Simulating the Effects of Alternative Management Practices on Suspended Sediment and Phosphorus Loads to Green Bay using the Soil and Water Assessment Tool (SWAT) and SNAP-Plus

Paul Baumgart, Kevin Fermanich, Nick Reckinger

University of Wisconsin – Green Bay

Lower Fox River Watershed Monitoring Program – www.uwgb.edu/watershed

Soil and Water Conservation Society

Managing Agricultural Landscapes for Environmental Quality

October 11-13, 2006,

Kansas City, Missouri

Full report: www.uwgb.edu/watershed/reports/LFox_Load-Allocation.pdf

Presentation Outline

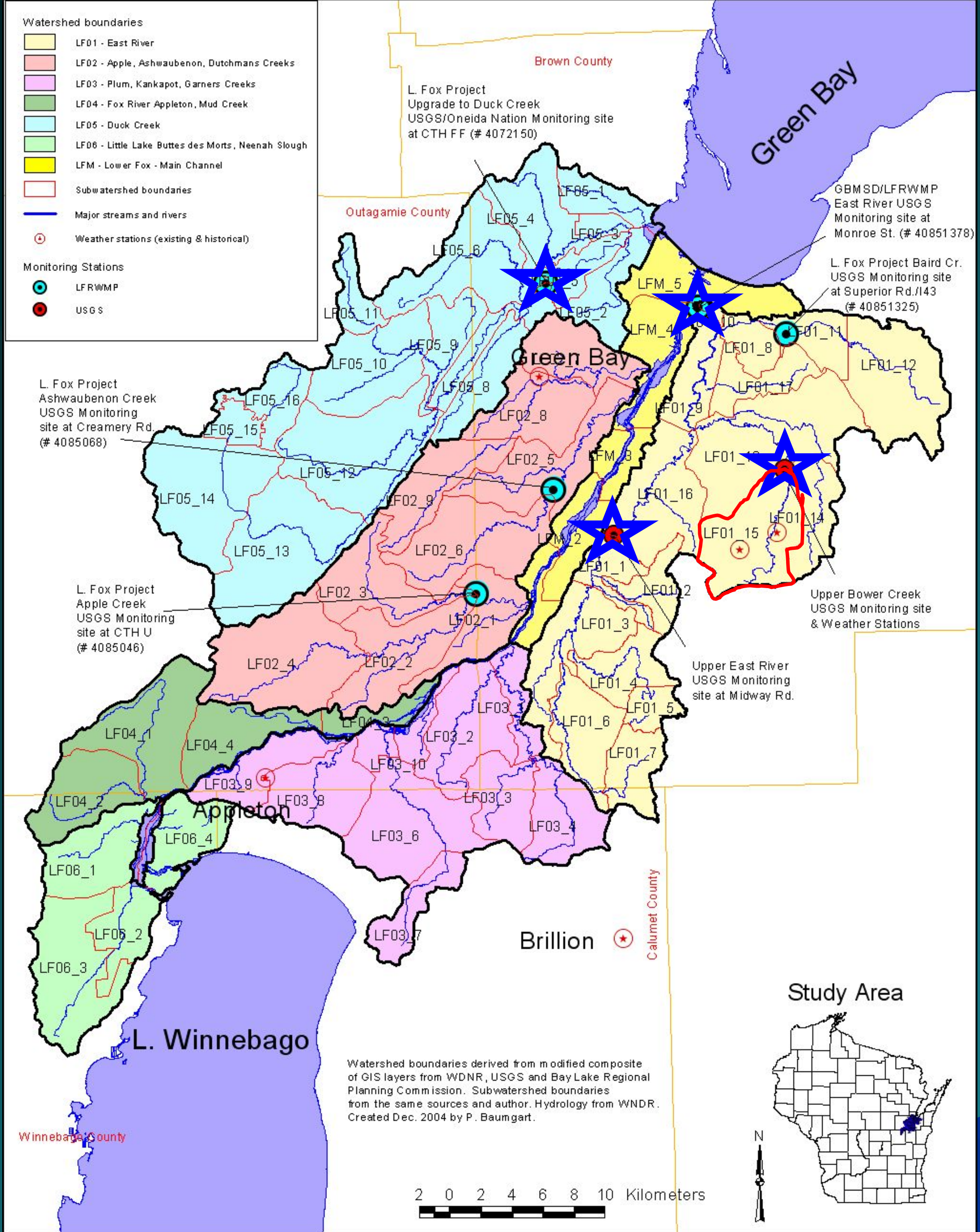
- Lower Fox River Sub-basin Description
- SWAT overview
- Modeling Methods and Inputs
- Calibration and Validation
- Model Results: Simulated Phosphorus and Suspended Sediment Export from Sub-basin
- Alternative Management Scenarios: Results
- Farm-based analysis: SNAP-Plus

Primary objectives

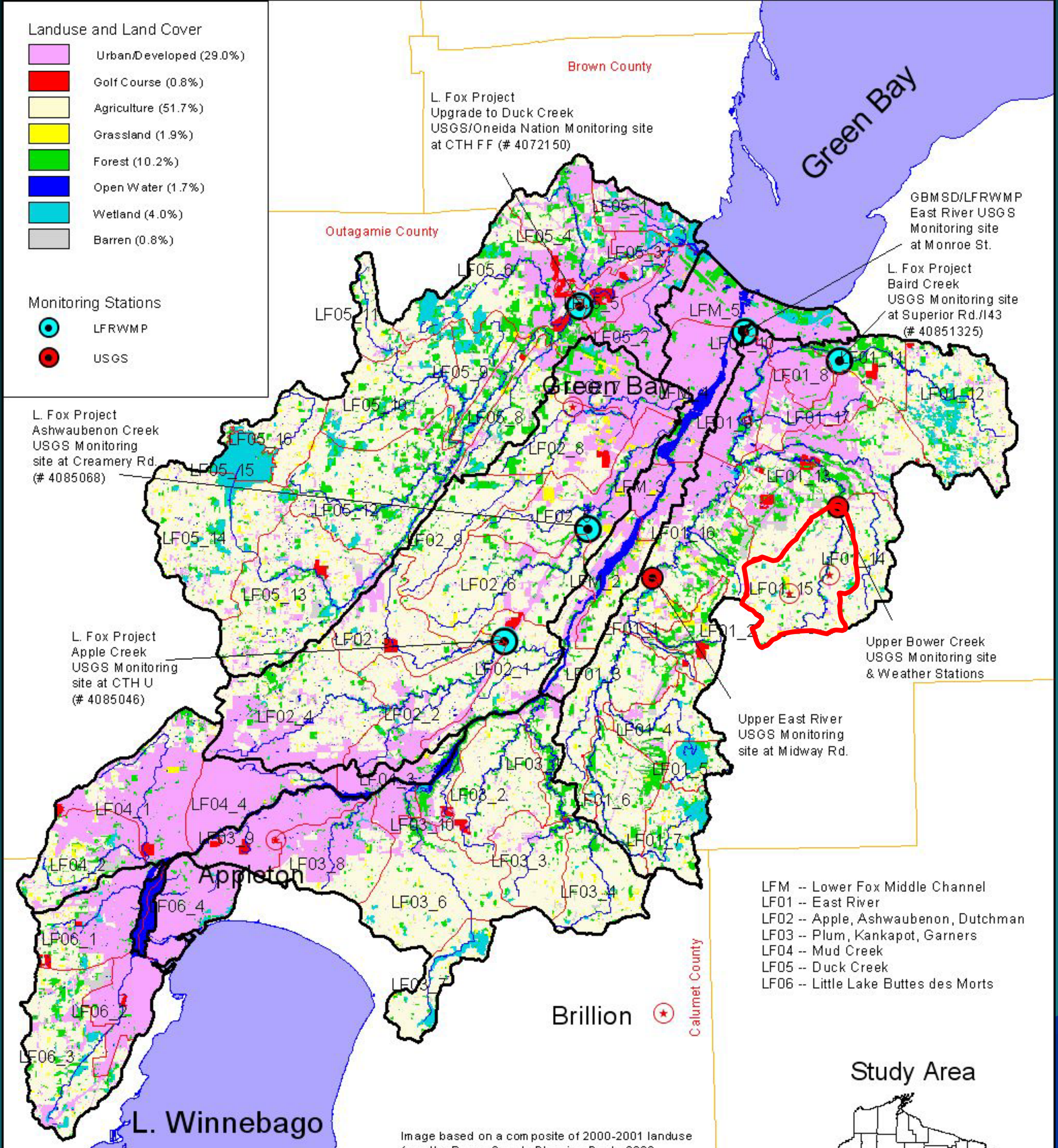
1) Utilize watershed simulations to support watershed load allocations and predict impact of sediment and phosphorus reduction strategies within Lower Fox River Sub-basin (1580 km^2)

2) Develop relationships between water quality observations and results from farm-based analysis tool (SNAP)

