Lower Fox River Suspended Sediment and Phosphorus Load Allocations and Reduction Strategies to Green Bay using the Soil and Water Assessment Tool (SWAT)

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

SWAT International Conference

October 17-19, 2008

Beijing, China

UNIVERSITY of WISCONSIN GREEN BAY

THE LOWER FOX RIVER watershed monitoring program

With additional support from EPA funding of the Integrated Watershed Approach Demonstration Project A Pollutant Reduction Optimization Analysis for the Lower FoxRiver Basin and the Green Bay Area of Concern (Laura Blake of The Cadmus Group and Sam Ratick of Clark University)

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

Paul Baumgart

- A watershed modeler with "one boot in the field"
- Responsible for monitoring and modeling in the Lower Fox River Basin.
- 15 years experience with SWAT

Presentation Outline

- Background: Lower Fox River Sub-basin Description
- Modeling Methods and Inputs
- Calibration and Validation
- Model Results: Simulated Phosphorus and Suspended Sediment Export from Sub-basin
- Alternative Management Scenarios

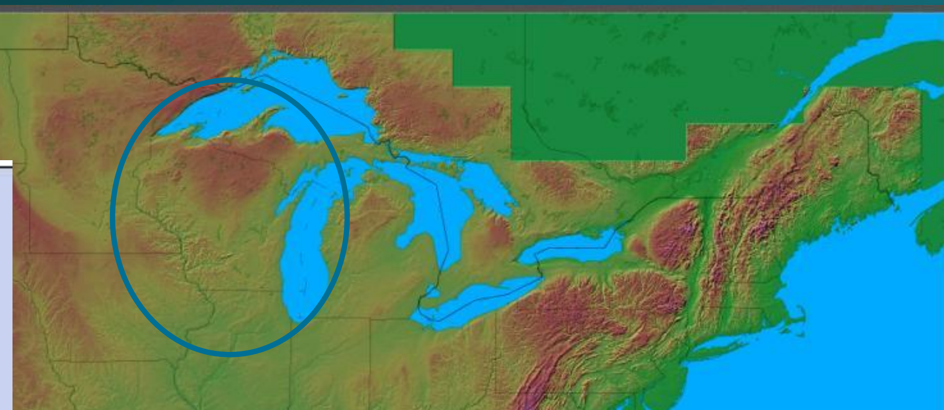
Primary objective

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

TMDL = Total Maximum Daily Load

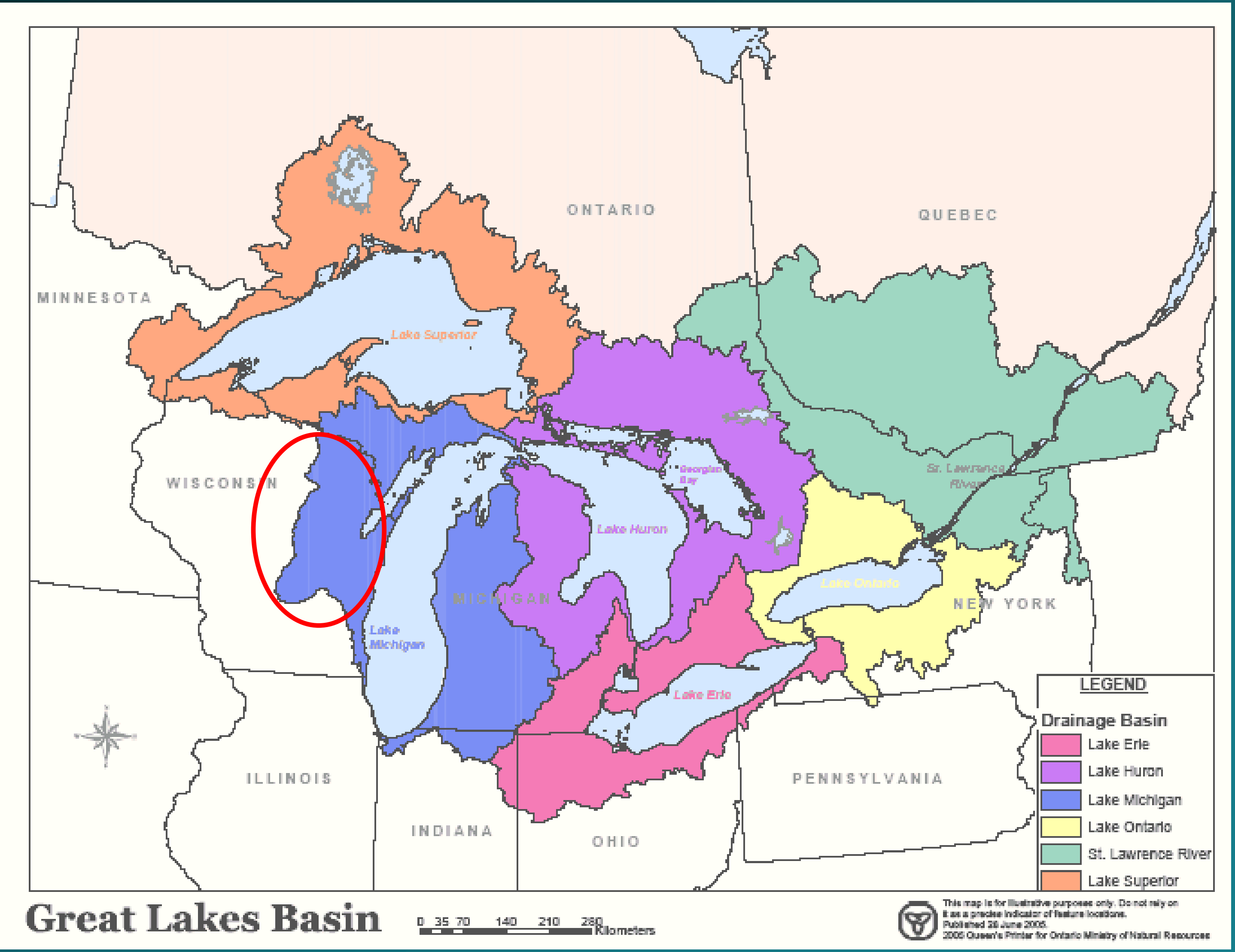
= Watershed pollutant load reduction plan

