Phosphorus and TSS Trends in Duck Creek, Northeastern Wisconsin

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AWRA March, 2014

Acknowledgement

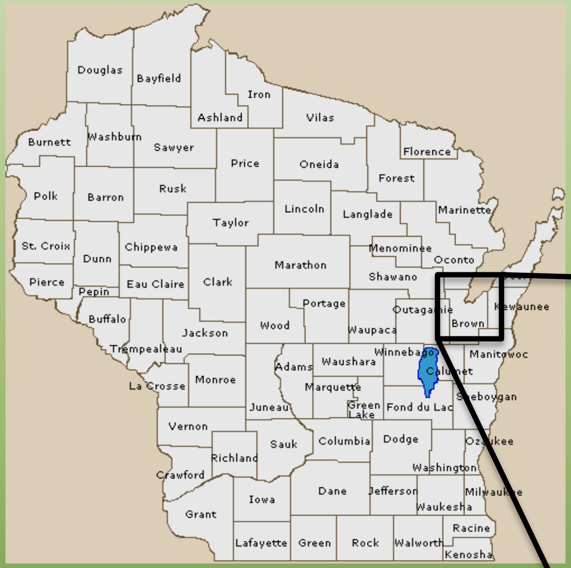
- This presentation is based in part on thesis work conducted by Daniel Cibulka, Environmental Science and Policy Graduate Program at UW-Green Bay
- Funding for the overall study was provided by the Lower Fox River Watershed Monitoring Program, the Oneida Nation of Wisconsin, cooperative funding with the USGS (plus other monitoring), and the WDNR

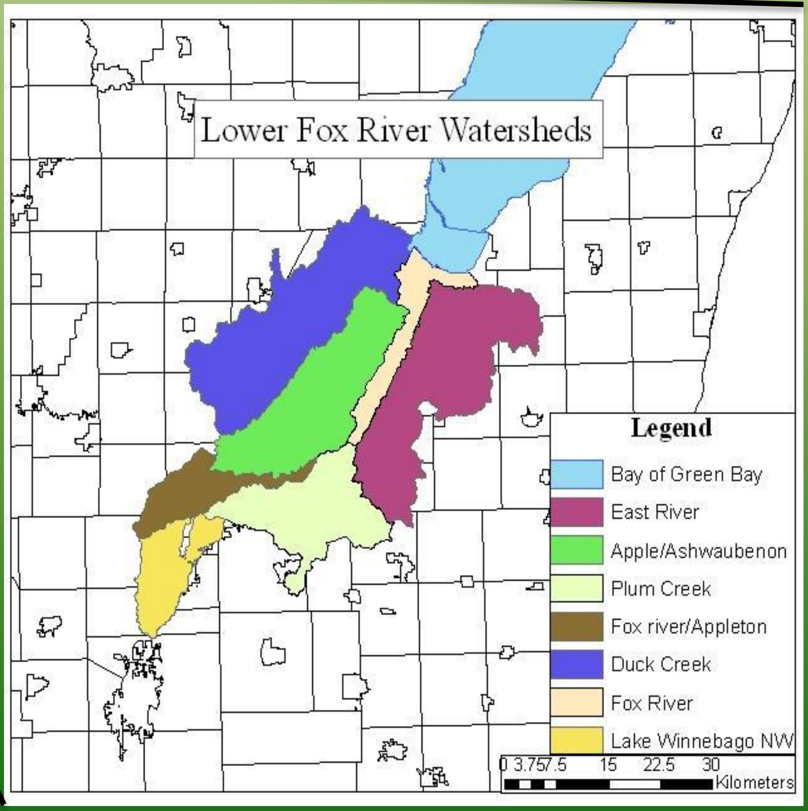
Presentation Outline

- Project Background, Objectives
- Overview of Land Use / Management Changes
- Duck Creek WQ Statistical Analysis:
  - 1st Round: 1989 to 2008
  - 2nd Round: 2004 to 2013
- Project Summary

Project Background

Lower Fox River Watershed

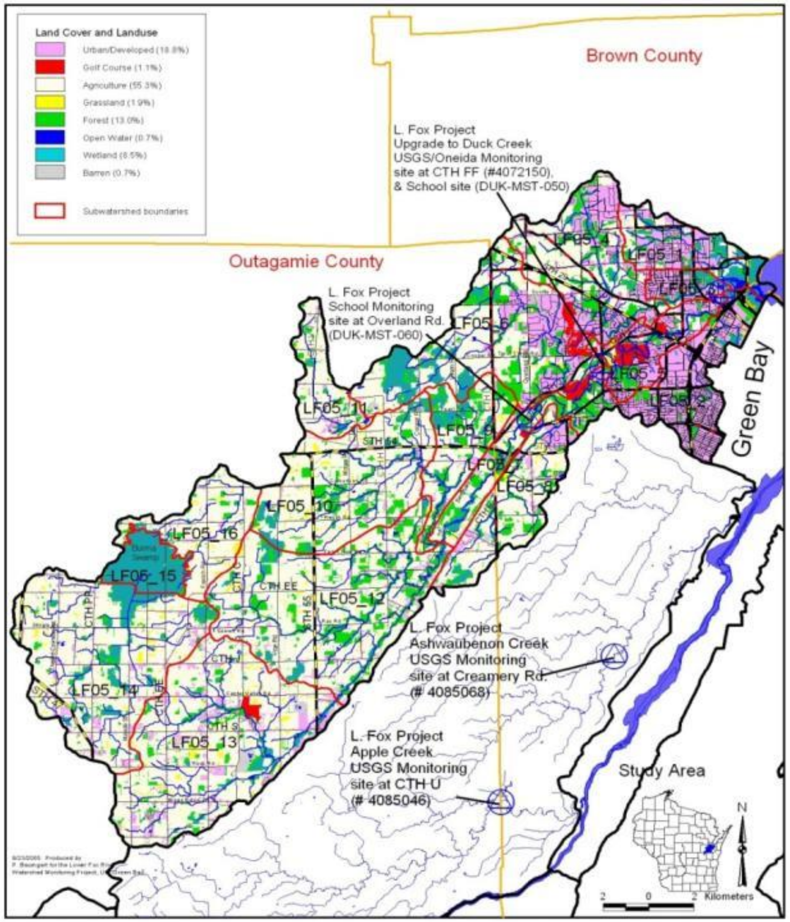




- 1,654 km^2 basin
- Brown, Calumet, Outagamie, Winnebago Counties

Duck Creek Watershed

- 392 km^2
- Predominately agriculture (55%), small urban impact
- Census data: population increase of 24% from 1990 to 2007



Landuse and land cover in the 392 sq. km Duck Creek Watershed. Image based on composite of: 2001 landuse from Brown County Planning Dept.; 2000 landuse from East Central Regional Planning Commission, and 1992 WISCLAND land cover from WDNR.

Mainstem Duck Creek Conditions

- 39.5 of 57.6 stream miles on Wisconsin “Impaired Waters” list
  - Sediment, phosphorous, ammonia primary pollutants
  - Aquatic life rated “poor to fair”
  - Streambank erosion, barnyard animal lots and sediment runoff from croplands major concern
  - Tributary streams have shown higher water quality, biotic integrity

Objective

20+ years of watershed management activities…So….

- Have efforts to restore watershed been effective?
- Have phosphorus or sediment concentrations declined?

