Development and Application of SWAT Models in the Fox-Wolf Basin of Green Bay

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THE LOWER FOX RIVER watershed monitoring program

UNIVERSITY of WISCONSIN GREEN BAY

Great Lakes SWAT Modeling Workshop 2014 Ann Arbor

Primary objectives

- Expand current Lower Fox TMDL and integrative watershed approach for quantifying inputs of nutrients and suspended sediments to Green Bay to include entire Fox-Wolf Basin (apply SWAT model)
- Assess efficacy of the implementing land use best management practices throughout the watershed
- Assess impact of future regional climate change projections (WICCI data)
- Collaboration and Management: Work with partners, scientists and resource managers to provide information that will improve capabilities of managers to devise more robust mitigation strategies, and defend those strategies to stakeholders.

Soil and Water Assessment Tool - SWAT

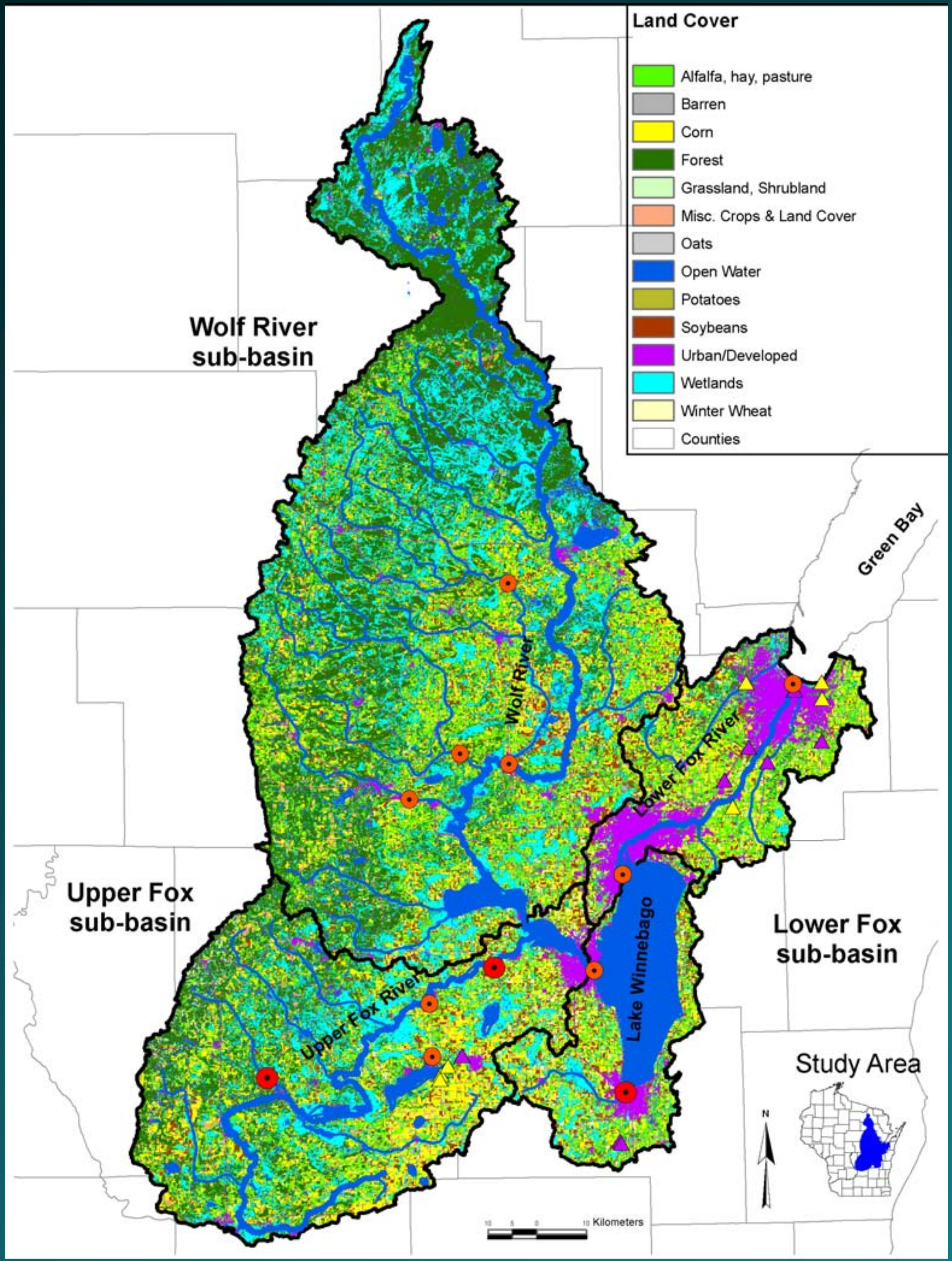
- USDA – ARS model: J.G. Arnold, J.R. Williams, Temple Texas
- Continuous daily time step, river basin/watershed scale model ------- physically based
- Routes water, sediment, nutrients and pesticides to watershed and basin outlets
- Predict impacts of management on water, sediment and chemical yields
- Long-term simulations of many decades
- Tracks crop growth, tillage, fertilizer/manure application, nutrient cycling on a daily basis

- Daily inputs of climate data

Soil and Water Assessment Tool - SWAT

- USDA – ARS model: J.G. Arnold, J.R. Williams, R. Srinivasan, S. Neitsch, N. Sammons, others
- Previous Modeling at University of Wisconsin-Green Bay (1980's under McIntosh), plus:
  - Marcus (SWRRB; 1993)
  - McIntosh et al. (EPIC, SWRRB, AGNPS; 1993a, 1993b, 1994)
  - Qui (SWRRB; 1993); Sugiharto et al. (EPIC; 1994)
  - Baumgart (SWAT: L. Fox1994, 1998, Green Bay Basin 2000, L. Fox 2005 – 2008; Parsons Cr. TMDL; L. Fox TMDL - 2010).

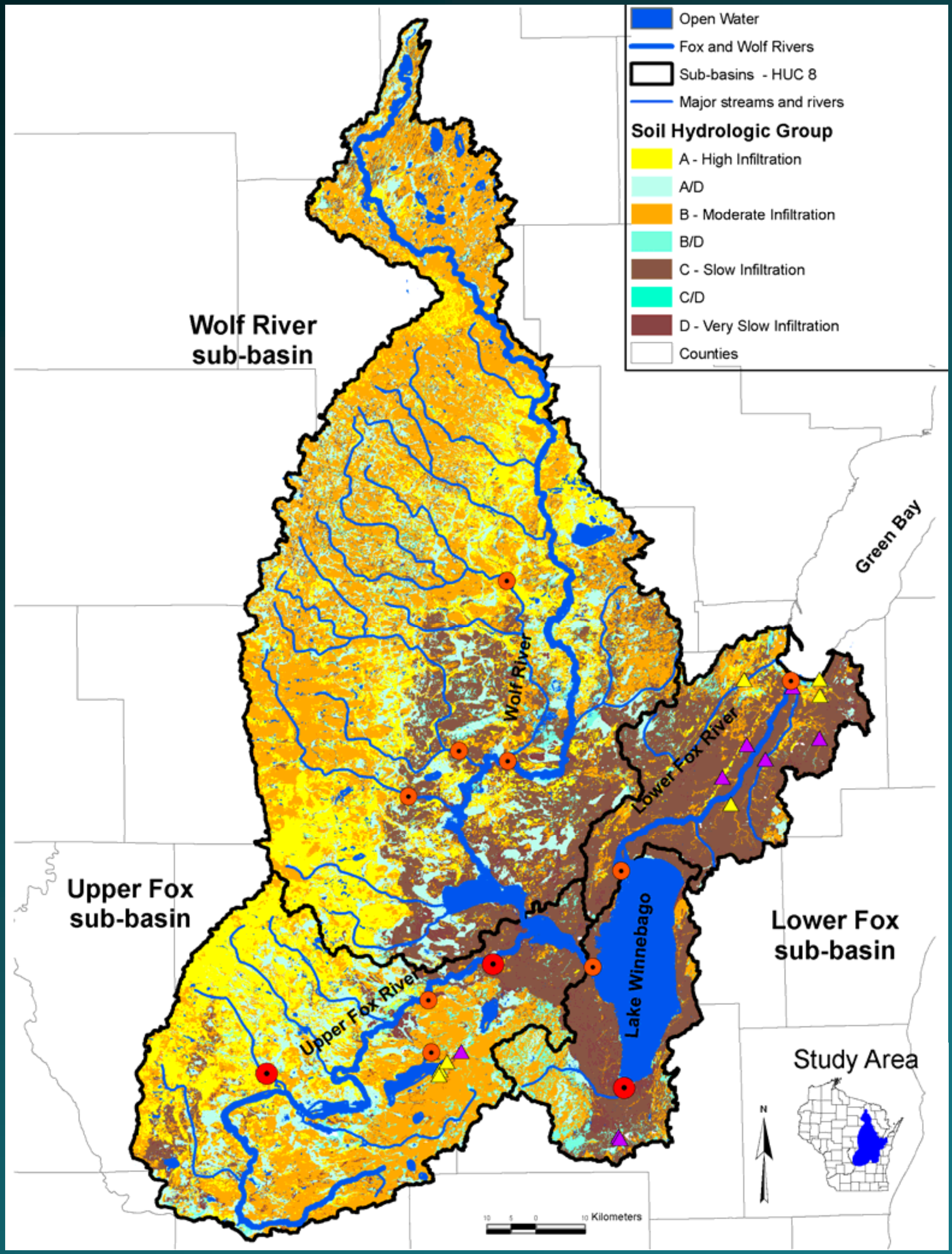
- SWAT-Previously: GIS > spreadsheet > auto-export to SWAT & reversed for output: to allow more flexible/complex management files;
- This Upper Fox & Wolf sub-basins Project:
- Apply *<u>modified version</u> of ArcSWAT 2009.93.7b code*
  - *ArcSWAT 2012 still in beta at start of project*



Fox-Wolf Basin Year 2011 NASS Cropland Land cover

(however, modeled as combination of multiple NASS CDL's & other images)

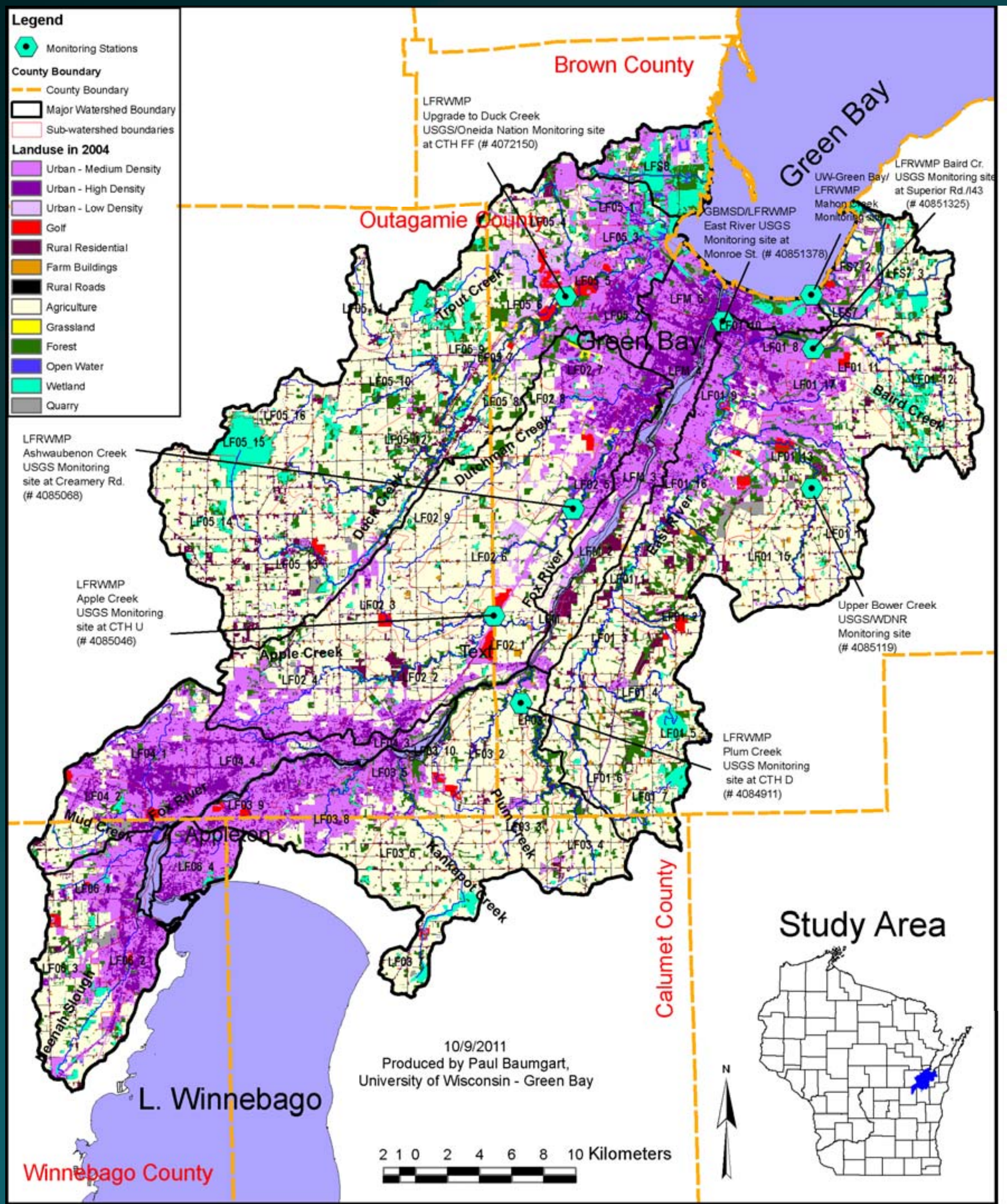
Fox-Wolf Basin Soil Hydrologic Group



Soils with more clay in L. Fox and east Upper Fox sub-basins (higher runoff %, less base flow)

