HIGH ROCK LAKE DATA REVIEW

NCDP - Aug 18, 2015

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Division of Water Resources – Water Planning

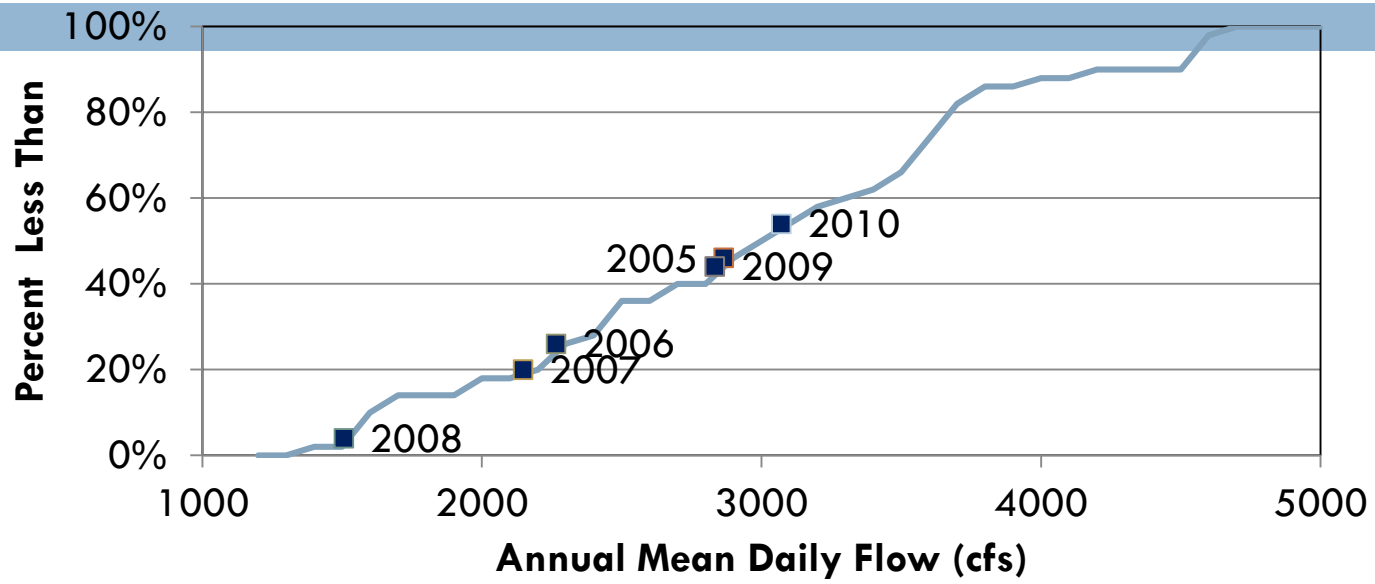
NC Department of Environment & Natural Resources

Acknowledgement

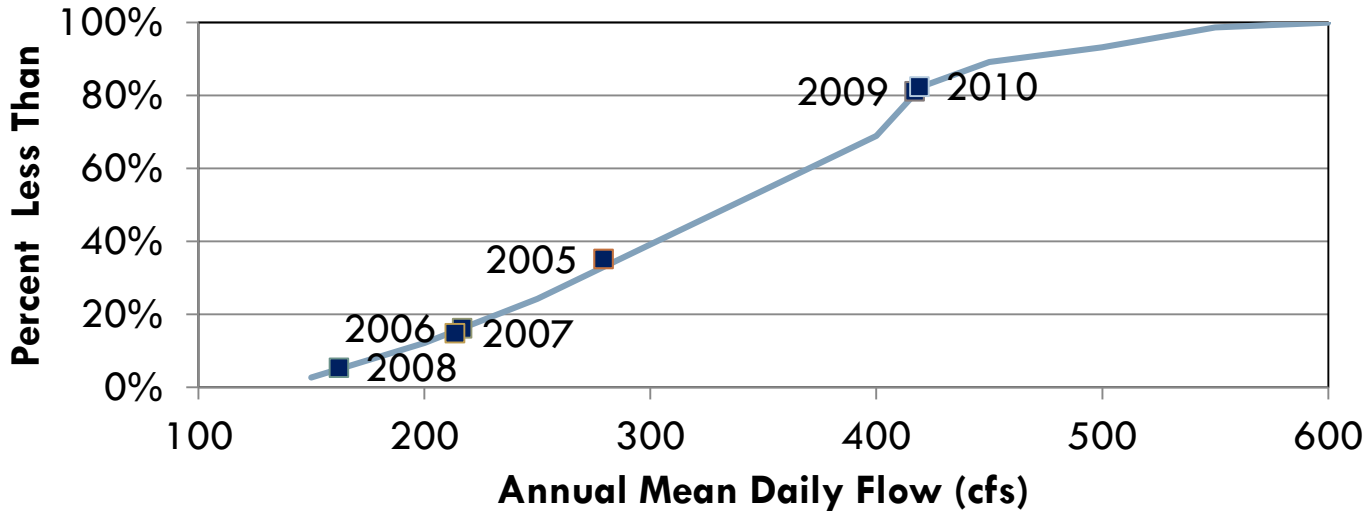
- Tetra Tech, 2004, Water Quality Data Review Report (1973 – 2001)
- Chris Wu, 2007, Scoping Study Data Review (2005-2006)
- Limno Tech, 2010, Intensive Monitoring Final Report (April 2008 – March 2010)
- Tetra Tech, 2012, Watershed Model Report
- Tetra Tech/DWR, 2015, Nutrient Response Models

http://portal.ncdenr.org/web/wq/ps/mtu/specialstudies

Hydrology Representation (2005-2010)



Yadkin River
Yadkin College
1963-2013
(57.4%)



South Yadkin River
Near Mocksville
1939-2013
(7.7%)

Outline

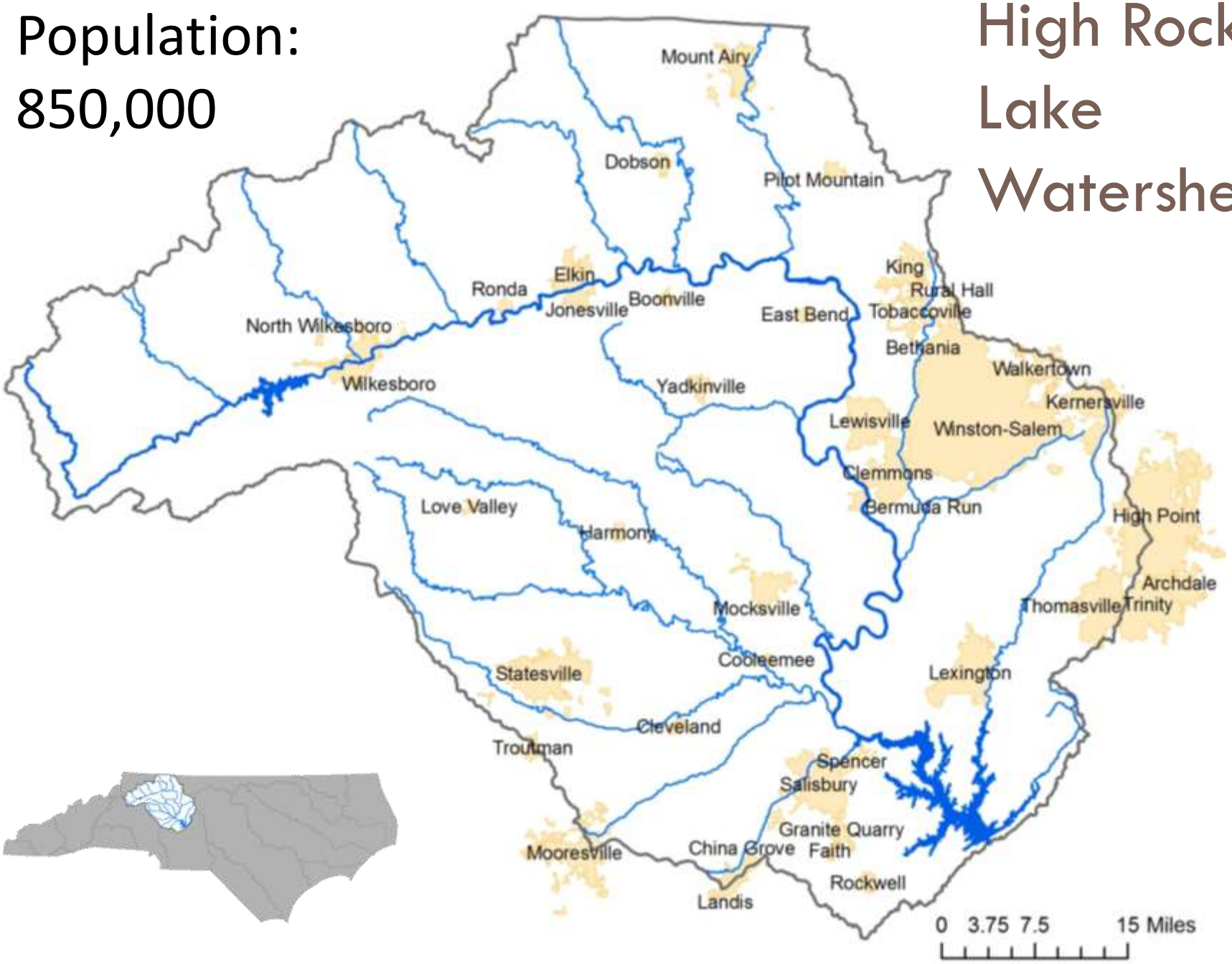
- **High Rock Watershed**
- Lake Physical Characteristics
- Lake Biochemical Characteristics

Introduction

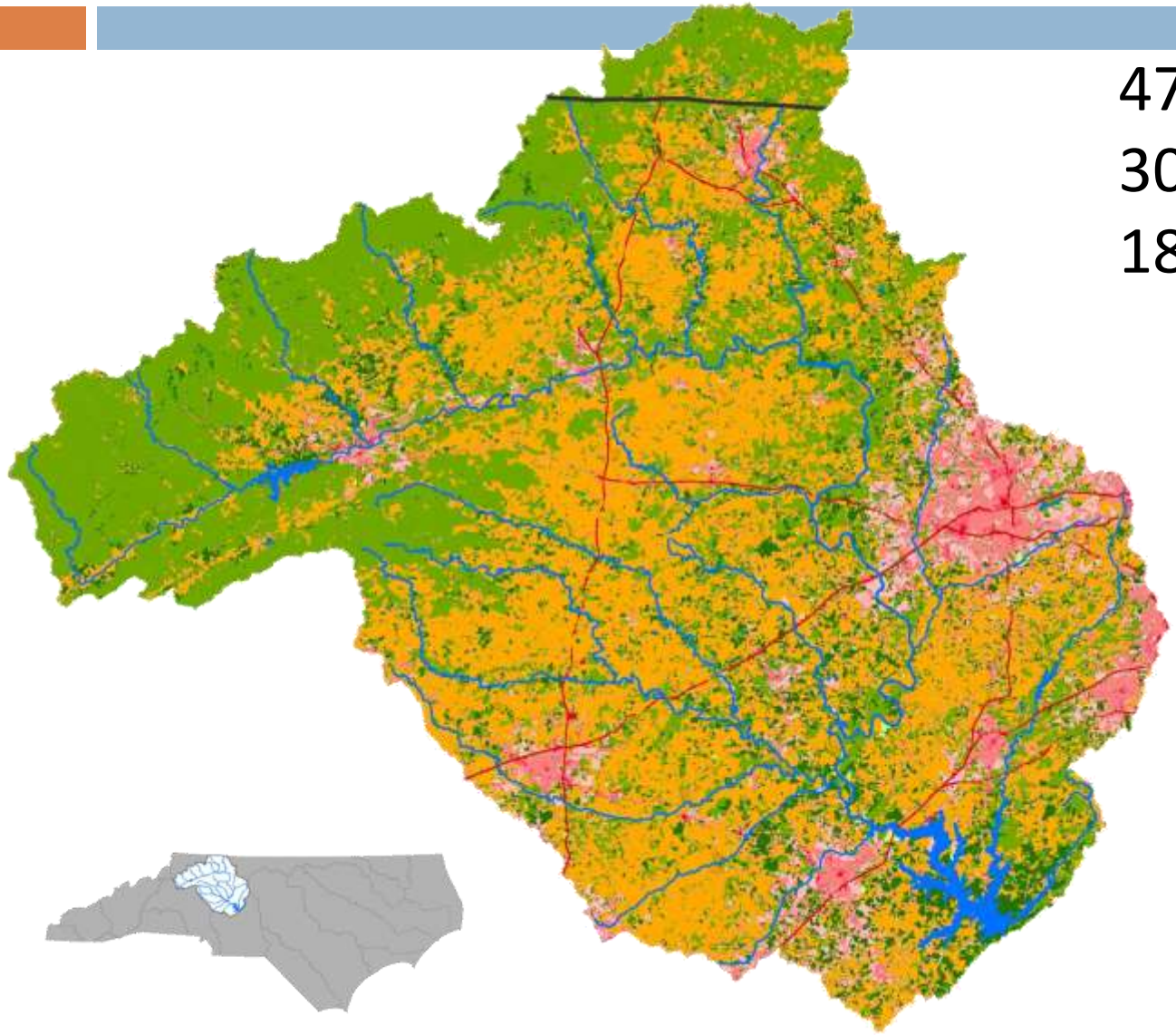
- Yadkin-Pee Dee
- 1928 - Dam construction completed
- Dam owned and operated by Alcoa Power Generating, Inc

High Rock Lake Watershed

Population:
850,000



2007 Land Cover



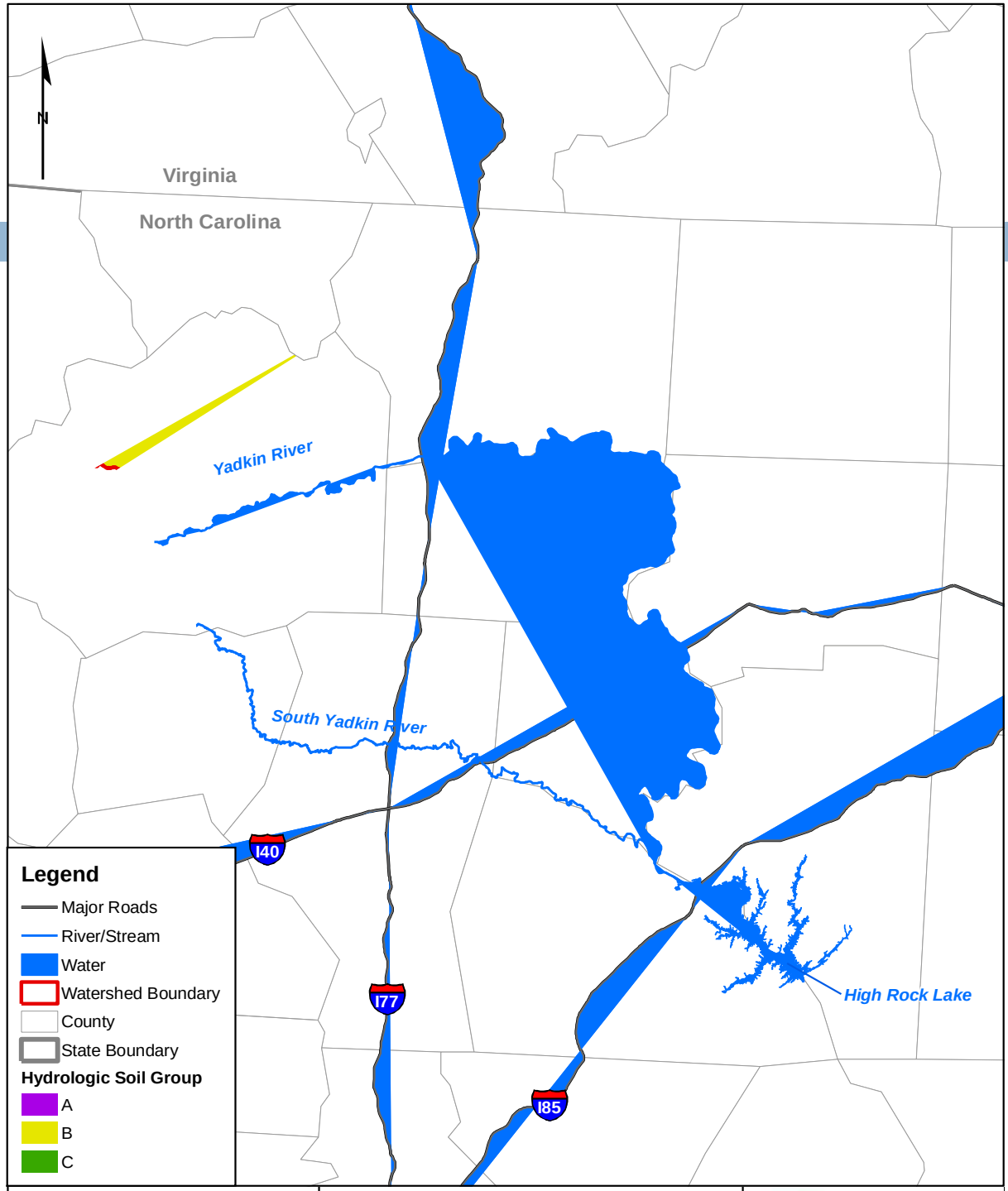
47% Forest

30% Pasture/Crop

18 % Developed

Soil Type

Hydrologic Soil Group	Soil Texture
B	Silt loam or loam
C	Sandy clay loam

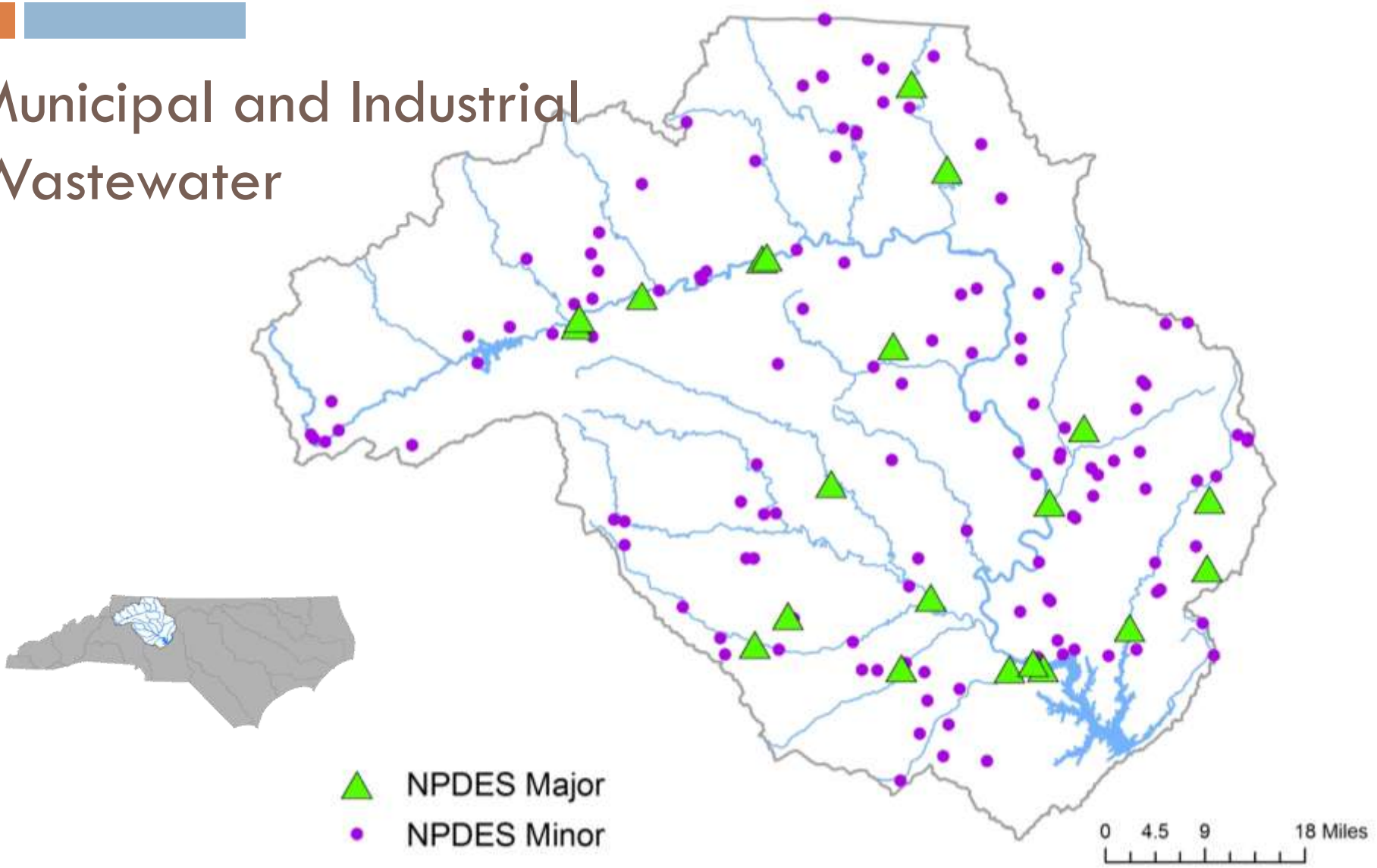


Groundwater to the lake

- Direct groundwater inflow is not measured or known;
- however, the contribution is expected to be relatively small because
  - regional groundwater flow systems are of limited extent in the Piedmont, and
  - the watershed model is fit without a significant component of “deep” groundwater losses that do not show up at stream gages.

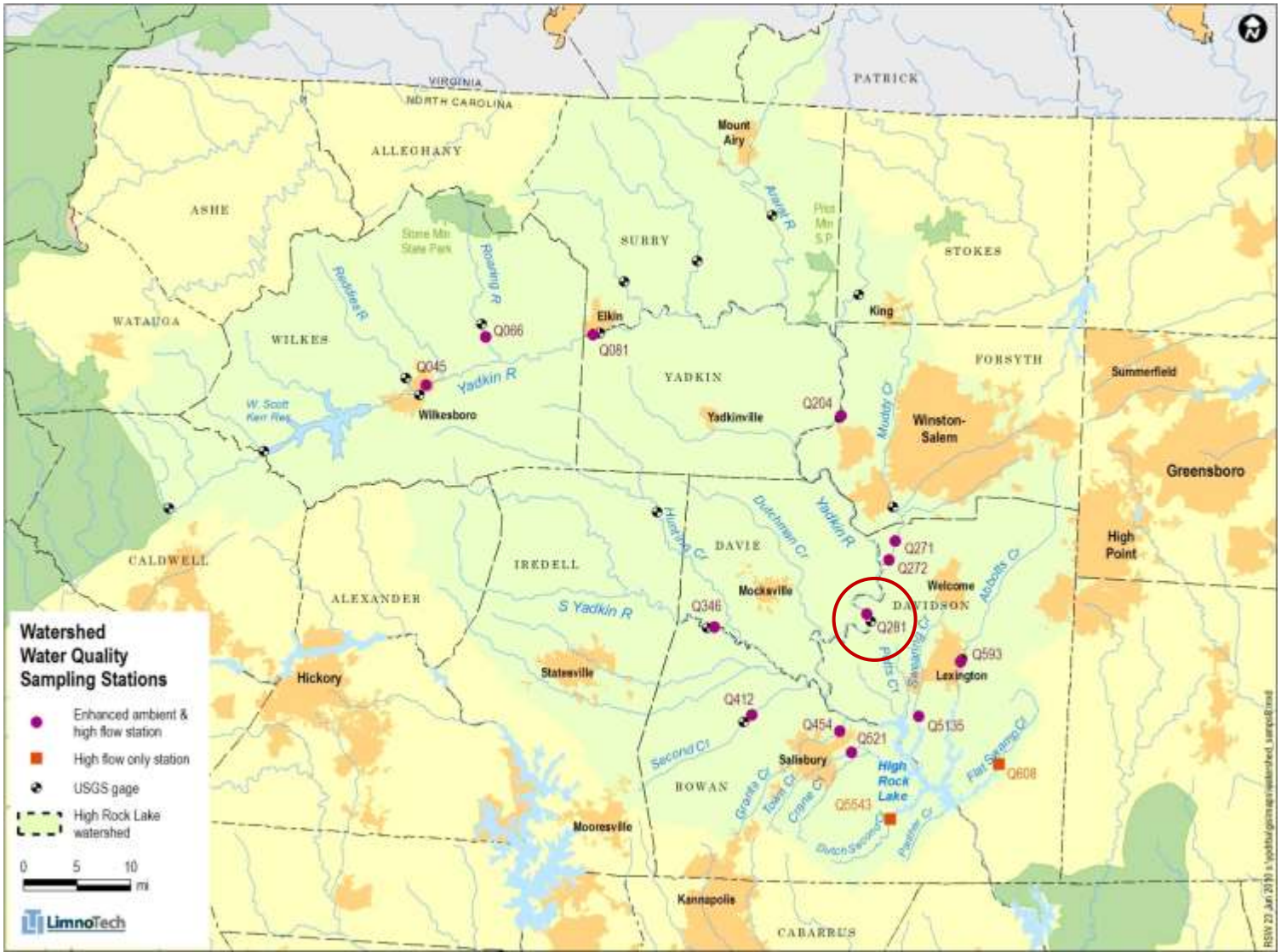
Point Sources

Municipal and Industrial Wastewater

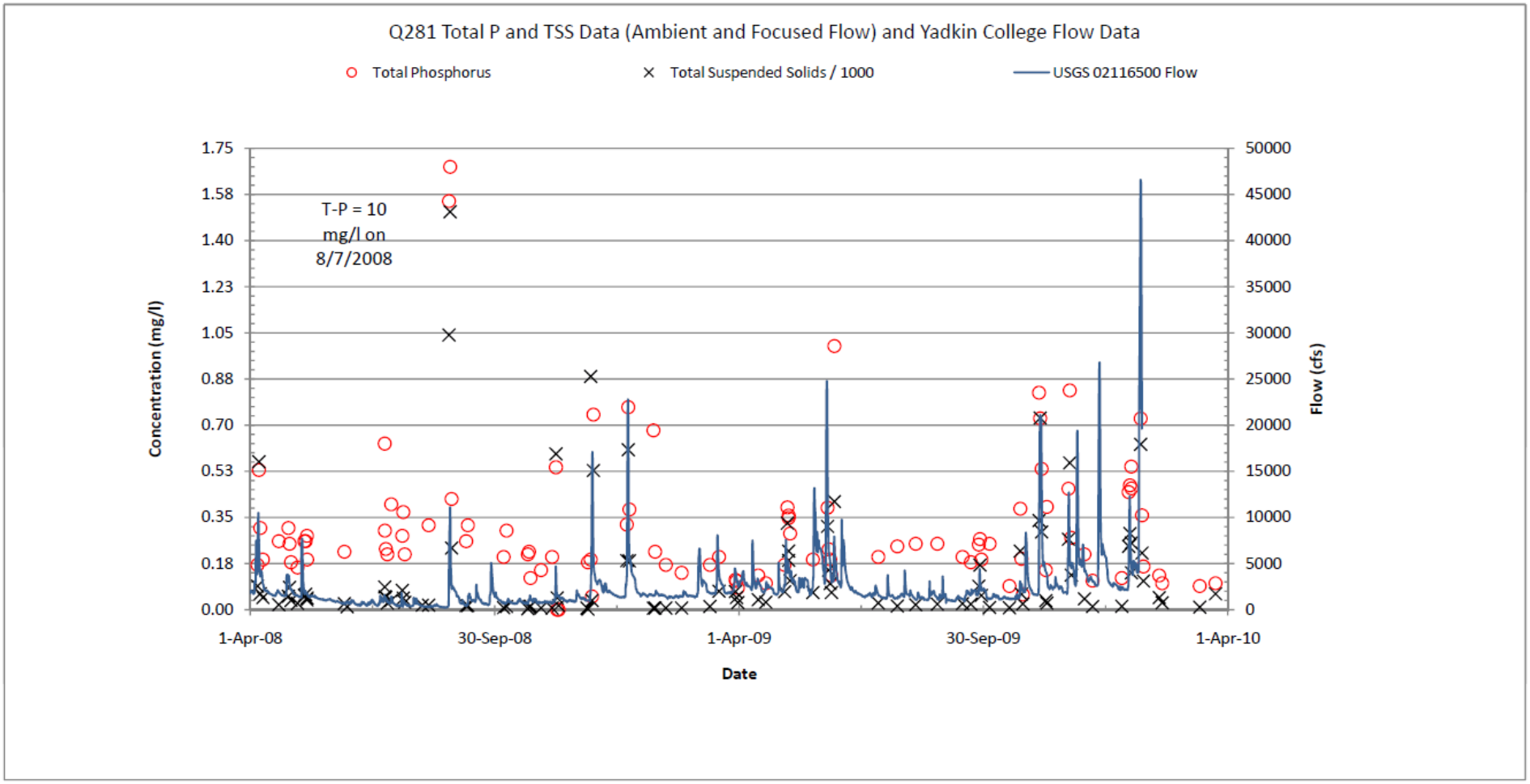


Watershed Monitoring

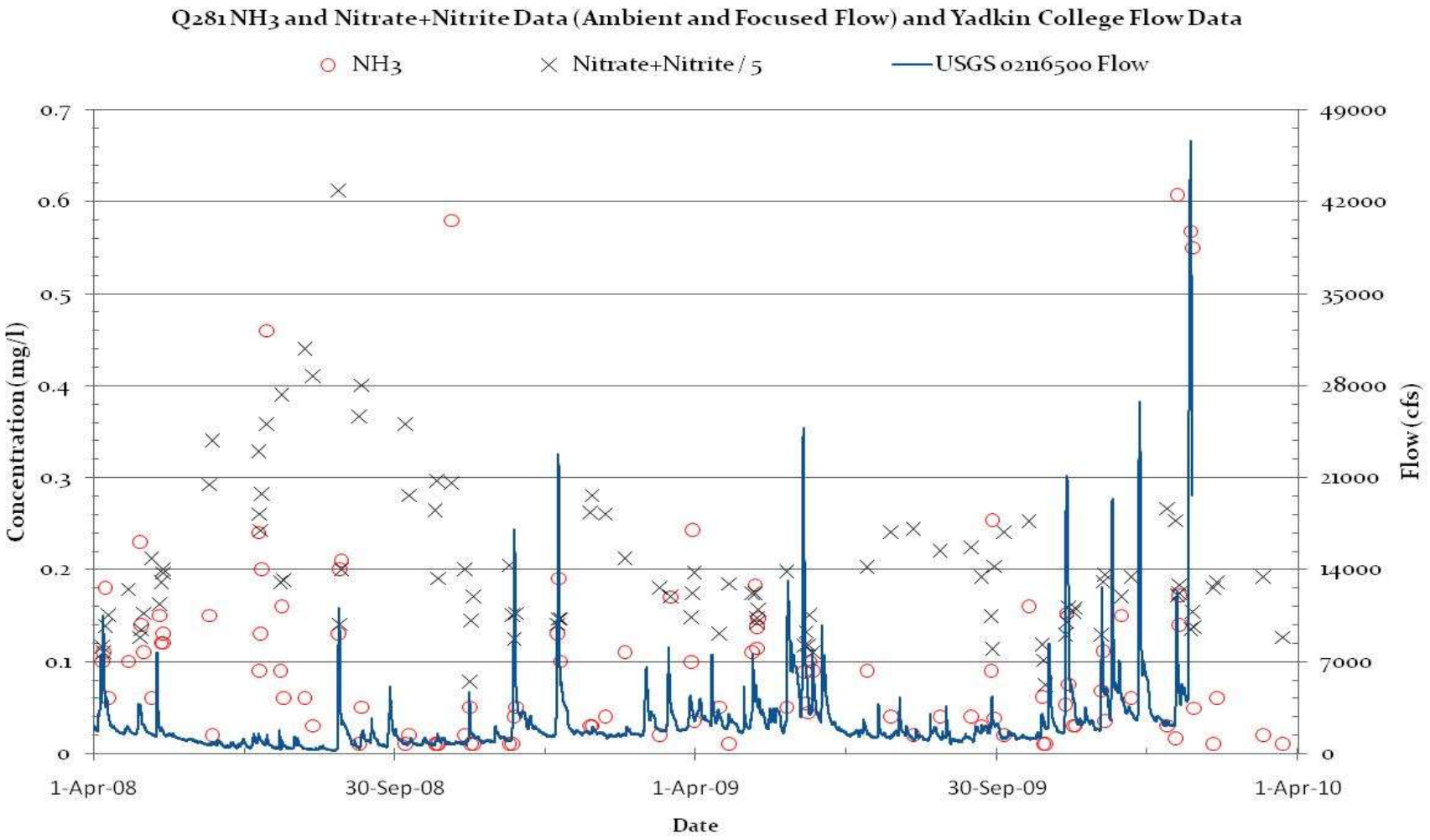
(focused flow and enhanced ambient monitoring 08-10)



