Source Allocation of Suspended Sediment and Phosphorus Loads to Green Bay from the Lower Fox River Sub-basin Using the Soil and Water Assessment Tool (SWAT)

Paul Baumgart

University of Wisconsin – Green Bay

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

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

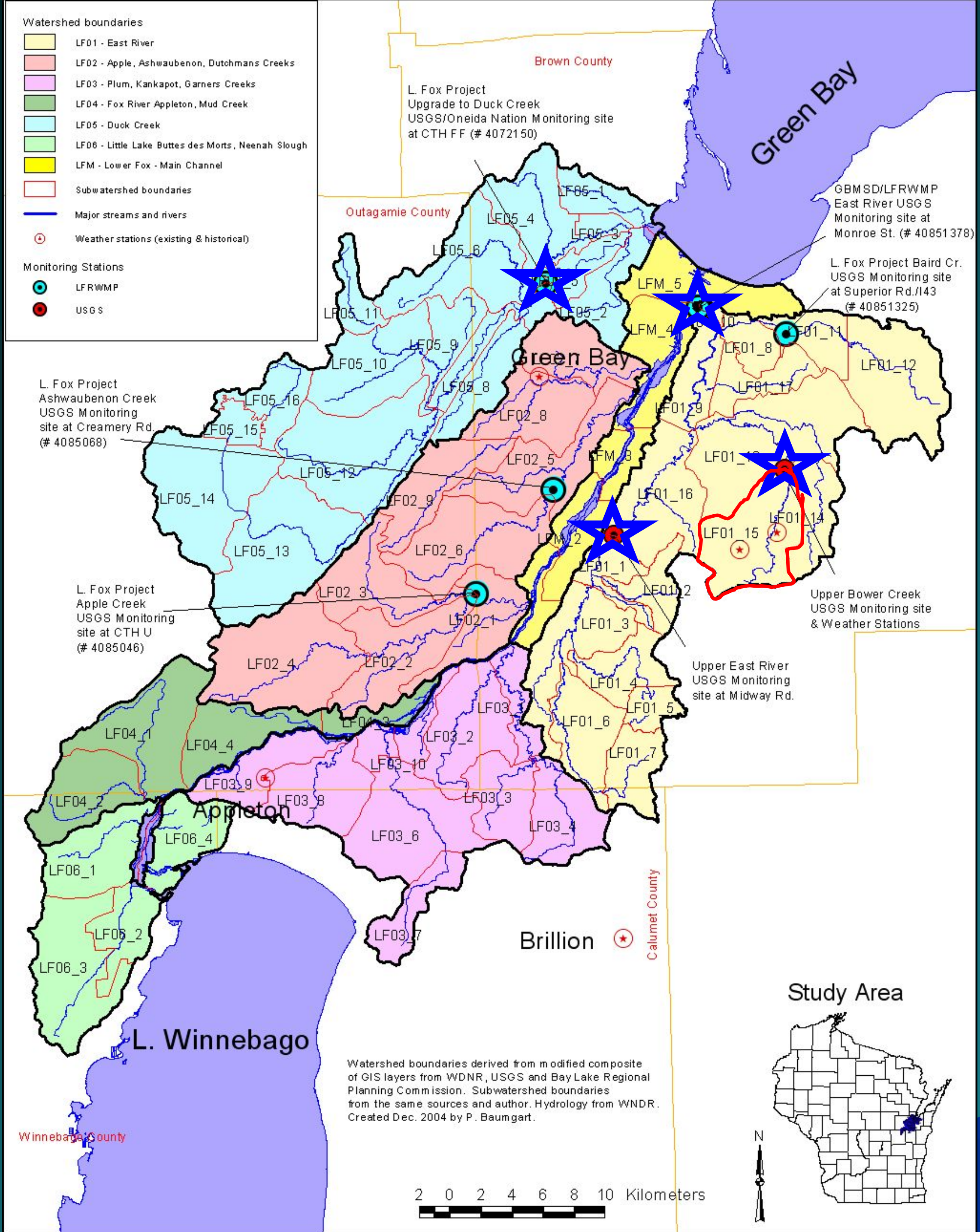
Presentation Outline

- Lower Fox River Sub-basin Description
- SWAT overview
- Modeling Methods and Inputs
- Calibration and Validation results
- Model Results: Simulated Phosphorus and Suspended Sediment Export from Sub-basin
- Allocation of P & Suspended Sediment Loads under Simulated Baseline Conditions
- Alternative Management Scenarios: Results