Lower Fox River, Wisconsin, Great Lakes Basin

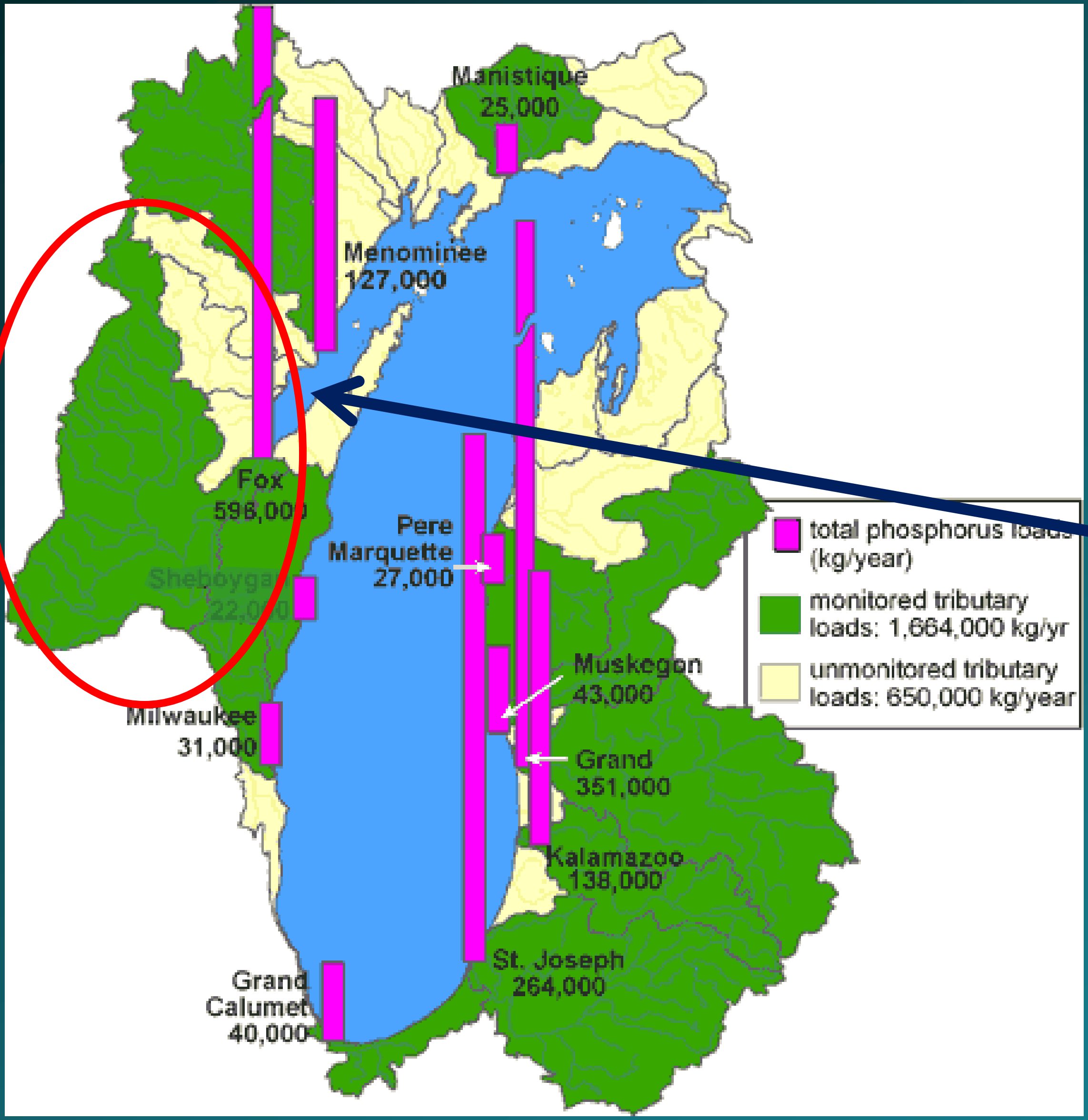


Lower Fox River, Wisconsin, Great Lakes Basin

Lower Fox River, Wisconsin, Great Lakes Basin



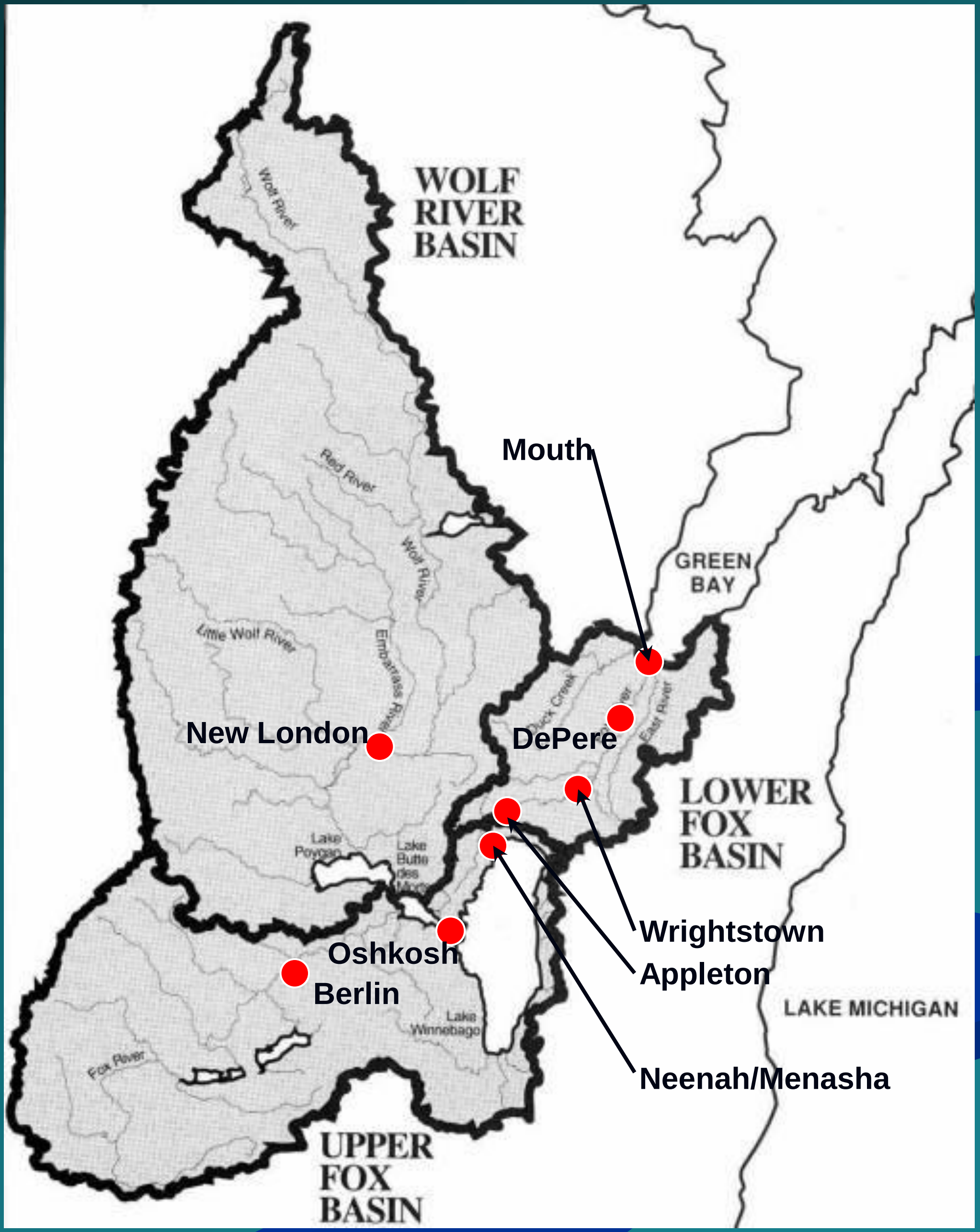
Tributary Loads of P to L. Michigan

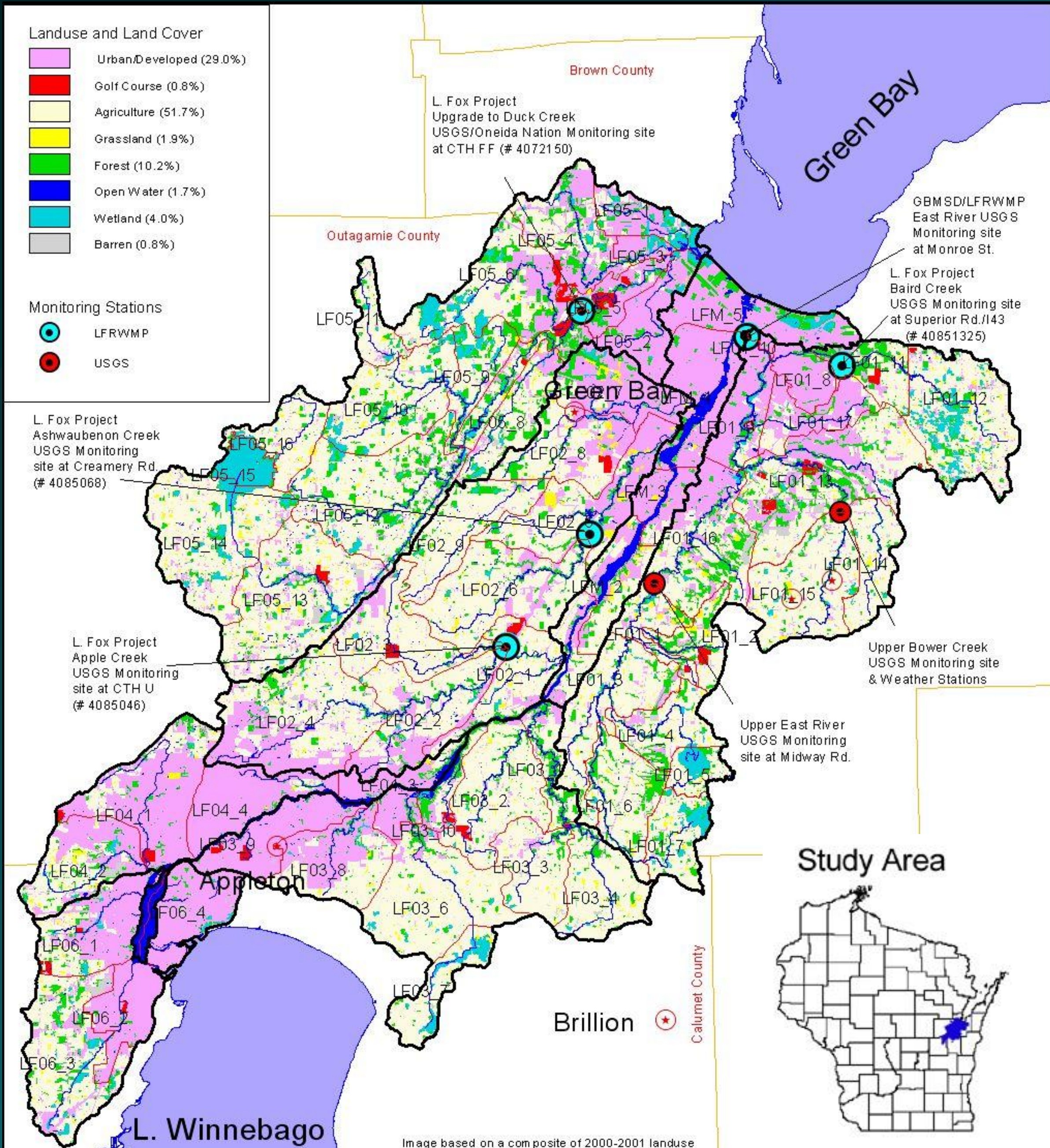


- Fox River ~ 25% of total annual load to L. Mich.
- 15% of L. Mich. Watershed Area
- 70% of P load to Green Bay

Fox-Wolf Basin

- Total P Load from Fox River into Green Bay:
  ~ 540,000 kg/yr
  ~ 80% from runoff
- Lower Fox Basin
  - 1580 km^2 (10% of FWB)
  - ¼ P
  - ½ Suspended Solids





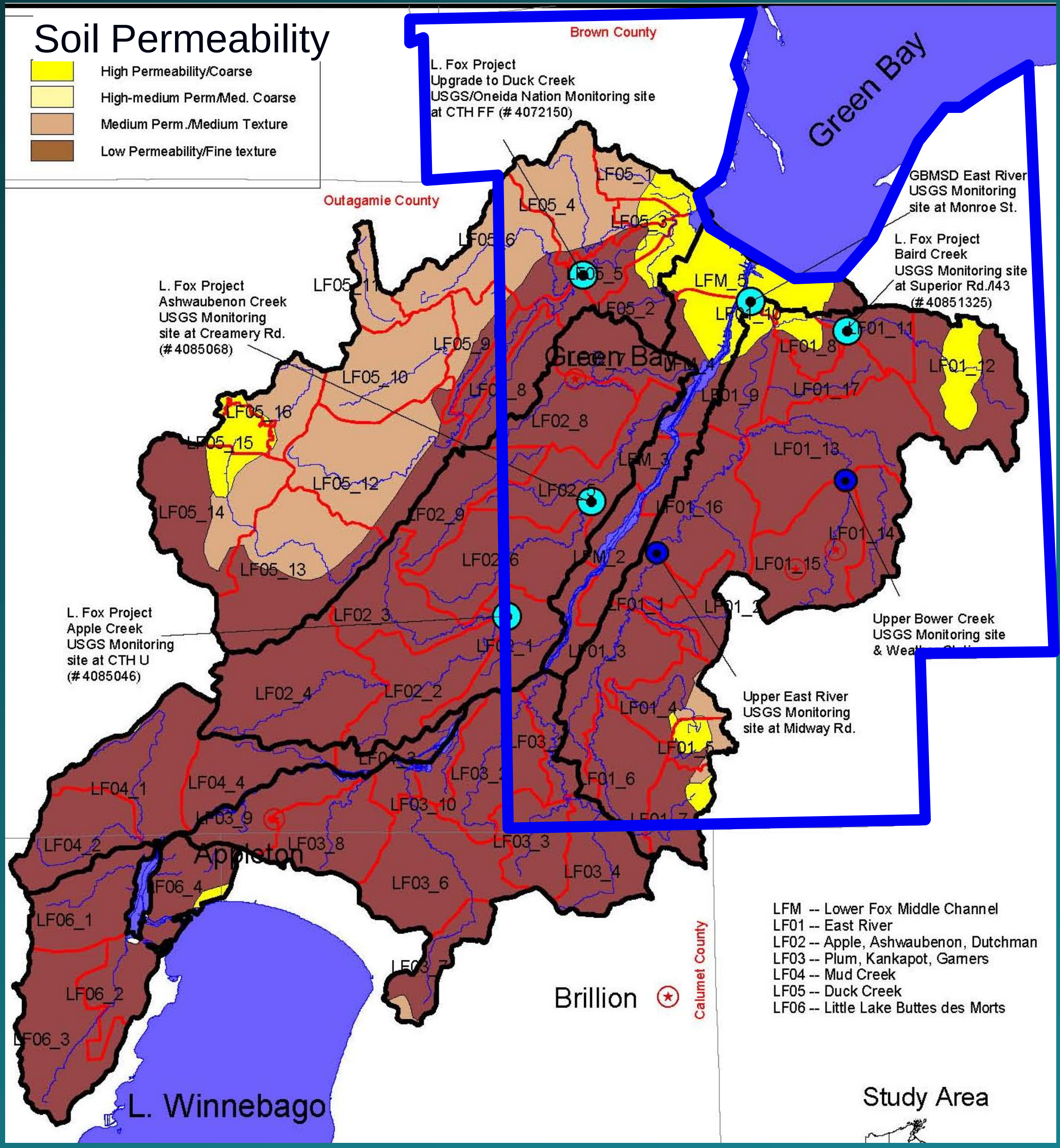
2002 Landuse and Land Cover

- 52% Ag/Rural
- 29% Urban/Dev.
- 10% Forest
- 4% Wetland

- Significant reduction of P and Sediment from Ag. needed

Watershed background:

- Clay soils
- High % runoff
- 730 mm precip avg
- ~ 200-240 mm flow
- ~ 16-27% baseflow



Runoff Sources of P & Suspended Solids

Soil and Water Assessment Tool - SWAT

Previous Modeling at University of Wisconsin-Green Bay:

- Marcus (SWRRB; 1993)
- McIntosh et al. (EPIC, SWRRB, AGNPS; 1993a, 1993b, 1994)
- Qui (SWRRB; 1993); Sugiharto et al. (EPIC; 1994)
- Baumgart (SWRRB and SWAT; 1994a, 1994b, 1998, 2000, 2005 - 2007).

This Study:

- Applied *modified version of SWAT 2000 code*
- GIS > spreadsheet > SWAT 2000 & reversed for output: to allow more flexible/complex management files

Model Inputs – GIS layers

- Landuse – land cover
  - Wisconsin1992; local agencies – 2000 to 2004
  - Trends LULC
- Soils – County SSURGO
  - sub-watershed area-weighted averages
- Slope – 30 m DEM, land cover specific (i.e. wetland forest, ag, urban)
- Watershed boundaries – state, federal, local
- Wisconsin Stream hydrology 1:24k, + County Buffers
- ARC-INFO, ARCVIEW, Spatial Analyst (ESRI)
- Climate: 1976-2000 daily, 3 NWS long-term stations (long-term scenarios)
  - Plus 15 UWGB & USGS tipping buckets & loggers
- Point source loads from WDNR

Primary Hydrologic Response Units (HRUS)

- Agriculture - DAIRY (6 year crop rotation of corn-grain, corn-silage, soybean, 3 years of alfalfa); **~ 80%**
  - 1 Conventional tillage practice
  - 2 Mulch-till (>30%)
  - 3 No-till
  - 4 Barnyards
- Ag – CASH CROP (1 yr corn, 1 yr soybean); **~ 20%**
  - 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
- 31 HRU's Constant = (dairy 6 x 3) + (cash crop 2 x 3) + barnyard + 6 (non-ag); 0.0000001 if area = 0

Agricultural HRU's

- Percent crops in subwatersheds derived from WISCLAND land cover
  - adjusted to fit Wisconsin Ag. Statistics

- 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) separated into DAIRY and CASH CROP
  c) construct SWAT dairy and cash crop management files