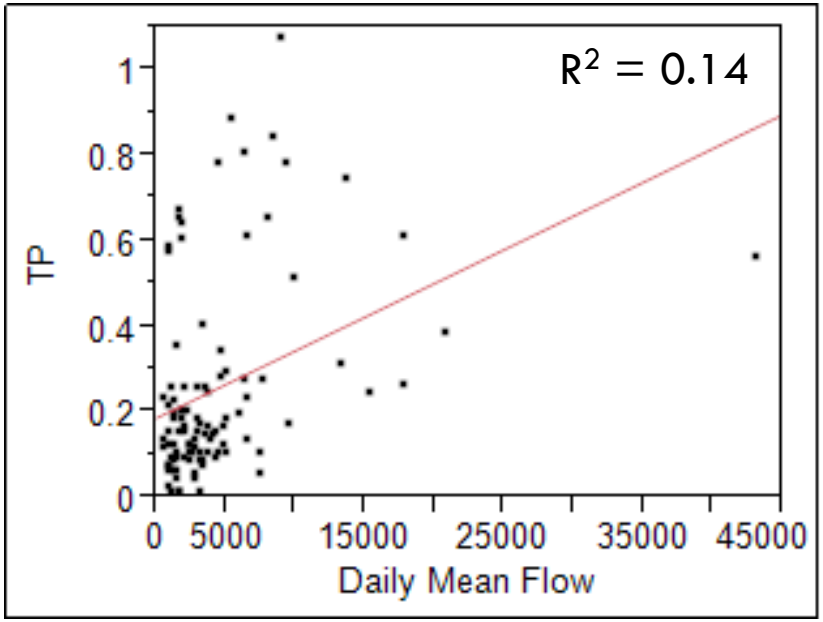
TP, TSS and Flow

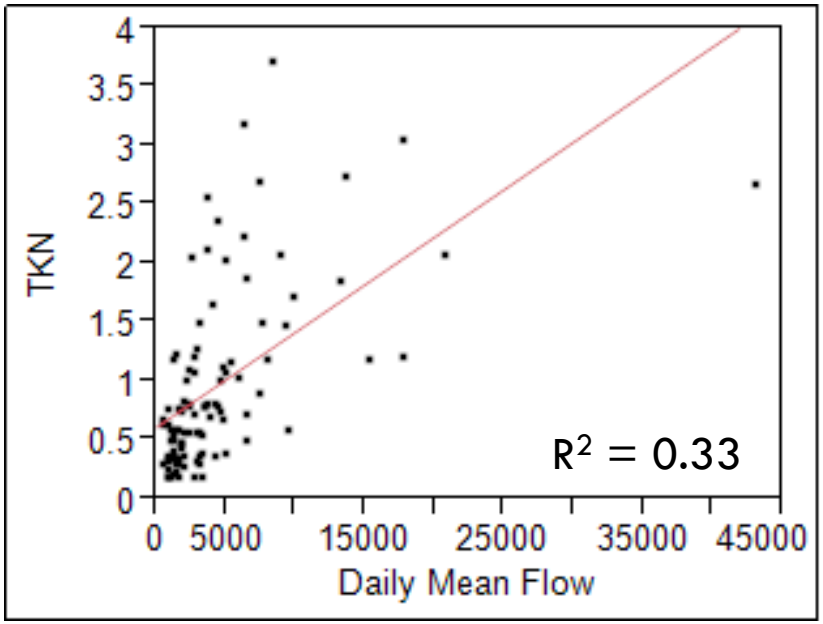


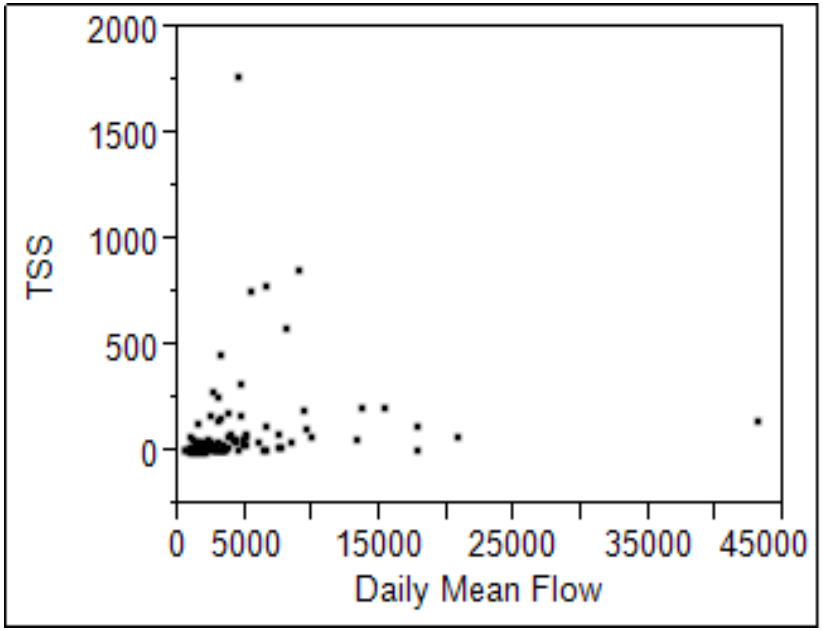
Nitrogen and Flow

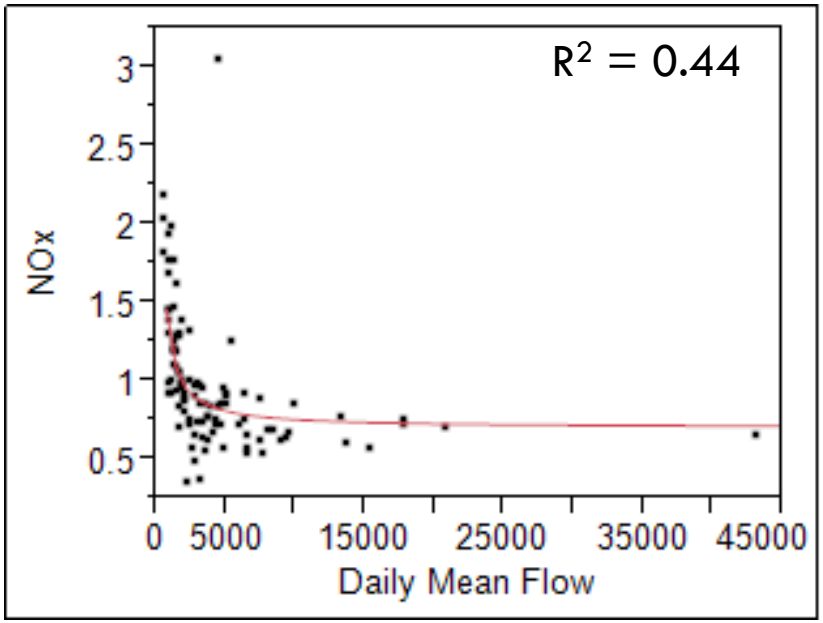


Q281 and Yadkin College





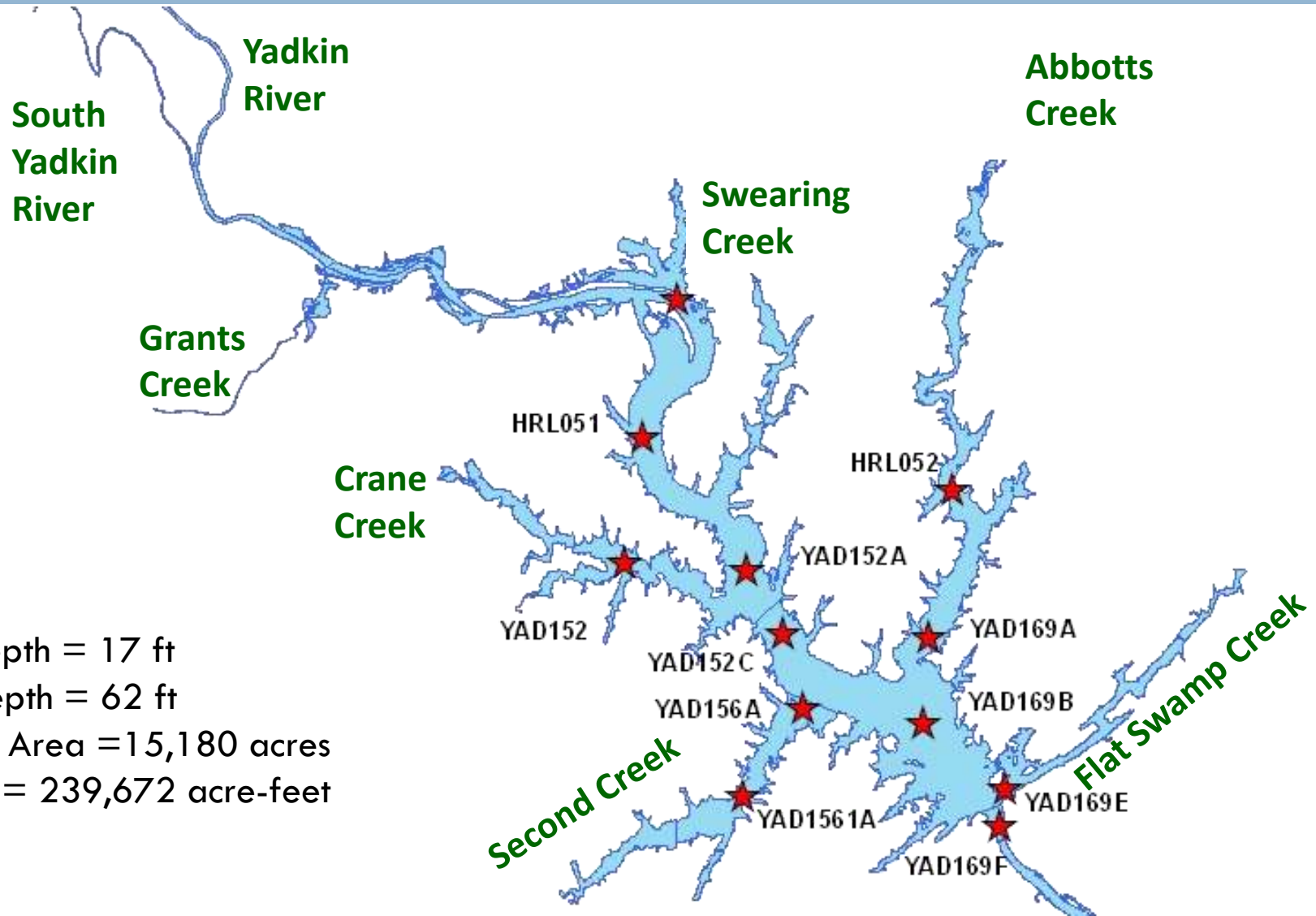




Outline

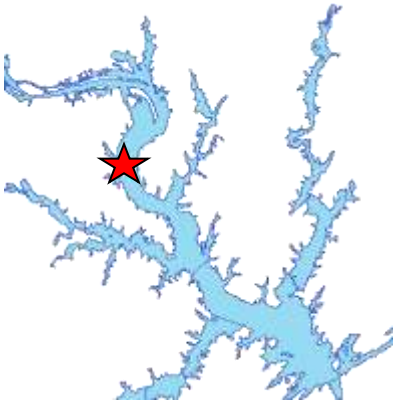
- High Rock Watershed
- **Lake Physical Characteristics**
- Lake Biochemical Characteristics

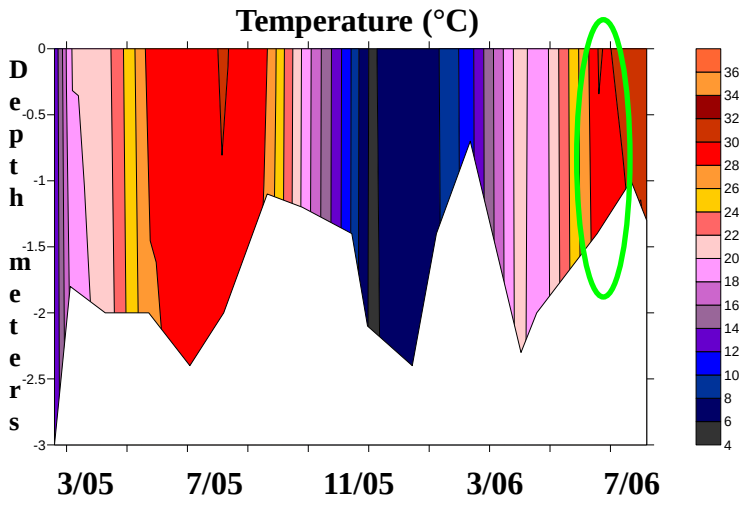
High Rock Lake

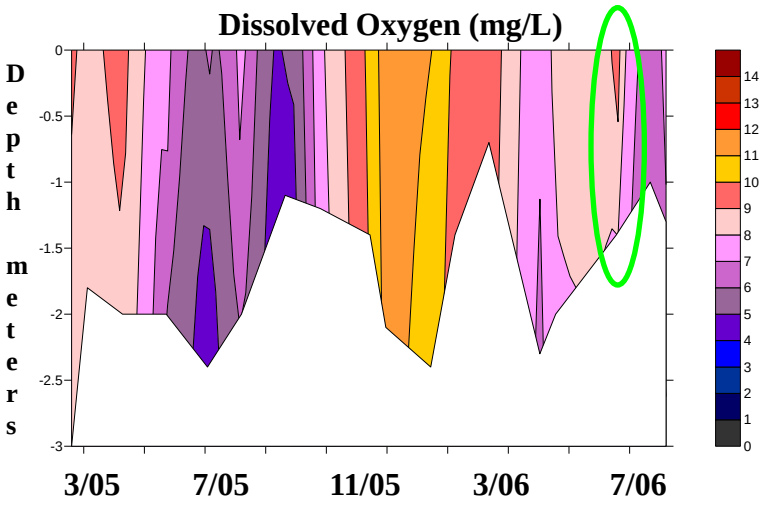


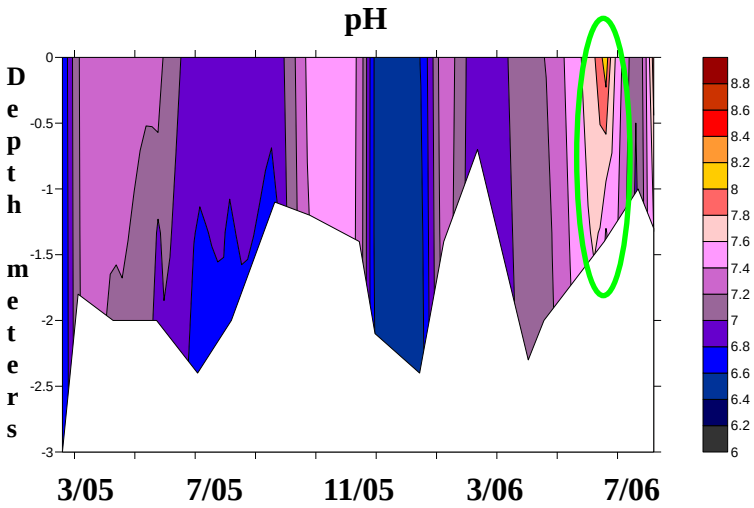
Avg. Depth = 17 ft
Max Depth = 62 ft
Surface Area =15,180 acres
Volume = 239,672 acre-feet

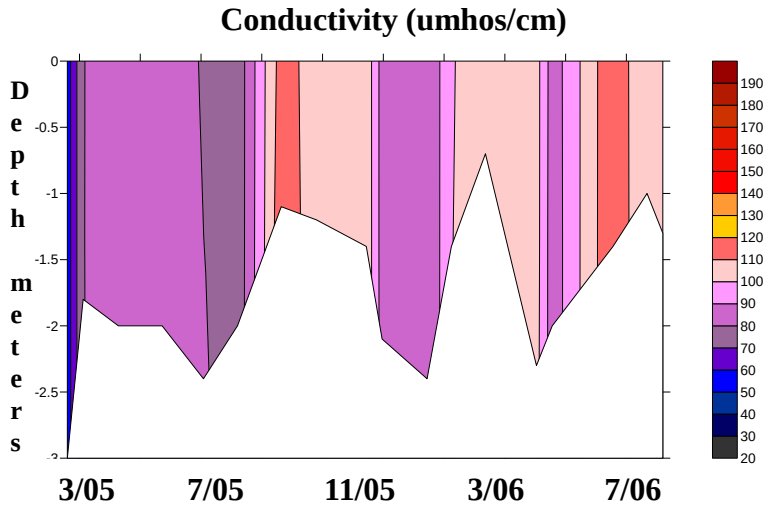
Physical Profiles: Station HRL051



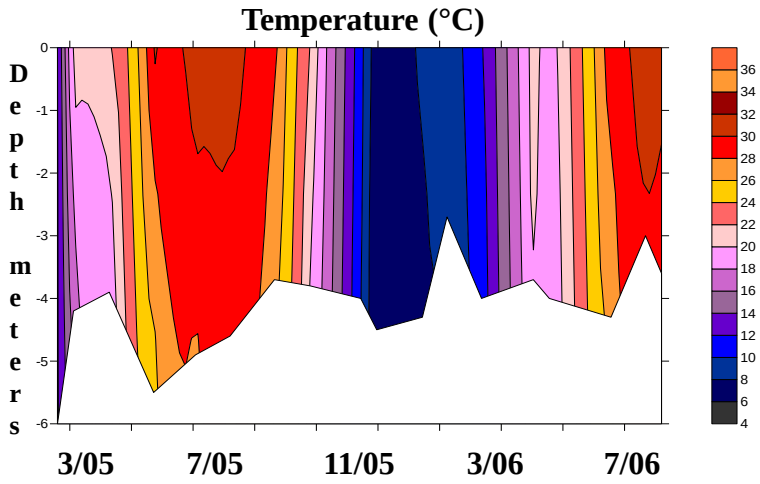


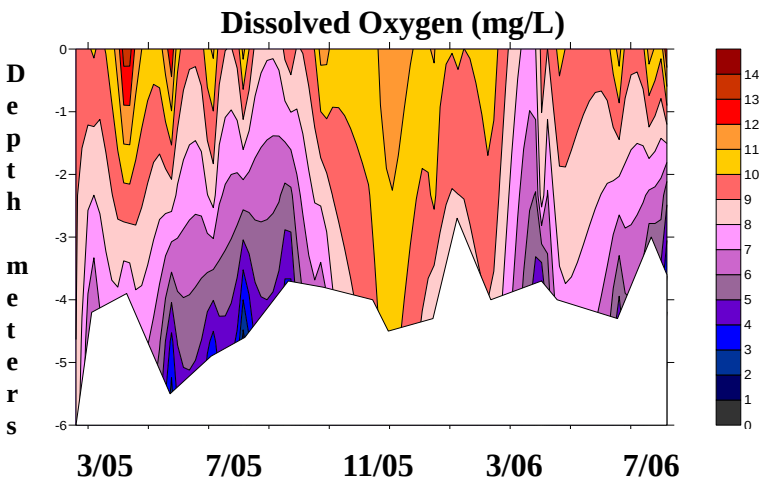


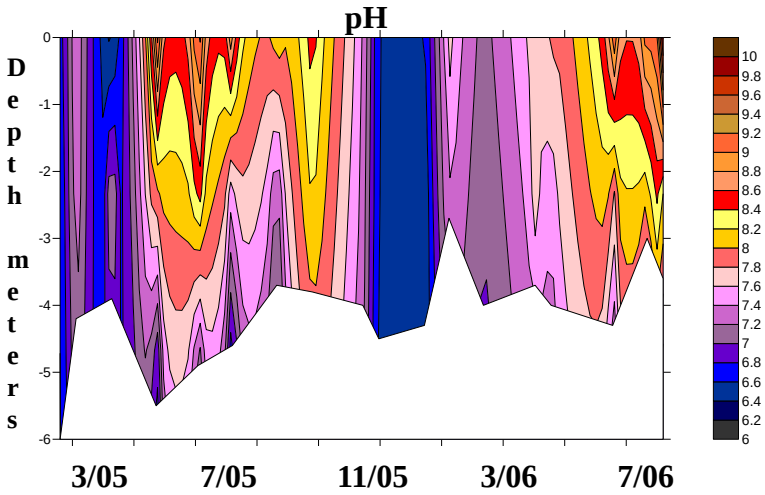


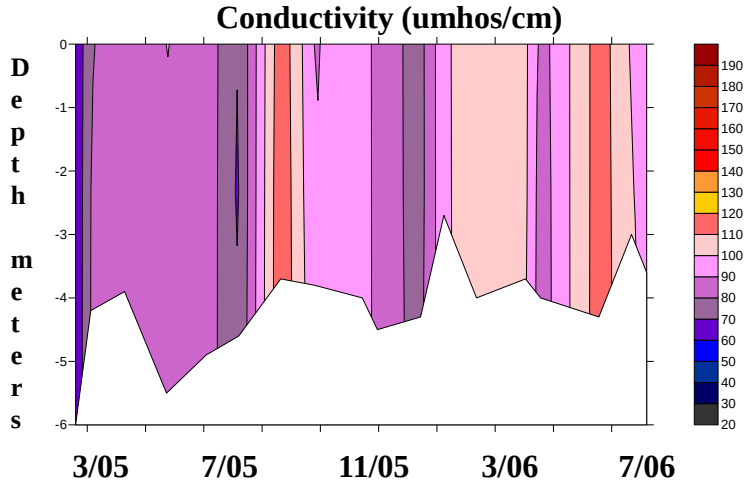


Physical Profiles: Station YAD152A

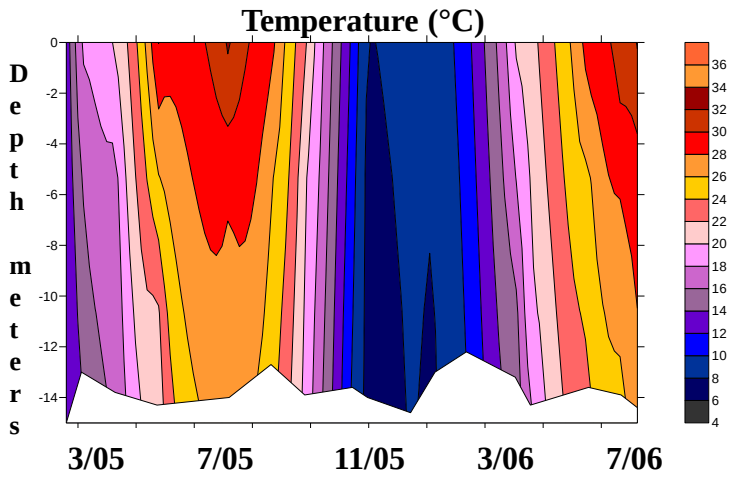


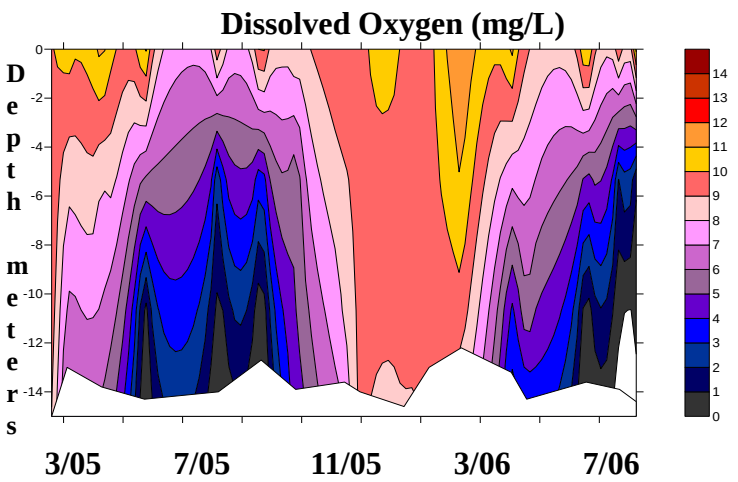


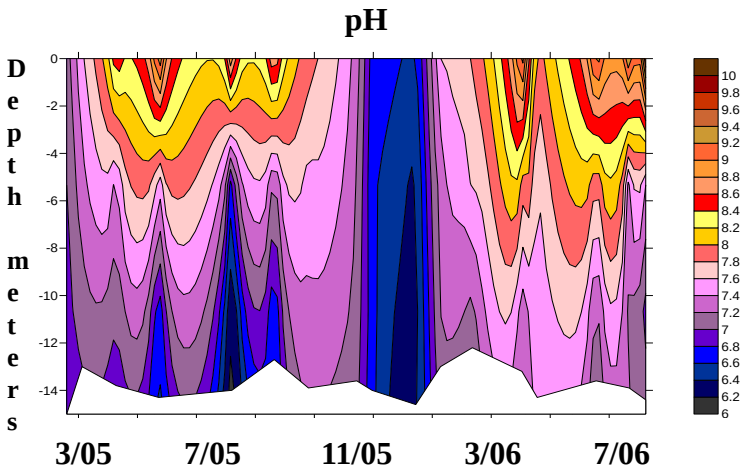


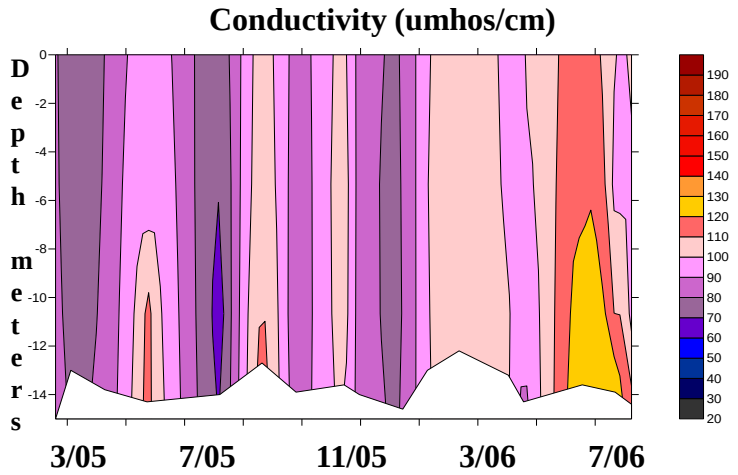


Physical Profiles: Station YAD169F









Residence Time

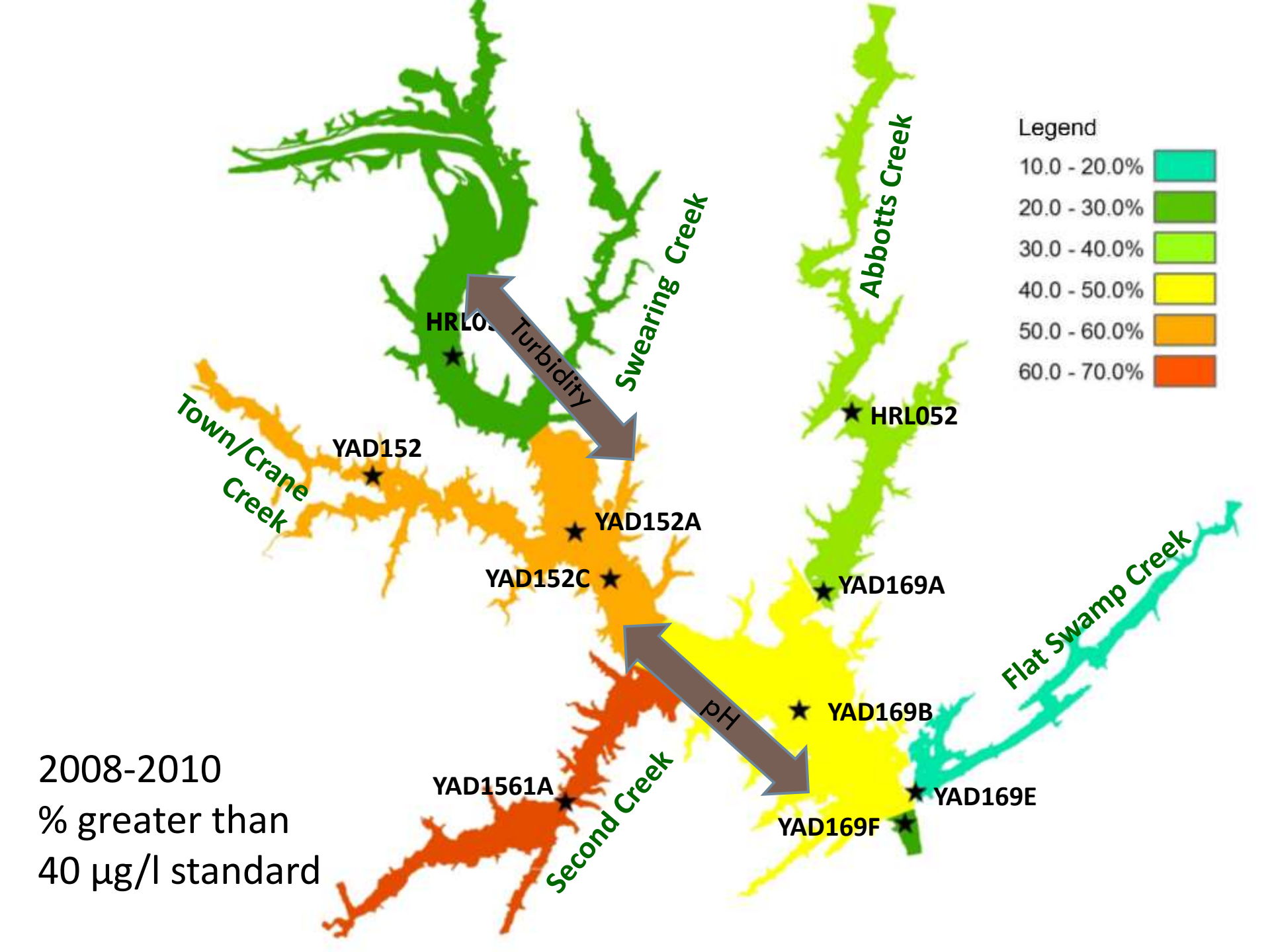
- High Rock Lake*: 4 – 50 days
- Falls Lake# annual average (05-07):

  4 – 7 months

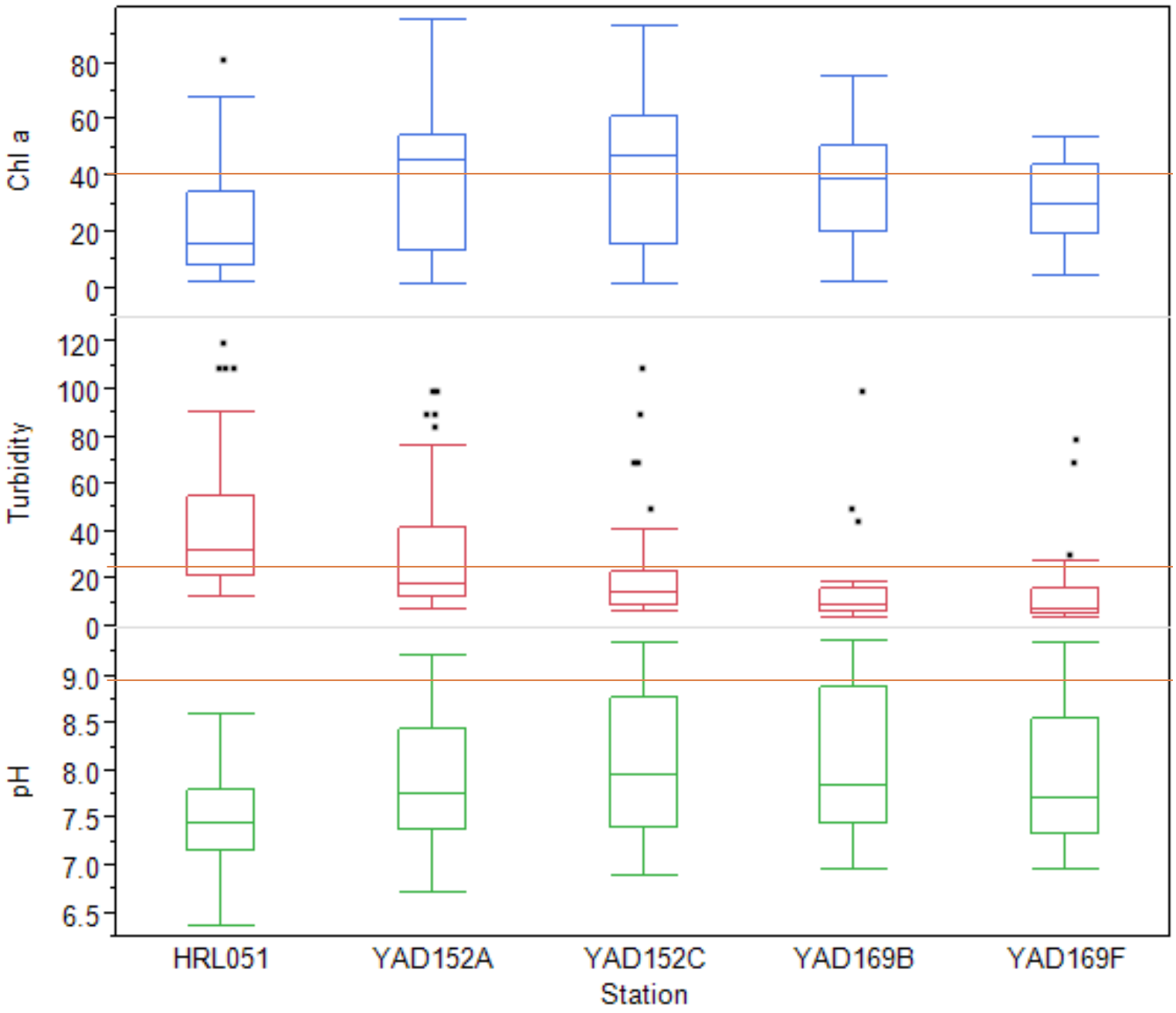
* APGI (2006)
# Lin et al (2011)