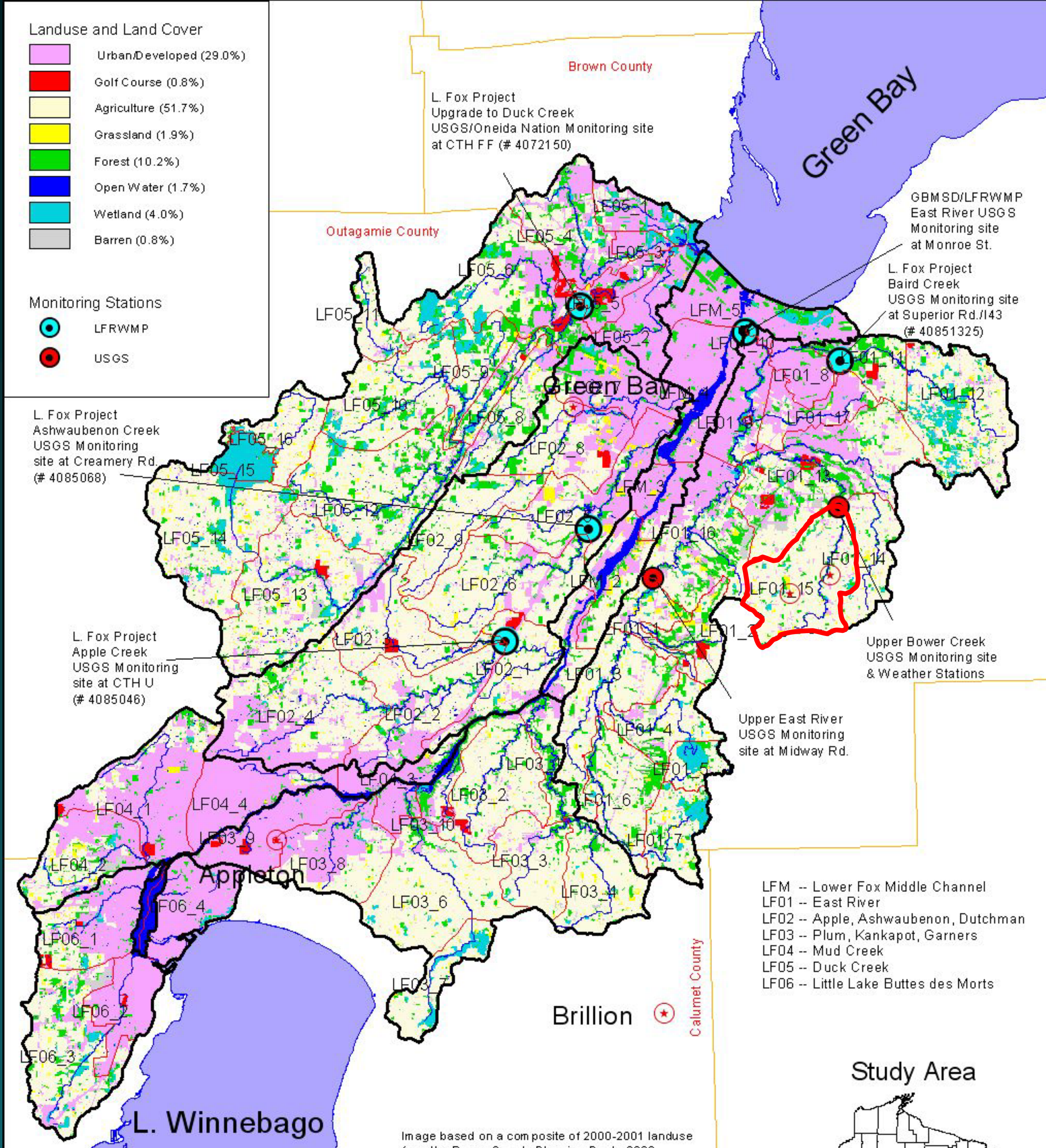
Primary objective

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)

Lower Fox River watersheds & subwatersheds



Lower Fox River Year 2000 Landuse and Land cover



Soil and Water Assessment Tool - SWAT

- USDA – ARS model: J.G. Arnold, J.R. Williams, Temple Texas
- Applied modified version of SWAT 2000 code
- 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
- 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 & 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