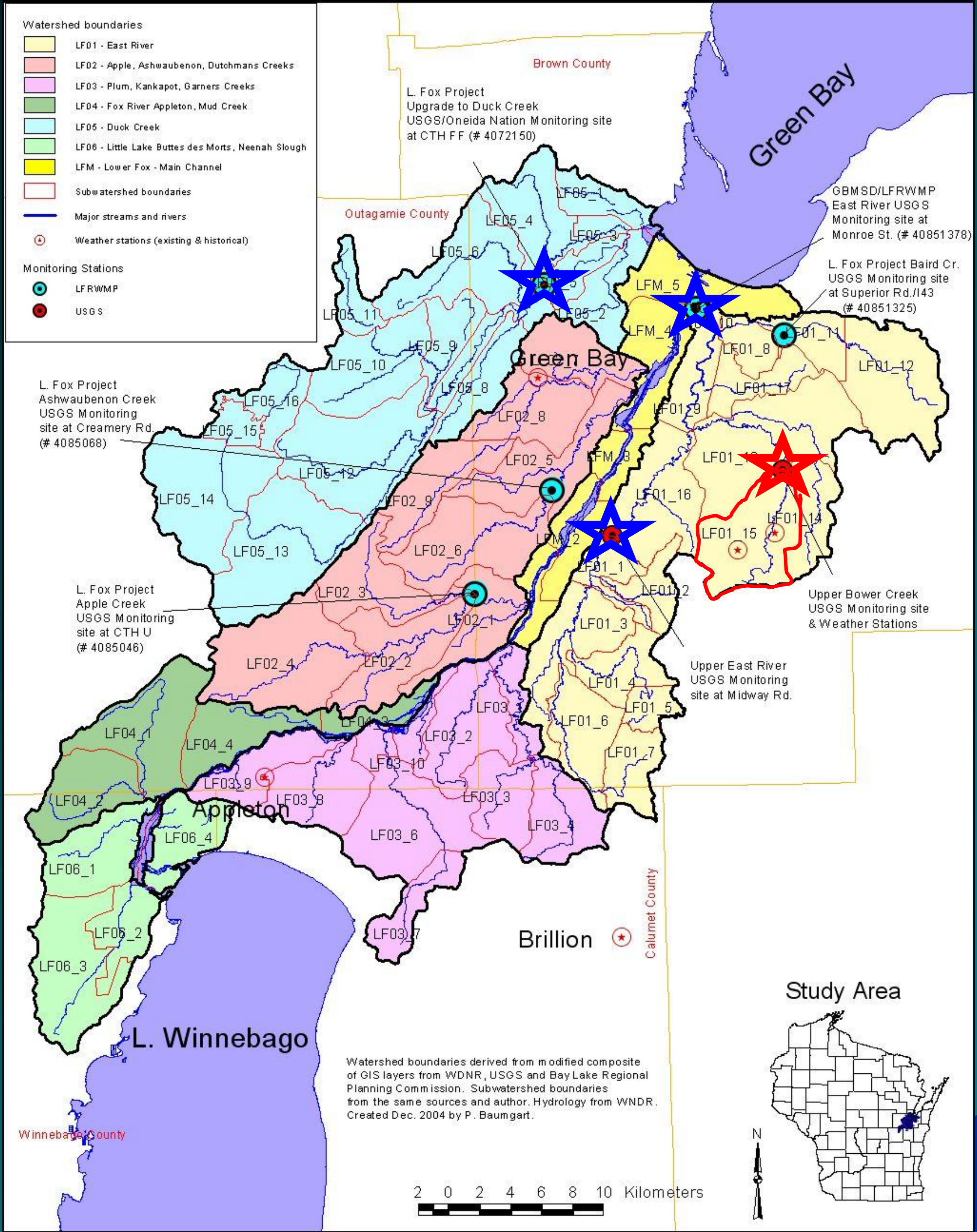
- Crop Yields Calibrated (Wisconsin Ag. Stats for Brown County)

- Barnyard loads - SWAT simulations calibrated HRU to BARNY modeled phosphorus loads (barn yard model)

- Manure and Fertilizer Inputs (UW-Ext Ag experts, NRCS and others)

Primary Model Modifications

- Potential Evapotranspiration equations modified
  - Water yield still low, so Hargreaves-Samini PET equation multiplied by 0.81 (all methods relatively similar results after HS & PT code fixes)
- C-factor equation separated: 1) surface residue 2) canopy biomass (else C in plowed field too close to no-till when crop well underway)
- MUSLE Sediment equation modified to EPIC/APEX form, calibration simplified for suspended sediment loads (ysed.f)
- HRU's utilize sub-watershed channel length & area in MUSLE
- NRCS curve numbers in management files altered automatically according to soil hydro group to reduce # of *.mgt files (readmgt.f)
- SWAT 2000 code fixes: wetland P trapping; perennial alfalfa kept growing after kill; allow min crop growth if < base temp, …
- Other changes: 1) Input Temp adjust to force snow/rain based on observed precip form; 2) QUAL2e P transport: excess P in chlorophyll from subwatersheds - minimize P content “temporary fix”



Calibration & Initial Validation Sites

PRIMARY SITE:
Daily flow and loads
Bower Creek - 36 km²

Calibrate 1991-94
Validate 1996-97

SECONDARY SITES for VALIDATION:

- *Daily flow and limited samples:*

  East River at Midway - 121 km²

  Duck Creek - 276 km²

  East River - 374 km²

Model Calibration & Assessment

- Calibrate:
  1. total flow & base flow
  2. crop yields, biomass and residue, soil nutrient levels
  3. suspended sediment
  4. phosphorus
  5. dissolved P

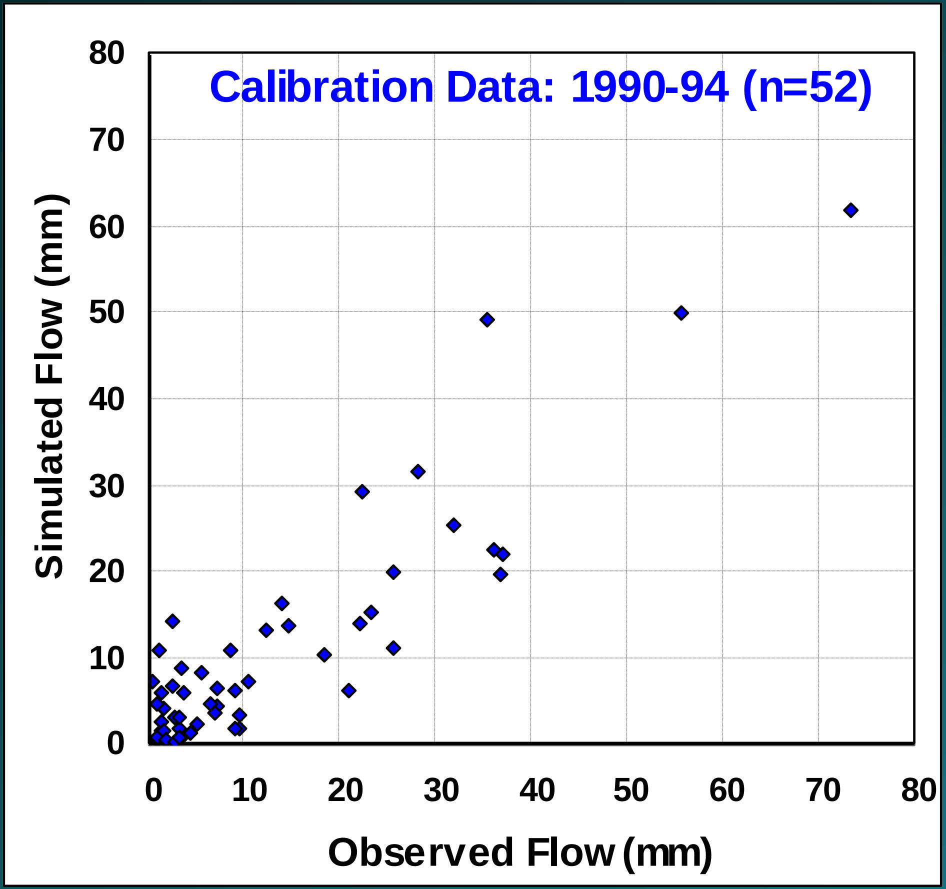
- Validate/assess: flow, SS, P at different time periods/sites
  - event
  - monthly
  - annual
  - total basis

Initial Calibration & Validation

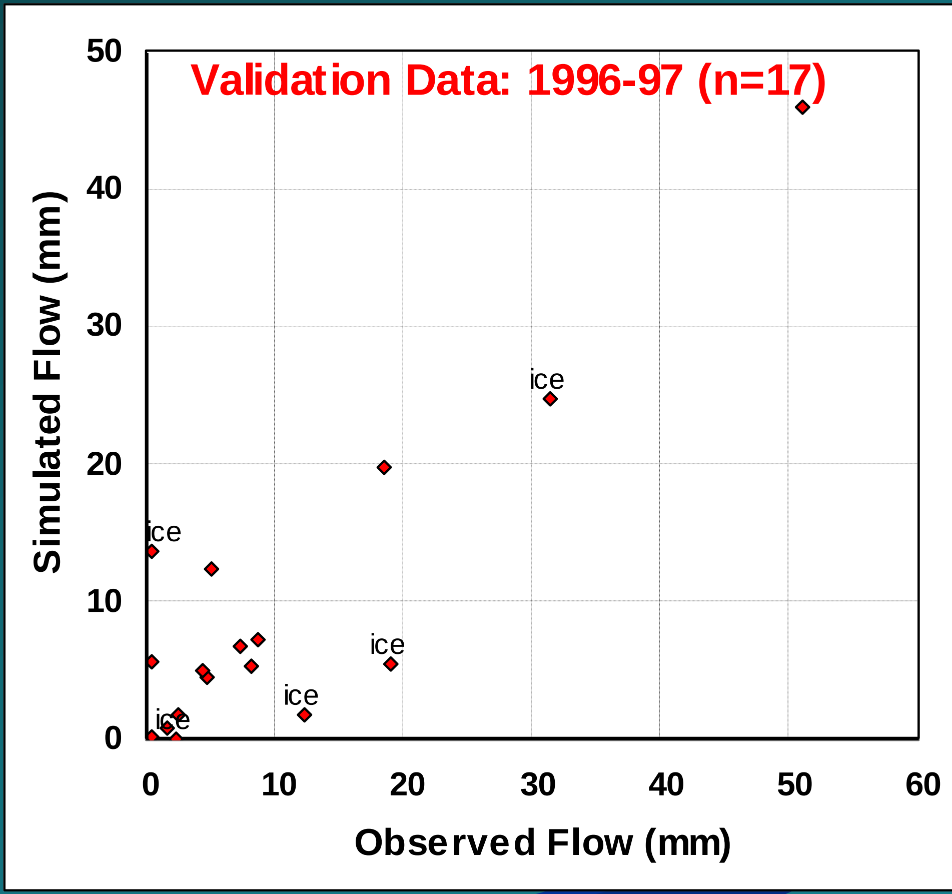
Examples

Stream Flow - EVENTS

Upper Bower Creek (36 km^2)

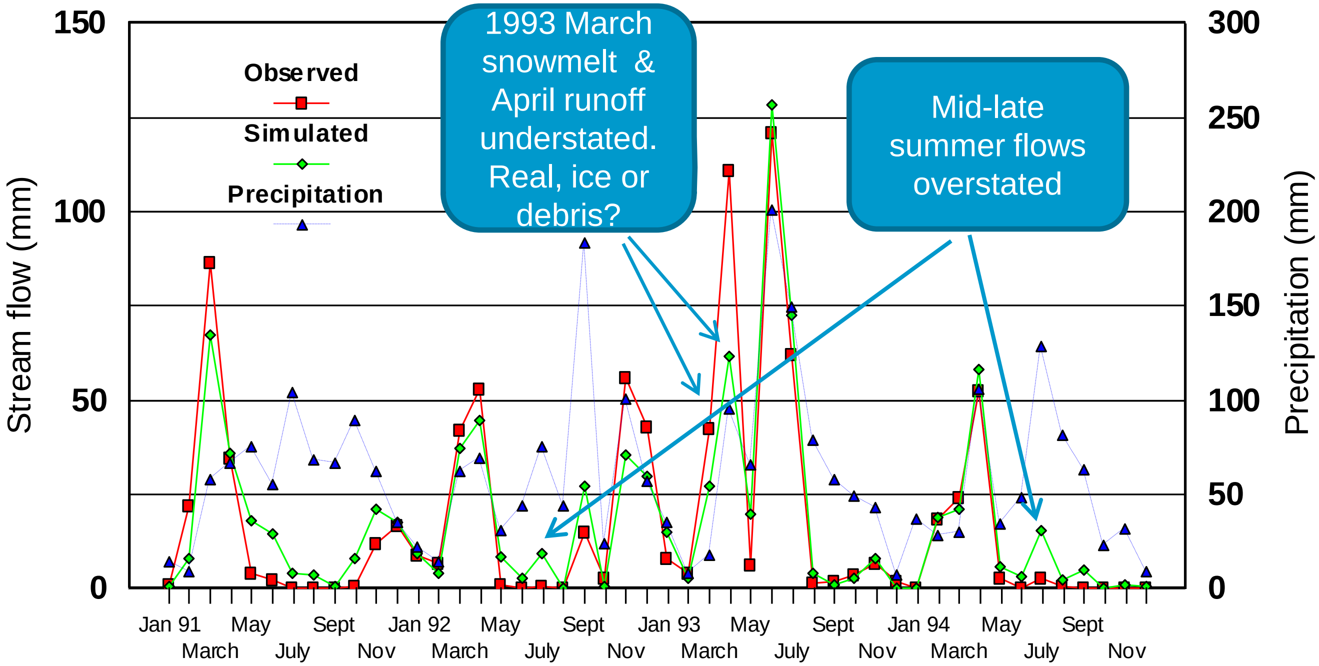


Untransformed: R^2 = 0.80, NSE = 0.80



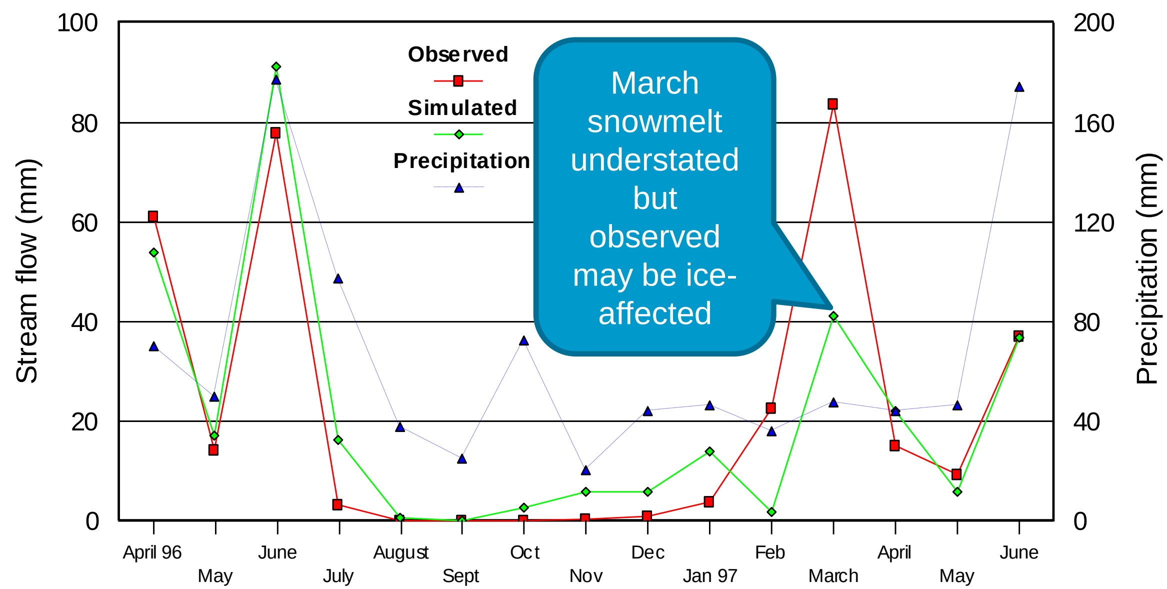
Untransformed: R^2 = 0.95, NSE = 0.94

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
Bower Creek
R^2=.87, NS=0.86