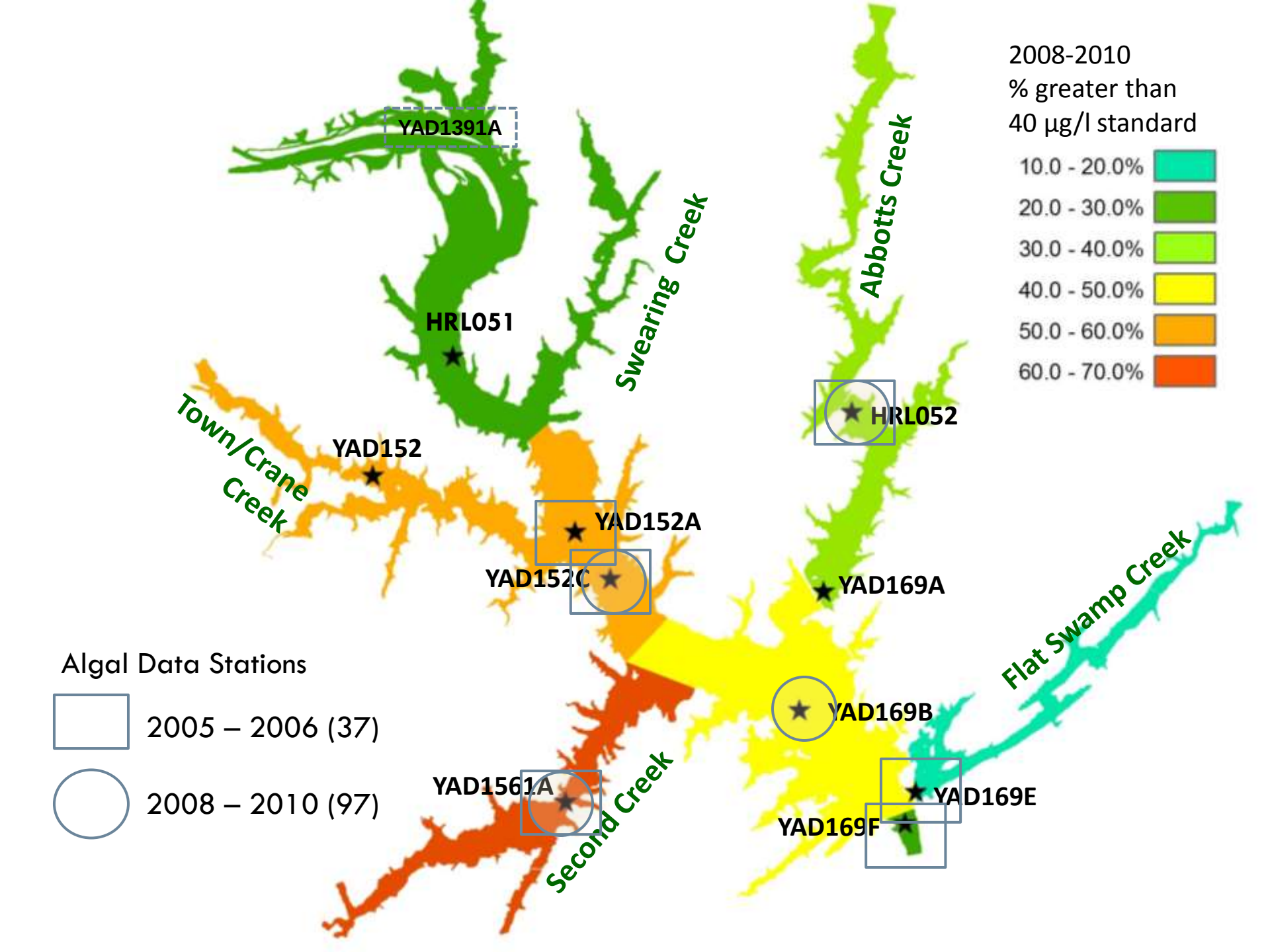
Outline

- High Rock Watershed
- Lake Physical Characteristics
- **Lake Biochemical Characteristics**
  - **Chl *a* and other problem indicator?**
  - **Chl *a* and nutrients?**

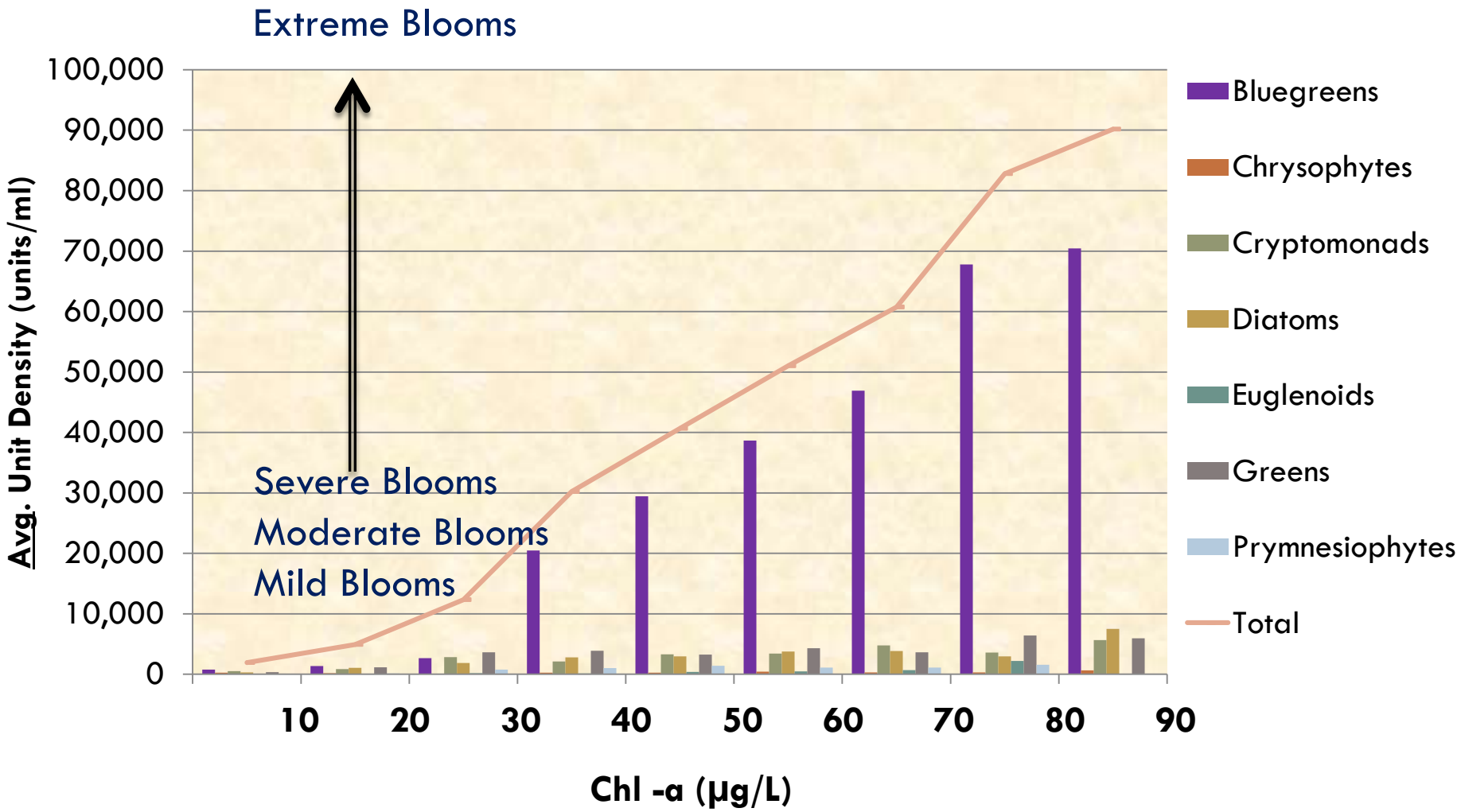

Legend
10.0 - 20.0%
20.0 - 30.0%
30.0 - 40.0%
40.0 - 50.0%
50.0 - 60.0%
60.0 - 70.0%
Swearing Creek
Abbotts Creek
Town/Crane Creek
Flat Swamp Creek
Second Creek
Turbidity
pH
HRL052
YAD152
YAD152A
YAD152C
YAD169A
YAD169B
YAD169E
YAD169F
YAD1561A
2008-2010
% greater than
40 µg/l standard

Upstream 2008-2010 Dam

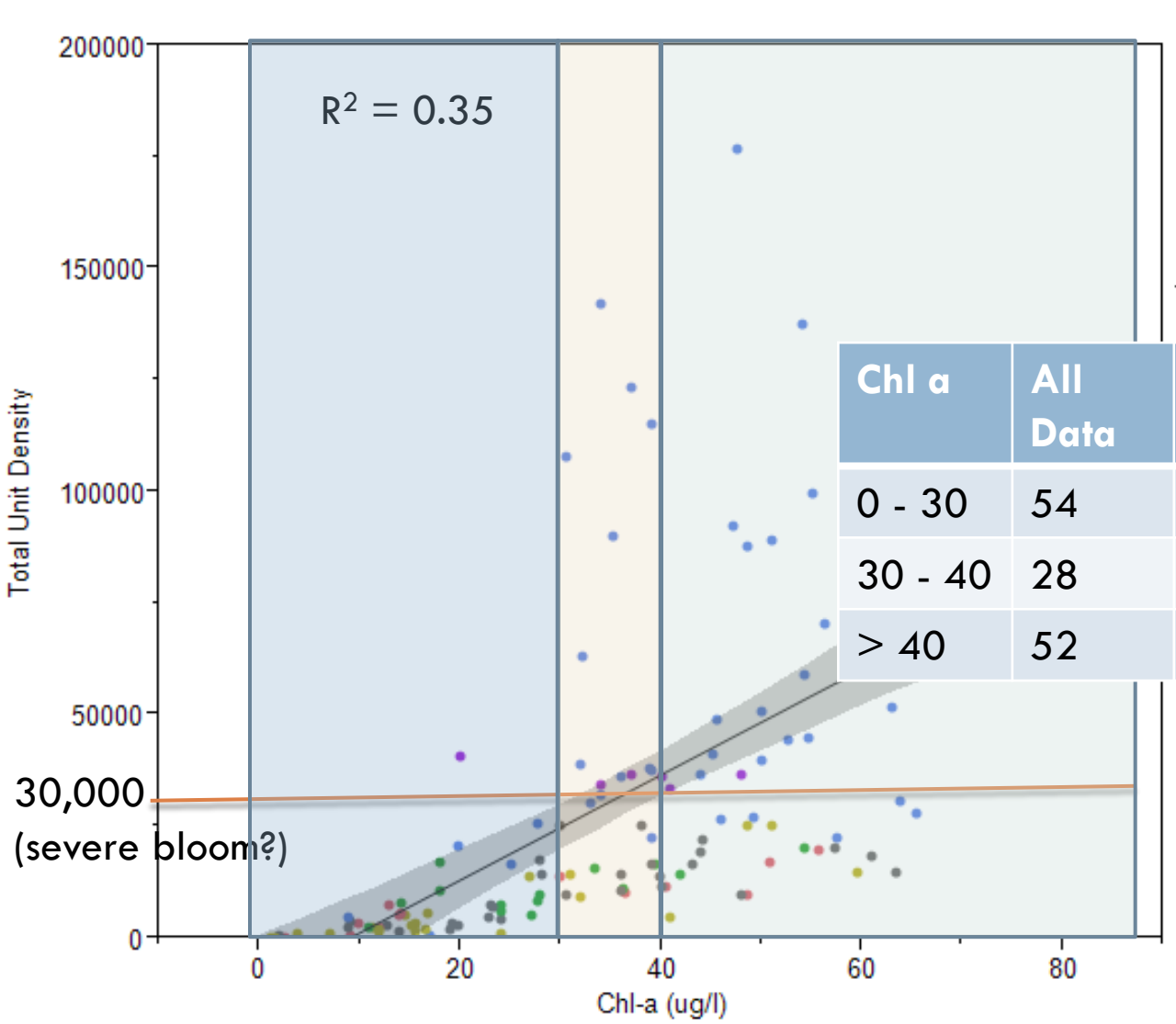



2008-2010
% greater than
40 µg/l standard
10.0 - 20.0%
20.0 - 30.0%
30.0 - 40.0%
40.0 - 50.0%
50.0 - 60.0%
60.0 - 70.0%
YAD1391A
HRL051
Swearing Creek
Abbotts Creek
HRL052
Town/Crane Creek
YAD152
YAD152A
YAD152C
YAD169A
Flat Swamp Creek
YAD169B
YAD169E
YAD169F
YAD1561A
Second Creek
Algal Data Stations
2005 – 2006 (37)
2008 – 2010 (97)

Algal Unit Density vs. Chl-a *(08-10)*



Algal Unit Density vs. Chl-a(05-10)

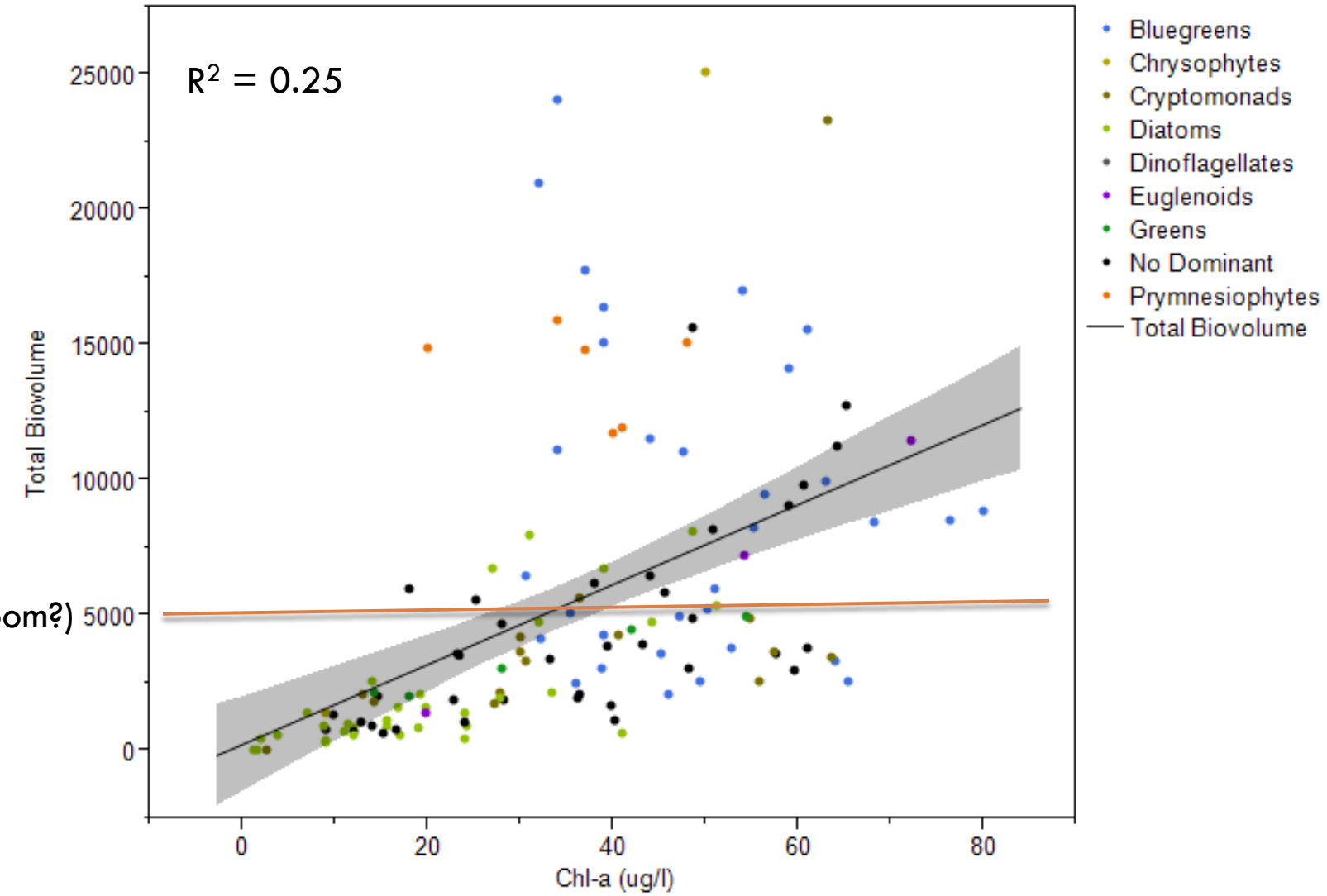


Dominant Algal Groups

- Bluegreens
- Cryptomonads
- Diatoms
- Greens
- No Dominant
- Prymnesiophytes
- Total Unit Density

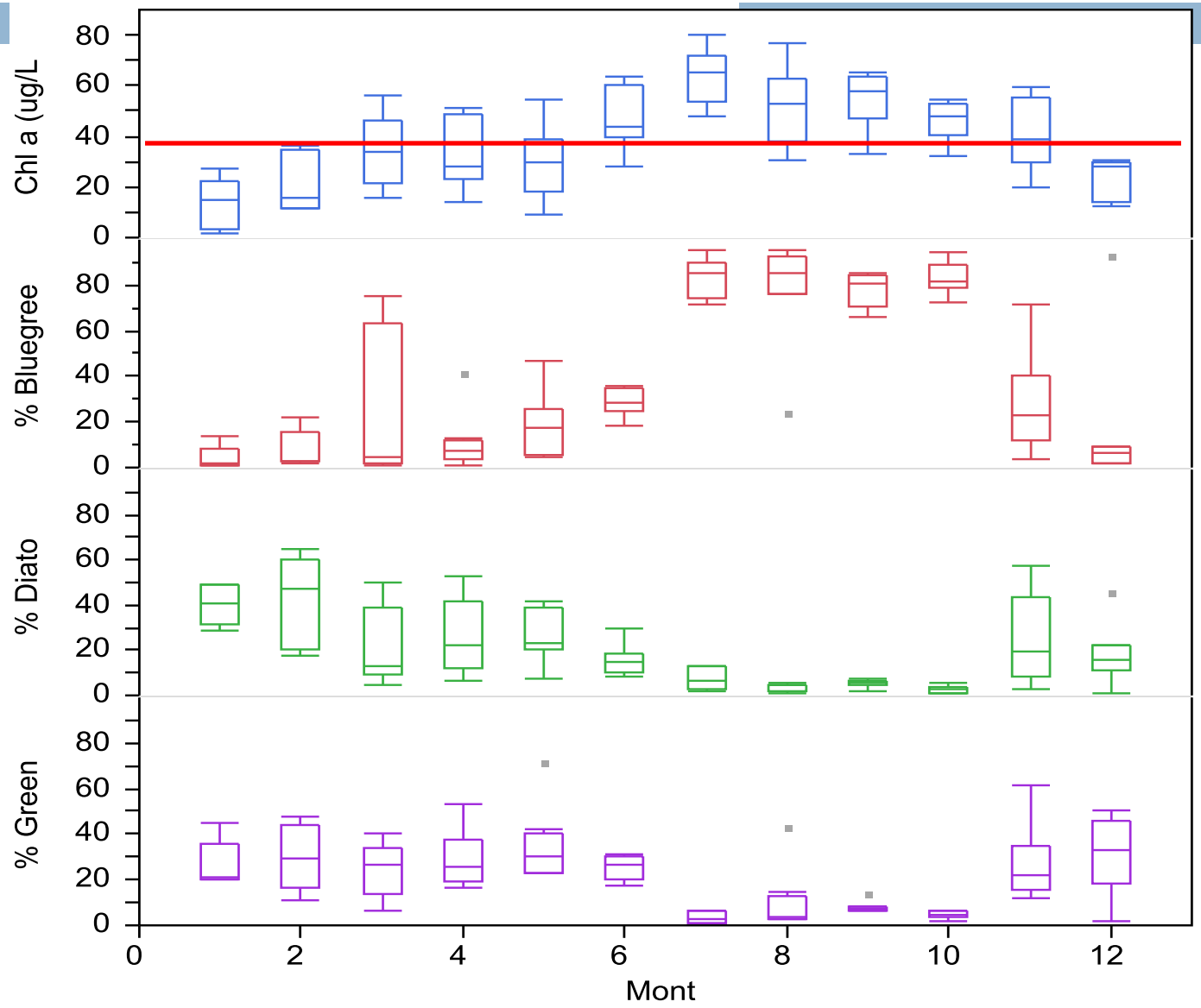
Chl a	All Data	Bluegreens Dominate	% Bluegreens Dominate
0 - 30	54	5	9.3%
30 - 40	28	13	46.4%
> 40	52	32	61.5%

Algal Biovolume vs. Chl-a(05-10)



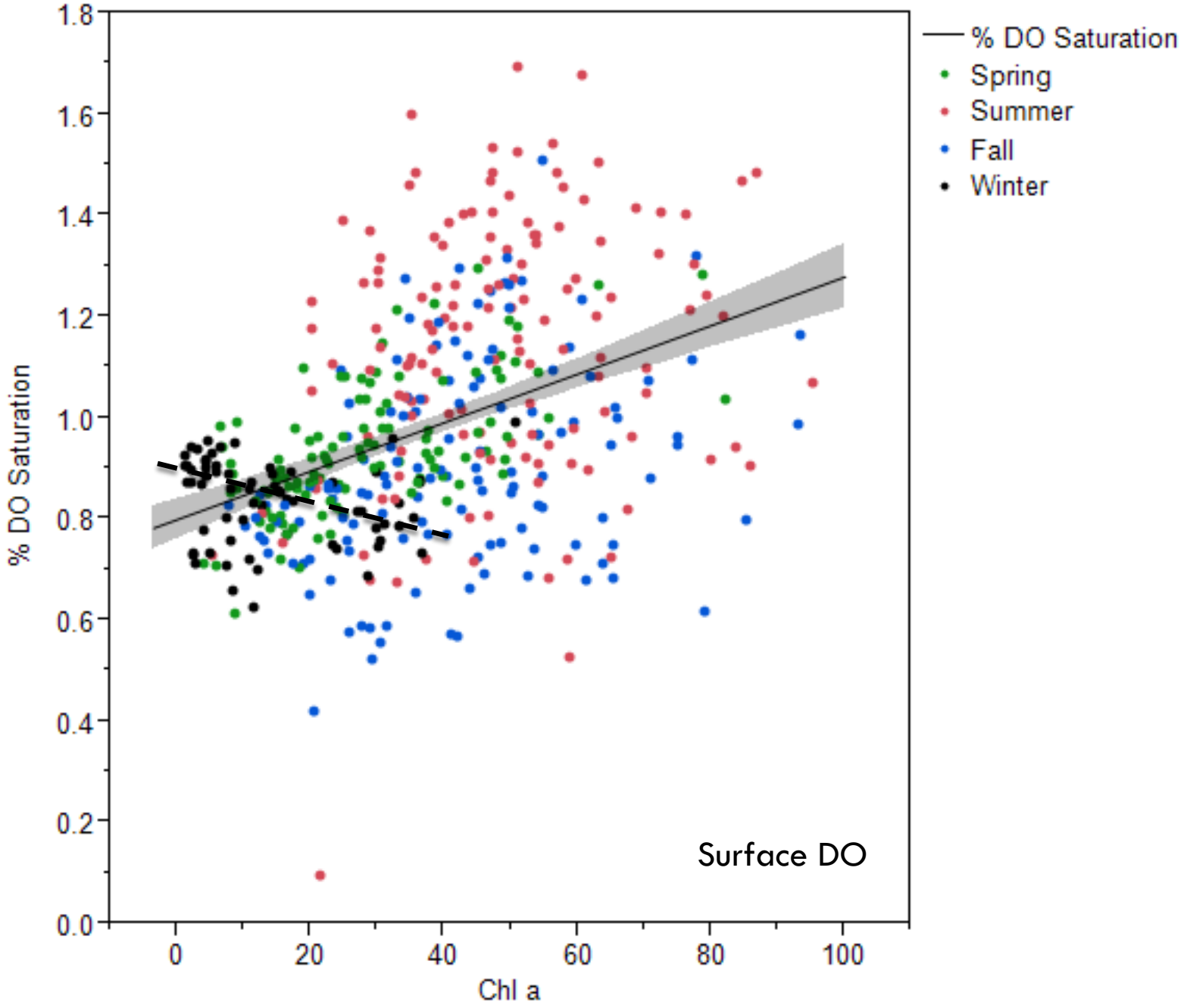
(bloom?)

Chl a and %Algal Unit Density (08-10)

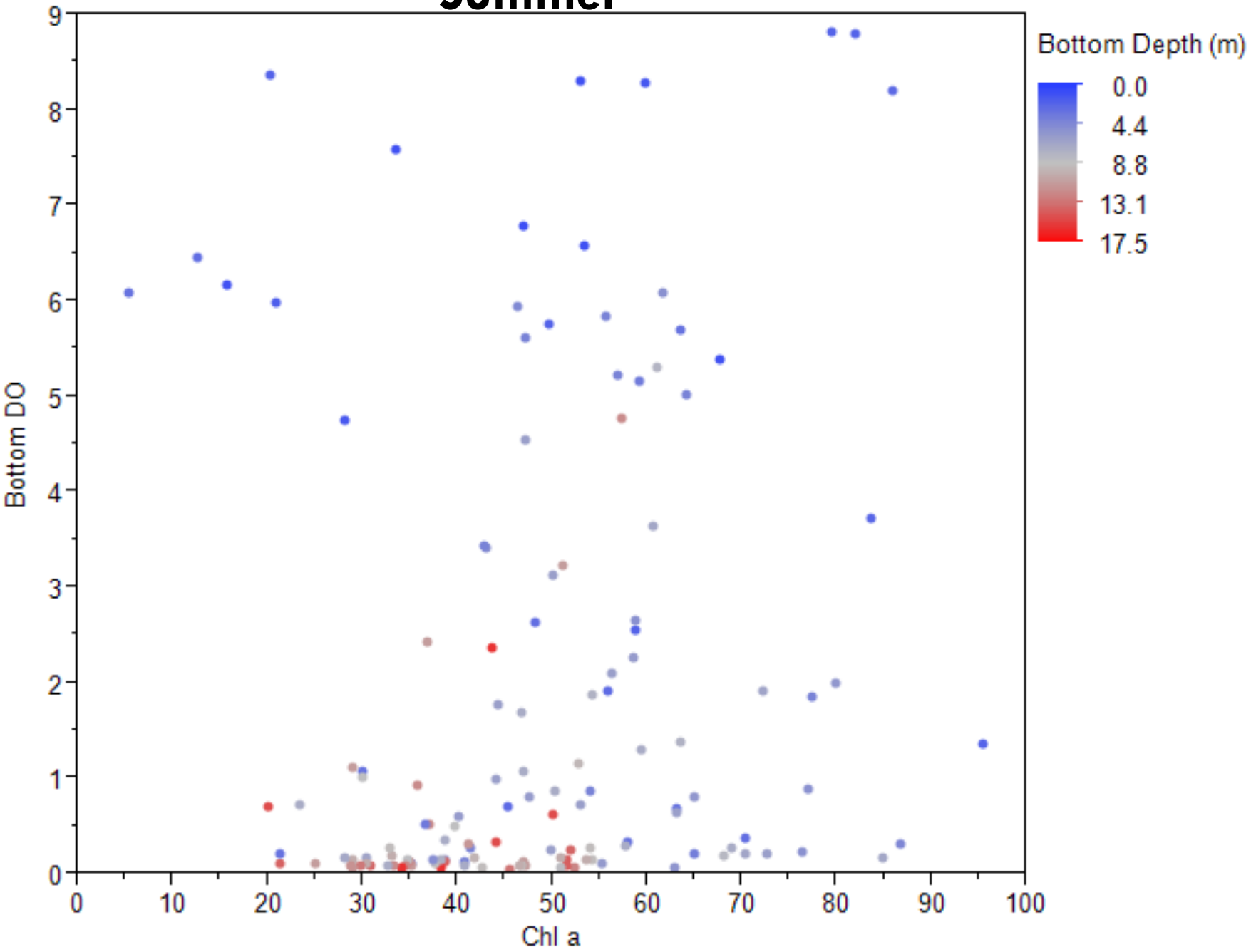


Correlations between Chlorophyll a and Other Problem Indicators

	Turbidity	pH	DO
Surface	**Negative** (all stations)	**Positive** (significant middle to lower lake stations)	**Negative** (winter) **Positive** (Summer & Spring) **Positive** (Temp>20)
Bottom			**Negative** (Winter & Spring)


% DO Saturation
Spring
Summer
Fall
Winter
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
% DO Saturation
0
20
40
60
80
100
Chl a
Surface DO

Summer


Bottom Depth (m)
0.0
4.4
8.8
13.1
17.5
Bottom DO
Chl a
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
90
100

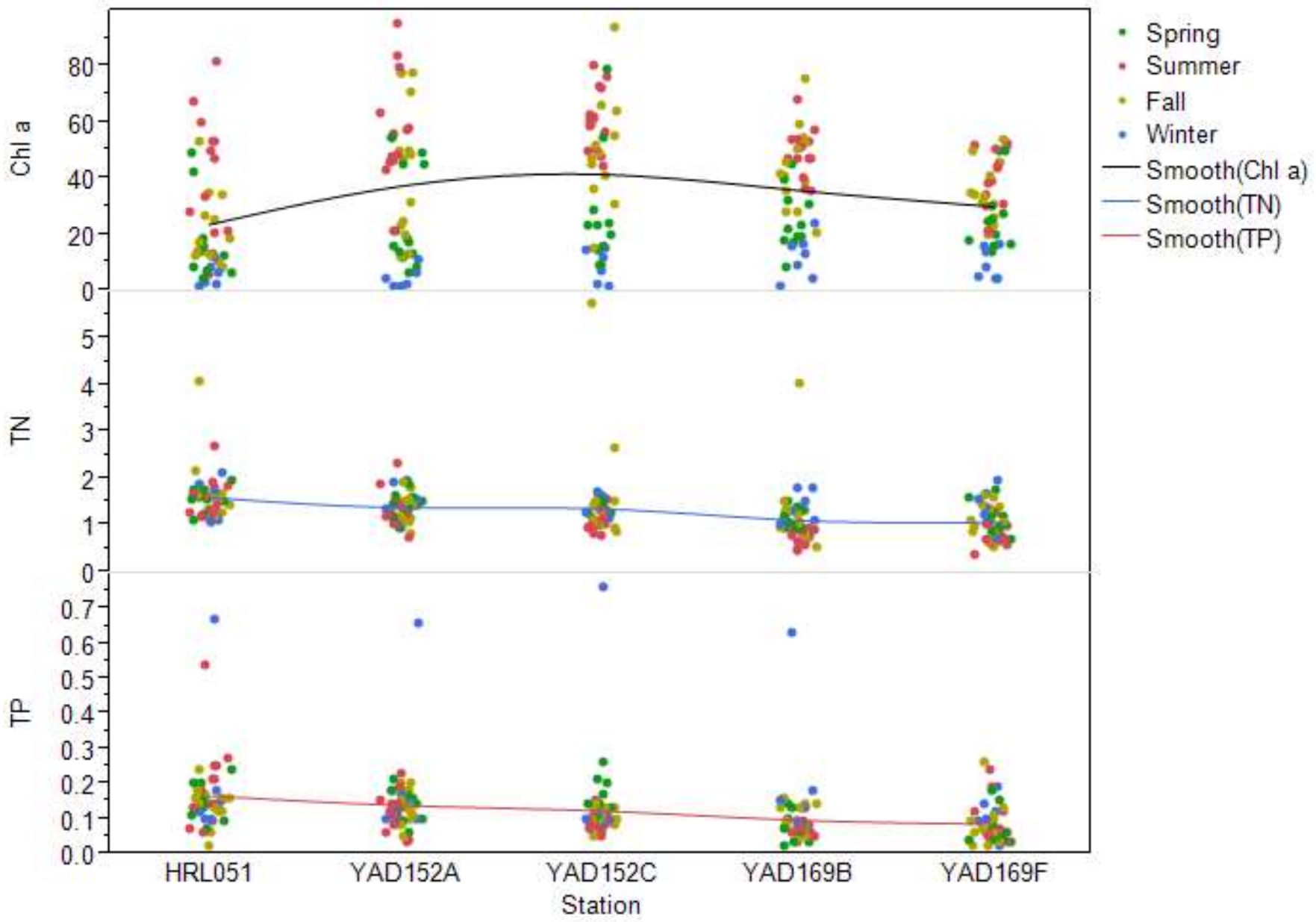
Bottom DO and Surface Chl *a*

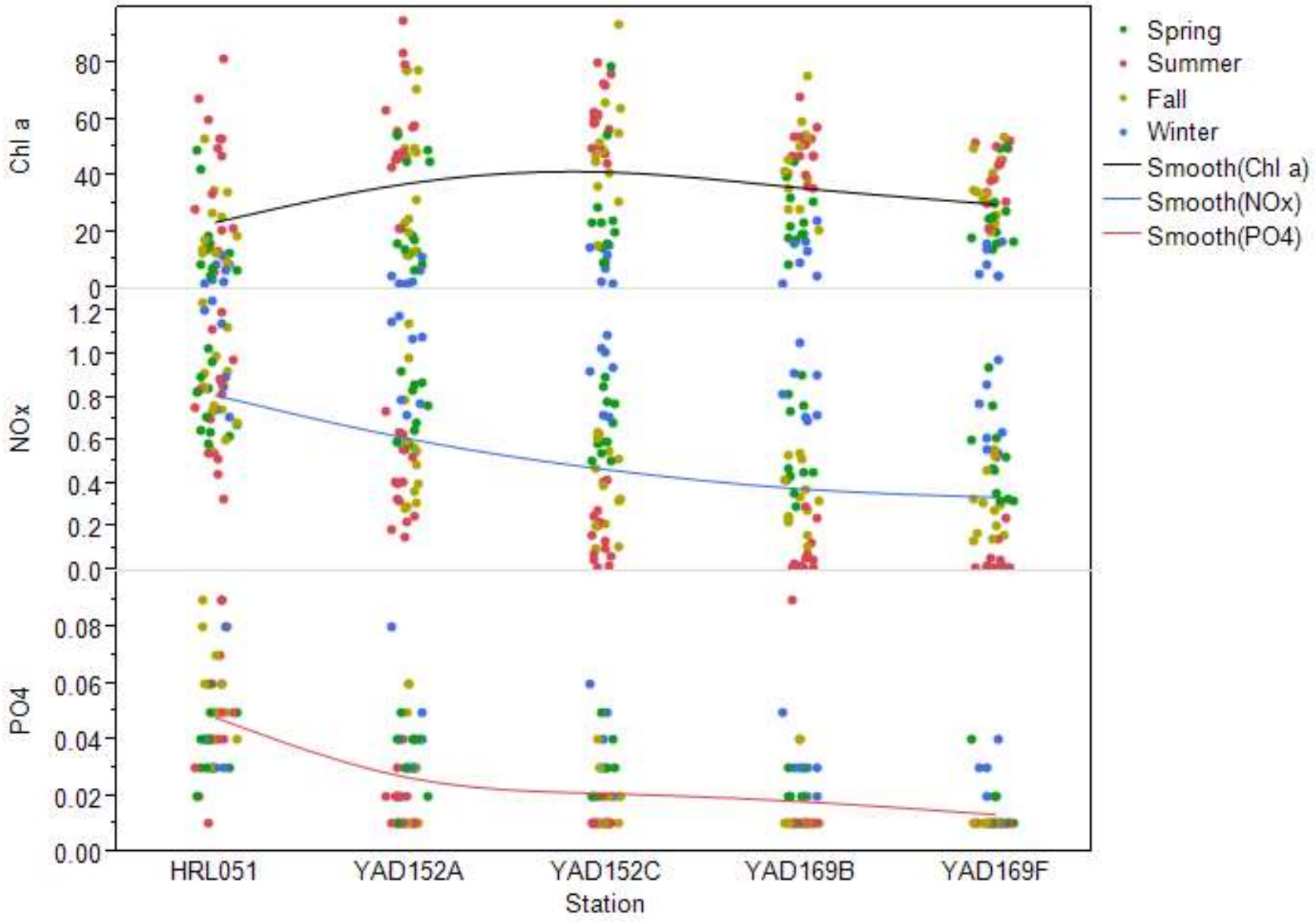
- Negative (Physical)
  - Higher T, lower DO saturation, lower DO
  - Higher T, higher Chl *a*
- Positive (Biological)
  - Higher PP, higher surface DO →bottom DO (mixing!)
  - Higher PP, higher Chl *a*
- Negative (Biological)
  - Higher PP, higher OM → lower bottom DO (Stratification)
  - Higher PP, higher Chl *a*