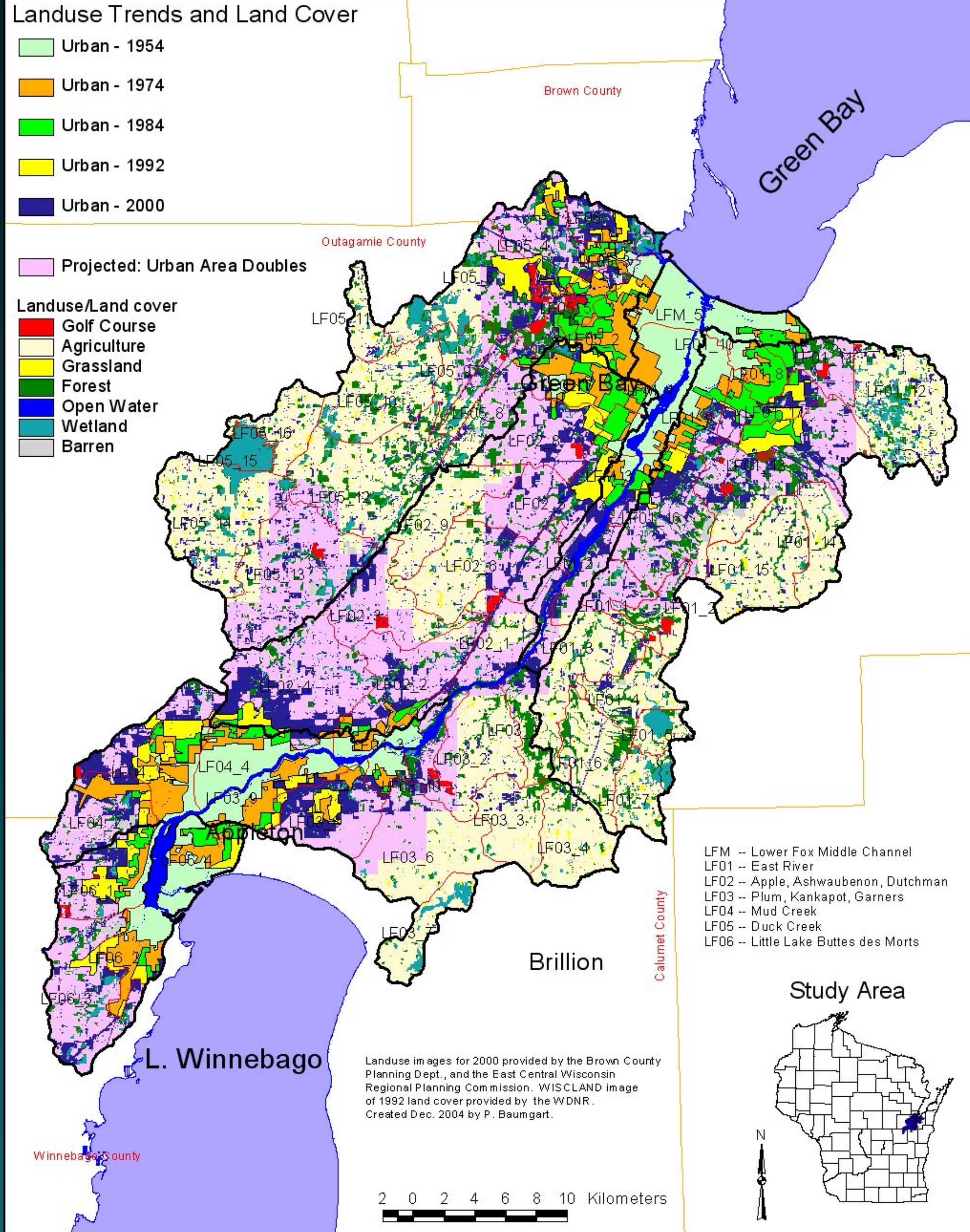
- Agriculture - Dairy (2000 - 6 year crop rotation of corn-grain, corn-silage, soybean, 3 years of alfalfa)
  - 1 Conventional tillage practice
  - 2 Mulch-till (>30%)
  - 3 No-till
  - 4 Barnyards
- Agriculture - Cash crop (2000 - 1 yr corn, 1 yr soybean)
  - 5 Conventional tillage practice
  - 6 Mulch-till (>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

Modeling Urban Areas

- Urban landuses lumped together into single urban HRU (medium density residential)
- Impervious surfaces modeled with buildup/washoff option (similar to SWMM)
- Pervious surfaces modeled as lawn grass with fertilizer applied
- SWAT buildup/washoff and management routines calibrated to:
  - USGS/WDNR monitoring of urban streams & storm sewers
  - RUST/Earth Tech SLAMM modeling for City of Green Bay