Lower Fox River watersheds & subwatersheds

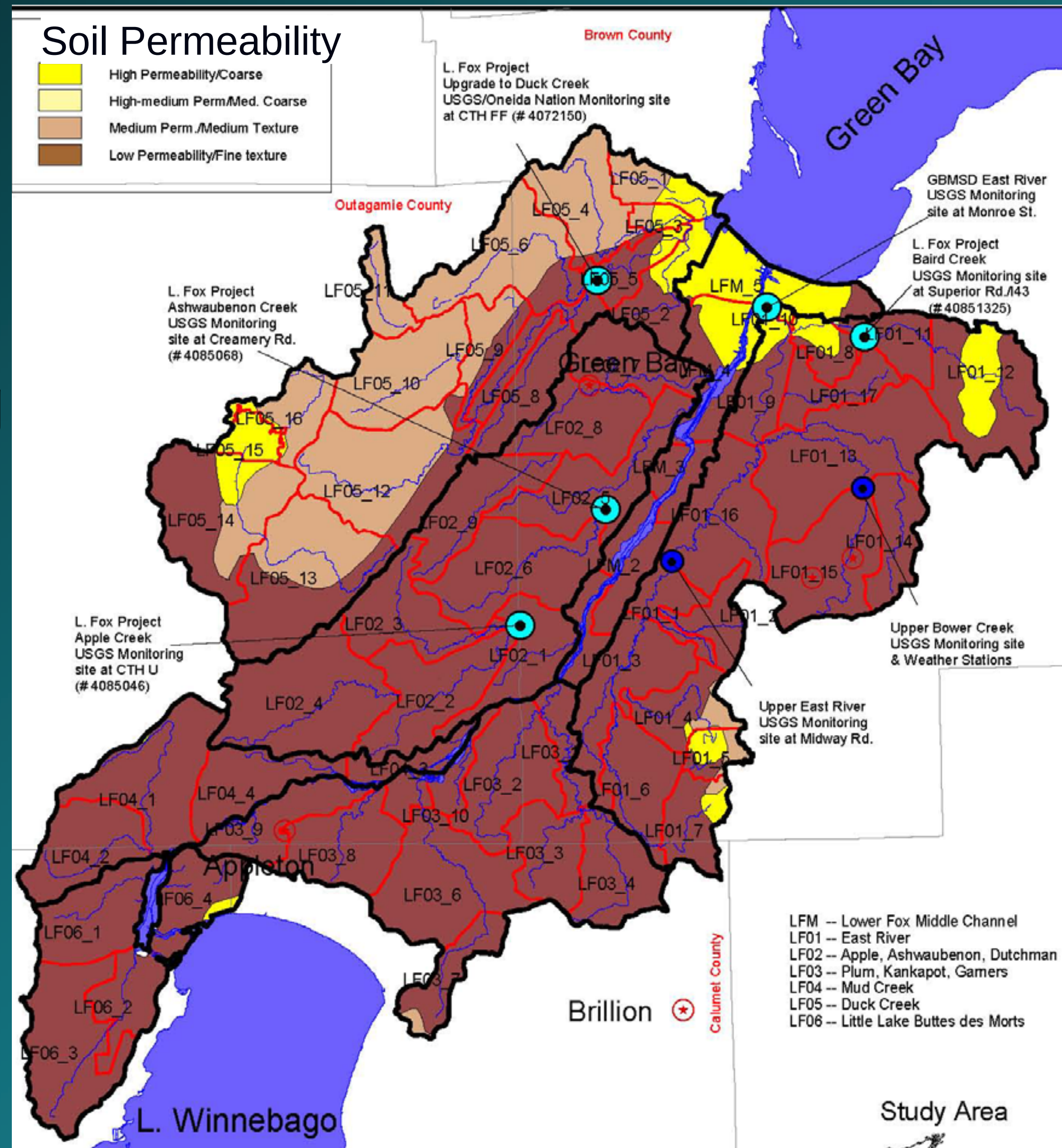


Lower Fox River Year 2000 Landuse and Land cover



Watershed background:

- Clay soils
- High % runoff
- 715 mm precip avg
- ~ 200 mm flow
- ~ 30 mm baseflow



Soil and Water Assessment Tool - SWAT

- USDA – ARS model: J.G. Arnold, J.R. Williams, Temple Texas
- Continuous daily time step, river basin/watershed scale model ------- physically based
- Routes water, sediment, nutrients and pesticides to watershed and basin outlets
- Predict impacts of management on water, sediment and chemical yields
- Long-term simulations of many decades
- Tracks crop growth, tillage, fertilizer/manure application, nutrient cycling on a daily basis
- Conservation Effects Assessment Project Tool (CEAP)
- Applied modified version of SWAT 2000 code
- GIS > spreadsheet > SWAT 2000: to allow more flexible/complex management files

Modeled Simulations

- 1977-2000 climatic period
- 1992 landuse Baseline conditions
- 2000 landuse Baseline conditions
- Alternative management scenarios
  - 2000 and
  - 2025-30 urban area doubles

Model Inputs – GIS layers

- Landuse – land cover
  - WDNR Wiscland land cover - 1992
  - Brown County, ECWRPC – 2000 to 2001
  - Trends: above plus USGS 1:24k topographic maps
- Soils – County SSURGO
  - sub-watershed area-weighted averages
  - 4 soil layers
  - AWC, bulk density, sat. cond, K, hydro-group, etc

- Slope – 30 m Digital Elevation Model
- Watershed boundaries - WDNR, USGS, BLRPC
- WNDR Stream hydrology 1:24k, Brown County Buffers
- PC ARC-INFO, ARCVIEW, Spatial Analyst (ESRI)

- Climate: 1976-2000 daily, 3 primary stations,
  - Plus 3 USGS stations in primary calibration watershed
- Upper Bower Creek (36 km^2) main calibration site
- Point source loads from WDNR

Primary Hydrologic Response Units

- Agriculture - Dairy (2000 - 6 year crop rotation of corn-grain, corn-silage, soybean, 3 years of alfalfa)
  - 1 Conventional tillage practice
  - 2 Mulch-till (>30%)
  - 3 No-till
  - 4 Barnyards
- Agriculture - Cash crop (2000 - 1 yr corn, 1 yr soybean)
  - 5 Conventional tillage practice
  - 6 Mulch-till (>30%)
  - 7 No-till
- Non-Agricultural
  - 8 Urban
  - 9 Grassland
  - 10 Forest
  - 11 Wetland
  - 12 Golf course
  - 13 Barren

Agricultural HRU’s

- Percent crops in subwatersheds derived from WISCLAND land cover
  - a) adjusted to fit 1992-93 and 2000-01 Wisc. Ag. Statistics in counties
  - b) Dairy rotation HRU's and Cash Crop rotation HRU's
- Crop Rotation phase altered: 1 HRU for each phase
  (6 dairy, 2 cash crop in year 2000 scenarios)
- Residue Level/Tillage Practices: NRCS & County Transect Survey - 1996/1999/2000 data applied on watershed basis
  a) partitioned: conventional till (CT), mulch till (MT) and no-till (NT)
  b) further separated into dairy and cash crop
  c) constructed SWAT dairy and cash crop management files
- Crop Yields Calibrated (Wisconsin Ag. Stats for Brown County)
- Barnyard loads - SWAT simulations calibrated to BARNY phosphorus loads
- Manure and Fertilizer Inputs

Primary Model Modifications

- Evapotranspiration equations modified
  - Water yield still low, so Hargreaves-Samini PET equation reduced by 0.81
- MUSLE Sediment equation modified to EPIC/APEX form, calibration simplified for suspended sediment loads
- C-factor equation separated into: (1) surface residue and (2) crop cover
- HRU's utilize sub-watershed channel length & area in MUSLE sediment equation
- NRCS curve numbers in management files altered automatically according to soil hydro group

Model Calibration & Assessment

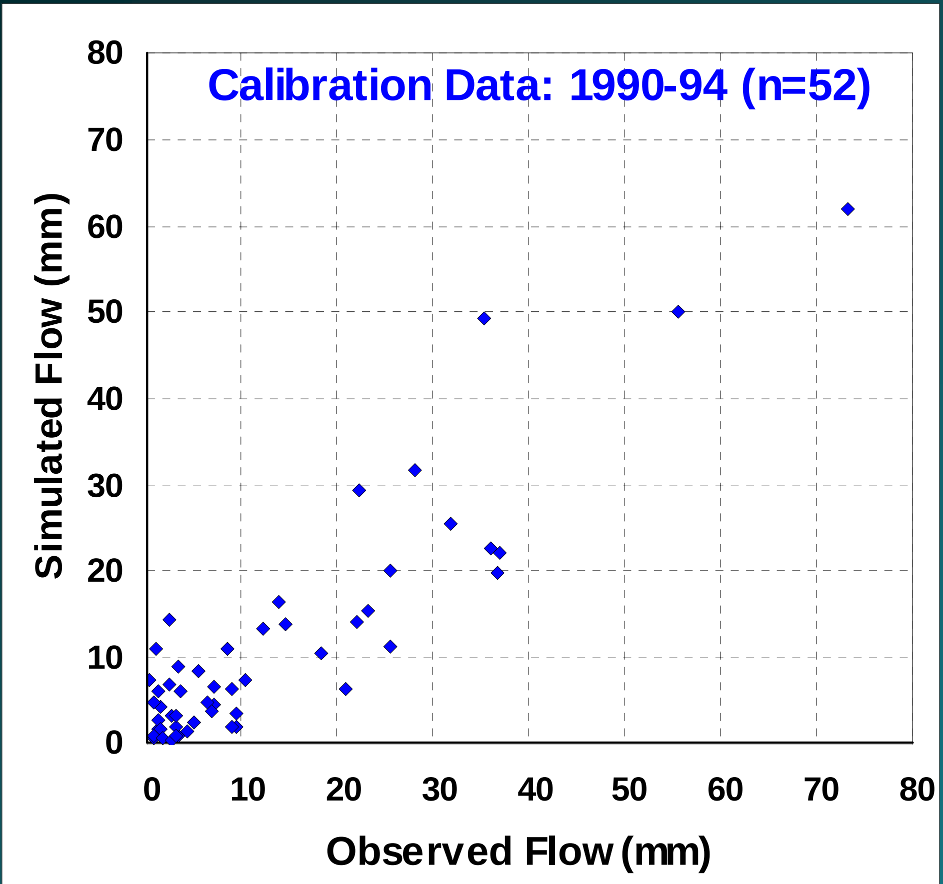
- Calibrate: 1) flow 2) crop yields and nutrient levels 3) suspended sediment 4) phosphorus 5) diss. P
- Validate/assess: flow, SS, P at different time and/or site
- Daily, event, monthly, annual, total basis
- Primary calibration/validation site:

