Reconstructing water quality conditions using Reservoir Limnology Theory: An empirical approach to phosphorus load reduction estimates in Beaver Lake, Arkansas

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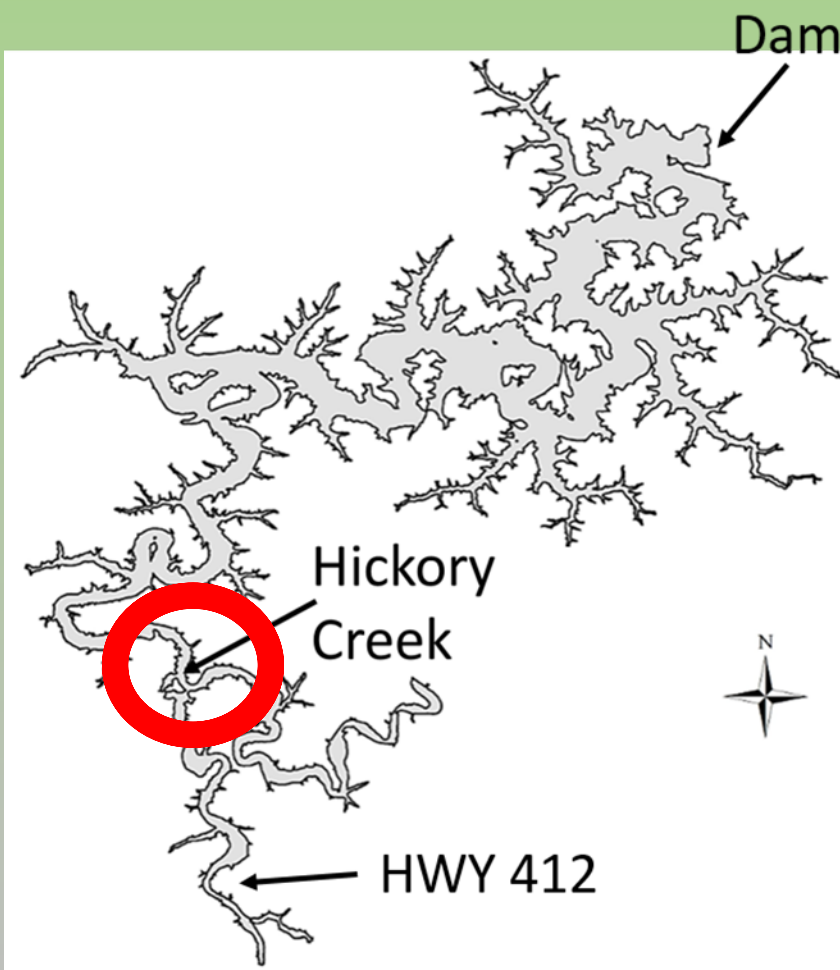
Introduction – Theoretical Concept

Phosphorus loading to Beaver Lake is causing excessive algal growth.



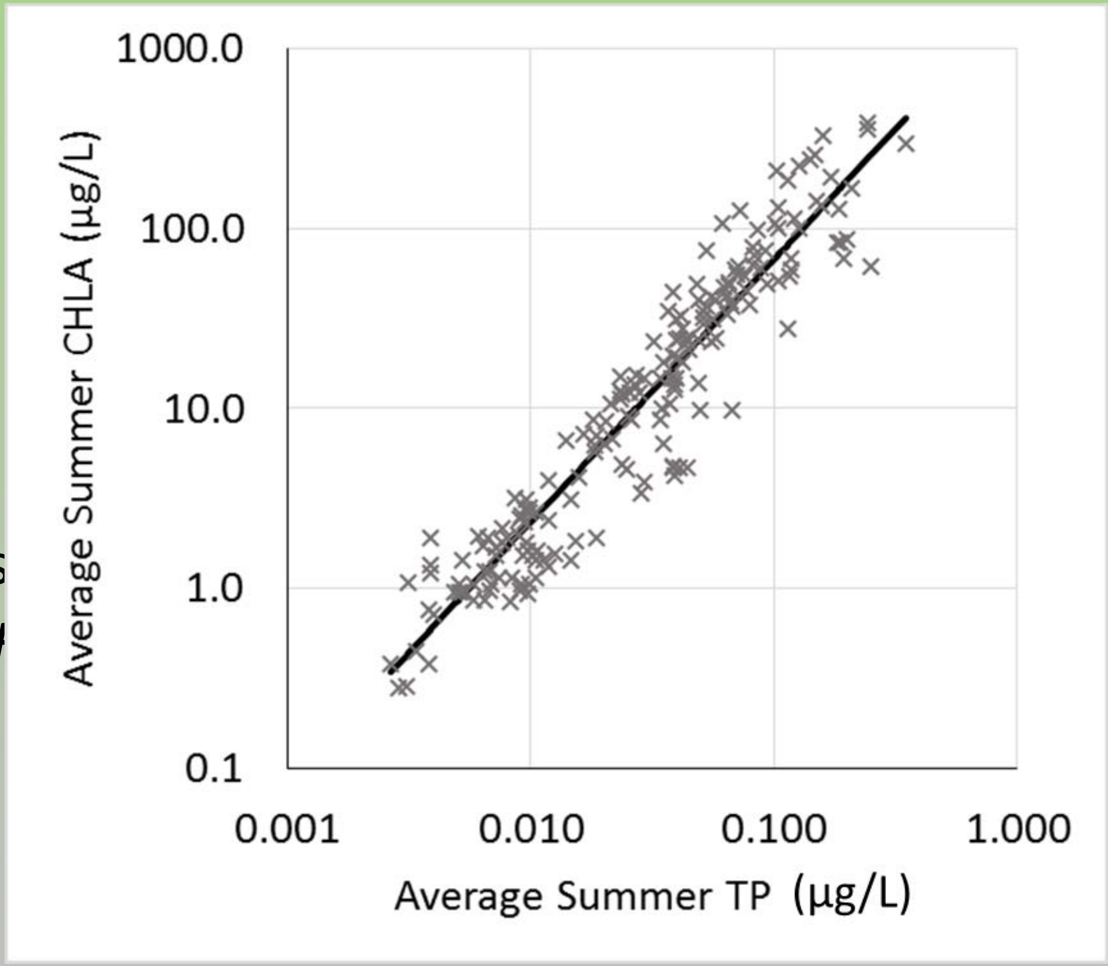
State of Arkansas recently adopted effects-based WQ criteria	
Growing Season Geometric Mean Chlorophyll (CHLA)	Annual Average Secchi Transparency (ST)
≤ 8 (μg/L)	≥ 1.1 (m)

Whole-lake steady-state production models can be used to derive phosphorus load reduction estimations that meet WQ criteria.

TP – CHLA Relationship

Predicting summer time levels of CHLA and TP in 143 lakes

Eq. 1



ler 1974)