Lower Fox River Year 2000 Landuse Trends

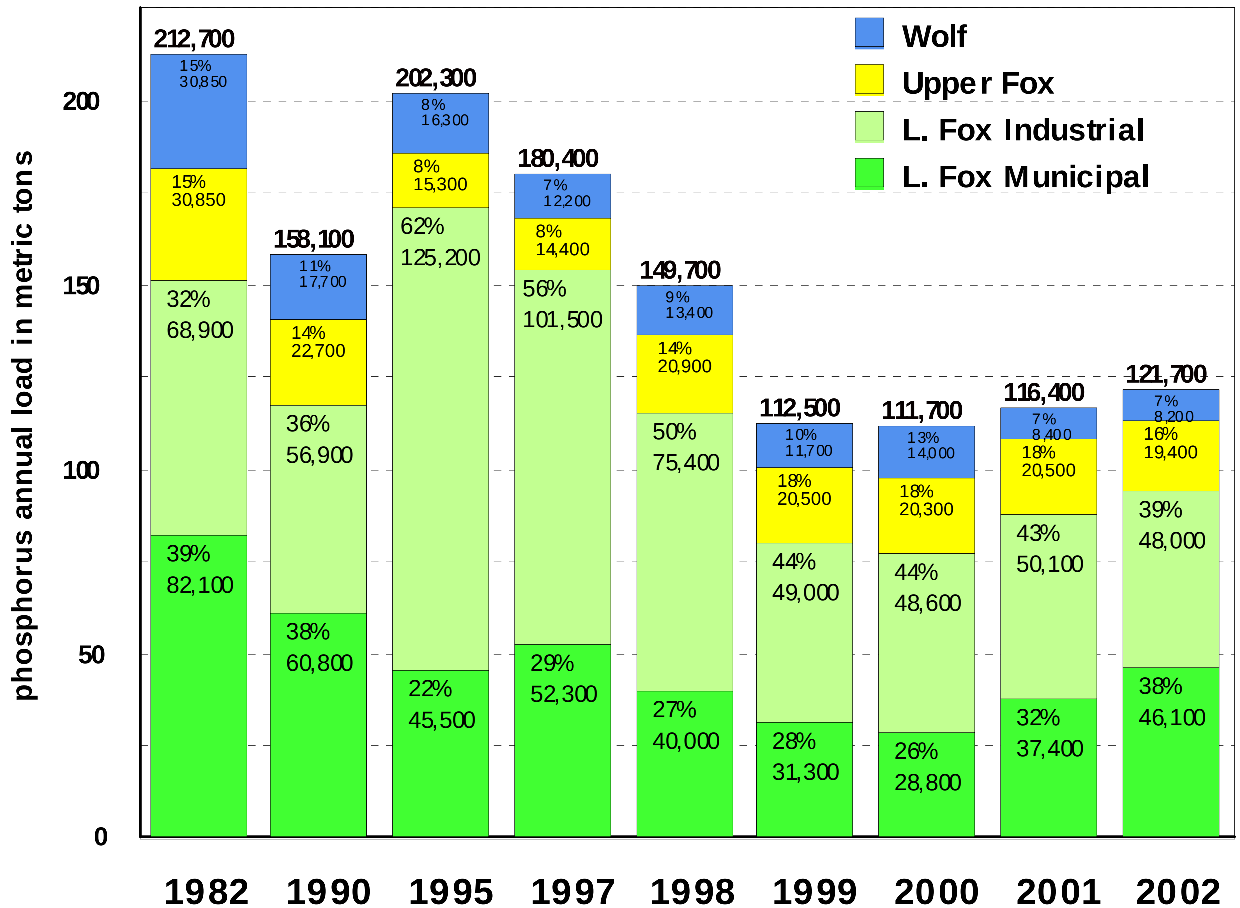
1954 to 2000, urbanization = 2.6%/year

Projected urban area doubles by 2025 to 2030

Point Source Phosphorus Loads

Figure 4-1. Fox-Wolf Basin Point Source Phosphorus Loads (1982-2002).

Average annual load from Fox River is 450,000 to 600,000 kg/year.



** 1982 combined load from from Wolf and Upper Fox basins divided equally as precise fractions not found

Annual loads obtained from the Wisc. Dept. of Natural Resources.

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
- Other code fixes and modifications