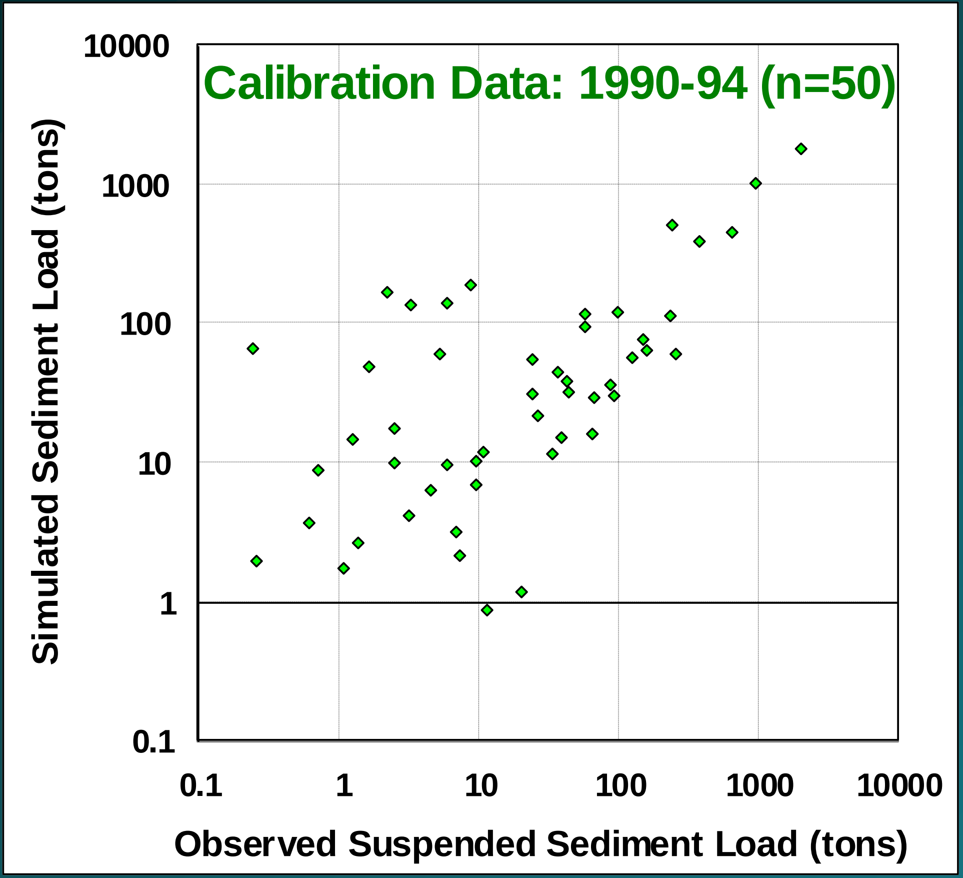


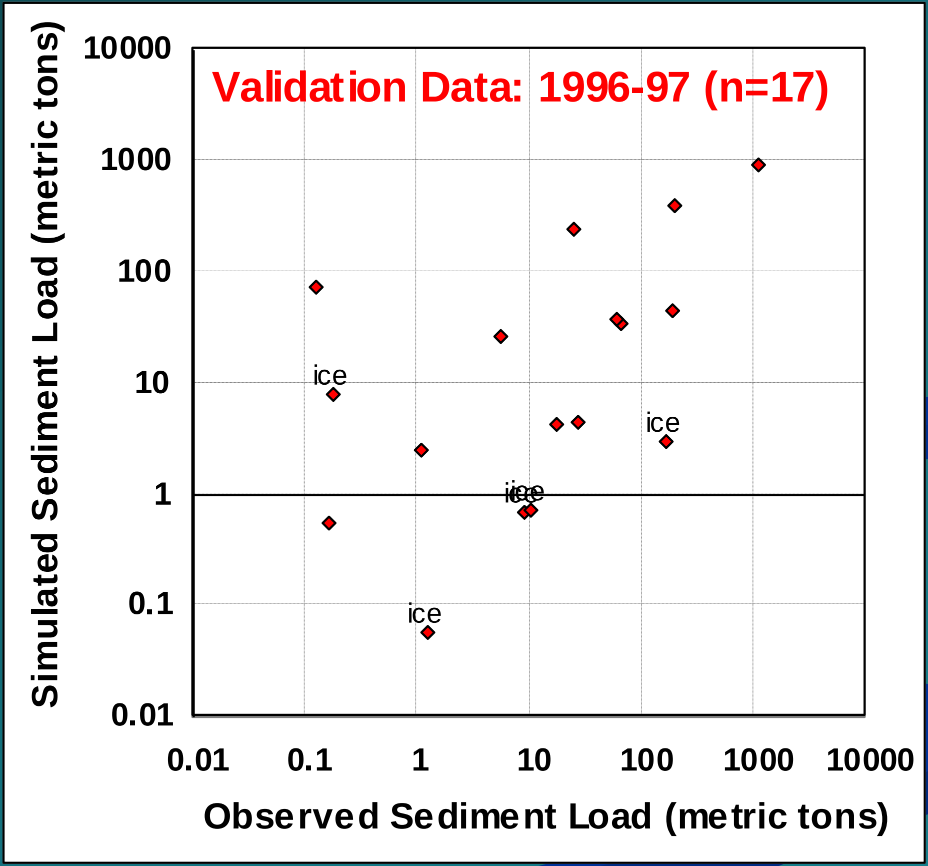
Observed and simulated monthly stream flow - Upper Bower Creek.
1996-97 validation period. Precipitation from USGS weather stations is also shown.