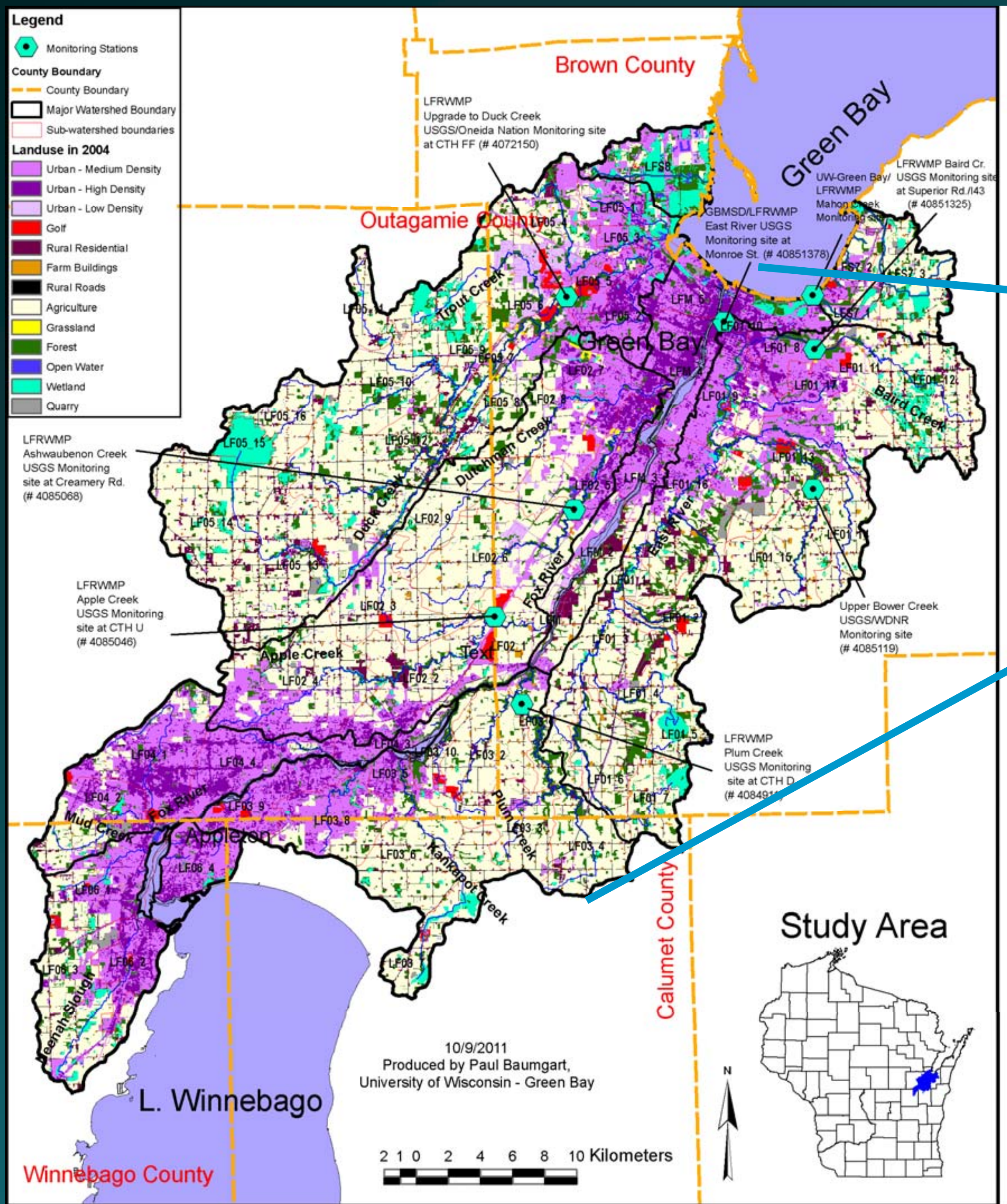
Coarse texture soils in west U. Fox (low runoff, high base flow)

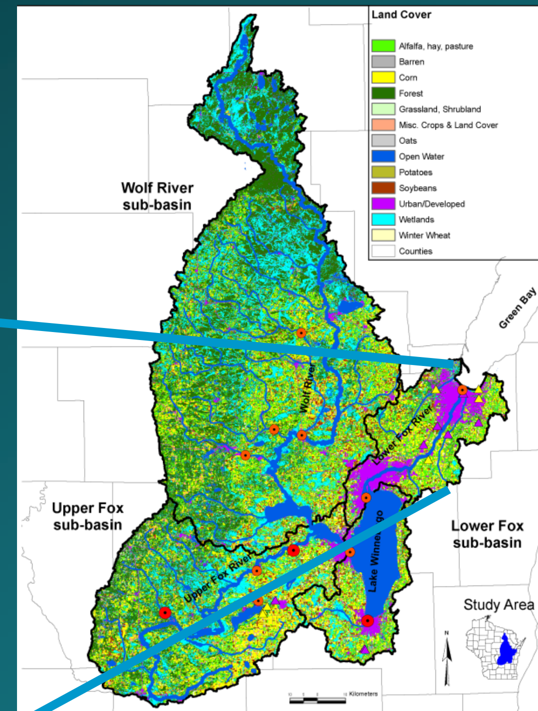
Lower Fox River TMDL



Lower Fox River TMDL Baseline 2004 Landuse and Land cover

- 1,650 km^2
- 50% Ag (dairy)
- 31% Urban/Dev.
- 10% Forest
- 5% Wetland
- Major reductions of P and Sediment from Ag. needed





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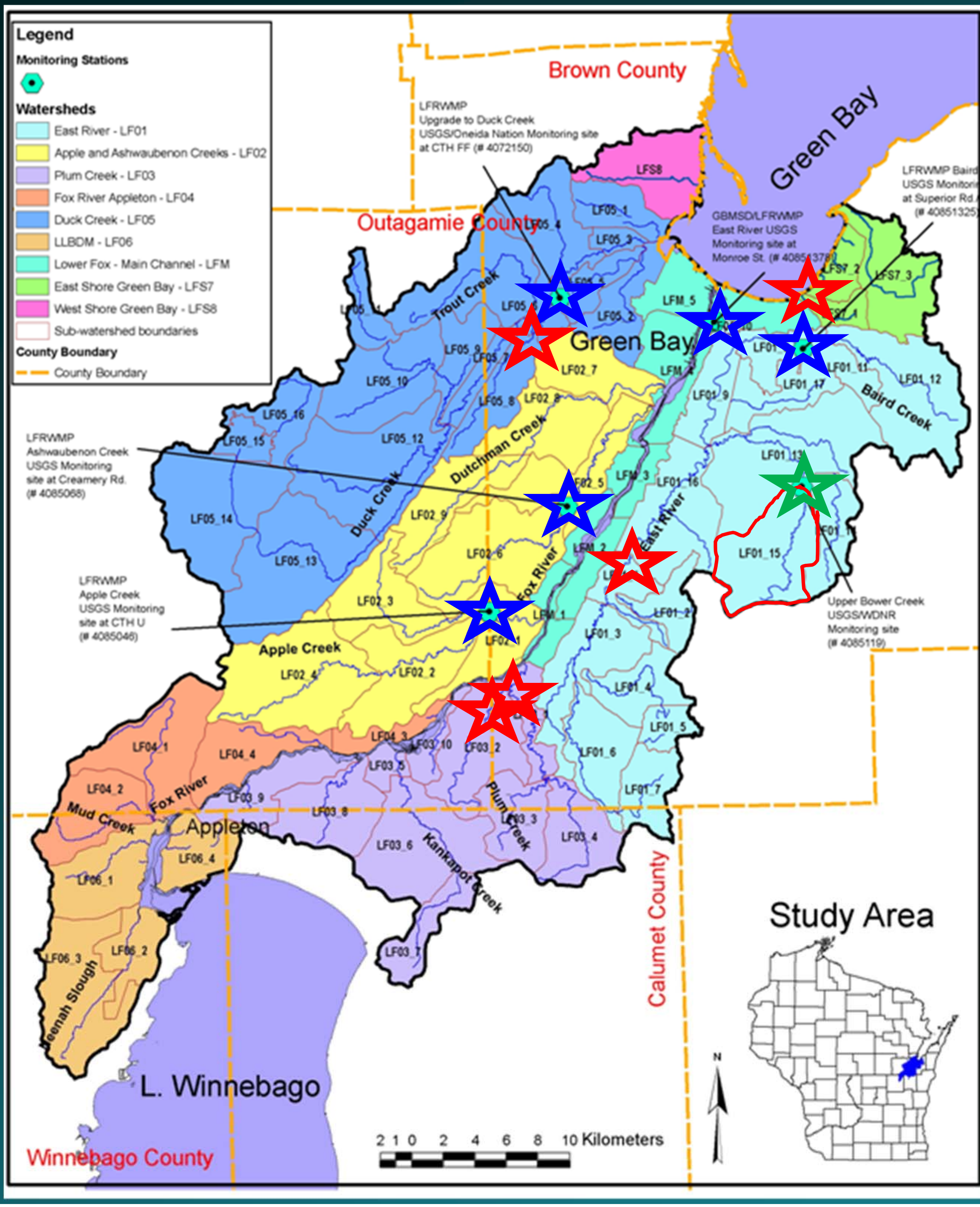


LFRWMP et al. Intensive Monitoring Stations (cont. flow, P & TSS daily loads): watersheds & sub-watersheds

- **Calibration: Bower (36 km^2)**
- **Validation:** Five LFRWMP Sub-Watersheds: 3 – 5+ years; WY2004 up to present
  - **Baird Creek (04-14)**
  - **Duck Creek (04-08)**
  - **East River (04-07)**
  - **Apple Creek (04–06)**
  - **Ashwaub. Creek (04-06)**
- Recent Additions:
  - Plum/Plum West (2011 >)
  - Upper East Riv. (2012 >)
  - Silver Creek (2014 >)
  - Mahon (2011 >)