Land Use / Management Changes

Changes in the Watershed

- Duck, Apple, Ashwaubenon Priority Watershed Project
  - Approved in 1997
  - Cost-sharing and technical assistance
  - Identification of “critical sites”

Oneida Initiatives

- Extensive buffering program
- Intensive rotational grazing plan for beef cattle on Oneida Farms (>600 acres)
- >1,000 acres of restored wetlands
- Nutrient management plans have been implemented on all Oneida Farms

Changes in the Watershed

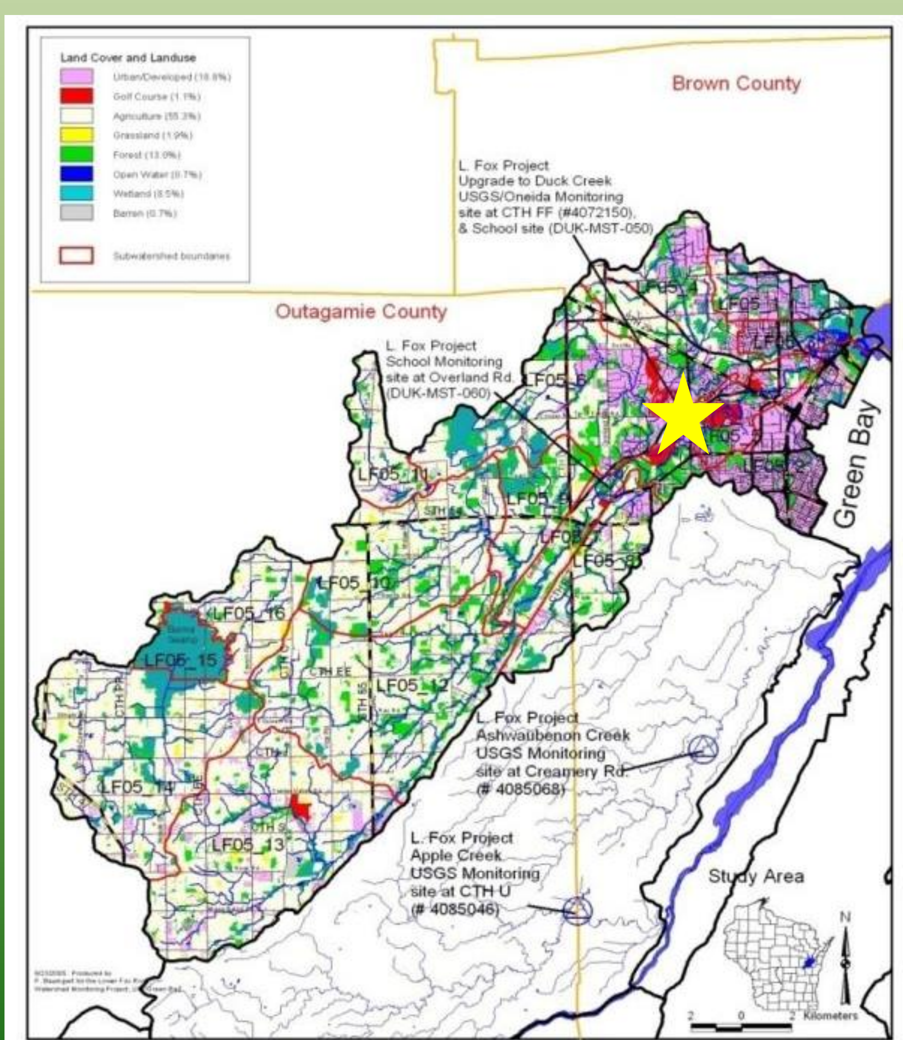
- Agricultural Tillage Survey
  - Survey completed spring 2009 by UWGB
  - Conservation tillage from 2002 to 2009

Year	Survey Time	Conv. Till	Mulch Till	No Till
2009	Before spring tillage	50%	**41%**	9%
2002	After spring planting	96%	**4%**	0%
1999/2000	After spring planting	69%	29%	2%
1996	After spring planting	74%	26%	0%

- General trend of increasing corn and decreasing forage proportions between 1992 and 2013

Duck Creek Water Quality Trend Analysis

Water Quality Monitoring



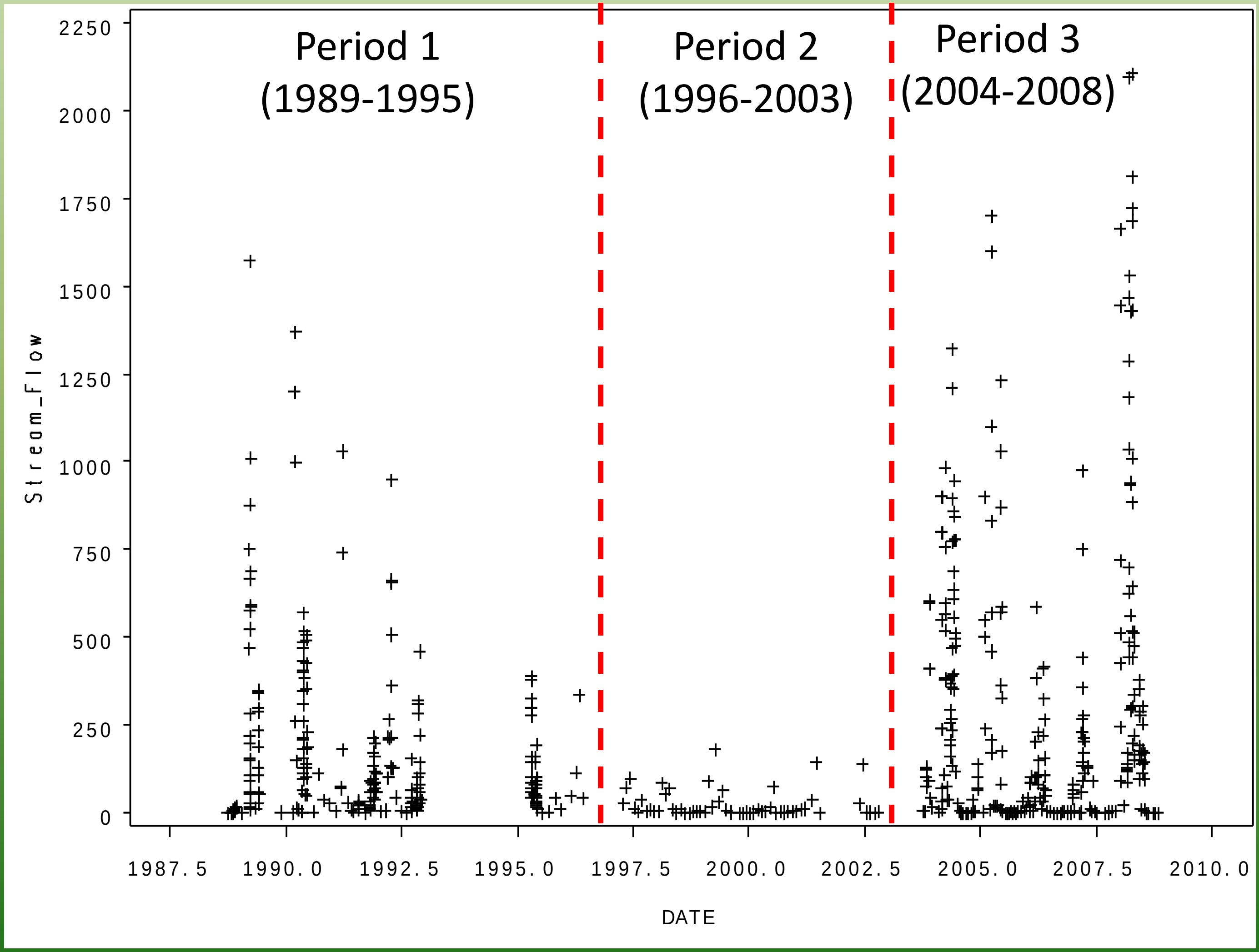
- USGS monitoring station # 4072150
  - Area: 276 km^2
  - Mostly AG & Hyd-group B soils, with some C
  - Flow (25 yr, 1989-2013)
  - TP & DP (25 yr)
  - TSS (2004-13)

1st Round: Statistical Analysis (1989 to 2008)

- Null hypothesis: phosphorus concentrations increased or stayed the same during or between the period(s) in question
- Alternative hyphothesis: phosphorus concentrations decreased during or between the period(s) in question

Water Quality Monitoring

sampling protocol changes



Statistical Analysis Tests

- 5 Statistical Tests Run on Dataset
  - 20-year multiple linear regression
  - Period specific regressions
  - Period comparisons using Wilcoxon Rank sum test with data censoring
    - Same, but with additional data censoring (data set sub-sampled monthly and weekly)
  - Period specific regressions of monthly and weekly sub-sampled data sets

Dataset Modifications

- Duplicate samples flagged and removed
- TP "outliers" (>1.3 mg/L) were removed
- 4-month period in 1999 sub-sampled
- TP and DP concentrations log-transformed

Regression Model

- Based on USGS LOADEST Program, run with SAS

$$\text{LN-constituent} = a0 + a1\ \text{LN\_Q} + a2\ \text{LN\_Q}^2 + a3\ \text{SIN}(2\pi \text{DEC\_TIME}) + a4\ \text{COS}(2\pi \text{DEC\_TIME}) + a5\ \text{DEC\_TIME}$$