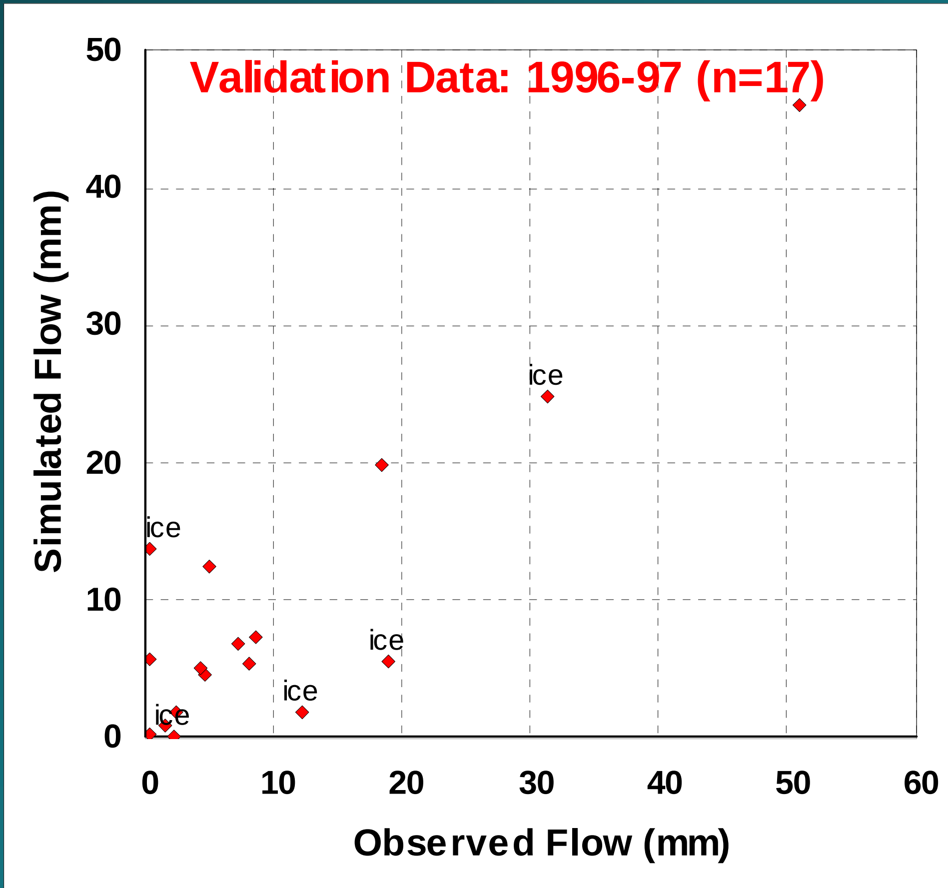
  USGS/WDNR - Upper Bower Cr. (36 km^2)

Calibration & Validation

Examples

Calibrate – Validate: Stream Flow
Upper Bower Creek events

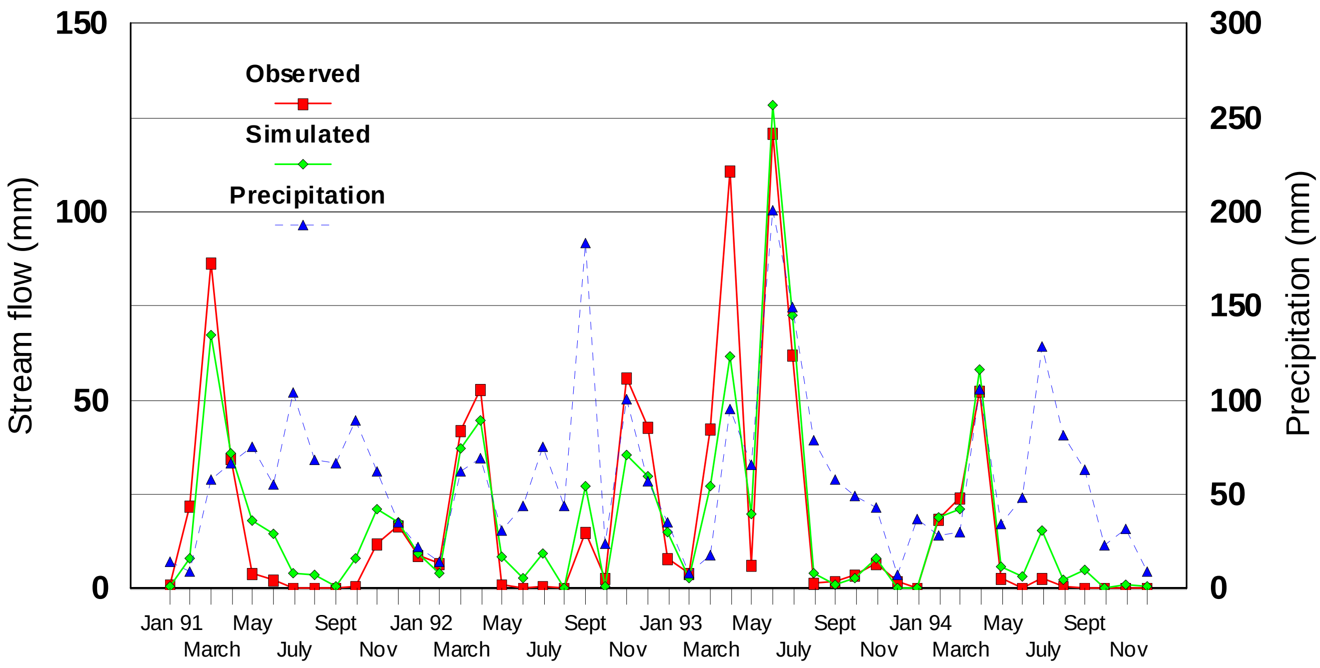




Untransformed: R^2 = 0.80, NSE = 0.80

Untransformed: R^2 = 0.95, NSE = 0.94

for n = 12, not ice-affected events



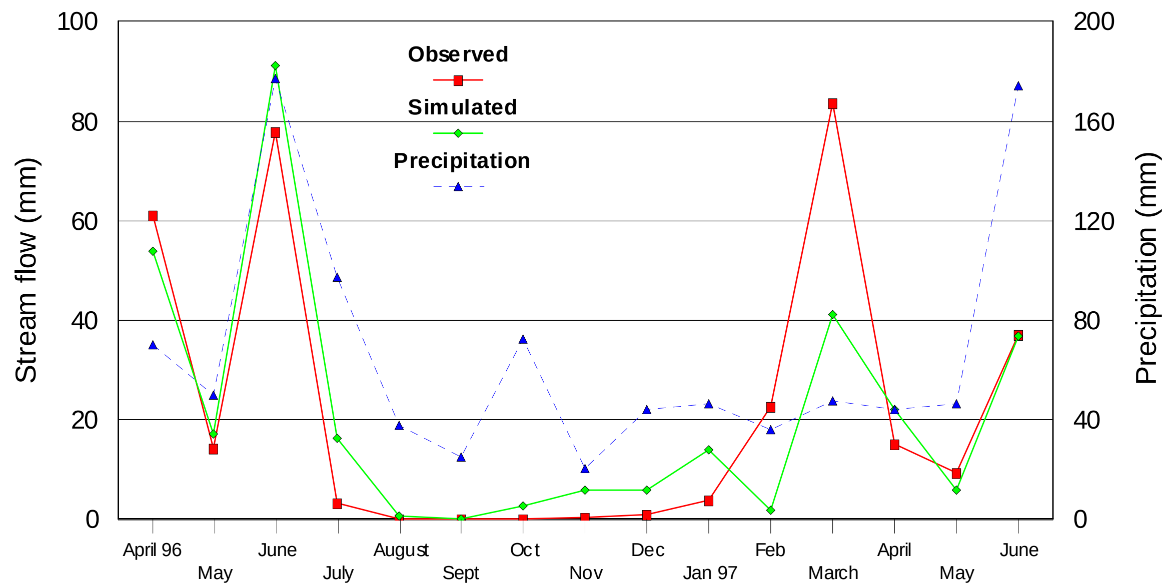
Observed and simulated monthly stream flow - Upper Bower Creek.
1990-94 calibration period. Precipitation from US