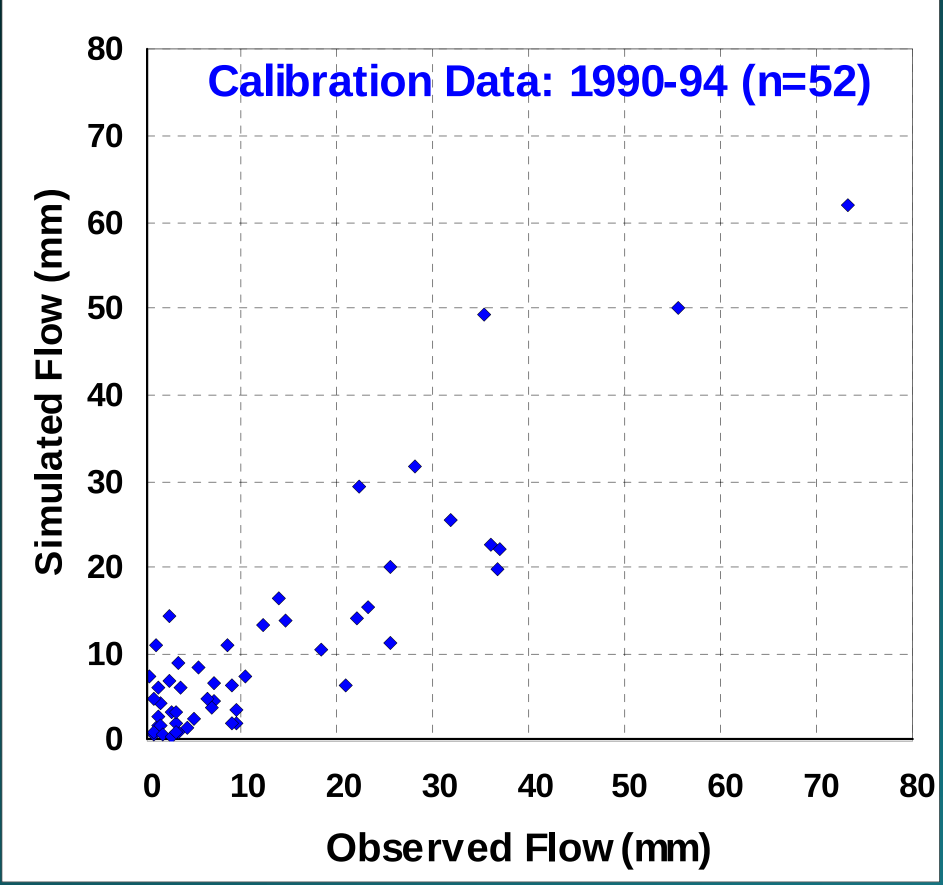
Model Calibration & Assessment

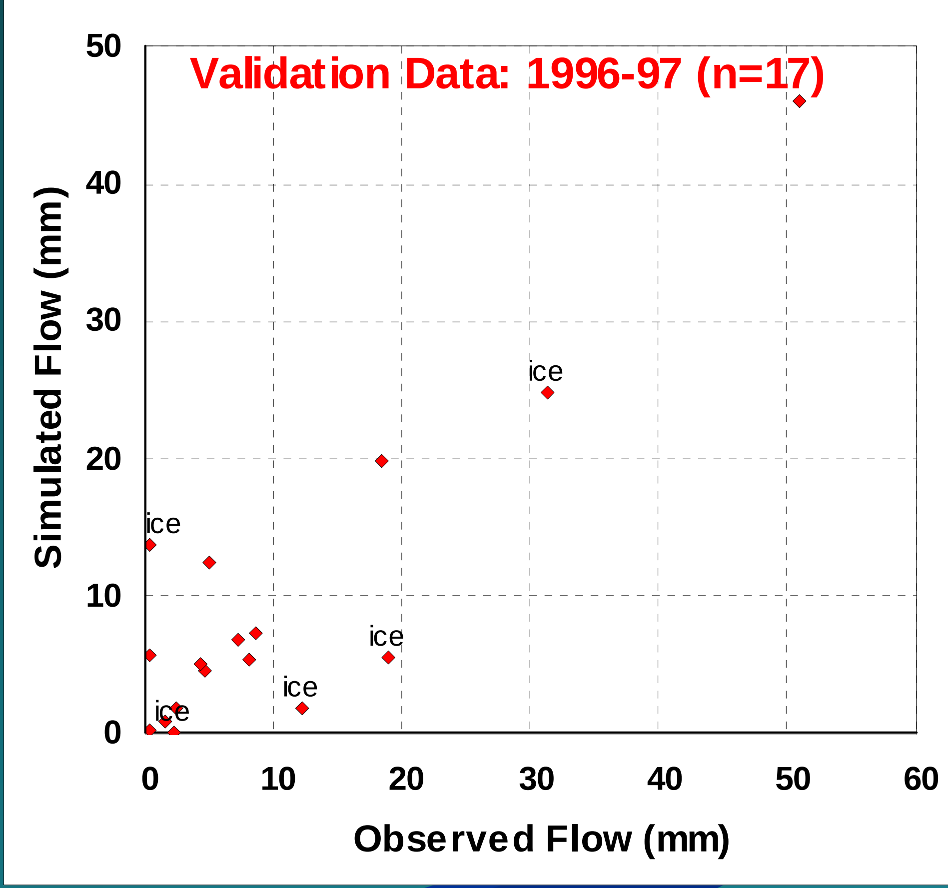
- Calibrate: 1) flow 2) crop yields and nutrient levels 3) suspended sediment 4) phosphorus
- Validate/assess: flow, SS, P at different time and/or site
- Daily, event, monthly, annual, total basis
- Primary calibration/validation site:
  USGS/WDNR - Upper Bower Cr. (36 km^2)
- Other sites:
  - USGS - Upper East River @ Midway Rd. (122 km^2)
  - USGS/Oneida Nation - Duck Creek @ CTH FF (276 km^2)
  - USGS East River in Green Bay (367 km^2), loads only
- All primarily rural/agricultural landuse
- Compare simulated export to Green Bay to loads calculated by others