- *(BOD, runoff, SOD)*

Outline

- High Rock Watershed
- Lake Physical Characteristics
- Lake Biochemical Characteristics
  - Chl *a* and other problem indicator?
  - **Chl *a* and nutrients?**

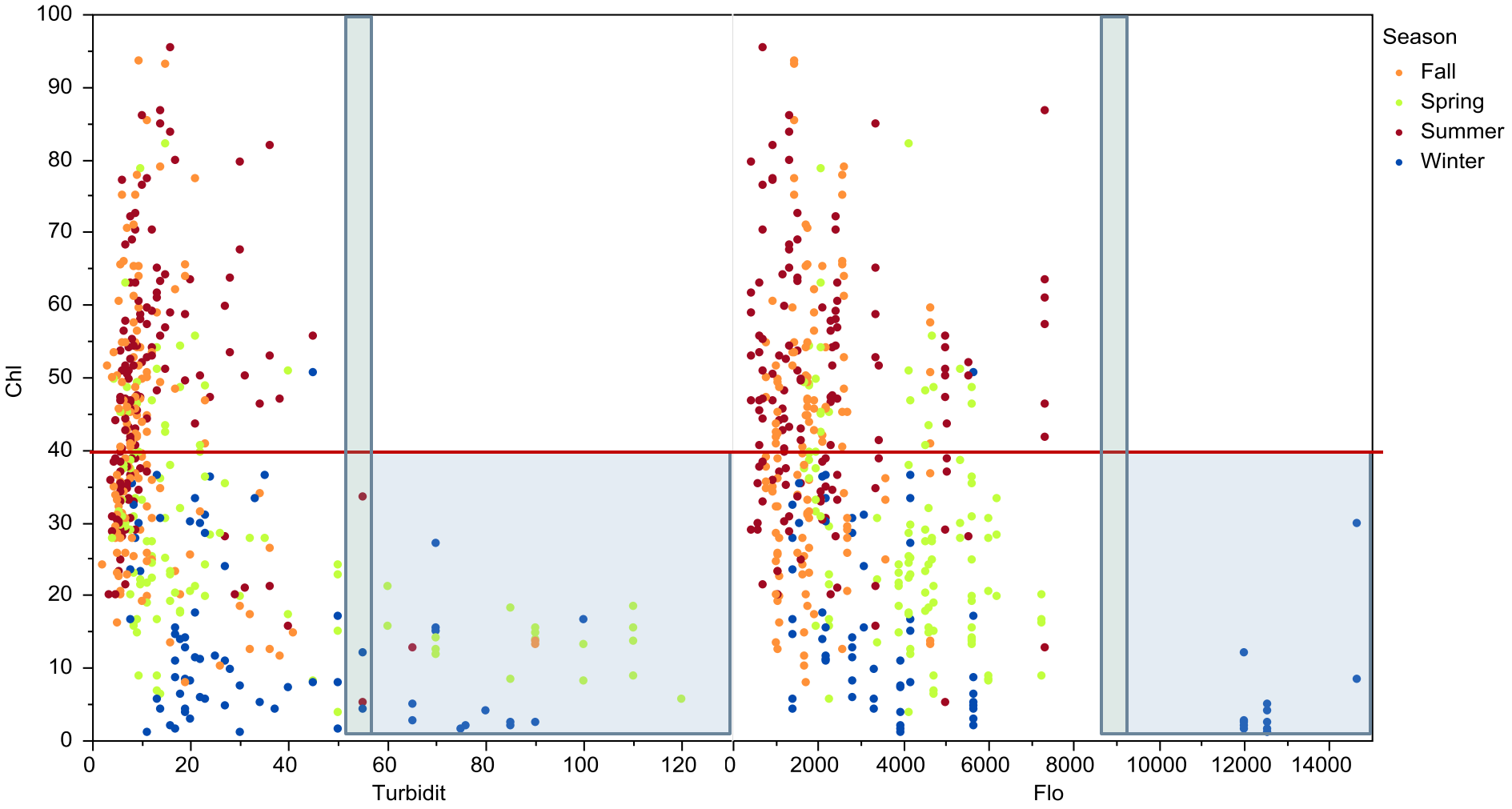

Upstream
Dam
Chl a
TN
TP
Spring
Summer
Fall
Winter
Smooth(Chl a)
Smooth(TN)
Smooth(TP)
HRL051
YAD152A
YAD152C
YAD169B
YAD169F
Station

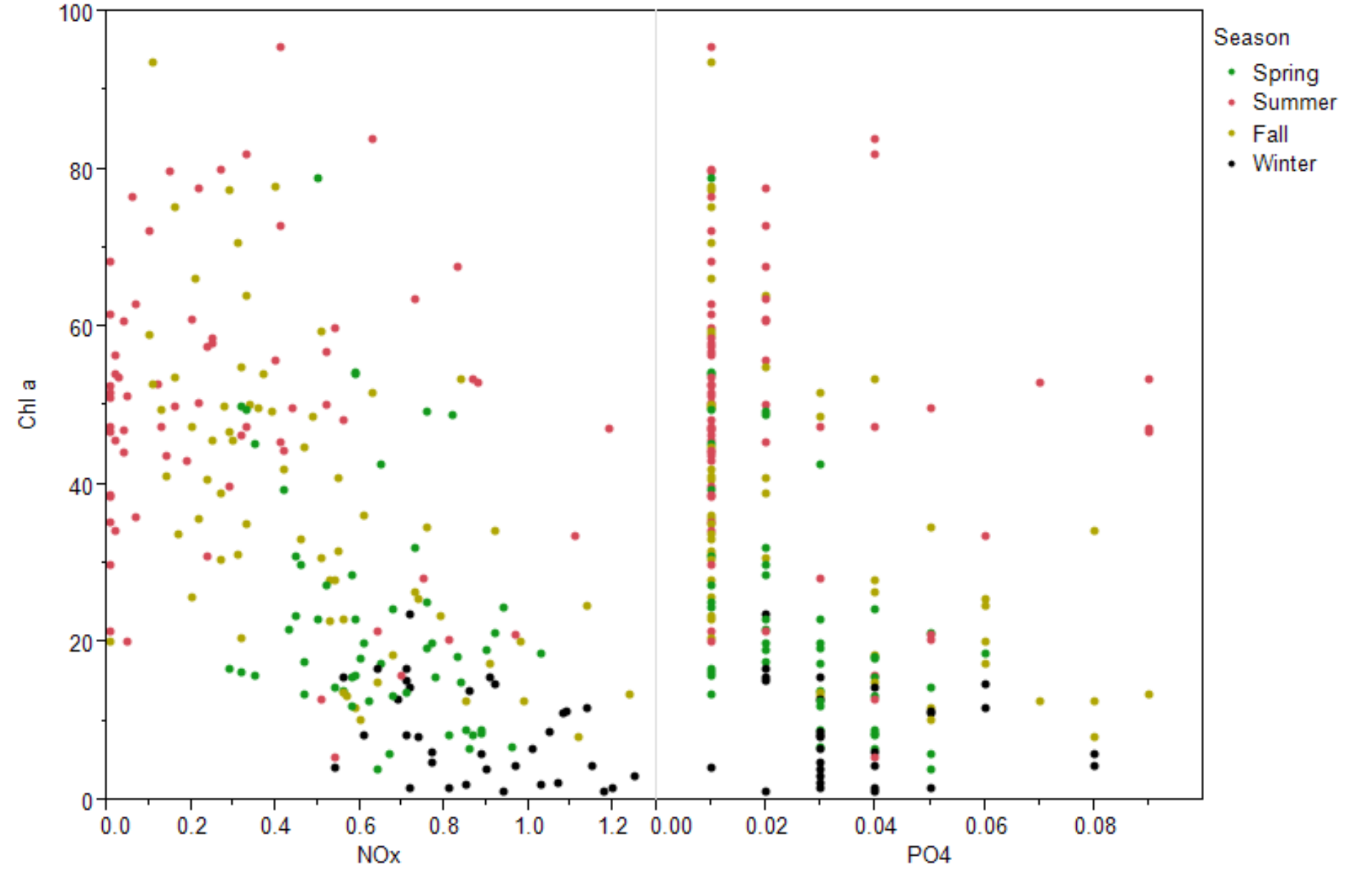

Chl a
NOx
PO4
Spring
Summer
Fall
Winter
Smooth(Chl a)
Smooth(NOx)
Smooth(PO4)
HRL051
YAD152A
YAD152C
YAD169B
YAD169F
Station

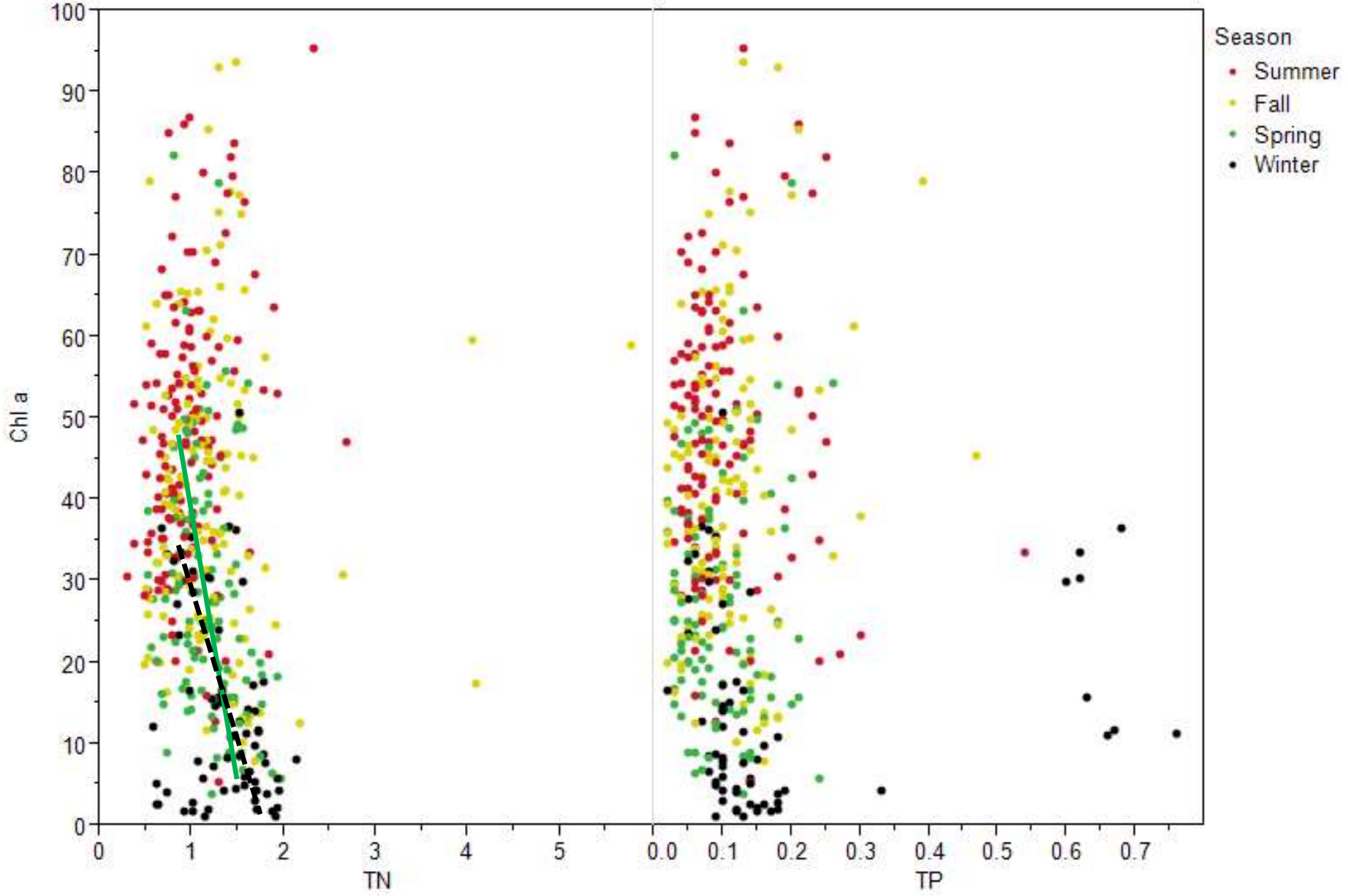
Correlations between Chlorophyll a and Other Parameters

	IN	TN	IP	TP	Temp	Flow
Winter	**-0.59**	**-0.32**	**-0.57**	0.11	**0.40**	**-0.38**
Spring	**-0.46**	**-0.25**	**-0.54**	0.07	**0.28**	**-0.41**
Summer	-0.04	**0.25**	-0.07	-0.04	**0.17**	-0.06
Fall	**-0.38**	0.003	**-0.45**	0.16	**0.47**	0.04

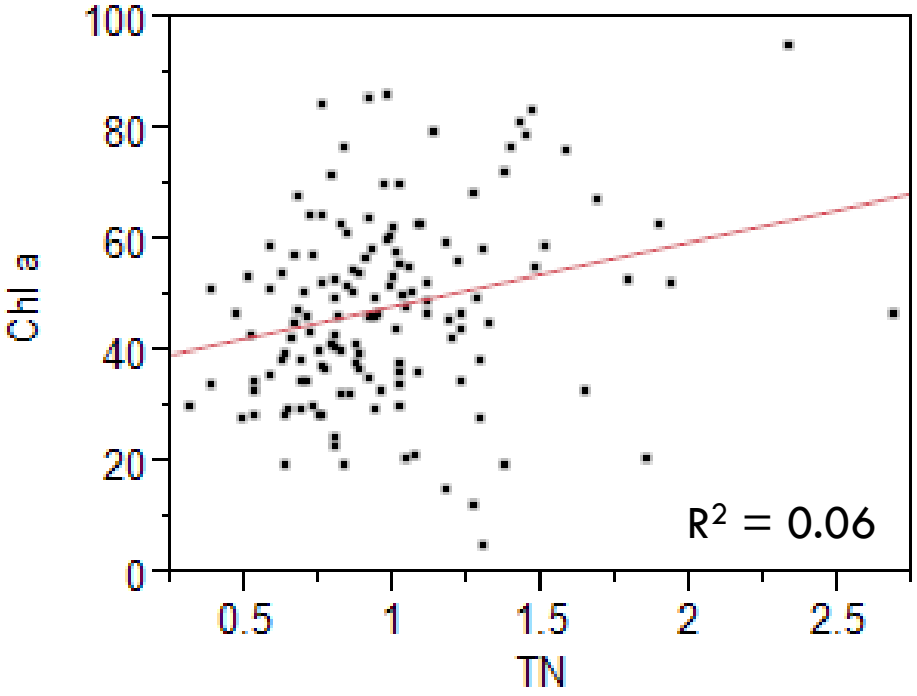
Impacts of Turbidity and Flow on Chl a

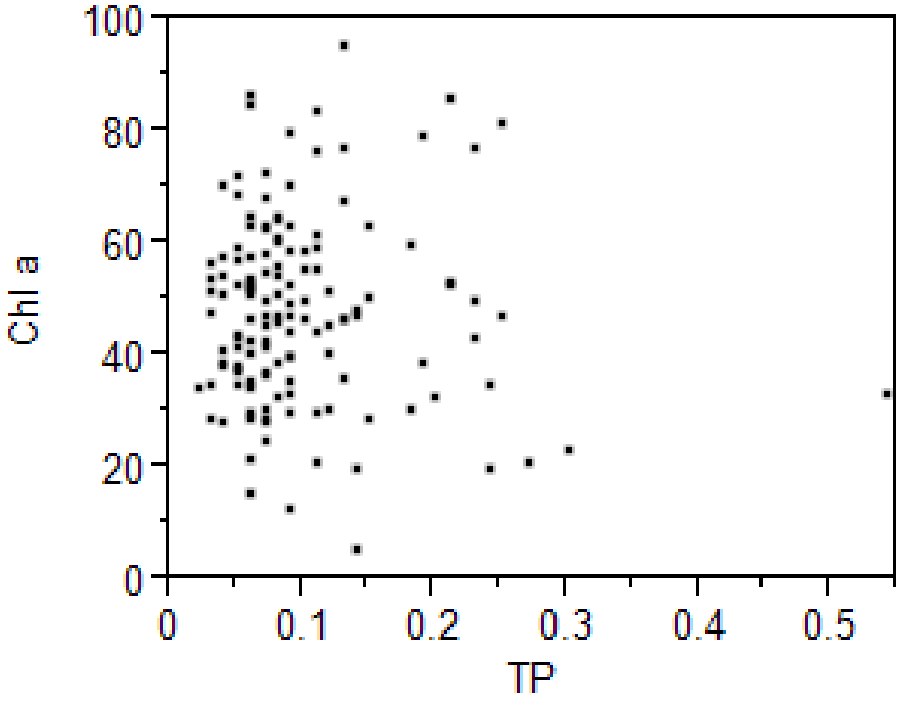


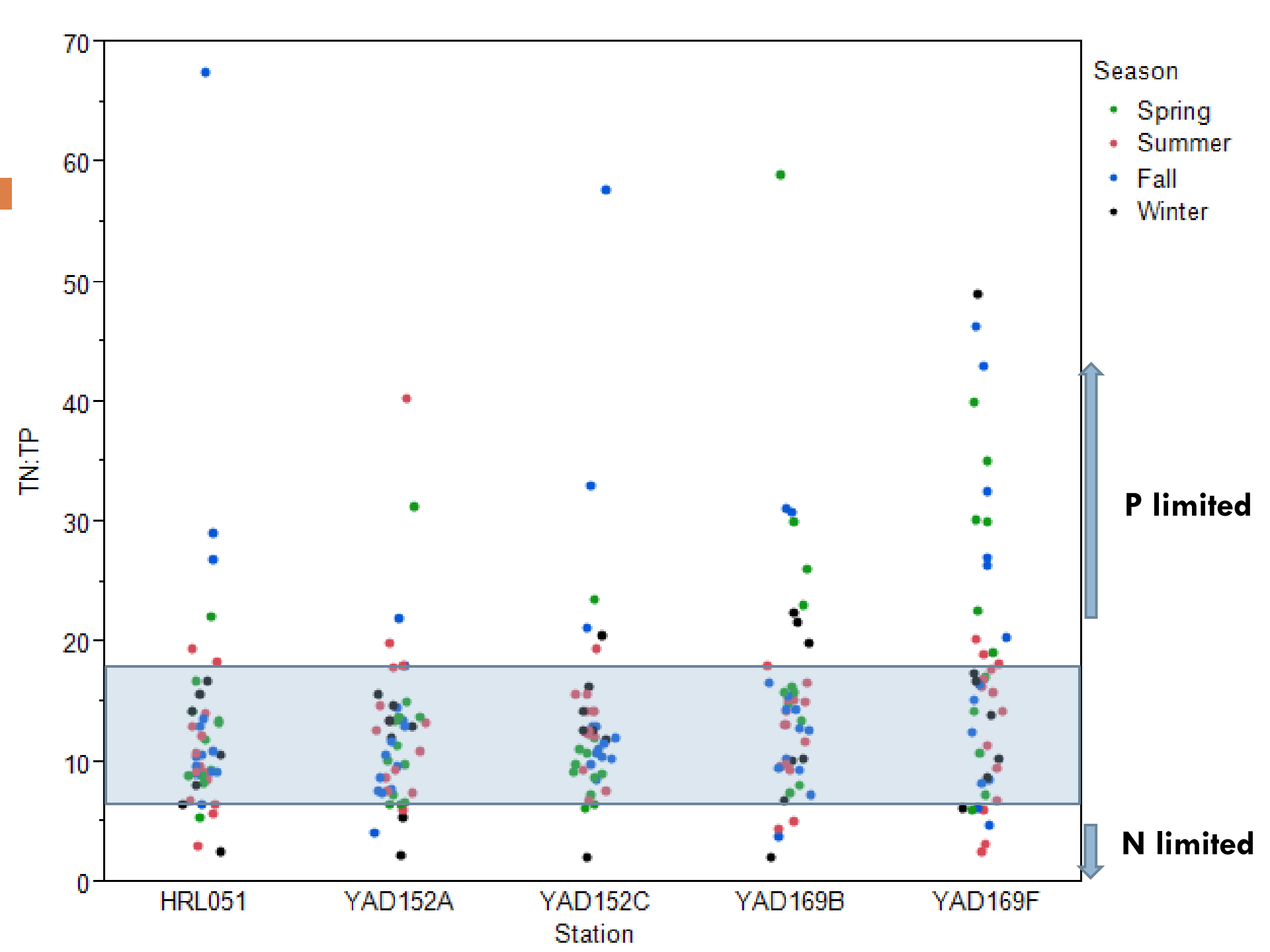

Season
Spring
Summer
Fall
Winter
Chl a
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
NOx
0.00
0.02
0.04
0.06
0.08
PO4

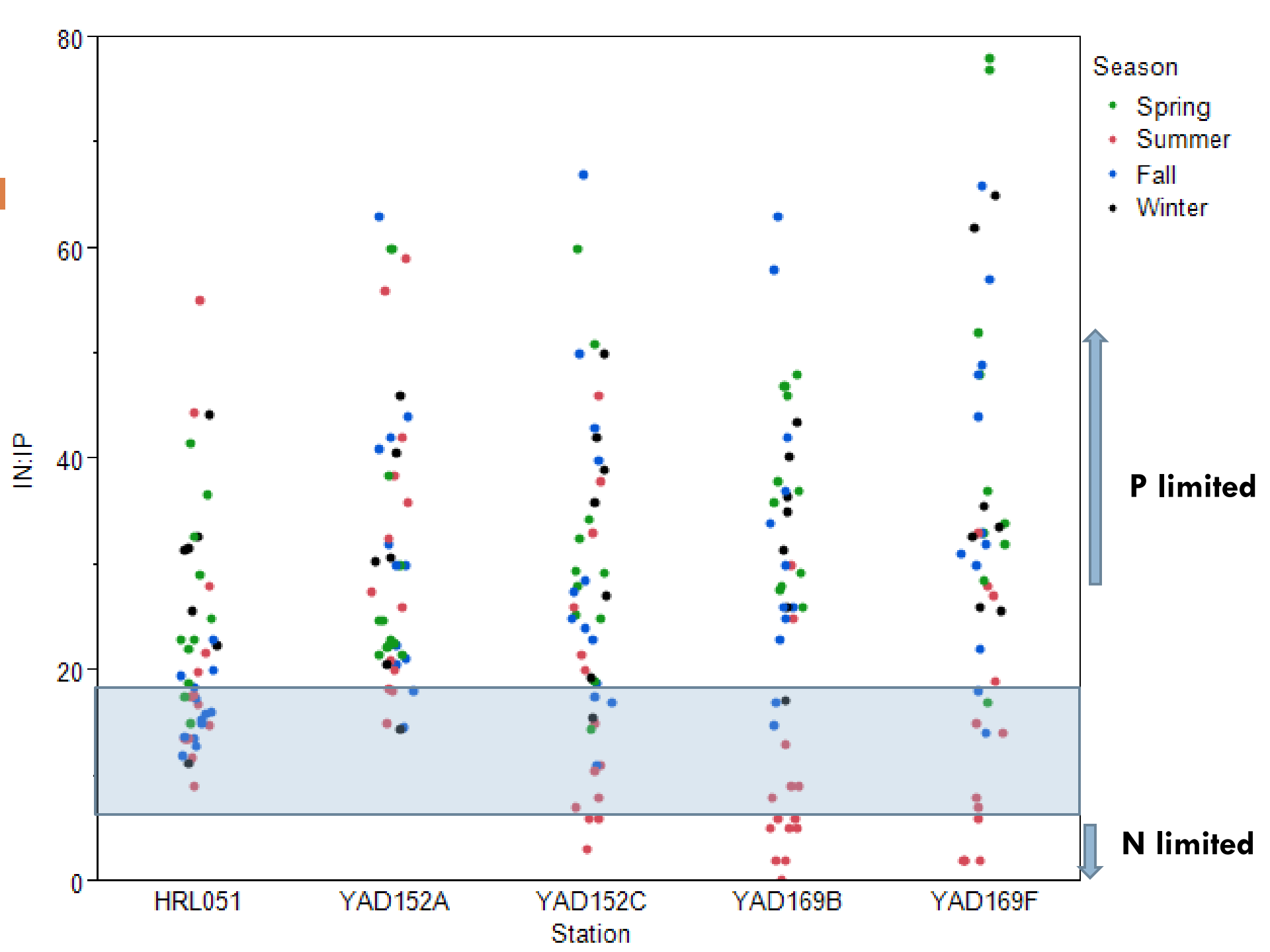

Chl a
TN
TP
Season
Summer
Fall
Spring
Winter

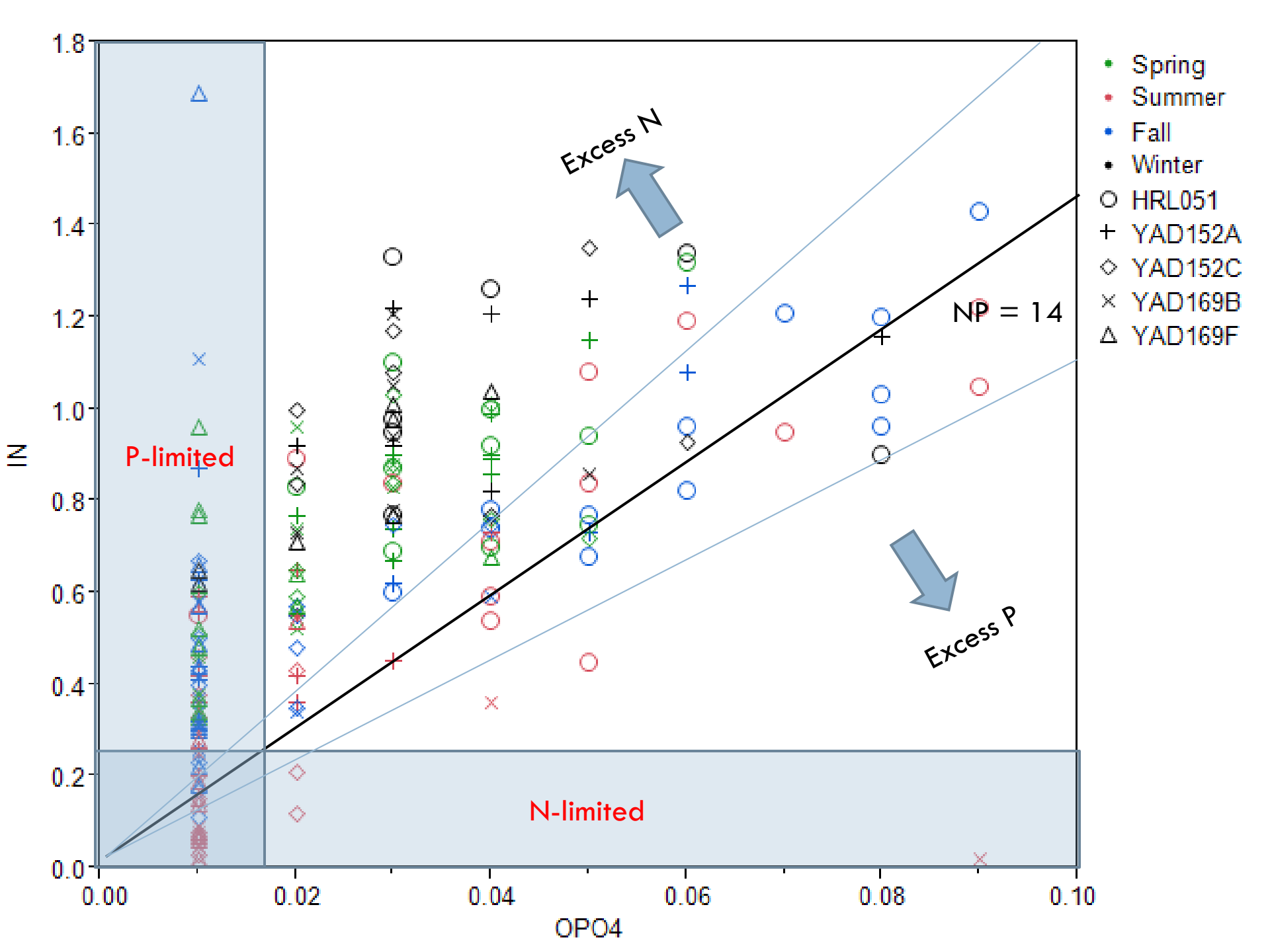
Summer


Chl a
TN
$R^2 = 0.06$
0
20
40
60
80
100
0.5
1
1.5
2
2.5

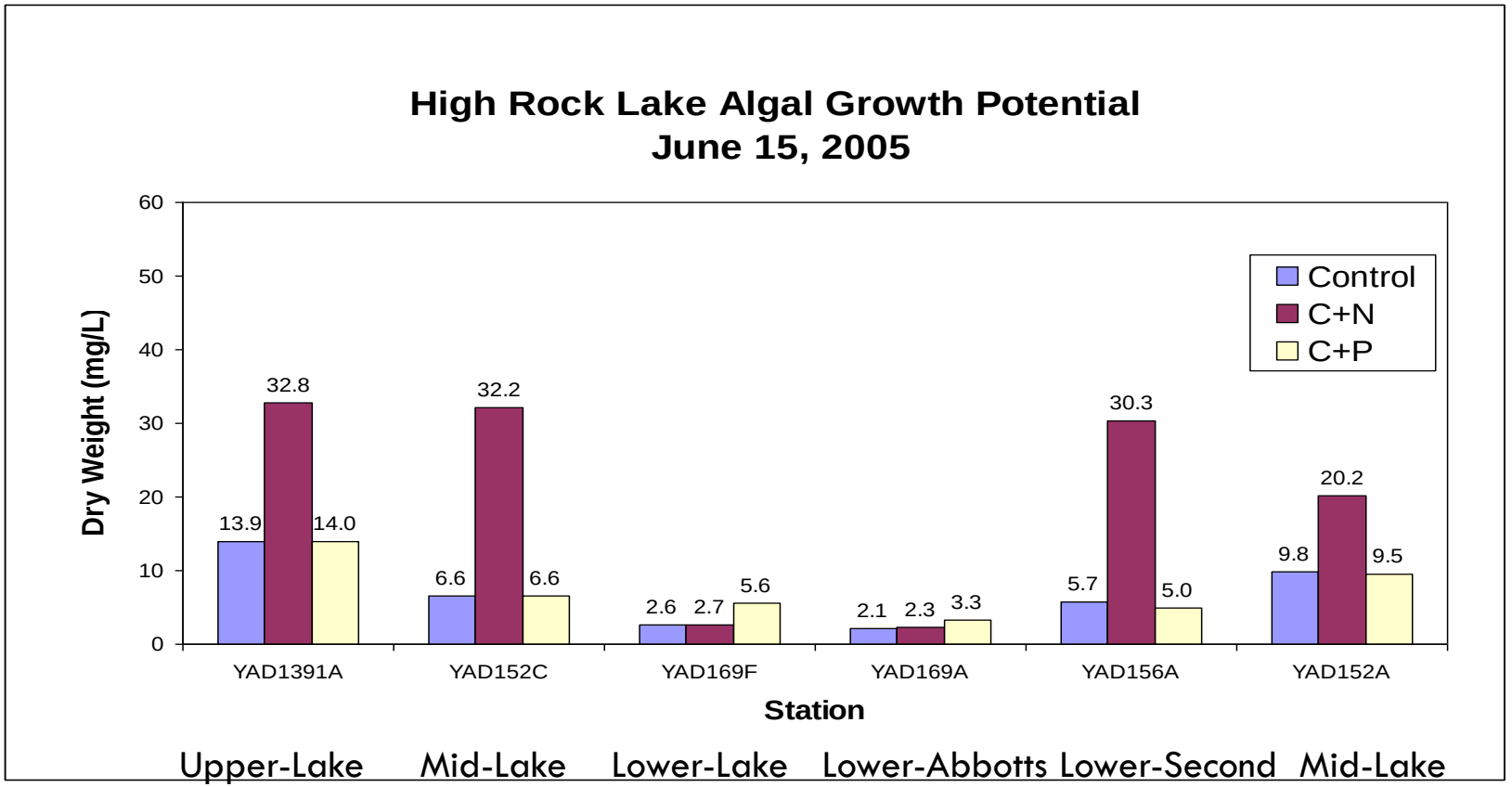

Chl a
TP
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5


70
60
50
40
30
20
10
0
TN:TP
HRL051
YAD152A
YAD152C
YAD169B
YAD169F
Station
Season
Spring
Summer
Fall
Winter
P limited
N limited