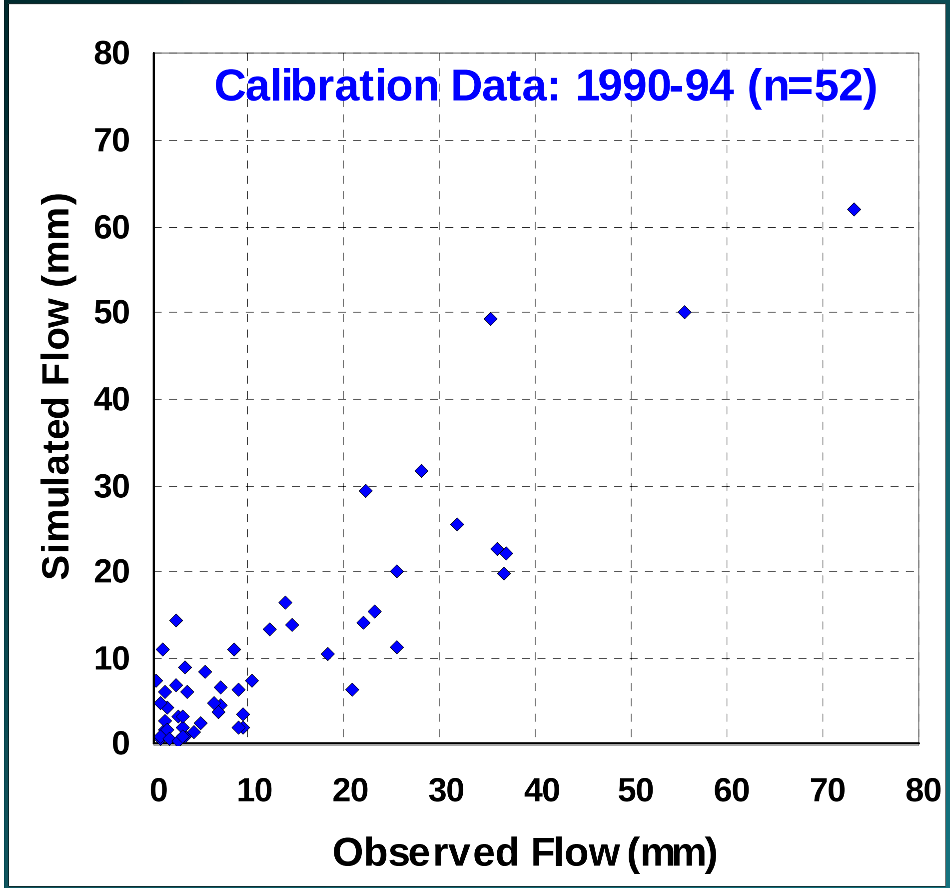
Total~ 54% of LFB area

Plus: Farm Catchment sites (BMP evaluation

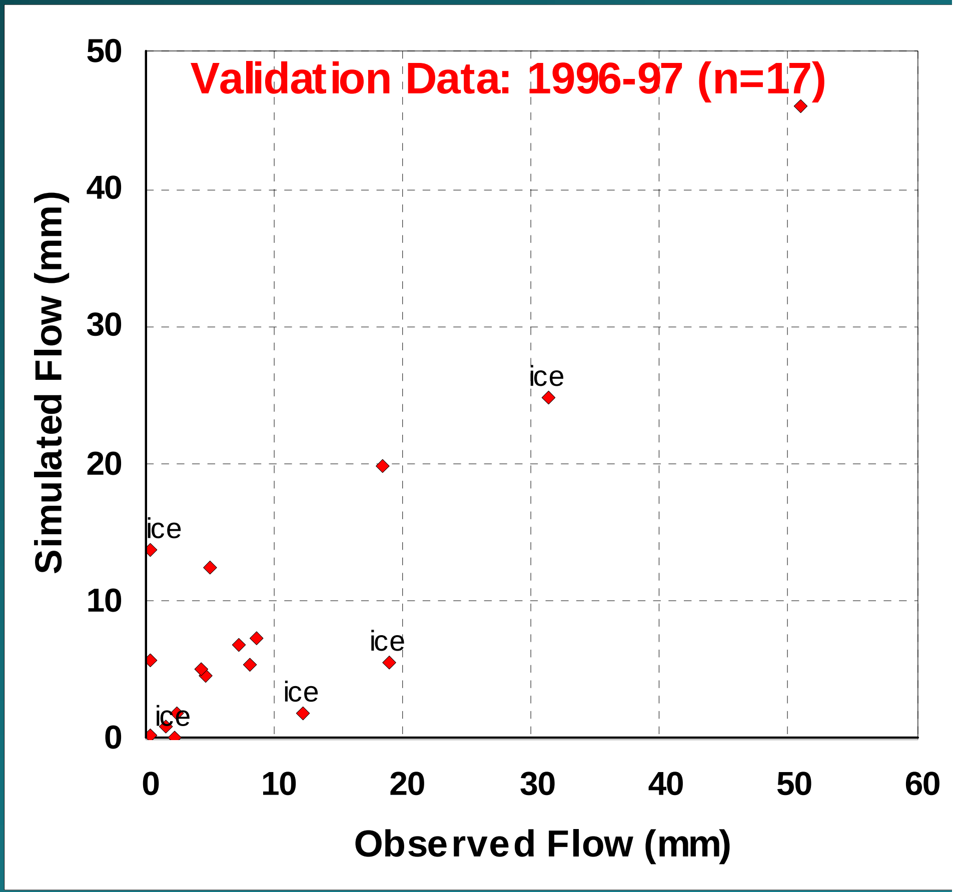
Initial Calibration & Validation

Examples

Calibrate – Validate: Stream Flow
Upper Bower Creek (36 km²) - EVENTS



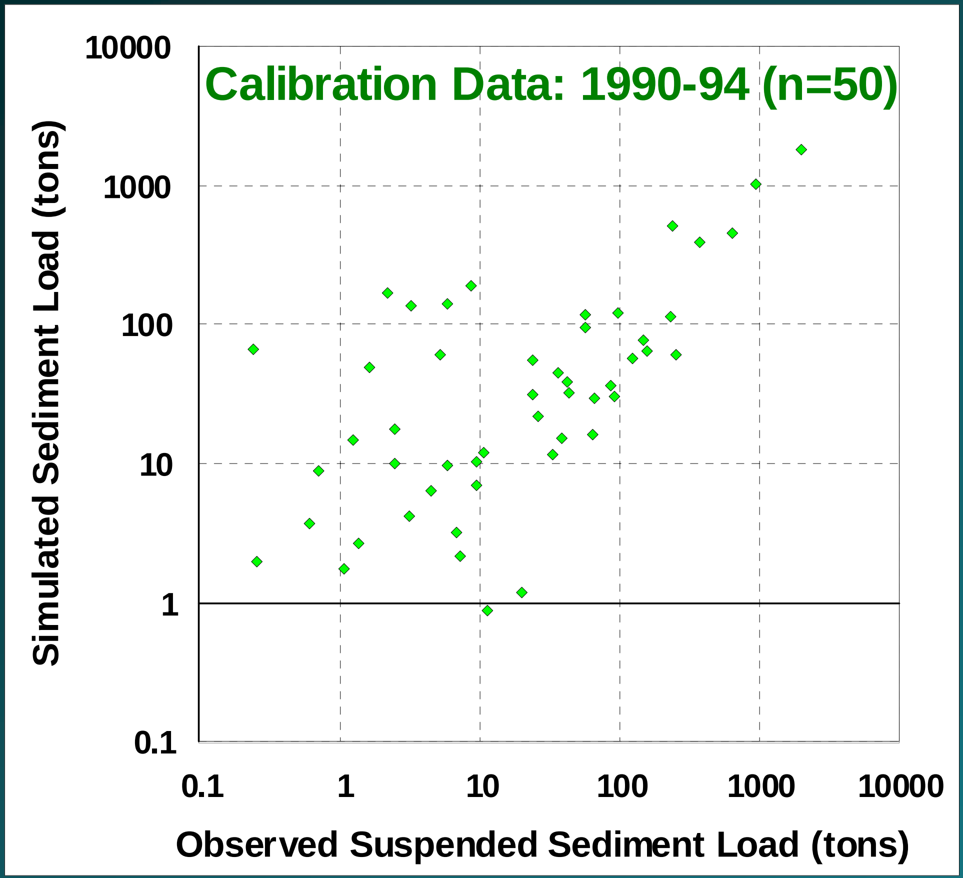
Untransformed: R^2 = 0.80, NSE = 0.79



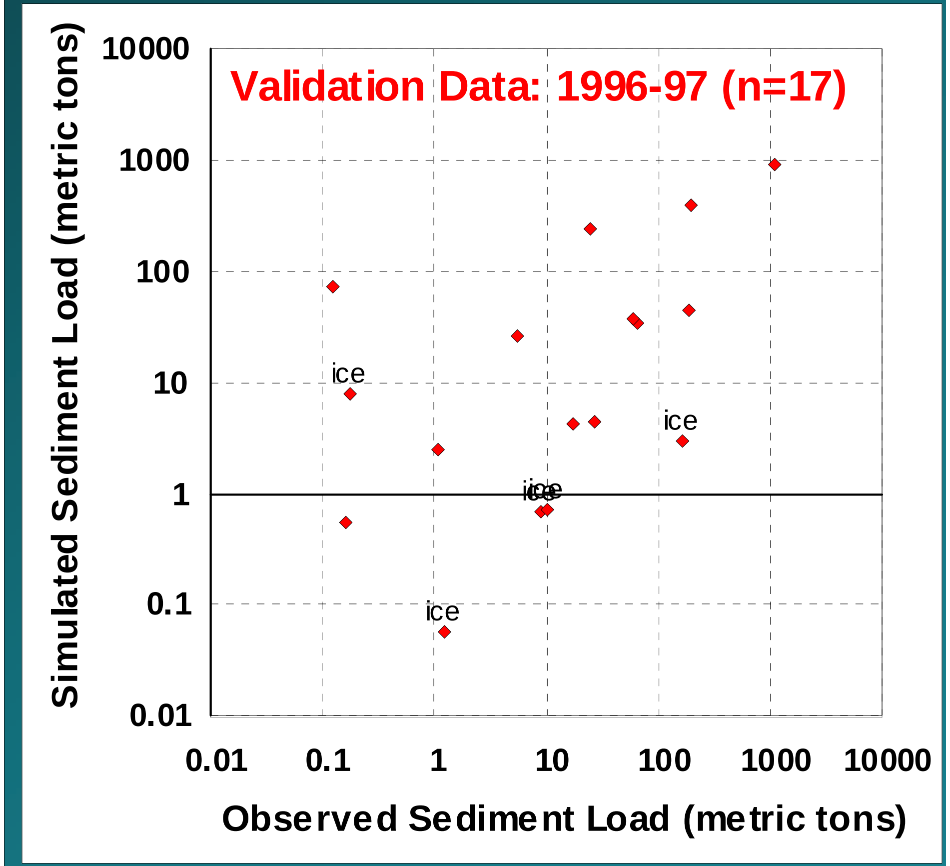
Untransformed: R^2 = 0.96, NSE = 0.96

for n = 12, not ice-affected events

Calibrate – Validate: Suspended Sediment
Bower Creek - EVENTS



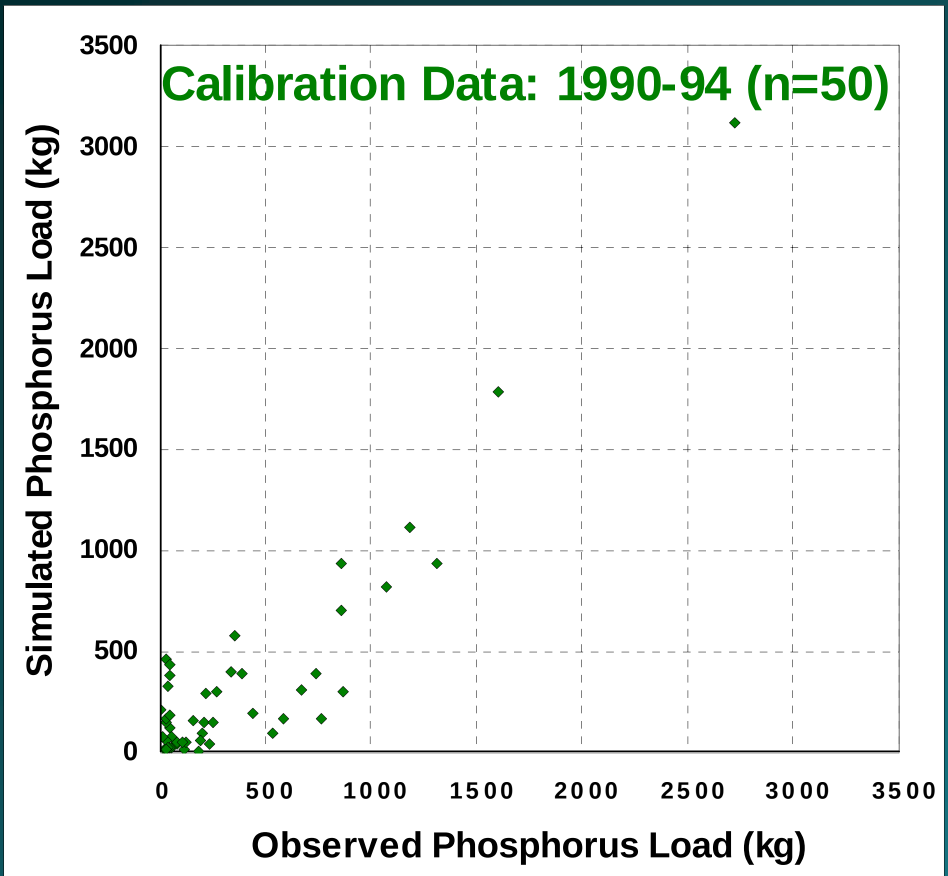
Untransformed: R^2 = 0.93, NSE = 0.91



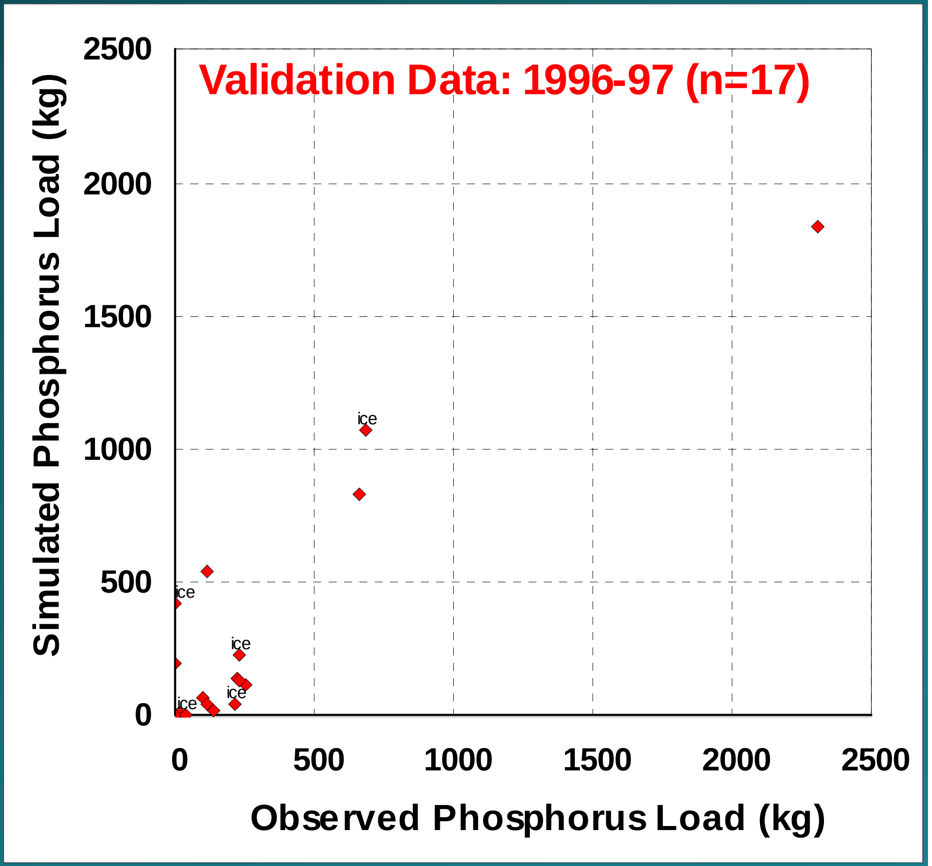
Untransformed: R^2 = 0.89, NSE = 0.85

With 12 non-ice affected events

Calibrate – Validate: Total Phosphorus
Bower Creek - EVENTS