- Centered option to reduce collinearity
- Sine & Cosine terms: seasonality
- Flow terms: flow variation
- Time term as decimal time: <u>trend analysis</u>

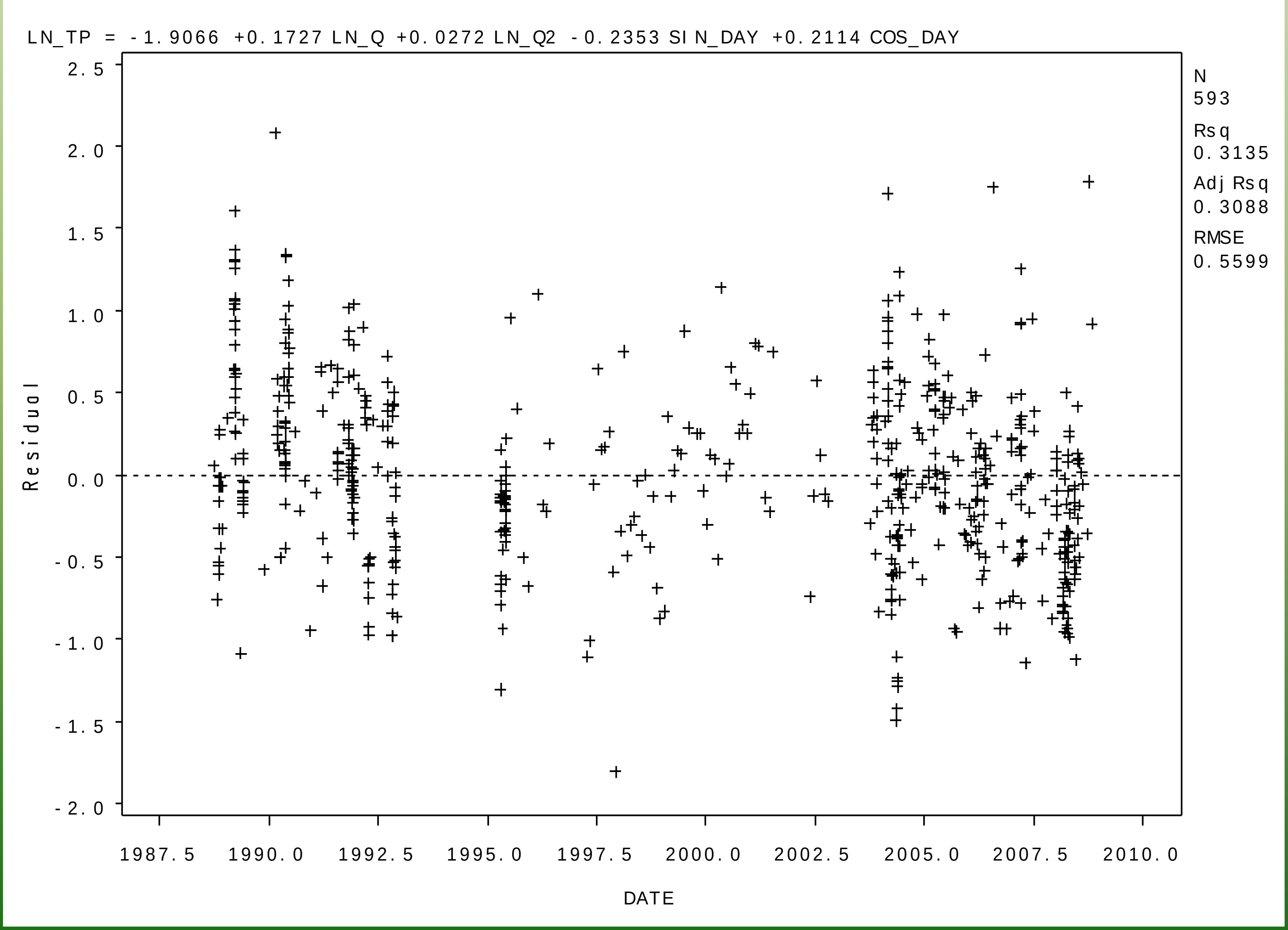
20-Year Regression Results (test 1)

- TP, DP concentrations decreased significantly ($p < 0.0001$)
- However, decreasing trend not linear since it occurred primarily during Period 1
- Linear regression not valid when applied over 20 year record, so applied separately to Periods 1 and 3

Residual Plots

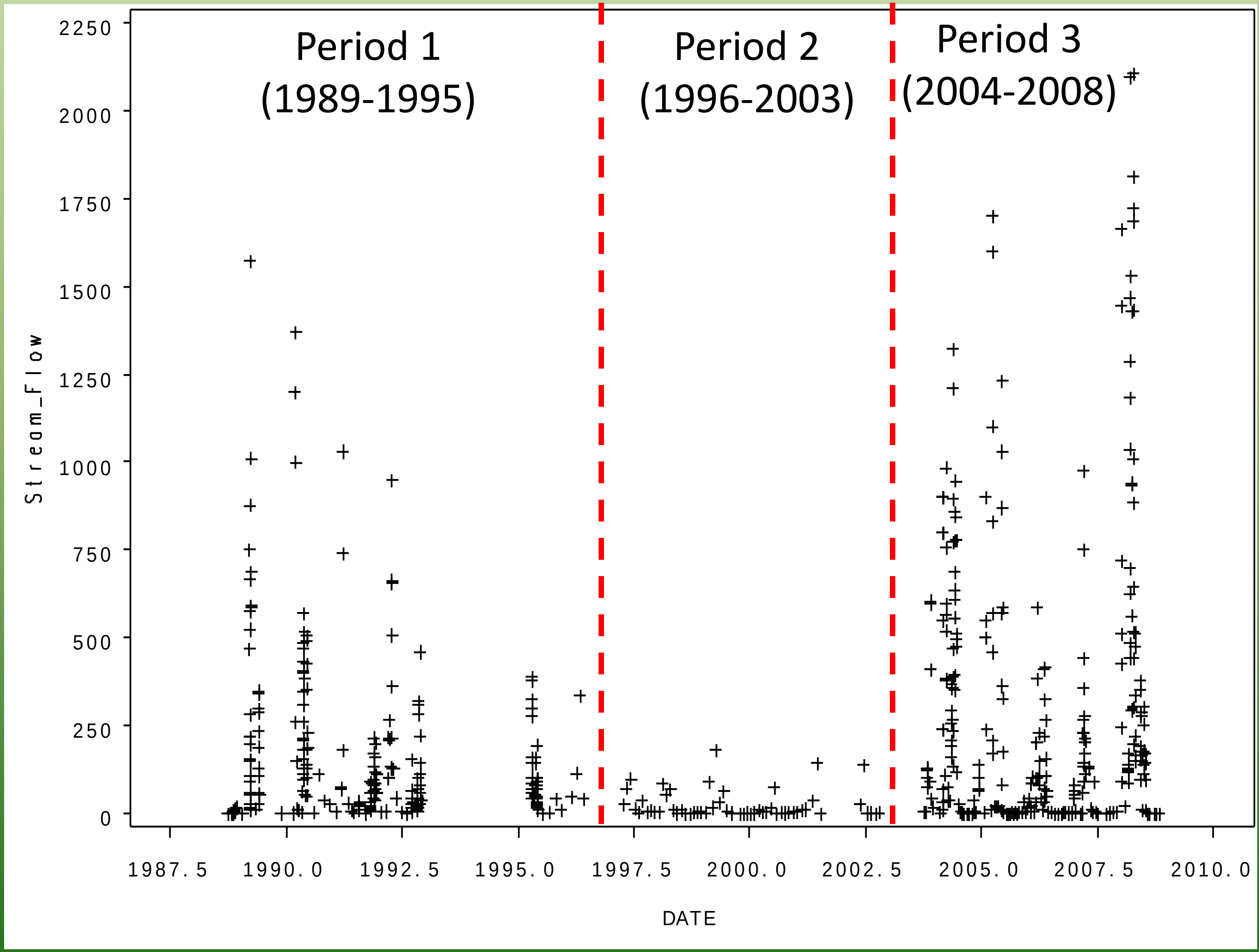
- Residuals, or model error, essentially remove the effect of flow and seasonality on LN TP and DP concentrations.
- So, the residuals express the variation in LN TP and DP concentrations over time, over and above the variation due to flow and seasonality

