Comparison of Phosphorus Forms at Different Spatial Scales and Assessment of an Area-Weighted P-Index to Multi-Field Watersheds

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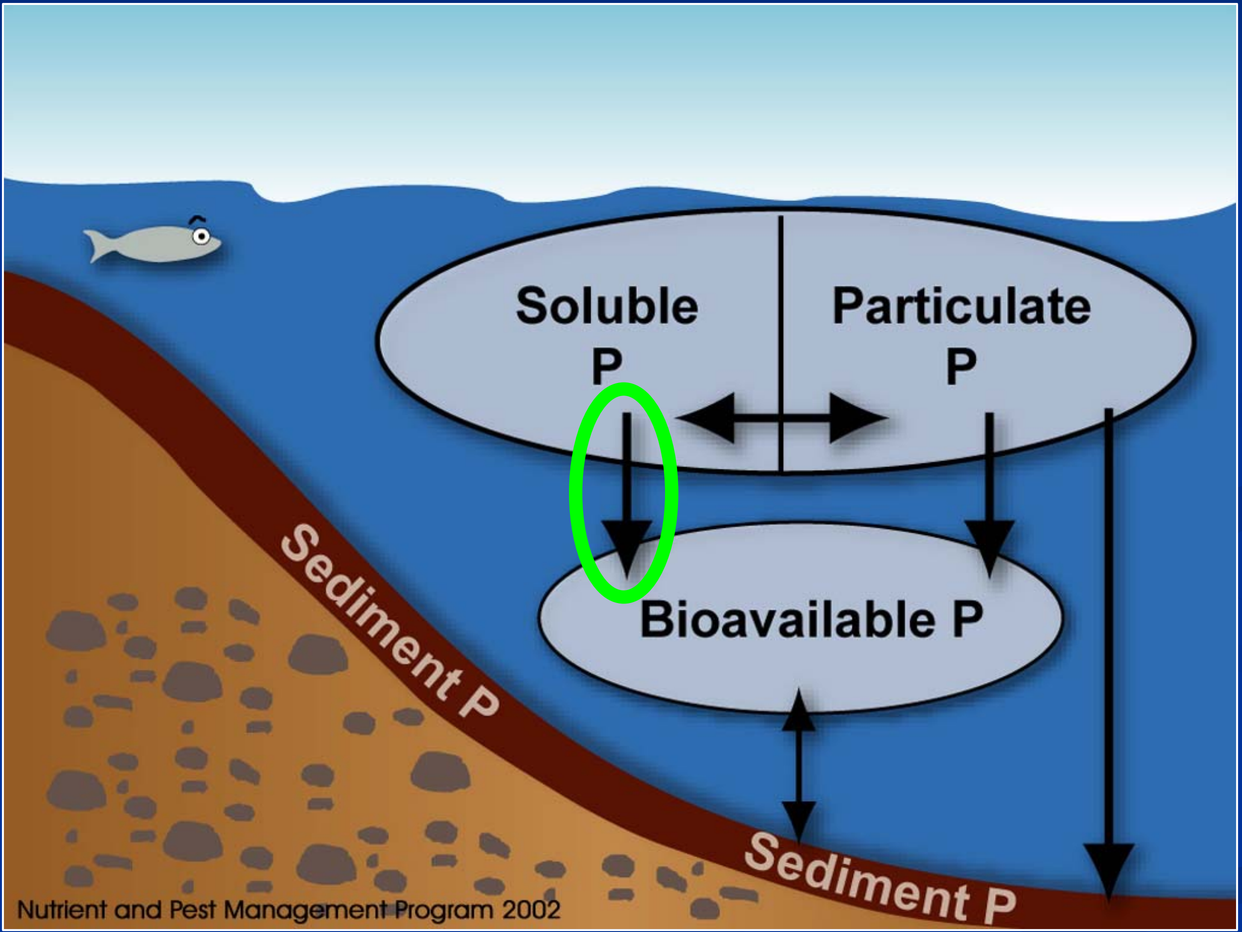
Primary Project Goal

- To better understand and predict the forms of phosphorus in agricultural watersheds to enhance management decisions and improve the usability and biological integrity of our water resources.

Presentation Outline

- Overview of P forms and the Lower Fox River Sub-Basin
- Project Objectives
- Tributary Water-Quality
- P Forms at Different Spatial Scales
- Assessment of P-Index
- Conclusions

Background - Phosphorus Forms

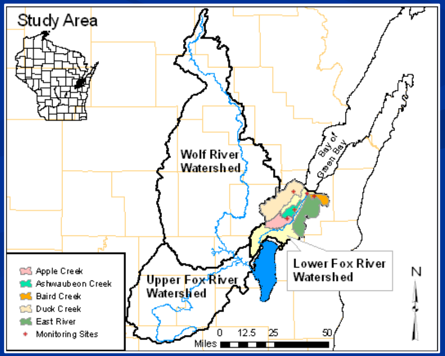


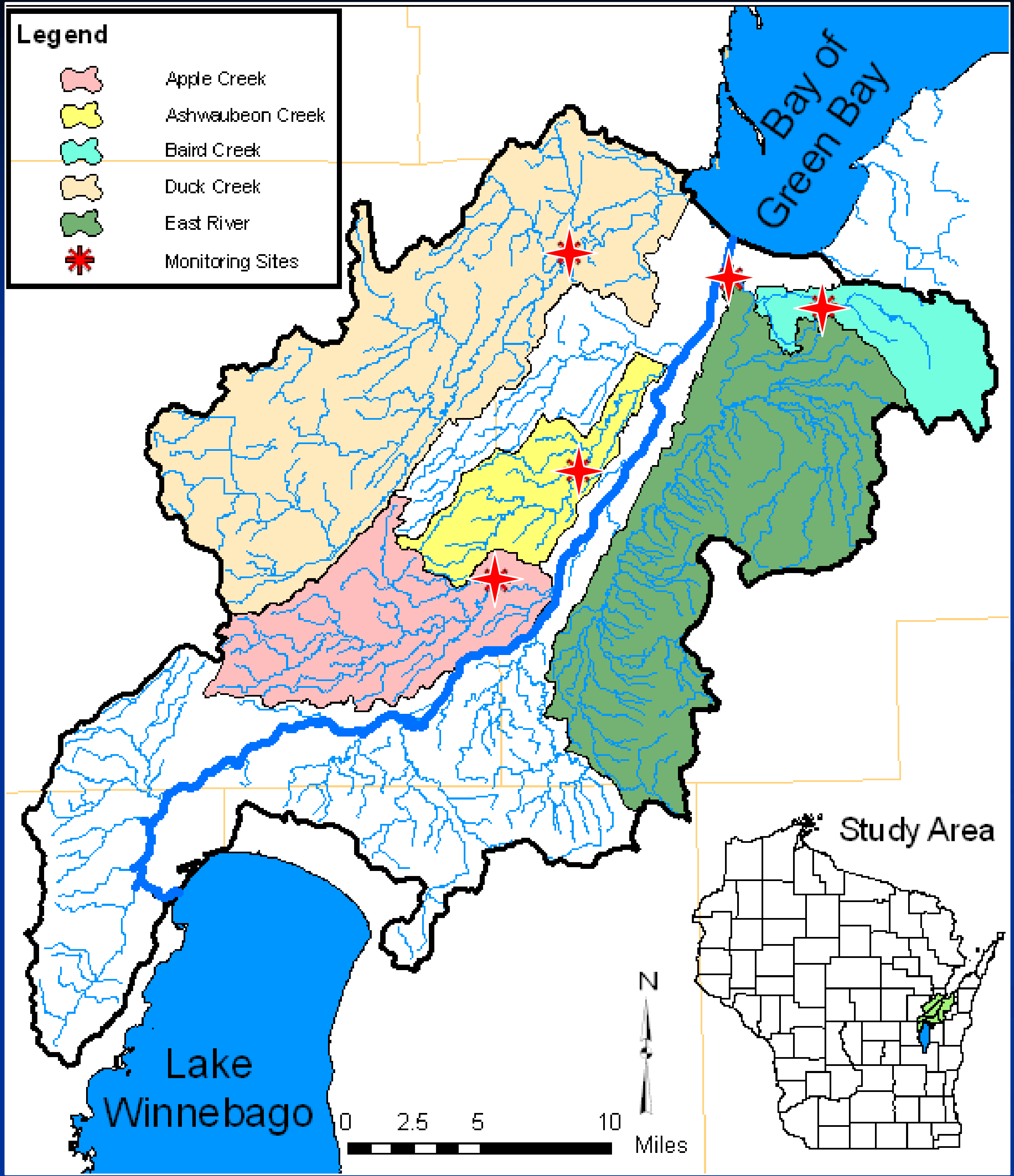
Controlling Phosphorus: Buffer/Grassed Waterway

Up stream of Site 1b on November 30, 2007

Overview: Lower Fox River Sub-Basin

- 1,580 km^2 LFRS-B (16,400 km^2 Fox-Wolf Basin)
- Fox-Wolf basin represents 15% of the Lake Michigan drainage basin
- Bay of Green Bay impacted by excess P and TSS
- Annual P loads from the Lower Fox River:
  - Approx. **70%** of total loads to Green Bay and **25%** of total to Lake Michigan (Robertson, 2004; Klump et al, 1997; Pauer et al., 2005)
  - About half originates in LFRS-B

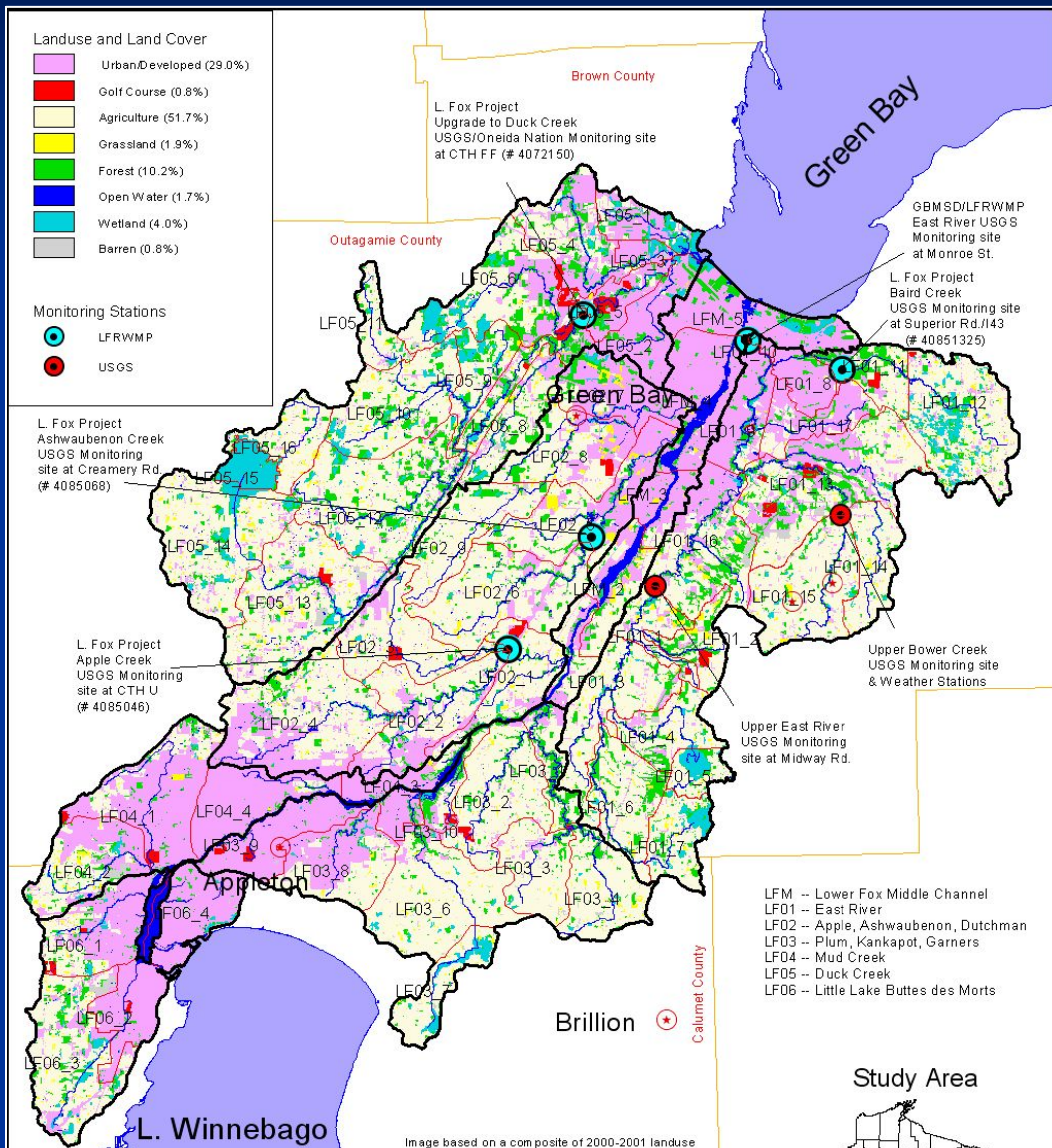




Lower Fox River Sub-Basin and Monitoring Sites

- Apple Creek
- Ashwaubenon Creek
- Baird Creek
- Duck Creek
- East River

2000 Landuse in LFR Watershed



- 52% Agriculture (Tan)
- Large Urban centers near outlet of Lake Winnebago and outlet of LFR - 29% (Pink).
- 10% Forest (Green)

Agriculture in the LFRS-B

- Primarily Dairy Operations
- Contribution to Lower Fox River:
  - 49% of annual P loads
  - 61% of annual suspended sediment loads
  - Baumgart, 2005 (SWAT - 2000 baseline conditions).
- Significant reduction from agricultural operations necessary to meet water quality objectives

Water Quality in LFR tributaries

- P and SS are primary stressors of the bay of Green Bay
- Nearly all of the LFRS-B tributaries are ranked as priority watersheds or 303d listed
- Past studies: Dissolved P fraction of 40% to 70% (WDNR, FWB2K, USGS, 1988-2002)

Objectives

- Compare P forms and sediment among four Lower Fox River tributaries
  - What proportion of TP is dissolved?
  - Are there differences among tributaries?
  - Can watershed characteristics explain variations among tributaries?
- Evaluate Phosphorus forms at different spatial scale
- Comparison of Wisconsin P-Index to water-quality measurements

Tributary Analysis

Lower Fox River Sub-Basin

Methodology

- Event and low-flow (bi-weekly) samples
  - WY 2004-2006
- Four refrigerated automated monitoring stations (USGS & LFRWMP operated)
- Precipitation measured at 22 locations

Automated Monitoring Station

- ISCO 3700R refrigerated automated sampler
- Gas-bubble water level measuring system
- Tipping bucket rain gauge
- Data logger and modem



Sample Collection

- Event
  - Automated samples triggered by gauge height to represent storm hydrograph
  - Samples colleted in one liter ISCO bottles and spilt for TSS, TP, and TDP (filtered)
- Low-Flow
  - Equal Width Increment (EWI) Method

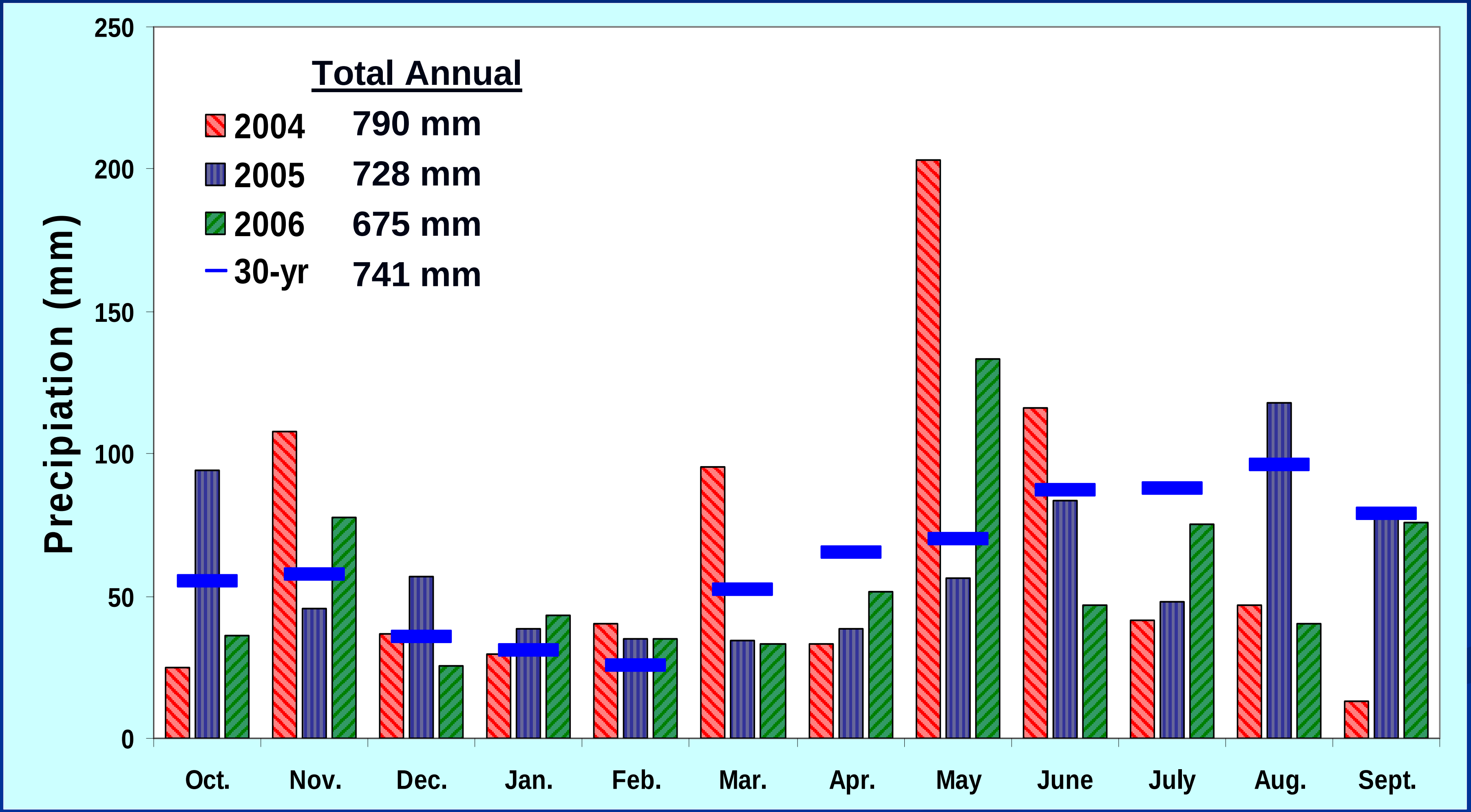
Data Analysis

- Statistics (SAS 9.1, SPSS 15.0, and Microsoft Excel)
  - Natural log transformation for non-normal data
  - TUKEY Multiple Comparison Procedure
    - Concentration comparisons among sites
  - Simple linear and multiple regressions