Calibration & Validation

Examples

Calibrate – Validate: Stream Flow
Upper Bower Creek events





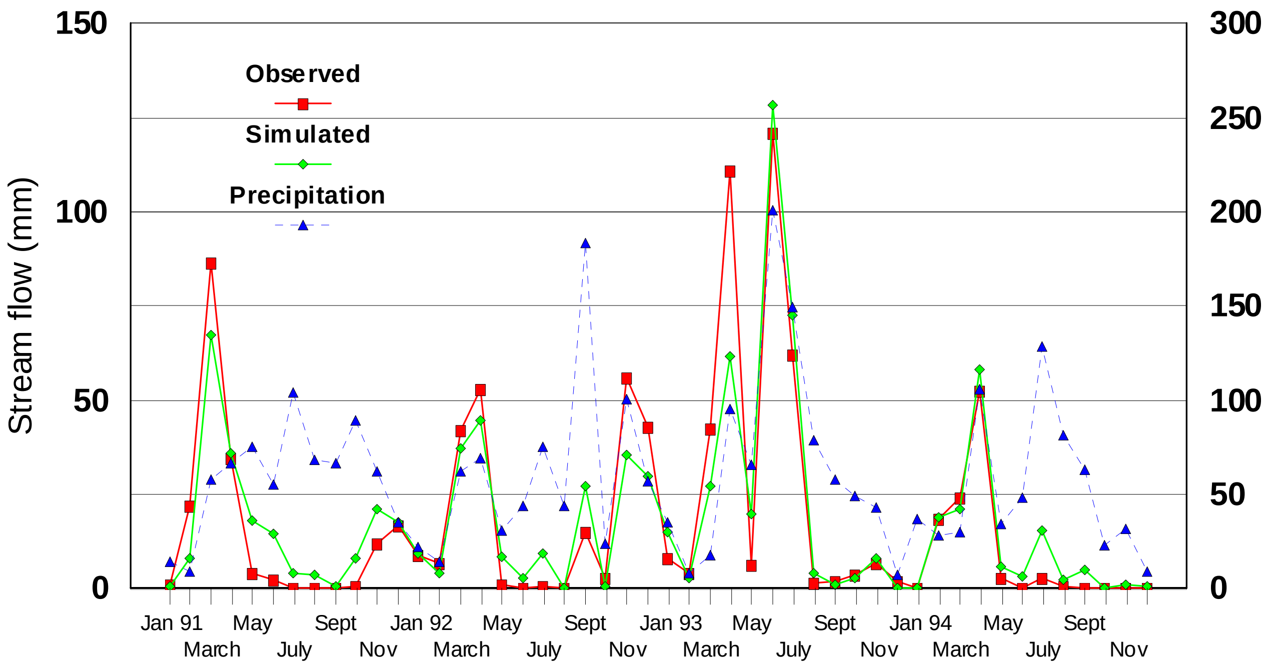
Untransformed: R^2 = 0.80, NSE = 0.80

Untransformed: R^2 = 0.95, NSE = 0.94

for n = 12, not ice-affected events

Calibrate Monthly Stream flow Upper Bower Creek

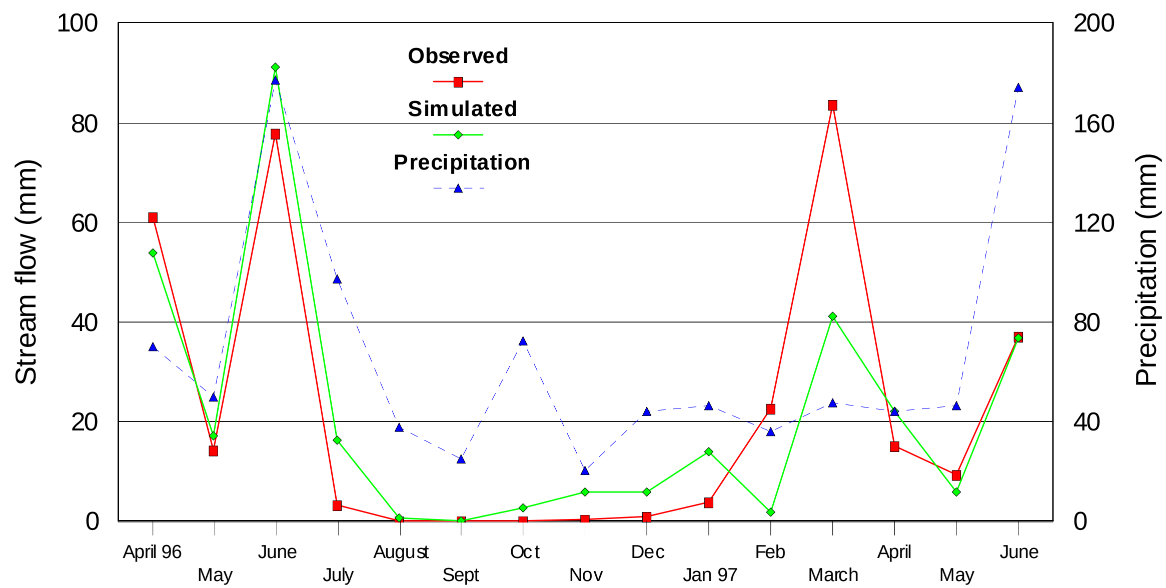
R^2=.87, NS=0.86



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

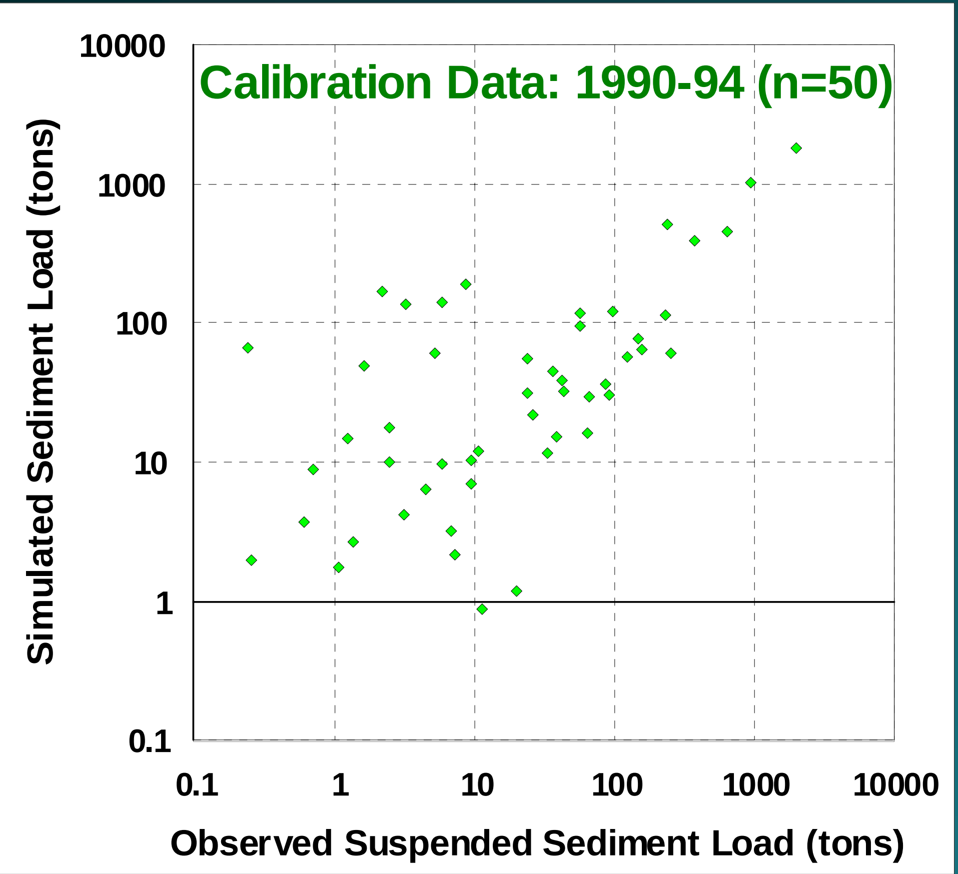
Validate Monthly Stream flow Upper Bower Creek

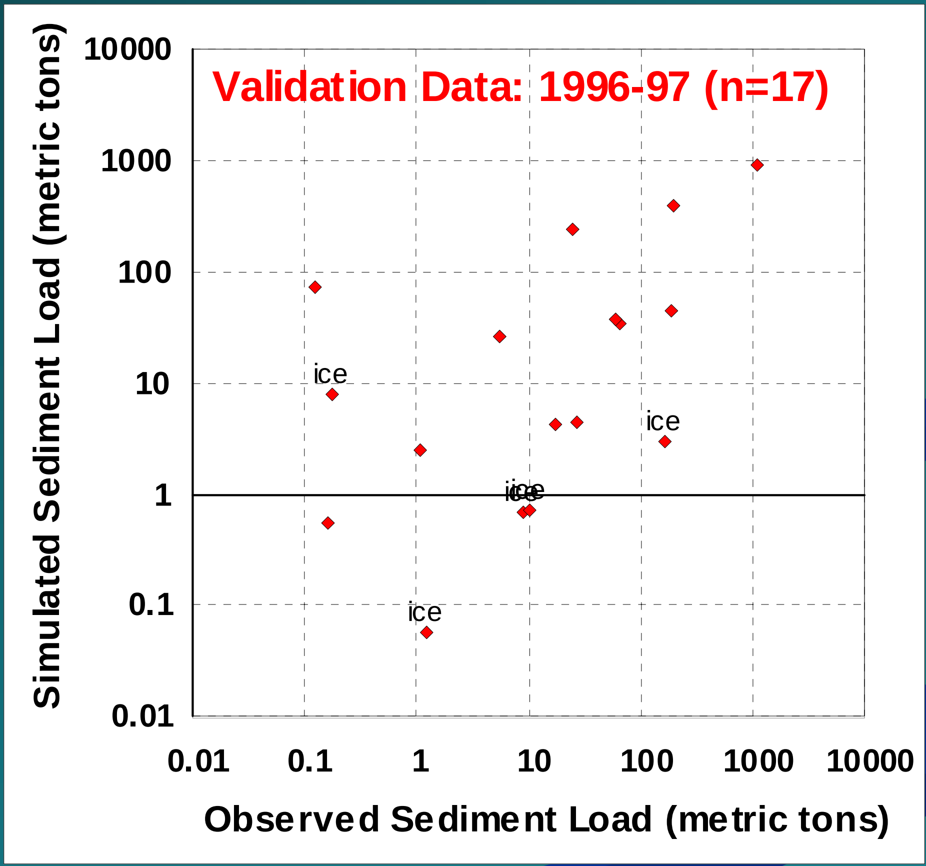
R^2=0.76, NS=0.76



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

Calibration & Validation Summary

	Nash-Sutcliffe Coefficient of Efficiency Statistic									
			Flow			**Suspended**			**Phosphorus**	
		area				**Sediment**				
		(sq. km)	**Cal.**	**Valid.**		**Cal.**	**Valid.**		**Cal.**	**Valid.**
Event	**Bower ***	**36**	0.80	**0.94**		0.93	**0.89**		0.75	**0.88**
Daily	**East River @ Midway**	**122**		**0.74**			***			***
Daily/event	**Duck at CTH FF**	**276**	0.69d				***			**0.68e**
Event	**East River @ Monroe**	**376**					**0.87**			**0.54**
Monthly	**Bower**		0.86	**0.76**		0.91				
	East River @ Midway			**0.92**						
	Duck at CTH FF **		0.82	**0.56**						
Annual	**Duck at CTH FF**		0.76							
	Validation period: % difference between observed and simulated totals									
	Bower			**-4.2%**			**4.3%**			**-9.1%**
	East River @ Midway			**-10.5%**						
	Duck at CTH FF **			**-9.0%**						