20-Year Residual Plot: flow & seasonally-adjusted Decrease of TP occurred primarily in Period 1



Water Quality Monitoring

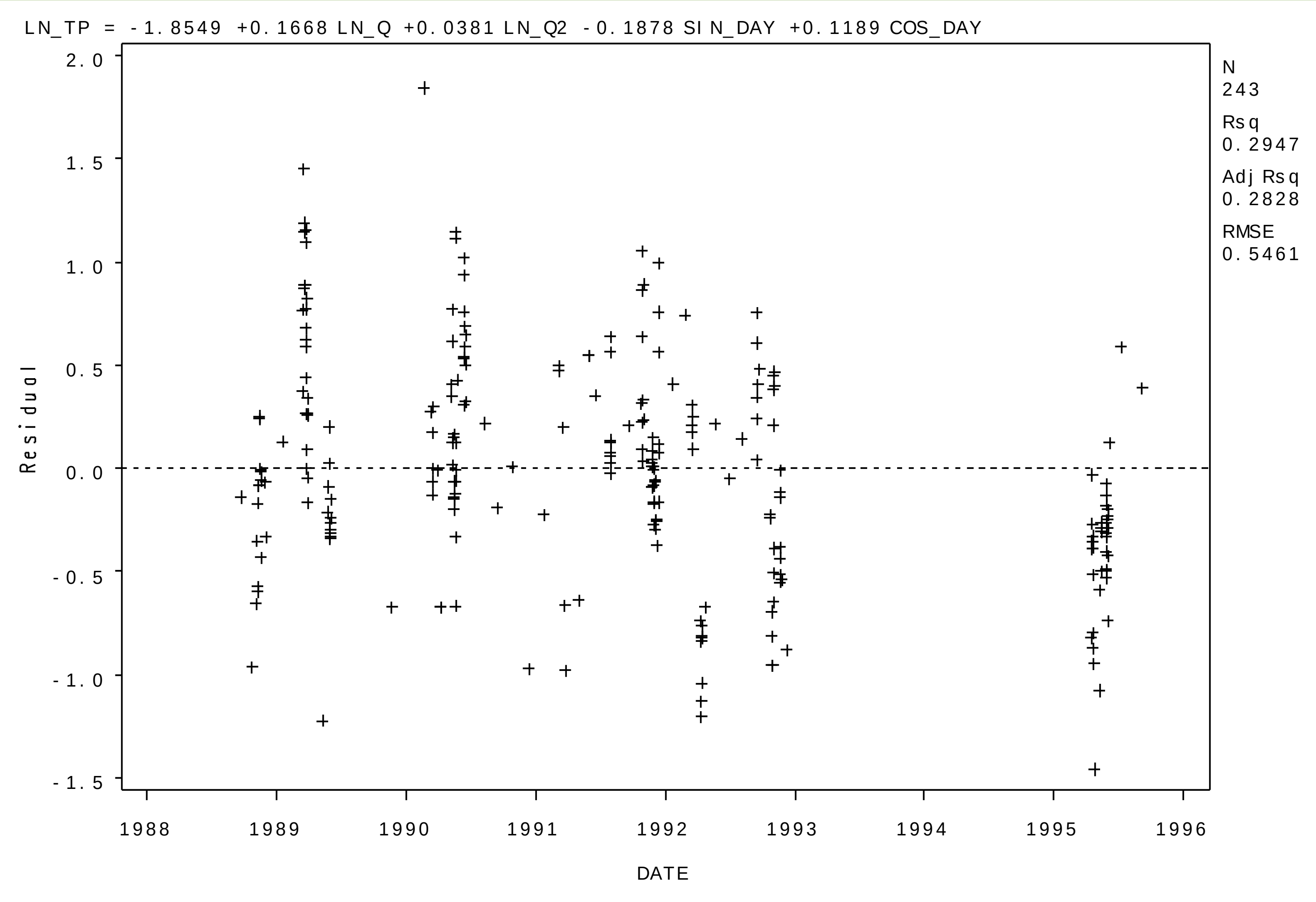
sampling protocol changes



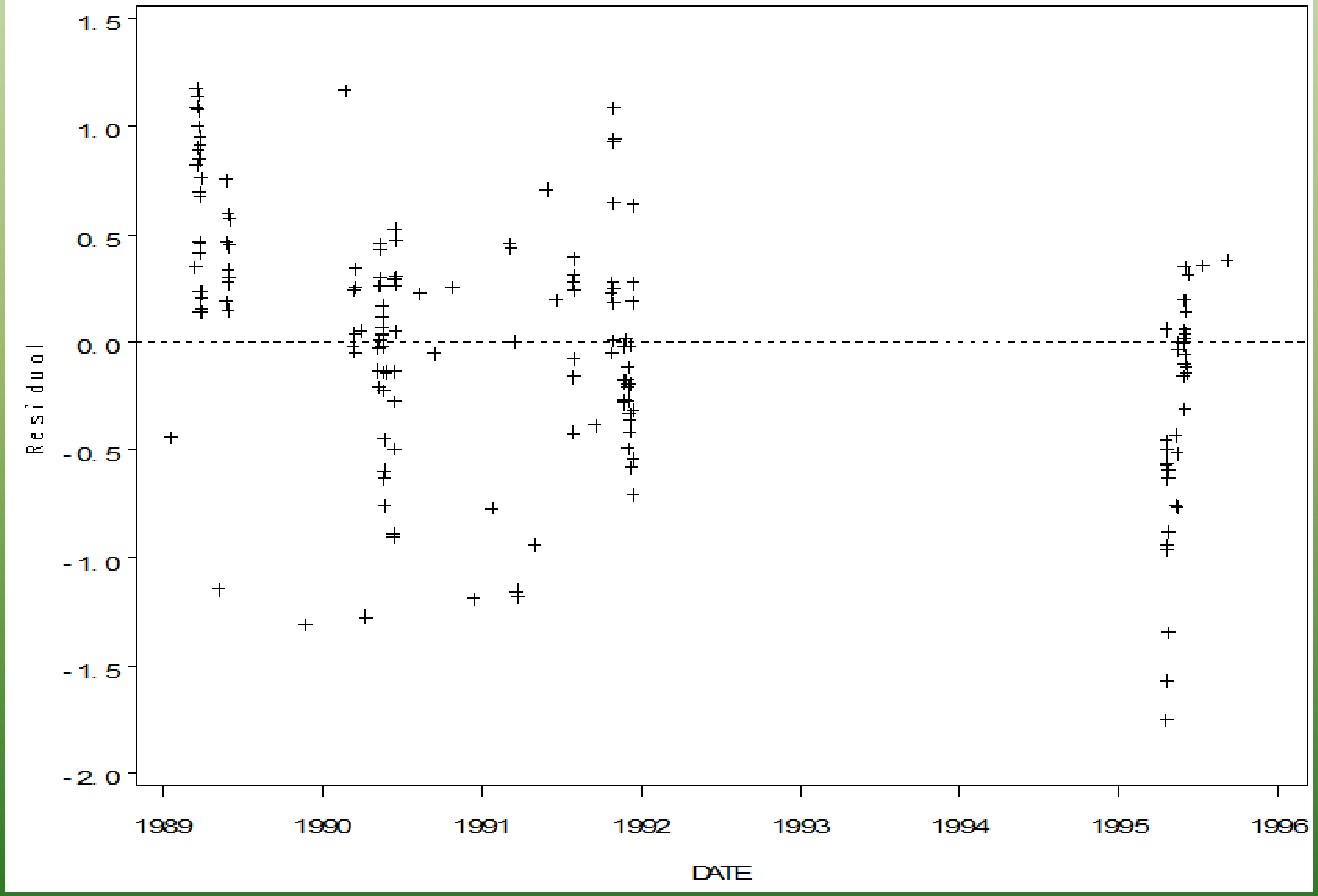
Period Specific Regressions (test 2)