80
60
40
20
0
IN:IP
HRL051
YAD152A
YAD152C
YAD169B
YAD169F
Station
Season
Spring
Summer
Fall
Winter
P limited
N limited


Spring
Summer
Fall
Winter
HRL051
YAD152A
YAD152C
YAD169B
YAD169F
Excess N
Excess P
NP = 14
P-limited
N-limited
TN
OPO4
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0.00
0.02
0.04
0.06
0.08
0.10

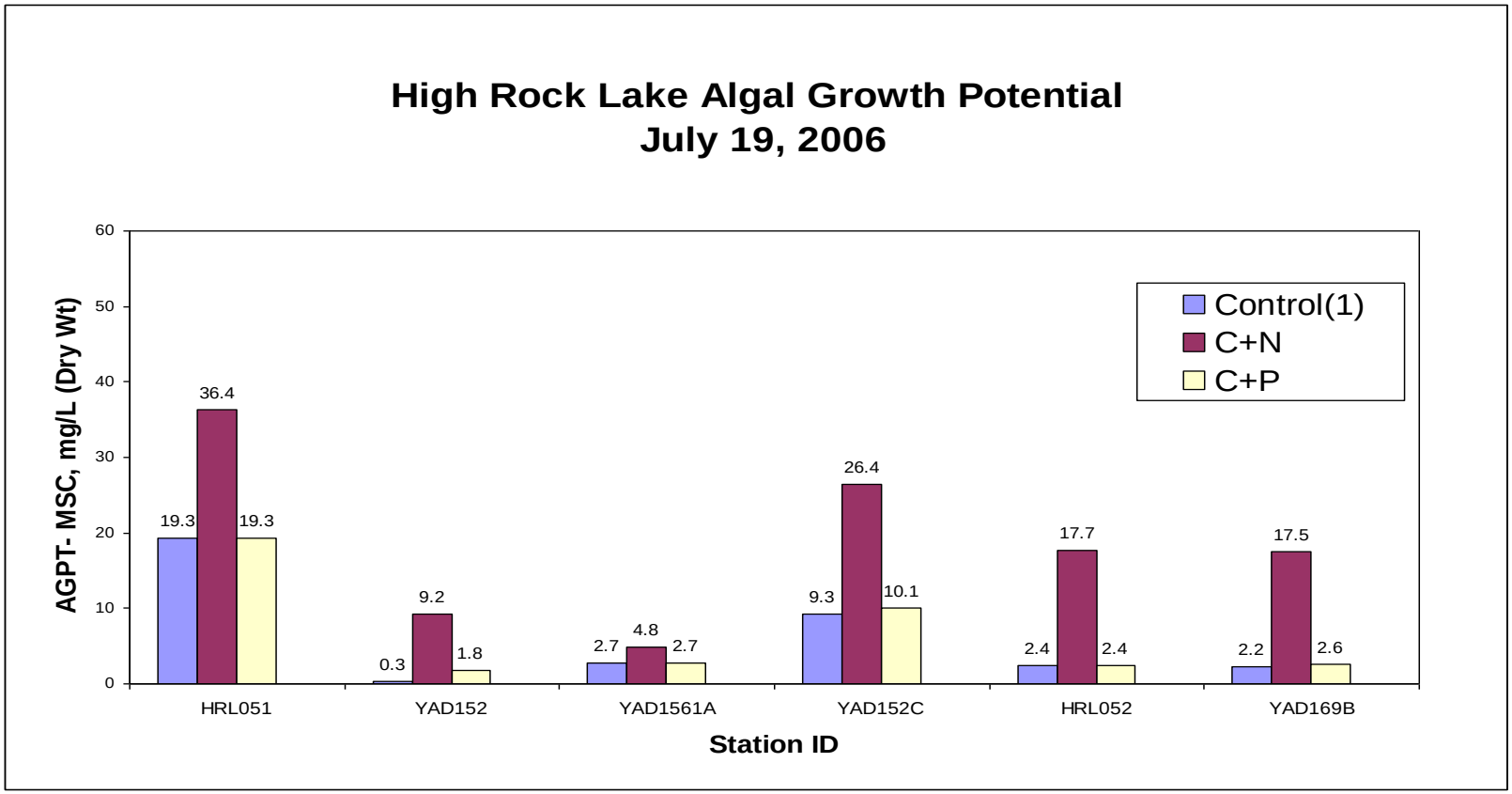
High Rock Lake: 2005 Algal Growth Potential



C+N = Control + 1.0 mg/L Nitrate-N

C+P = Control + 0.05 mg/L Phosphate-P

High Rock Lake:
2006 Algal Growth Potential



C+N = Control + 1.0 mg/L Nitrate-N
C+P = Control + 0.05 mg/L Phosphate-P

Summary:

- Chl a – indicator for algal density and community
- Chl *a* concentrations are influenced by physical factors such as flow and turbidity
- High pH is likely caused by high algal growth
- Bottom Hypoxia mainly controlled by physical parameters such as depth, temperature, flow, and vertical stratification.
- Summer Chl a is positively correlated with TN
- Overall, HRL appear to be N abundant, but during summer phytoplankton growth tends to be N-limited or co-limited by both N and P.

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Questions?

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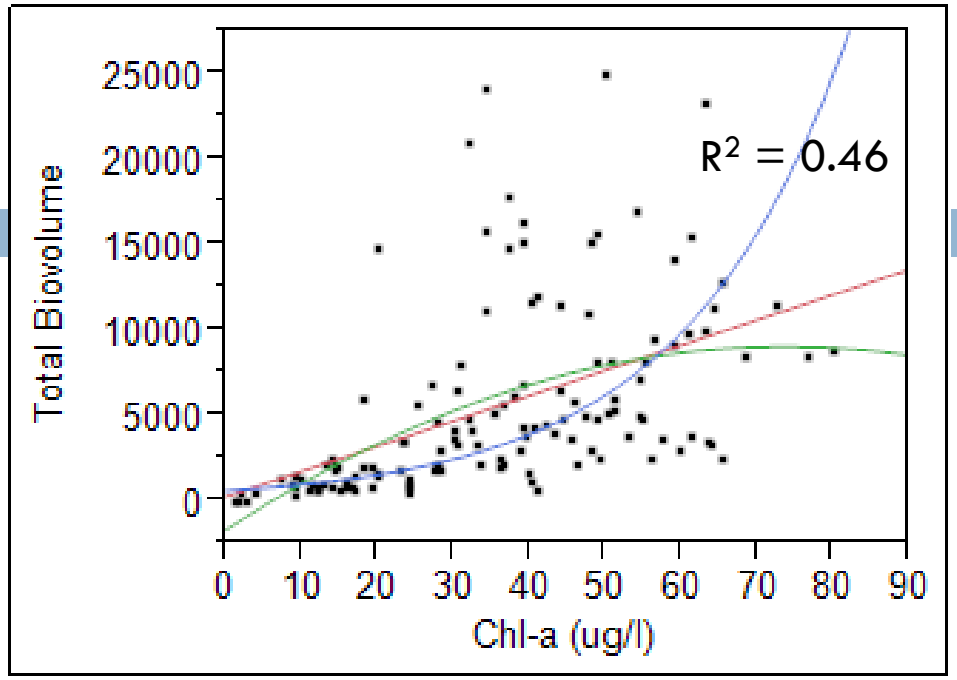
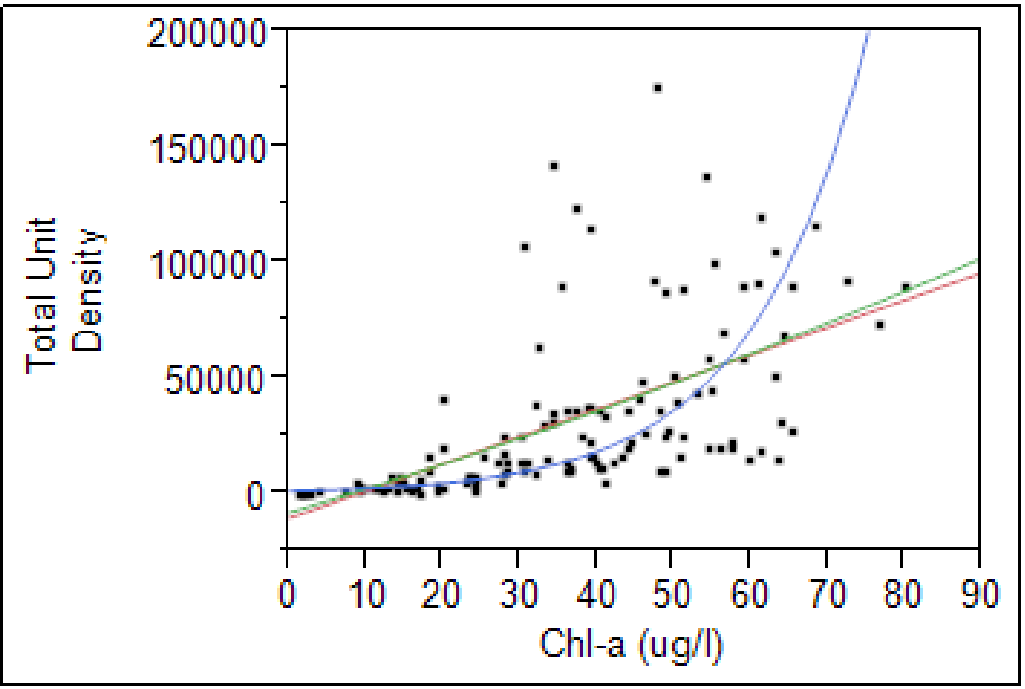
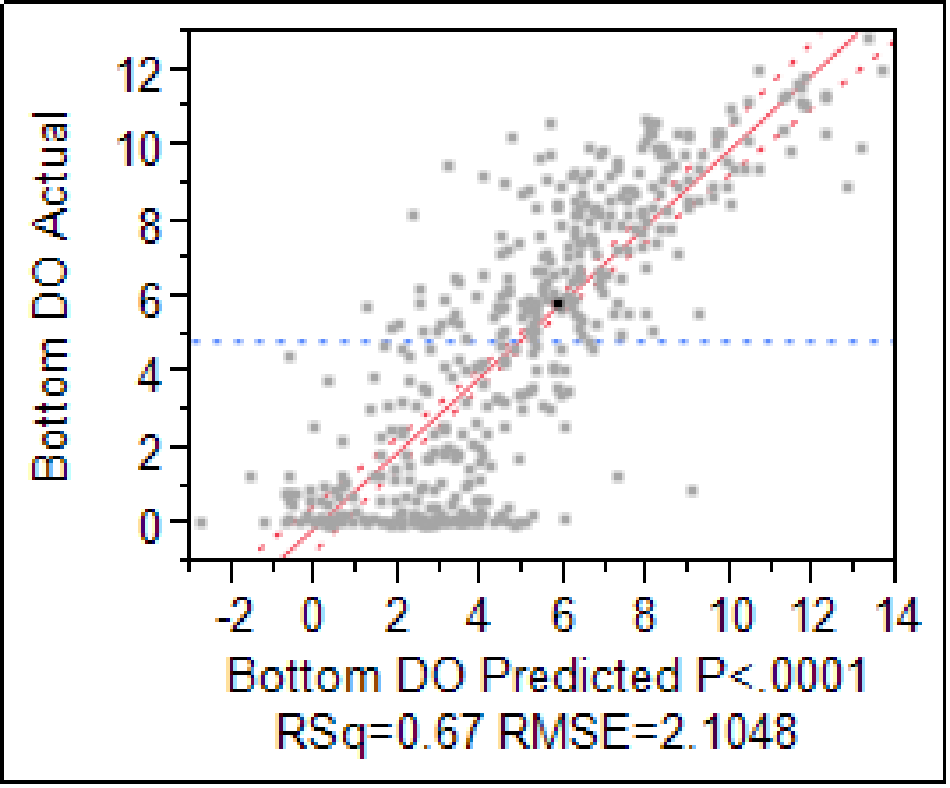
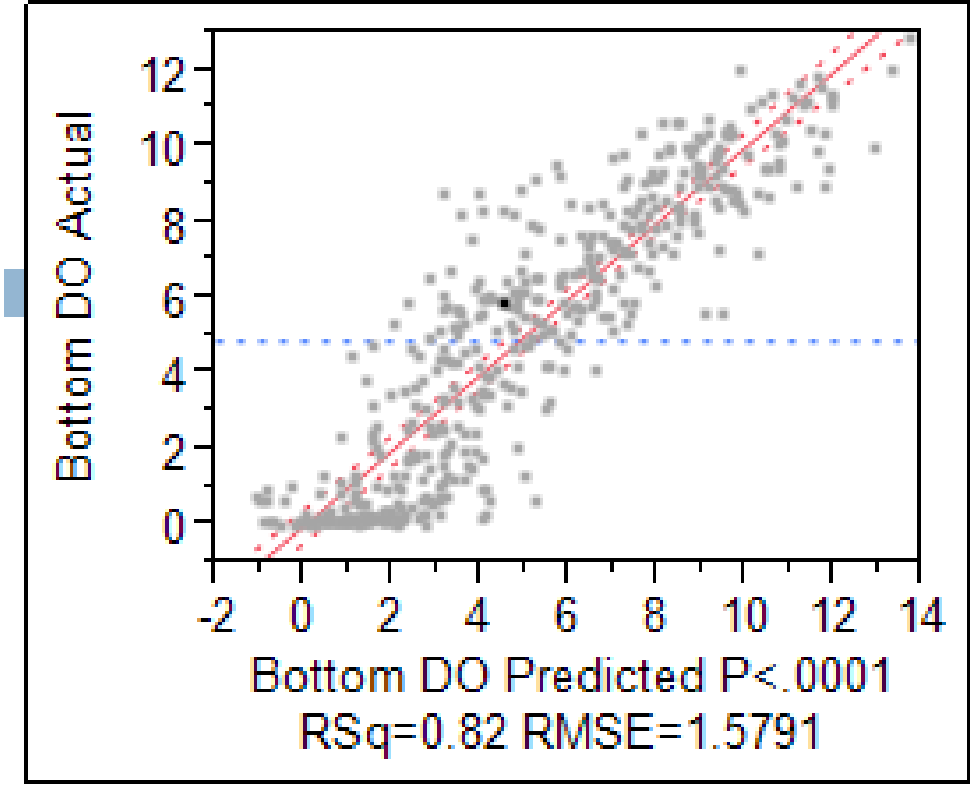
STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY


Total Biovolume
25000
20000
15000
10000
5000
0
$R^2 = 0.46$
0 10 20 30 40 50 60 70 80 90
Chl-a (ug/l)


Total Unit Density
200000
150000
100000
50000
0
0 10 20 30 40 50 60 70 80 90
Chl-a (ug/l)





Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t
Intercept	4.835177	0.719692	6.72	<.0001*
Surface DO	0.8151283	0.054725	14.90	<.0001*
Bottom Depth (m)	-0.152359	0.027169	-5.61	<.0001*
Temp Diff	-1.977676	0.13353	-14.81	<.0001*
BOD	-0.56758	0.132968	-4.27	<.0001*
TOC	-0.34087	0.086298	-3.95	<.0001*
Chl a	-0.037621	0.006678	-5.63	<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.078752	0.352183	42.82	<.0001*
Avg Temp	-0.340061	0.012505	-27.19	<.0001*
Bottom Depth (m)	-0.198506	0.020246	-9.80	<.0001*
Temp Diff	-0.906243	0.098054	-9.24	<.0001*
Chl a	0.0129233	0.004895	2.64	0.0086*
TOC	-0.46258	0.06227	-7.43	<.0001*

Tasks for SAC

1. What concentration/frequency/duration of chlorophyll-*a* is right to protect aquatic life? **How to express N&P?**
2. **Is chlorophyll-*a* standard enough as a response indicator? Are other response indicators appropriate?**
3. Is resulting criteria translatable to other lakes?

High Rock Lake Watershed Model

Pam Behm

3rd NCDP SAC Meeting

August 18, 2015

Watershed Model

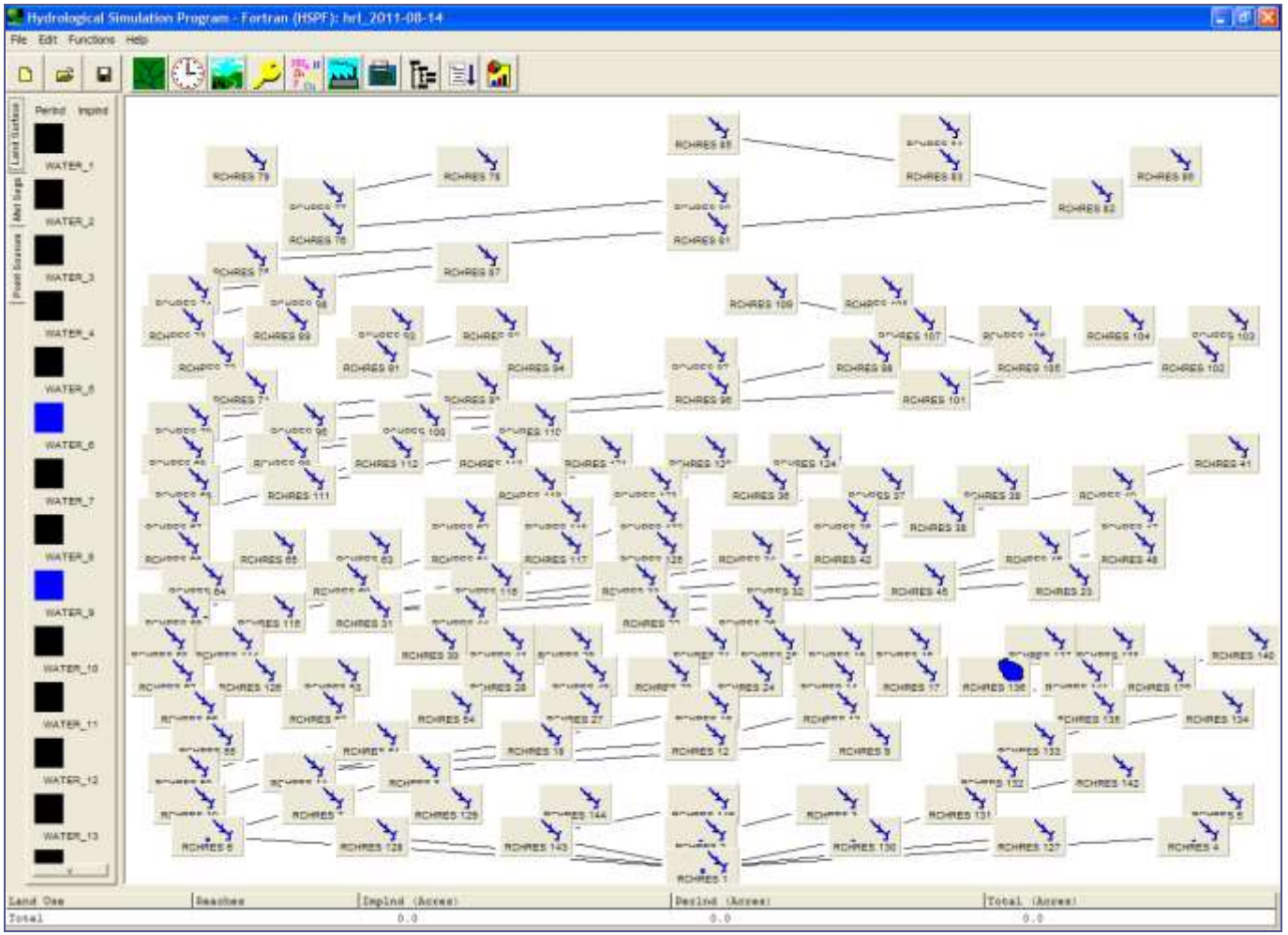
- Estimates what is happening on land that results in nutrient export to receiving water (i.e. High Rock Lake)

- Provides relative loading by source (agriculture, developed, point sources, etc.)

Project Background

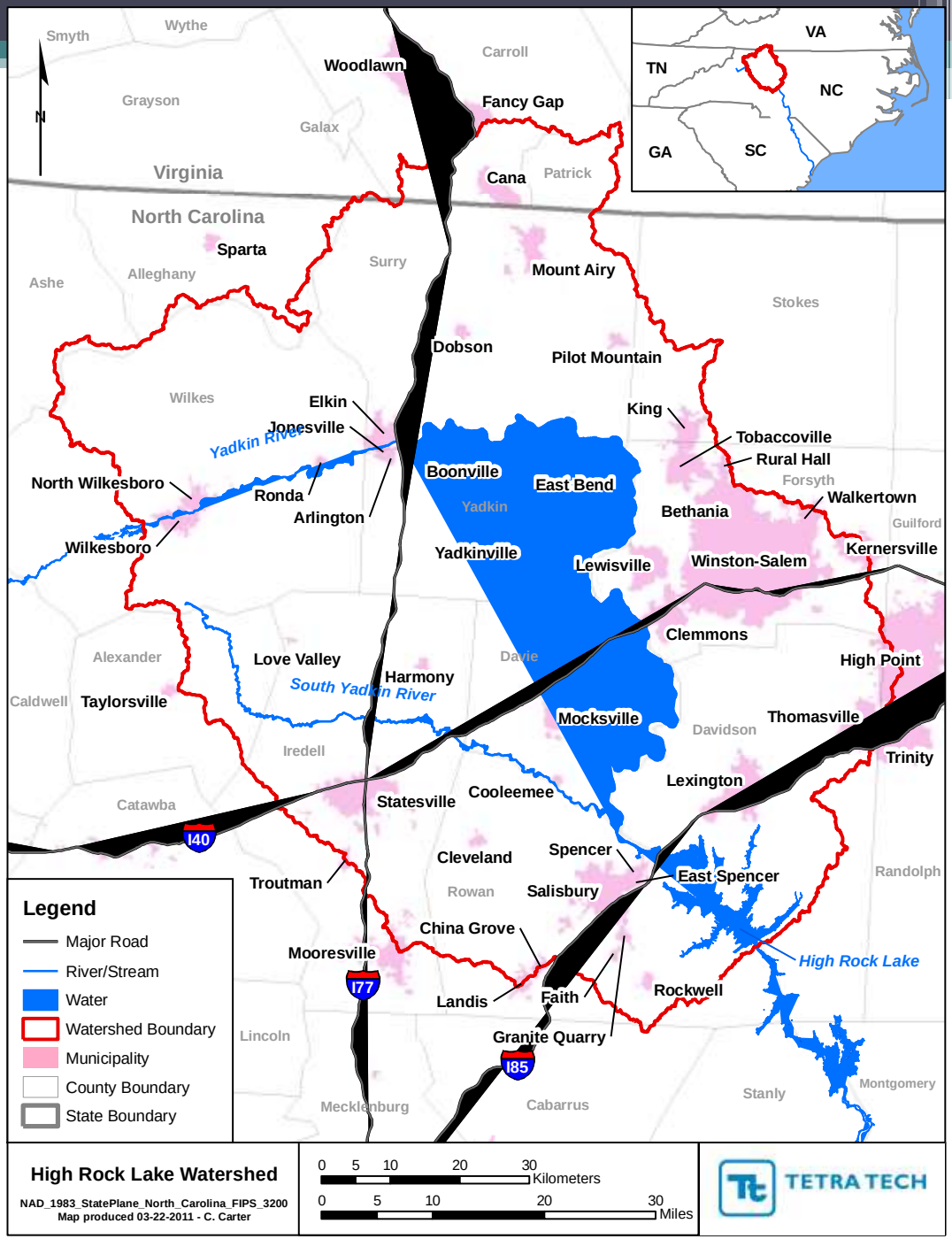
- EPA Region 4 contracted Tetra Tech to support then-DWQ
- HSPF chosen for watershed model
- Approximately 40 dischargers were considered in the combined modeling.
- Watershed model simulates 2000 – 2010
- Considers range of sources including point source, MS4, DOT, septic, atmospheric, agriculture

Hydrologic Simulation Program - FORTRAN (HSPF)



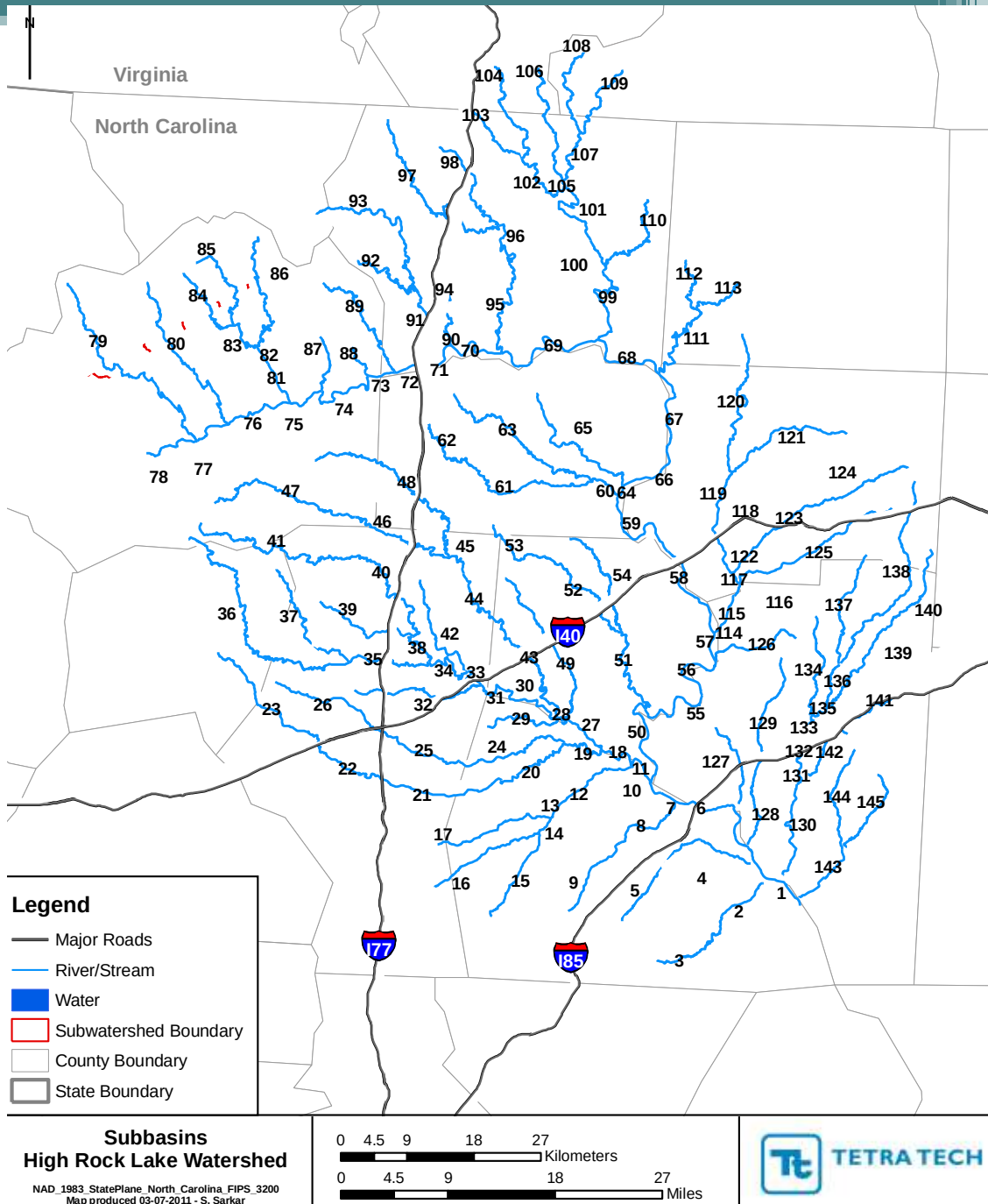
High Rock Watershed

- 3,974 acres in NC and VA
- Area above W. Kerr Scott Reservoir omitted from model (represented as a boundary condition)



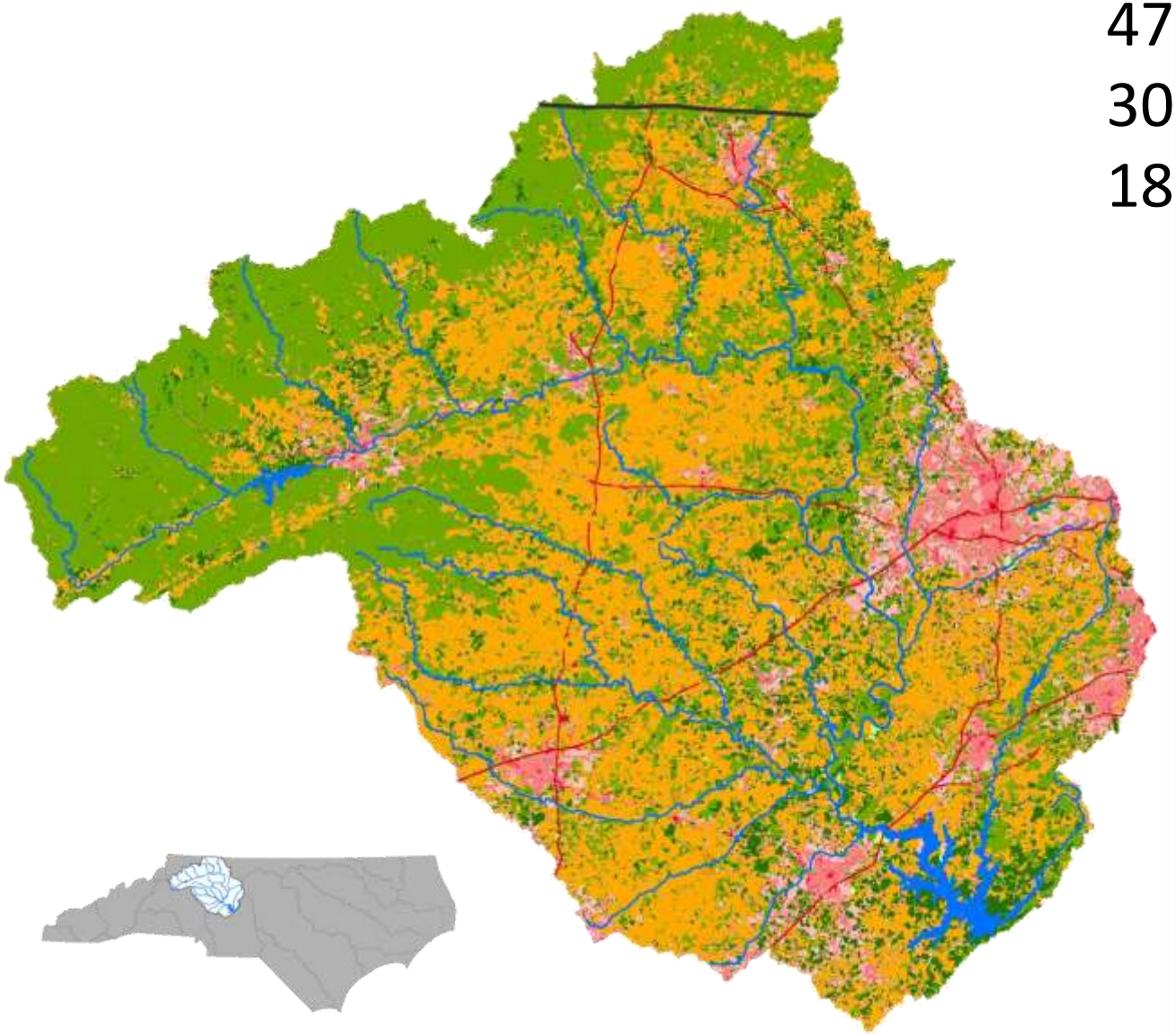
Subbasins

- Divided into 145 subbasins
- Allows use of multiple weather stations
- Assignment of source loads to specific areas and jurisdictions