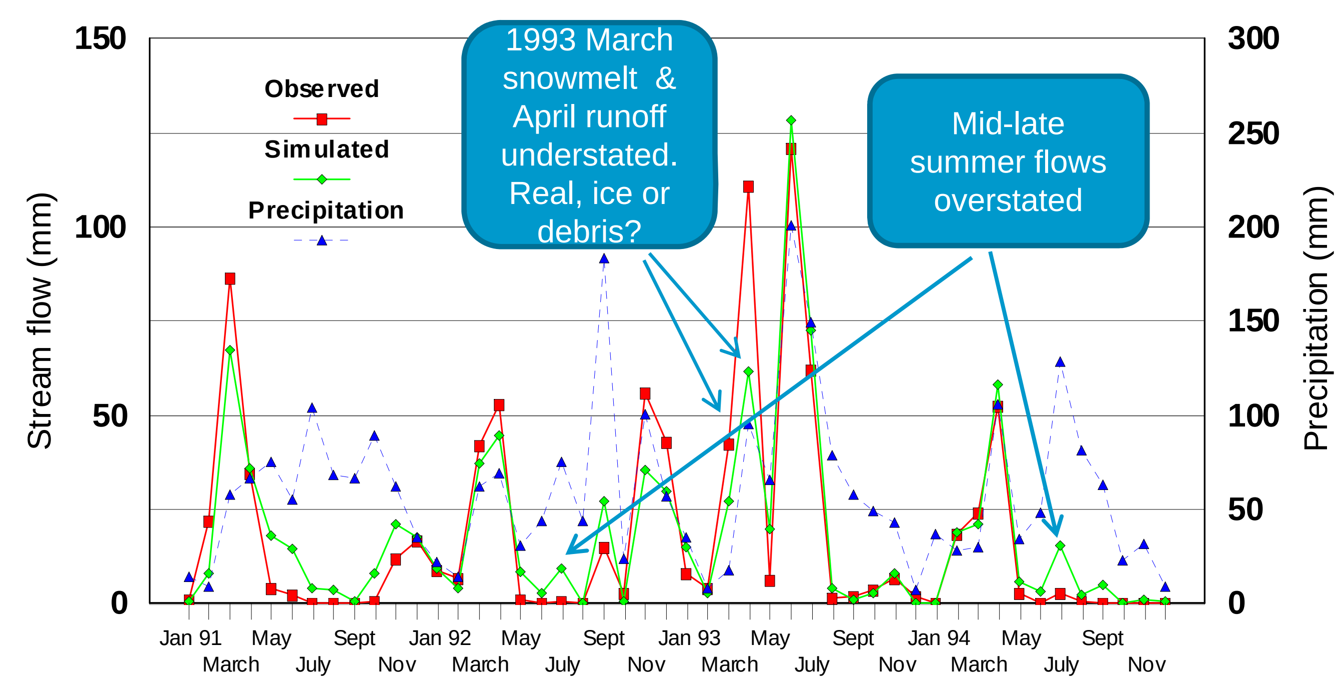


Untransformed: R^2 = 0.81, NSE = 0.79



Untransformed: R^2 = 0.91, NSE = 0.86

With 12 non-ice affected events



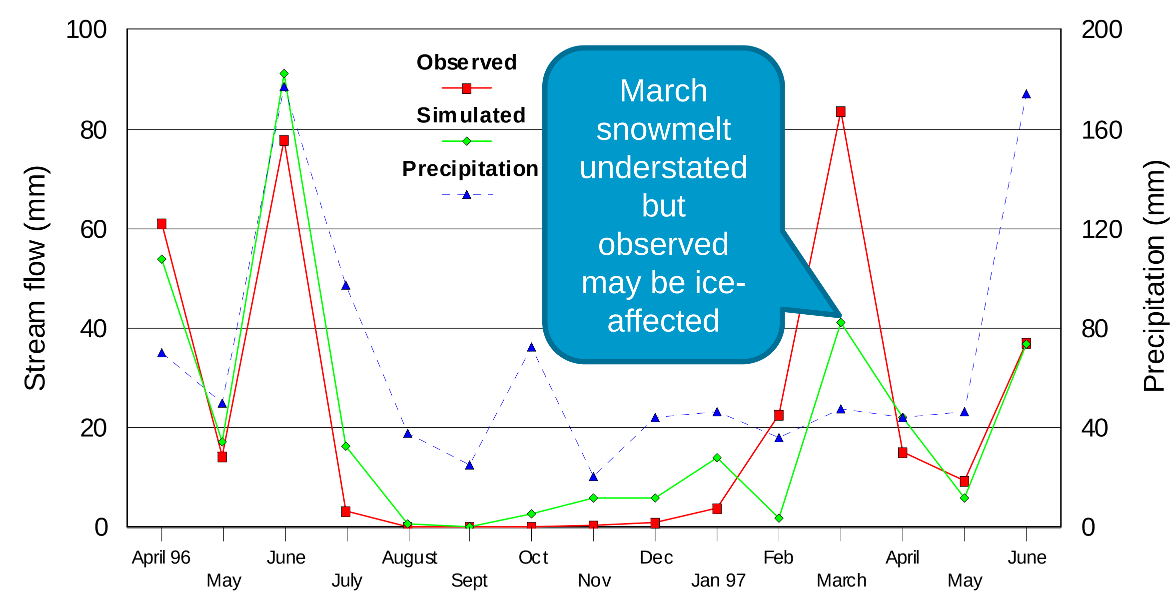
Observed and simulated monthly stream flow - Upper Bower Creek.
1990-94 calibration period. Precipitation from US

Calibrate Monthly Stream flow Bower Creek

R^2=.86, NS=0.86

Validate Monthly Stream flow Bower Creek

R^2=0.83, NS=0.83



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

Calibrate & Validate: Flow, TSS & Phosphorus
Bower Creek – MONTHLY (events: similar results)

- Calibration – (1991-94)

	NSCE	relative diff.
Flow	NSCE = 0.86	(+ 0.8%)
TSS	NSCE = 0.89	(+ 4.2%)
Phosphorus	NSCE = 0.77	(- 5.1%)

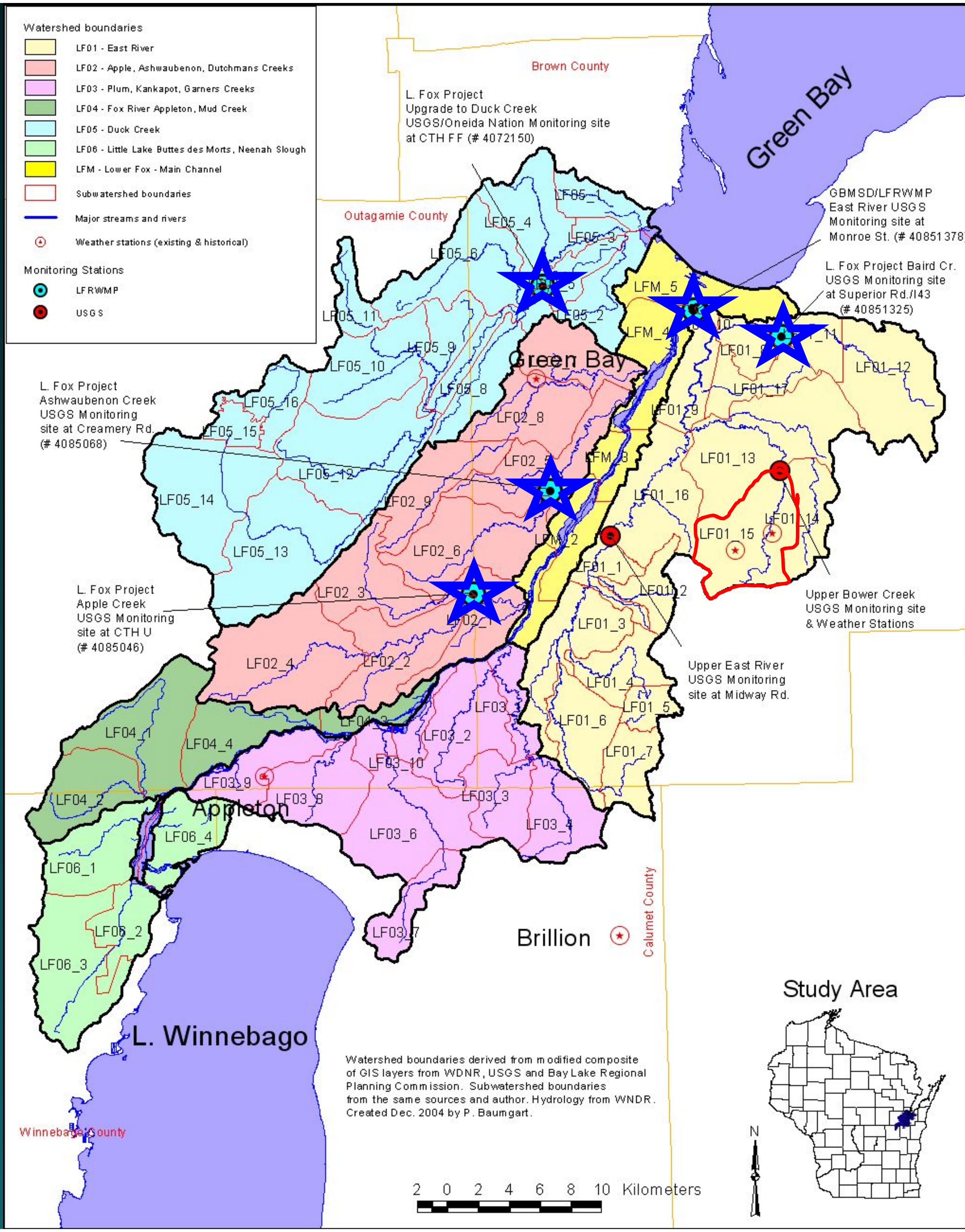
- Validation – (4/1/1996 to 6/30/1997)