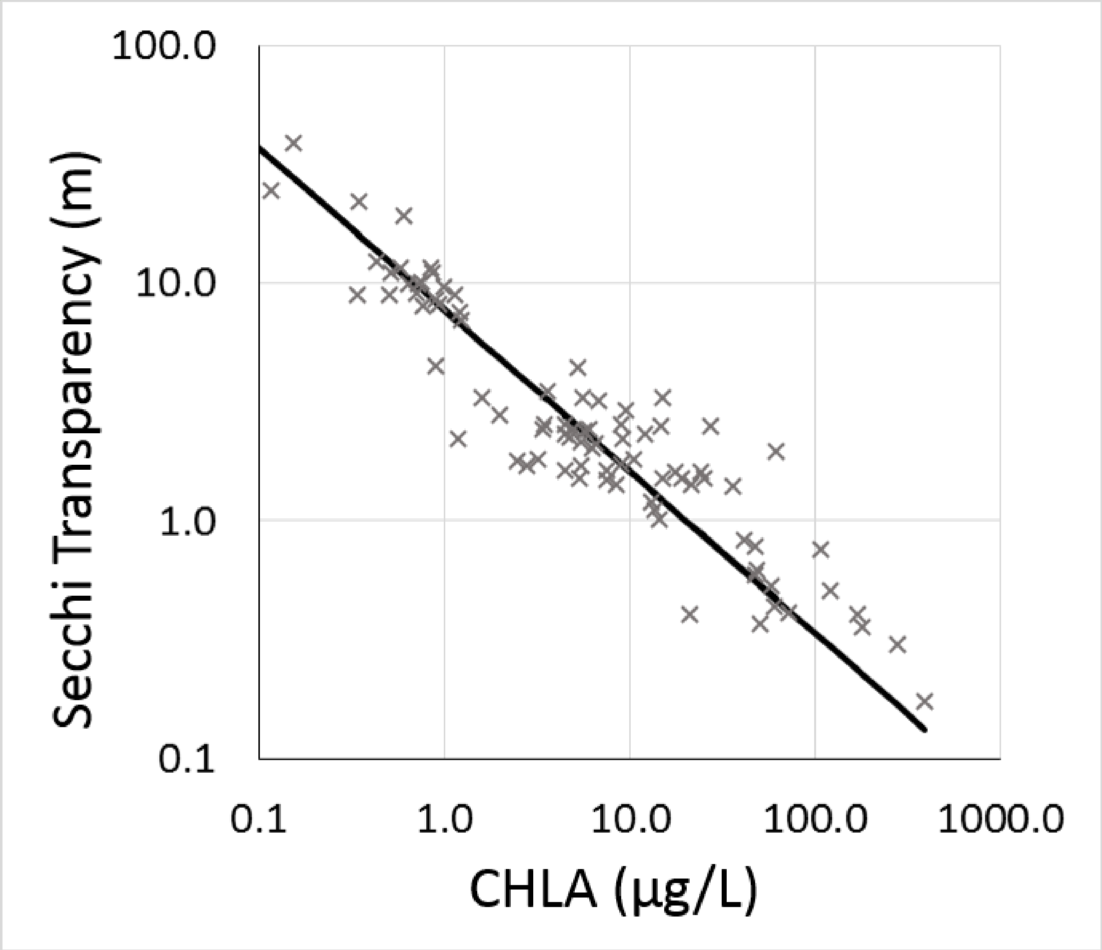
TP_C is … g/L)

C… L)

CHLA – ST Relationship

Predicting average annual levels of ST and TP in 86 lakes

Eq. 2



TP_C is ... g/L)

ST is ...)

Vollenweider Steady State Model

Link annual average [TP] of reservoir to P loading rates from watershed

Eq. 3

$$L_{Pc} = \left(\frac{TP_c}{1.55}\right)^{\frac{1}{0.82}} (1 + \sqrt{\tau_w}) q_s$$

(Vollenweider and Kerekes 1982)

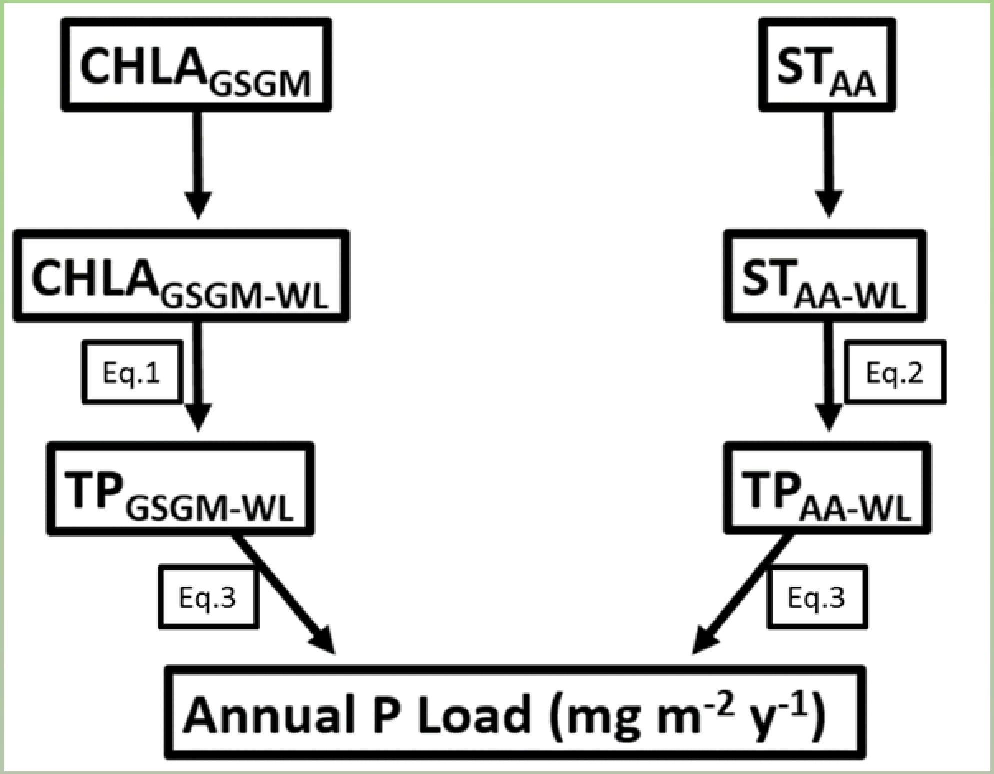
TP_C is the average annual concentration of TP (µg/L)

τ is the water residence time (yr)

q_s is the annual water loading rate (m^3/yr)

L_{PC} is the critical P loading rate (mg/m^2/yr)

Vollenweider to estimate P loading



Growing Season Geometric Mean Chl-a and Annual Average Secchi Transparency at all sites

Calculate the Whole-lake GSGM Chl-a and Whole-lake AAST based on volume-weighted site averages

Relate Whole-lake averages to Whole-lake Total Phosphorus concentrations

Relate WLTP to annual external P load

P-Load Reduction Estimations

Calculate 6 whole lake P-loads: (ST and CHLA)

- Measured (USGS)
- Modeled (2015)
- WQ standards at Hickory Creek

Calculated P loads from WQ models
<u>-Target P loads from WQ standards</u>
P load reduction estimation

Methods

12 sites along riverine to lacustrine transect (~78 km).

Sampled near the 1st and 15th May through October

- (defined growing season)

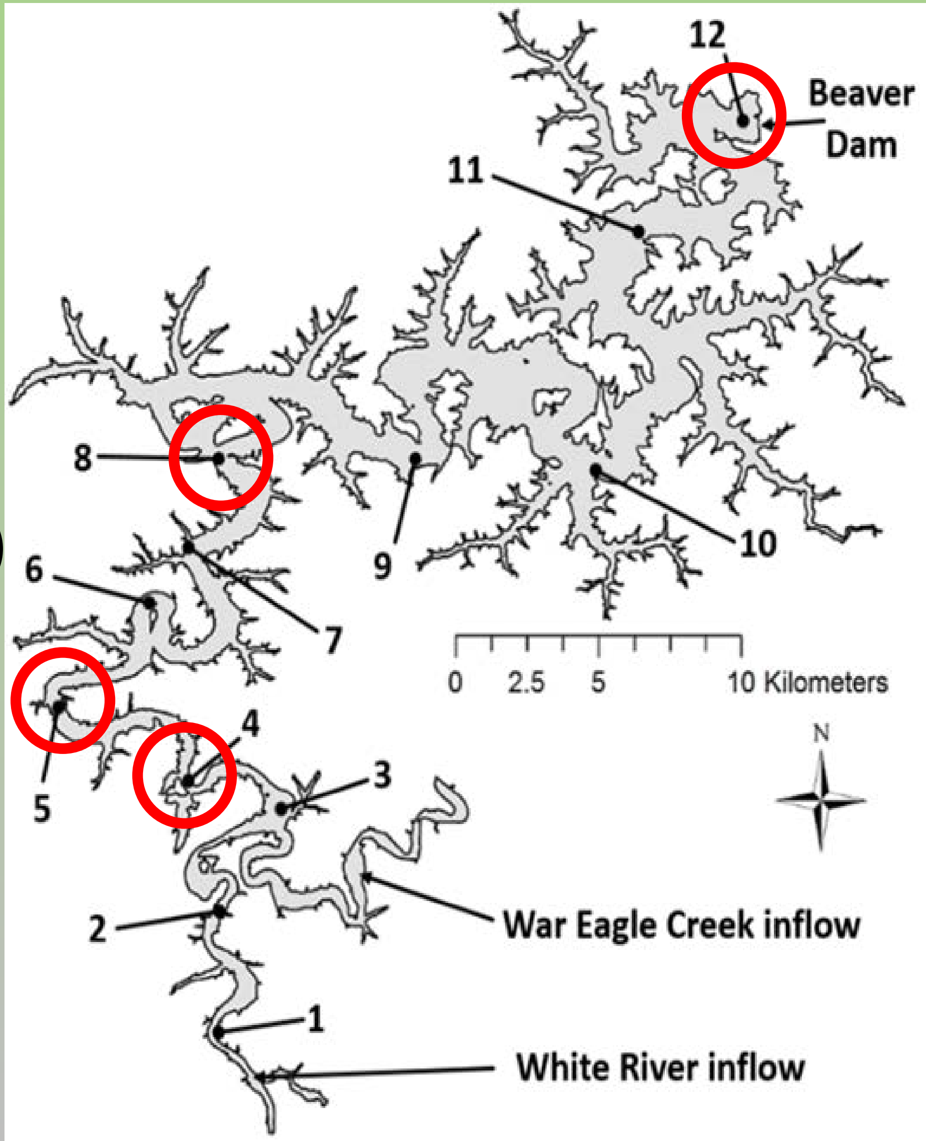
Secchi transparency (Lind 1985)