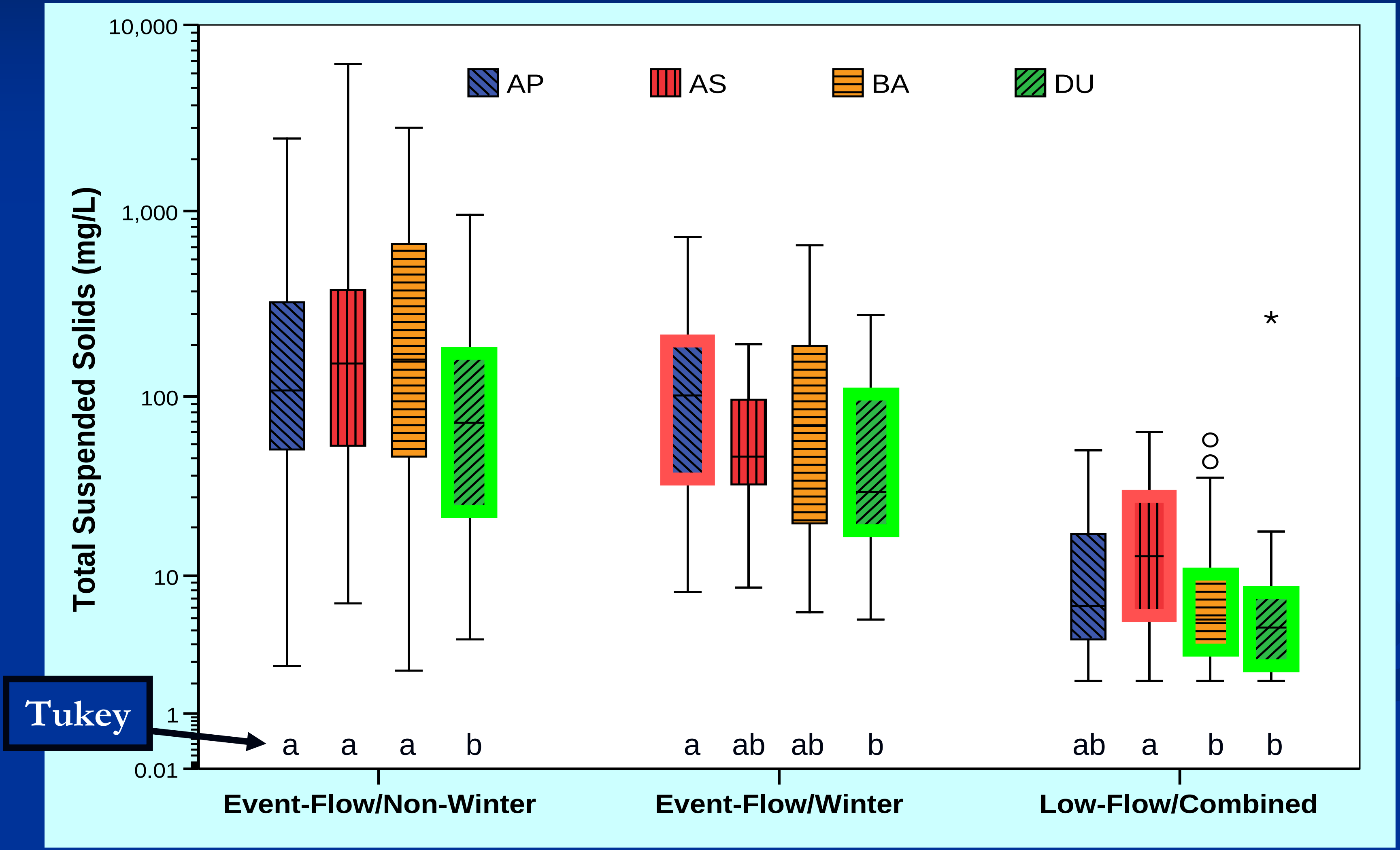
- Sample Classification
  - Event and low-flow (determined by examination of hydrograph)
  - Winter (frozen ground) and Non-winter
    - December/January through March

Results: Tributary Concentration Comparisons (TSS, TP, and TDP)

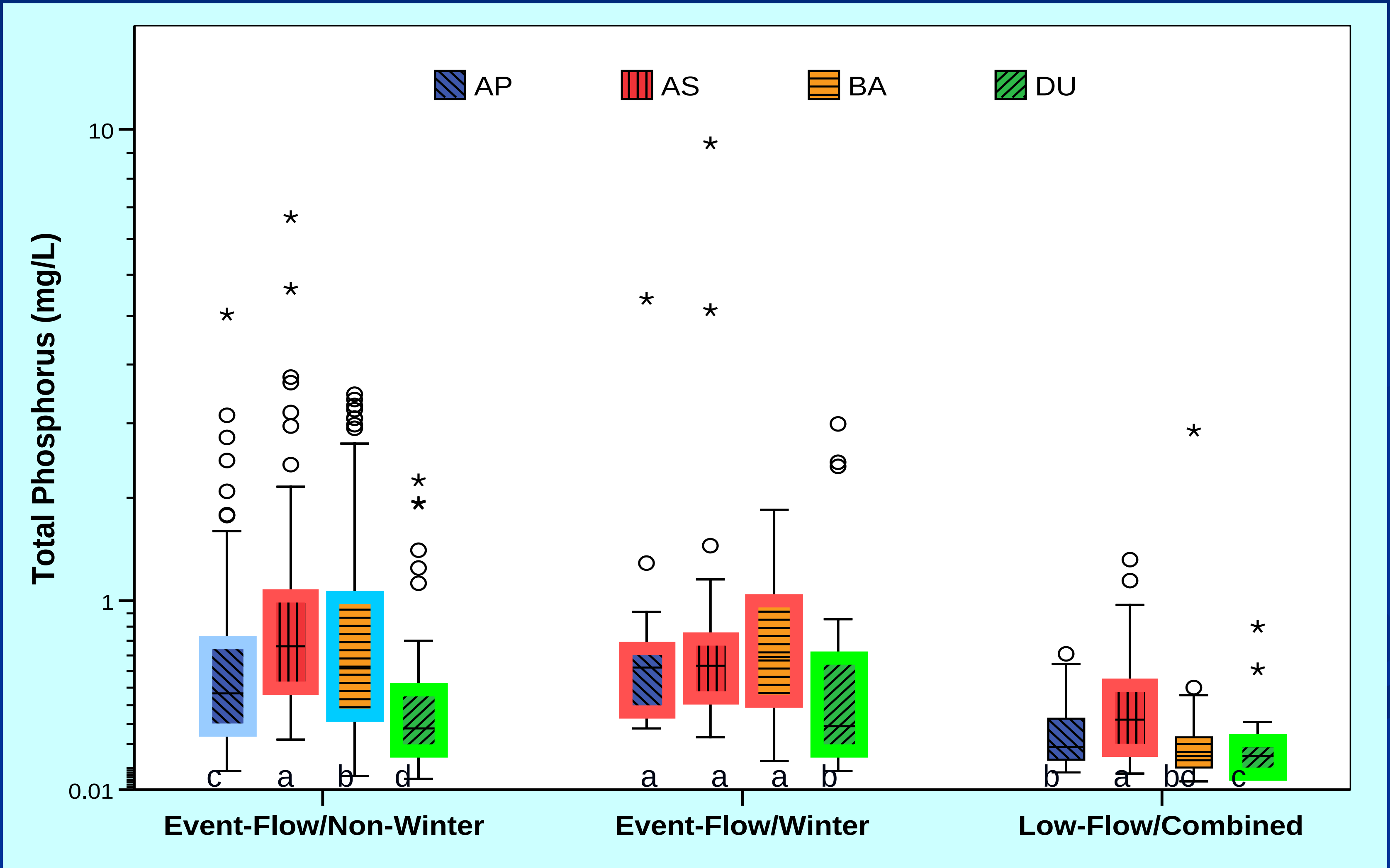
LFRS-B Precipitation (WY 2004-06)



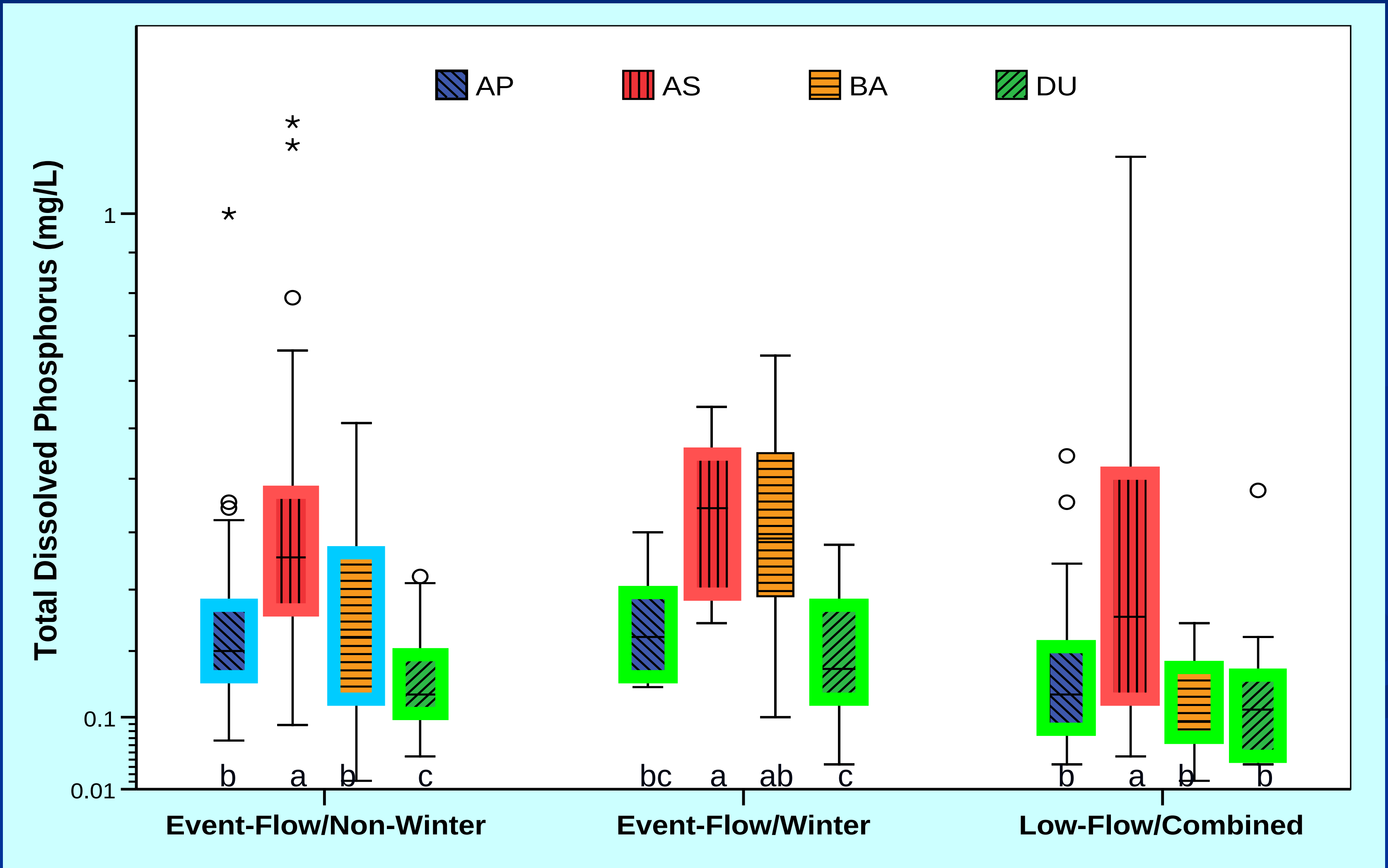
Total Suspended Solids (2004-2006)



Total Phosphorus (2004-2006)



Total Dissolved Phosphorus (2004-2006)



TDP Concentration Fraction (04-06)

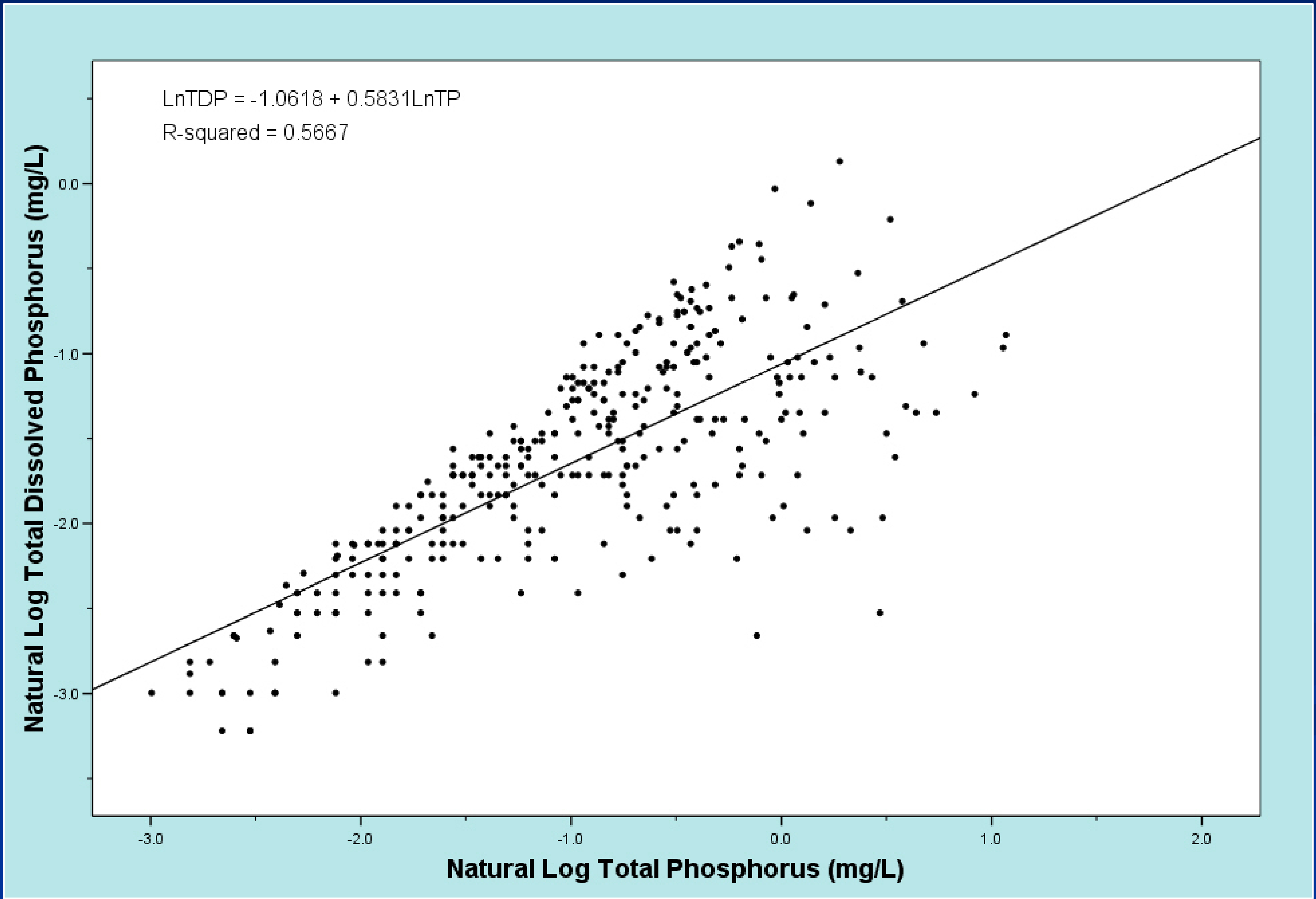
Condition	Total Dissolved Phosphorus Concentration Fraction (%)*			
	AP	AS	BA	DU
Event-Flow/ Non-Winter	48	47	36	51
Event-Flow/ Winter	57	66	49	59
Low-Flow/ Non-Winter	71	80	66	78
Low-Flow/ Winter	82	82	82	91