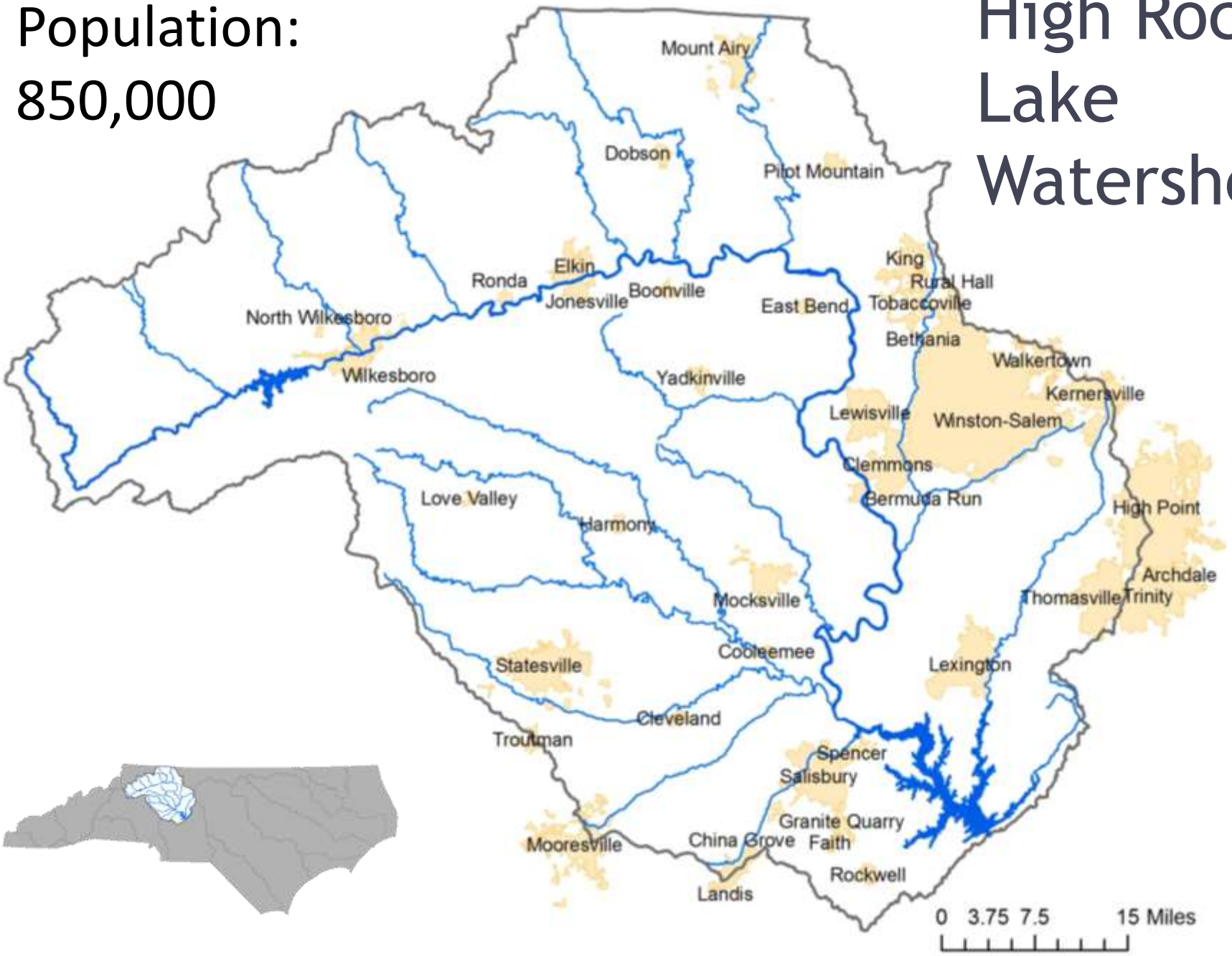
2007 Land Cover

47% Forest
30% Pasture/Crop
18 % Developed



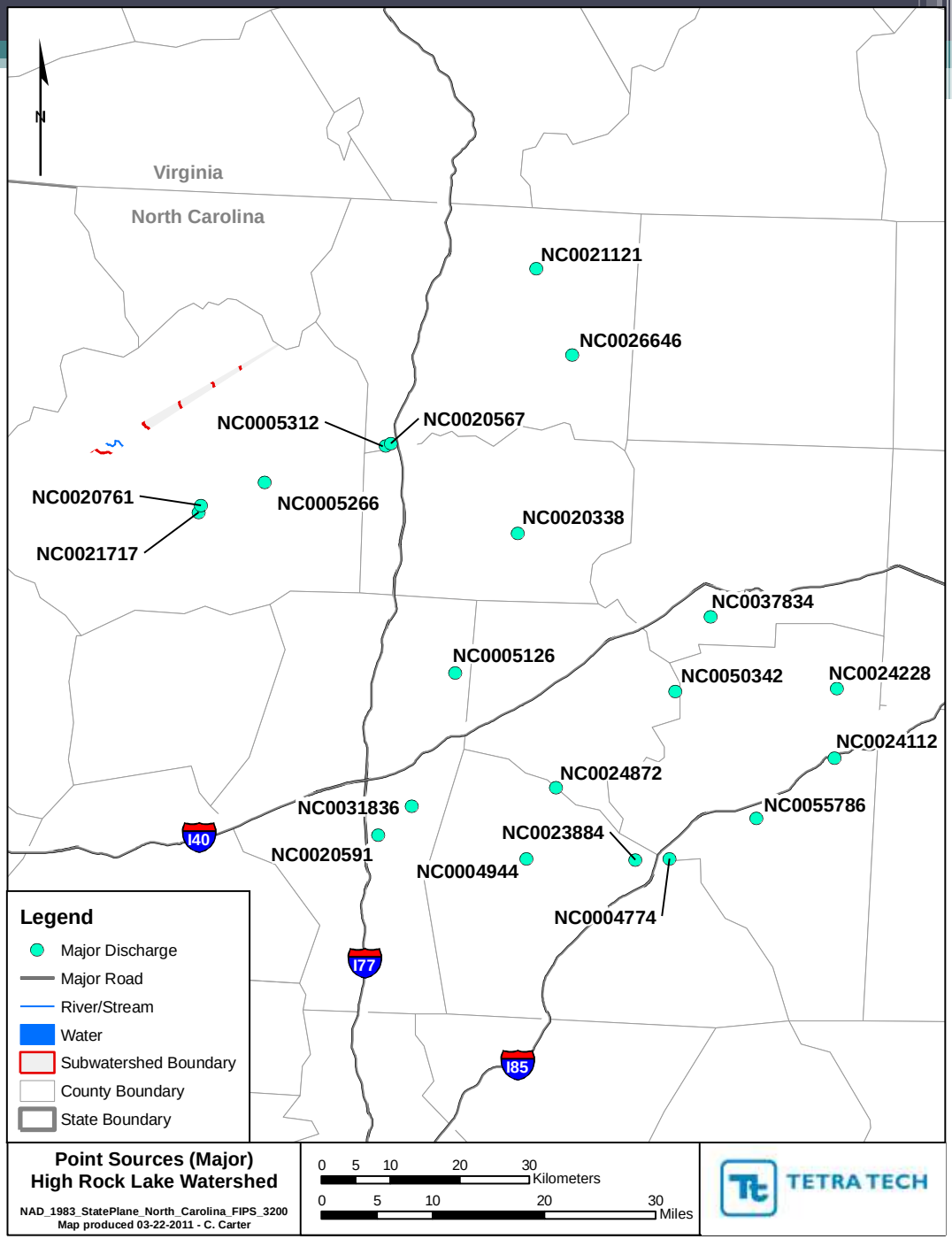
High Rock Lake Watershed

Population:
850,000



Discharges and Withdrawals

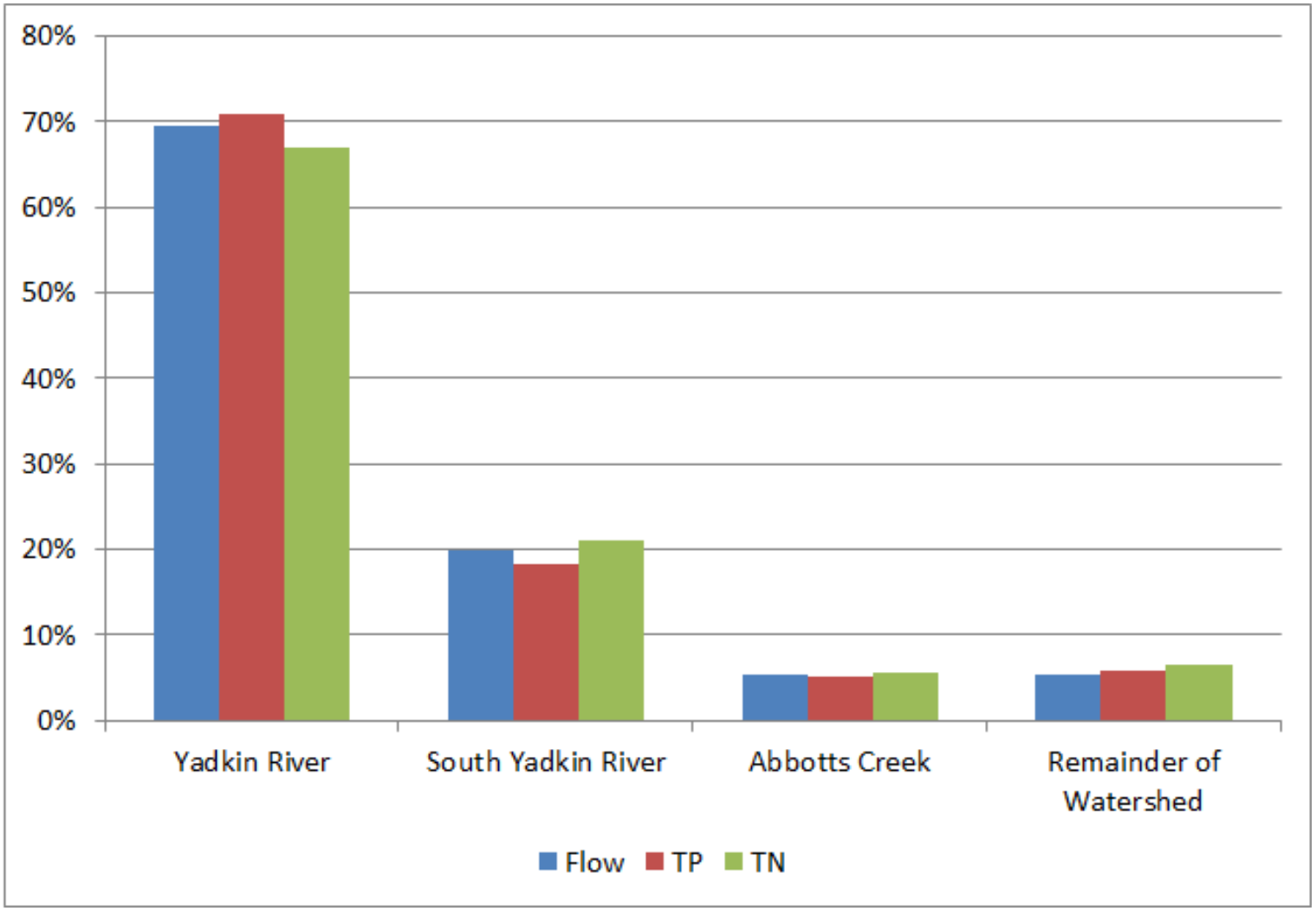
- 22 major discharges (> 1 MGD)
- 18 minor discharges
- Onsite wastewater load estimates
- 21 water withdrawals



Watershed Model

- TAC Review – Jan 25/Mar 9 – Apr 25, 2012
  - Resulted in additional information/clarification added to report. No model changes.
- Uncertainties
  - Discharger data (frequency, reporting of nitrogen species)
  - Flow gage spatial distribution
  - Precipitation coverage
- Model finalized August 2012

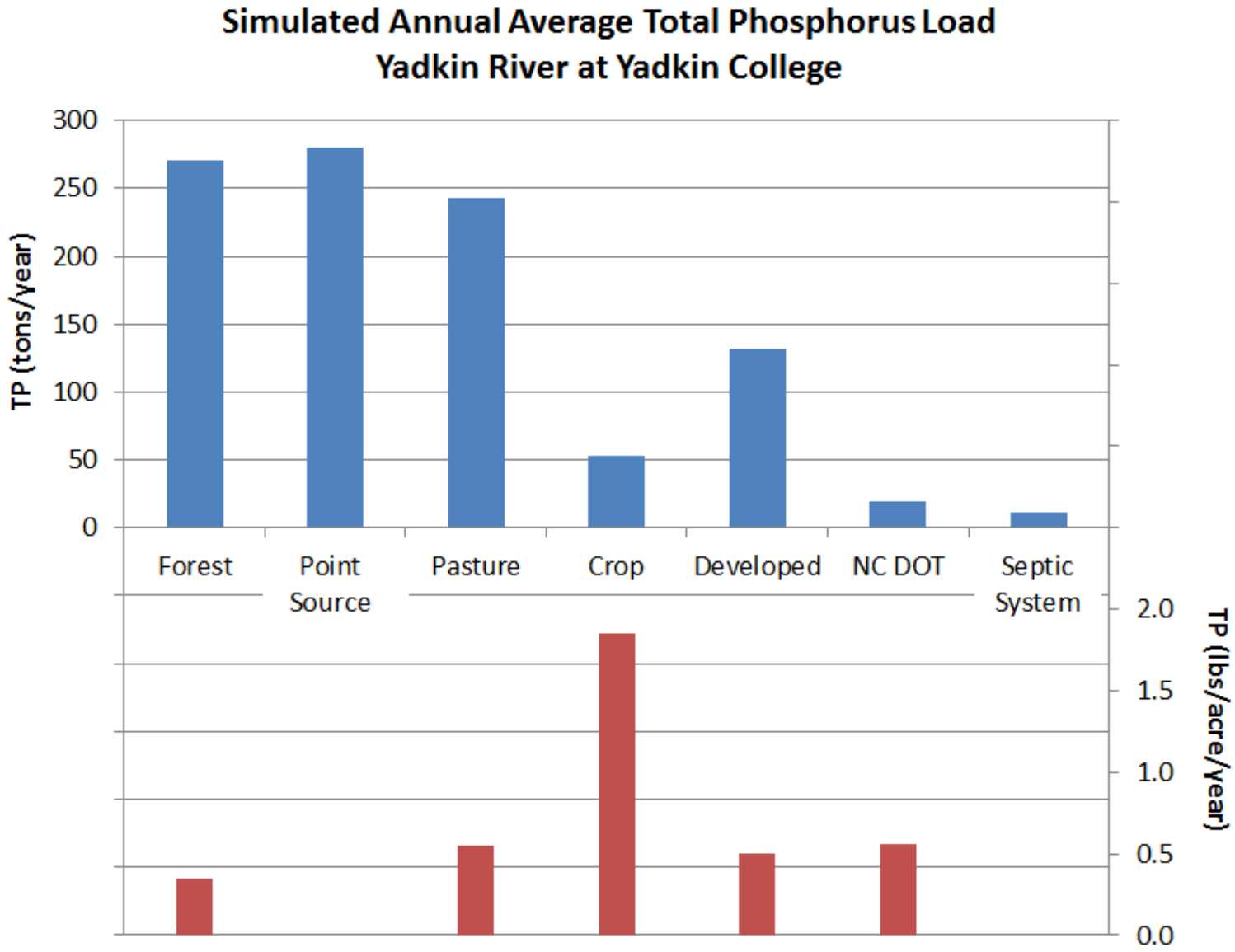
Watershed Model Results



Spatial Distribution of Flow and Nutrient Loading to High Rock Lake

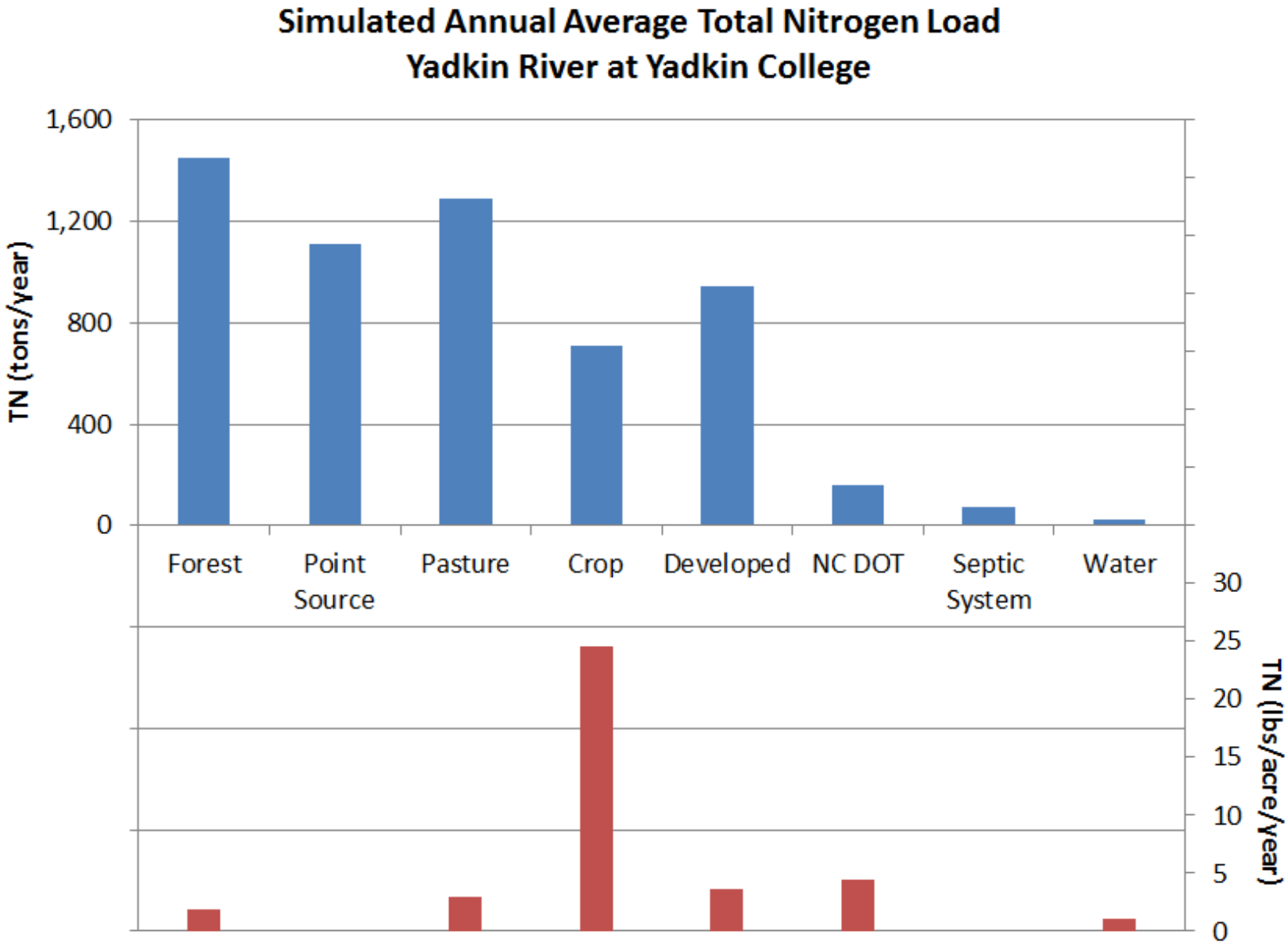
Sources of Loading

2000 - 2009

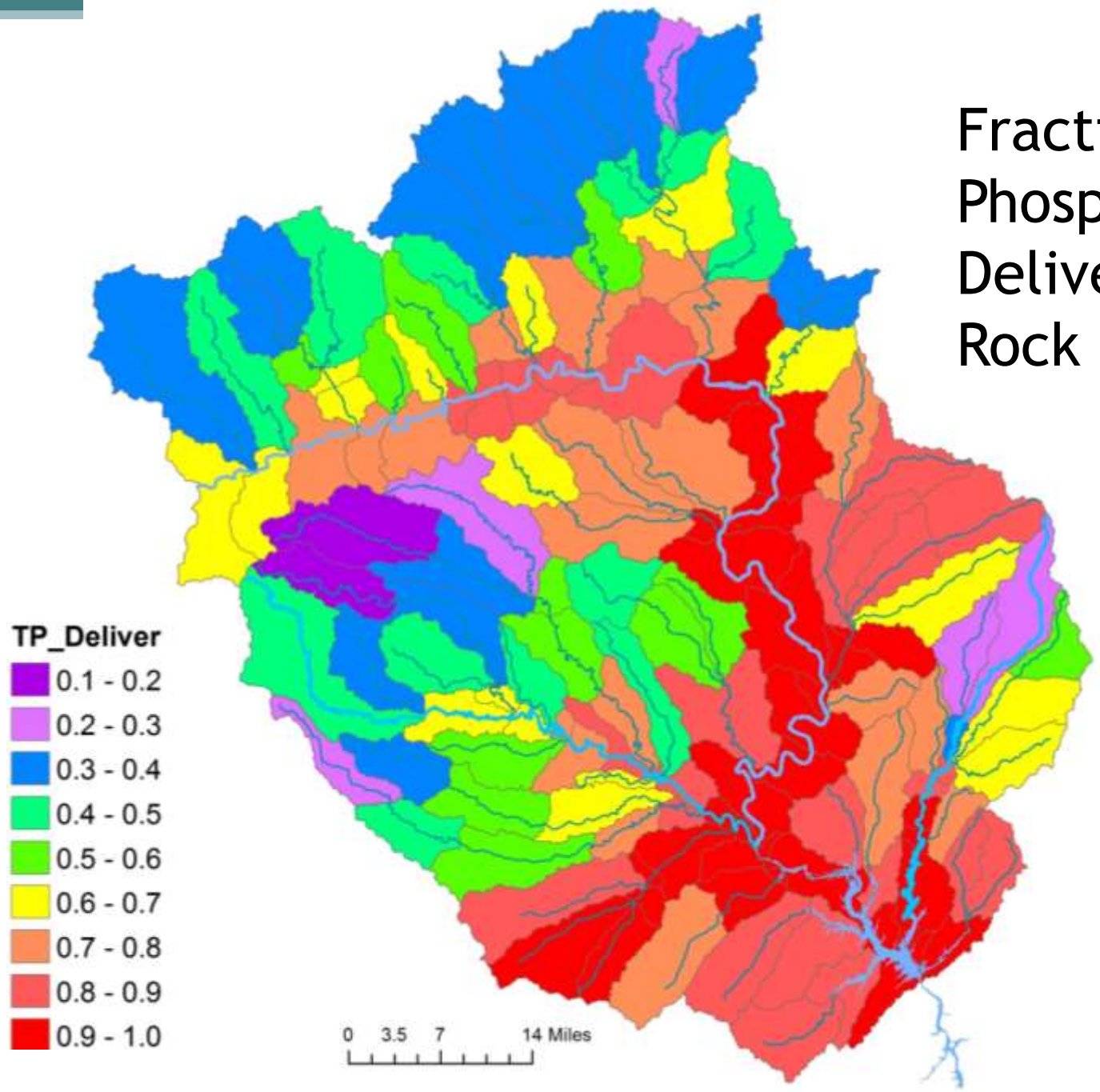


Sources of Loading

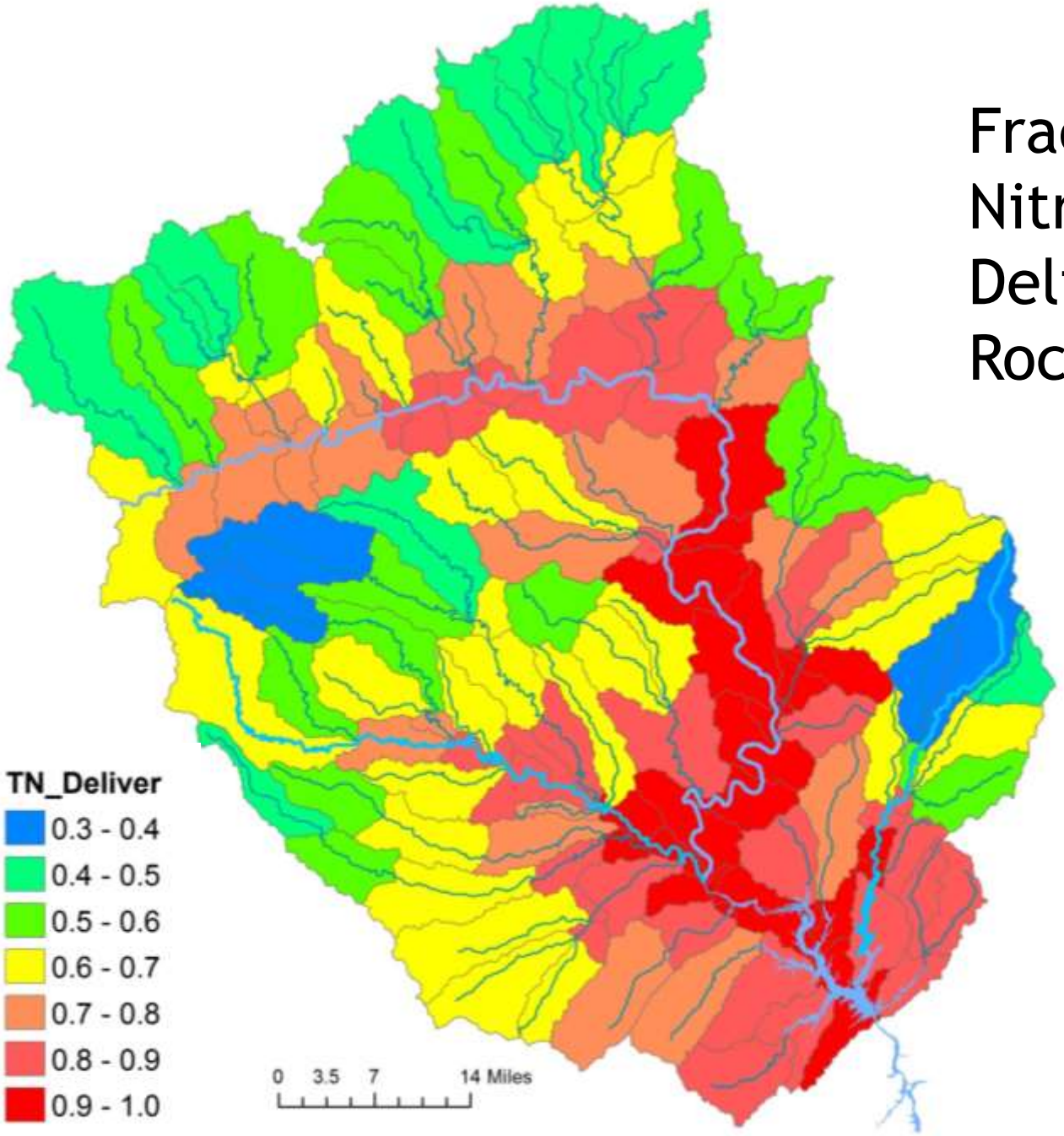
2000 - 2009



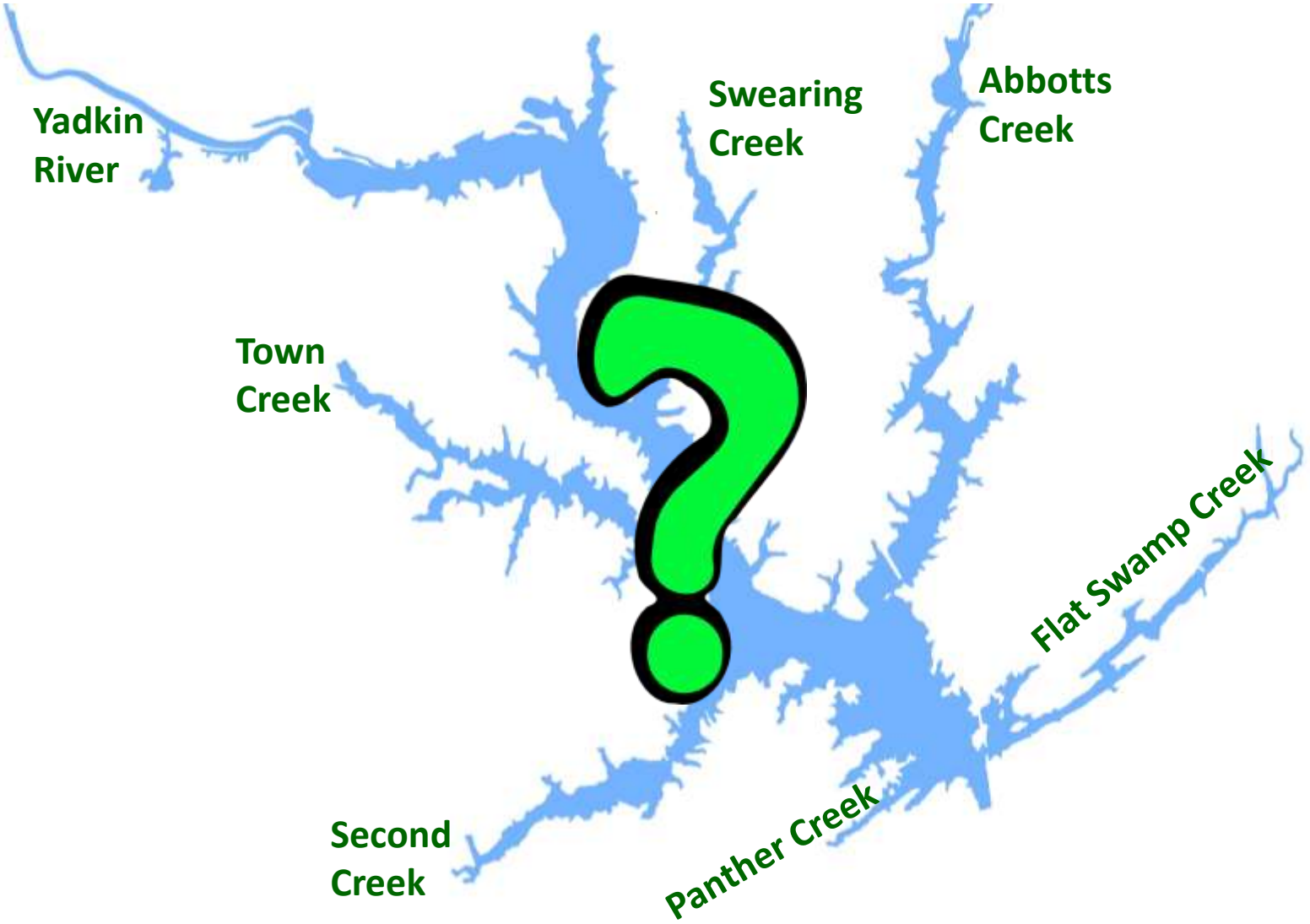
Fraction of Total Phosphorus Load Delivered to High Rock Lake



Fraction of Total Nitrogen Load Delivered to High Rock Lake



High Rock Lake



Questions

- Where are the nutrients coming from and how much?
  - Tool: Watershed Model

- **What reductions in nutrient loading are necessary to achieve water quality standards in the lake? Nitrogen? Phosphorus? Both?**
  - **Tool: Nutrient Response Model**

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Questions?