Chl-*a* at multiple depths (APHA 2005)

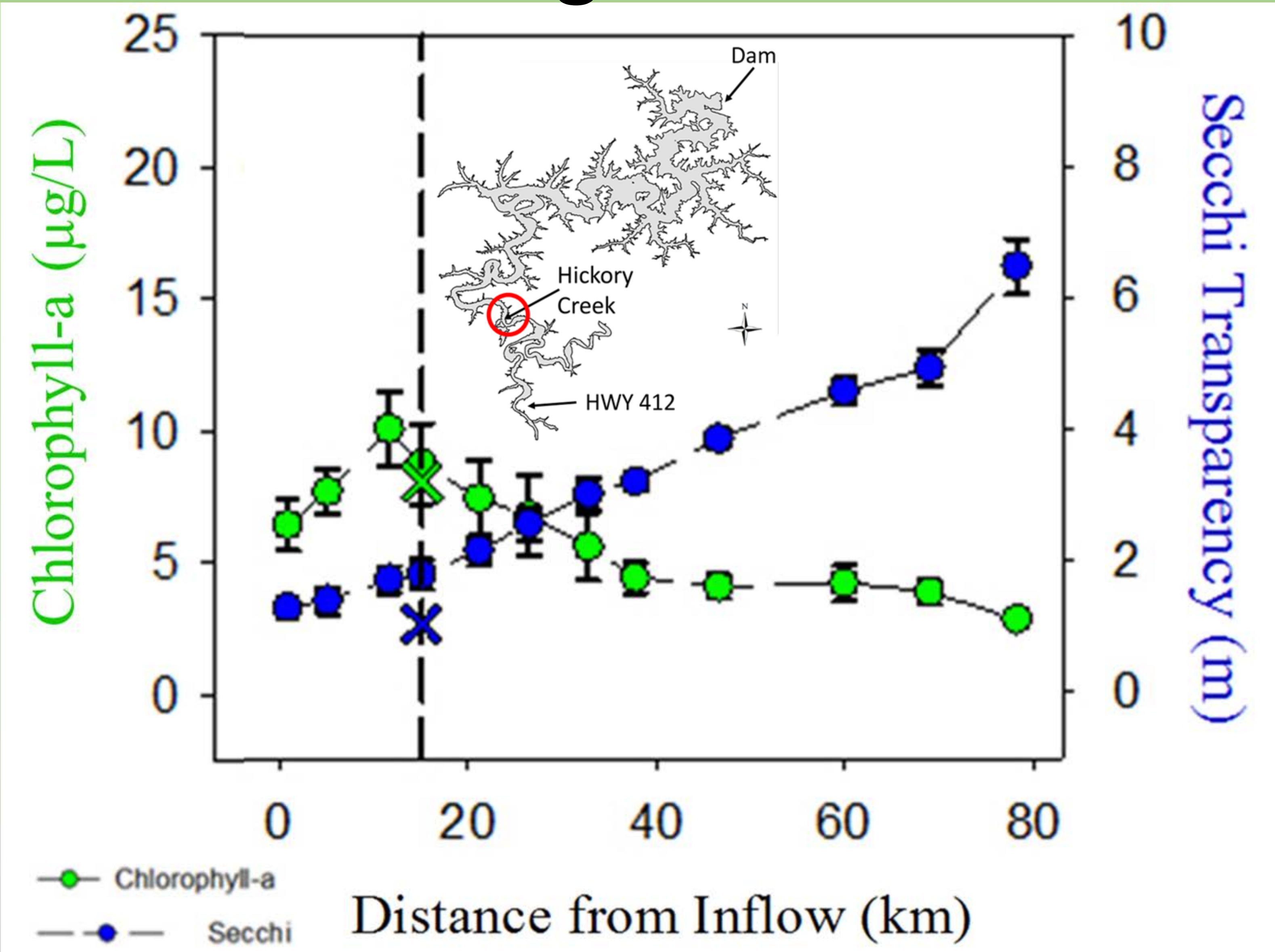
TNTP at same depths

Euphotic depth

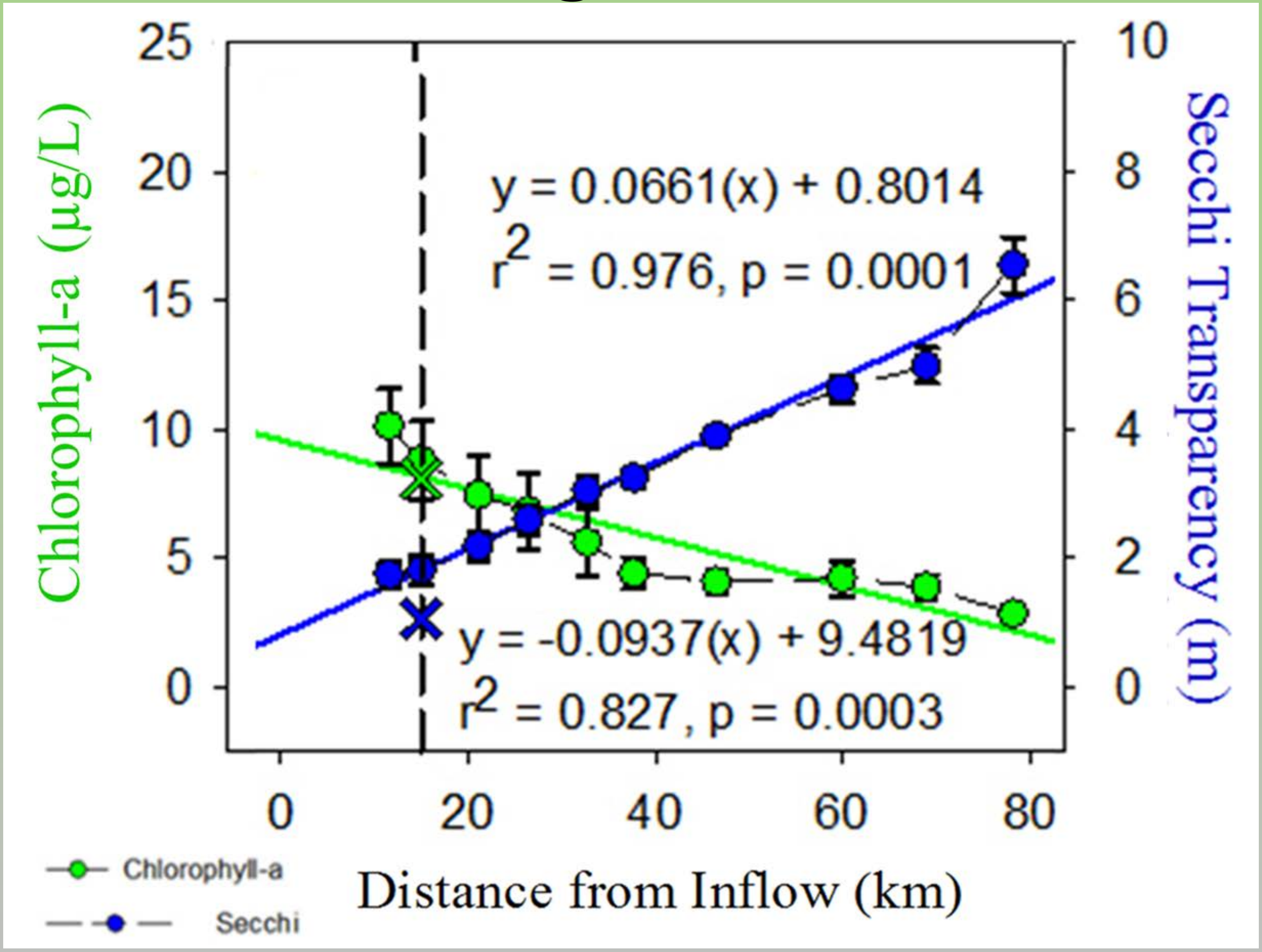
USGS sampled 4 of these since 2001