* No significant differences at the 0.05 probability level among sites

Simple Linear Regression

- LnTP significantly correlated with LnTDP at all sites ($r^2 = 0.49$ to 0.60)
  - Coefficients not significantly different
- LnTSS significantly correlated with LnTDP at all sites except Ashwaubenon Creek
  - However, small R-squares ($r^2 = 0.07$ to 0.20)

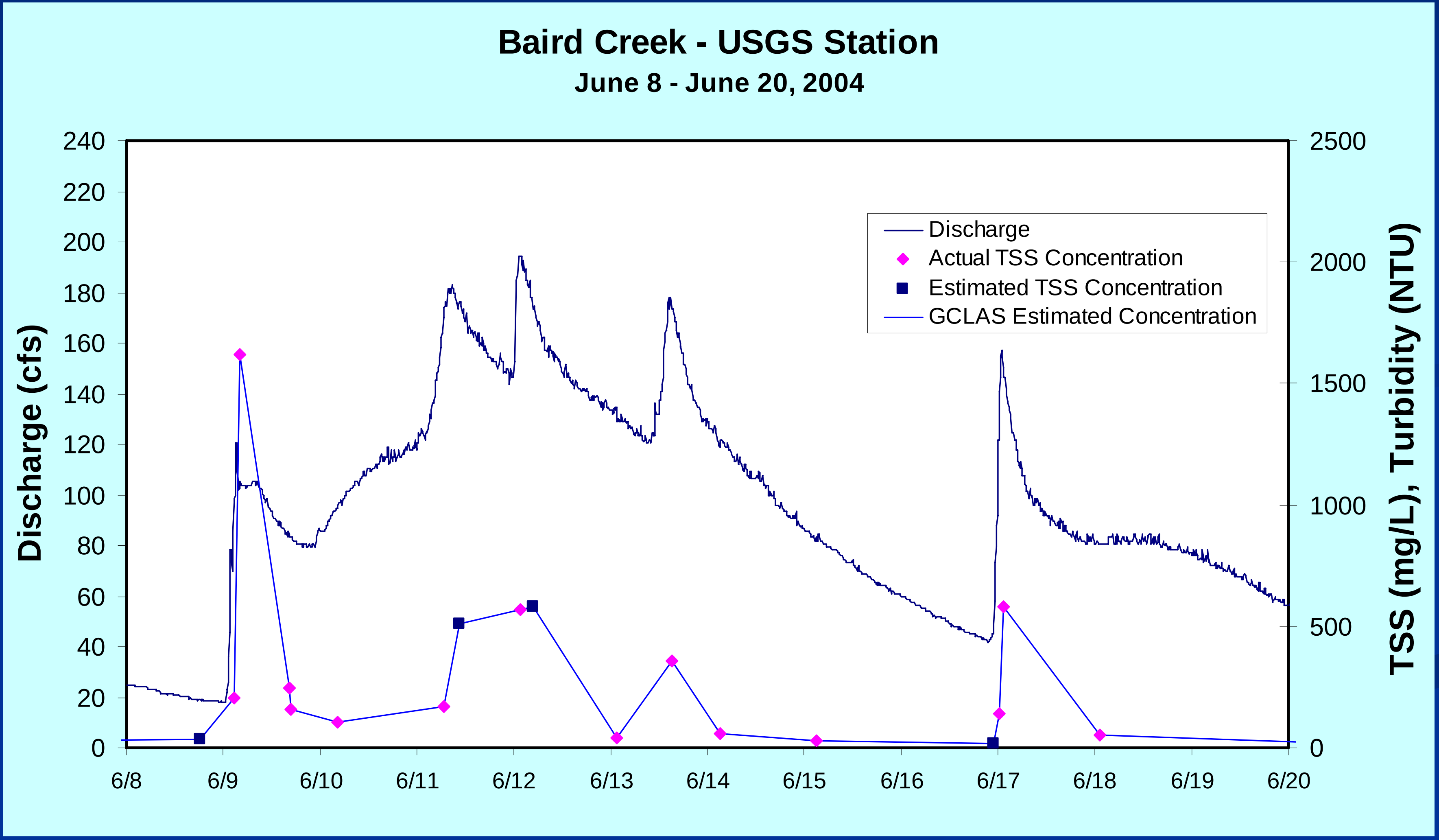
TDP significantly correlated w/ TP



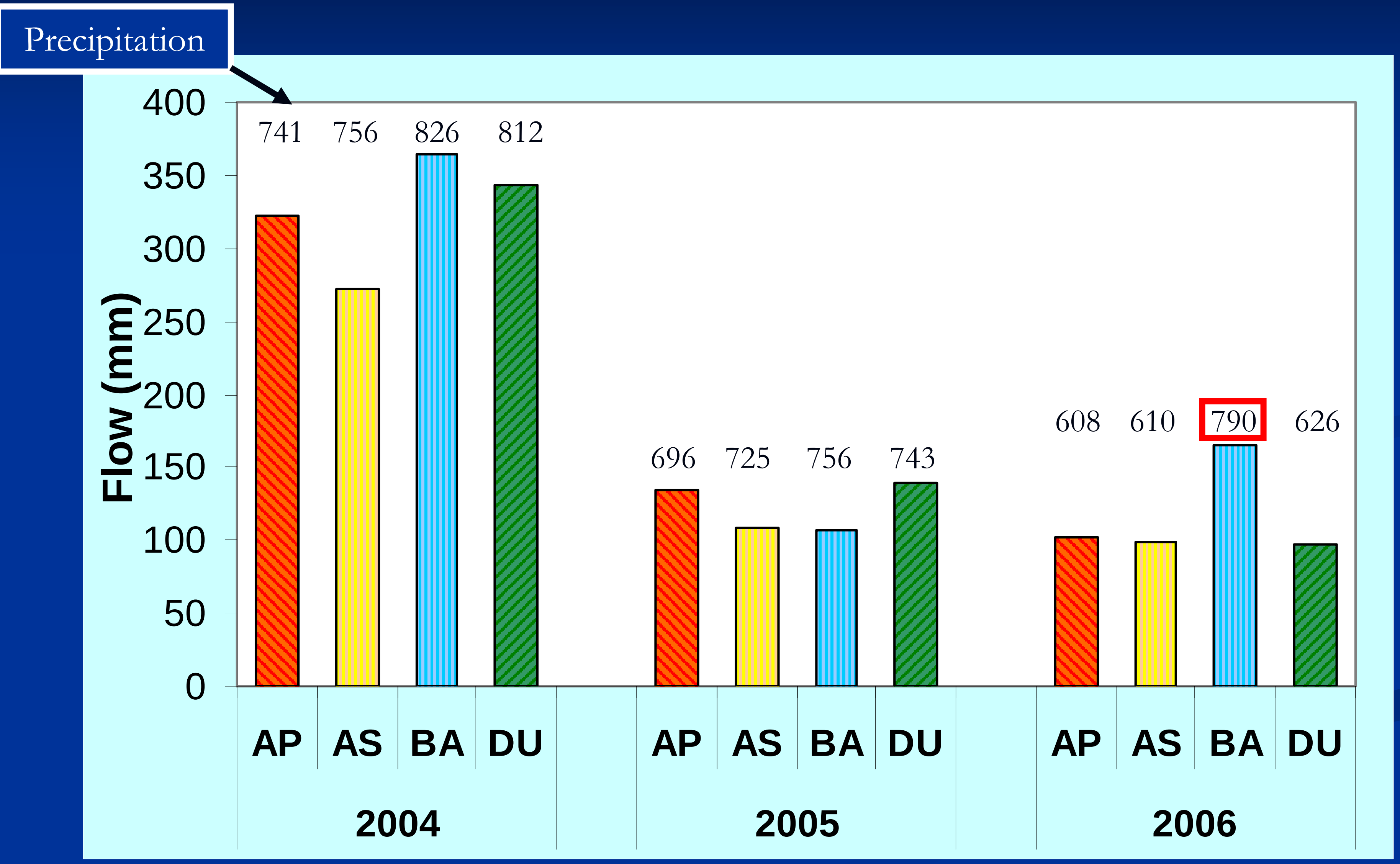
Load Calculations

- USGS determined TSS and TP loads using Graphical Constituent Loading Analysis System (GCLAS)
- TDP loads determined using regression analysis

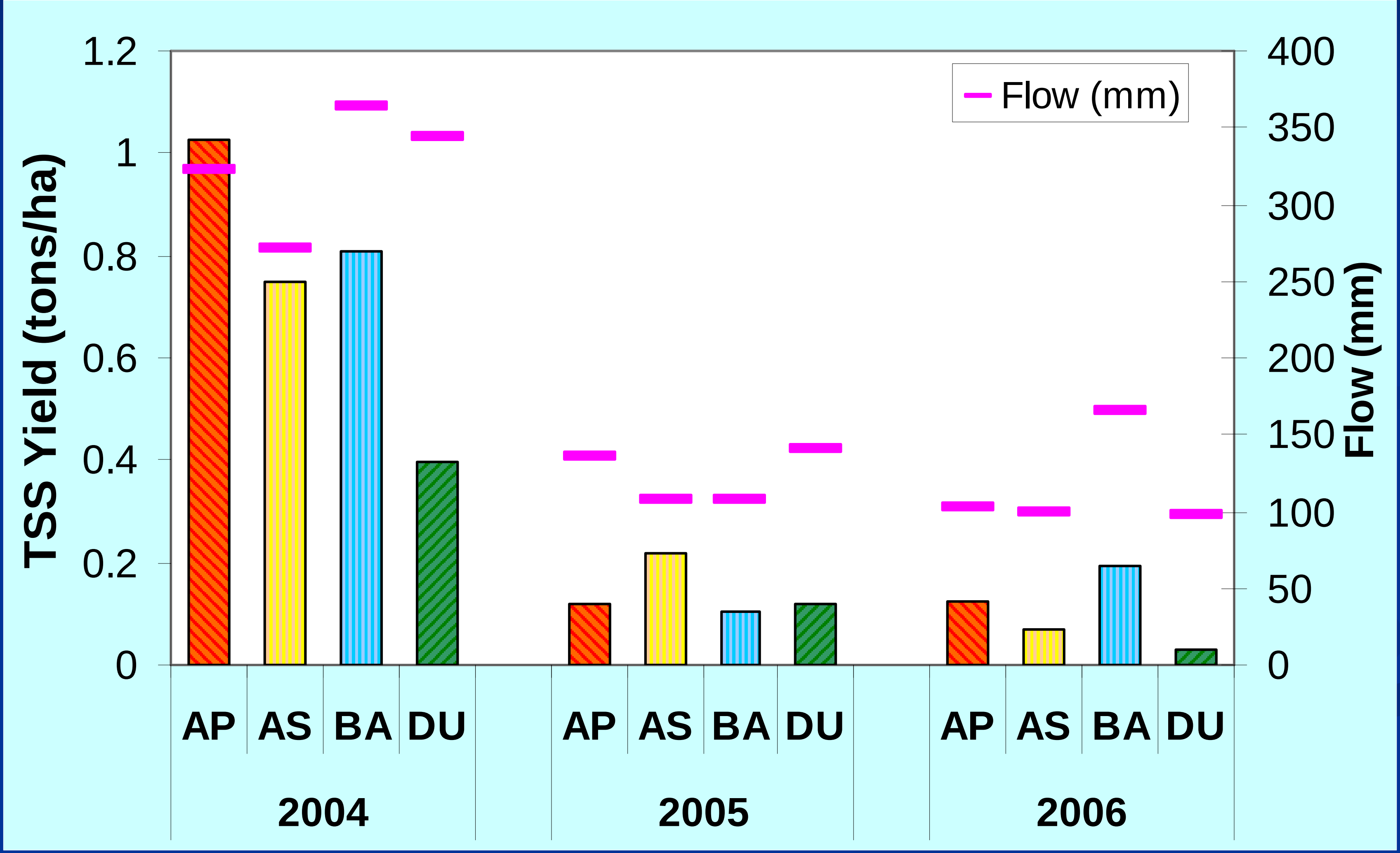
Load Calculation (GCLAS)



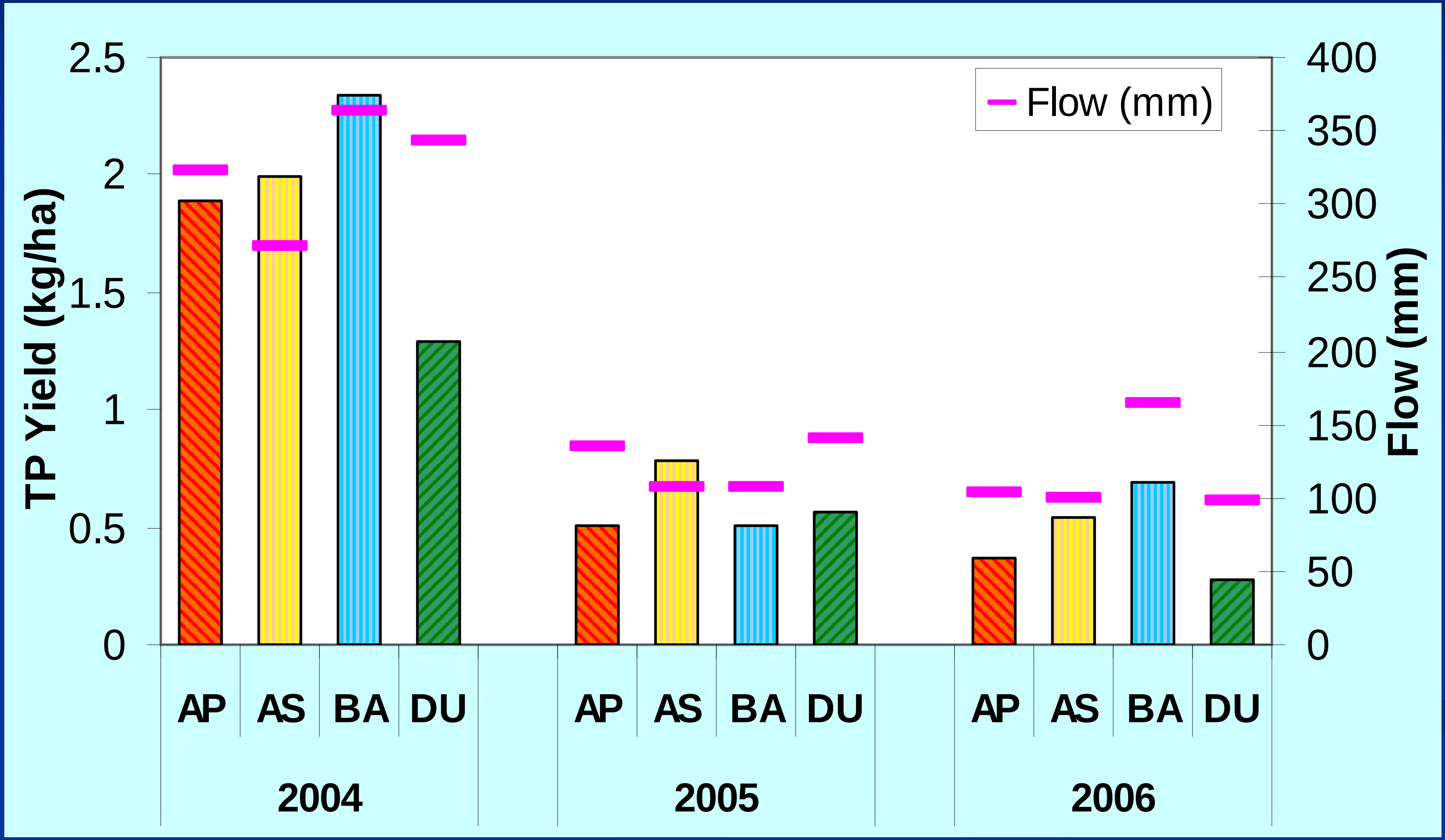
Tributary Flows – mm (2004-2006)



TSS Yield – tons/ha (2004-2006)



TP Yield – kg/ha (2004-2006)