Validate
Monthly
Stream flow
Bower Creek
R^2=0.76, NS=0.76

Suspended Sediment - EVENTS

Bower Creek





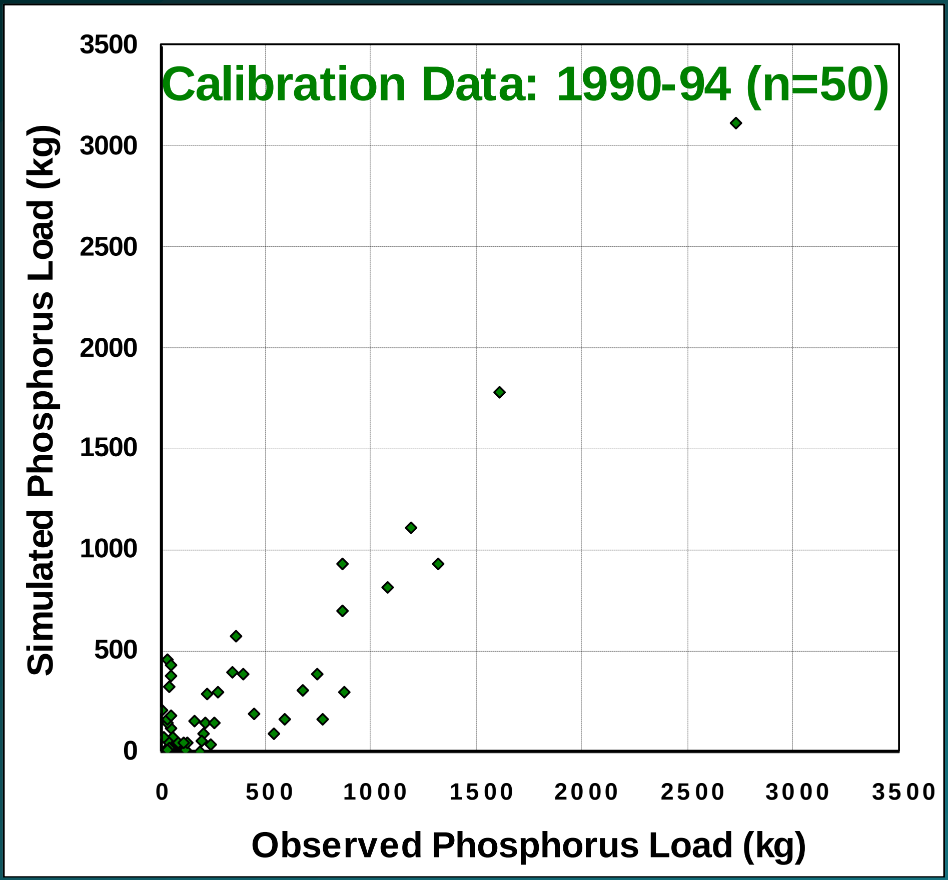
Untransformed: R^2 = 0.93, NSE = 0.92

Untransformed: R^2 = 0.87, NSE = 0.88

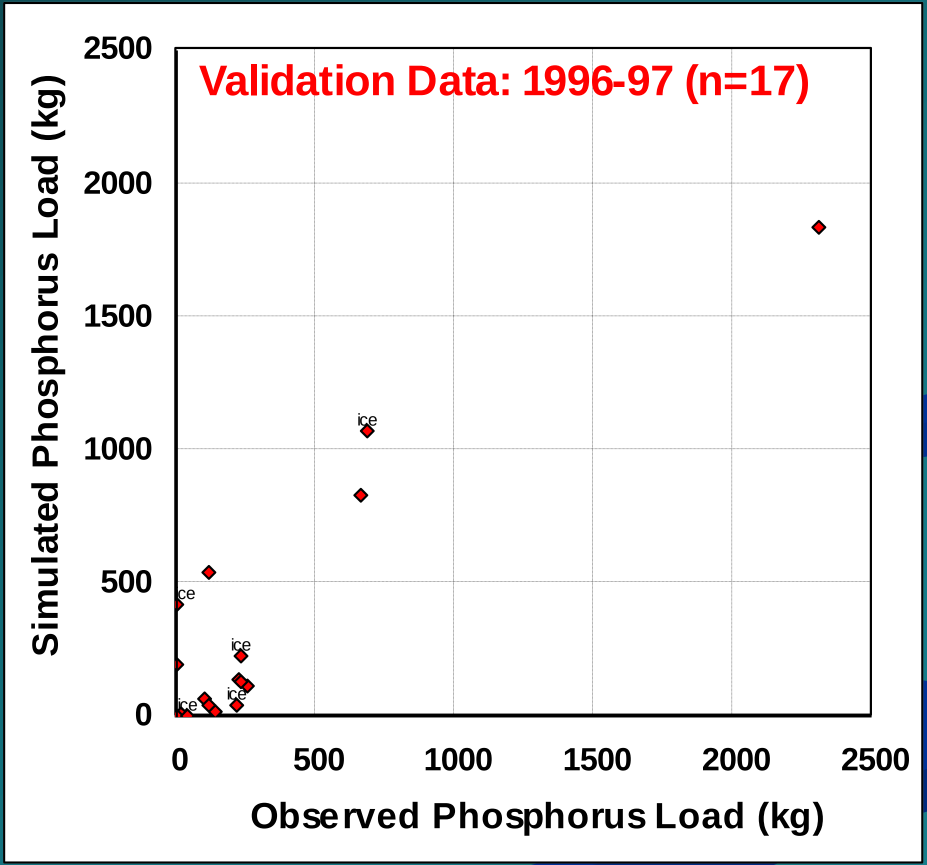
With 12 non-ice affected events

Total Phosphorus – EVENTS

Bower Creek



Untransformed: R^2 = 0.82, NSE = 0.80



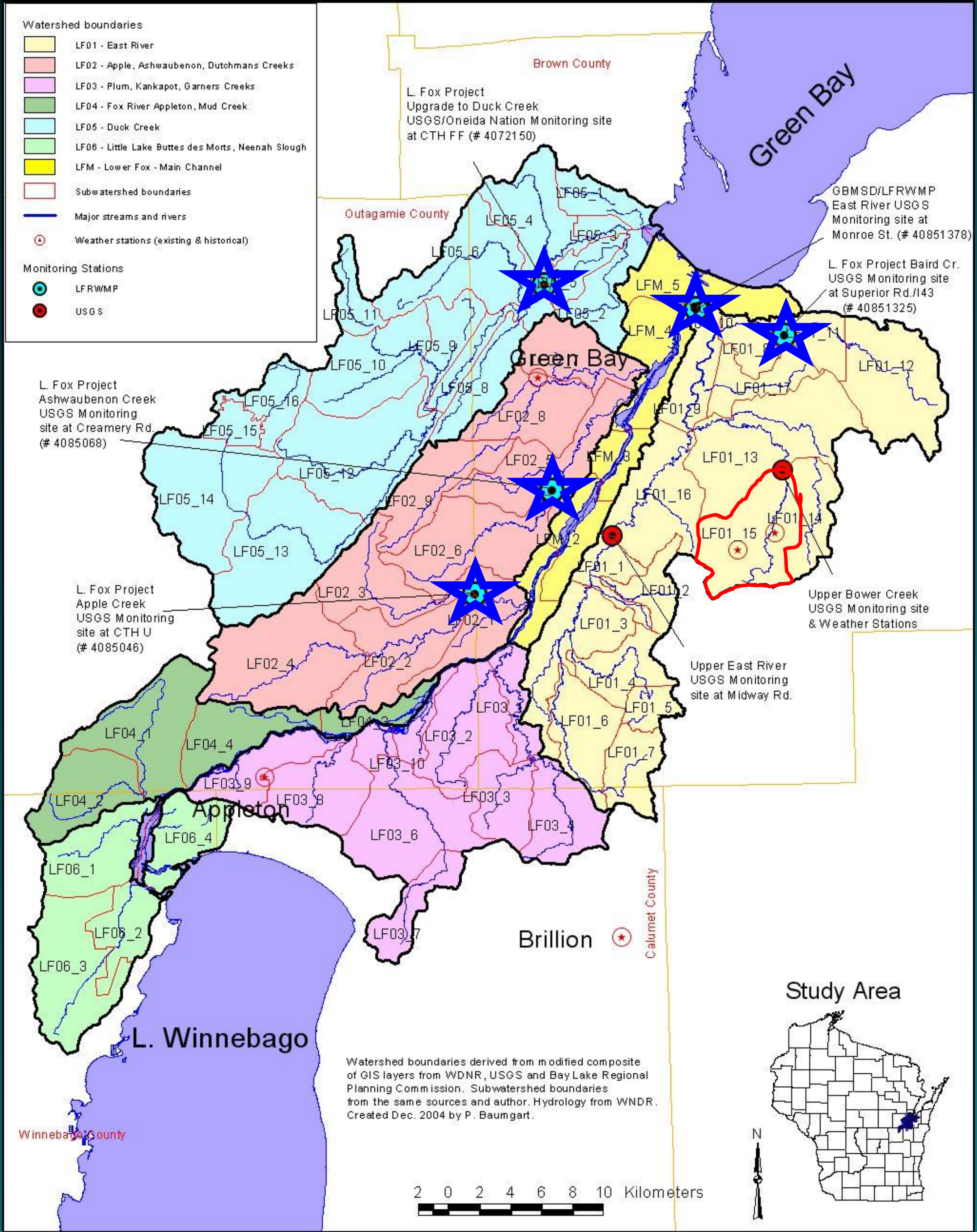
Untransformed: R^2 = 0.88, NSE = 0.90

With 12 non-ice affected events

Additional Monitoring and Model Assessment

- Model VALIDATED, good fit for flow, TSS, TP
  - Initial validation data set limited
- 1993 LFRWMP added 5 automated USGS monitoring stations
  - Continuous flow
  - Event and low flow sampling
  - Daily TSS and P loads with GCLAS
  - DP with regression model

ISCO Sampler Apple Creek



LFRWMP Validation Sites

2004-06 daily flow & TSS loads & P loads

Apple Creek - 117 km²

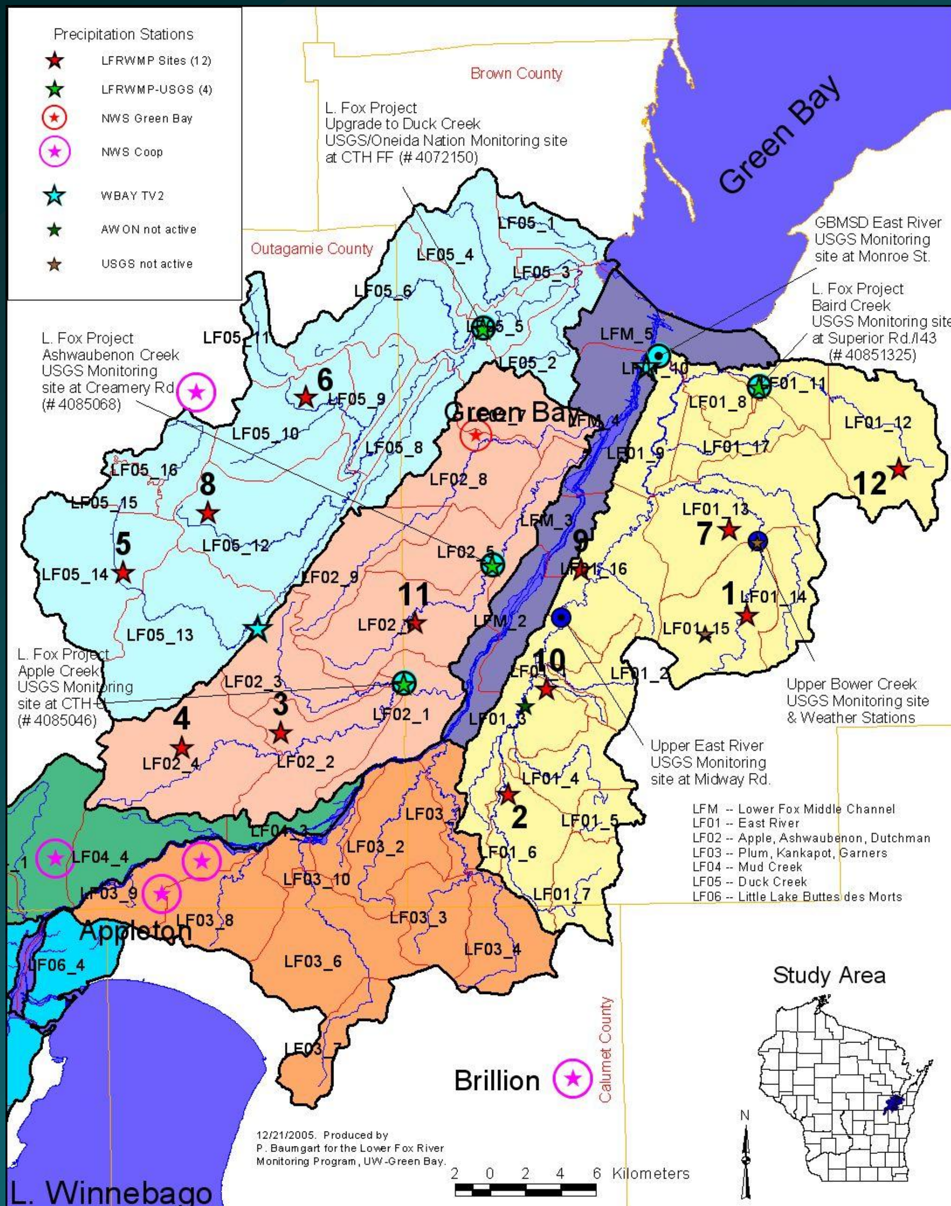
Ashwaub. Cr. - 48 km²

Baird Creek - 54 km²

Duck Creek - 276 km²

East River - 374 km²

Model Inputs – Rain Gauge Network

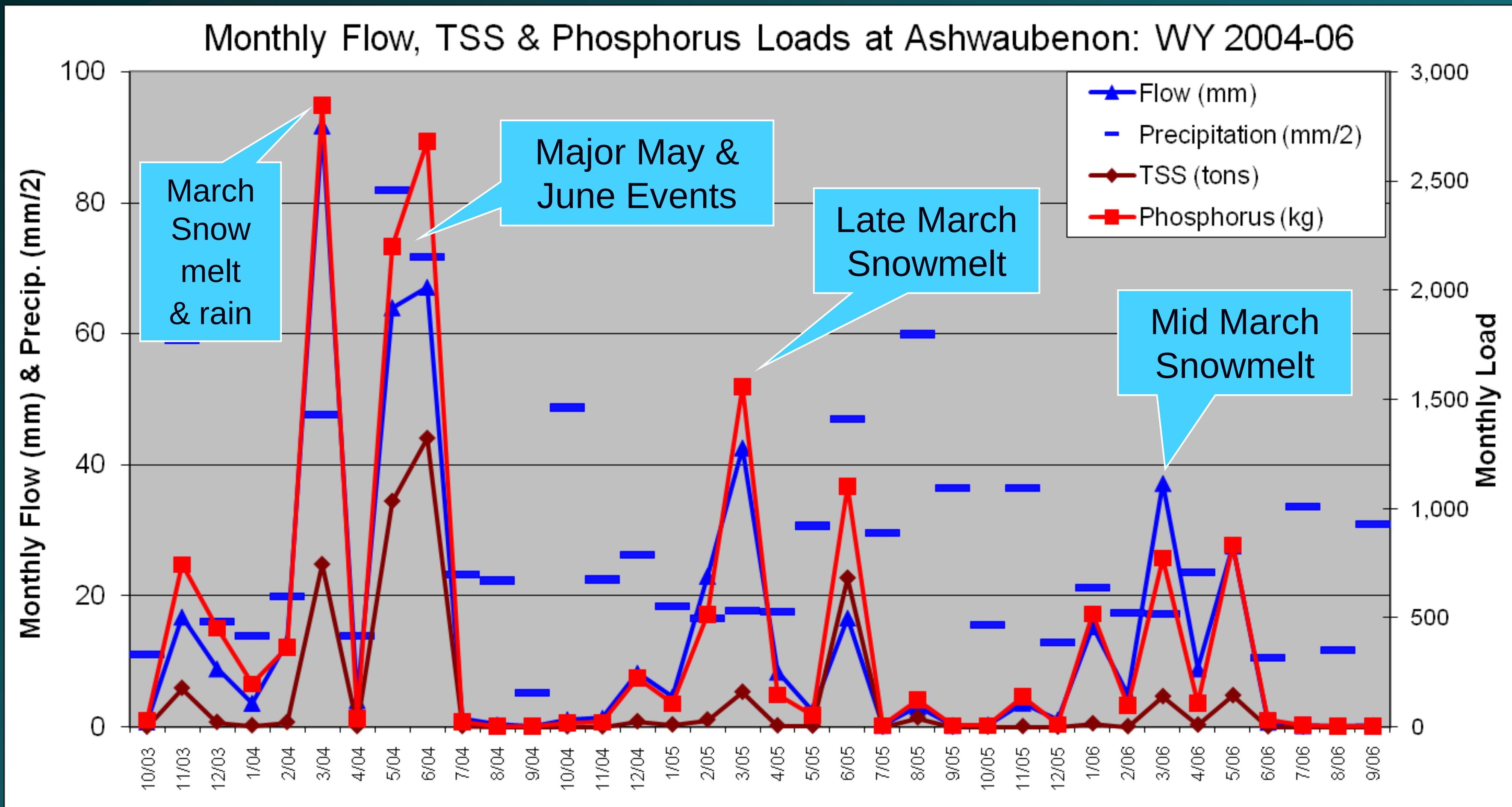


Climate:

- 3 long-term NWS stations
- PLUS 15 recording rain gauges
  - 2003-present
  - Other sources

2004-06 monthly monitoring data

48 km^2 watershed



2004 many large events in March, May and June, followed by dry years dominated by snowmelt/rain contributions in March

Assessment/Validation Summary: Unadjusted model applied to 5 watersheds (2004-05 data)

- 2004 Wet year; 2005 very Dry & dominated by snowmelt

		Flow			SS			Phosphorus	
Stream	R^2	NSCE	% diff	R^2	NSCE	% diff	R^2	NSCE	% diff
Apple	0.86	0.86	6.3%	0.87	0.77	-21.7%	0.81	0.81	-3.6%
Ashwaubenon	0.90	0.85	26.1%	0.69	0.69	1.9%	0.82	0.82	-3.1%
Baird	0.84	0.83	16.6%	0.66	0.65	-3.7%	0.70	0.66	-0.9%
Duck	0.86	0.84	-12.5%	0.77	0.75	3.0%	0.67	0.64	25.5%
East River	0.94	0.93	-8.0%	0.72	0.59	45.6%	0.86	0.86	7.6%

- Simulated & observed monthly statistics. Relative differences for entire period.
- Validation criteria objective: R^2 or NSCE of 0.6 or greater (with some qualifications)

Model Assessment/Validation
(2004-05 data)

- Acceptable results from model
- Reasonable fit: flow, TSS, P for most streams
- East River high sediment, Duck somewhat high P, still acceptable

- BUT Adjusted model to hopefully get more accurate predictions (Optimization & TMDL)
  - East River (sediment) and Duck Creek TP only

Assessment/Validation Summary:
ADJUSTED* Duck Cr. & East River (2004-05)

- East River: sediment transport factor (800 mg/L to 500 mg/L)
- Duck Creek: P sorption coefficient and P partitioning coef.*