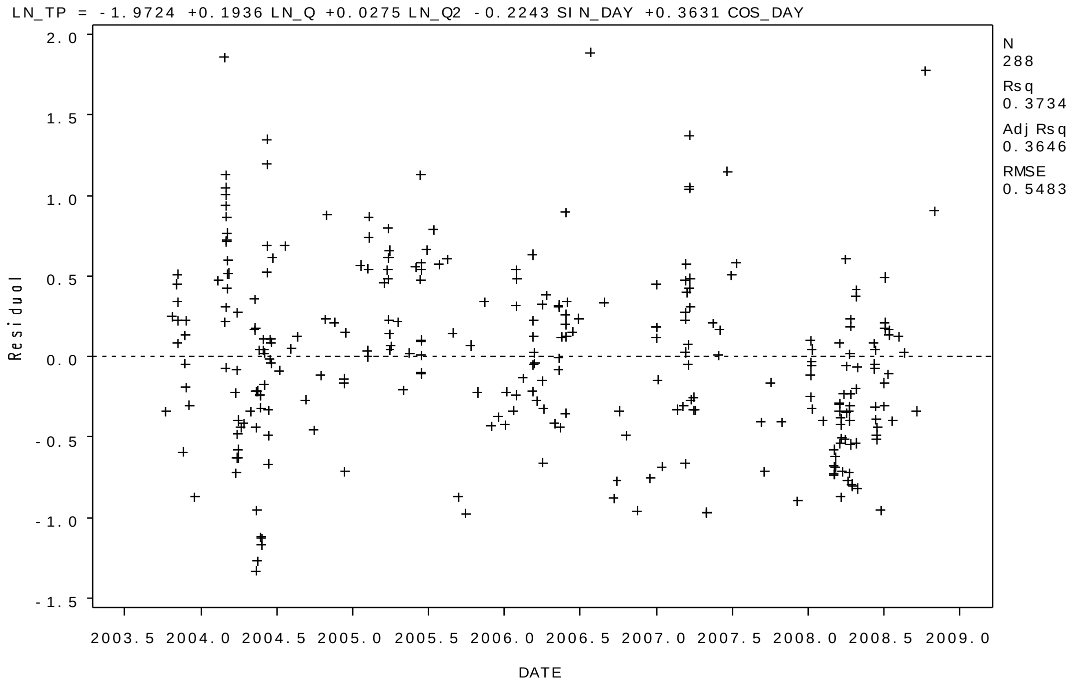
- Same Regression Model Applied to Period 1 and 3
  - Period 1 (1989-1995):
    - Slope of time term sig. different than zero
    - TP and DP significantly decreased ($p<0.0001$)
      - roughly 10% and 11% per year
  - Period 3 (2004-2008):
    - TP and DP no significant change when 2008 excluded ($p = 0.79$ for TP)
    - Significant decrease in TP and DP detected ONLY when year 2008 included, BUT 2008 likely ANOMALY or outlier
      - Issues with ISCO sampling line and high flow samples
      - Record snowfall, high snowmelt
      - Analysis of TSS data confirmed 2008 was probable anomaly

Period 1 declining trend of TP



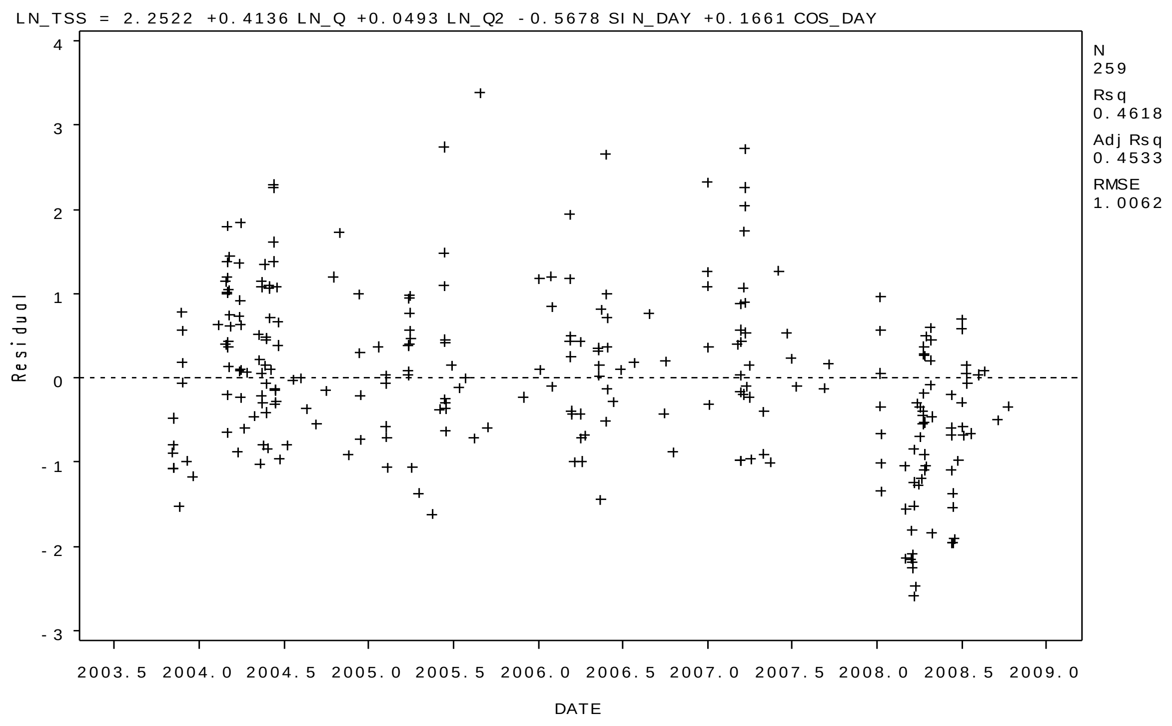
Period 1 declining trend of DP





Period 3 TP, no obvious trend, but lower TP in 2008 (likely anomaly)

Period 3 TSS, no obvious trend, but much lower TSS in 2008 (likely anomaly)



Period Specific Comparisons (test 3)

- Wilcoxon Rank Sum-Test between Period 1 & 3
- TP, DP lower in Period 3 ($p<0.05$, $p<0.002$)
  - For all flow (cfs) and data censoring scenarios*

Variable	All Flow	w/o 1995	Flow < 1000	Flow < 750	Flow < 500	Flow < 250	Flow < 75	Flow > 75 and < 750	Flow > 75 and < 750 w/o 2008
TP		For all flow scenarios Period 3 Concentrations < Period 1							
DP									
DP/TP	P1=P3	**P1>P3***	P1=P3	P1=P3	P1=P3	P1=P3	P1=P3	P1=P3	P1=P3
		Ratios not significantly different between Period 3 & Period 1							
N for TP	243 – P1	205	199	196	182	157	98	97	97
	288 – P3	288	264	237	210	167	89	148	102

*** All flow scenarios omit water-year 1995, except "All Flow"**

Sub-Sampling Comparisons (tests 4 & 5)
Period 1 (1989-1995) vs Period 3 (2004-08)

Potential for Serial Correlation in Dataset

- Sub-sampled once per month, nearest to mid-month
  - TP, DP concentrations still Lower in Period 3 ($p=0.023$ for both constituents), than Period 1
    - Wilcoxon Rank sum test
  - Sub-sampled dataset once per week with similar results

- Regression performed on Period 1 and Period 3 for sub-sampled data
    - All tests NOT significant ($p>0.05$)
    - BUT, weight-of-evidence from other tests and visual inspection of trends supports conclusion that TP and DP concentrations have decreased

1st Round: Duck WQ Trend Summary

- 4 Statistical tests indicate significant DECREASE in TP and DP concentrations
  - DECREASE occurred in Period 1 (1989-1995)
  - Phosphorous concentrations MAY have decreased since then, though evidence insufficient … So

2nd Round: Duck WQ 2004 to 2013 Objectives

- 48 additional samples were collected at Duck Creek from 2010 to 2013 to determine:
  - 1) if TP, DP and TSS concentrations declined during the most recent period (**2004 to 2013**); and
  - 2) whether TP concentrations are at or below the TMDL target of a summer median concentration of 0.075 mg/L.