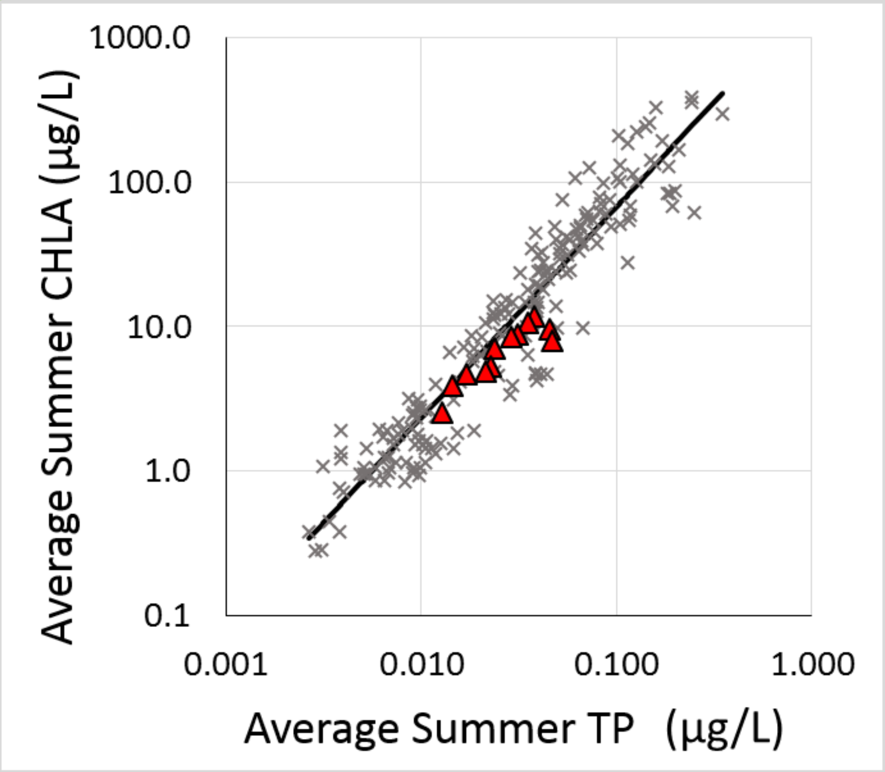
2015 Monitoring data



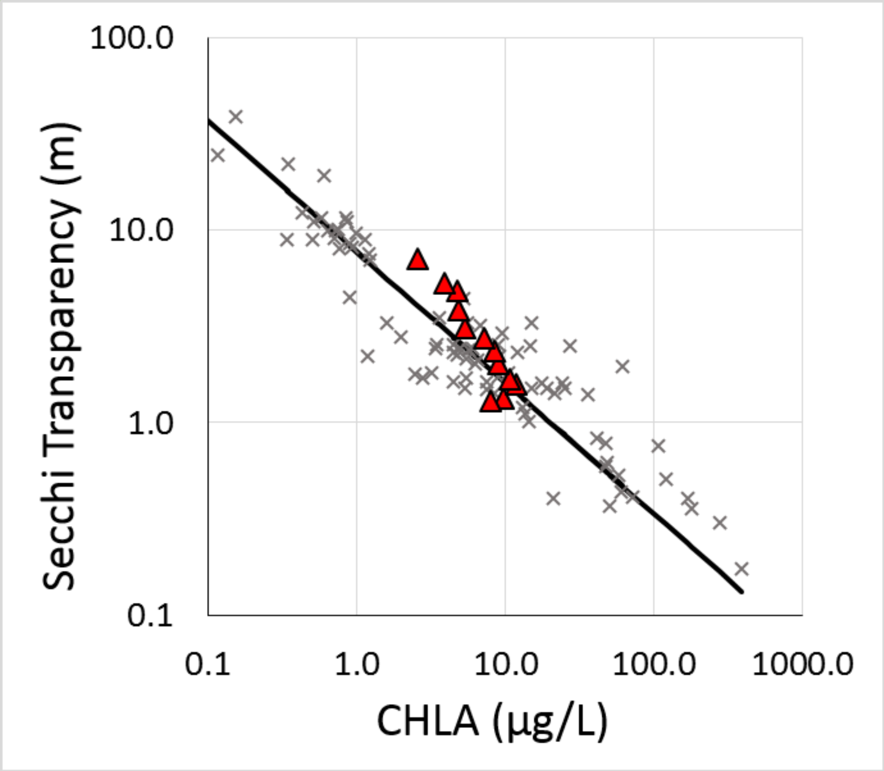
2015 Monitoring data



TP – CHLA – ST Relationships



(Dillon and Rigler 1974)



(Carlson 1977)

