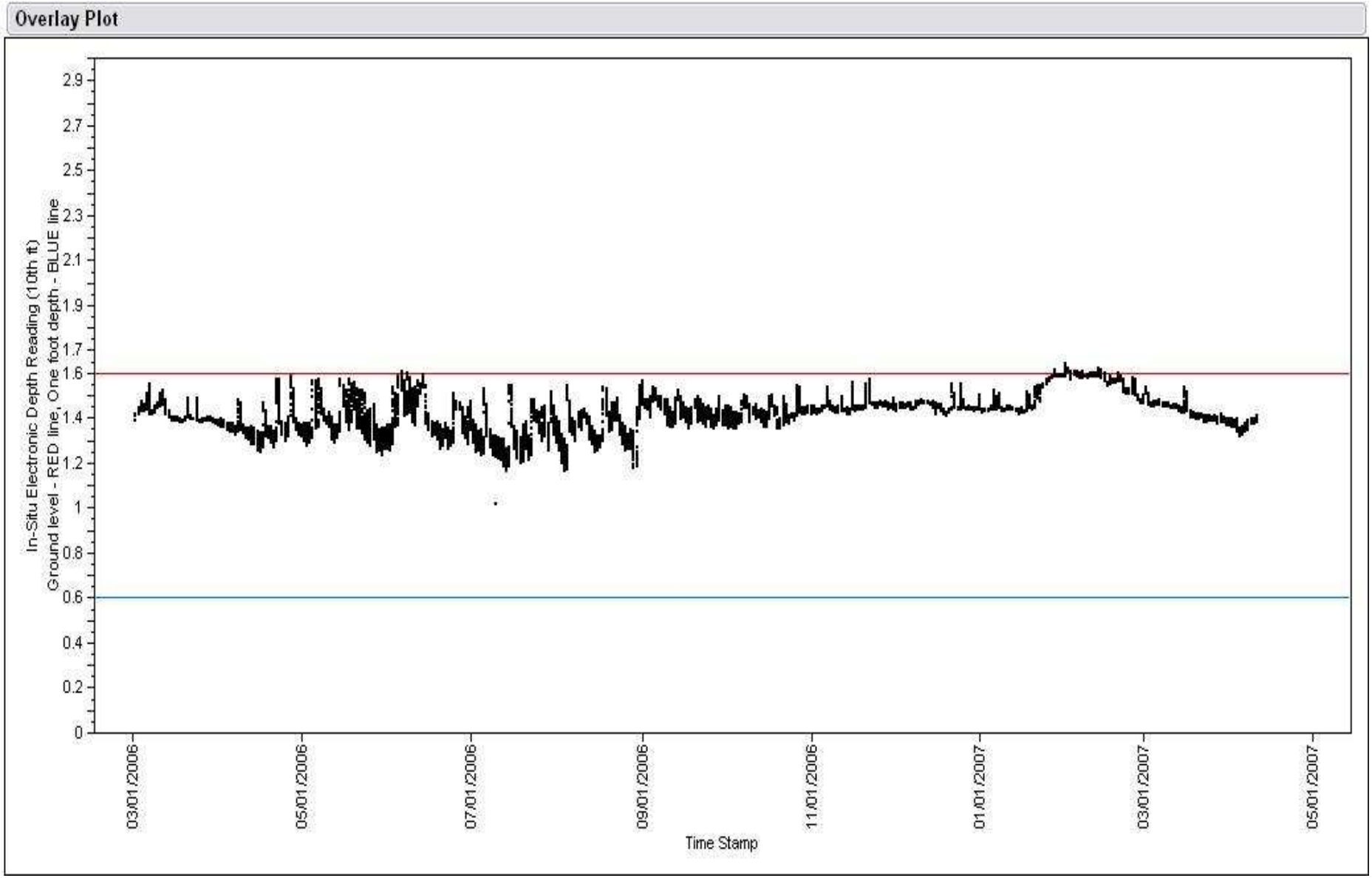
Spring Garden – Piedmont, Natural



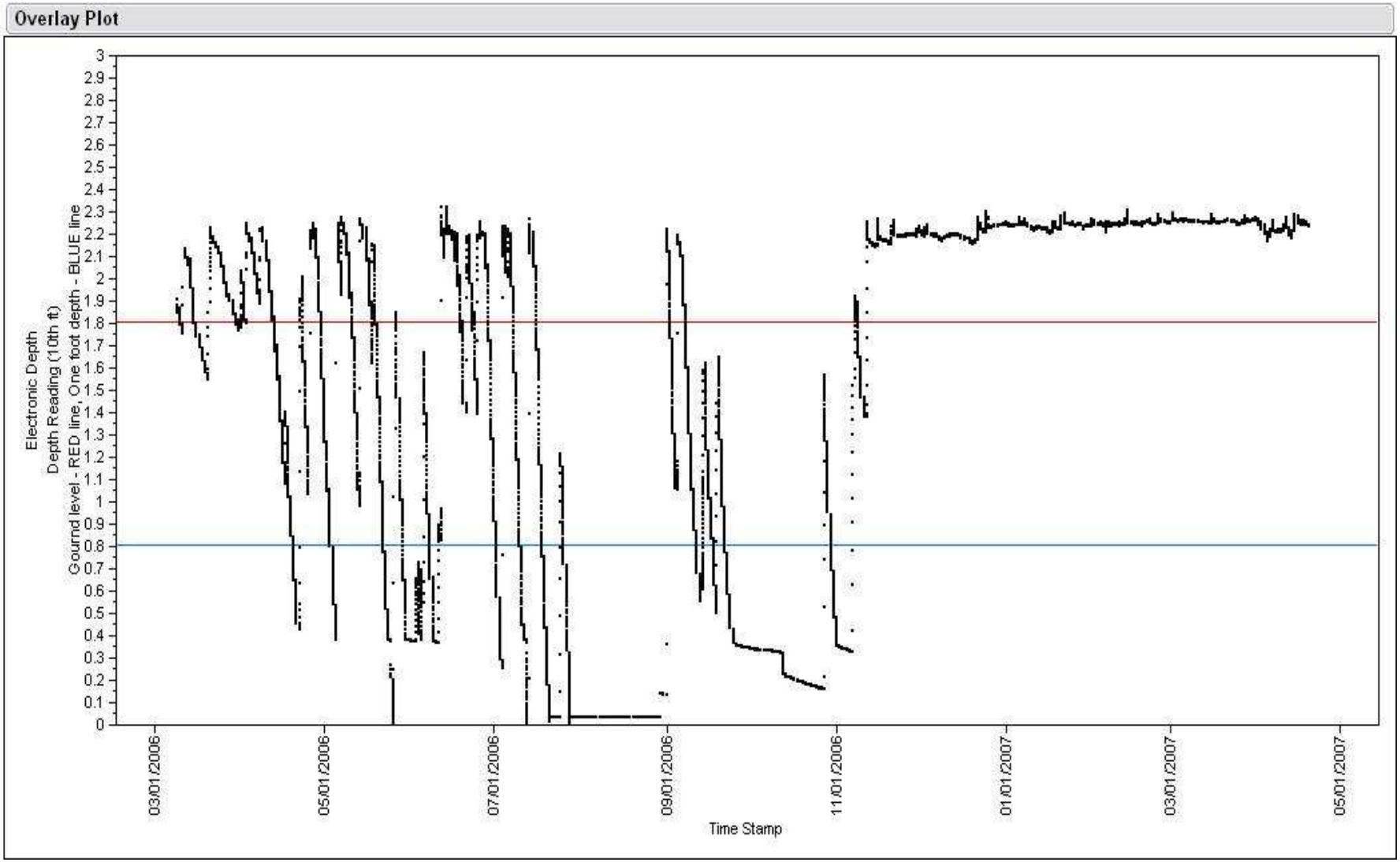
Troxler – Piedmont, Urban



Hog Farm Upper – Coastal Plain, Rural



Boddie Noell – Coastal Plain, Urban



Headwater Soil Lab Analysis

- Levels of major plant nutrients, including phosphorus, potassium, calcium and magnesium
- Levels of plant micronutrients, including copper, manganese, sulfur and zinc
- Levels of sodium
- pH
- Exchangeable Acidity
- Sum Cation
- Percent base saturation
- Percent humic matter
- Cation exchange capacity
- Weight-to-volume ratio