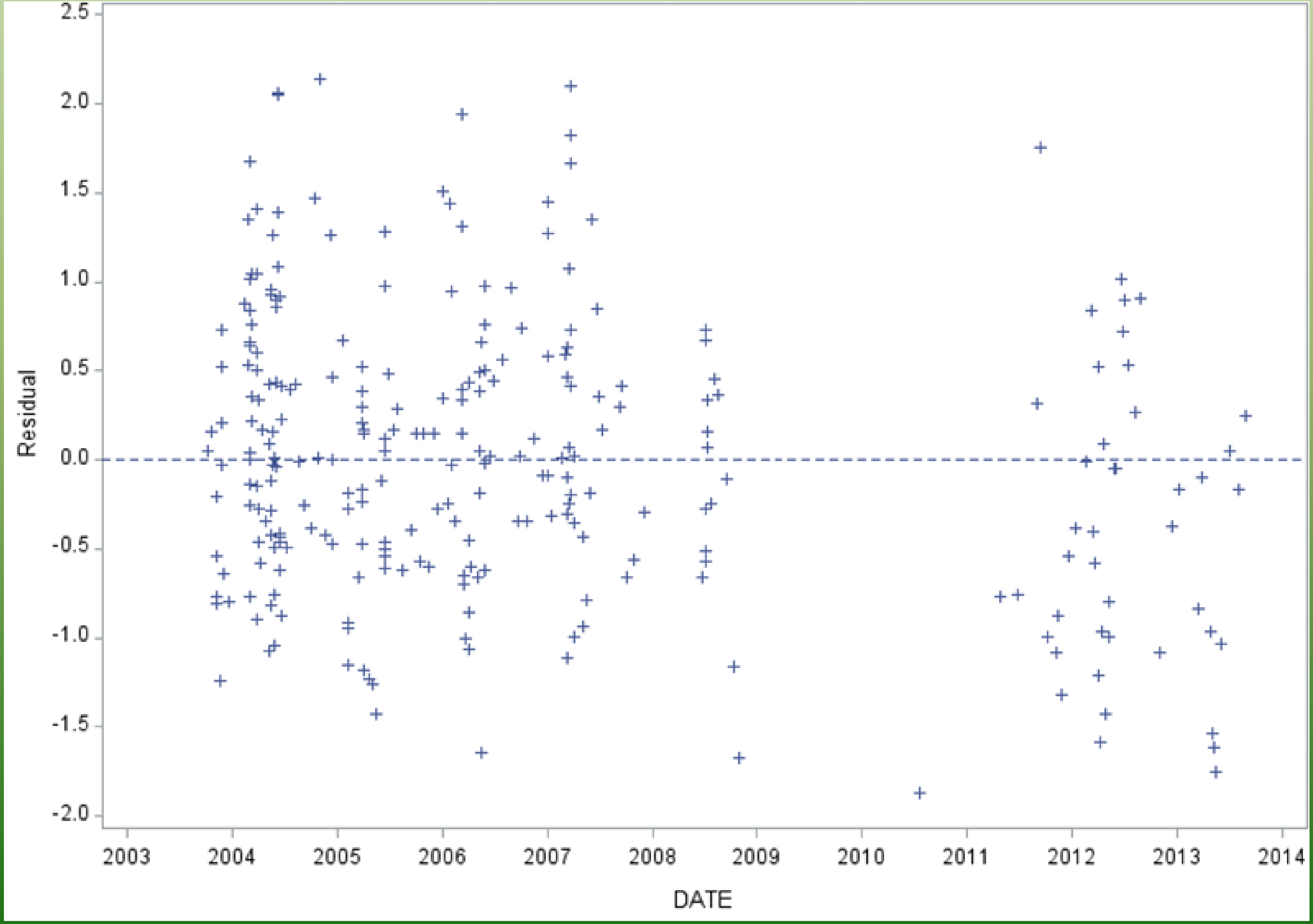
Dataset Modifications

- Duplicate samples flagged and removed
- TP "outliers" (>1.3 mg/L) were removed; some tests to see effect of adding back in
- TP, DP, TSS concentrations log-transformed
- 58 samples from 2008 removed from primary analysis (but tested with & w/o censored data)

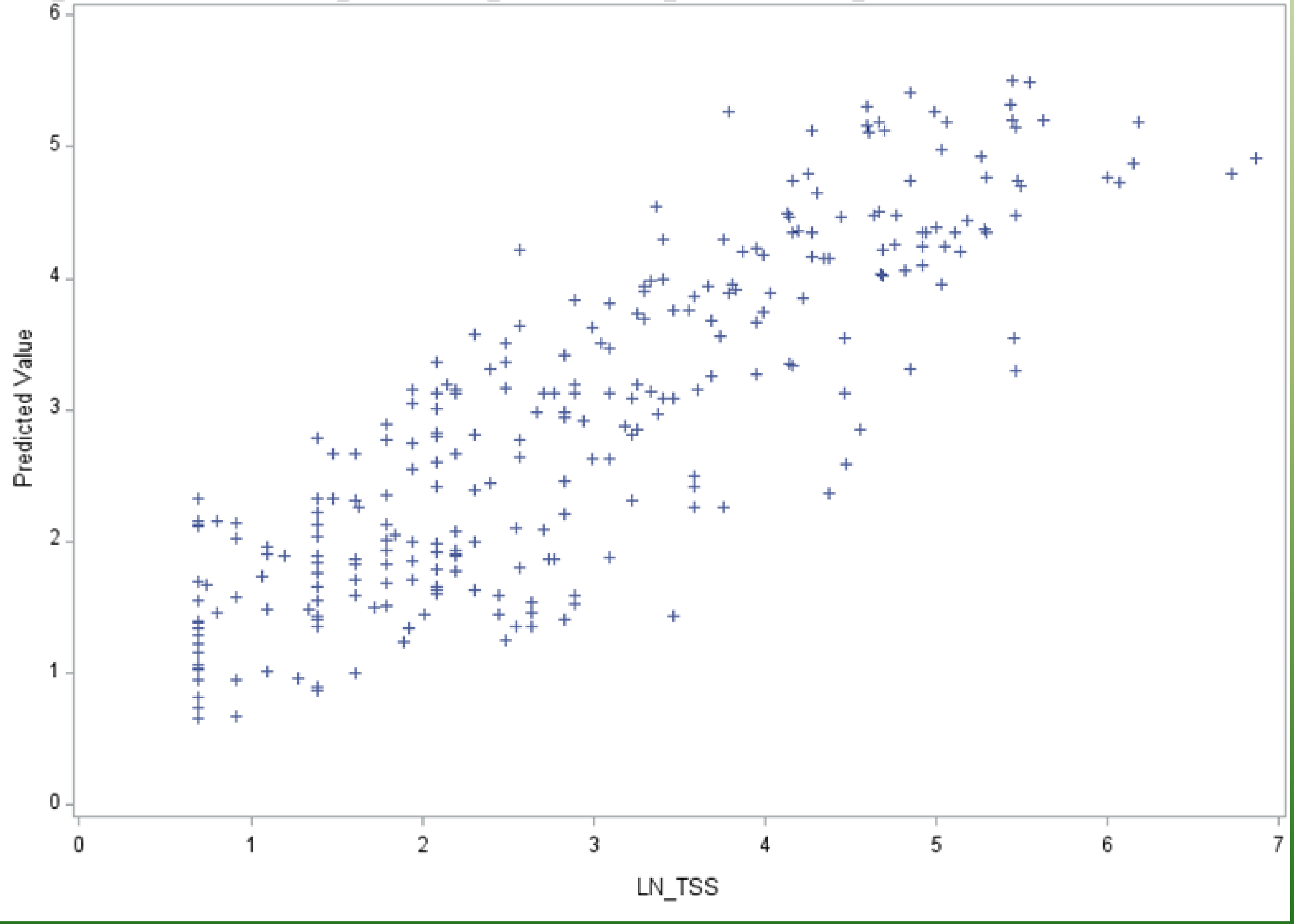
Multiple Regression Analysis: Model estimates, std errors, and P-values of coefficients in Duck Creek LN_TSS, LN_TP, and LN_DP concentration regression models: 2004 to 2013.