Data Manipulations

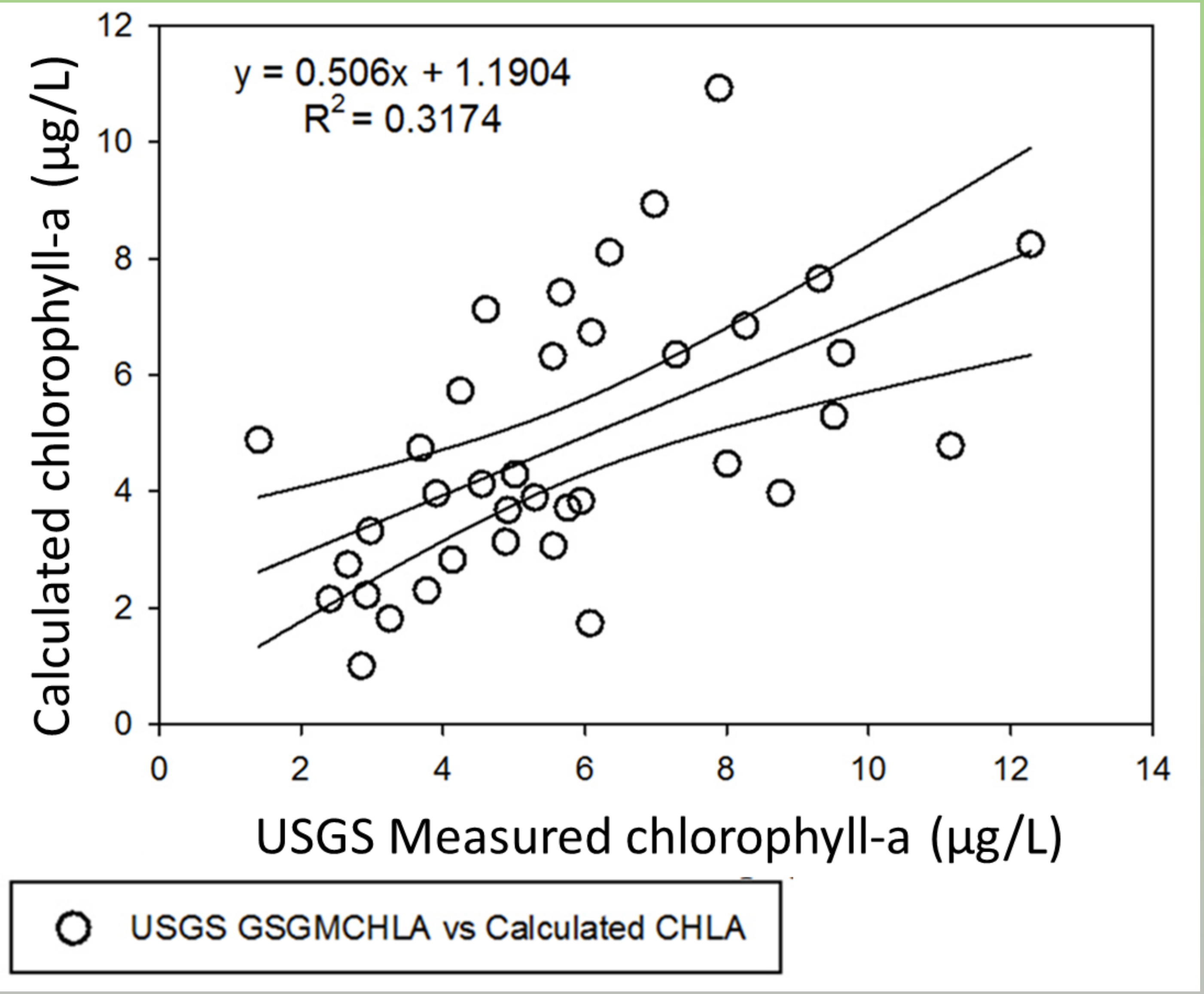
$$\frac{\text{CHLA}_{\text{GSGM-SITE}}}{\text{CHLA}_{\text{GSGM-DAM}}} = \text{FracDAM}_{\text{CHLA}} = \frac{9.69\ \mu g/L}{2.27\ \mu g/L} = 4.27$$

River Km	Site (#)	$\text{FracDAM}_{\text{CHLA}}$	$\text{FracDAM}_{\text{ST}}$
15	HC (4)	4.27	0.30
21.1	BWD (5)	3.54	0.36
37.7	HWY 12 (8)	2.05	0.52
78.2	Dam (12)	1.00	1.00

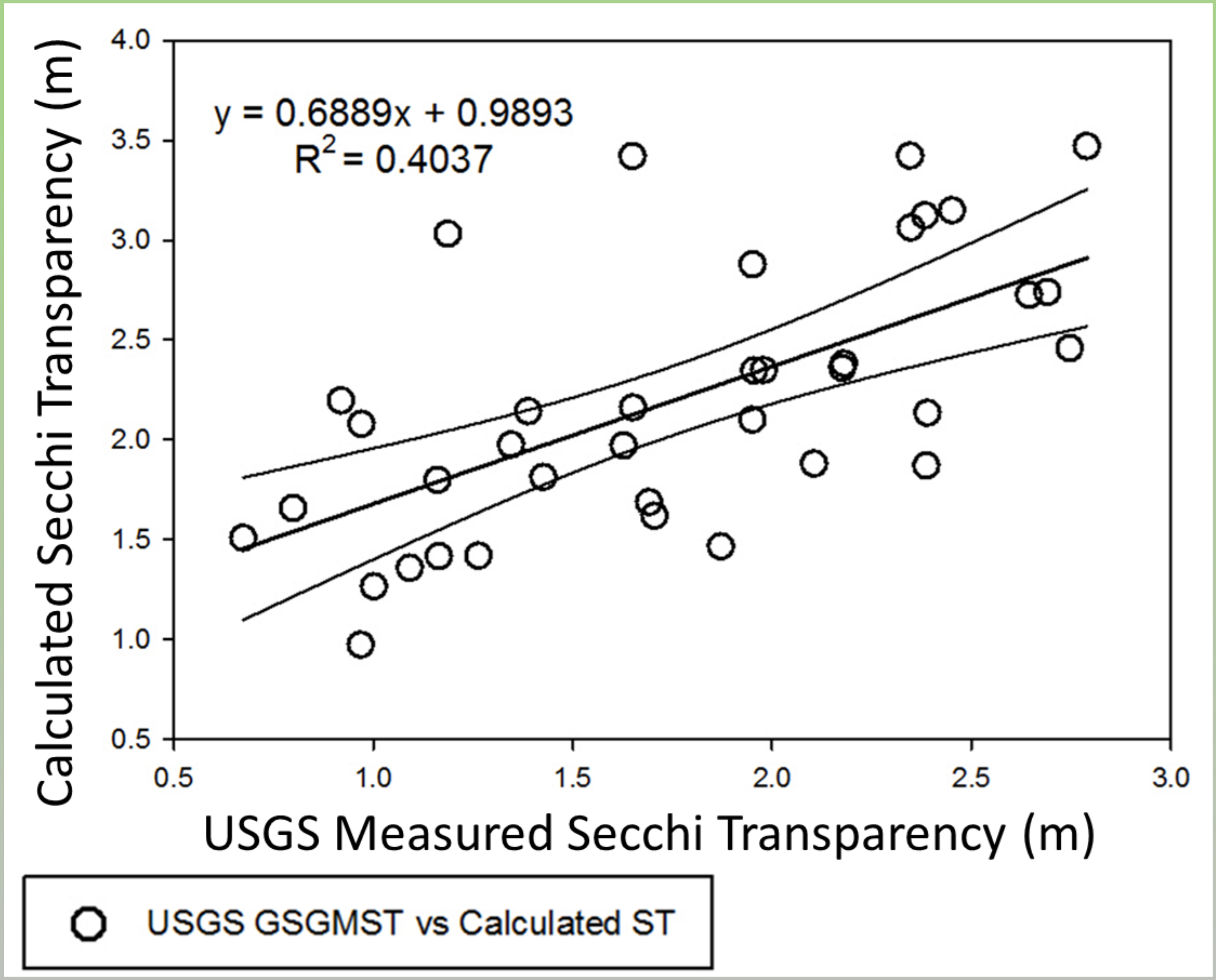
Hindcasting USGS Data

	Site	Measured Chl-a	$FracDAM_{CHLA}$	Calculated CHL-a
2011	HC (4)	6.98	4.27	8.93
2011	BWD (5)	5.66	3.54	7.42
2011	HWY 12 (8)	5.01	2.05	4.29
2011	Dam (12)	2.09	1.00	

Hindcasted vs. USGS Measured data



Hindcasted vs. USGS Measured data



P-Load Reduction Estimations

USGS Measured

Year	WL-ST (m)	WL-CHLA (µg/L)	WL-TP (µg/L)	WL-TP (µg/L)	Crit P load (mg/m^2/yr)	Crit P load (mg/m^2/yr)	P reduction (mg/m^2/yr)	P reduction (mg/m^2/yr)
2009	2.0	8.5	24.2	26.6	655	734	293	254
2011	2.0	6.5	24.2	22.2	800	722	439	241
2013	2.4	6.7	20.1	22.7	409	474	48	0
2015	2.3	4.6	20.8	17.3	673	541	312	60
Target	3.2	5.2	15.0	19.0	361	481		

P-Load Reduction Estimations

P-Load reduction (kg) to attain WQ standard		
	ST	CHLA
Measured	20293	9597
Modeled	12800	10170

P-Load reduction (%) to attain WQ standard		
	ST	CHLA
Measured	35.0%	17.5%
Modeled	26.3%	20.2%