Headwater Summary of Soil Results

- Soil Parameter Correlation with ORAM (High Disturbance) -phosphorous, zinc, copper, Nitrate-Nitrogen
- Soil parameters correlated LDI (Disturbance as measured by development)- (copper and zinc)
- Flatter wetlands (Coastal Plain) had higher levels of nutrients and metals than the bowl shaped wetlands (Piedmont)
- The upland soils samples also had less nutrients and metals than the wetland samples – headwater wetlands are a sink for potential pollutants and potential for improving water quality

Final Conclusions - Water Quality, Hydrology and Soils Headwater Wetland

- There is a direct correlation between the headwater wetland water quality and the condition of the surrounding watershed.
- Headwater wetlands affectively reduce the amount of pollutants entering downstream waters.
- Headwater wetlands are very individual systems.
- The hydrology of headwater wetlands remains active during the growing season.

Biotic Communities Surveys

Amphibians

Macroinvertebrates

Plants

Acris crepitans

Rana sphenocephala

Hyla cinerea

Rana clamitans & catesbeiana

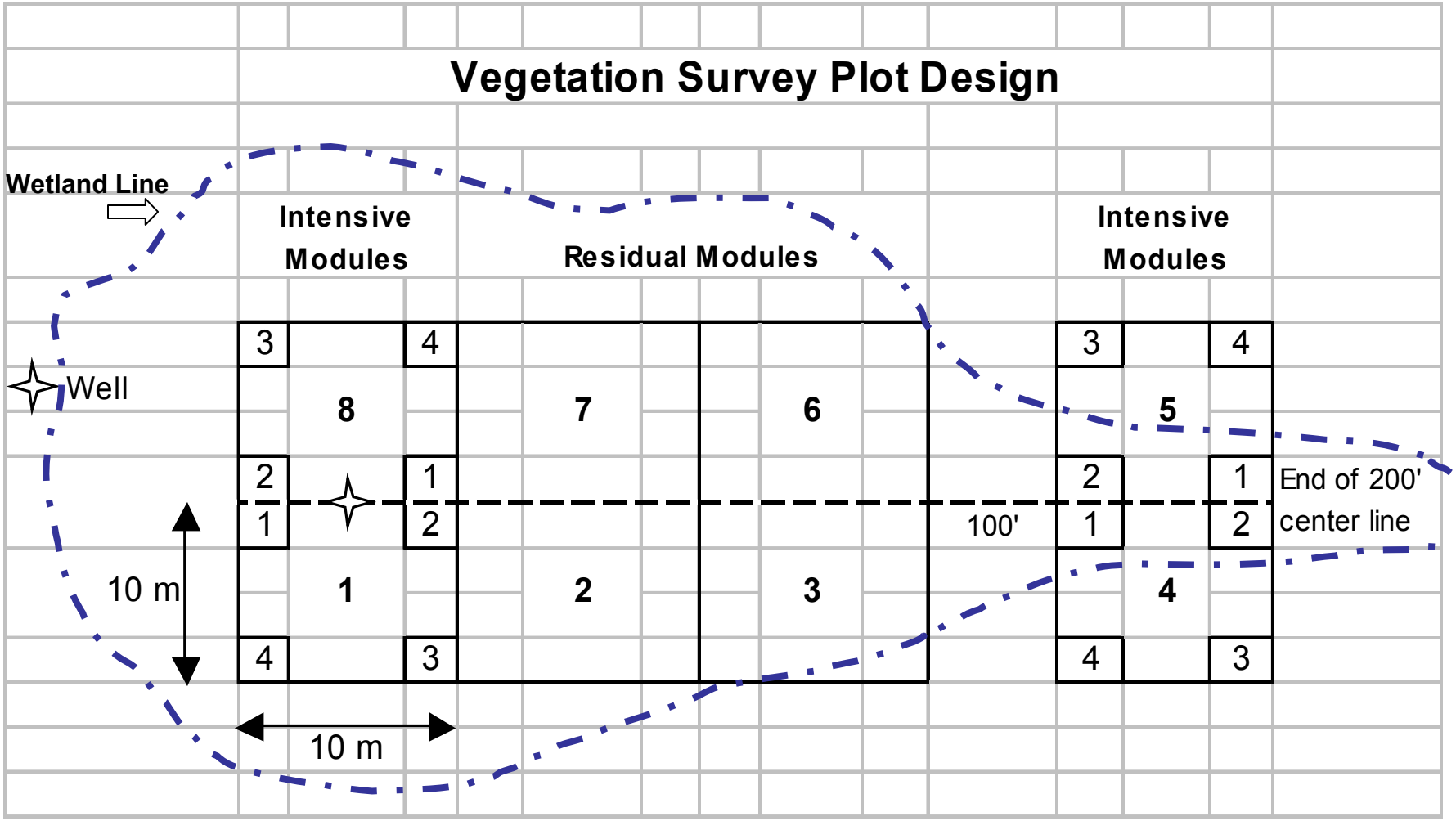
Aquatic Macroinvertebrate Survey Methods