		Intercept (a0)	LN_Q (a1)	LN_Q^2 (a2)	SIN_DAY (a3)	COS_DAY (a4)	DEC_TIME (a5)	N
LN_TP	**Coefficient (a0 to a5)**	-1.82223	0.24218	0.03570	0.30594	0.06600	-0.04297	269
	t-value	-34.71	10.83	7.88	4.46	1.20	-3.14	
	std error	0.0525	0.0224	0.0045	0.0687	0.0552	0.0137	
	P value	<0.0001	<0.0001	<0.0001	<0.0001	0.2330	**0.0019**	
LN_TSS	**Coefficient (a0 to a5)**	2.55502	0.58634	0.06512	0.23070	0.47879	-0.07205	269
	t-value	36.88	19.87	10.89	2.55	6.57	-3.98	
	std error	0.0693	0.0295	0.0060	0.0906	0.0729	0.0181	
	P value	<0.0001	<0.0001	<0.0001	0.0115	<0.0001	**<0.0001**	
LN_DP	**Coefficient (a0 to a5)**	-2.21462	0.11174	0.00975	0.30716	0.12570	-0.04572	125
	t-value	-30.98	3.51	1.71	3.24	1.55	-2.76	
	std error	0.0715	0.0319	0.0057	0.0949	0.0809	0.0166	
	P value	<0.0001	0.0006	0.0900	0.0016	0.1227	**0.0067**	

Regression Analysis: Flow and Seasonally-adjusted Residuals of **LN TSS** ---- water years 2004-2013. Declining Trend ($p < 0.0001$, $n = 269$).

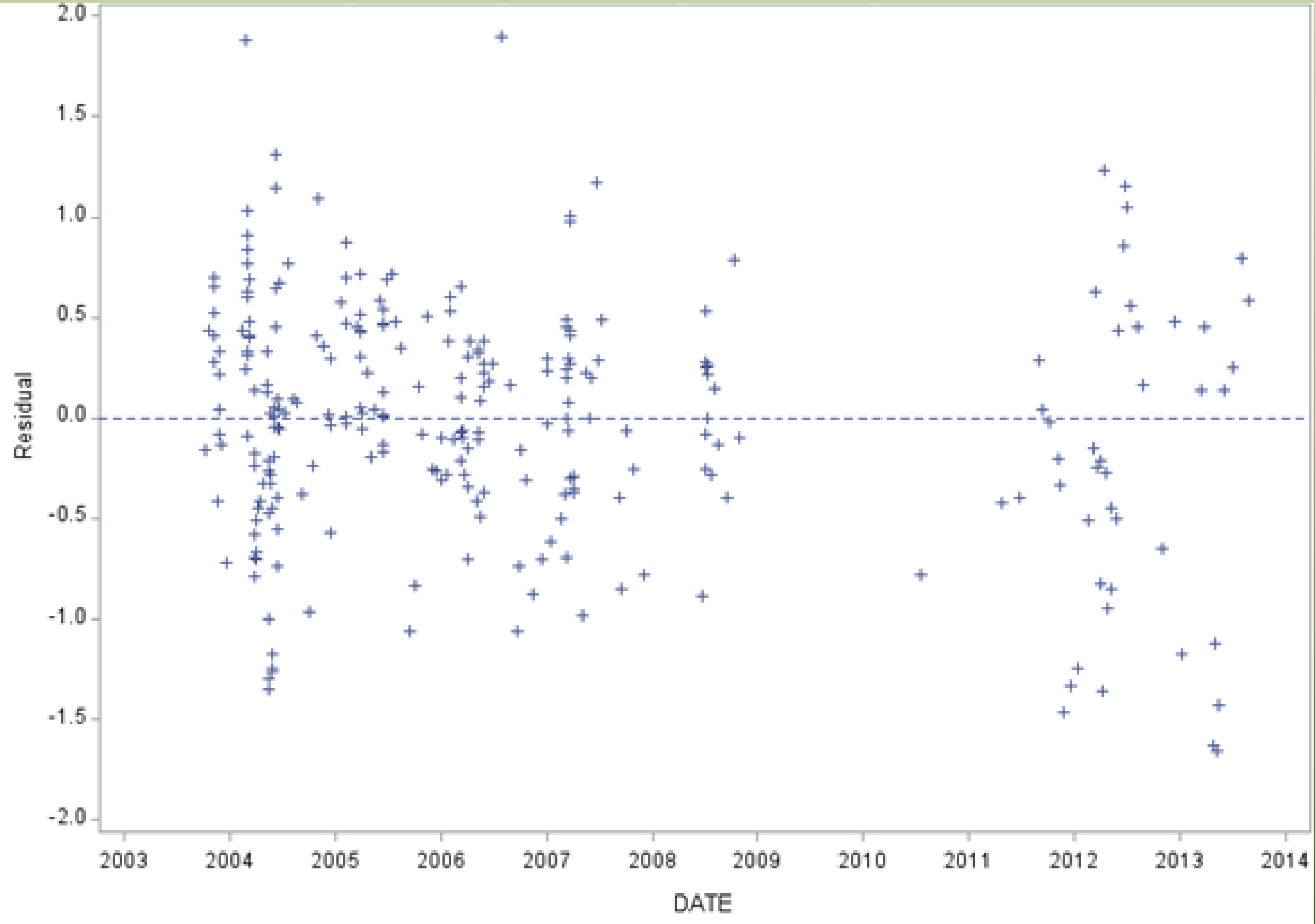


Observed and predicted **LN TSS** concentrations during 2004 to 2013 period with regression model (adjusted R^2 = 0.72).

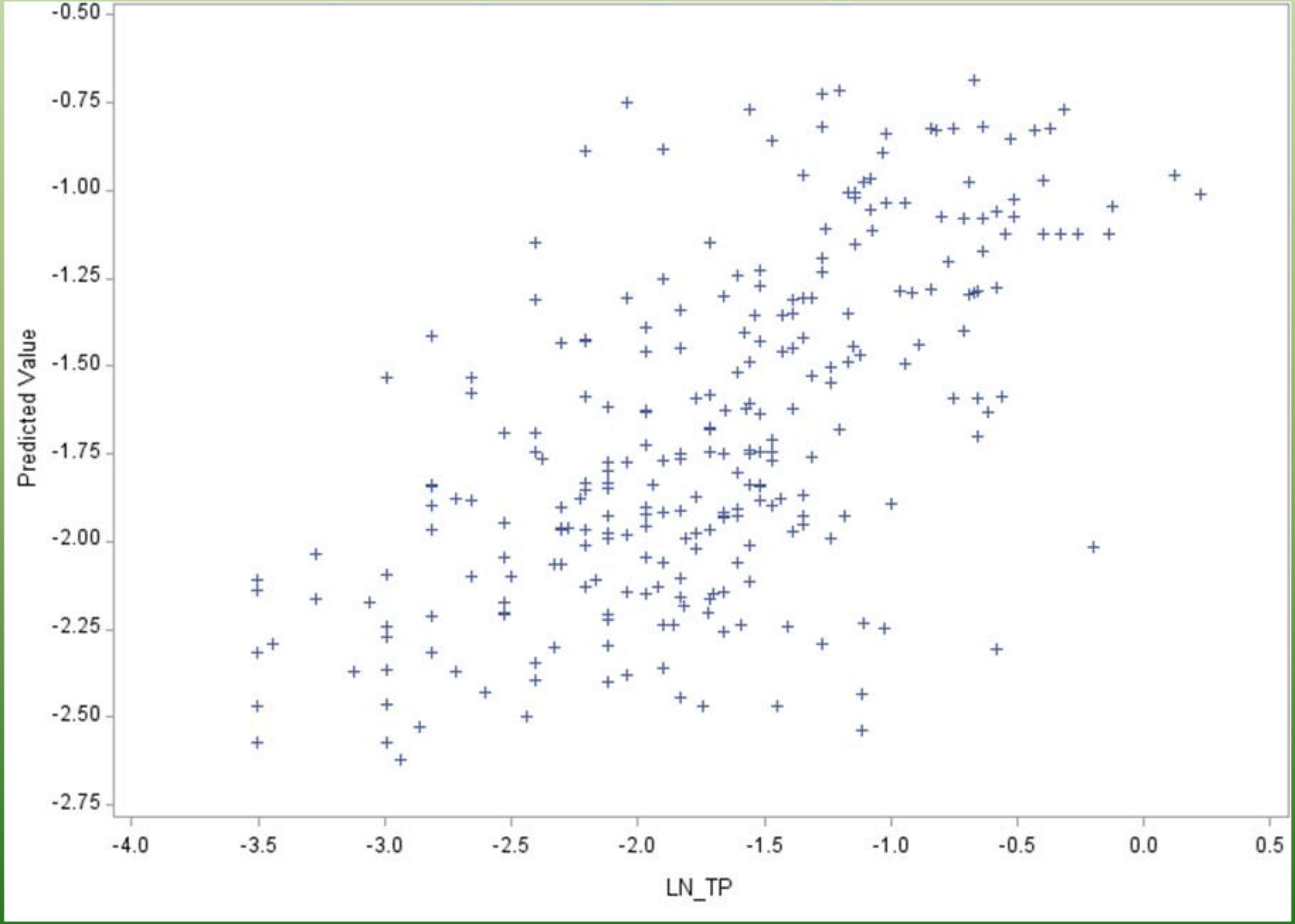


Regression Analysis: Flow and Seasonally-adjusted Residuals of **LN TP** ---- water years 2004-2013.