Calibrate Monthly Stream flow Upper Bower Creek

R^2=.87, NS=0.86

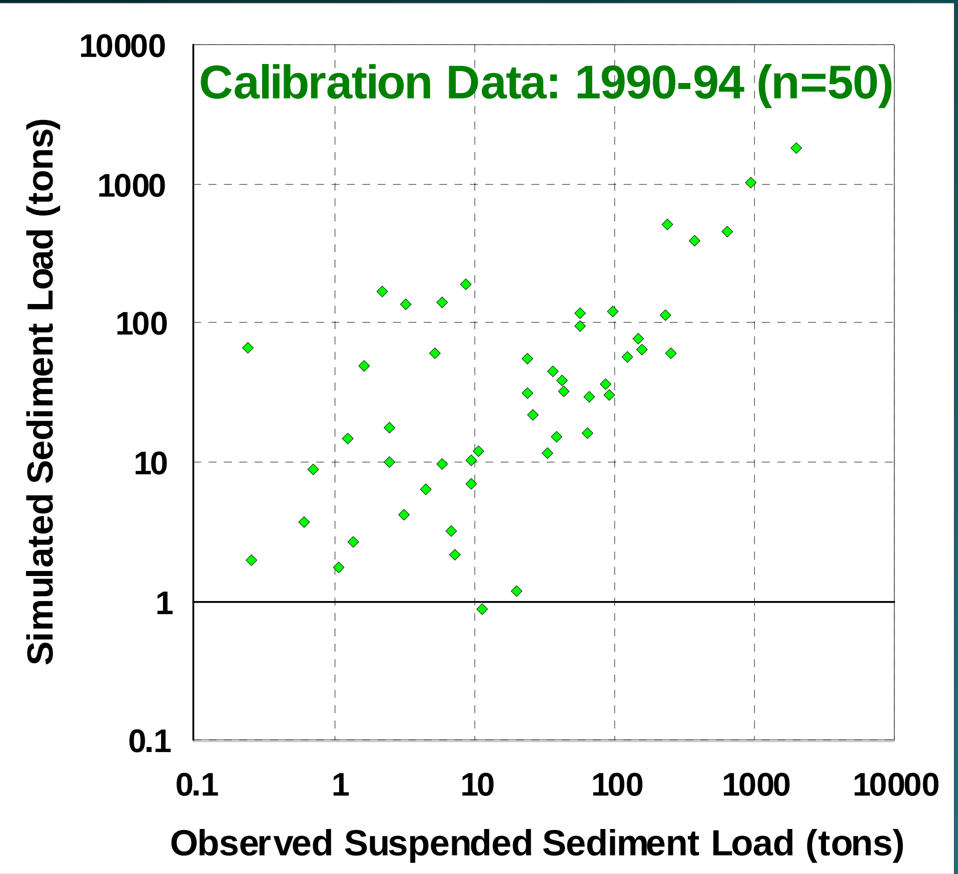
Validate Monthly Stream flow Upper Bower Creek

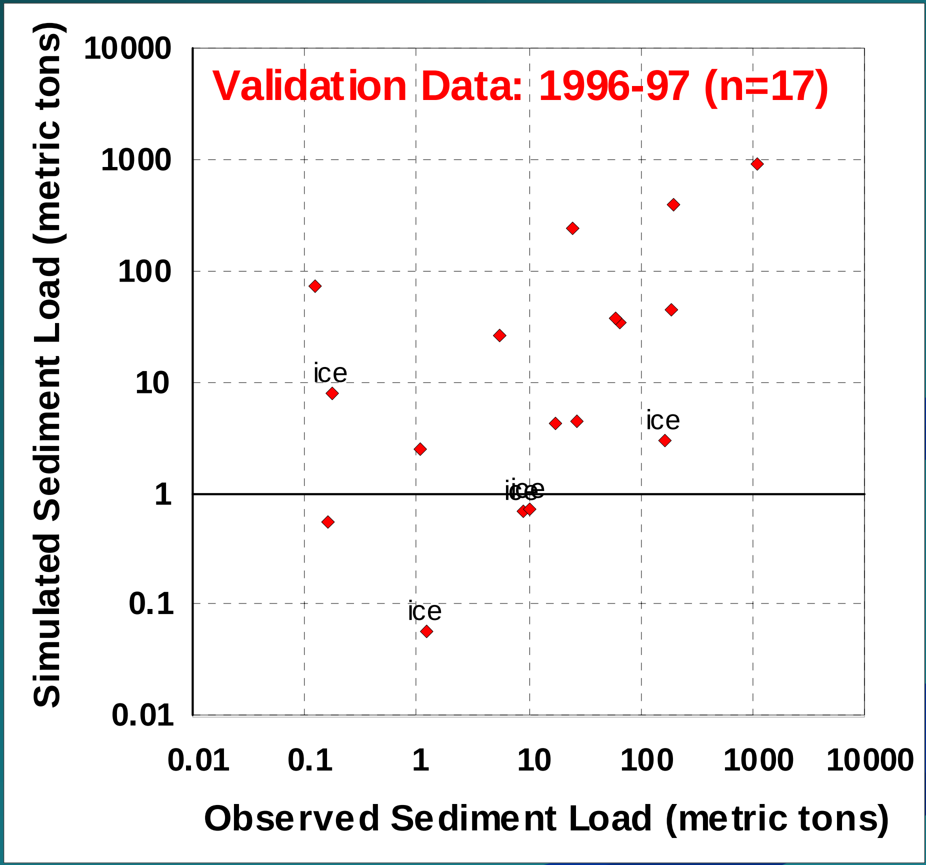
R^2=0.76, NS=0.76



Observed and simulated monthly stream flow - Upper Bower Creek.
1996-97 validation period. Precipitation from USGS weather stations is also shown.

Calibrate – Validate: Suspended Sediment Upper Bower Creek events





Untransformed: R^2 = 0.96, NSE = 0.95

Untransformed: R^2 = 0.85, NSE = 0.85

Model Assessment Summary

- In general, a fairly good correspondence between simulated and observed stream flow and loads of phosphorus and suspended sediment (daily, event, monthly, annual, totals)
- Model response acceptable for predictive simulations in sub-basin
- Model least able to predict flow and loads:
  - from small events, affected phosphorus loads most
  - after prolonged dry periods
  - during snow melt periods
- Current LFRWMP monitoring project will greatly assist in improving and/or validating model (5 watersheds)