Acknowledgements

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Dr. Michelle Evans-White
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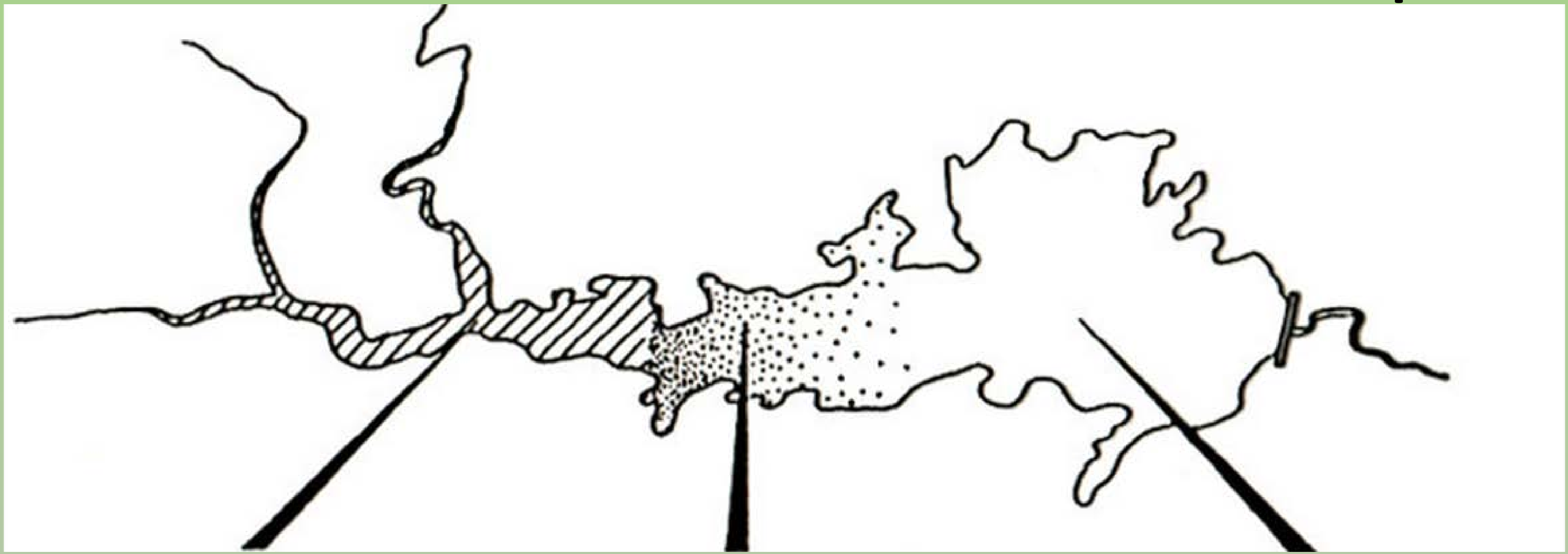
Questions?

Supplemental slides

Introduction – Theoretical Concept



Riverine Zone
- Narrow basin
- High velocity
- High susp. solids
- Low light availability
- More “eutrophic”

Transitional Zone
- Broader, deeper basin
- Reduced velocity
- Lower susp. solids
- More light
- Intermediate

Lacustrine Zone
- Lake-like basin
- Low velocity
- Lowest susp. solids
- Most light
- More “oligotrophic”

Modified from Kimmel and Groeger 1984

Project Overview

Linear models of spatial patterns throughout Beaver Reservoir

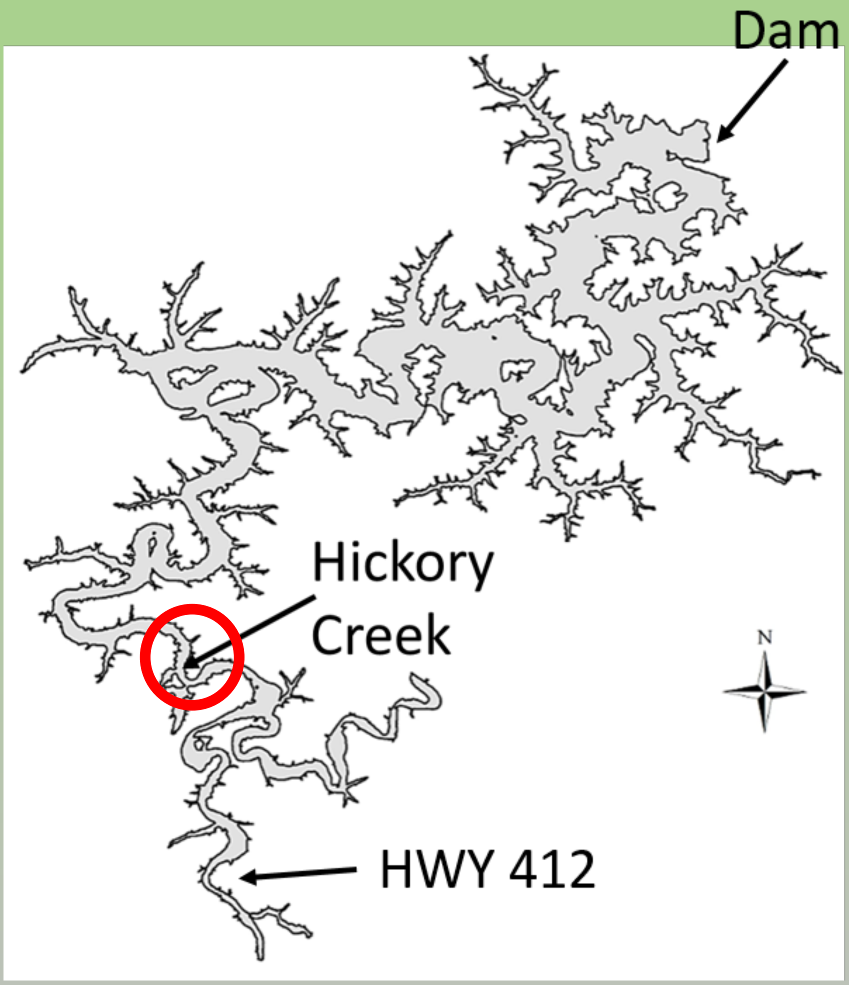
Use these linear models to predict chlorophyll-a and Secchi depth

Using common limnological models:

- Compute whole-lake Chl-a and ST and how they relate to TP
- Compute whole-lake Chl-a and ST that relate to WQ standards
- Calculate P loading for all years

$$\frac{Observed\ P\ loads\ from\ WQ\ models\ - Target\ P\ loads\ from\ WQ\ standards}{P\ load\ reduction\ estimation}$$

Introduction



State of Arkansas recently adopted effects-based WQ criteria	
Growing Season Geometric Mean Chlorophyll (CHLA)	Annual Average Secchi Transparency (ST)
≤ 8 (µg/L)	≥ 1.1 (m)