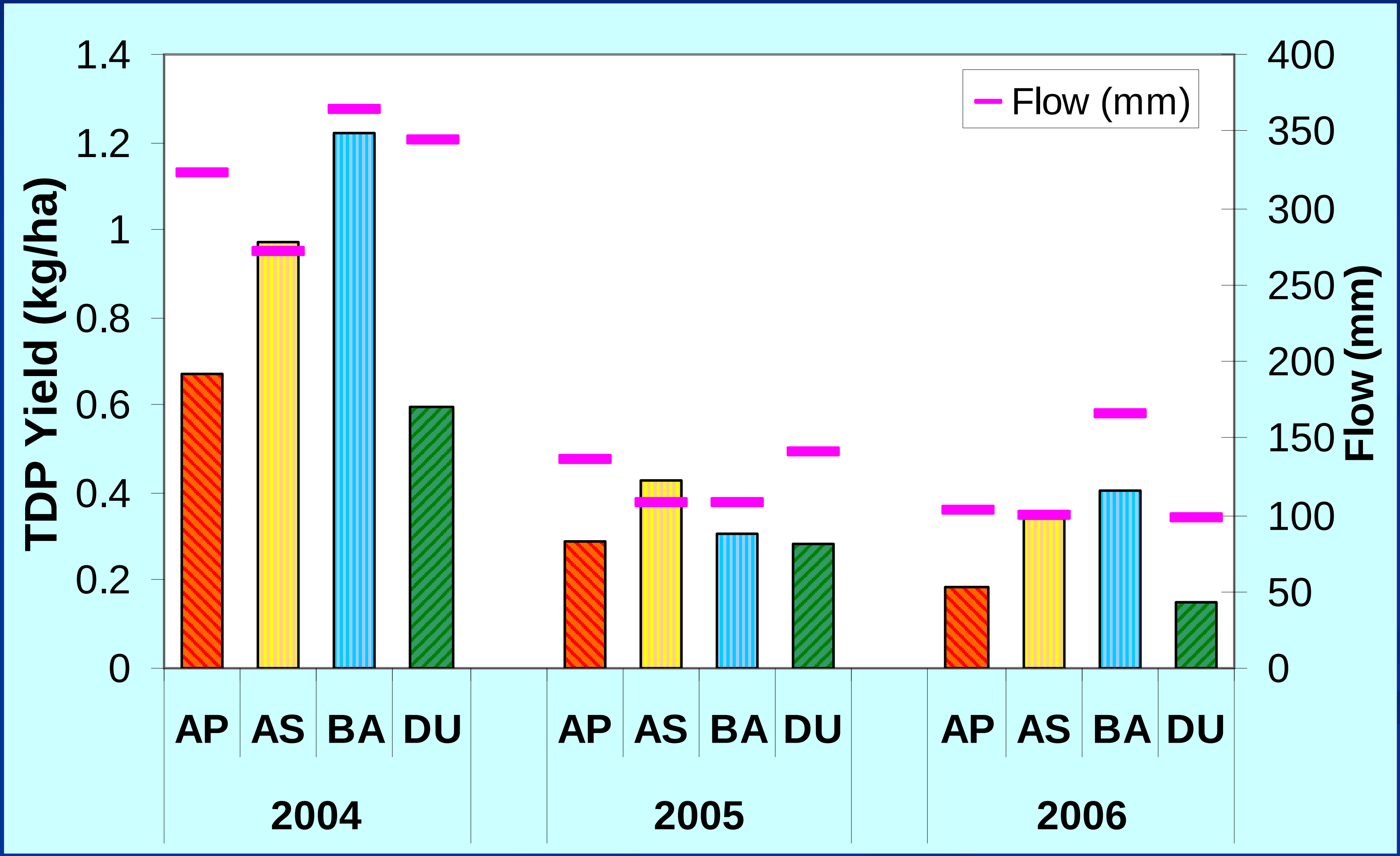
Multiple Regression

- Used TSS, TP, and discharge to determine unit value TDP concentrations
- Separate equations for non-winter and winter climate conditions
- Example:
  - Duck Creek:

Non-winter → $\ln TDP = -0.592 + 0.854(\ln TP) – 0.002(TSS) – 0.0003(Q)$ ($r^2 = 0.75$)

Winter → $\ln TDP = -0.354 + 0.914(\ln TP) – 0.004(TSS)$ ($r^2 = 0.93$)

TDP Yield – kg/ha (2004-2006)



TDP Load Fraction

Water Year	Total Dissolved Phosphorus Load Fraction (%)			
	AP	AS	BA	DU
2004	36	49	52	50
2005	57	55	61	50
2006	49	63	59	56

Tributary Summary

- In General,
  - Ashwaubenon Creek had largest concentrations of TSS, TP, and TDP
  - Duck Creek had lowest concentrations
- TDP factions consistent with earlier studies
  - TDP loads ranged from 36% to 63% of TP
- TDP concentrations correlated well with TP concentrations
- Small differences in environmental characteristics among sites

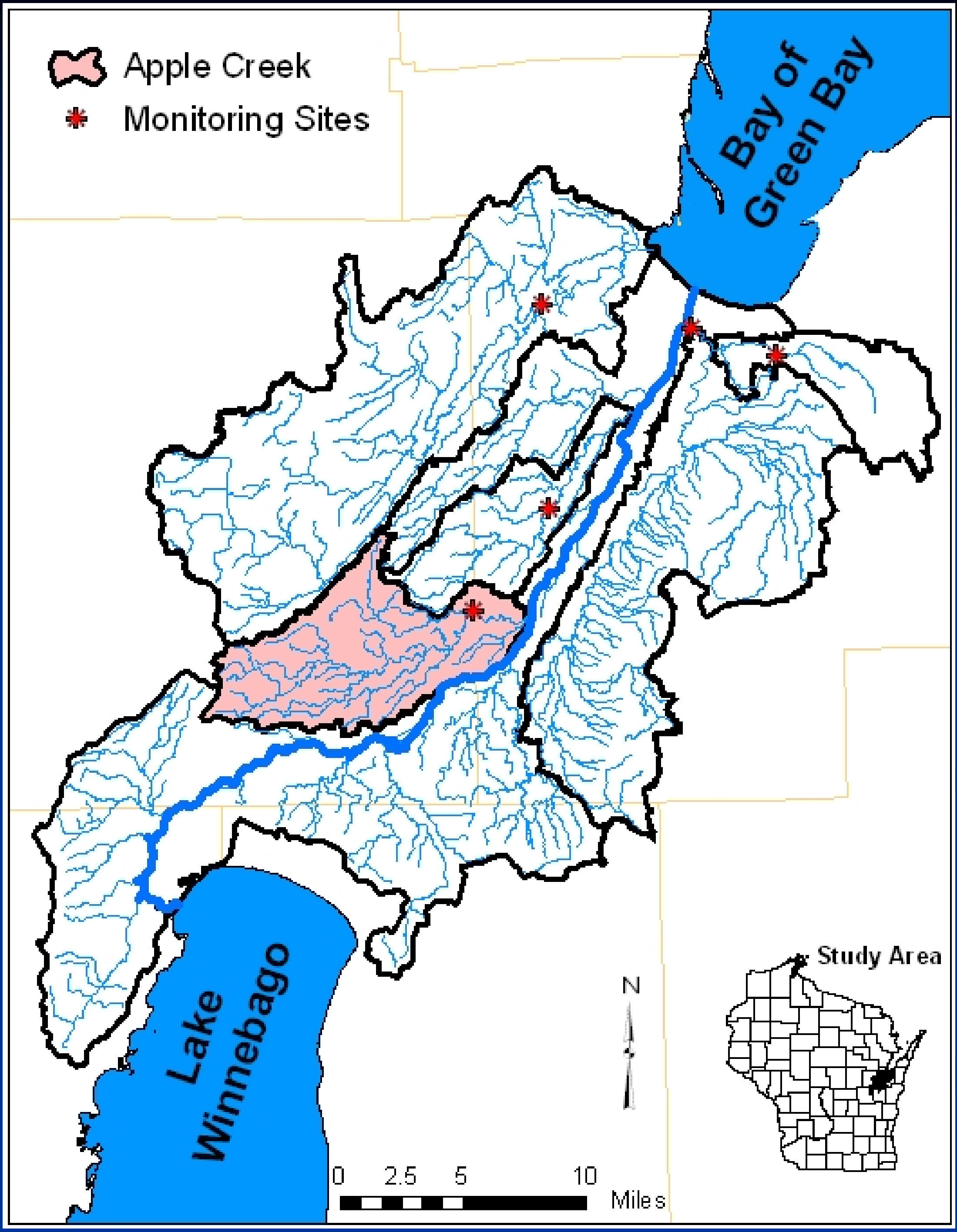
P Forms at Different Spatial Scales

Objectives

- Compare P forms and sediment among Lower Fox River tributaries
- Evaluate Phosphorus forms at different spatial scale
  - How do P forms change along a flow path?
  - Will contributing area characteristics explain variation among sites?
- Comparison of Wisconsin P-Index to water-quality measurements

Overview: Apple Creek Watershed

- Predominantly agriculture (non-tile-drained in project area)
- 303d listed by the WDNR
- Large contributor of TSS and P to Lower Fox River

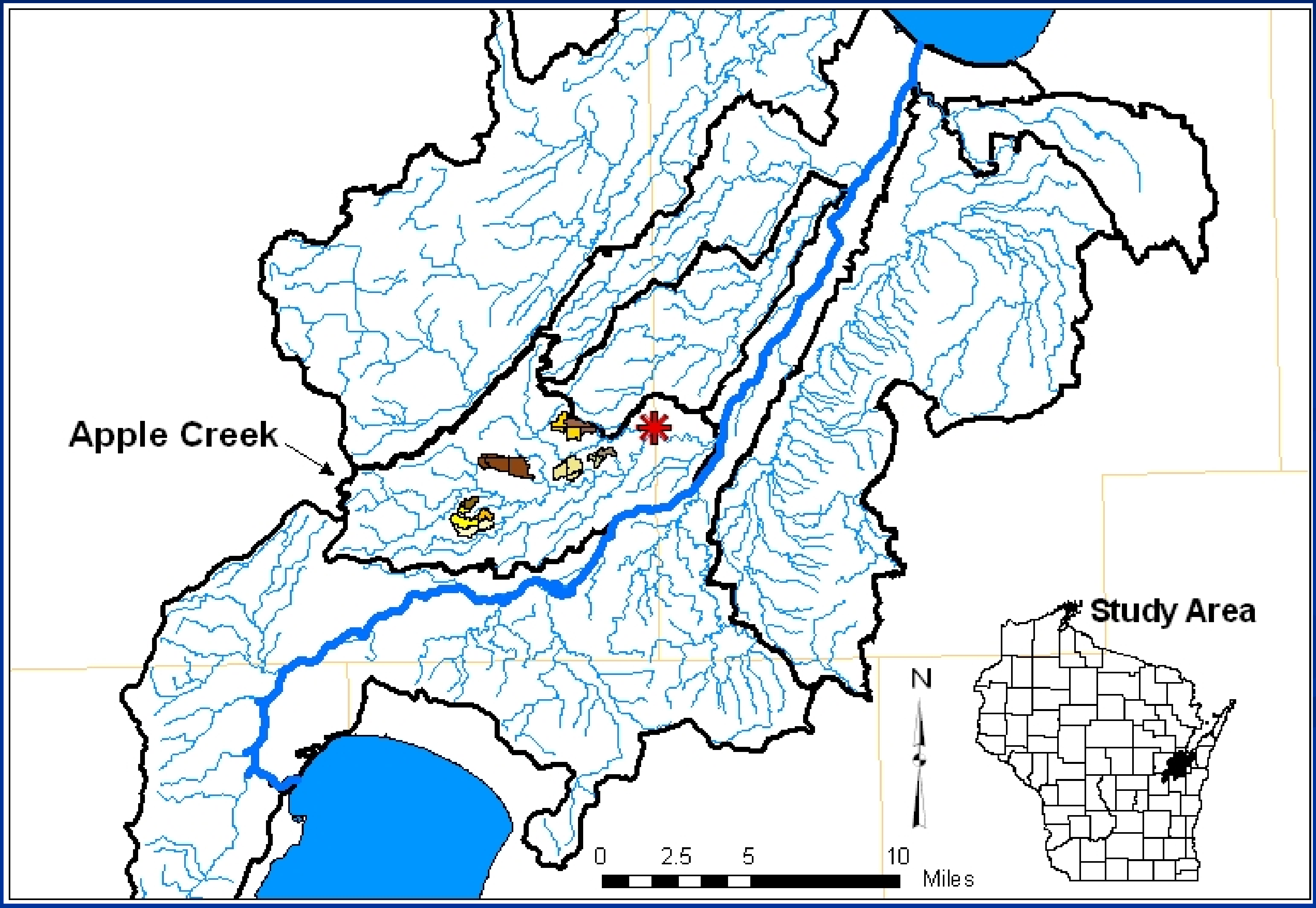


Apple Creek Watershed

- 117 km^2
- In 2000,
  - 63% Agriculture
  - 26% urban development
- Rapidly urbanizing southern section

Methodology

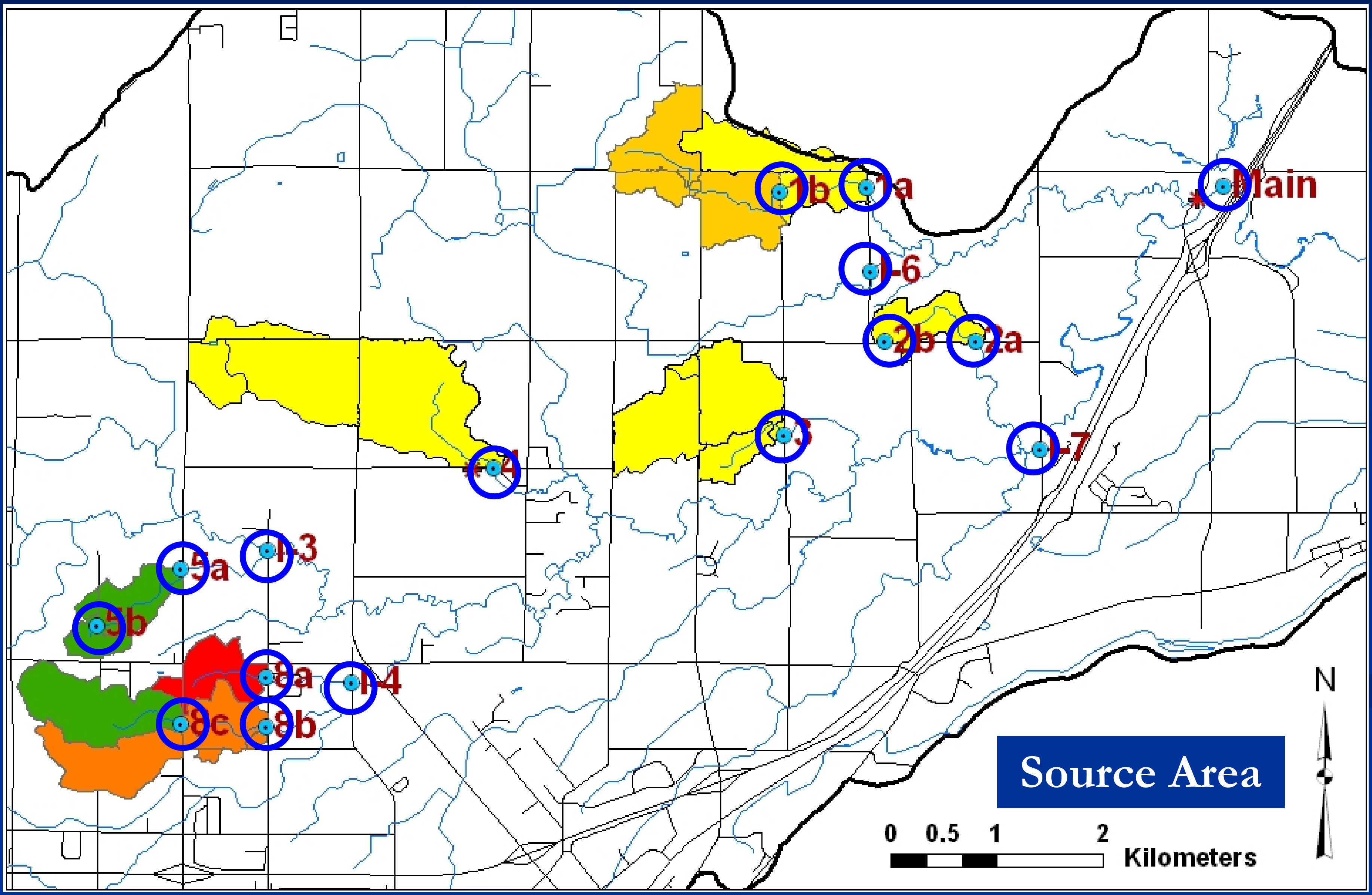
Apple Creek Source Area Watersheds



Monitoring

- Study Period: 2004 – 2006
  - Five events in 2004, one in 2005, and two in 2006
- EVENT SAMPLING: Targeted uniform precipitation events
  - Grab samples at 11 source area (0.2 to 2.3 km^2) and four integrator sites (12 to 85 km^2), at or near peak flow
- Main stem site: Continuous discharge & automated sample collection (117 km^2)
- TSS, TP, and TDP analysis at Green Bay Metropolitan Sewage District Lab