	Flow			SS			Phosphorus		
Stream	**R^2**	**NSCE**	**% diff**	**R^2**	**NSCE**	**% diff**	**R^2**	**NSCE**	**% diff**
Apple	0.86	0.86	6.3%	0.87	0.77	-21.7%	0.81	0.81	-3.6%
Ashwaubenon	0.90	0.85	26.1%	0.69	0.69	1.9%	0.82	0.82	-3.1%
Baird	0.84	0.83	16.6%	0.66	0.65	-3.7%	0.70	0.66	-0.9%
Duck*	0.86	0.83	-12.8%	0.75	0.73	3.9%	0.66	0.66	5.6%
East River*	0.94	0.93	-8.0%	0.74	0.72	20.7%	0.86	0.86	7.6%

Unadjusted

	Flow			SS			Phosphorus		
Stream	**R^2**	**NSCE**	**% diff**	**R^2**	**NSCE**	**% diff**	**R^2**	**NSCE**	**% diff**
Apple	0.86	0.86	6.3%	0.87	0.77	-21.7%	0.81	0.81	-3.6%
Ashwaubenon	0.90	0.85	26.1%	0.69	0.69	1.9%	0.82	0.82	-3.1%
Baird	0.84	0.83	16.6%	0.66	0.65	-3.7%	0.70	0.66	-0.9%
Duck	0.86	0.84	-12.5%	0.77	0.75	3.0%	0.67	0.64	25.5%
East River	0.94	0.93	-8.0%	0.72	0.59	45.6%	0.86	0.86	7.6%

Final: Assessment/Validation (2004-06)

2006 data added later to validate; dry year, mostly snowmelt, so model didn't perform as well

Stream	Flow R^2	Flow NSCE	Flow % diff	TSS R^2	TSS NSCE	TSS % diff	Phosphorus R^2	Phosphorus NSCE	Phosphorus % diff
Apple	0.84	0.83	14.7%	0.79	0.73	-8.3%	0.76	0.75	7.8%
Ashwaubenon	0.89	0.82	30.4%	0.65	0.64	23.1%	0.82	0.82	4.4%
Baird	0.84	0.82	21.6%	0.60	0.60	12.2%	0.67	0.66	11.9%
Duck*	0.85	0.83	-8.4%	0.73	0.71	21.3%	0.64	0.64	13.2%
East River*	0.92	0.91	-6.6%	0.66	0.59	37.6%	0.80	0.79	16.1%

Model Assessment Summary

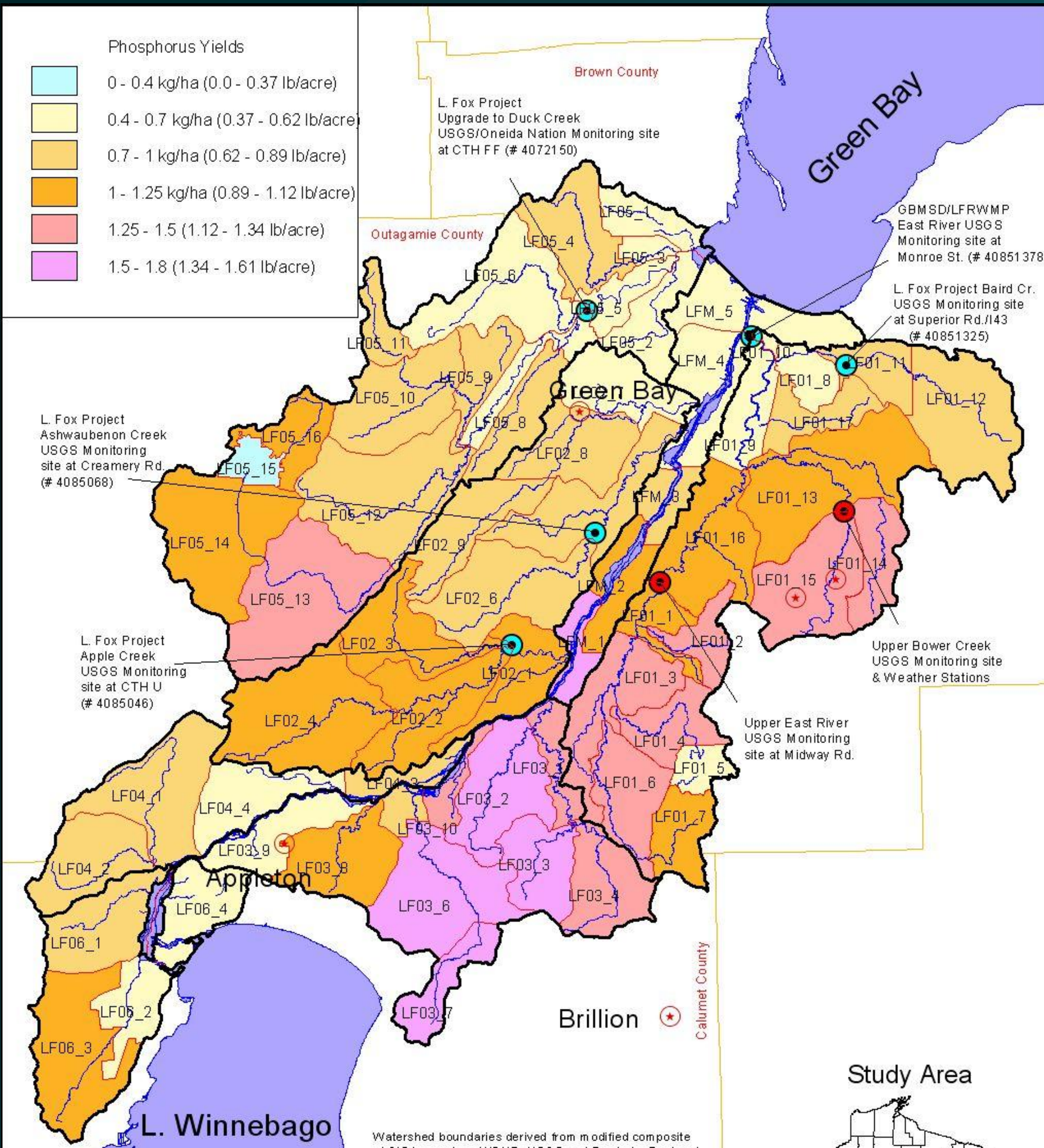
- In general, good correspondence between simulated and observed stream flow and loads of P and SS (monthly, annual, totals)
- Model response acceptable for predictive simulations in sub-basin
- Model least able to predict flow and loads:
  - small events, affected phosphorus loads most
  - after prolonged dry periods
  - during snow melt periods
  - from East River at this time (sediment loads)

Uncertainty in Observed Flow & Loads, so don't expect perfect fit

Uncertainty in Observed Flow & Loads, so don't expect perfect fit

Uncertainty in Observed Flow & Loads
Missing or invalid samples

Model Results – Baseline Conditions



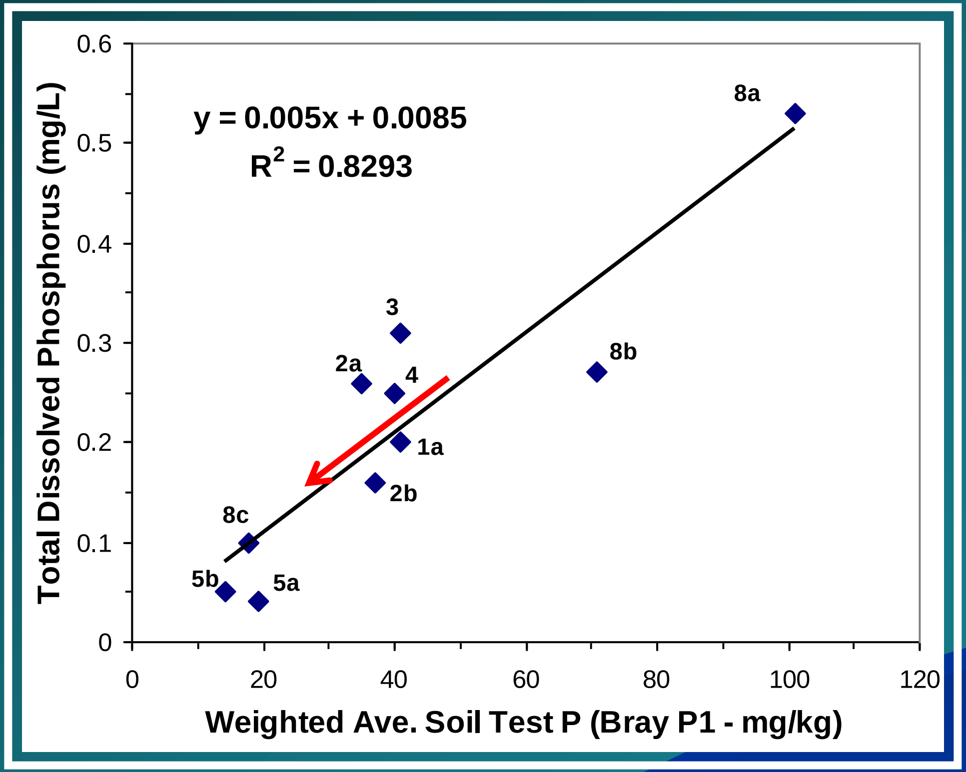
- Stream flow and loads at sub-basin, watershed and sub-watershed scales
- Total and by HRU/landuse category

Modeling Multiple BMP Scenarios

- 1977-2000 climatic period for simulations
- 2004 landuse Baseline conditions
- Alternative management scenarios over same period

Modeling Multiple BMP Scenarios

- Conservation Tillage: simply increase HRU areas for No-Till and Mulch Till;   export txt files to *.hru
- Stabilize Soil P Levels at Current Level (40 ppm) and at level from mid-1970's (25 ppm)
  - Reduce P in feed ration & fertilizer P (copy new Fert2000.dat)



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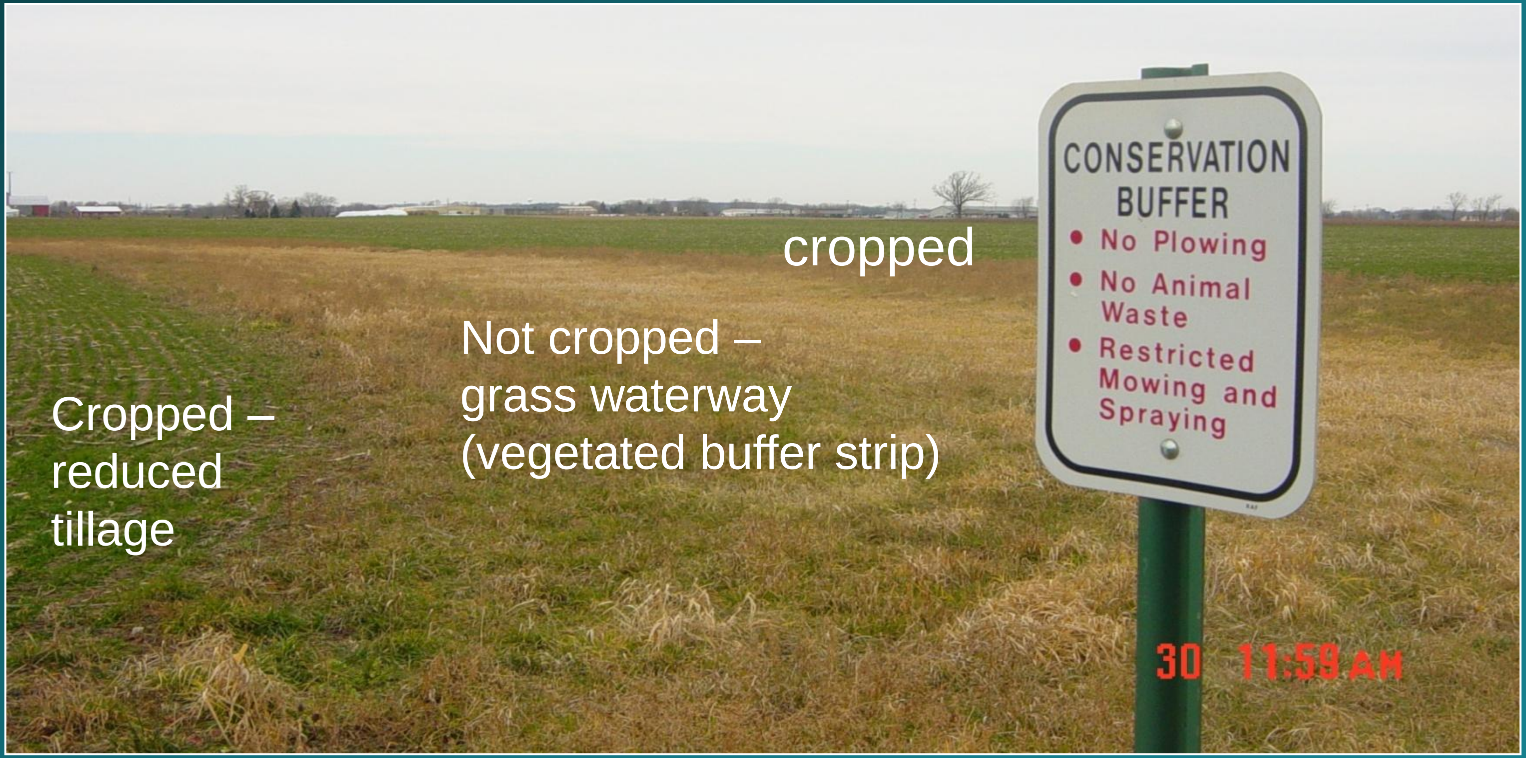
  - Reduce P in feed ration & fertilizer P (copy new Fert2000.dat)
- Vegetated Buffer Strips