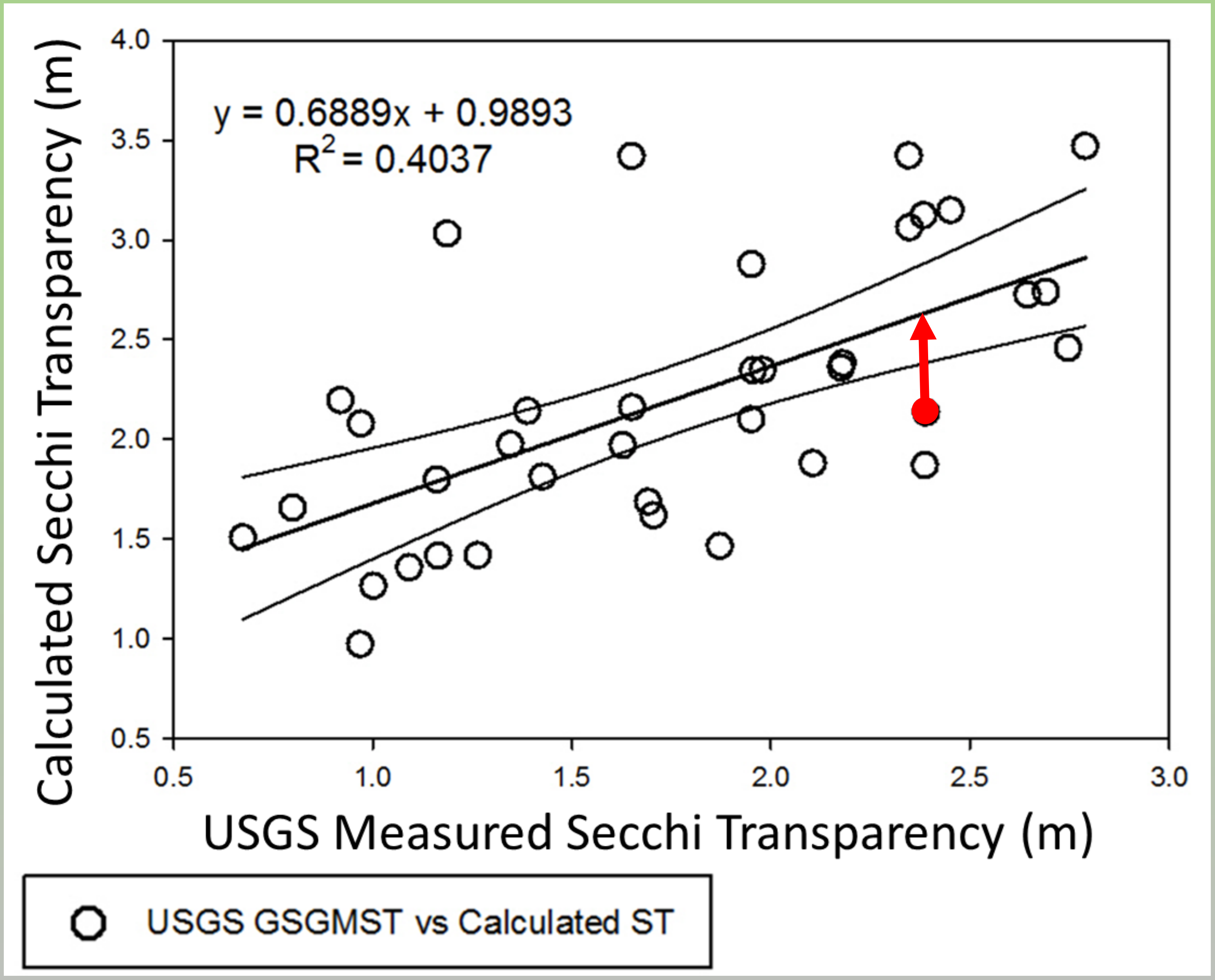
(APCEC 2012)

Based on projected long term CHLA and ST averages (Scott and Haggard 2015)

Assuming normal data distribution, half of all water quality assessments would end in impairment status (Scott and Haggard 2015)

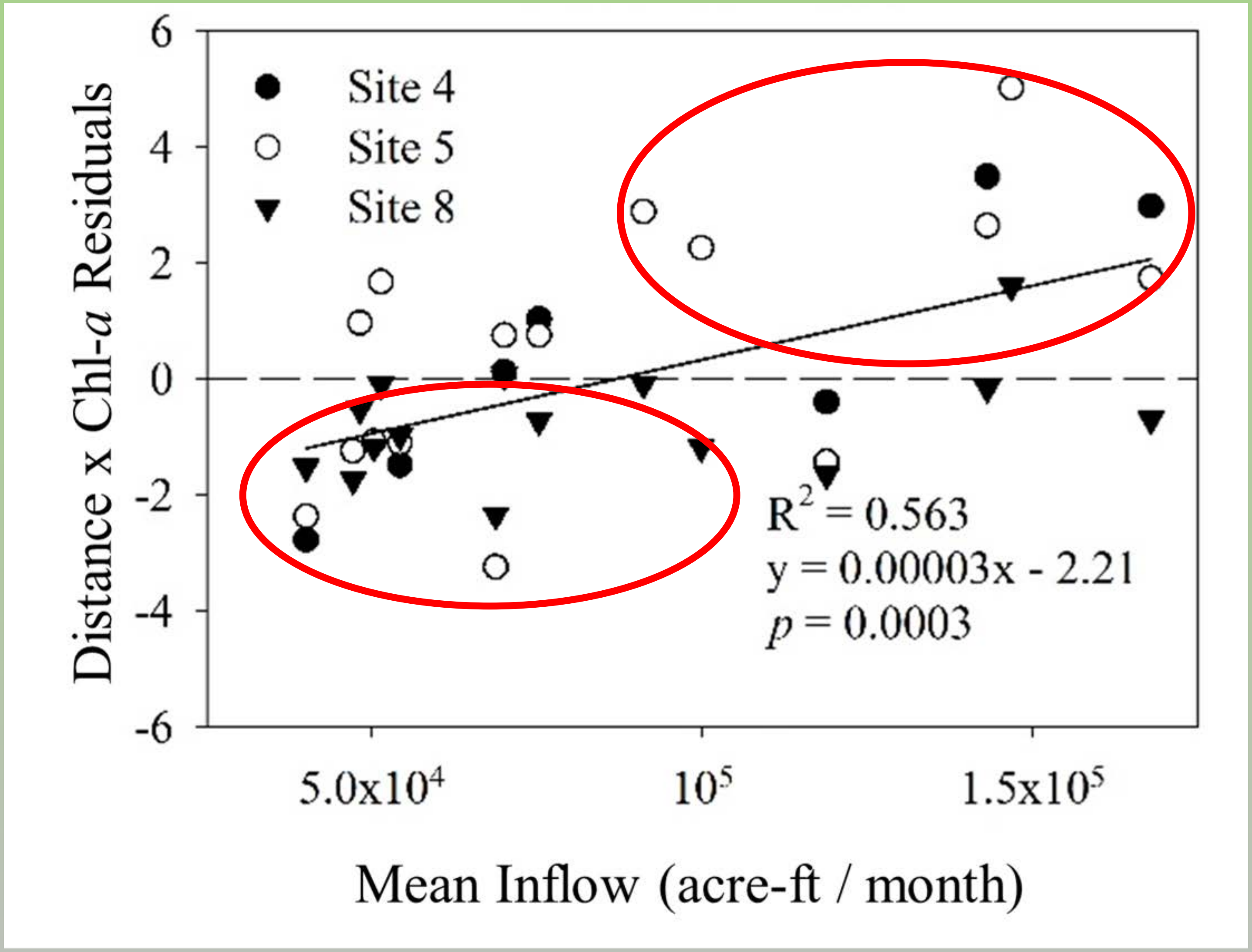
Must be met ≥80% of 5 year period (ADEQ)

Results



y = 0.6889x + 0.9893
R2 = 0.4037
Calculated Secchi Transparency (m)
USGS Measured Secchi Transparency (m)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.5
1.0
1.5
2.0
2.5
3.0
USGS GSGMST vs Calculated ST