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HIGH ROCK LAKE NUTRIENT RESPONSE MODEL

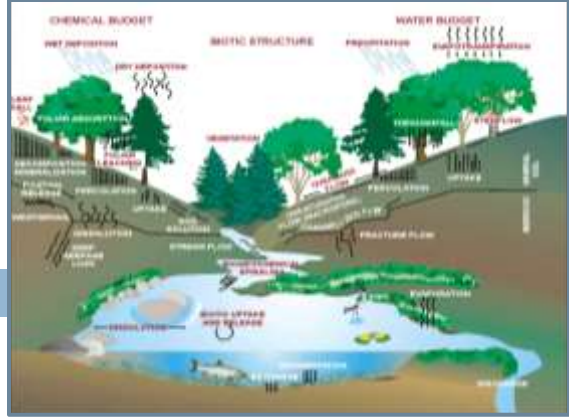
NCDP - Aug 18, 2015

Jing Lin

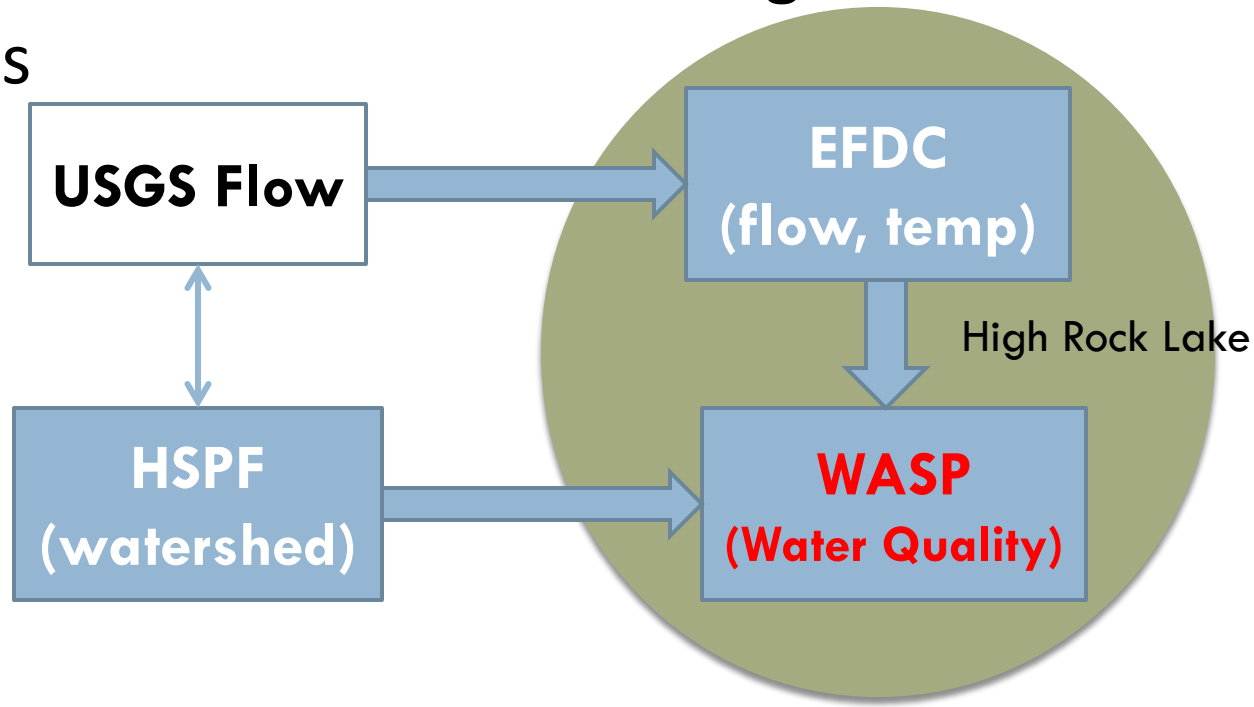
Division of Water Resources – Water Planning

NC Department of Environment & Natural Resources

Development of Models



- TetraTech under contract for both watershed and nutrient response model development
- EPA revised WASP model according to TAC comments



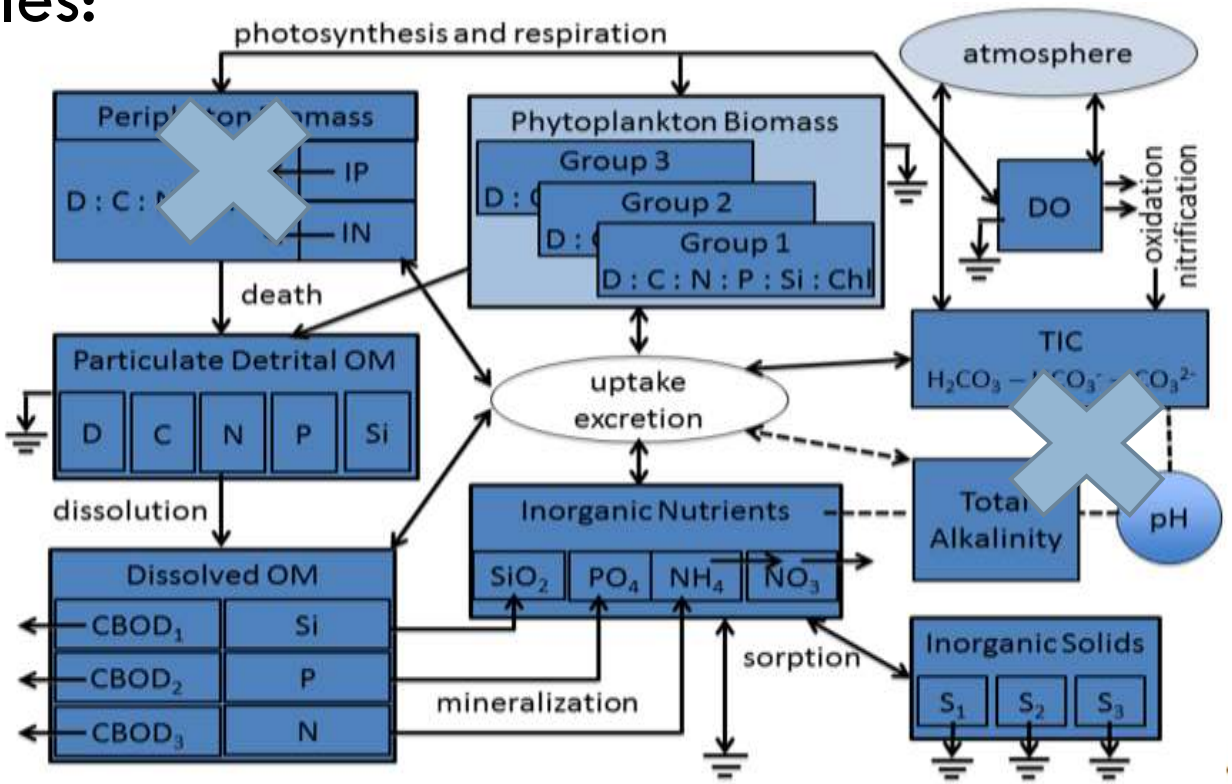
EFDC (Environmental Fluid Dynamics Code)

- Developed by Tetra Tech, Supported by EPA
- 1, 2, 3- dimensional Hydrodynamic Model
- Flow, Surface Elevation, and Water Temperature
- Curvilinear-orthogonal
- Sigma – Hybrid (generalized vertical grid)

http://www.epa.gov/athens/wwqtsc/html/efdc.html

WASP(Water Quality Analysis Simulation Program)

- EPA
- State Variables:

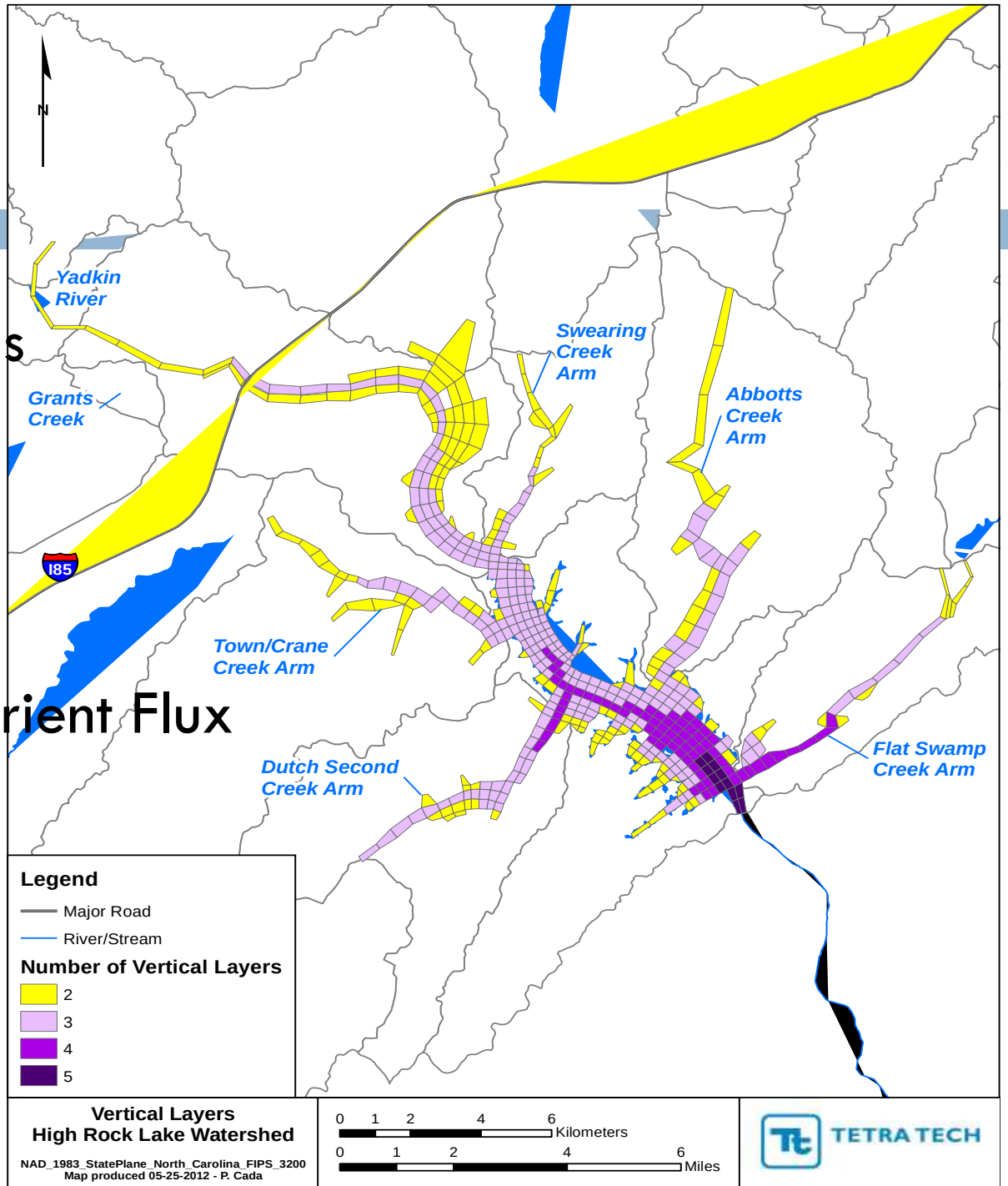


WQ state variables simulated in WASP

http://www.epa.gov/athens/wwqtsc/html/wasp.html

EFDC/WASP

- 538 horizontal grids
- Up to 5 layers
- 11 tributaries
- Surface Boundary
- Specified SOD, Nutrient Flux



WASP Model

- Two Algal Groups: Warm-water Algae and Cold-water Algae
- *One sediment class – silt and clay*
- *Spatial varying background light extinction coefficient*
- *Model will not be used to address Turbidity*
- Dynamic Memory Allocation - Model Run time

Calibration/Validation Criteria

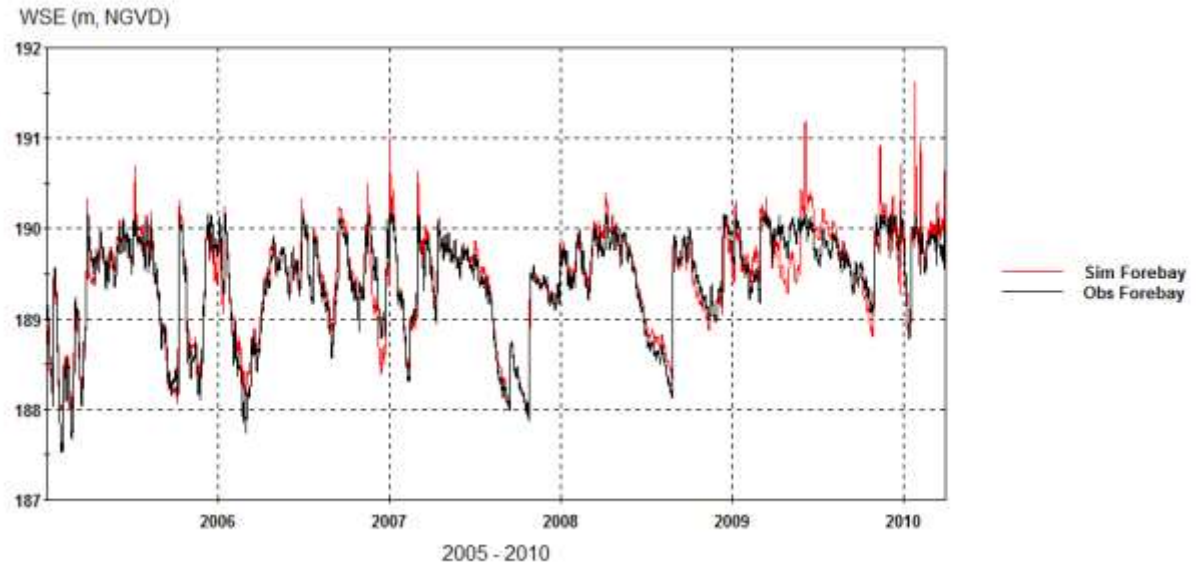
- Type of Calibration/Validation
- EPA guidance Criteria
- Challenges

	Hydrodynamic	Chemical Water Quality	Chlorophyll a
Relative Error (RE)	±30%	±45%	±16% (±25%)
Coefficient of Variation (CV)	≤10%	≤90%	≤70%
Correlation Coefficient (r)	≥0.94	≥0.60	≥0.70

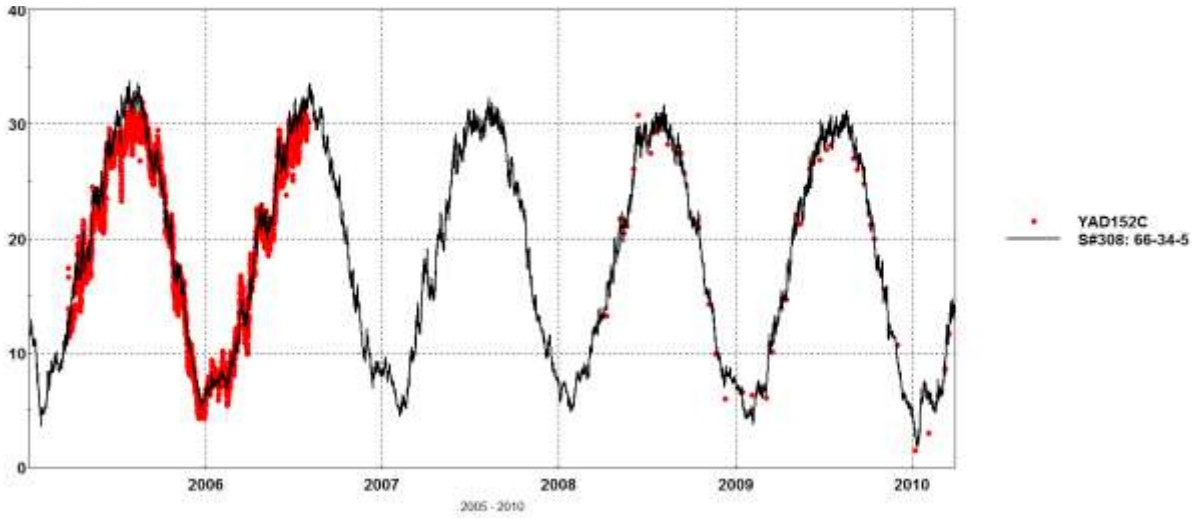
(EPA, 1990)

EFDC calibration/validation (original)

Water Surface Elevation

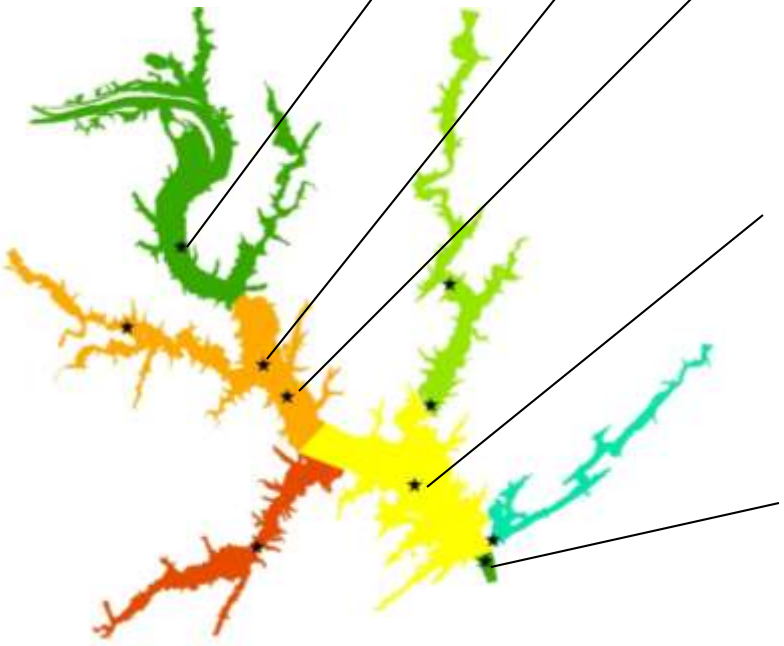


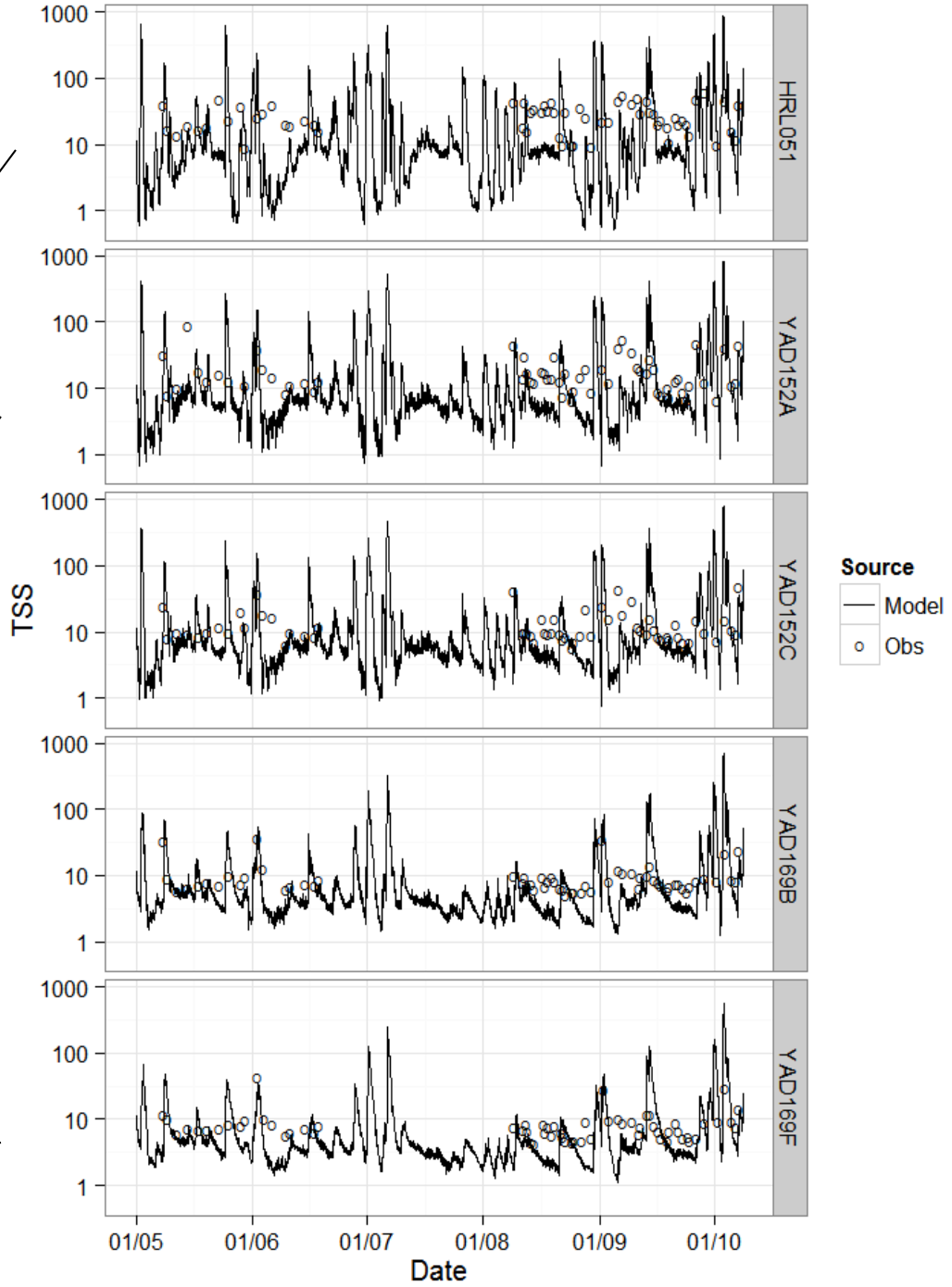
Water Temperature



WASP results

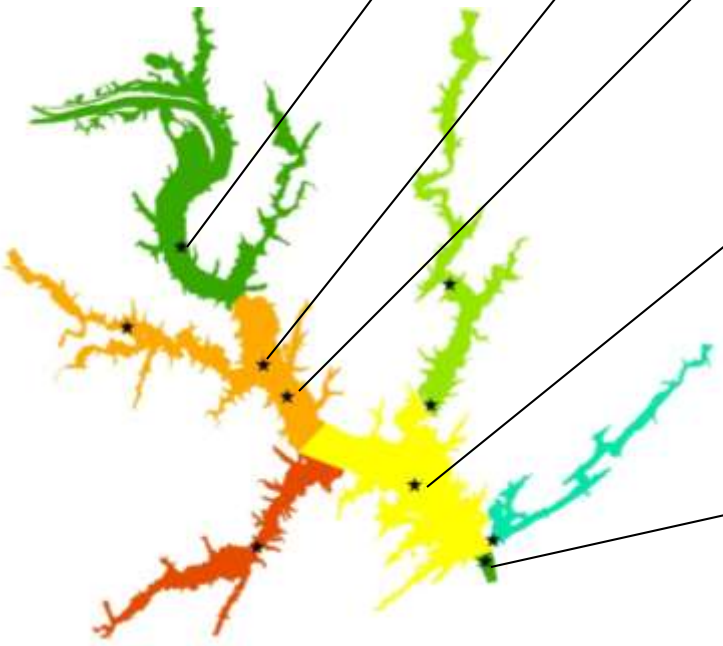
Model-Simulated and Observed TSS time series

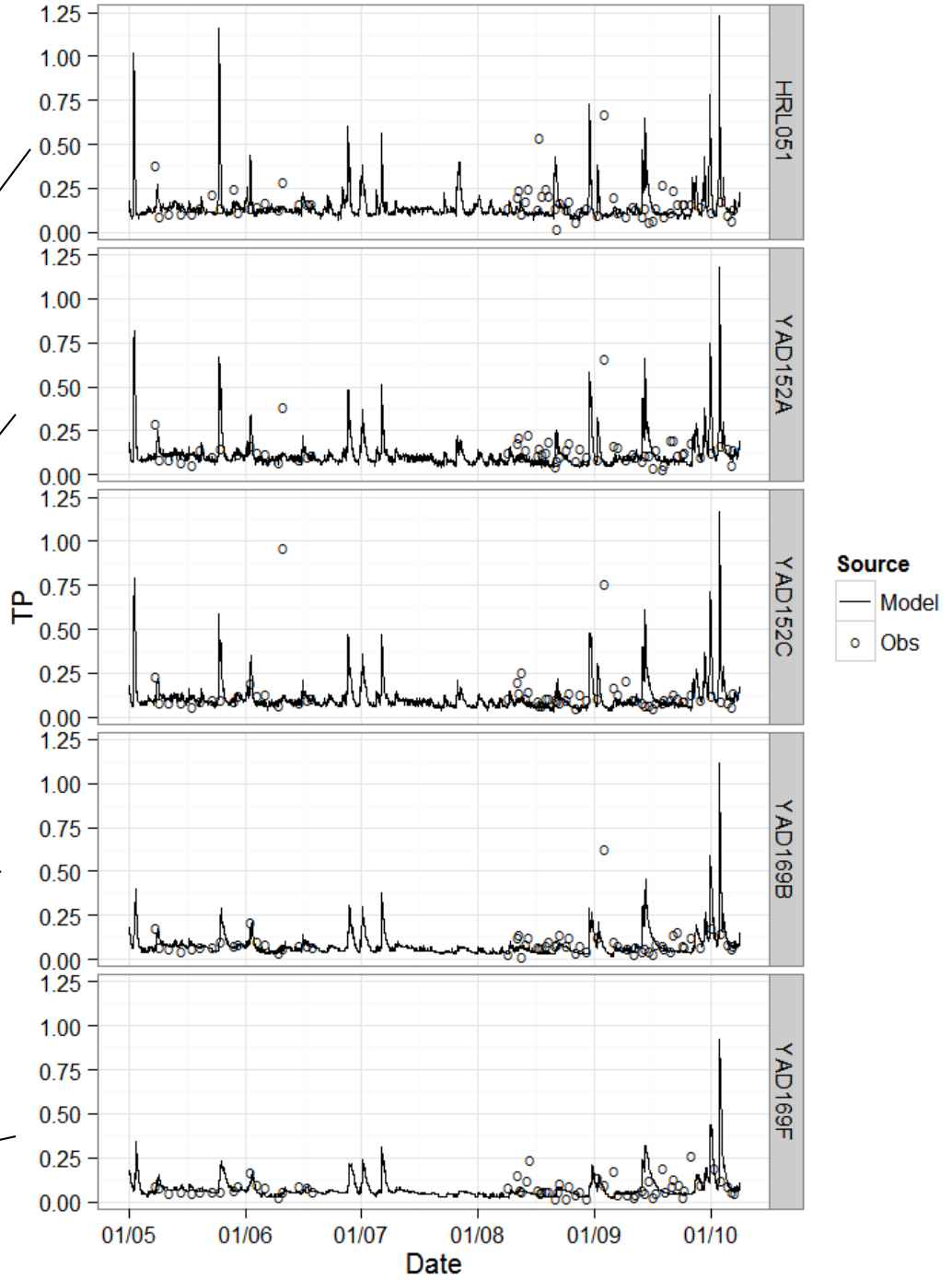




WASP results

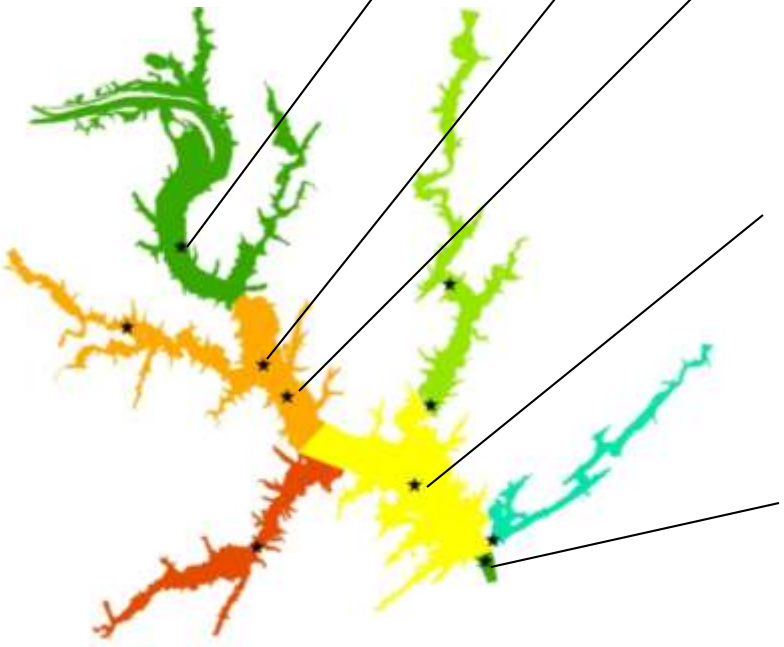
Model-Simulated and Observed TP time series

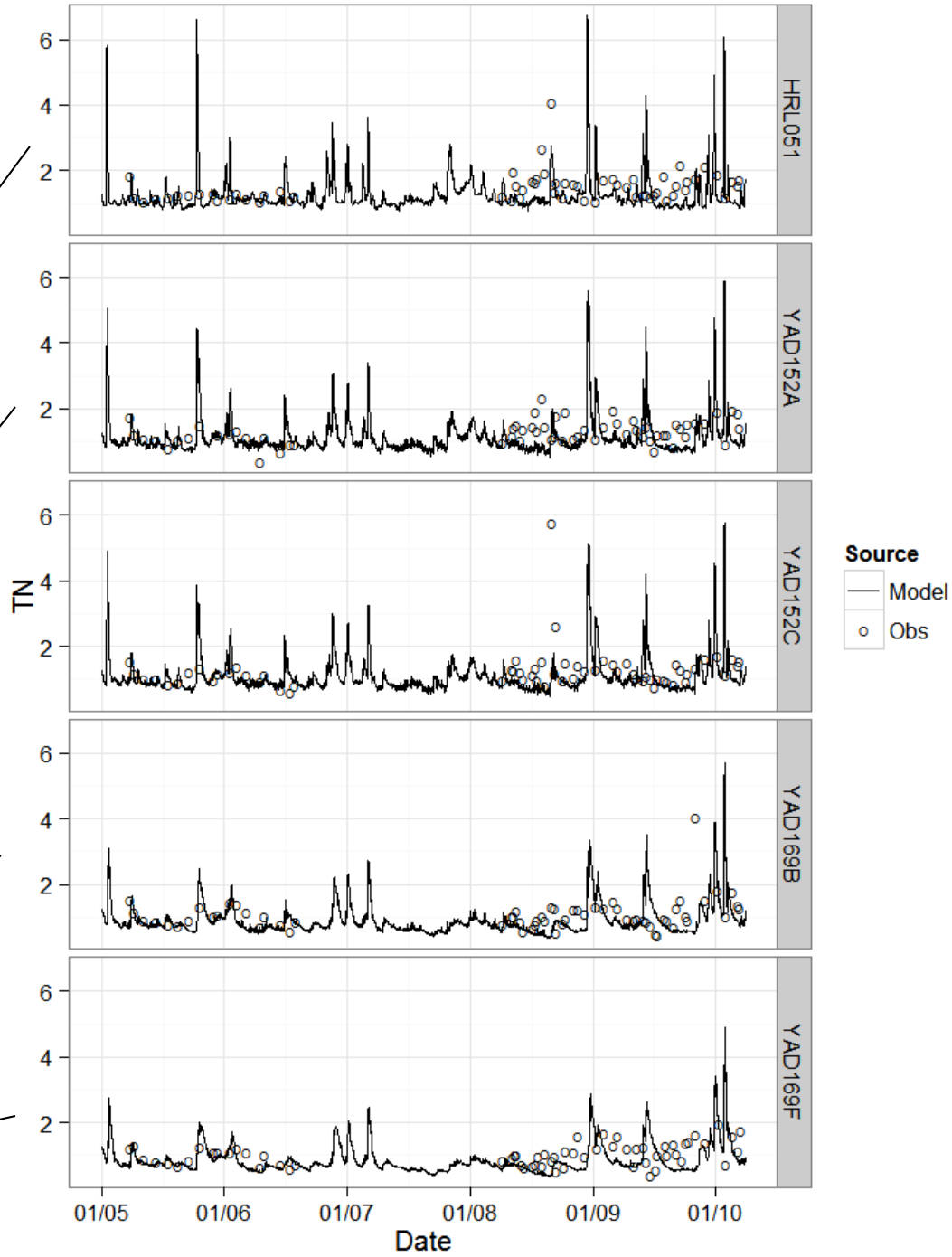




WASP results

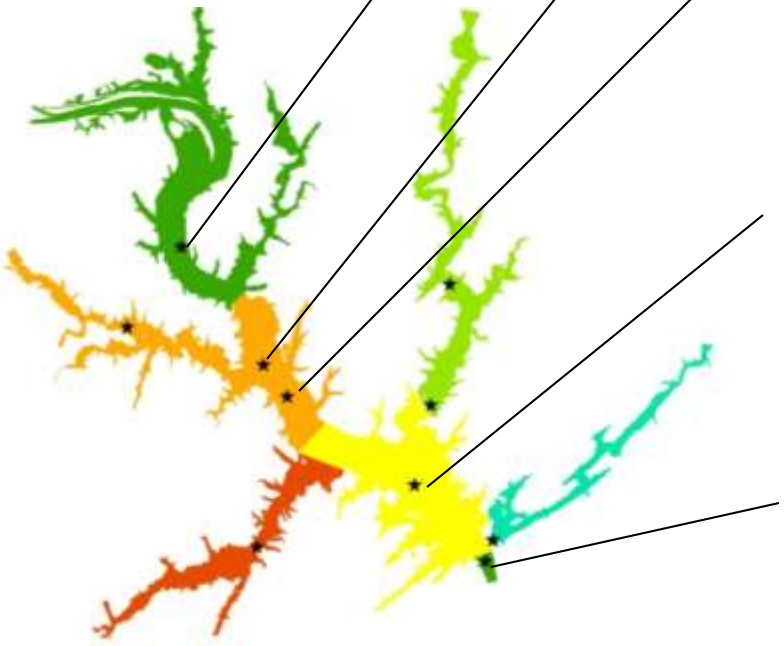
Model-Simulated and Observed TN time series