Sampling Sites in Apple Creek Watershed



Site 8a Photo – Up Stream

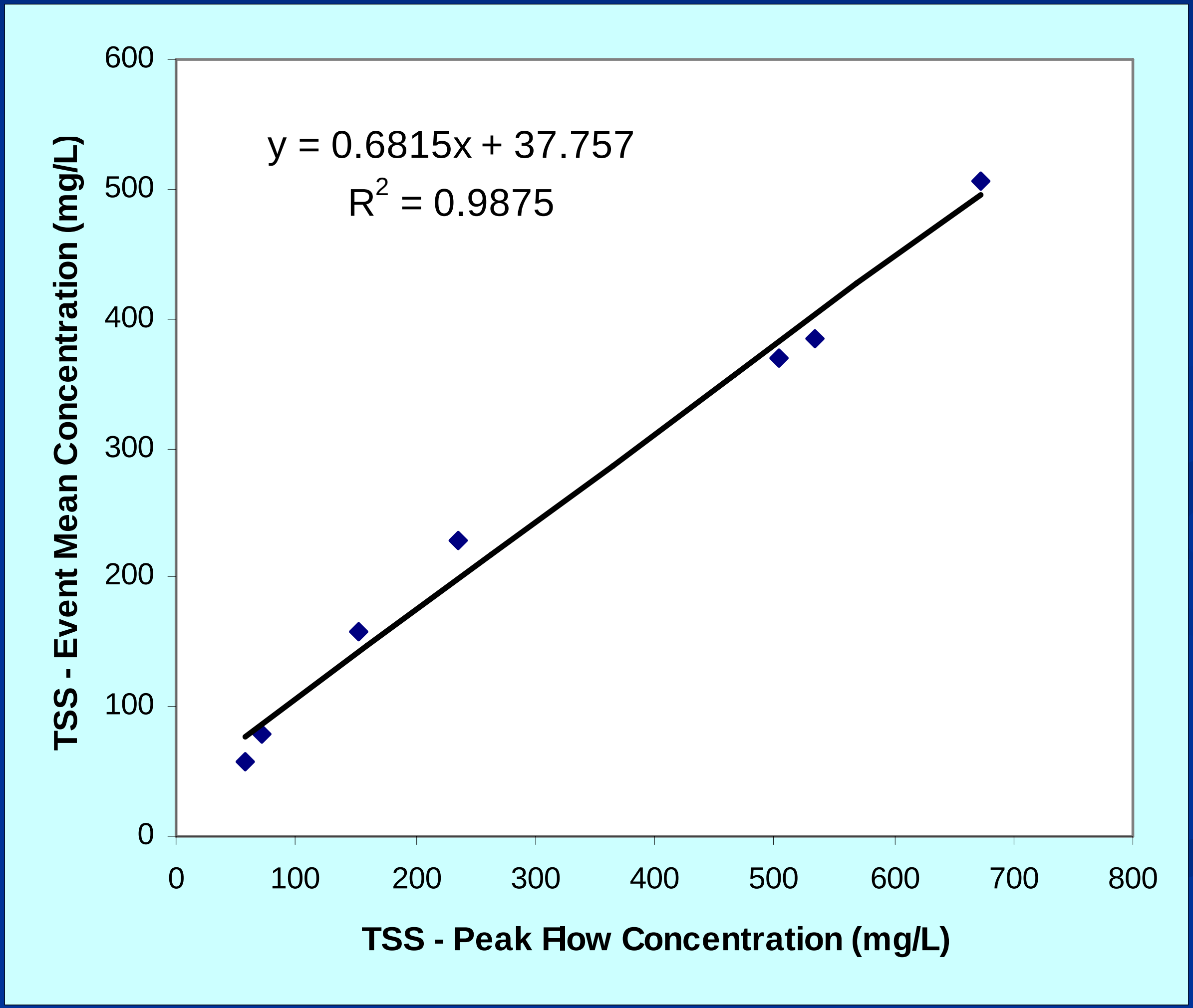
Tape-down Measurement

Data Analysis

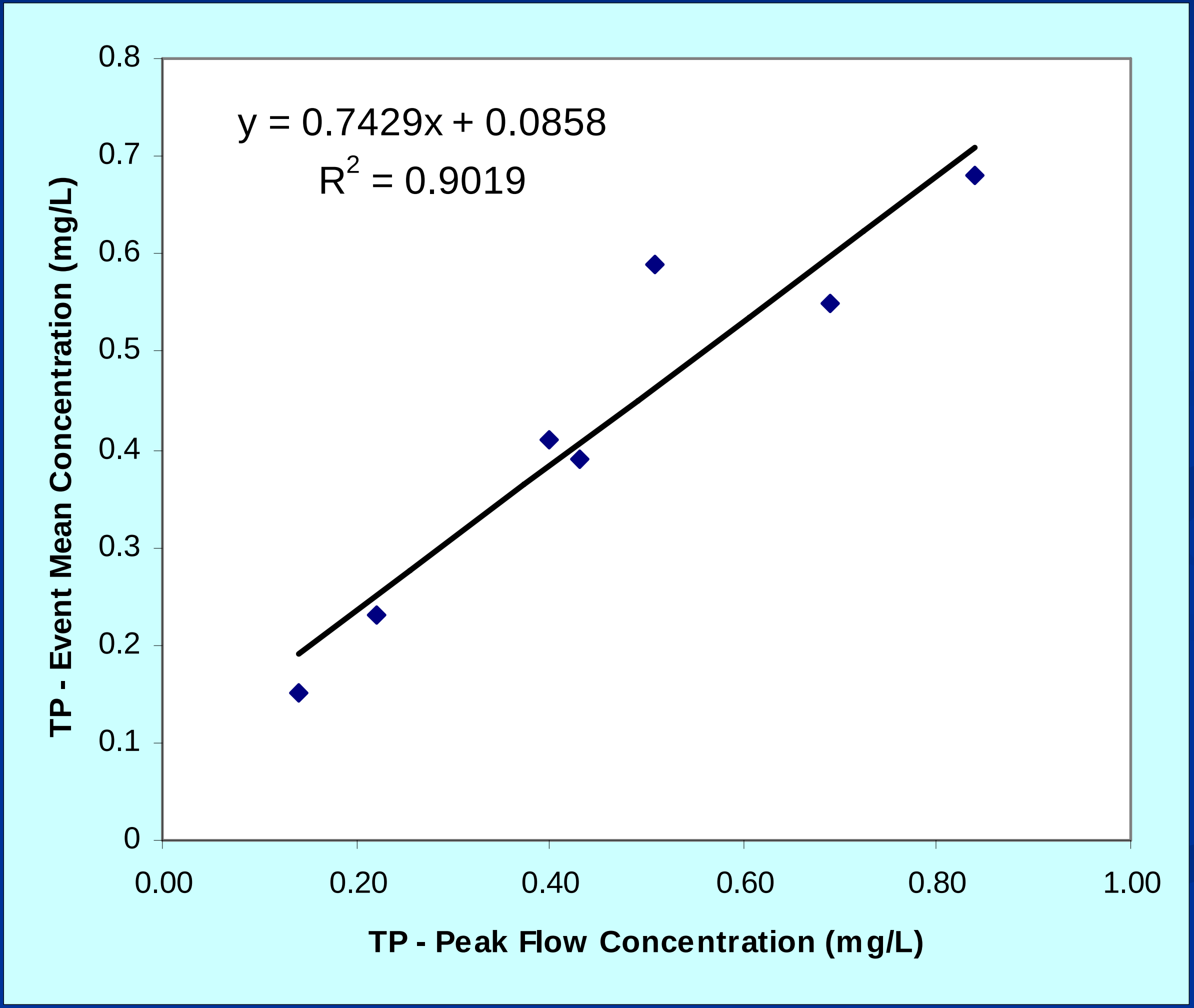
- Linear Regression
  - Representativeness of peak flow grab sampling procedure using the main stem monitoring station
- Tukey Multiple Comparison Procedure
  - Site and Scale Comparisons

Results: P Forms at Different Spatial Scales

Representativeness of Peak Flow Grab Sampling Procedure - TSS



Event Mean Conc. vs. Peak Flow Concentration - TP

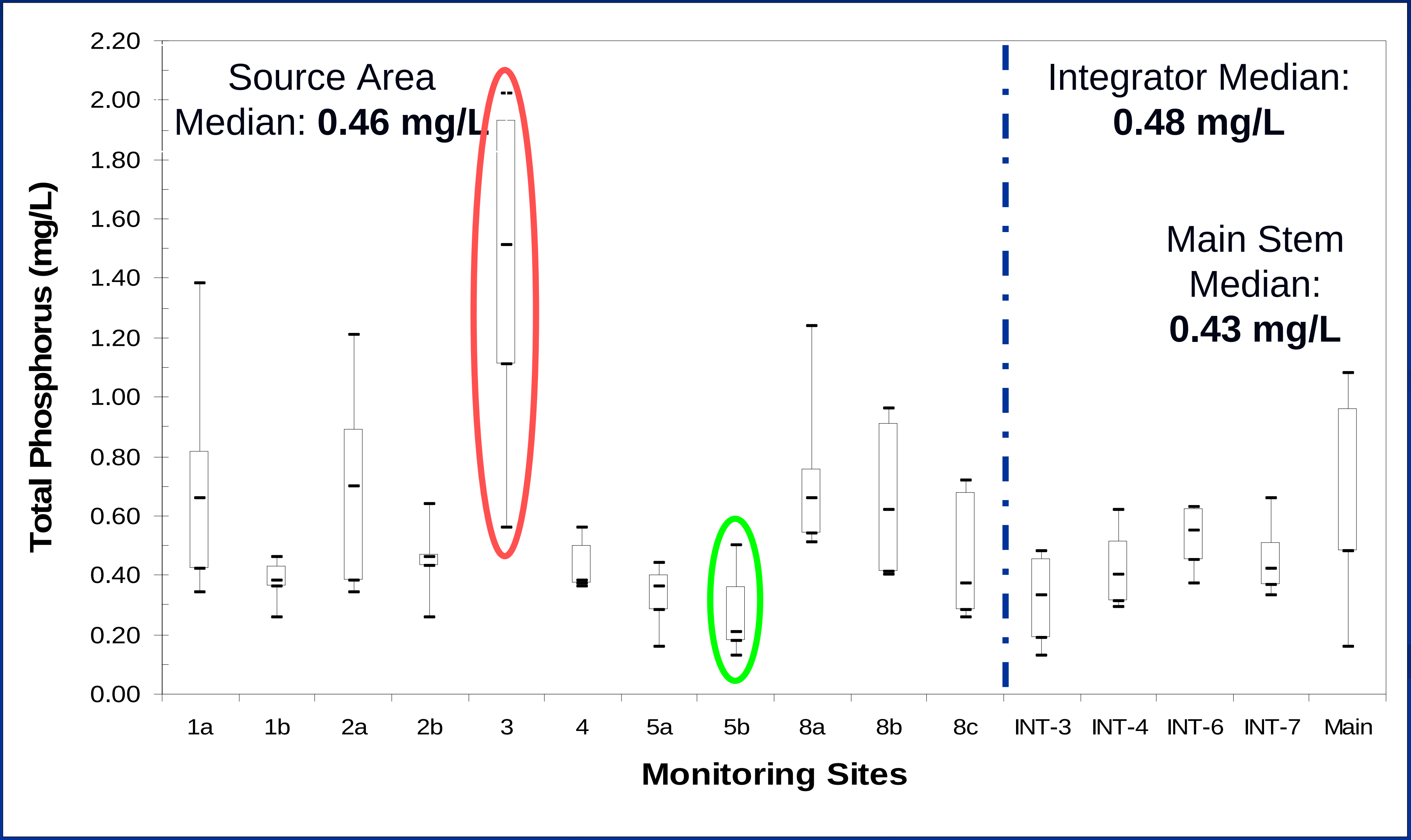


Event Precipitation

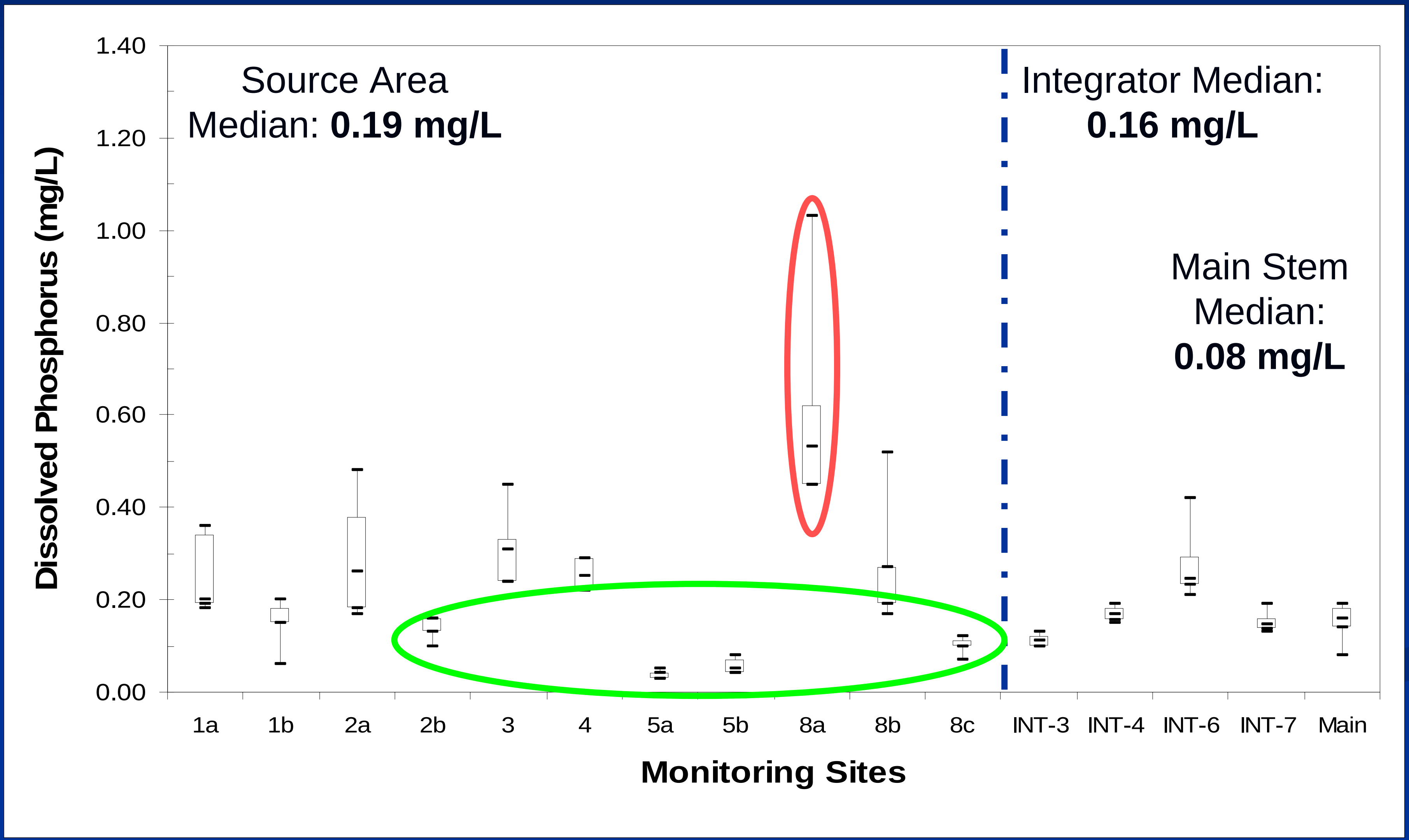
Event	Date	----------Precipitation-------- Day of Event (mm)	7-day (mm)	Intensity (5 min max.-mm)	Main-stem peak flow (cfs)
1	**3/28/2004**	**14.7**	**21.3**	**0.76**	**587**
2	**5/14/2004**	**8.9**	**63.1**	**0.25**	**205**
3	**5/21/2004**	**13.2**	**38.6**	**0.51**	**249**
4	**5/23/2004**	**45.5**	**89.9**	**3.30**	**1073**
5	**6/11/2004**	**17.0**	**42.2**	**0.51**	**520**
6	6/13/2005	48.3	58.9	12.19	367
7	1/29/2006	15.5	0.0	-	61*
8	5/14/2006	6.6	79.5	0.25	208

*Average daily flow (ice-affected)