Flow	NSCE = 0.77	(- 2.4%)
TSS	NSCE = 0.85	(+ 22.2%)*
Phosphorus	NSCE = 0.90	(+ 8.4%)

* March 1996 snow melt event(s)

Additional Monitoring and Model Assessment for TMDL project

- Model VALIDATED, good fit for flow, TSS, TP
- BUT initial validation data set limited
- SO, LFRWMP added 5 automated USGS monitoring stations
  - Continuous flow
  - Event and low flow sampling – refrigerated sampler
  - Daily TSS and phosphorus loads with GCLAS
  - Dissolved phosphorus with regression model
  - LFRWMP, USGS, GBMSD, Oneida Nation funded



LFRWMP Validation Sites

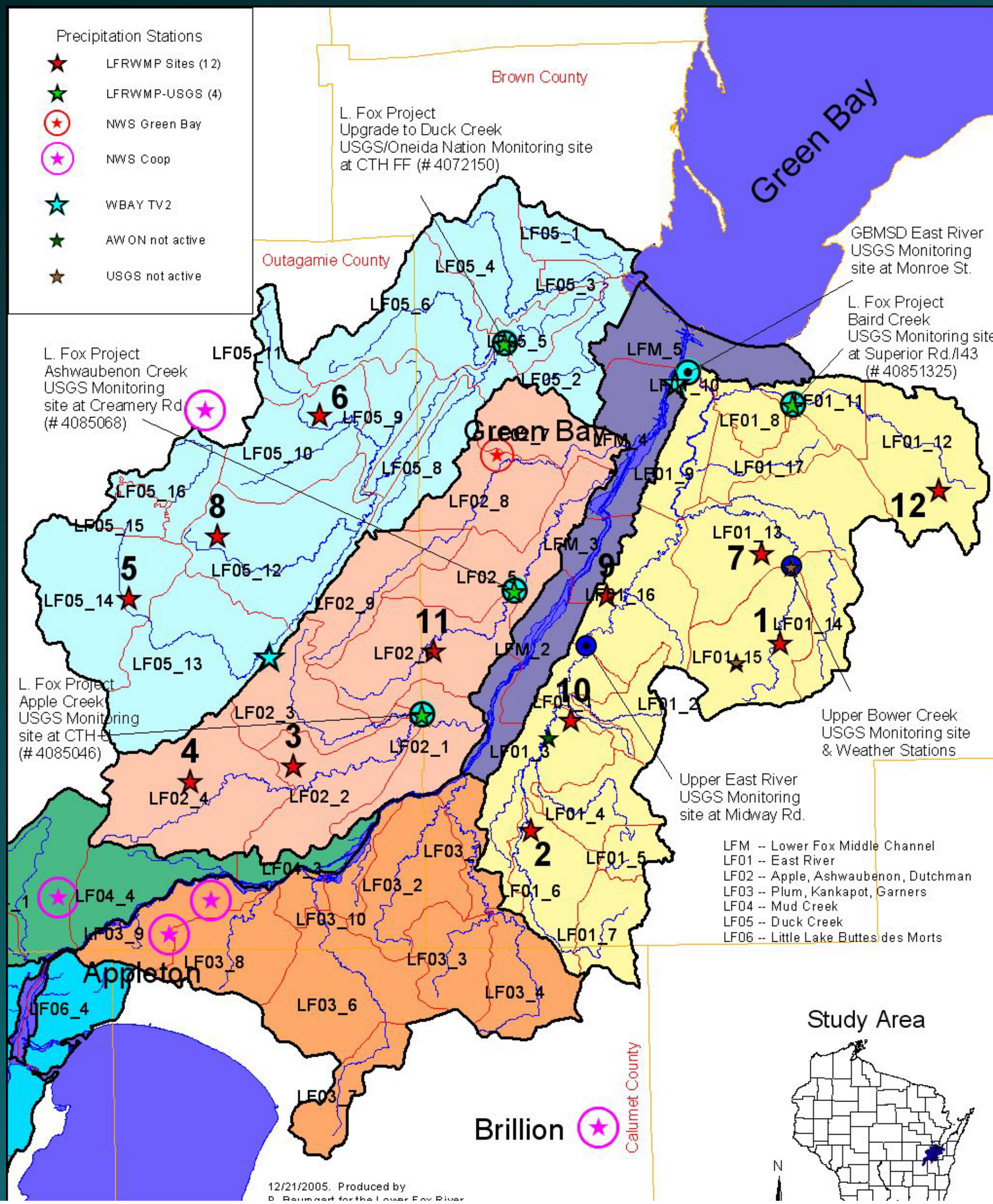
2004-08 daily flow & TSS loads & P loads

Apple Creek - 117 km²
Ashwaub. Cr. - 48 km²
(2004-06)

Baird Creek - 54 km²
Duck Creek - 276 km²
(2004-08)

East River - 374 km²
(2004-07)

Model Inputs – Rain Gauge Network



Climate:
1976-2013 daily Green Bay NWS, Appleton, Brillion, 3 long-term stations

PLUS 15 UWGB & USGS tipping buckets & loggers 2003-present

Other sources

Assessment/Validation Summary: Adjusted* Duck Cr. & East River (2004-08)

Simulated and observed MONTHLY flow, TSS and TP statistics: WY2004-08. Results based on adjusted LFR calibration parameters* (Relative differences for entire period).

	Flow			TSS			Phosphorus		
Stream	**R^2**	**NSE**	**% diff**	**R^2**	**NSE**	**% diff**	**R^2**	**NSE**	**% diff**
Apple	0.85	**0.83**	14.1%	0.81	**0.72**	-16.2%	0.78	**0.78**	4.2%
Ashwaubenon	0.89	**0.83**	26.7%	0.66	**0.66**	2.1%	0.82	**0.82**	-5.6%
Baird	0.81	**0.80**	19.0%	0.66	**0.66**	9.0%	0.71	**0.69**	8.5%
Duck*	0.89	**0.87**	-7.9%	0.73	**0.72**	**30.3%**	0.69	**0.68**	17.4%
East River*	0.91	**0.91**	-6.5%	0.66	**0.65**	4.8%	0.79	**0.78**	13.5%

* Duck Creek: adjusted P absorption coefficient and P partitioning coef.

* East River: adjusted sediment transport factor (800 mg/L to 500 mg/L)

Model Assessment Summary

- In general, good correspondence between simulated and observed stream flow and loads of phosphorus and suspended sediment (monthly, annual, totals)
- Model response acceptable for predictive simulations in L. Fox 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 Duck Creek at this time (sediment loads during snow melt periods especially when no rainfall)

Modeling Multiple Ag BMP Scenarios

- 1977-2000 climatic period for simulations; or other
- 2004 landuse Baseline conditions
- Alternative management scenarios over same period
- Conservation Tillage: simply increase HRU areas for Ridge-Till and Mulch Till; link table or paste to HRU MS-Access database
- Stabilize Soil Phosphorus Levels at Current Level (e.g. 40 ppm B. Cty) and at level from mid-1970's (25 ppm)
  - Reduce P in feed ration & fertilizer P (copy new Fert2000.dat)
- Vegetated Buffer Strips
- Biofuel Production: switchgrass: Add HRU?
- Rotational grazing for dairy operations: Add HRU?
- Cover Crop on corn-silage and soybean fields
  - Substitute *.mgt files)
- Increase Manure incorporation
- Others

Impact of Alternative Scenarios on TSS and Phosphorus Non-point Loads to Green Bay from Plum-Kankapot Creek Watershed

(mostly AG: LF-03 = 218 km^2 or ~ 13% of LFR area)

BMP Scenarios	TSS (ton)	Total P (kg)	% reduced TSS	% reduced Total P
Baseline 2004 Conditions	9,700	25,800	0	0
1. Nutrient Management: Dairy P Feed Ration: Reduce by 25% (implement 90%)	9,700	24,500	0.0%	4.7%
2. Nutrient Management: incorporate 85% of manure (from 50%)	9,700	24,200	0.1%	6.2%
3. Nutrient Management: Stabilize Soil P (implement 90%)	9,700	22,700	0.0%	11.9%
4. Conservation Tillage - CT40%, MT45%, RT15%	7,700	23,400	20.5%	9.0%
5. Cover Crops on corn silage and some soybean fields	9,400	25,400	2.5%	1.2%
6. Buffer Strips installed on 100% of 1:24k hydrology streams	9,200	24,400	5.1%	5.1%
7. Reduce Soil P to 25 ppm (implement 35%)	9,700	20,800	0.0%	19.4%
8. Biofuel Switchgrass crop; 7% of total crop acres	9,200	24,800	4.9%	3.6%
9. Combination - ALL BMP's	**6,699**	**16,257**	**30.8%**	**36.9%**

From: Lower Fox River and Green Bay TMDL, unpublished values from P. Baumgart

Impact of Alternative Scenarios on TSS and Phosphorus Non-point Loads to Green Bay from LFR Sub-basin

Scenarios	TSS (ton)	Total P (kg)	% reduced TSS	% reduced Total P
Baseline 2004 Conditions	47,000	145,000		
1. Nutrient Management: Dairy P Feed Ration: Reduce by 25% (implement 90%)	47,000	138,700	0.0%	4.3%
2. Nutrient Management: incorporate 85% of manure (from 50%)	47,000	136,600	0.1%	5.8%
3. Nutrient Management: Stabilize Soil P (implement 90%)	47,000	129,100	0.0%	11.0%
4. Conservation Tillage - CT40%, MT45%, RT15%	40,700	135,100	13.4%	6.8%
5. Cover Crops on corn silage and some soybean fields	46,100	143,400	1.8%	1.1%
6. Buffer Strips installed on 100% of 1:24k hydrology streams	45,500	139,300	3.1%	3.9%
7. Reduce Soil P to 25 ppm (implement 35%)	47,000	119,800	0.0%	17.4%
8. Biofuel Switchgrass crop; 7% of total crop acres	45,100	140,600	4.0%	3.0%
9. Combination - ALL BMP's	**37,100**	**99,000**	**21.0%**	**31.7%**