Model Results – Year 2000 Baseline Conditions

- Stream flow and loads at sub-basin, watershed and sub-watershed scales

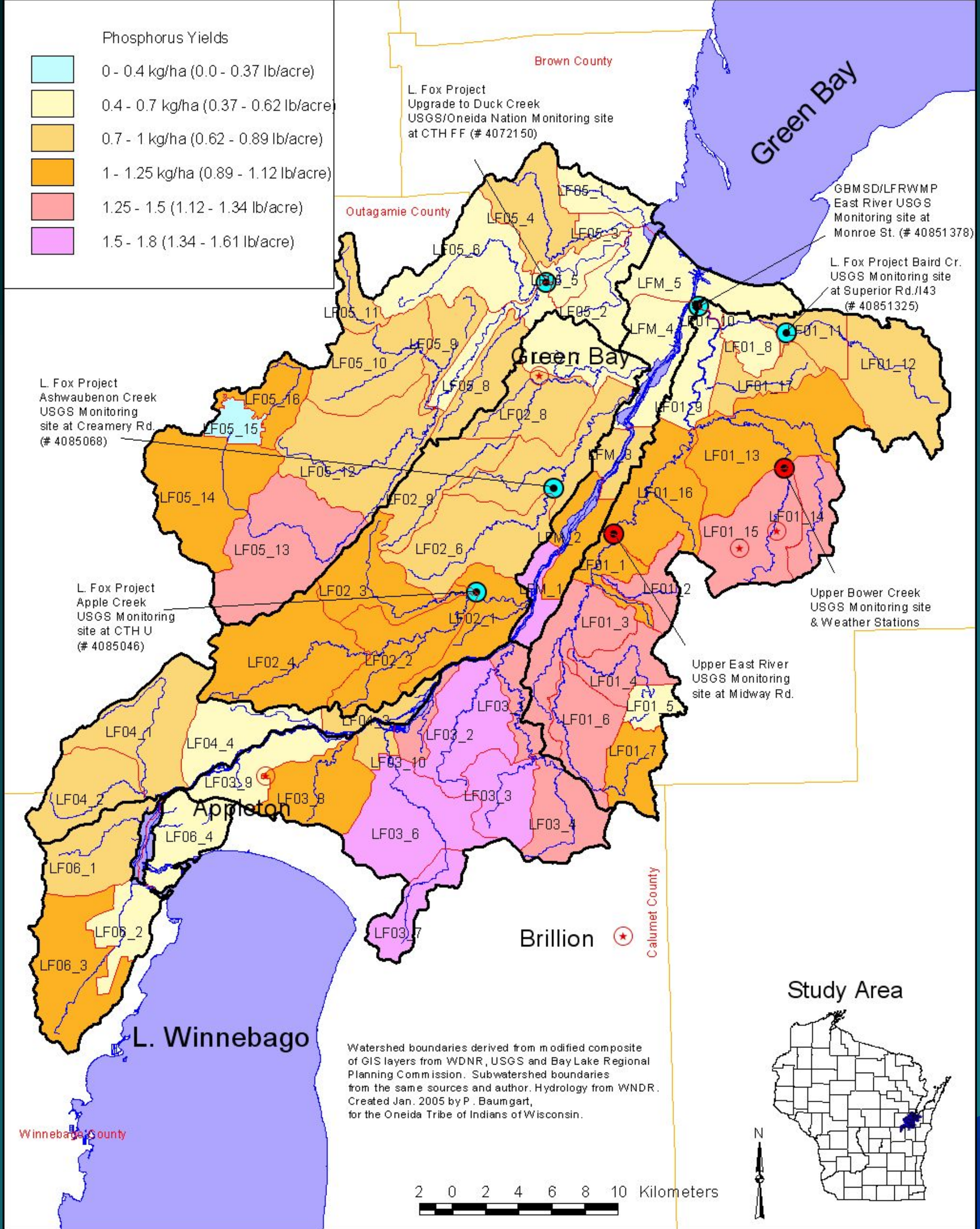
- Total, and by HRU/landuse category

- Examples of modeled output

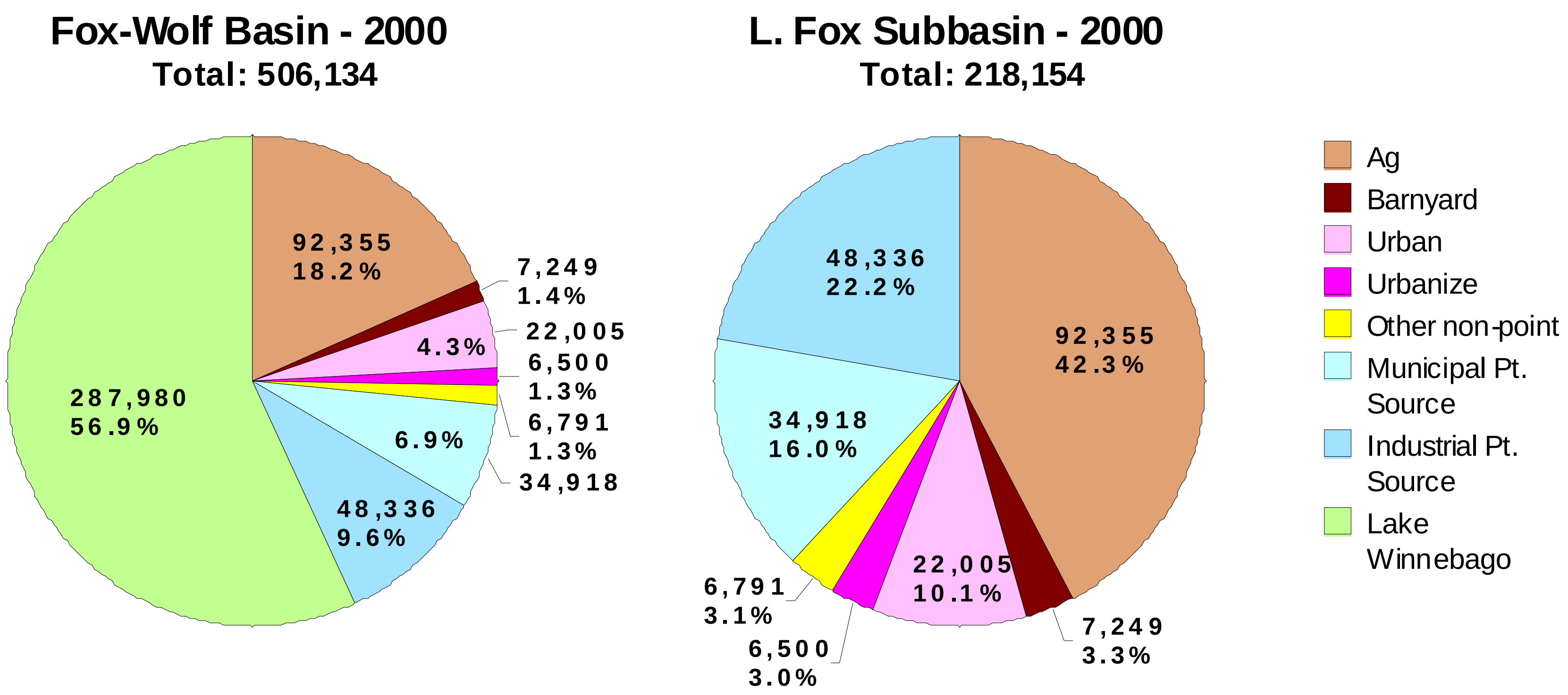
Lower Fox River Watershed

Simulated Subwatershed Phosphorus Yield (kg/ha)