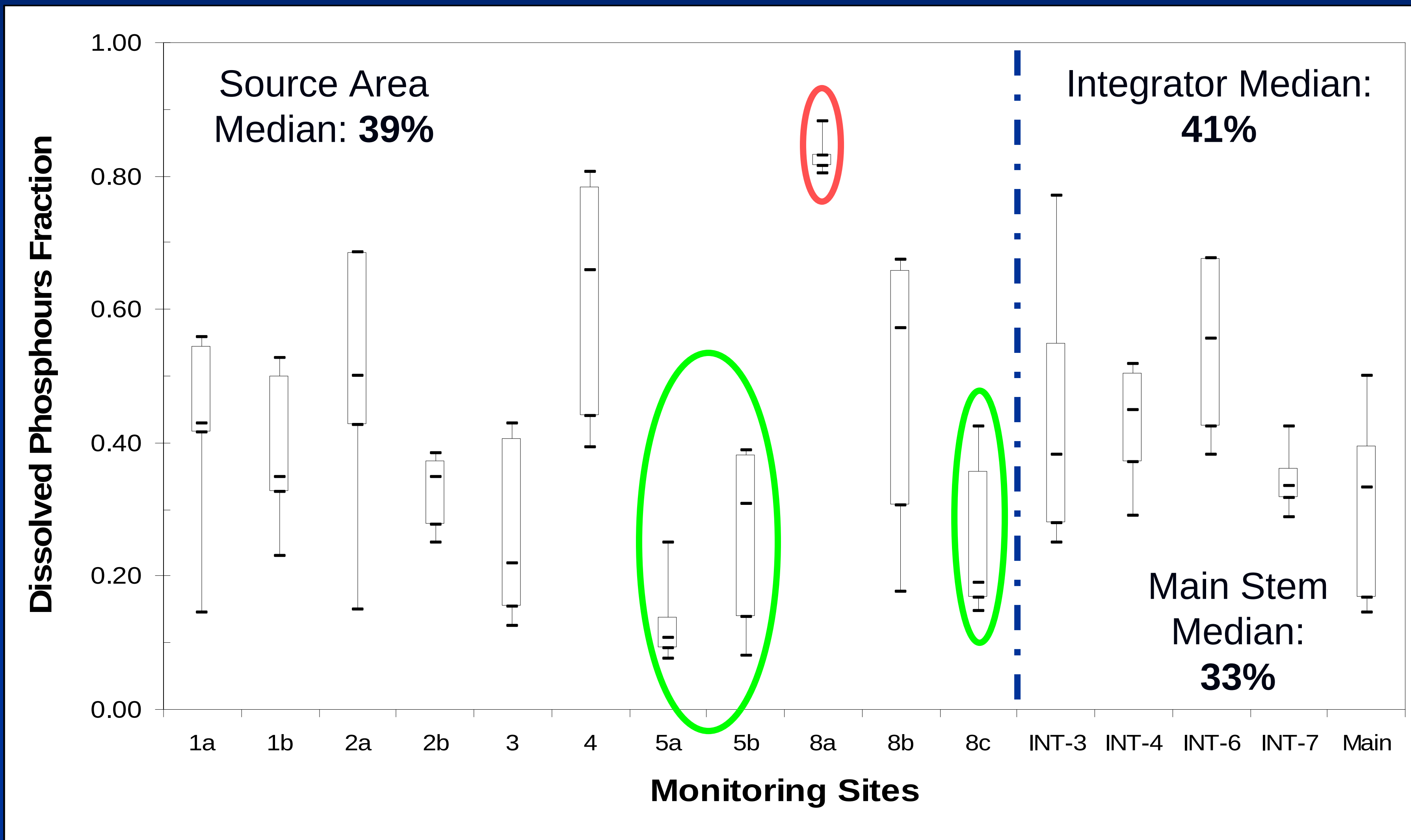
Total Phosphorus – 2004



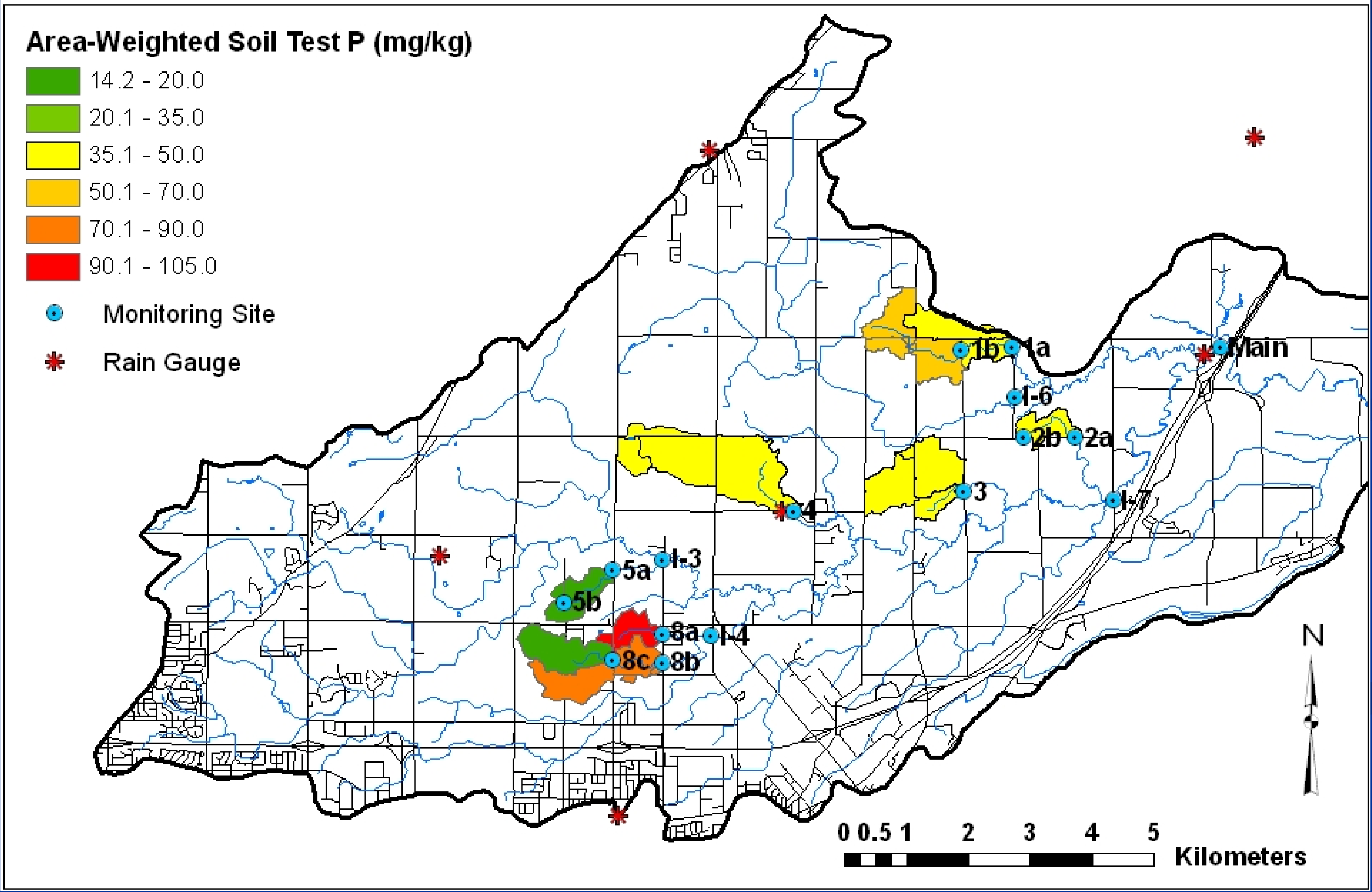
Total Dissolved P – 2004



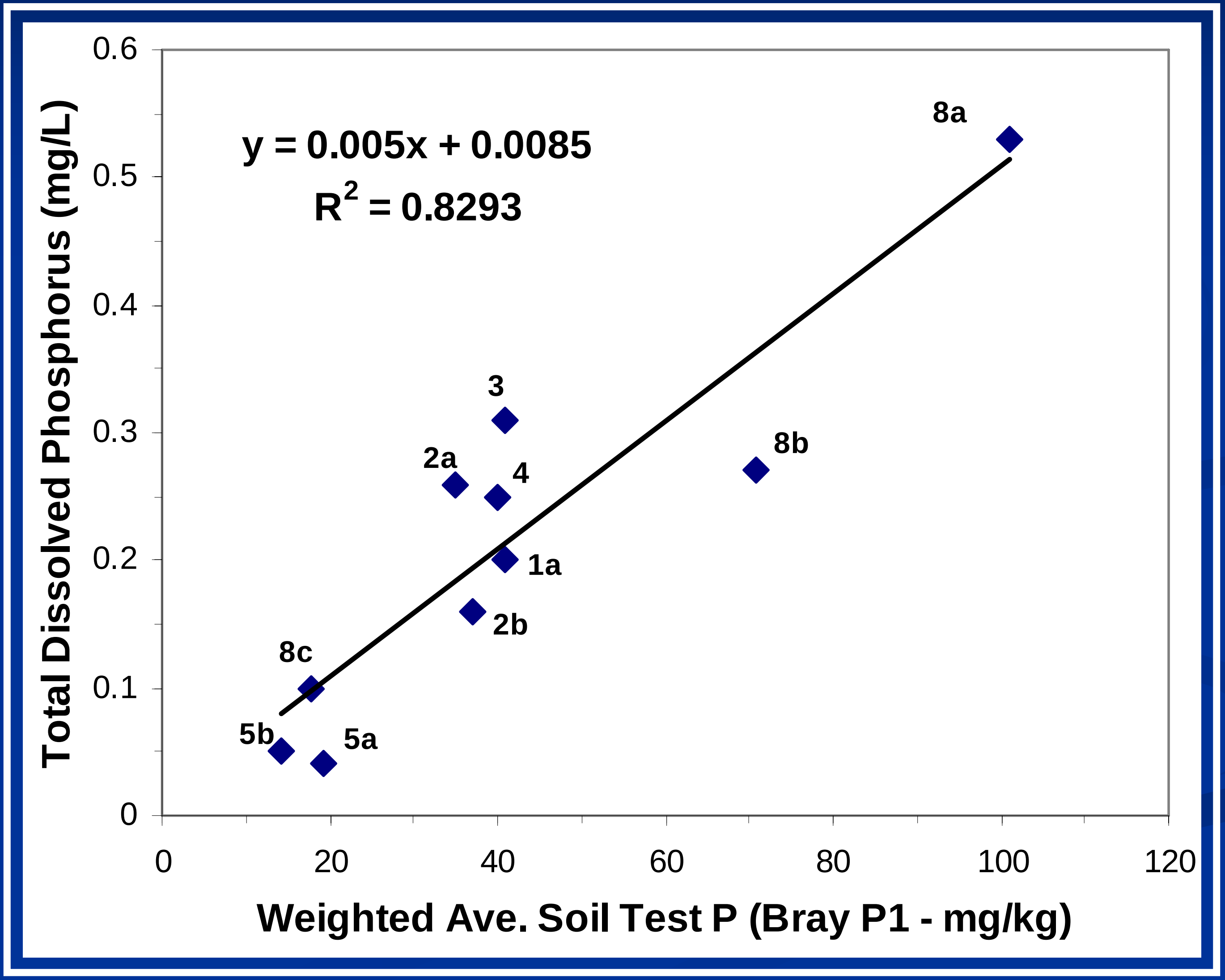
TDP/TP Fraction – 2004



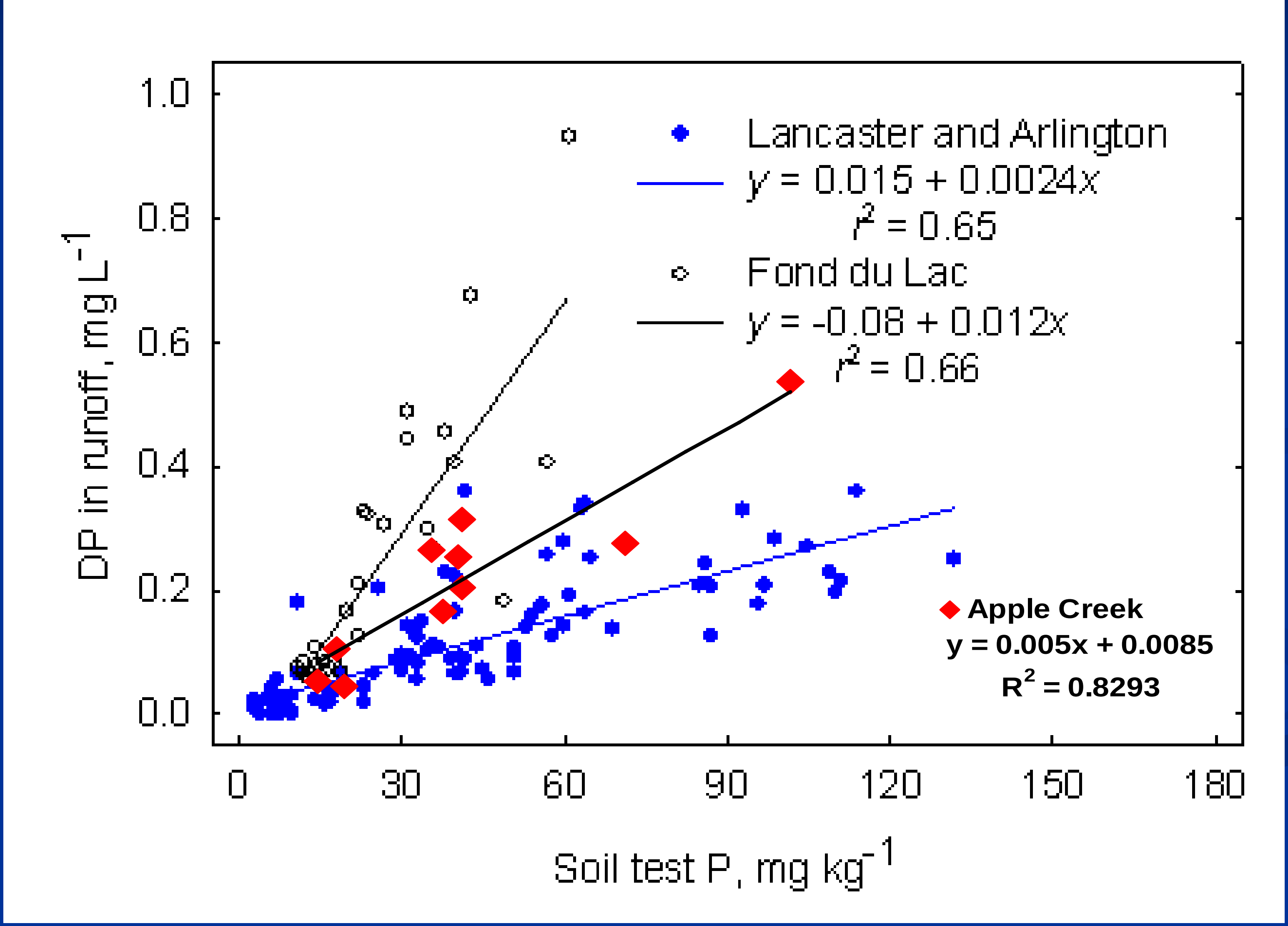
Source Area Soil P



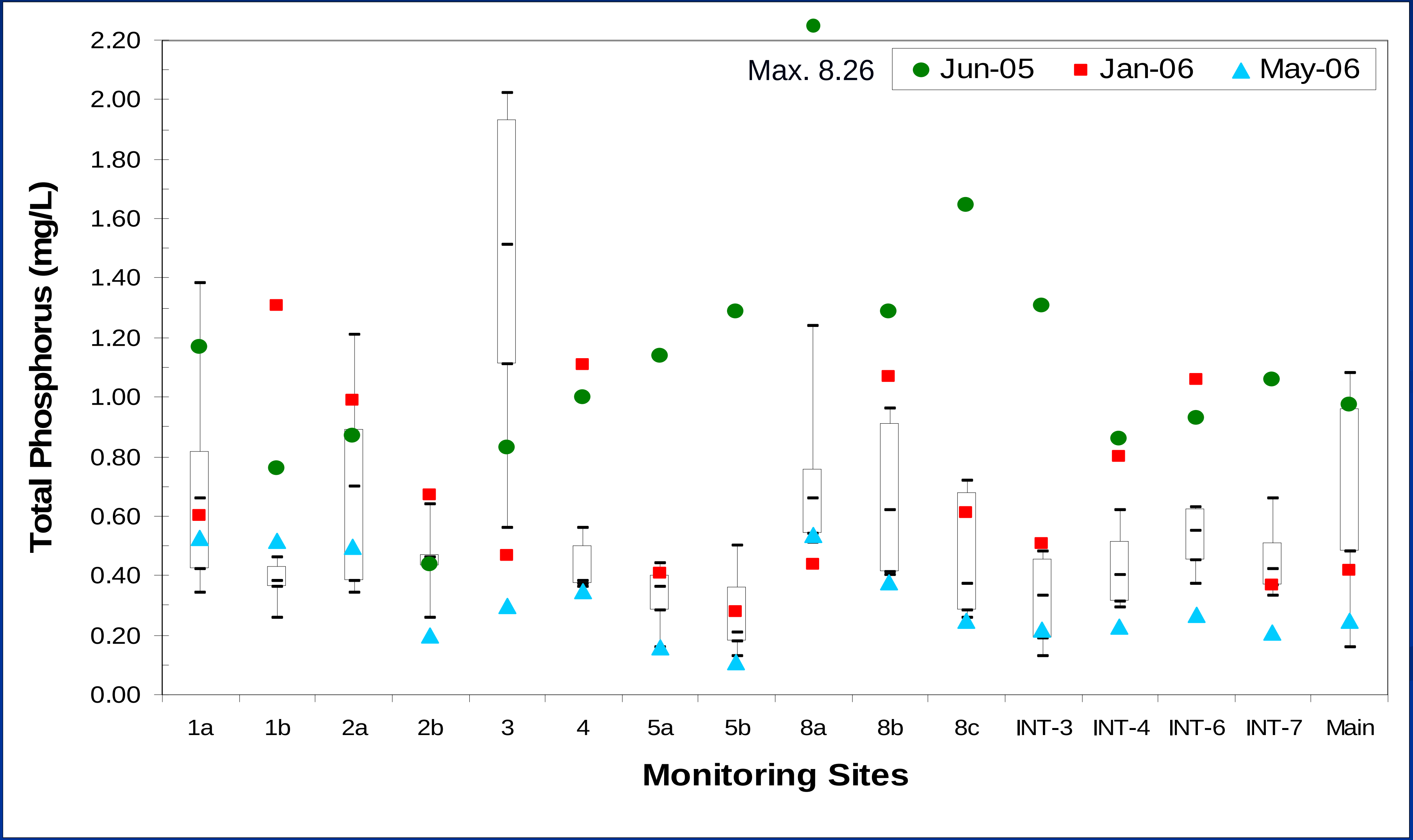
Soil Test P vs. TDP is Surface Runoff



Comparison to Andraski and Bundy (2003)