From: Lower Fox River and Green Bay TMDL, unpublished values from P. Baumgart

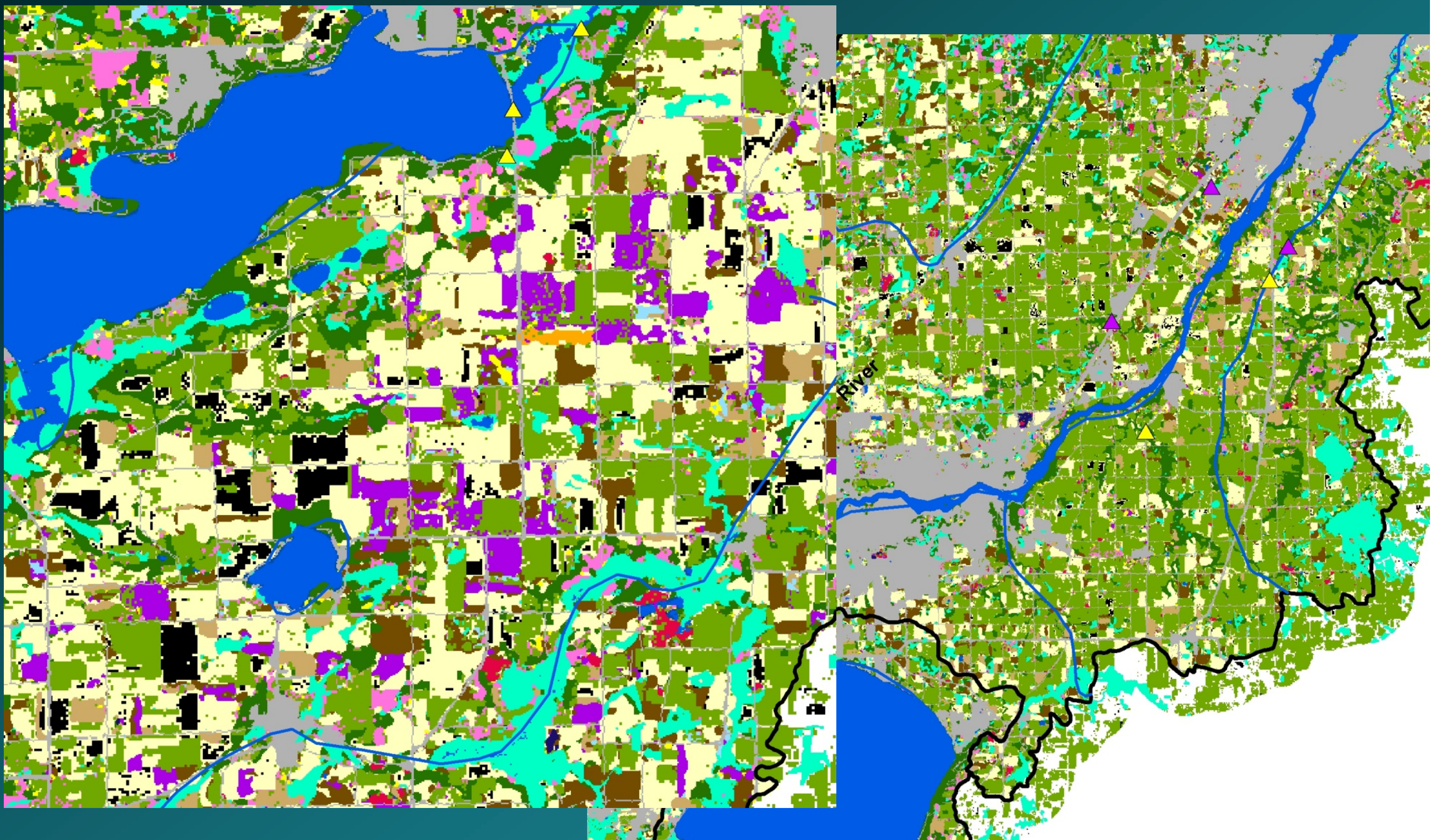
Upper Fox and Wolf River sub-basins

Model Inputs – GIS layers

- Landuse – land cover
  - NASS Cropland Image: 2006 – 2011
    - Combined 2006-2011 for cropland: any alfalfa in 6 years classed as DAIRY
    - Other crops & land covers
  - wetlands = WISCLAND land cover
- Soils – NRCS County SSURGO (from Soil Map Viewer and ArcGIS extension)
- Slope/topography – 10 m DEM created

- Major Watershed boundaries – 12 digit HUC, with modifications for monitoring sites, etc.; user-defined
- WDNR Stream hydrology 1:24k
- Climate: ~1976-2013 daily; NOAA NWS & NWS-coop stations (calibration and scenario periods)
- Point source loads from WDNR

DAIRY in green (land cover SWAT input): Green Lake vs Lower Fox



Upper Fox-Wolf: Primary Hydrologic Response Units (HRUS)

- Agriculture - DAIRY (6 year crop rotation of corn-silage/grain, corn-silage, wheat, 3 years of alfalfa);
  1 Conventional tillage practice
  2 Mulch-till (>30%; plus 15-30% split with CT)
  3 No-till , ridge-till, zone-till
- Ag – CASH CROP (1 yr corn OR 1 yr soybean);
  4 Conventional tillage practice
  5 Mulch-till (>30%)
  6 No-till, ridge –till, zone-till

  7 plus Vegetables
  Need to accommodate Rotational Grazing, Biofuel like Switchgrass …
- Non-Agricultural
  8 Urban
  9 Grassland
  10 Forest
  11 Wetland
  12 Quarry, others

Agricultural HRU's

- Crop Rotation phase: 6 sets of dairy HRU's, 1 hru/rotation phase
- Residue Level/Tillage Practices: NRCS & County Transect Survey data
  - construct SWAT dairy and cash crop mgt files for each tillage class (CT, MT, ZT)
  - conv. till, mulch till, zone till %'s apportioned in MS Access HRU table for each HRU (i.e., fractional areas)
- Small number of Dairy, Cash Crop, other mgt files created and copied in batch file to create 1,000's of *.mgts
- County Soil P data: area wt. avg to get sub-watershed Soil P levels: linked/pasted into *.chm files (lower for non-Ag)
- County cattle #'s (cows, heifers, calves, other) >> Manure rate >> area wt. to get sub-watershed rates
  - then normalized value assigned to **<u>tlaps</u>** in *.sub and multiplied by manure rate from *.mgt (only when fert code is #9 for manure)
- Crop Yields Calibrated (NASS Ag. Stats)

SWAT Model Modification Options

- Original SWAT Version 2009-93.7b ---- modified
- MUSLE sediment equation: added leading coefficient and Qvol, Qpeak, DA exponents
- Evapotranspiration: leading coefficient to reduce PET*
- USLE K factor Wt. Average to limit # of soils (input in *.sol)
- NRCS Soil Hydro-group Wt. Average Default Curve #'s to limit # of mgt files (input in *.sol)
- Sediment Yield: soil residue cover (separate living biomass and residue impacts)
- Sub-watershed channel length and area used for time-of-conc. & Peak Flow calculations in HRU's (since 1990's)
  - MUSLE altered to utilize sub-watershed area
- MISC: extend manure incorporation change, output, etc.

Model Modifications – Soil (*.sol)

NRCS Curve Number: To reduce the number of management files required in the SWAT model, a simple equation was added to the readmgt.f file. The following equation adjusts curve numbers associated with tillage operations according to the soil hydrologic group.

$$CNa = CN + ((CN\_soil-78)/7 * (101 - CN)/3)$$

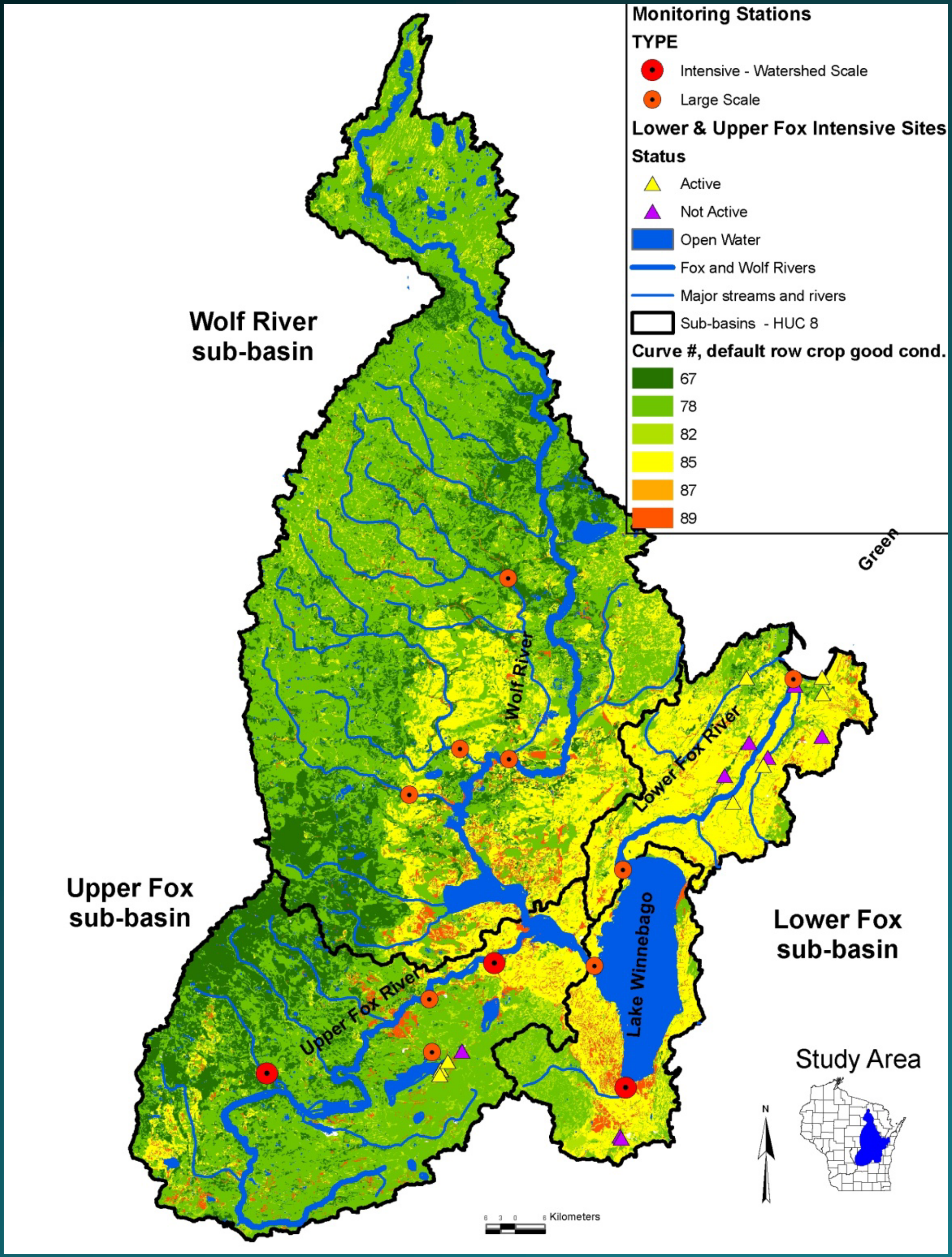
Where:

CNa = NRCS curve number associated with tillage practice and crop conditions, but adjusted for the actual soil hydrologic group

CN = NRCS curve number associated with the tillage practice and crop conditions, assuming B hydro group soil

CN_soil = NRCS curve number associated with actual soil, assuming standard crop of corn (67 for A, 78 for B, 85 for C soils); new variable added to readsol.f

So, only a single management file is required for each management practice; otherwise, each management practice requires a separate management file for each soil hydrologic group category that is represented. In addition, rather than being limited to representing only a small number of categories, this method allows the use of the actual weighted-average soil hydrologic group for each HRU within a subwatershed.