Funnel Trap

Sweep Net

Stove Pipe Sampler

Plant Community Survey Methods



What are Indices of Biotic Integrity?

IBIs are a numeric index which is composed of 5-10 metrics derived from biological attributes (e.g. species richness, evenness, percent predators etc). IBIs are used to represent a wetland's condition and provide a simple way to interpret the results of multiple biological attributes.

IBI Development

1. Identify Candidate Metrics

   (Biological attributes – e.g. Species richness, percent tolerant species, percent sensitive species etc)

2. Test Candidate Metrics by statistically correlating with disturbance measurements

   - GIS Analysis (LDI)
   - Rapid Assessment Method (ORAM)
   - Chemical & Physical Intensive Survey Summary Results

Amphibian Candidate Metrics

7 Candidate Metrics tested, **5 Metrics chosen**

1. **Species Richness**
2. % Tolerant (Species with C of C ≤ 3)
3. **% Sensitive (Species with C of C ≥ 6**
4. % State Listed
5. **% Headwater-Ephemeral-Seepage HW-EW- SW**
6. **% Ureodela (Salamander)**
7. **Amphibian Qualitative Assessment Index (AQAI)**

C of C = Coefficient of Conservatism

Amphibian Results (X = significant result)

Water Quality Disturbance Measurements	DO	Fecal Coliform	Ammonia	NO_2+NO_3	Phophorous	TKN	Cu	Zn	Pb	Ca	Mg	TSS	Turbidity	TOC	DOC	Relative Nutrients	Relative Metals	Combo	Specific Condo	Temp	pH
Species Richness	x									x	x										
% HW - EW - SW		x		x												x					
% Sensitive		x	x		x			x								x		x			
% Tolerant	x																				x
% Urodela			x		x			x	x			x	x				x				
% State Listed																					
AQAI	x		x		x									x	x						x

LDI, ORAM, and Soils Disturbance Measurements	LDI 300 M	LDI Watershe	LDI 50M	Oram	Soils pH	Soils Cu	Soils Zn
Species Richness	x	x		x	x	x	x
% HW - EW - SW		x			x		
% Sensitive					x		
% Tolerant							
% Urodela					x		
% State Listed							
AQAI					x		

Amphibian Score Assignment and IBI Results

Metric Score Assignment for Amphibians

Metric	0	3	7	10
AQAI	<3	<5	<7	≥7
% Sensitive	<5	<10	<25	≥25
% HW-EW-SW	<20	<50	<75	≥75
% Urodela	<10	<30	<50	≥50
Species Richness	<3	<5	<8	≥8

Region	Site Name	Metric Results					Metric Scores					IBI
		AQAI	% Sensitive	% HW-EW-SW	% Urodela	Species Richness	Metric AQAI	Metric % Sensitive	Metric % HW-EW-SW	Metric % Urodela	Metric Score Species Richness	Amphib IBI
Piedmont	Moonshine	2.7	0.0	0.0	8.5	5.0	0	0	0	0	7	7
	Kelly Rd	2.1	0.0	18.1	0.0	8.0	0	0	0	0	10	10
	Fire Tower	2.0	14.3	14.3	28.6	3.0	0	7	0	3	3	13
	Pete Harris	3.5	2.4	68.7	2.4	4.0	3	0	7	0	3	13
	Umstead	2.3	8.8	25.4	8.8	8.0	0	3	3	0	10	16
	Troxler	4.1	6.3	93.9	0.5	4.0	3	3	10	0	3	19
	Black Ankle Powerline	3.9	1.7	93.1	1.7	7.0	3	0	10	0	7	20
	Black Ankle Non-Powerline	3.9	2.4	90.2	4.0	8.0	3	0	10	0	10	23
	East of Mason	4.0	2.3	95.1	2.3	11.0	3	0	10	0	10	23
	Spring Garden	3.9	4.8	84.8	16.0	5.0	3	0	10	3	7	23
	Walmart	7.0	100.0	16.7	100.0	2.0	10	10	0	10	0	30
	Duke Forest	6.0	52.8	69.3	52.8	4.0	7	10	7	10	3	37