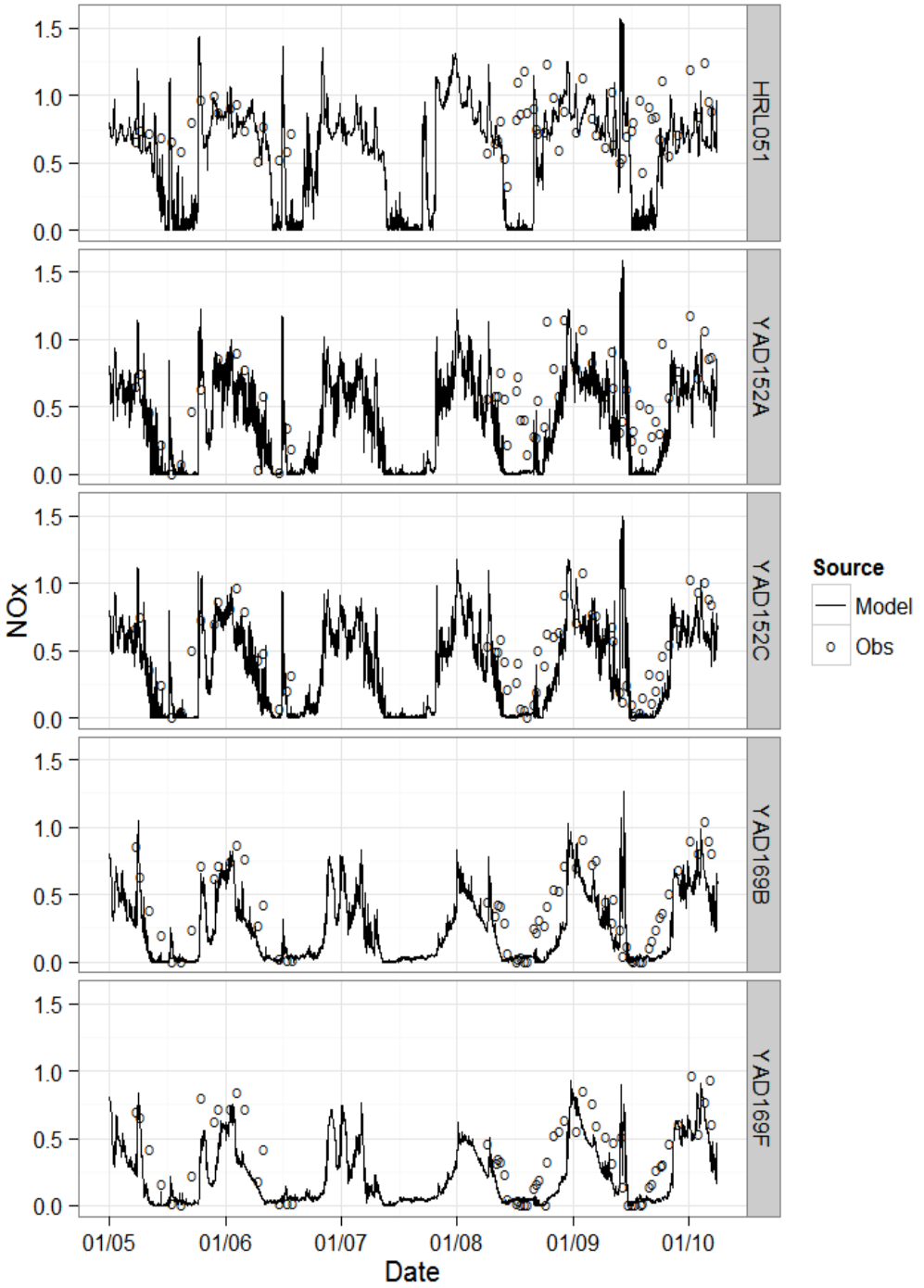




WASP results

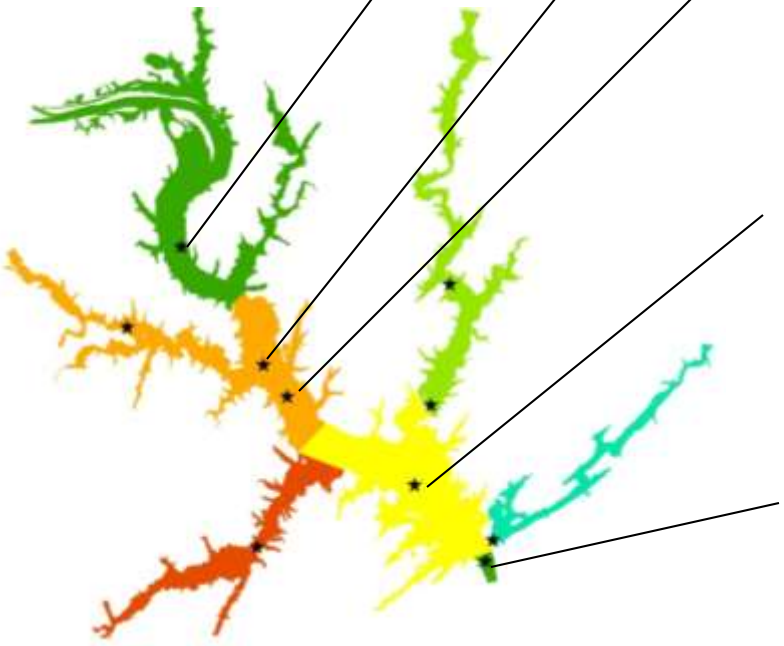
Model-Simulated and Observed NOx time series

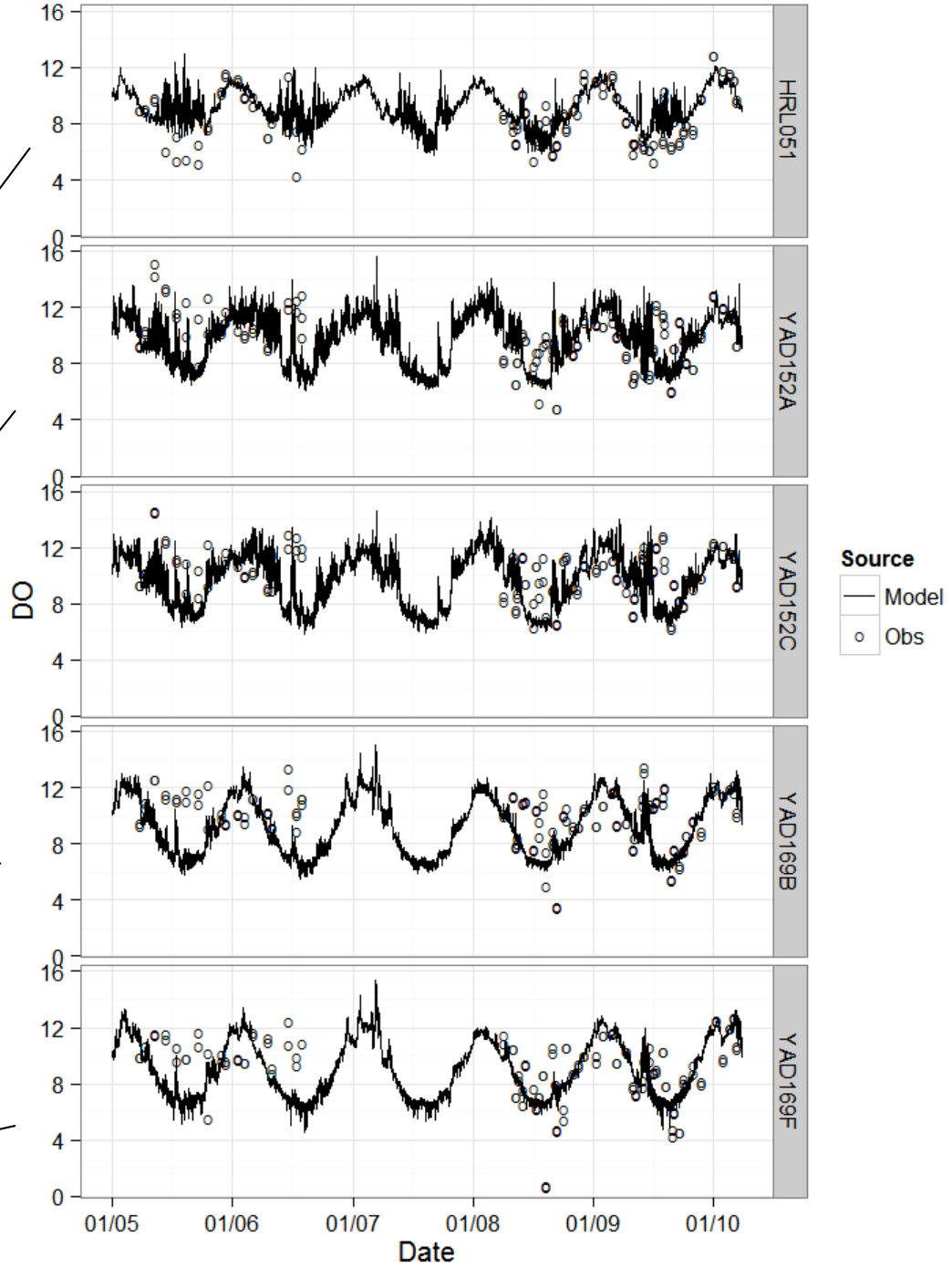




WASP results

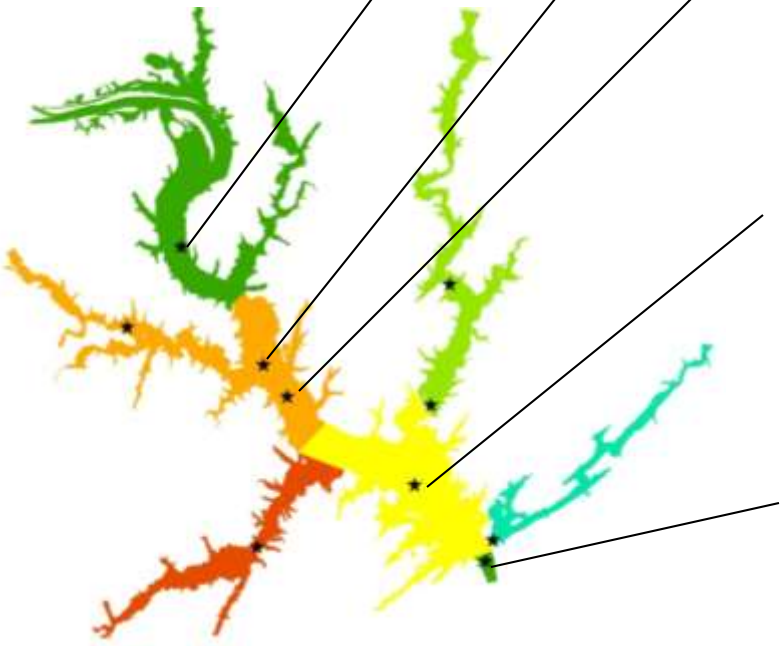
Model-Simulated and Observed DO time series

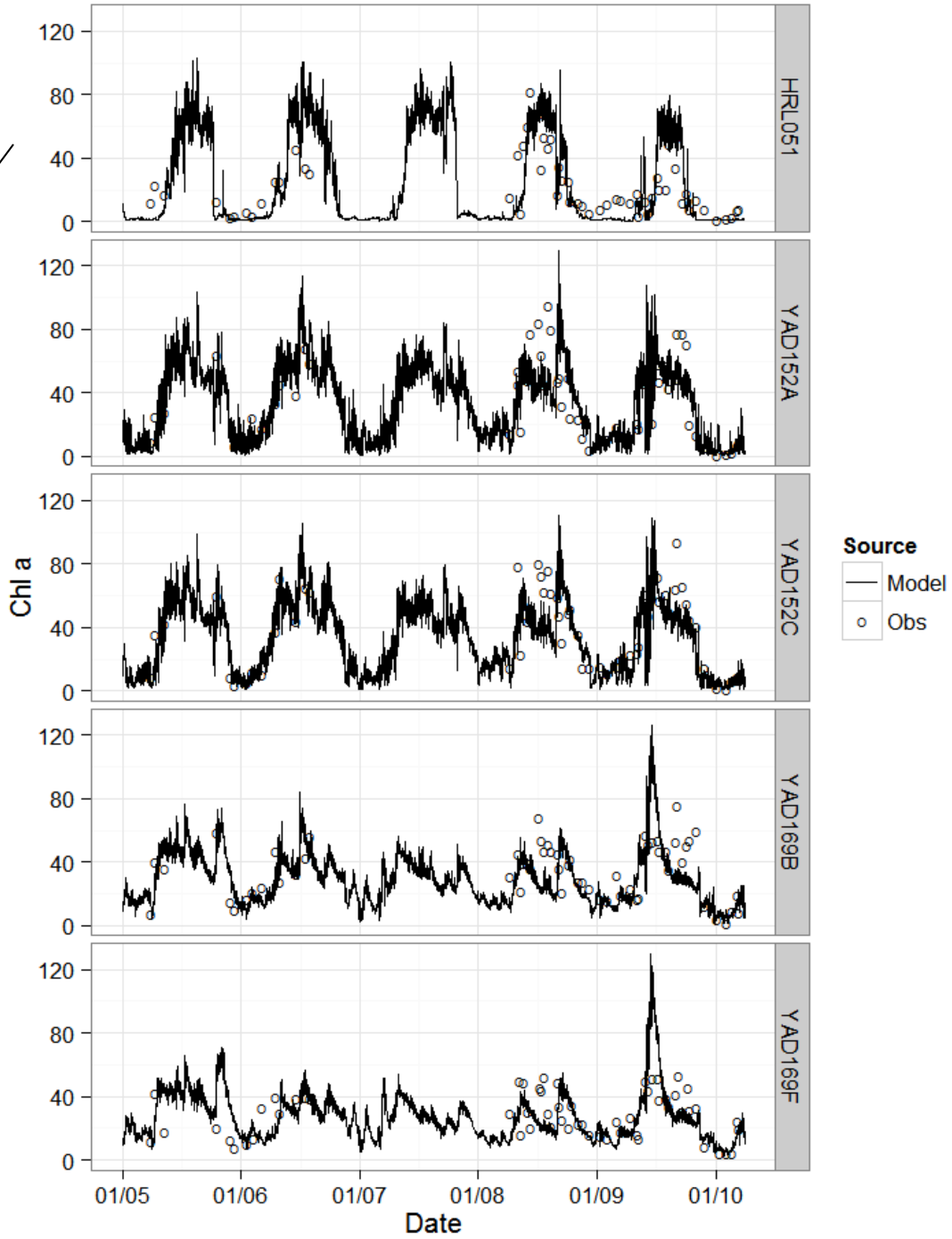




WASP results

Model-Simulated and Observed Chl a time series





Model Calibration Statistics – Chl a

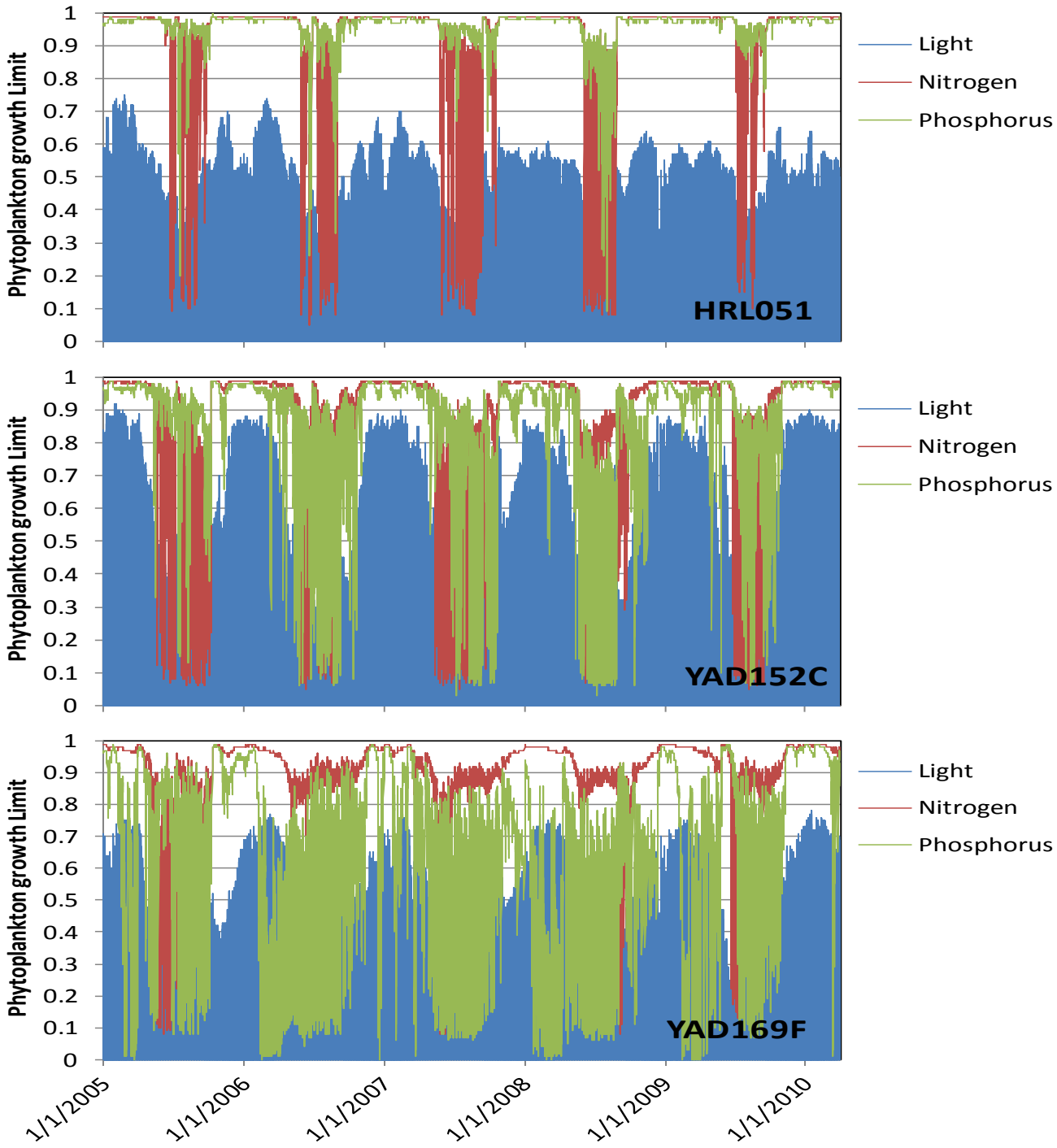
Station	Count	Observed Mean (µg/L)	RE	RAE	CV	r	RMSE
HRL051 (Upper HRL above Swearing Cr)	45	23.56	12.0%	57.1%	0.76	0.78	17.97
YAD152A (Middle HRL at Town/Crane Cr)	45	37.04	0.7%	41.9%	0.56	0.64	20.85
YAD152C (Middle HRL below Town/Crane Cr)	45	41.56	-14.3%	32.7%	0.44	0.72	18.38
YAD169B (Lower HRL below Abbotts Cr)	45	35.84	-12.1%	40.4%	0.54	0.49	19.18
YAD169F (Lower HRL at forebay)	45	30.06	1.1%	39.8%	0.54	0.58	16.13
YAD152 (Town/Crane Cr Arm)	45	46.22	-12.4%	42.9%	0.52	0.34	23.91
YAD1561A (Second Cr Arm)	45	47.09	-23.1%	40.0%	0.48	0.42	22.83
HRL052 (Upper Abbotts Cr Arm)	45	36.95	-12.8%	45.7%	0.57	0.10	20.96
YAD169A (Lower Abbotts Cr Arm)	44	33.58	-2.2%	48.0%	0.62	0.17	20.78
YAD169E (Flat Swamp Cr Arm)	45	30.44	3.0%	42.8%	0.62	0.46	18.83

Phytoplankton Growth Limit

Upper Lake

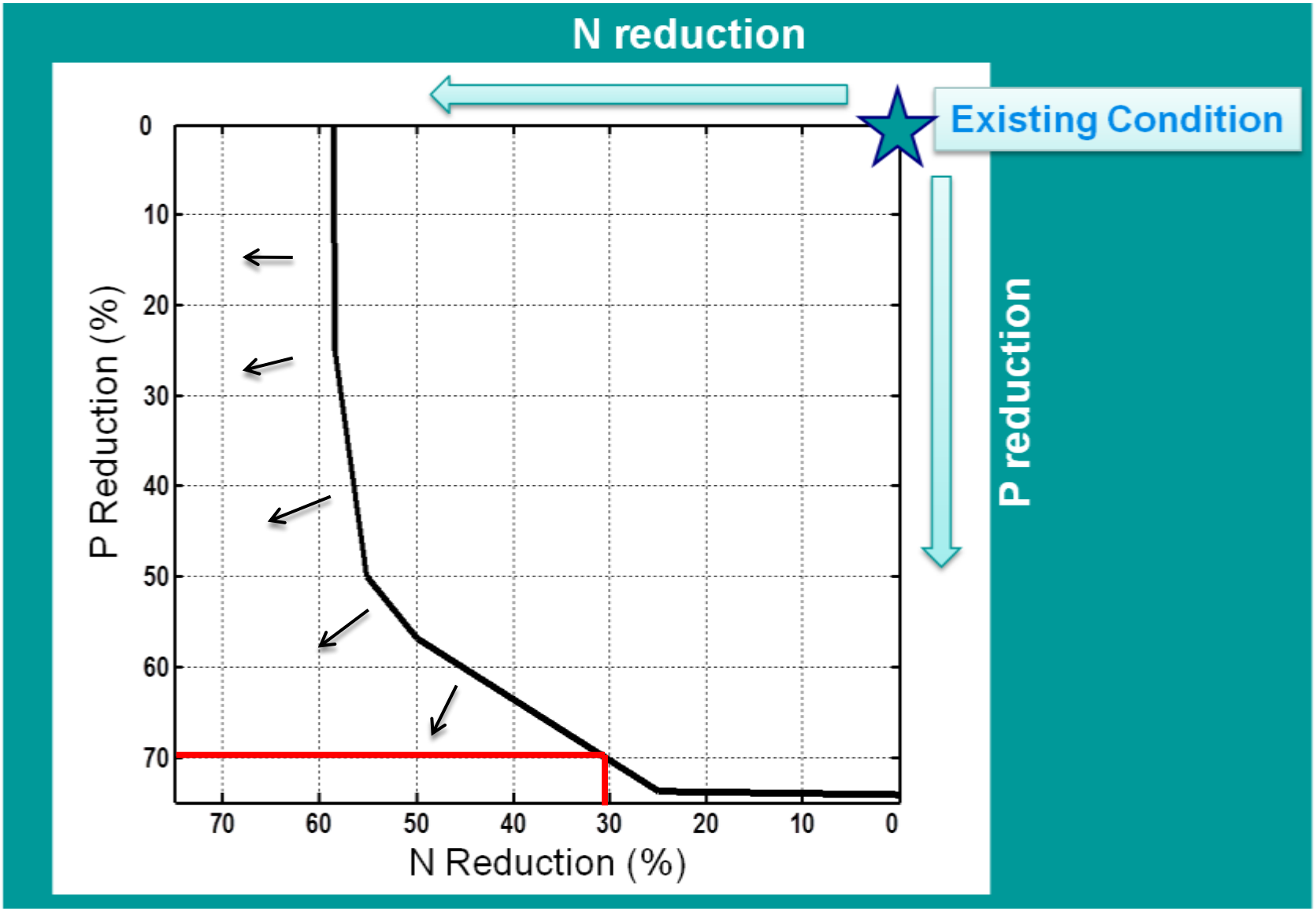
Middle Lake

Lower Lake



EXAMPLE: Falls Lake Model Results

Nitrogen and Phosphorus Reduction Curve



DWR
Division of Water Resources

Questions?

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ALCOA

TETRA TECH

Yadkin/Pee Dee River Basin Association

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

HIGH ROCK LAKE: CLASSIFICATION, DESIGNATED USES, AND IMPAIRMENT

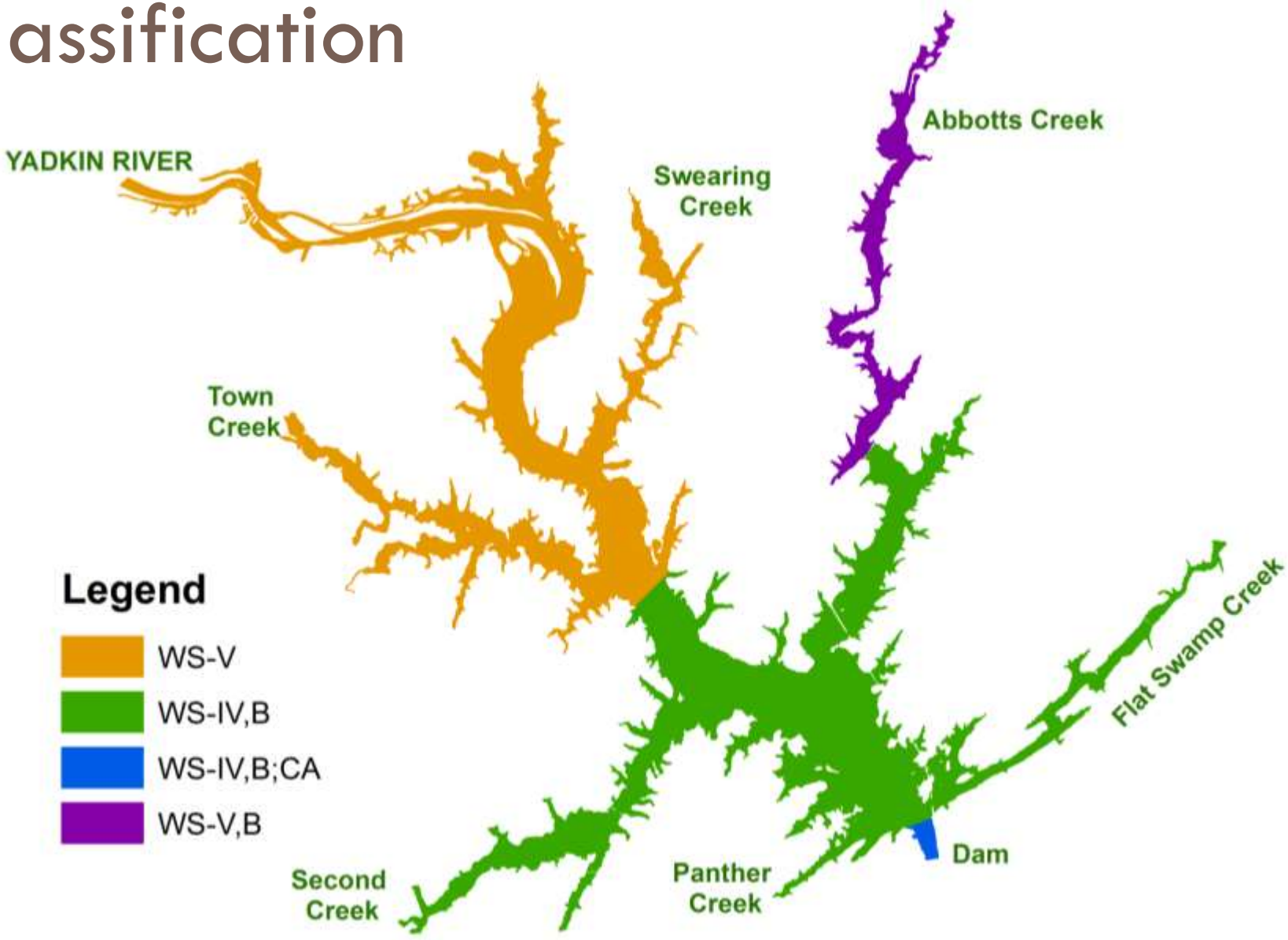
Pam Behm - NC Division of Water Resources

NC NCDP SAC

3rd Meeting

August 18, 2015

Classification



Designated Uses

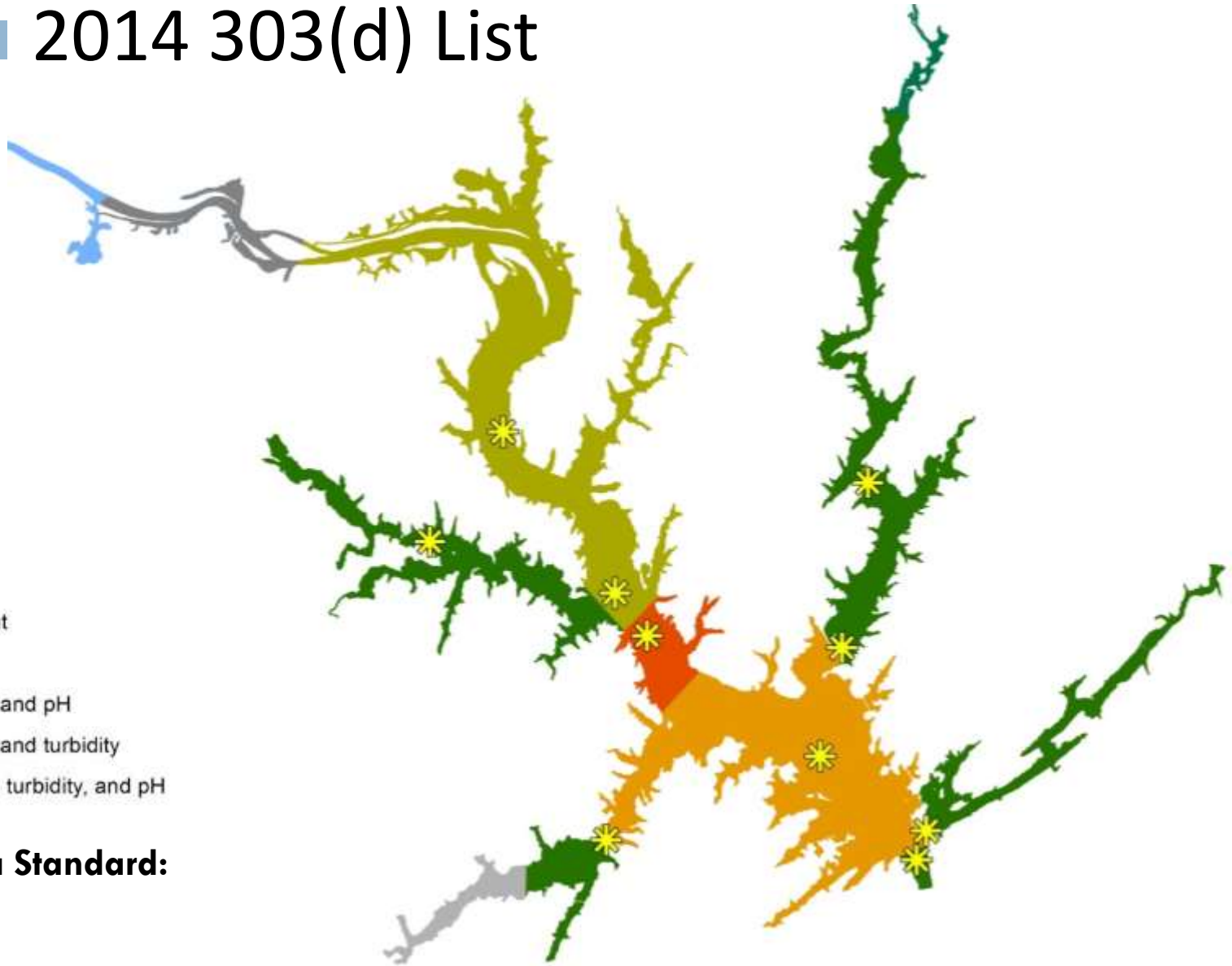
- Aquatic Life
- Fishing
- Fish consumption
- Wildlife
- Secondary Recreation (e.g. wading, boating)
- Agricultural uses (e.g. irrigation)
- Water Supply
- Lower lake: Primary Recreation – full human body contact (e.g. swimming, water skiing)

What USE(s) do we know are impacted?

- Aquatic Life – biological integrity
  - Existing evidence:
    - High chlorophyll-a
    - Elevated surface dissolved oxygen
    - High pH
    - Phytoplankton assemblages - blue-green algae dominated blooms

IMPAIRMENTS

Source: 2014 303(d) List



Chlorophyll-a Standard:
40 µg/L

Proposed Water Quality Goal

Decrease the severity of algal blooms in High Rock Lake to protect for aquatic life.

Discuss…