Fox-Wolf Basin NRCS Curve # for default row crop

GIS derived Wt. avg "CN_soil" parameter for each sub-watershed HRU then used to adjust Curve # from much fewer Management files

Model Modifications – Residue C-factor

Crop Residue Change: The model code was changed to separate the effect on the USLE C factor of above ground living biomass from the effect of any remaining ground residue. Otherwise, the above ground live biomass dwarfs any remaining ground residue that might remain with conservation tillage; in effect, this is the same as assuming that no-till corn is not much different than moldboard plow once the crop is well underway (on a C-factor basis). While a number of methods could be used as a remedy (e.g., crop canopy cover vs ground residue), the same methodology that is used in SWAT was utilized, but the effect of the two forms of erosion protection were separated in the USLE C factor calculation.

```
c          ***** ALTERED ZZZ option added for Baumgart routine 2/16/13 ***
           elseif(icfac == 1) then
            if (igro(j).eq.0) then
                      cmin1 = -2.3026 ! ln(0.1);cmin1 = -2.99573 = ln(0.05)
                      c = exp((-.2231-cmin1)*exp(-.00115*sol_cov(j))+ cmin1)
            else
                      cmin1 = cvm(idplt(nro(j),icr(j),j)) !replace ncr with idplt

                      cv_dm = .8*amax1(bio_ms(j),0.)
                      cv_rsd = amax1(sol_rsd(1,j),0.)
                      c=(exp((-.2231-cmin1)*exp(-.00115*cv_dm)+ cmin1))
c          *** multiply C due to dry matter from crop growing, by C due to residue below

                      c= c*(exp((-.2231+2.303)*exp(-.00115*cv_rsd)-2.303))/.8

                      cv_rsd = 0.0
                      cv_dm = 0.0
            end if
c          ************* END OF CHANGE ********************************
```

Model Modifications – Soil (*.sol)

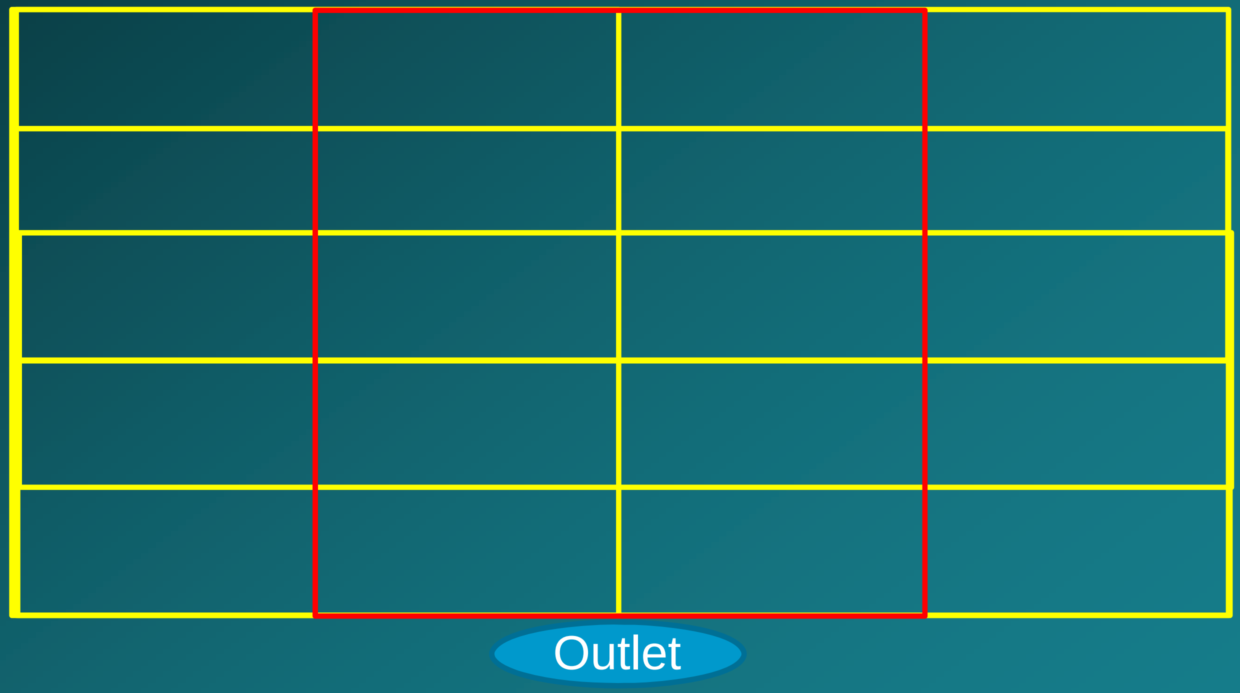
area wt: USLE K & normalized CN (hydro group B, corn)

.Sol file Watershed HRU:1 Subbasin:1 HRU:1 Luse:COct Soil: WI021LaB-1 Slope: 0-9999 11/2/2013 12:00:00 AM ArcSWAT 2009.93.7

Soil Name: WI021LaB-1				
Soil Hydrologic Group: B				
Maximum rooting depth(m) : 1520.00				
Porosity fraction from which anions are excluded: 0.500				
Crack volume potential of soil: 0.500				
Texture 1 : coarse-loamy				
Depth [mm]:	230.00	790.00	1520.00	
Bulk Density Moist [g/cc]:	1.35	1.43	1.45	
Ave. AW Incl. Rock Frag :	0.16	0.16	0.14	
Ksat. (est.) [mm/hr]:	82.80	32.40	100.80	
Organic Carbon [weight %]:	1.16	0.47	0.17	
Clay [weight %]:	10.00	17.50	13.00	
Silt [weight %]:	21.50	15.30	19.60	
Sand [weight %]:	68.50	67.20	67.40	
Rock Fragments [vol. %]:	3.00	3.00	9.00	
Soil Albedo (Moist) :	0.30	0.30	0.30	
Erosion K :	**28.14**	0.24	0.24	**USLE Erosion K-Factor *100 (area weighted average) /100 later**
Salinity (EC, Form 5) :	**78.23**	0.00	0.00.	**Curve Number Base (area weighted average)**

SWAT Modification: sub vs HRU dimensions

- Sub-watershed channel length and area used for time-of-conc. & Peak Flow calculations in HRU's (not HRU values)
  - MUSLE altered to utilize sub-watershed area
- WHY? Otherwise - math inconsistent – loads don't add up. Whether 1, 5, 10, 20 or 100 HRUs, TOTAL load should be same.



Model Calibration & Assessment

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

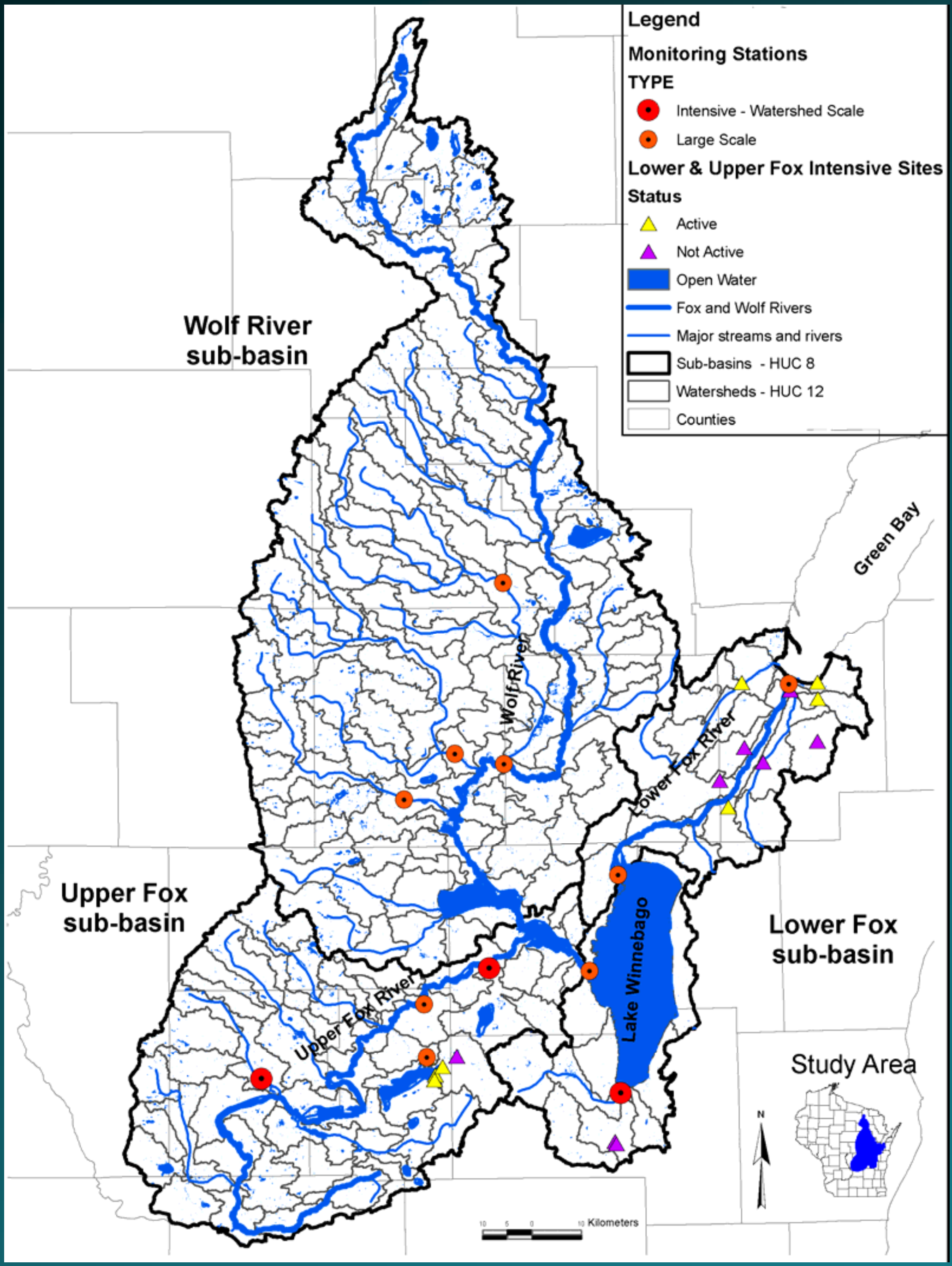
- Validate/assess: flow, TSS, P at different temporal and spatial scales

  event, monthly, annual, total basis

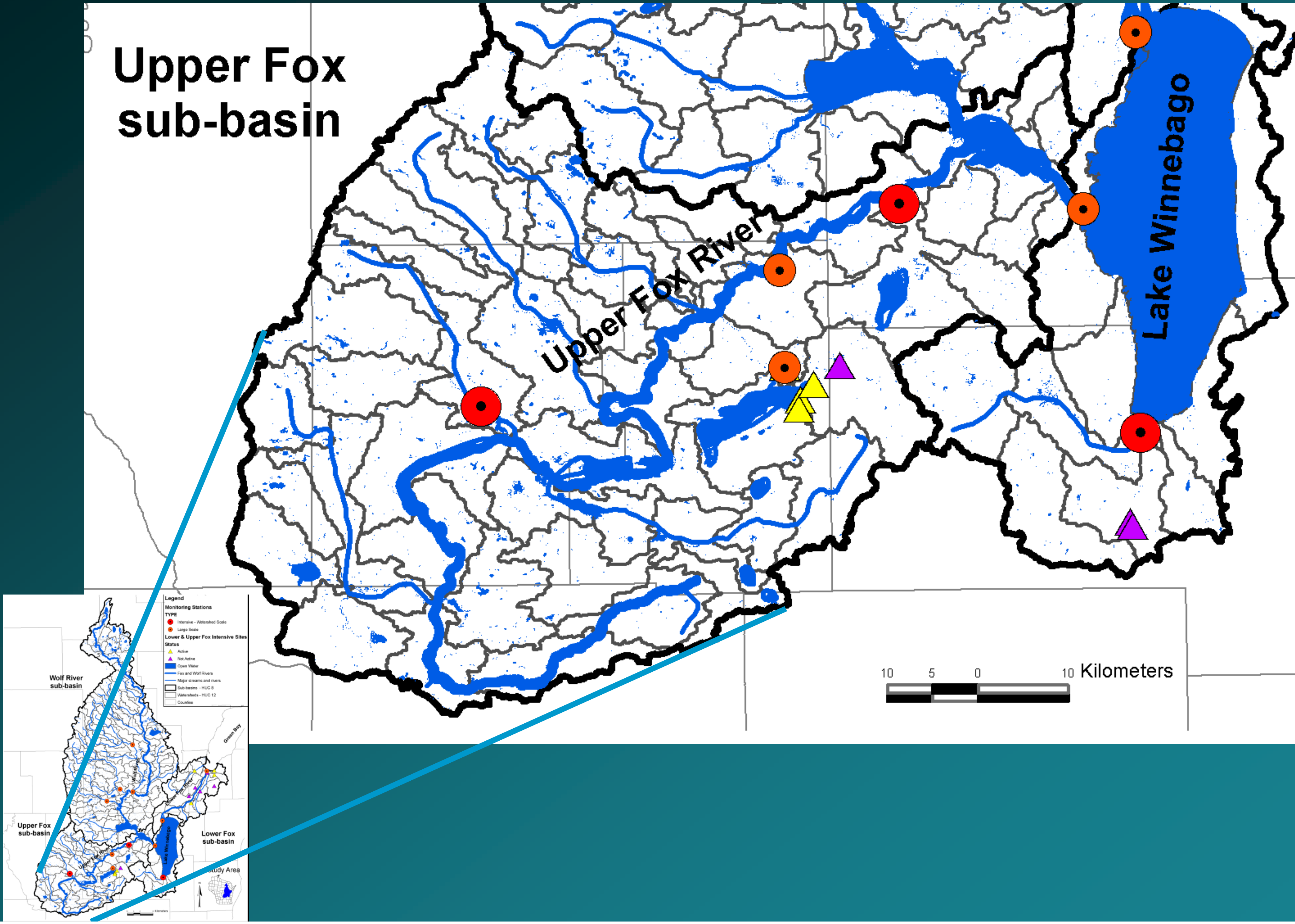
  small watershed scale to outlet at Green Bay