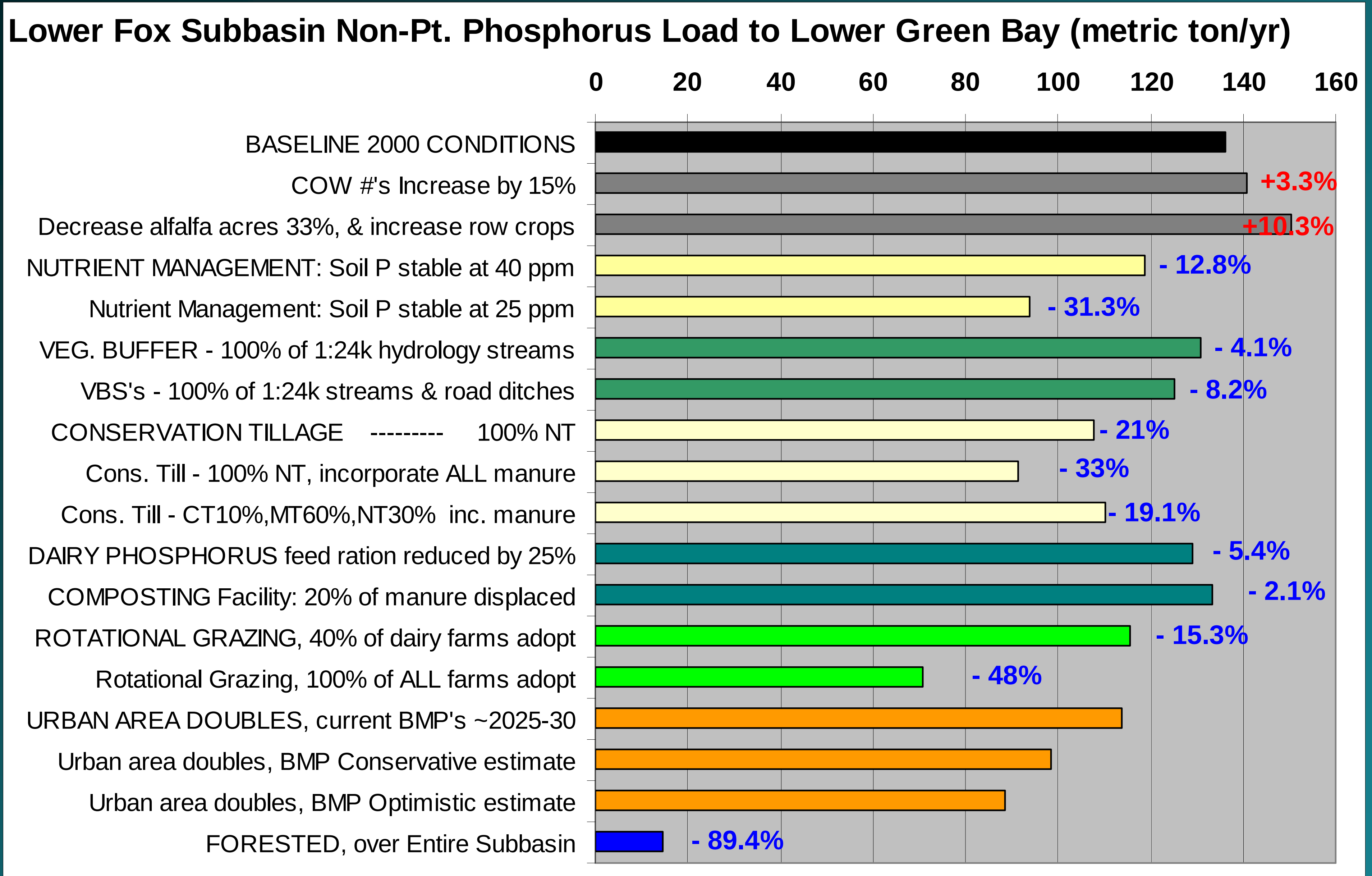
Baseline 2000 conditions



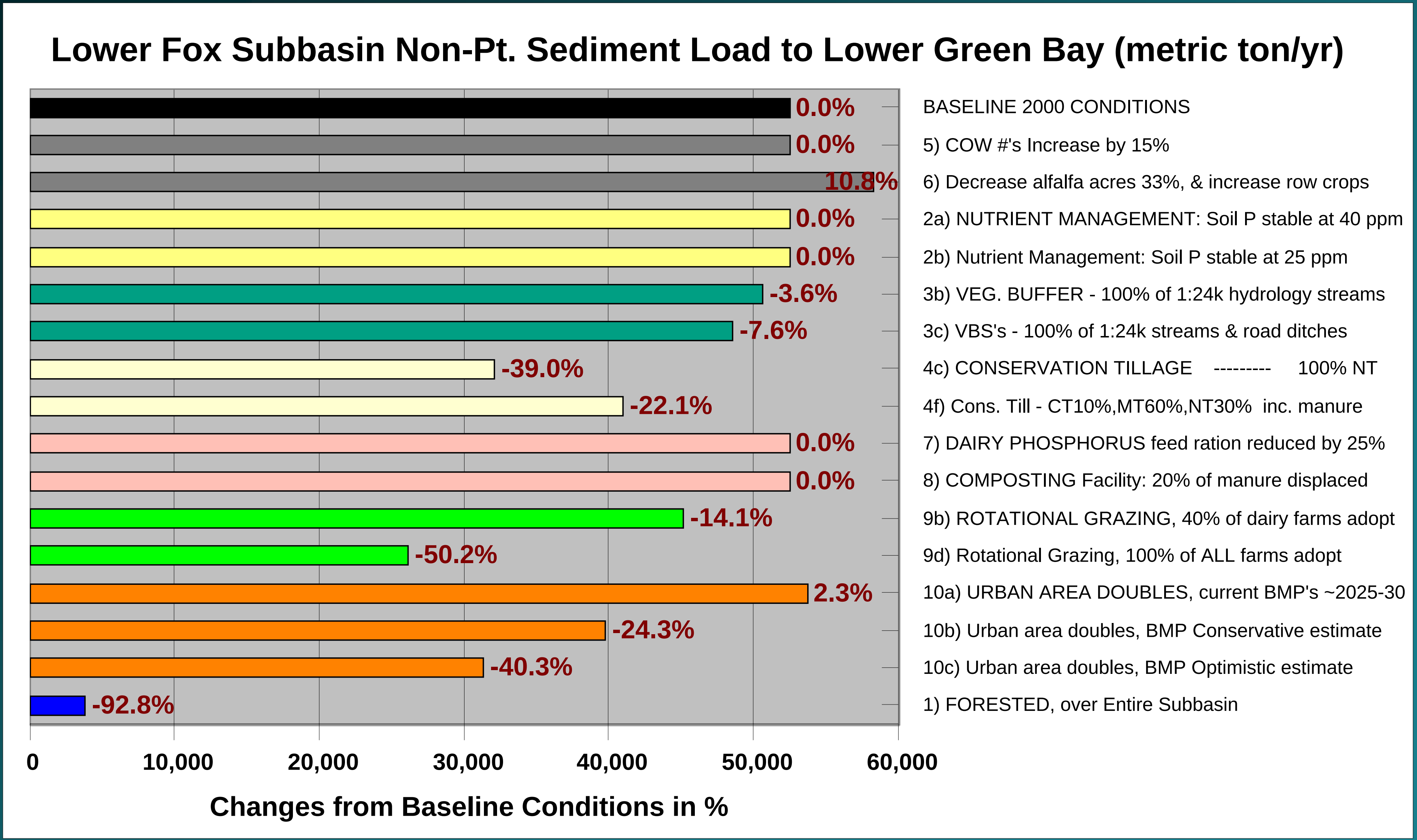
Phosphorus Load Allocation to Lower Green Bay (kg/year)



Alternative Management Scenarios



Alternative Management Scenarios



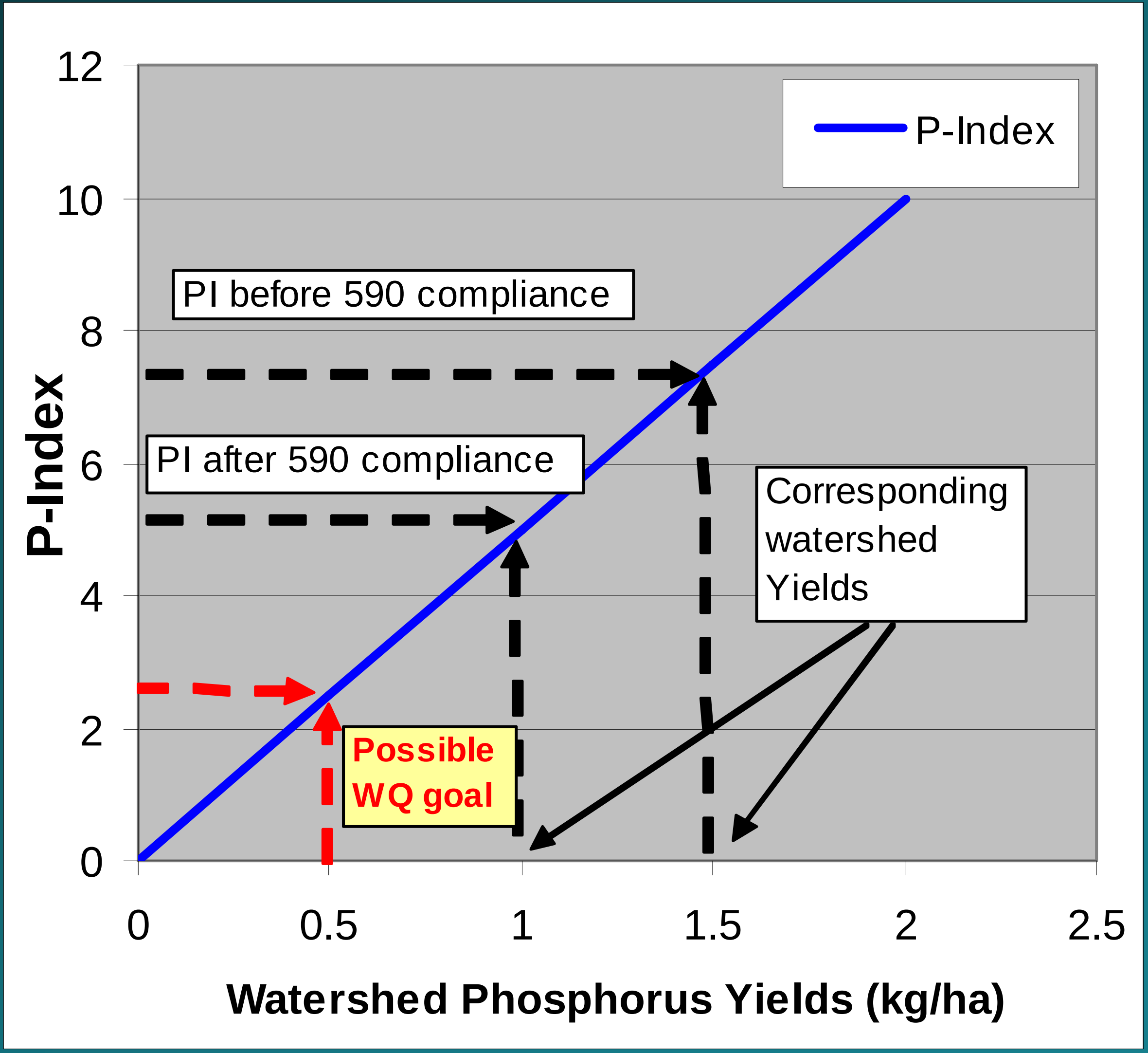
SWAT Simulations: Conclusions

- Overall, model performed reasonably well during calibration and validation periods
- Simulated P export to Green Bay close to loads estimated by V. Klump et al. (1997) D. Robertson (2004)
- Substantial variation among watershed yields was simulated within the sub-basin
- Relatively wide range in simulated P and SS reductions from alternative scenarios
- Greatest simulated P and SS Ag. reductions:
  1. Intensive rotational grazing, followed by:
  2. Conservation tillage
  3. Nutrient management
- Flow regime changes from urbanization will likely create unstable stream banks and stream beds. A revised model needs to account for these changes

SNAP-Plus P-Index Analysis

Primary Goal

- Can SNAP-Plus be utilized as a tool at the farm level to achieve water quality objectives?