Year Comparison
Total Phosphorus (2004 - 2006)



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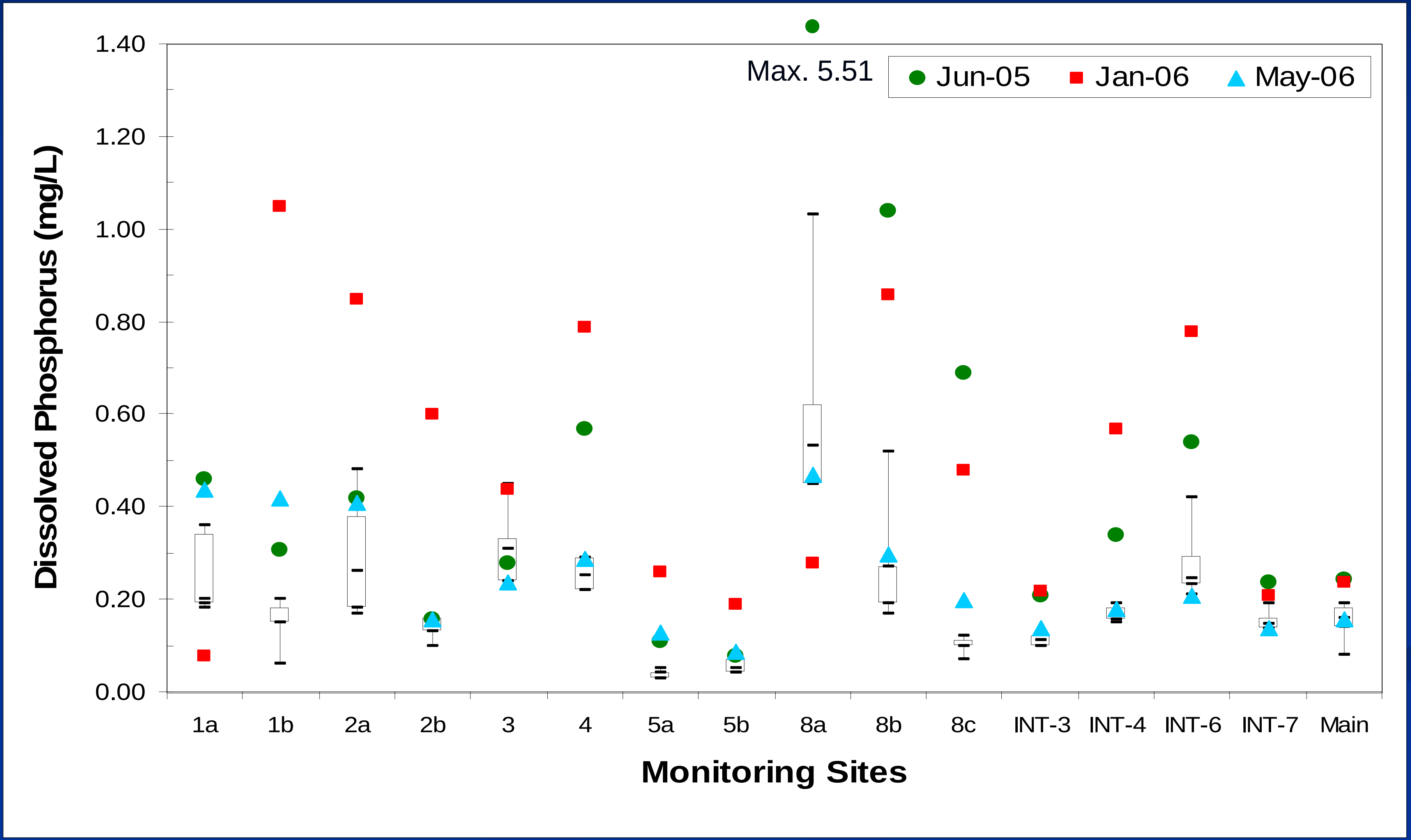
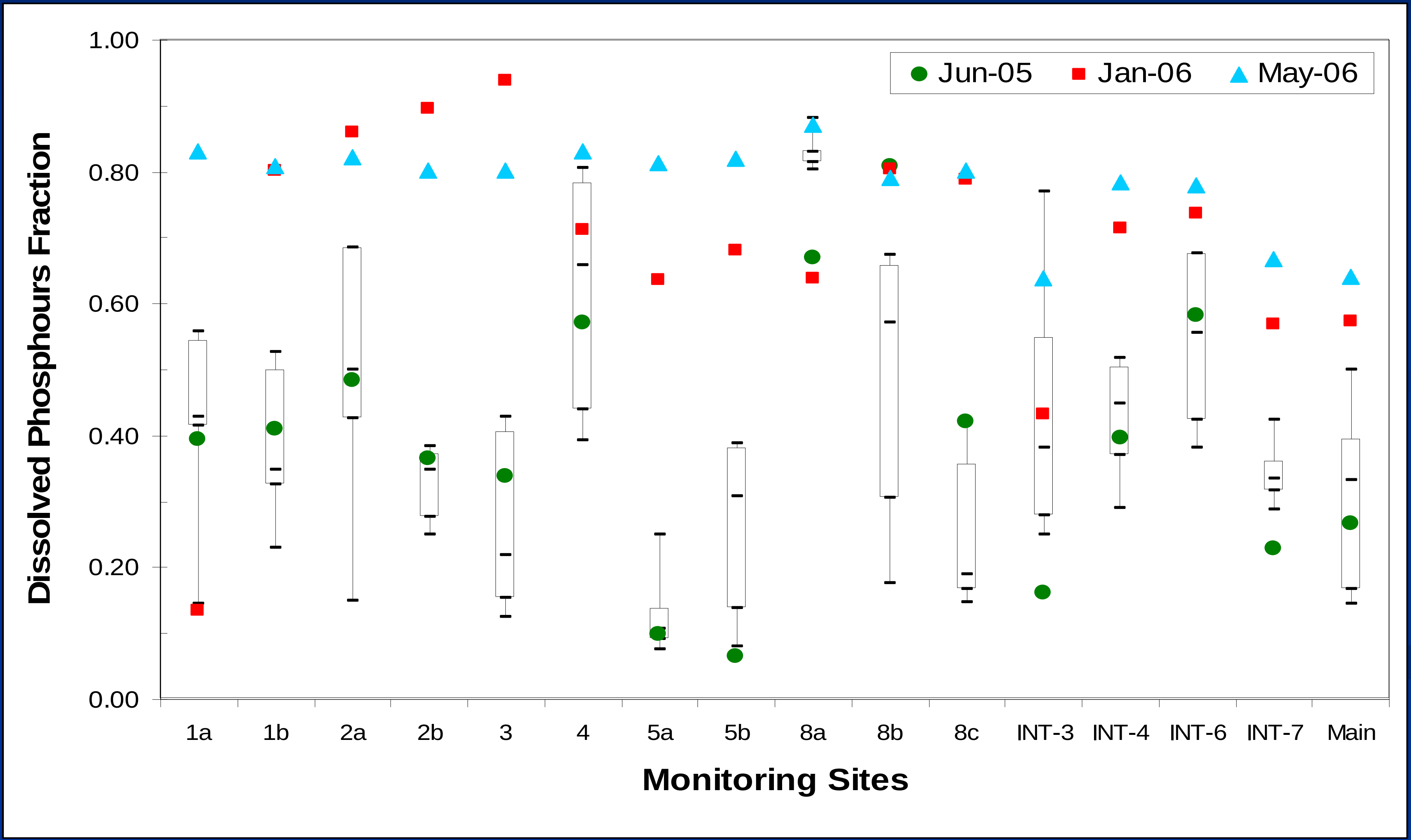
*Average daily flow (ice-affected)

Year Comparison
Total Dissolved P (2004 – 2006)



Year Comparison
TDP/TP Fraction (2004 – 2006)



Source Area Summary

- Significant variability among source area sites for TSS, TP, and TDP concentrations
- No affect of scale on TSS and TP concentrations
- TDP concentrations greater at source areas than main stem
- TDP concentration in surface runoff closely linked to area-weighted STP in source areas

Scale Comparison on Clay Loam Soils in Wisconsin

Scale	Size	TP	DP	DP:TP	SS
Andraski & Bundy	1 m^2	**2.49** ± 0.45	**0.68** ± 0.24	**28%** ± 10%	**2600** ± 1219
Discovery Farms (Kewaunee)	10-20ha	**0.78** ± 0.66	**0.38** ± 0.41	**45%** ± 21%	**181** ± 306
Source Areas	20-230ha	**0.70** ± 0.91	**0.40** ± 0.61	**50%** ± 26%	**267** ± 375
Apple Creek	11,700ha	**0.61** ± 0.60	**0.24** ± 0.13	**47%** ± 22%	**238** ± 334

- DP is significant in other studies

Assessment of Wisconsin P-Index

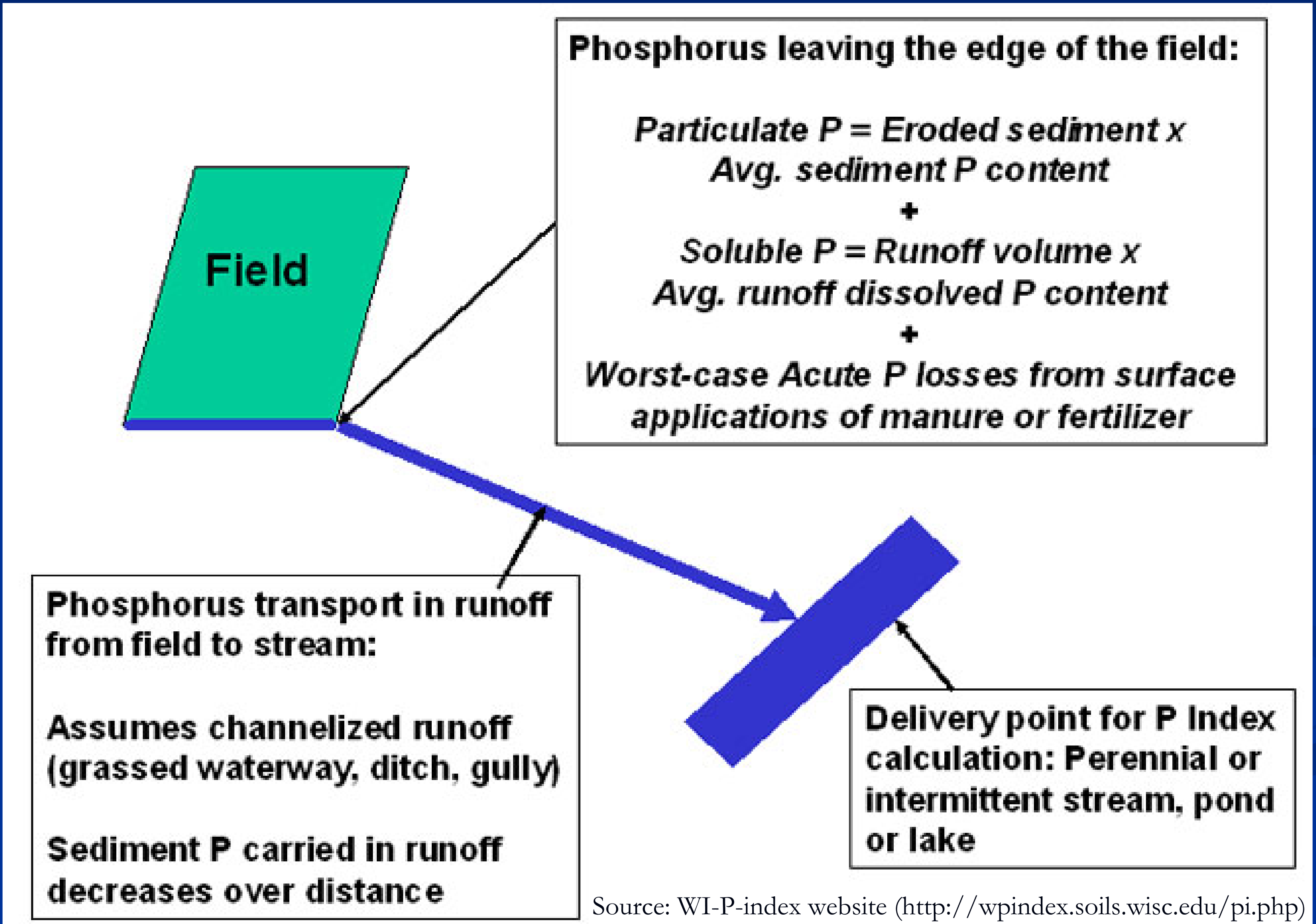
Objectives

- Compare P forms and sediment among Lower Fox River tributaries
- Evaluate Phosphorus forms at different spatial scale
- Comparison of Wisconsin P-Index to water-quality measurements at multi-field scale
  - How does P-loss predicted by Wisconsin P-index relate to measured P-loss in surface runoff?

SNAP-Plus

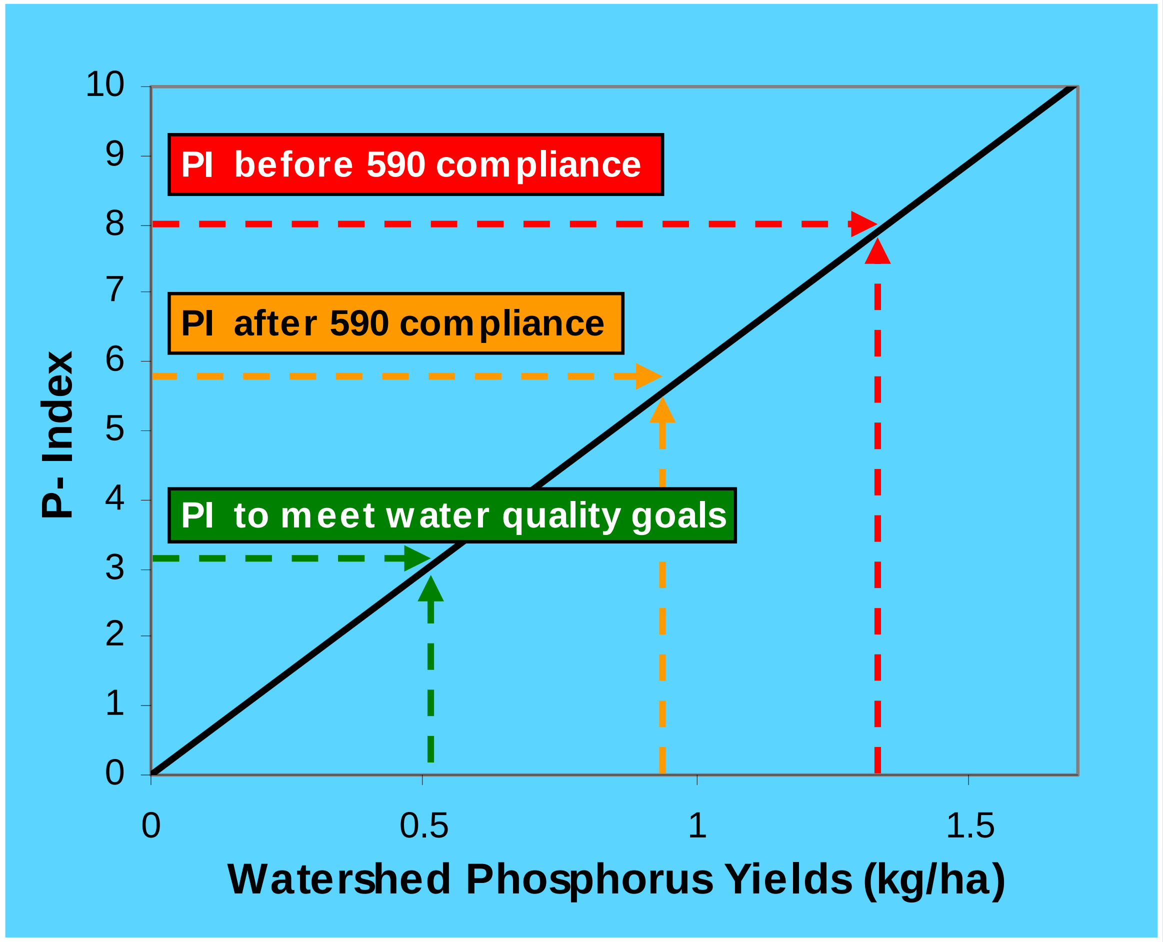
Wisconsin P-Index

P-Index Phosphorus Pathways



Source: WI-P-index website (http://wpindex.soils.wisc.edu/pi.php)

Achieving Water Quality Goals with the Wisconsin P-Index



- Will compliance with 590 standards meet water quality goals?