Modeling Multiple BMP Scenarios

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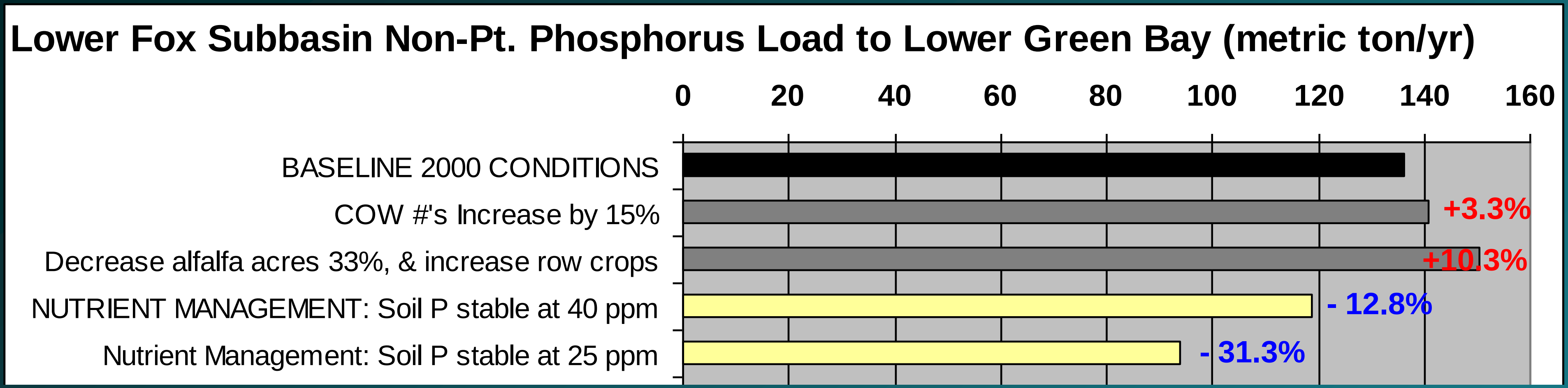
  - Reduce P in feed ration & fertilizer P (copy new Fert2000.dat)
- Vegetated Buffer Strips
- Cover Crop on corn-silage and soybean fields
  - Substitute *.mgt files

Corn Silage: with and without cover crops

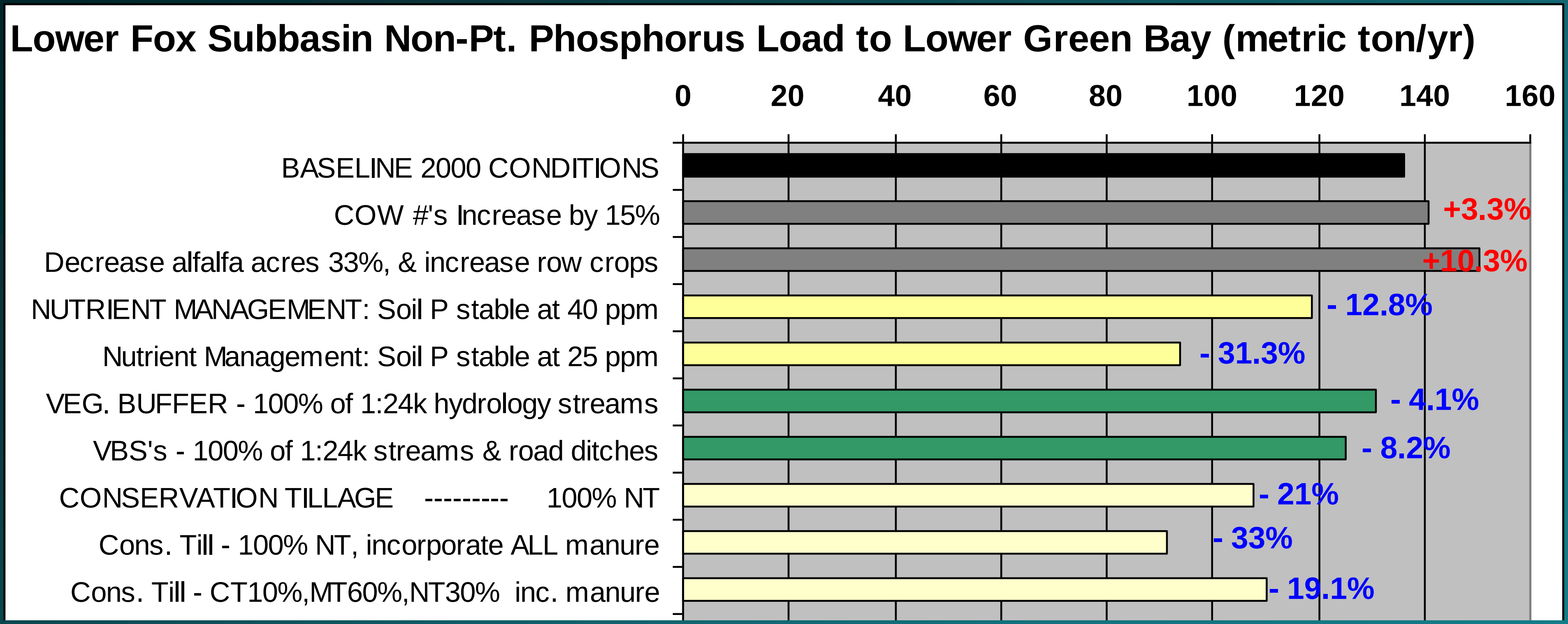
Modeling Multiple BMP Scenarios

- Conservation Tillage: simply increase HRU areas for No-Till and Mulch Till;   export txt files to *.hru
- Stabilize Soil P Levels at Current Level (40 ppm) and at level from mid-1970's (25 ppm)
  - Reduce P in feed ration & fertilizer P (copy new Fert2000.dat)
- Vegetated Buffer Strips
- Cover Crop on corn-silage and soybean fields
  - Substitute *.mgt files
- Biofuel Production: switchgrass: Added HRU
- Rotational grazing for dairy operations: Added HRU
- Increase Manure incorporation
- Others

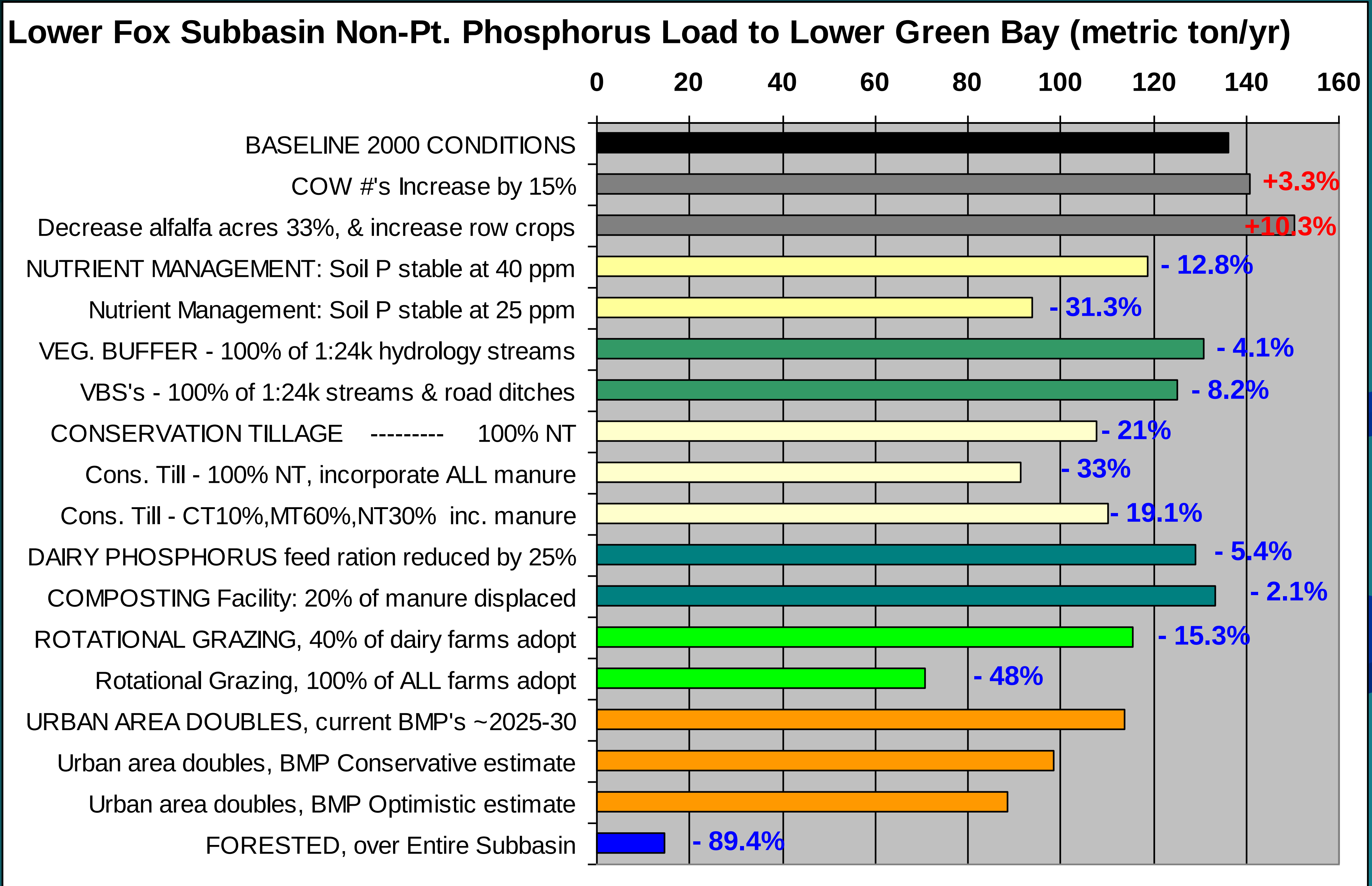
Results: Alternative Management Scenarios



Results: Alternative Management Scenarios



Alternative Management Scenarios

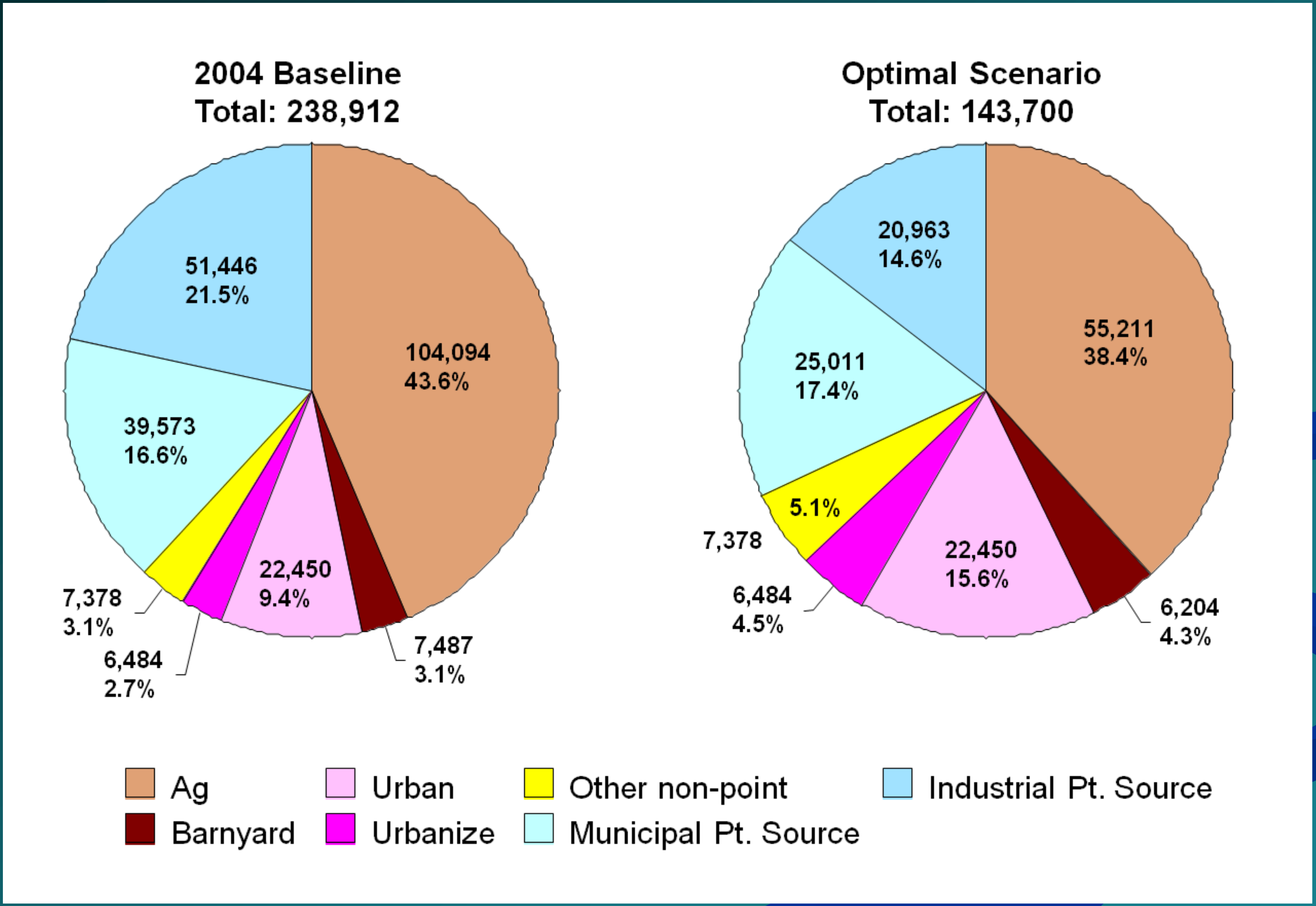


Optimization Model: impact and cost of optimal scenario on phosphorus non-point loads to Green Bay from LFR sub-basin.