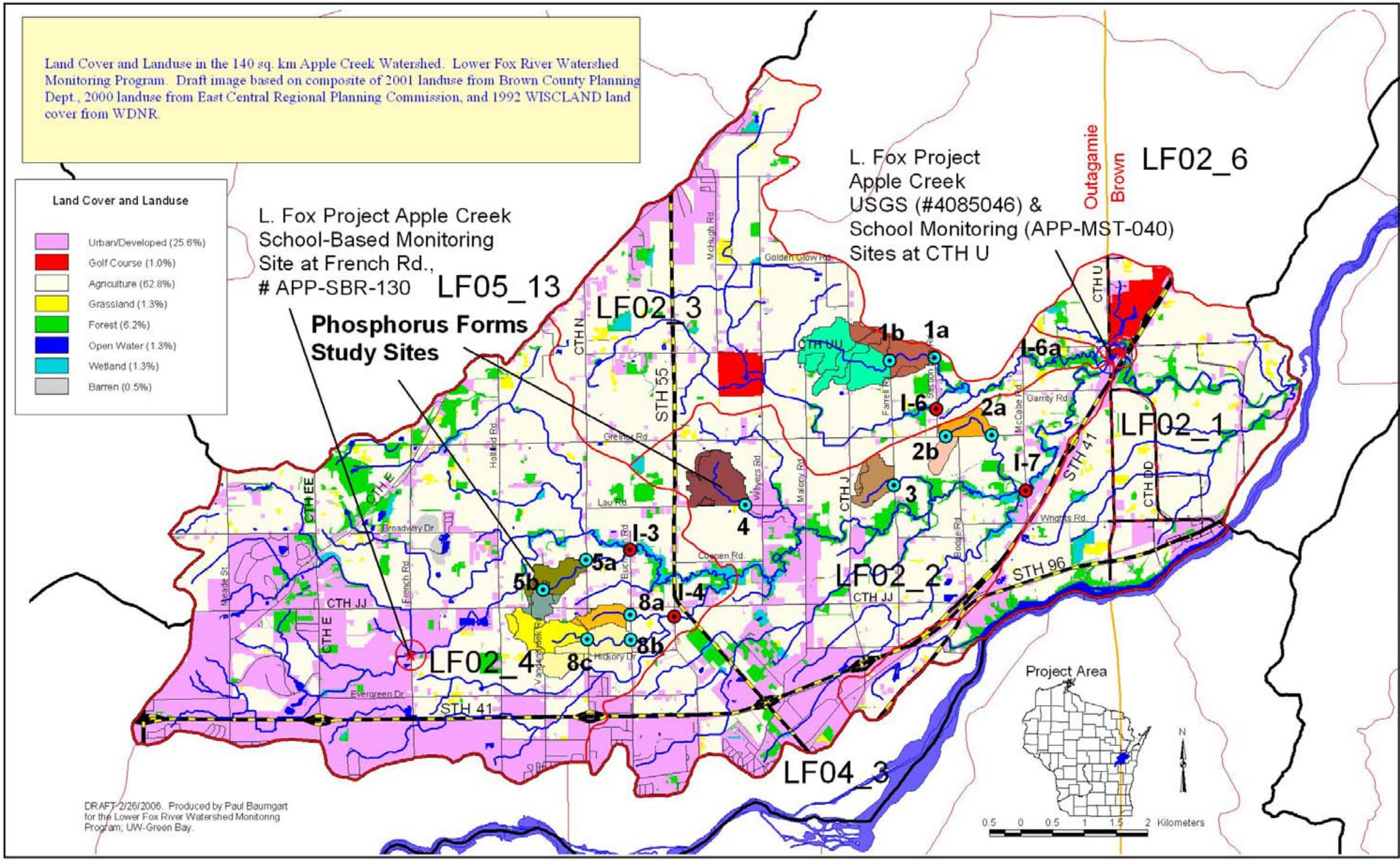
P-Index Analysis: Objective

- Compare stream water quality to P-Index values at:
  - sub-watershed scale (~ 0.25 to 3+ sq. km)
  - watershed scale (12 to 85 sq. km)
  - USGS watershed outlet (117 sq. km)

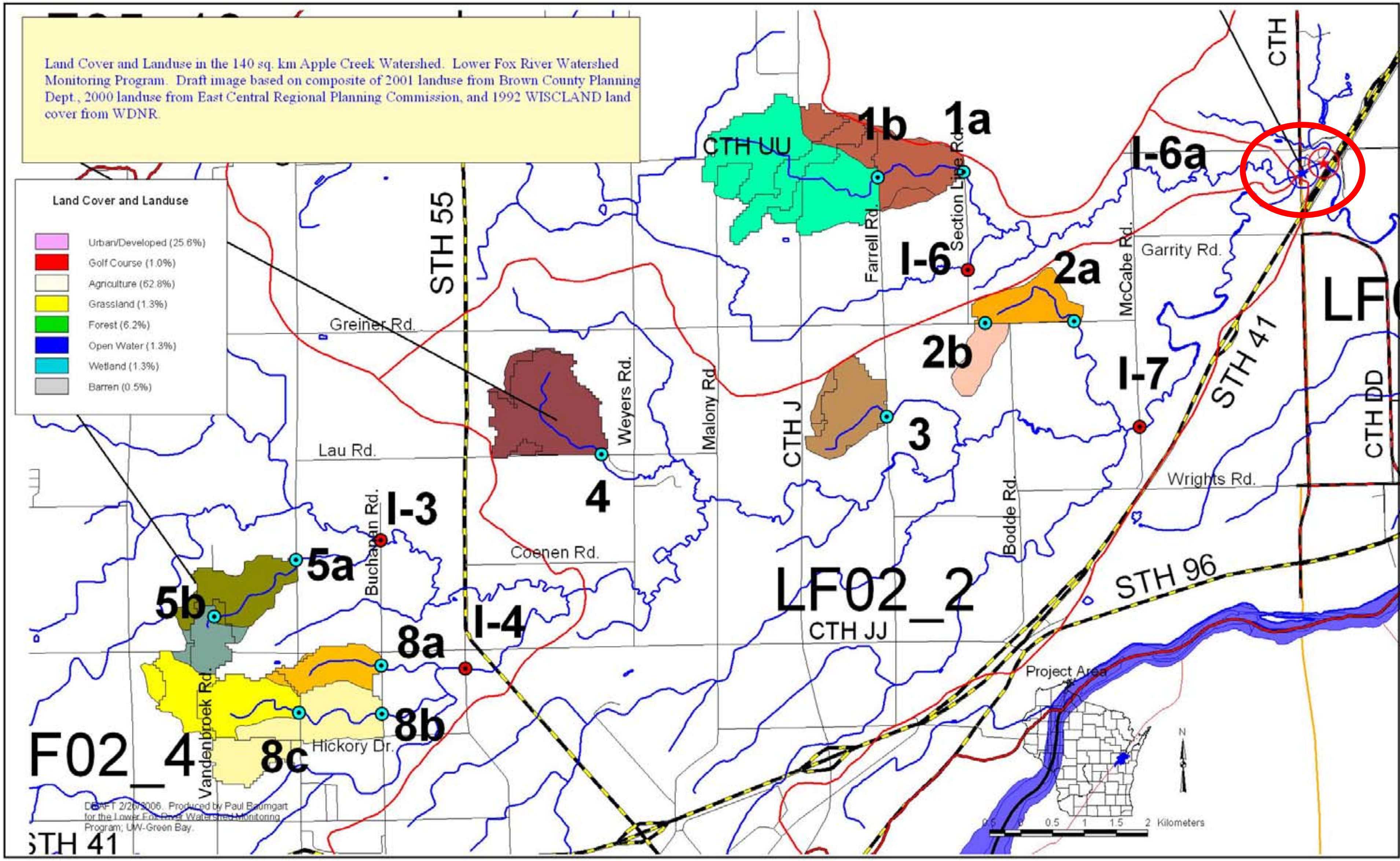
SNAP-Plus Model

- SNAP-Plus developed by University of Wisconsin (L. Bundy, L. Ward-Good, B. Pearson, P. Kaarakka & others)
- Farm management Tool, operates at field scale (farm and field outputs)
- Comprehensive Nutrient Management software:
  - Conservation Plan (RUSLE2)
  - Nutrient Management Plan (NRCS 590 – P based)
  - Record keeping and feed management program
  - Manure and wastewater manager
- Semi-Quantitative P-Index – Wisconsin research findings incorporated into model
- Validated with field scale WQ data (Discovery farms, etc.)
- RUSLE-2 to compute soil loss to field edge
- Particulate & soluble P components, plus P in runoff due to surface applied manure (frozen & non-frozen)

Water Quality Monitoring Sites and Landuse
Apple Creek P-Forms Study



Apple Creek P-Forms Study Monitoring Sites – close up



Monitoring Methods: Apple Creek

- RUNOFF EVENTS: Grab samples at 11 Source Area (0.2 to 3 km^2) and 4 integrator sites (12 to 85 km^2), at or near peak flow
  - Targeted uniform precip events
- Source area sites selected in quasi-random basis (agricultural landuse; suitable discharge, area not too large)
- Downstream Main Stem USGS Site: Continuous discharge & automated samples at campground (117 km^2)
- TSS, total P, dissolved P analysis
- Samples collected during 5 runoff events (March to June, 2004), plus 1 in 2005, 2 complete events 2006