SNAP-Plus Analysis

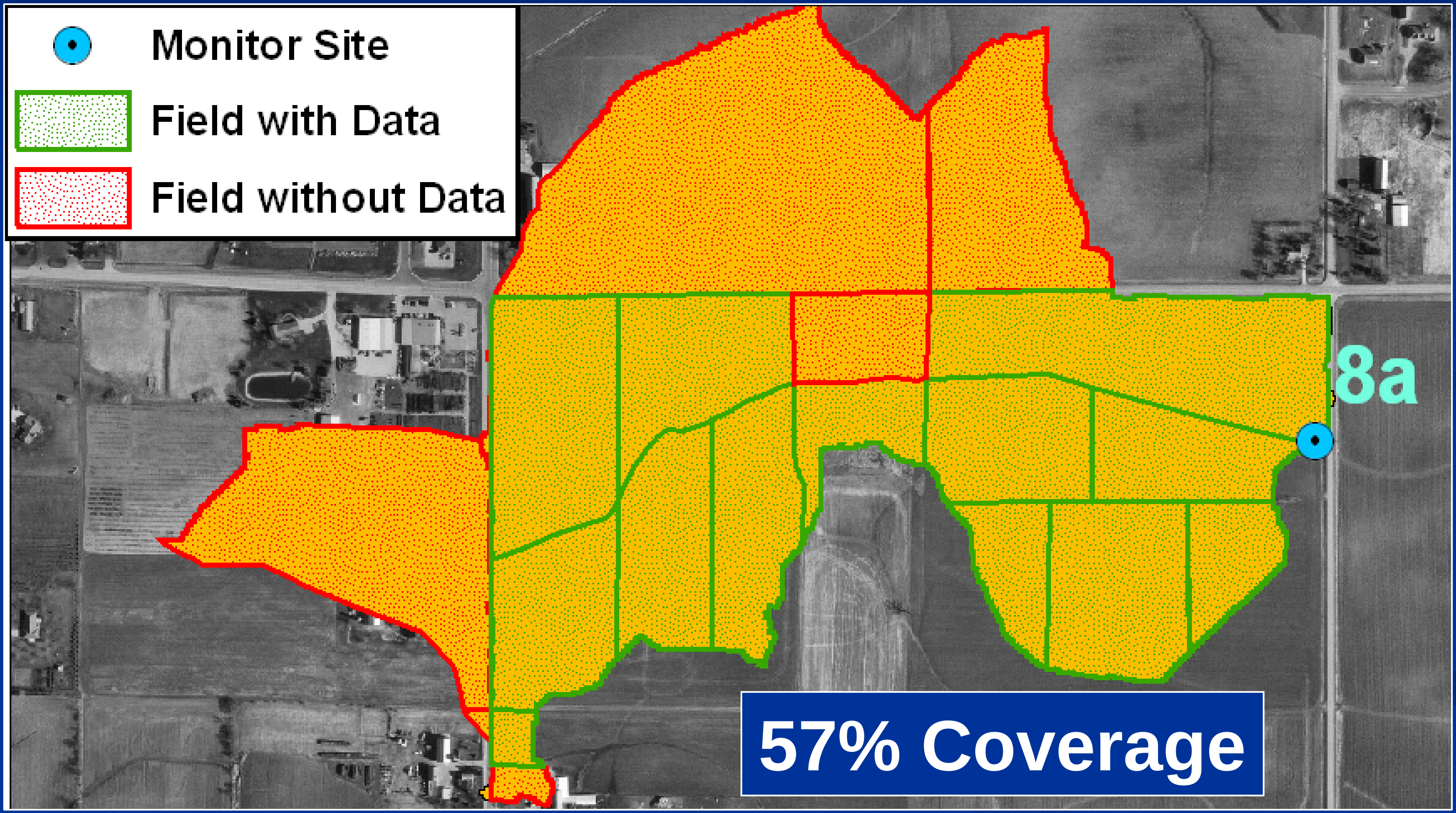
- Samples collected
  - **2004: 5 events (March to June)**
  - 2005: 1 event (June)
  - 2006: 2 events (January and May)

Excluded from current analysis

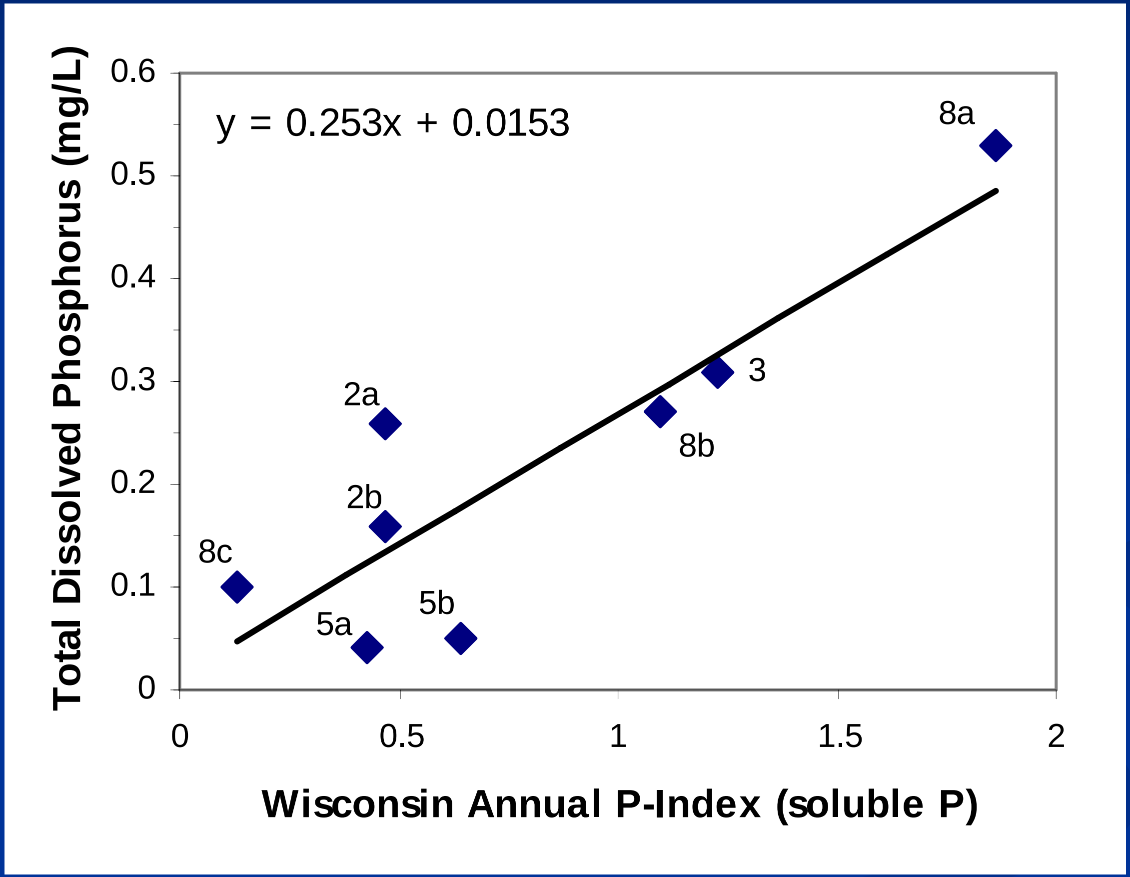
- Land management data for Snap-Plus
  - Nutrient management plans
  - Crop consultants
  - 8 out of 11 sites with good coverage (> 50%)

Results: Assessment of Wisconsin P-Index

Coverage Map – Apple 8a

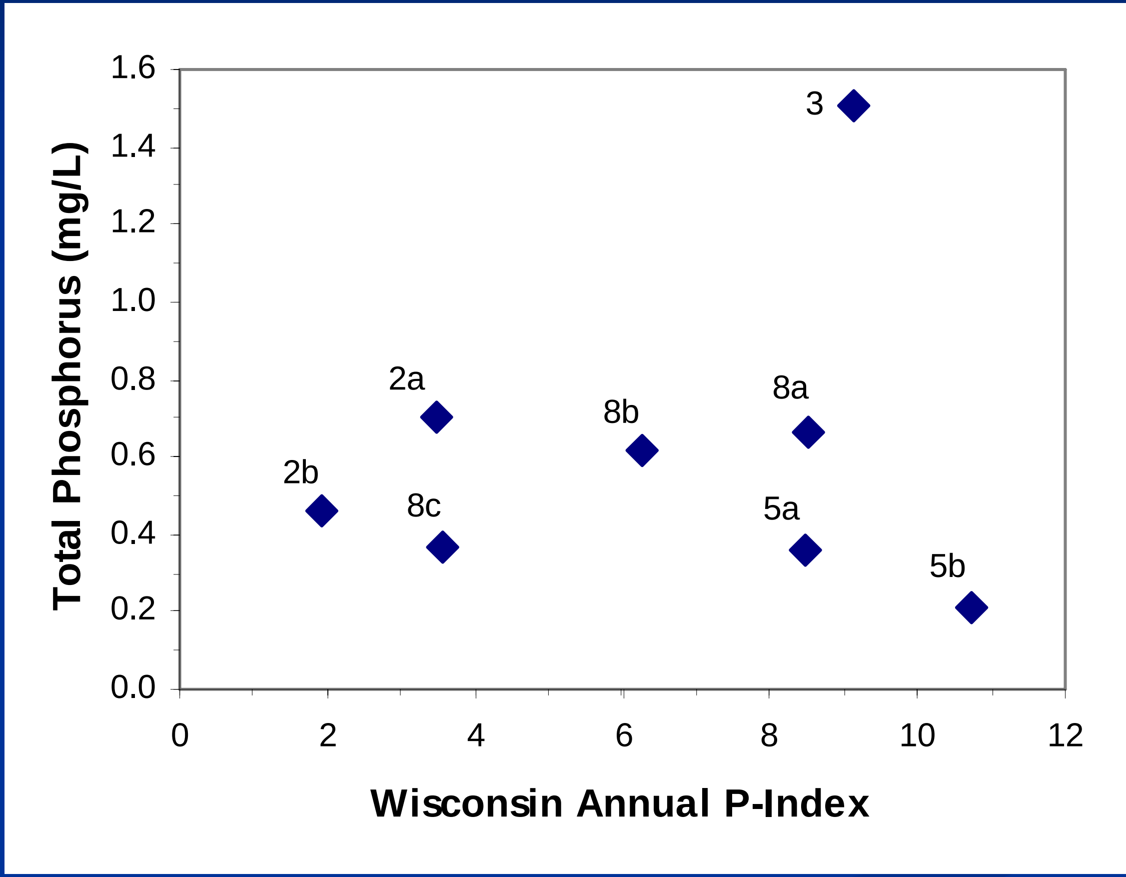


Solube P-Index vs. TDP in Stream



- Relationship between Soluble P-Index and median DP concentrations at sub-watershed outlets (5 events - 2004)

P-Index vs. Total P in Stream



- No relationship between P-Index and median TP concentrations at sub-watershed outlets (5 events -2004)

Study Limitations

- Incomplete Coverage
- Accuracy of Nutrient Management Plans
  - Manure and fertilizer applications
  - Crop rotation changes
  - Tillage
- "Average" weather year

P-Index Summary

- TDP is surface runoff predicted well by SNAP-Plus
- TP was not predicted well in eastern red clay soils

- Future P-Index Assessment Studies
  - Windshield survey to check crop planting and tillage practices
  - Accurate manure and fertilizer applications

Overall Conclusions

- TDP is significant portion of TP losses (consistent with previous findings in LFRS-B)
- Multi-field monitoring showed that TDP fraction was greater than or equal to larger scale monitoring
- TDP concentrations in surface runoff predicted well by Wisconsin P-Index
- No correlation between Total P-index and TP is surface runoff
- Erosion reduction strategies may not adequately reduce TP losses to meet water quality objectives

Acknowledgements

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  - Laura Ward Good (UW-Madison)
  - Laurie Miller (Outagamie FSA)
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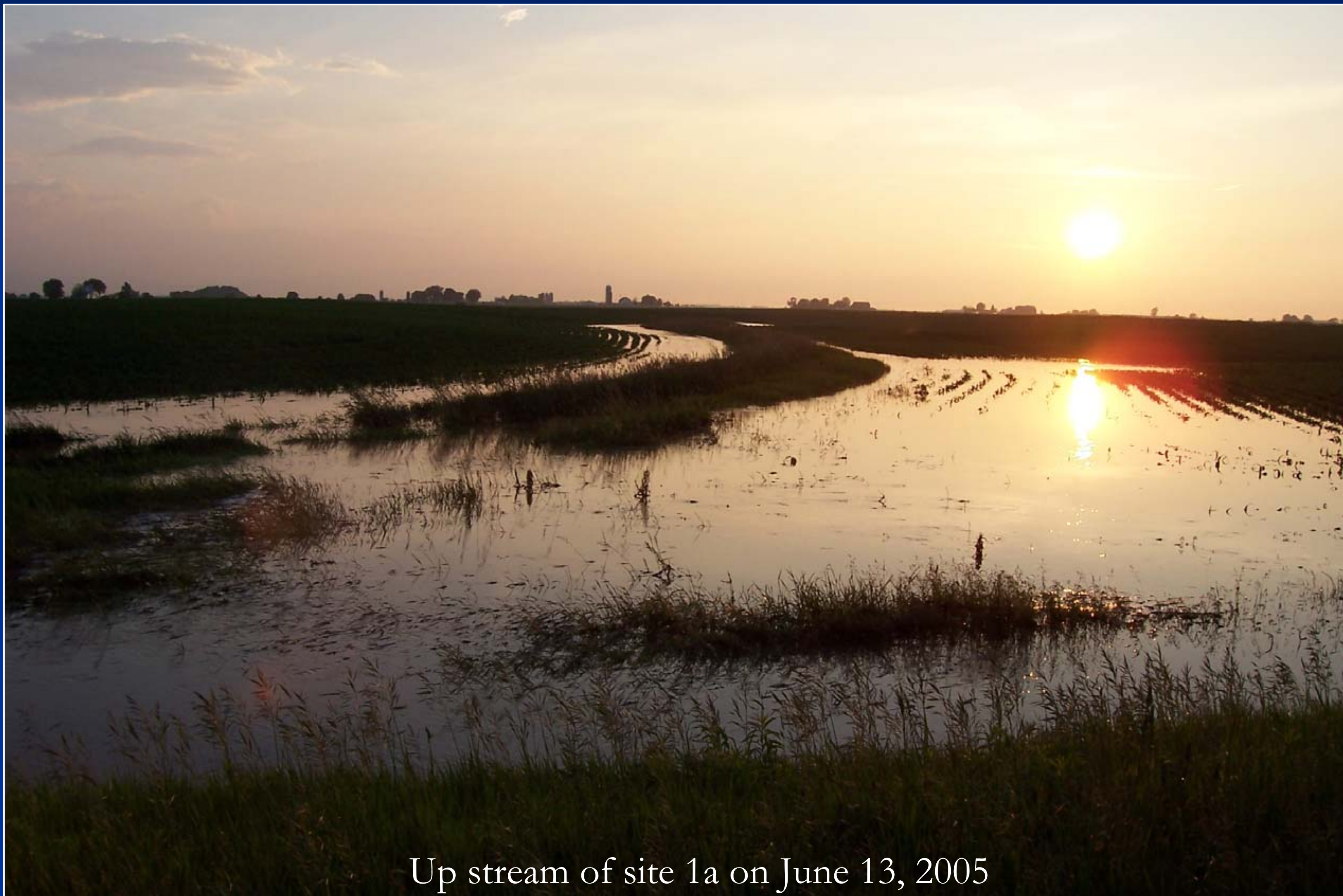
  - Arjo Wiggins Appleton, Inc.

Questions?



Up stream of site 1a on June 13, 2005