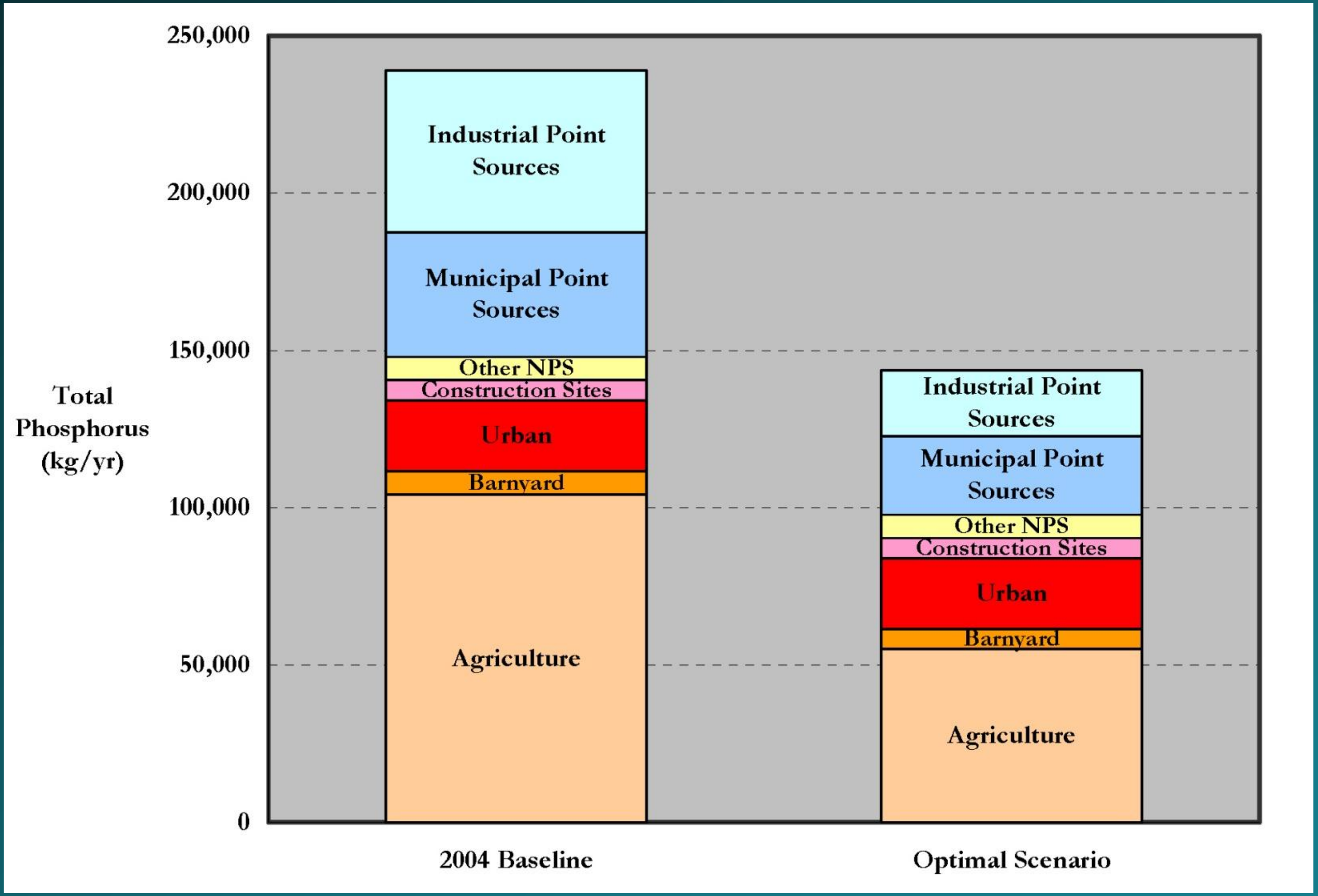
BMP Scenarios	Phosphorus (kg)	% Reduced	Total Cost	Avg Cost per kg of Phosphorus Reduced
Baseline 2004 Conditions	147,900			
1. Nutrient Management: Dairy P Feed Ration: Reduce by 25%; Implement 90%	140,600	4.9%	$0	$0.00
2. plus: Increase manure incorporation from 50% to 85%	133,800	9.5%	$394,000	$27.94
3. plus: Stabilize Soil P (90% implement)	125,300	15.3%	$1,646,000	$72.82
4. plus: Conservation Tillage - CT40%, MT45%, ZT15%	115,100	22.1%	$2,731,000	$83.25
5. plus: Cover Crops on corn silage and some soybean fields	111,600	24.5%	$3,200,000	$88.16
6. plus: Buffer Strips installed on 100% of 1:24k hydrology strear	107,600	27.2%	$3,372,000	$83.68
7. plus: Reduce Soil P to 25 ppm; Implemention = 35%	100,600	32.0%	$5,901,000	$124.75
8. plus: Biofuel Switch grass crop; 7% of all total crop acres	97,700	33.9%	$6,929,000	$138.03

From: Integrated Watershed Approach Demonstration Project A Pollutant Reduction Optimization Analysis for the Lower Fox River Basin and the Green Bay Area of Concern (Table 6). Prepared by Laura Blake of The Cadmus Group for U.S. EPA (with contributions by P. Baumgart of UW-Green Bay and Sam Ratick of Clark University)

Phosphorus Load Allocation from Lower Fox sub-basin to Lower Green Bay (kg/year)



Simulated P Load to Lower Green Bay from LFR Basin: 2004 Baseline vs. Opt. Scenario of Ag BMPs and Point Source Reductions (note: Winn load ~ 288,000 kg/yr)



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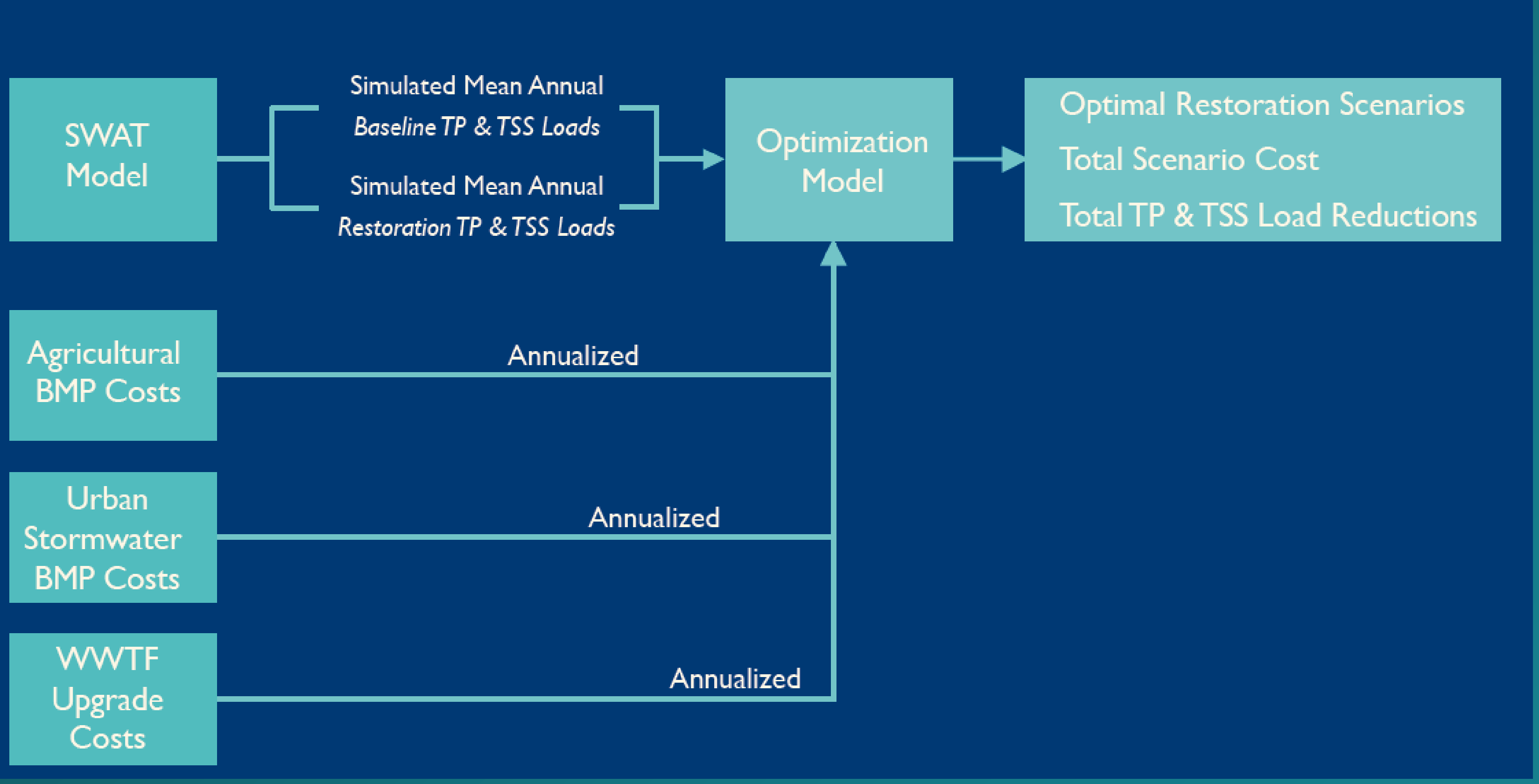
SWAT Simulations: Conclusions

- 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

Next Steps

- Refine SWAT stream bank erosion estimates - Sediment source tracing with radionuclides and other constitiuents
- Refined Load allocation, TMDL and Optimization

Figure 4. Pollutant Reduction Optimization Modeling Framework for the TMDL



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THE LOWER FOX RIVER
watershed monitoring program

Cooperators and Funding

- UW-Green Bay, UW-Milwaukee
- Arjo Wiggins Appleton Ltd
- US Geological Survey
- US Environmental Protection Agency
- Cadmus
- GBMSD, Oneida Tribe of Indians

Questions?

Up stream of site 1a on June 13, 2005

Example of SWAT Simulation Results for a Sub-set of Ag BMP Scenarios

Agricultural BMP Scenarios	Total P Load (kg)
Conservation Tillage - 100% MT;VBS (100%)	4,611
Conservation Tillage - 100% MT, Dairy P reduced-100%;VBS (100%)	4,225
Conservation Tillage - 100% MT, Stable soil P-100%;VBS (100%)	3,832
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%;VBS (100%)	2,835
Conservation Tillage - 50% MT & 50% CT;VBS (100%)	5,129
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%;VBS (100%)	4,734
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%;VBS (100%)	4,316
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%;VBS (100%)	3,115
Conservation Tillage - 25% MT & 75% CT;VBS (100%)	5,388
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%;VBS (100%)	4,989
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%;VBS (100%)	4,558
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%;VBS (100%)	3,254

MT = mulch tillage;VBS = vegetative buffer strips; CT = conventional tillage

From: Poster by Laura Blake and Sandra Brown of The Cadmus Group, Inc. and others 2007.

Simulated Phosphorus Load Reductions and Estimated Costs Associated with Implementing the Optimal Scenario of Agricultural BMPs

Agricultural BMP Scenarios	Total P (kg)	% Total P Reduced	Total Cost ($)	Average Cost per kg of Phosphorus Reduced ($)
Baseline 2004 Conditions	147,900			
1. Nutrient Management - Dairy P Feed Ration: Reduce by 25%; Implement 90%	140,600	4.9%	$0	$0.00
2. Plus: Increase manure incorporation from 50% to 85%	133,800	9.5%	$393,907	$27.94
3. Plus: Stabilize Soil P (90% implementation)	125,300	15.3%	$1,645,710	$72.82
4. Plus: Conservation Tillage - CT40%, MT45%, NT15%	115,100	22.1%	$2,730,621	$83.25
5. Plus: Cover Crops on corn silage and some soybean fields	111,600	24.5%	$2,730,621	$75.22
6. Plus: Buffer Strips installed on 100% of 1:24k hydrology streams	107,600	27.2%	$2,730,621	$67.76
7. Plus: Reduce Soil P to 25 ppm; Implementation = 35%	100,600	32.0%	$5,900,796	$124.75
8. Plus: Biofuel Switch grass crop; 7% of all total crop acres	97,700	33.9%	$6,929,204	$138.03

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