Aquatic Macroinvertebrate Candidate Metrics

36 Candidate Metrics tested

Taxonomic Richness

Taxonomic Composition

Trophic Structure

Tolerant / Sensitive

Aquatic Macroinvertebrate IBI Results

6 Coastal Plain Metrics Chosen

% Coleoptera, % Crustacea, % Diptera, % Orthocladiinae, % POET (Plecoptera, Odonata, Ephemeroptera, Trichoptera), POET Richness

7 Piedmont Metrics Chosen

% Tolerant, % Mollusk, % Coleoptera, POET Richness, Family Richness, Chironomidae Richness, Predator Richness

Plant Community Metrics

41 Candidate Metrics tested - 10 Metrics chosen

Community Balance

- Native Species Evenness Metric

Floristic Quality

- Floristic Quality Assessment Index (FQAI) Metric
- Average C of C Metric
- Invasive Shrub Cover Metric

Wetness Characteristics

- Native Wetland Plant Richness Metric

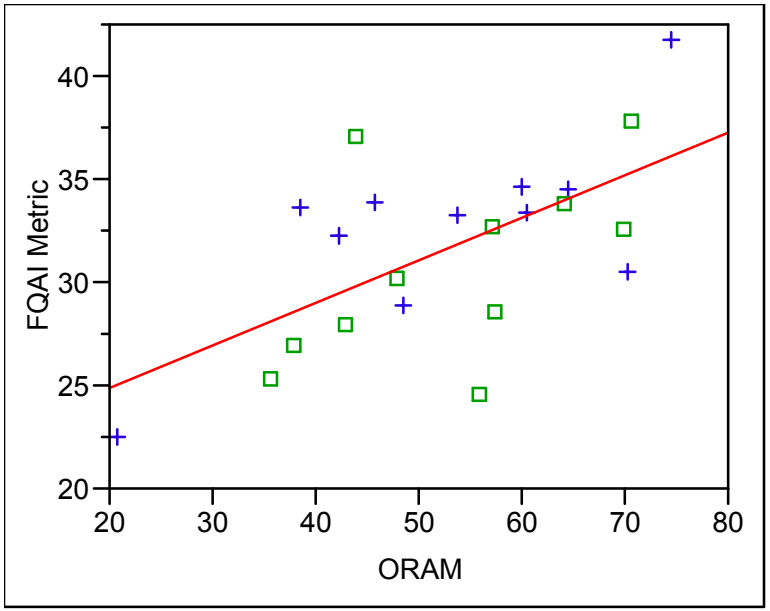
Functional Group

- Poaceae, Cyperaceae, and Juncaceae Cover Metric

Community Structure

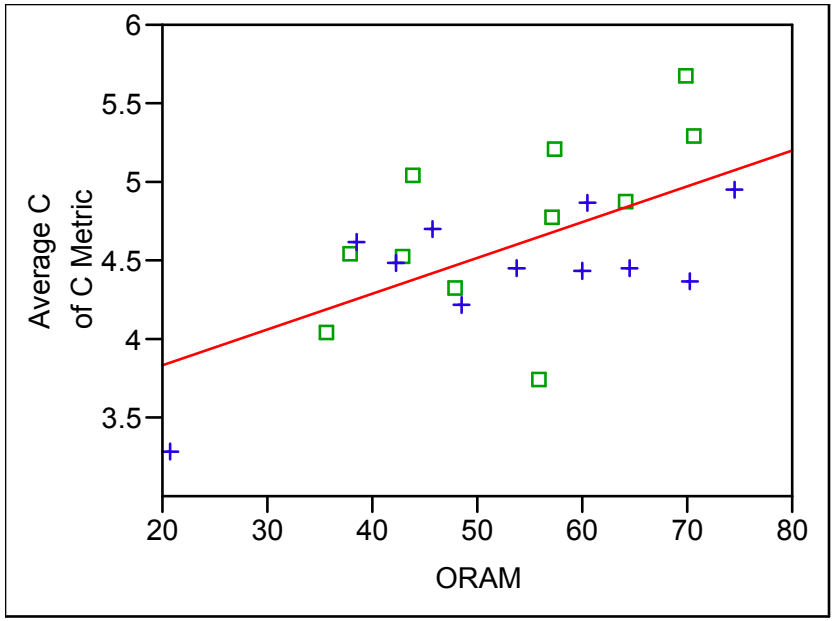
- Native Herb Richness Metric
- Shade Metric
- Pole Timber Density Metric
- Average Importance Shrub Metric

Plant Community Metric Results-FQAI, C of C, and Invasive Shrub Cover by ORAM



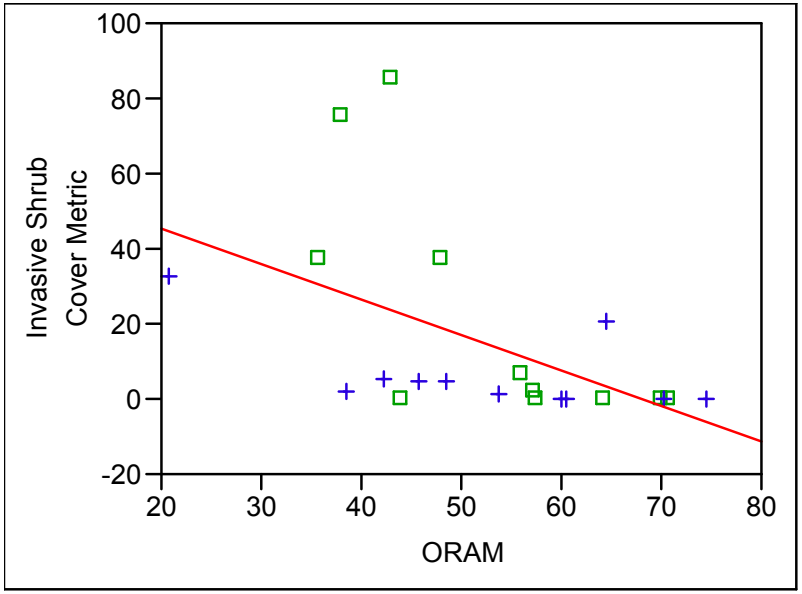
FQAI vs ORAM

p=0.007, r2=0.56



Ave C of C vs ORAM

p=0.03, r2=0.47



Invasive Shrub Cov vs ORAM

p=0.0002, r2=-0.72