Apple Creek trib: May 23 2004 site #3 downstream

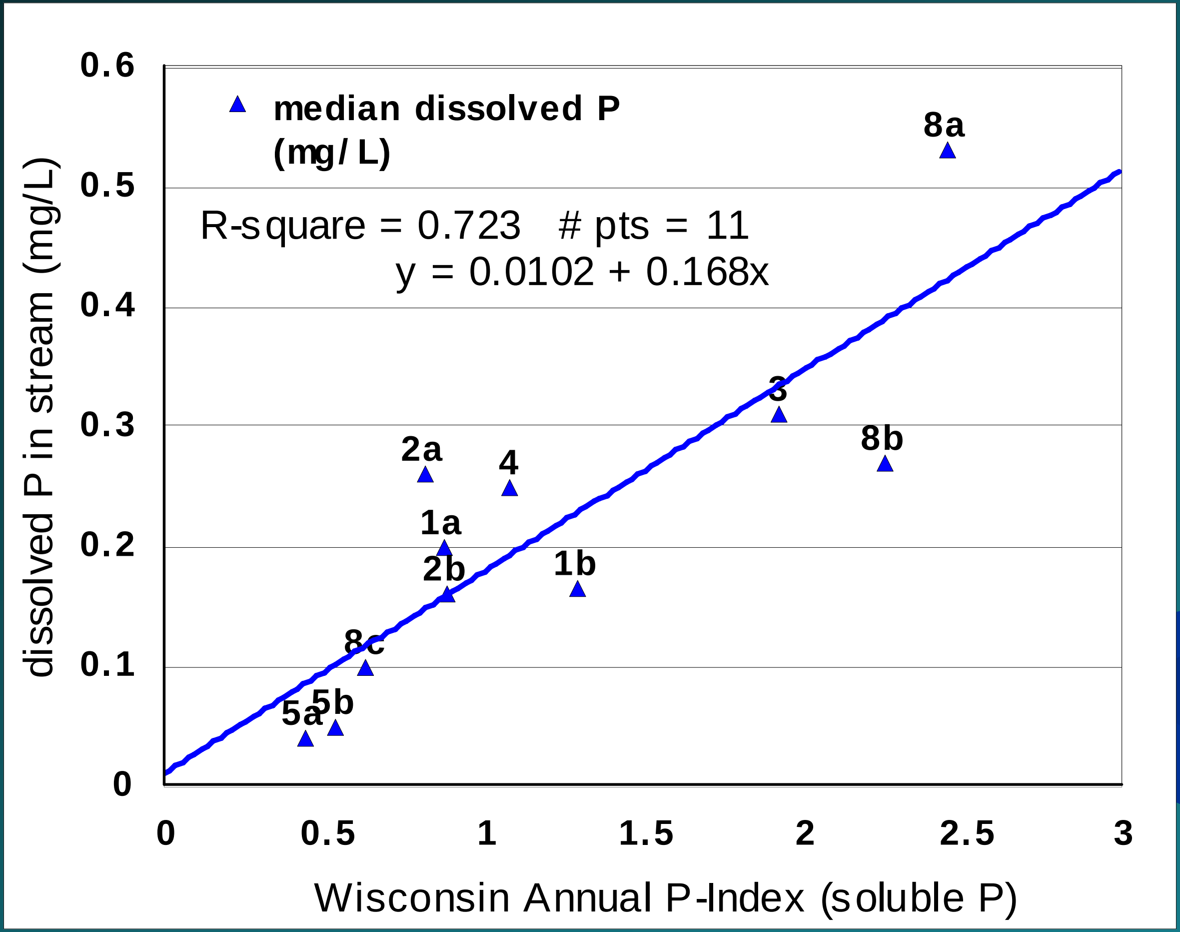
P-Index and Farm Field Analysis

- Farm field input data: Nutrient Management Plans and WPDES Permits → SNAP-Plus P-Index model
- Soils, slope, crops, tillage, fertilizer/manure, etc.
- Farm field data collection not complete
- Nutrient Management Plan data input to SNAP-PLUS
- Applied SNAP-Plus → Preliminary P-Index values
- SNAP database output linked to GIS to derive area-weighted sub-watershed P-Index values

Preliminary P-Index Results

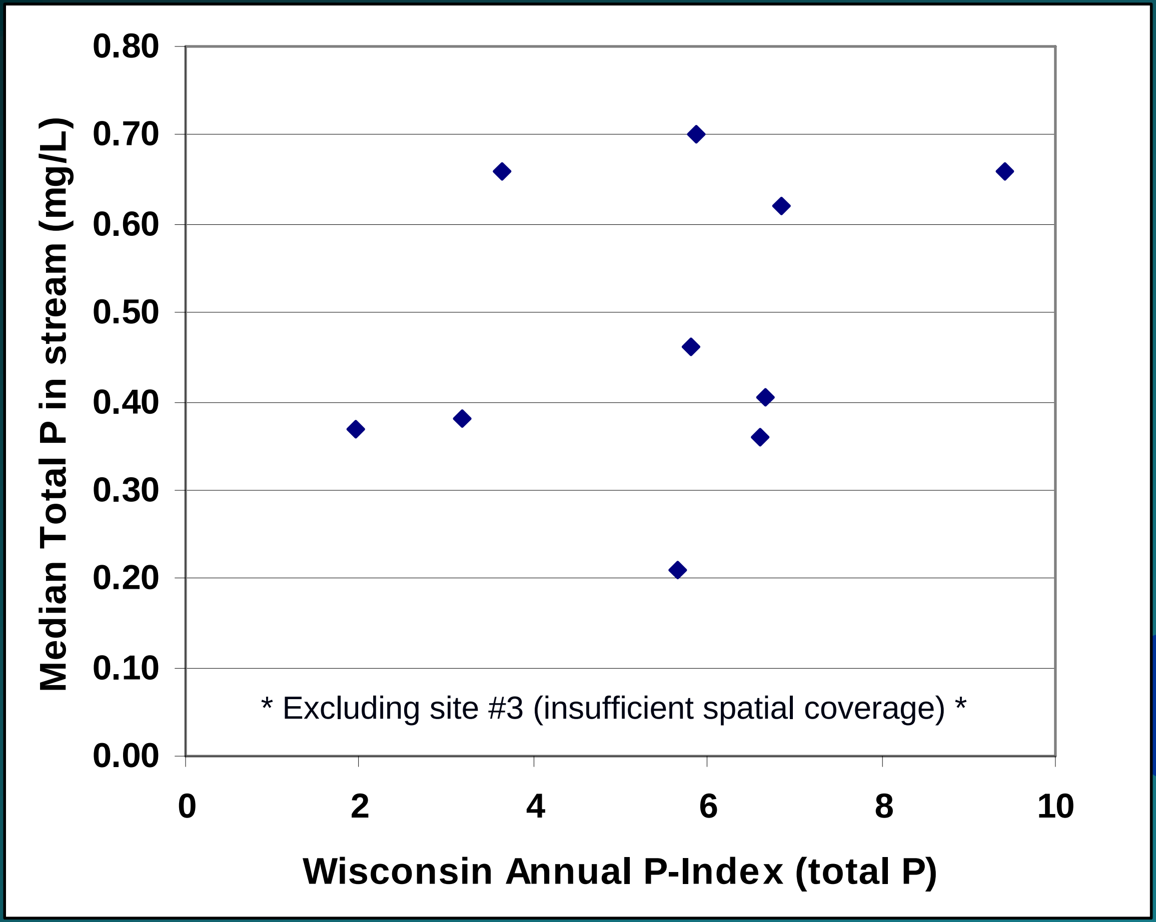
- 2004 data with 5 uniform events analyzed (moderate to high events)
  - 2005: 1 event
  - 2006: 2 complete events thus far
  - these events not included in analysis yet

P-Index vs In-stream (dissolved P)



- Preliminary: P-Index for dissolved P correlated to median dissolved phosphorus concentrations at subwatershed outlets (5 moderate to large runoff events in 2004)

P-Index vs In-stream (total P)



- **Preliminary**: P-Index for total P not well correlated to median total phosphorus concentrations at sub-watershed outlets (5 moderate to large runoff events in 2004)

P-Index Watershed Assessment

FURTHER WORK NEEDED!

P-Index vs Stream data Explanations for differences in total phosphorus measures

- PRELIMINARY FIRST-CUT ANALYSIS
- Farm field inputs - insufficient spatial coverage
- Highly sensitive to crop differences (e.g., alfalfa vs corn silage)
- Soil loss estimates - likely major factor (dissolved P OK)
  - Sediment delivery to sub-watershed outlets
  - Default 0-300’ distance to channel used as input

P-Index Analysis - Conclusions

- Relative P-Index values generally reflect WQ measurements for dissolved P at 11 sub-watershed outlets
- Data inputs need to be refined (TP, TSS)
  - Increase spatial coverage, extrapolate where data missing
- In-stream DP closely parallels Soil-test P (Bray-P1), where data available
  - Available soil-P implicated as major source of stream DP
- Dissolved P fraction average of 45% at 11 sub-watersheds and 4 integrator sites.
  - Coincides with earlier findings in Lower Fox tributary monitoring
- LFRWMP: DP loads ~45% to 55% in 2004-05

Next Steps

- Complete P-Index modeling in Apple Creek
- Complete SWAT modeling at different spatial scales in Apple Creek and for 5 LFRWMP watersheds (refine calibration/validation)
- Refine SWAT stream bank erosion estimates - Sediment source tracing with radionuclides
- Compare P-Index and SWAT model results to observed data at different scales
- Evaluate ability of models to mimic relative or absolute monitoring results for total P, dissolved P, and TSS

Acknowledgements

Special thanks to the following people for their assistance with this project:

- Dave Graczyk, Paul Reneau, Dale Robertson and Troy Rutter -- U.S. Geological Survey
- John Kennedy and Tracy Valenta, GBMSD
- Oneida Nation
- Outagamie LCD (Sue McBurney, Jim Poweleit, Ann Francart
- Laura Ward Good (UW-Madison)
- Bud Harris, Dave Dolan -- UWGB
- Jesse Baumann, Jessie Fink, Jon Habeck, Erika Sisal -- UWGB
- Arjo Wiggins Appleton, Inc.

Questions?

Email: baumgarp@uwgb.edu

Full reports: www.uwgb.edu/watershed/reports/LFox_Load-Allocation.pdf (and other reports)