Residual Analysis

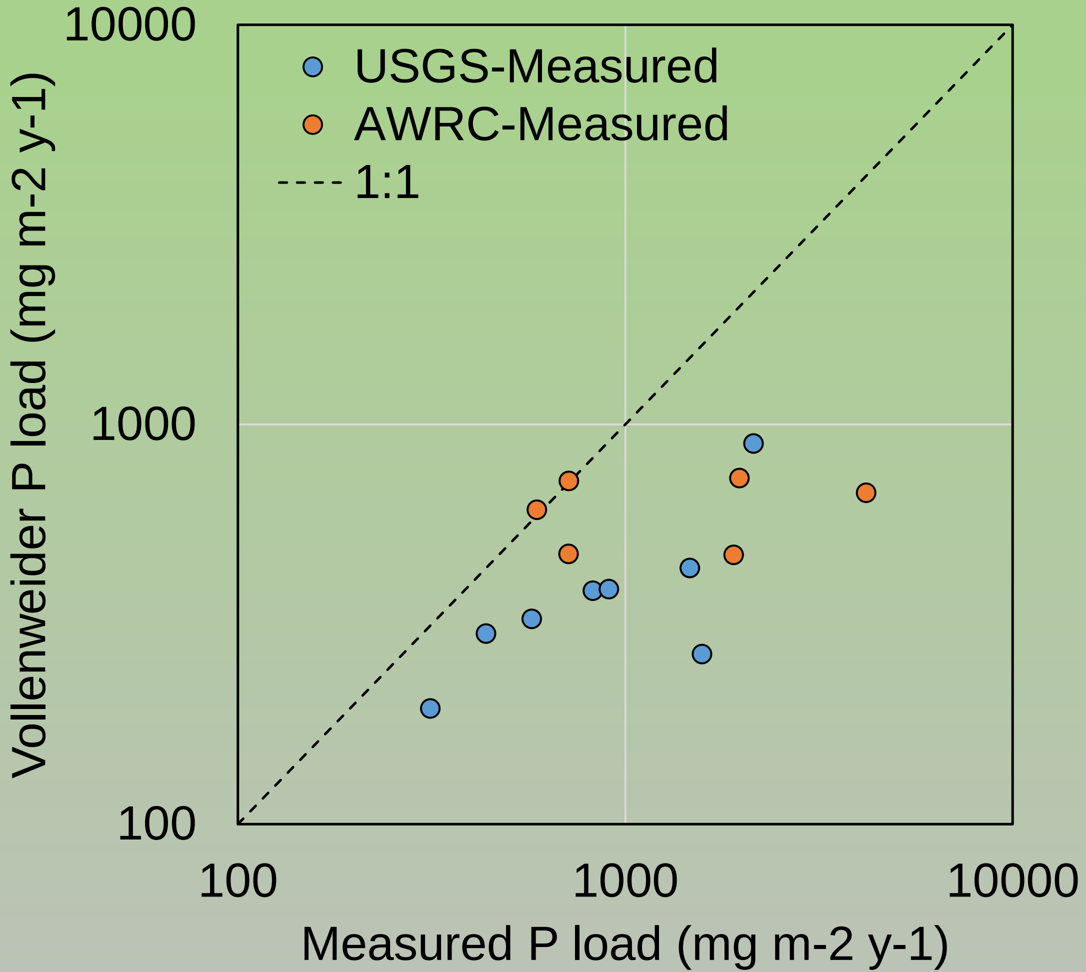


Supplemental

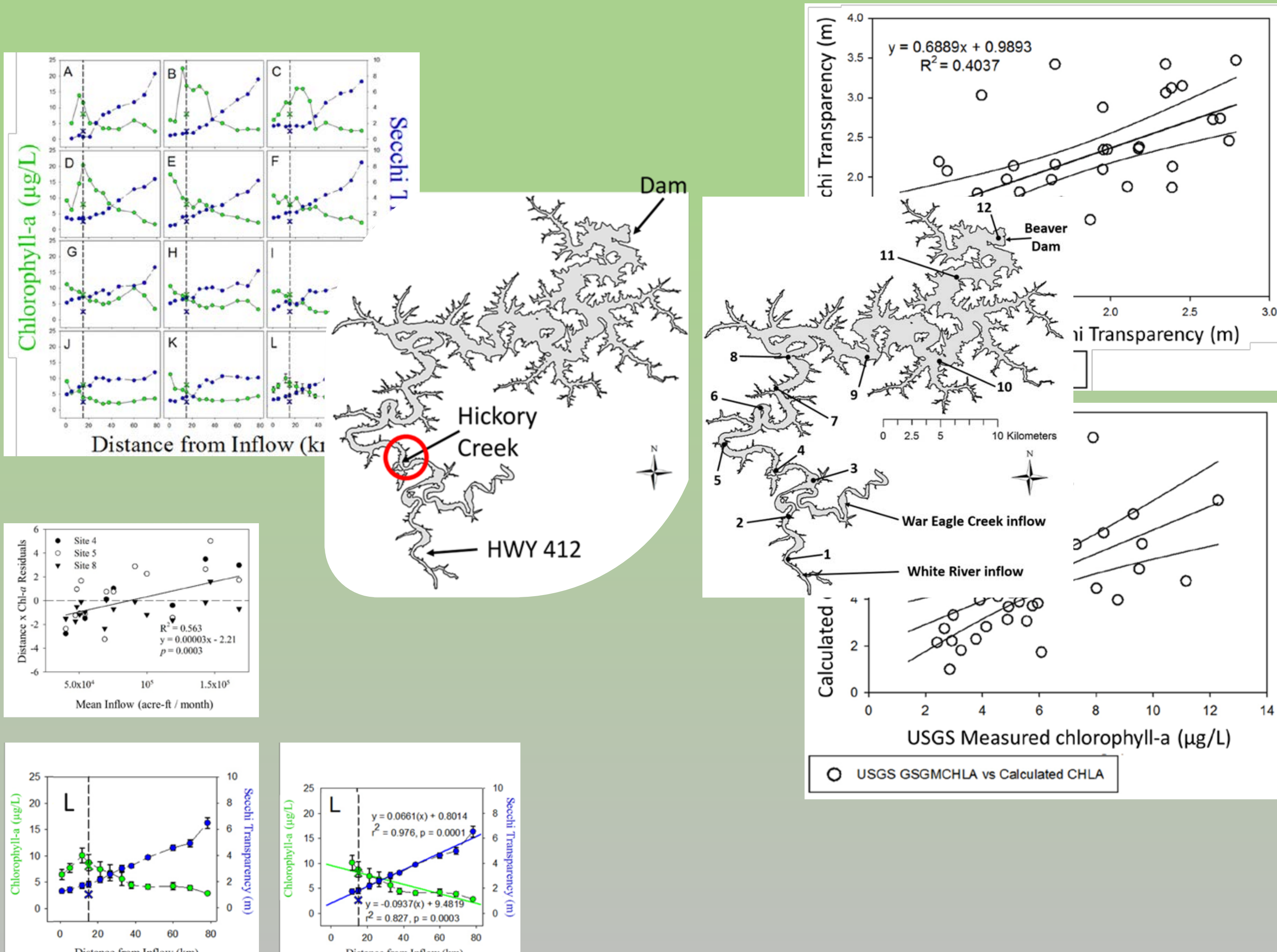
Site #	River km	Latitude	Longitude
12	78.2	36° 25' 28"	93° 51' 15"
11	68.9	36° 23' 17"	93° 53' 23"
10	59.9	36° 19' 51"	93° 54' 05"
9	46.5	36° 20' 02"	93° 57' 27"
8	37.7	36° 20' 06"	94° 01' 09"
7	32.7	36° 18' 28"	94° 01' 29"
6	26.4	36° 17' 36"	94° 02' 15"
5	21.1	36° 15' 37"	94° 04' 07"
4	15.0	36° 14' 29"	94° 01' 43"
3	11.6	36° 14' 23"	94° 00' 01"
2	5.0	36° 12' 31"	94° 00' 59"
1	0.0	36° 10' 34"	94° 01' 11"

Photic Depth (m)	# of depths sampled
0-0.9	1
1-2.9	2
3-4.9	3
5-6.9	4
7-8.9	5
9-10.9	6
11+	7

Supplemental



Courtesy of J. Thad Scott



Chlorophyll-a (µg/L)
Secchi T
Distance from Inflow (km)
Dam
Hickory
Creek
HWY 412
Beaver
Dam
War Eagle Creek inflow
White River inflow
10 Kilometers
y = 0.6889x + 0.9893
R^2 = 0.4037
Secchi Transparency (m)
Calculated
USGS Measured chlorophyll-a (µg/L)
USGS GSGMCHLA vs Calculated CHLA
Site 4
Site 5
Site 8
Distance x Chl-a Residuals
R^2 = 0.563
y = 0.00003x - 2.21
p = 0.0003
Mean Inflow (acre-ft / month)
Chlorophyll-a (µg/L)
Secchi Transparency (m)
Distance from Inflow (km)
y = 0.0661(x) + 0.8014
r^2 = 0.976, p = 0.0001
y = -0.0937(x) + 9.4819
r^2 = 0.827, p = 0.0003

Project Overview