Headwater Wetland IBI Conclusions

- The Amphibian and Macroinvertebrate IBI metric correlation analysis results showed that these communities respond more directly to water quality and soil chemistry than the more the ORAM general wetland GIS (LDI) and rapid assessment (ORAM) disturbance measurements.
- The Plant IBI metric correlation analysis showed that there is a significant correlation between the condition of plant communities and the rapid assessment (ORAM) and GIS (LDI) disturbance measurements.

Future Wetland Monitoring Work Plans

- Further development of IBIs on headwater, bottomland hardwood, riverine swamp, and basin wetlands
- Further testing and development of water quality, soils, and hydrology monitoring and analysis methods
- Calibration and validation of NCWAM through comparison with Level III intensive surveys

Additional Wetland Monitoring Projects

- Continuation of Wetland Monitoring with Basin, Riverine Swamp Forest, Bottomland Hardwood Forest wetlands
- Examination of Coastal Plain isolated wetlands through probability based sampling
- Regional (GA, MS, AL, SC, NC) wetland Piedmont and Coastal Plain assessment project
- National Wetland Conditional Assessment

Questions?

h2o.enr.state.nc.us/ncwetlands/pdu.htm – Under Wetlands Monitoring

Rick Savage rick.savage@ncdenr.gov

Ginny Baker virginia.baker@ncdenr.gov