Declining Trend, not as obvious ($p < 0.0019$, $n = 269$).



Observed and predicted **LN TP** concentrations during 2004 to 2013 period with regression model (adjusted $R^2 = 0.39$).



Further Investigation

Did flow affect results? Not too much.

Same <u>Regression Models</u> under different flow censoring scenarios: 2004-2013 (*italics* when sig. $p < 0.05$)

Flow < (cfs)	N	Decimal time coef.	t Value	Pr > |t|
------------------------ LN-TSS -------------------------------				
75	115	-0.0373	-1.64	0.1035
250	179	-0.0479	-2.26	*0.0249*
500	213	-0.0532	-2.74	*0.0067*
750	233	-0.0642	-3.32	*0.0011*
1000	258	-0.0665	-3.56	*0.0004*
All	269	-0.0721	-3.98	*<0.0001*
------------------------ LN-TP ---------------------------------				
75	115	-0.0414	-2.17	*0.0323*
250	179	-0.0614	-3.87	*0.0002*
500	213	-0.0387	-2.64	*0.0090*
750	233	-0.0419	-2.95	*0.0036*
1000	258	-0.0421	-2.99	*0.0030*
All	269	-0.0430	-3.14	*0.0019*

LN TSS Regression models with different combinations of explanatory variables (2004-2013). Date/Time still sig. for all combinations ($p < 0.05$).

Model description	Variable	Coef. Est.	Std. Error	t Value	Pr > |t|	Adjusted-RSquared	F-value	P-value
						Overall model stats		
------------------------------------ LN Total Suspended Solids--								
complete regression model	LN_Q	0.5863	0.0295	19.87	<0.0001	0.7218	140.06	<0.0001
	LN_Q2	0.0651	0.0060	10.89	<0.0001			
	SIN_DAY	0.2307	0.0906	2.55	0.012			
	COS_DAY	0.4788	0.0729	6.57	<0.0001			
	DATE	-0.0721	0.0181	-3.98	<0.0001			
without flow	SIN_DAY	-0.6508	0.1120	-5.81	<0.0001	0.3083	40.81	<0.0001
	COS_DAY	0.6727	0.1132	5.94	<0.0001			
	DATE	-0.1895	0.0269	-7.04	<0.0001			
without seasonal factors	LN_Q	0.5800	0.0279	20.78	<0.0001	0.6725	184.41	<0.0001
	LN_Q2	0.0723	0.0064	11.31	<0.0001			
	DATE	-0.0569	0.0193	-2.94	0.004			
without flow-sq.	LN_Q	0.3960	0.0286	13.85	<0.0001	0.5979	100.62	<0.0001
	SIN_DAY	0.2825	0.1088	2.60	0.01			
	COS_DAY	0.6098	0.0864	7.06	<0.0001			
	DATE	-0.1156	0.0212	-5.45	<0.0001			
date/time only	DATE	-0.1867	0.0300	-6.23	<0.0001	0.1236	38.79	<0.0001
without date	LN_Q	0.6250	0.0287	21.82	<0.0001	0.7061	161.99	<0.0001
	LN_Q2	0.0704	0.0060	11.74	<0.0001			
	SIN_DAY	0.2551	0.0929	2.74	0.007			
	COS_DAY	0.4342	0.0740	5.87	<0.0001			

LN TP Regression models with different combinations of explanatory variables (2004-2013). Date/Time still sig. for all combinations ($p < 0.05$).

Model description	Variable	Coef. Est.	Std. Error	t Value	Pr > |t|	Overall model stats: Adjusted-RSquared	F-value	P-value
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Non-parametric Wilcoxon Rank Sum test Period 3 (2004-07) vs Period 4 (2010-13)
--- 2008 and 2009 assumed transitional ---

Applied under different flow censoring scenarios (*italics* when sig. p < 0.05). TSS & TP lower in Period 4 (except < 75 cfs scenario)

	All Flow	Flow < 1000	Flow < 750	Flow < 500	Flow < 250	Flow < 75
TSS	*P3>P4 p<0.0001*	*P3>P4 p<0.0001*	*P3>P4 p<0.0001*	*P3>P4 p<0.0009*	*P3>P4 p<0.0043*	P3=P4 p=0.3042
TP	*P3>P4 p<0.0012*	*P3>P4 p<0.0010*	*P3>P4 p<0.0058*	*P3>P4 p<0.0217*	*P3>P4 p<0.0114*	P3=P4 p=0.3724
DP	*P3>P4 p<0.0227*	*P3>P4 p<0.0335*	*P3>P4 p<0.0405*	P3<P4 p=0.0635	*P3>P4 p<0.0089*	P3=P4 p=0.1991
Flow	*P3>P4 p=0.0040*	*P3>P4 p=0.0019*	*P3>P4 p=0.0157*	P3=P4 p=0.0693	P3=P4 p=0.0993	P3=P4 p=0.2299
N for TP	P3 = 208 P4 = 44	199 42	175 41	156 40	129 35	76 29

Weekly sub-sampled data

Analysis A: Same Regression Models; ALL sig. $p < 0.05$

Analysis B: Wilcoxon Rank-Sum NP test --- Period 3 & 4 No difference

	Weekly sub-sampled data			
	Analysis B			**Analysis A**
	Median & number of samples		**Wilcoxon Rank-Sum**	**Linear Regression Decimal time**
Variable	**Period 3**	**Period 4**	**Slope and significance**	**Slope and significance**
TSS (mg/L)	7.00 mg/L n = 95	6.90 mg/L n = 40	P3 = P4 p = 0.4435	*-0.04089* *p = 0.0359*
TP (mg/L)	0.14 mg/L n = 95	0.15 mg/L n = 40	P3 = P4 p = 0.1838	*-0.04342* *p = 0.0096*
DP (mg/L)	0.11 mg/L n = 44	0.08 n = 33	P3 = P4 p = 0.1626	*-0.04415* *p = 0.0299*

2nd Round: Duck WQ Trend Summary

- All but one Statistical Test indicated significant DECREASE ⬇ in LN of TP, DP and TSS concentrations
- Weight of evidence indicates TP, DP and TSS concentrations declined during the 2004 to 2013 period

Are total phosphorus concentrations at or below the TMDL target of a summer median concentration of **0.075 mg/L**?

- SAS statistical software applied to TP concentration data (sampled after June 2010
- Only samples collected from May through October
- Removed outliers (> 1.3 mg/L)
- RESULTS: median concentration of **0.179 mg/L** TP (n = 23)
- So, TP concentrations in Duck Creek at CTH well above the TMDL target of 0.075 mg/L.
- However, during the entire period of record, TP concentrations near or below the TMDL target of 0.075 mg/L were not rare.
- Including “outliers” (> 1.3 mg/L) didn’t change results much: 0.193 mg/L TP (n = 26) and 0.122 mg/L DP (n = 21)

Project Summary

Project Summary

- Land Management changes occurred, although not all well documented
  - Barnyard reductions substantial during early period
- WQ 1st Round (1989 to 2008): Weight of Evidence Approach
  - 4 statistical tests indicate significant Decrease of TP and DP concentrations in Duck Creek at CTH FF ($p < 0.05$)
  - Most reductions seen between 1989-1995
  - Only one statistical test did not show a decrease
  - Role of improved barnyards, less winter spreading of manure or greater manure incorporation?
- WQ 2nd Round (2004 to 2013): Weight of Evidence Approach
  - Multiple statistical tests indicate significant Decrease of TP, DP and TSS concentrations in Duck Creek at CTH FF ($p < 0.05$)
  - Only one statistical test did not show a decrease
  - Implementation of Ag BMP's by Oneida Nation, LCD's, NRCS, etc.?

Questions