- Lower Fox Sub-basin TMDL model (many sites already used to calibrate & validate)

Stream Monitoring Stations for calibration & validation



Upper Fox calibration & validation sites

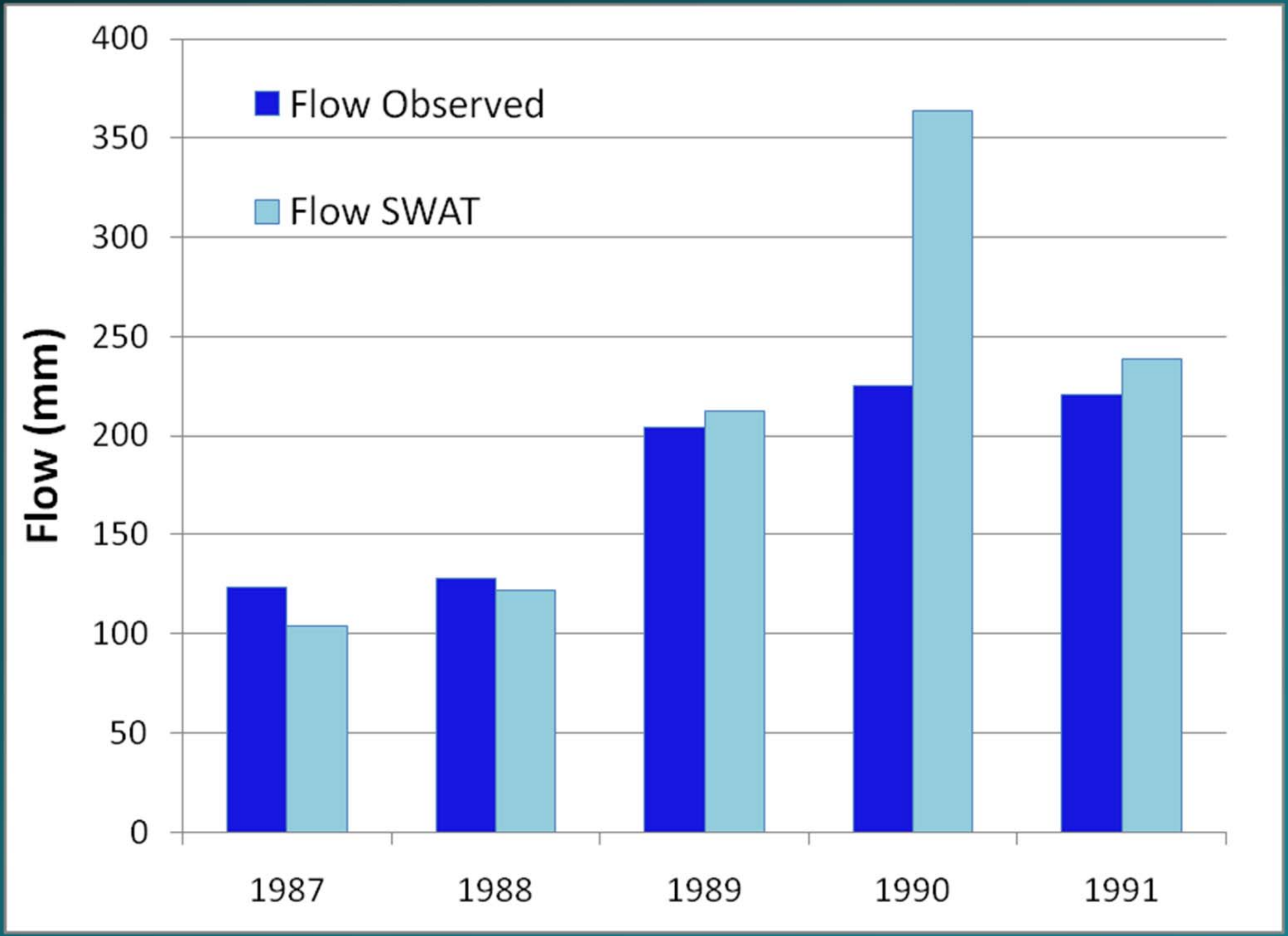


Model Calibration and Validation Sites: flow and loads (all USGS stations)

			daily load		TSS/SSC/P	Daily Discharge Available		
Upper Fox	**USGS ID**	**area (km^2)**	**TSS/SSC**	**phosphor**	**concentrations**	**begin**	**end**	
White Creek at Spring Drive Road near Green Lake	04073462	8	X	X		1981-1988, .	Oct-1996-present	
Silver Creek at South Koro Road near Ripon	040734644	94	X	X		1987	1996	
Puchyan River DS N. Lawson Drive near Green Lake	04073473	272			~ 82 samples	1996	present	
Silver Creek at Spaulding Road near Green Lake	04073466	116			~100 samples	2005	2011, Nov 30	
Parsons Creek downstream site near Fond du Lac	04083425	15	X	X		1998	2001	
Parsons Creek middle site near Fond du Lac	04083423	15	X	X		1998	2001	
Parsons Creek upstream site near Fond du Lac	04083420	14	X	X		1998	2001	
Fond du Lac River @ W. Arndt St. at Fond du Lac	04083545	435	X	X		2008	2011	
Montello River near Montello	04072845	337	X	X		2008	2011	
Waukau Creek near Omro	04073970	228	X	X		2008	2011	
Fox River at Berlin	04073500	3,470	regression est.			1899	present	
Wolf River								
Waupaca River near Waupaca	04081000	686	regression est.		*(project, 2011-13)* [a]	2009	present	(1916 >, major breaks)
Embarrass River near Embarrass	04078500	994	regression est.		*(project, 2011-13)* [a]	1994	present	(1919 >, breaks)
entire Embarrass River, near New London			regression est.		*(project, 2011-13)* [a]	estimated by USGS		
Little Wolf River at Royalton	04080000	1,313	regression est.		*(project, 2011-13)* [a]	2009	present	(1914 >, major breaks)
Wolf River at New London	04079000	5,853	regression est.		*(project, 2011-13)* [a] , +	1914	present	
Fox River at Oshkosh (L. Winn. Major Inlet	04082400	13,751	regression est.			1992	present	
Fox River at Neenah (L. Winn. Outlet)		14,700	regression est.					
Fox-Wolf Outlet								
GBMSD: Fox River at Oil Tank Depot at Green Bay	040851385	16,393	regression estimate		GBMSD & WDNR samp	1989	present	

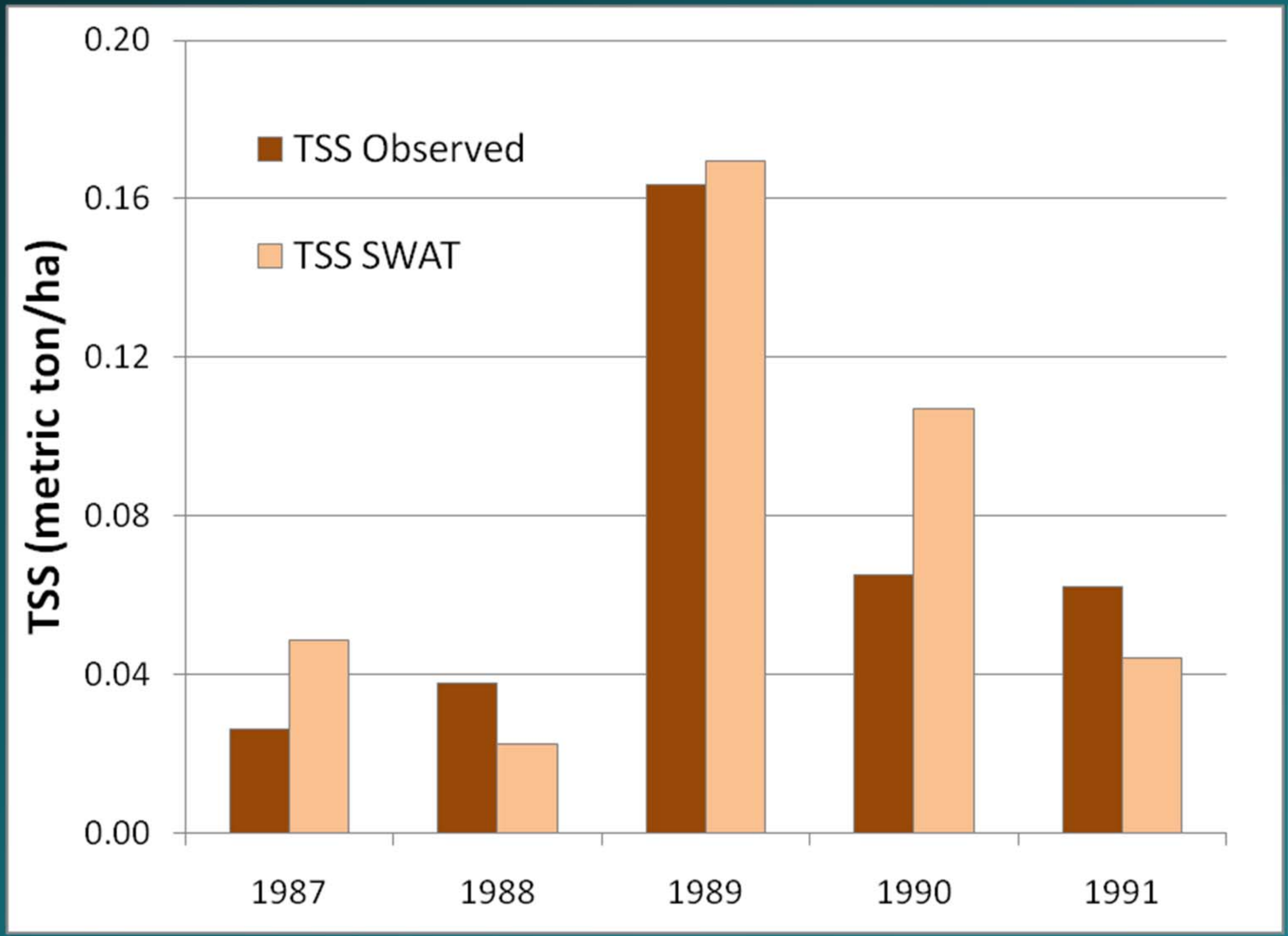
a. ~ 30 samples/year for first 3 years of NOAA project

Calibration: FIRST CUT, Silver Creek @ Koro Rd. near Green Lake in Upper Fox (1987-1991; 94 km^2) *Stream FLOW*



Calibration: FIRST CUT, Silver Creek @ Koro Rd. near Green Lake in Upper Fox (1987-1991; 94 km^2)

Total Suspended Sediment



Potential Issues

- Particle size distribution: So far, All silt from Ag. If no initial difference, then how route OK?
  - What have others found?
- Routing through reservoirs if particle sizes from sources all the same, and stay the same
  - i.e., far upstream vs near bottom of basin
- Multiple saved *.eve files possible?

Next Steps

- Finish model for Upper Fox, then calibrate and validate model (Green Lake streams)
- Finished Wolf River trib monitoring – Now est. Loads
- Expand model to Wolf River
- Combine Lower Fox, Upper Fox and Wolf River models: to Green Bay
- Estimate efficacy of Alternative Management Scenarios and Climate Scenarios
- Continue to collaborate with NRCS, EPA, LCD’s, others to further info sharing, BMP demonstration sites and implementation

Thank You!

Aerial photo taken 4/12/2011. Photo credit: Steve Seilo (www.photodynamix.com)

The Lower Bay, Mouth of Duck Creek, Mouth of the Fox River.