* Ice-affected events excluded from validation phase data sets

** Validation data excluded 7/8/2000 very localized extreme precipitation event over NOAA NWS site

*** Most event loads generally corresponded closely with observed loads, but # of events small

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, which affected phosphorus loads most
  - after prolonged dry periods
  - during snow melt periods

- If possible, performance could be improved somewhat in N.E. Wisconsin if model could better respond to extreme conditions and small events

- Current LFRWMP monitoring project will greatly assist in improving and/or validating model (5 watersheds)

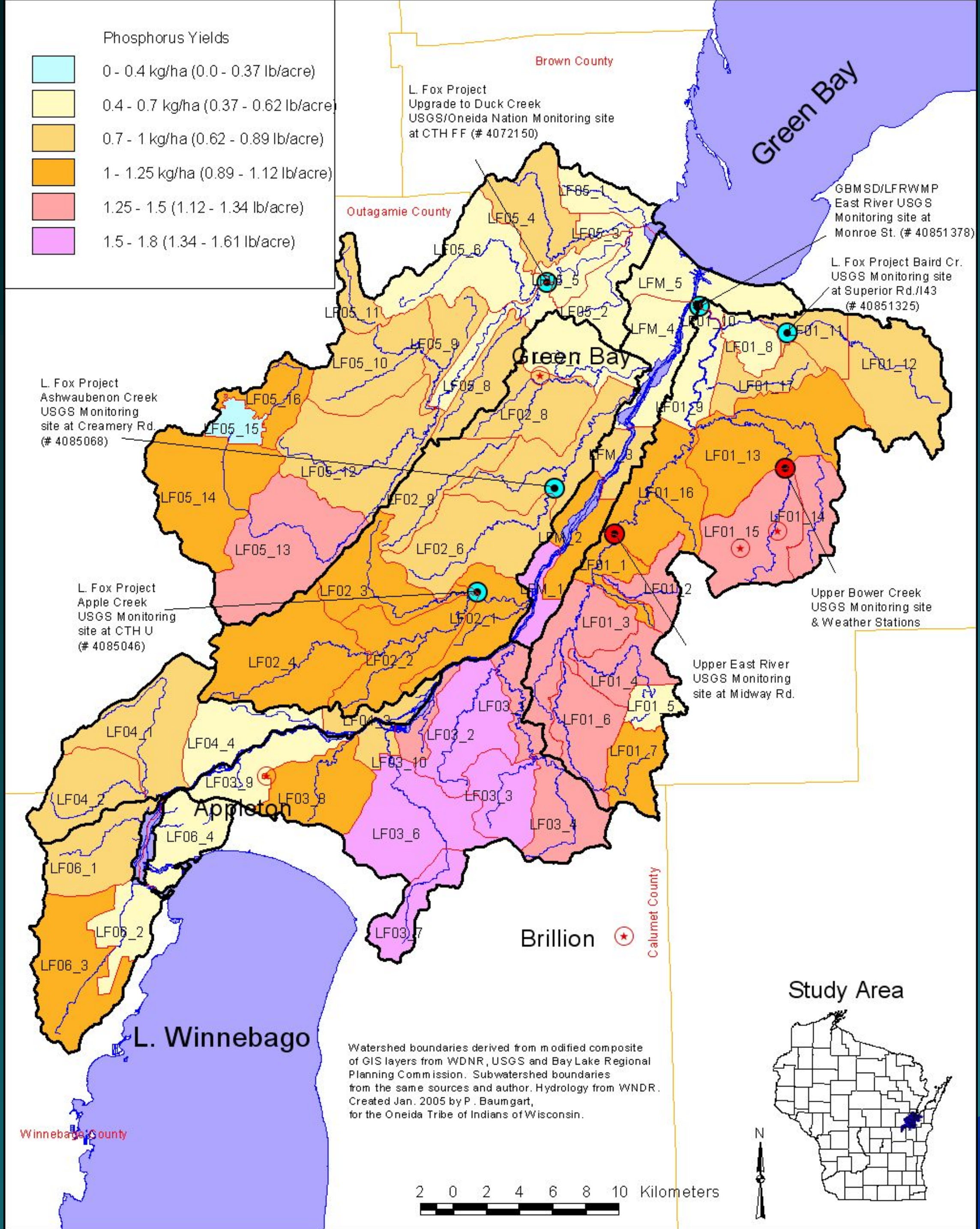
Model Results – Year 2000 Baseline Conditions

- 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)

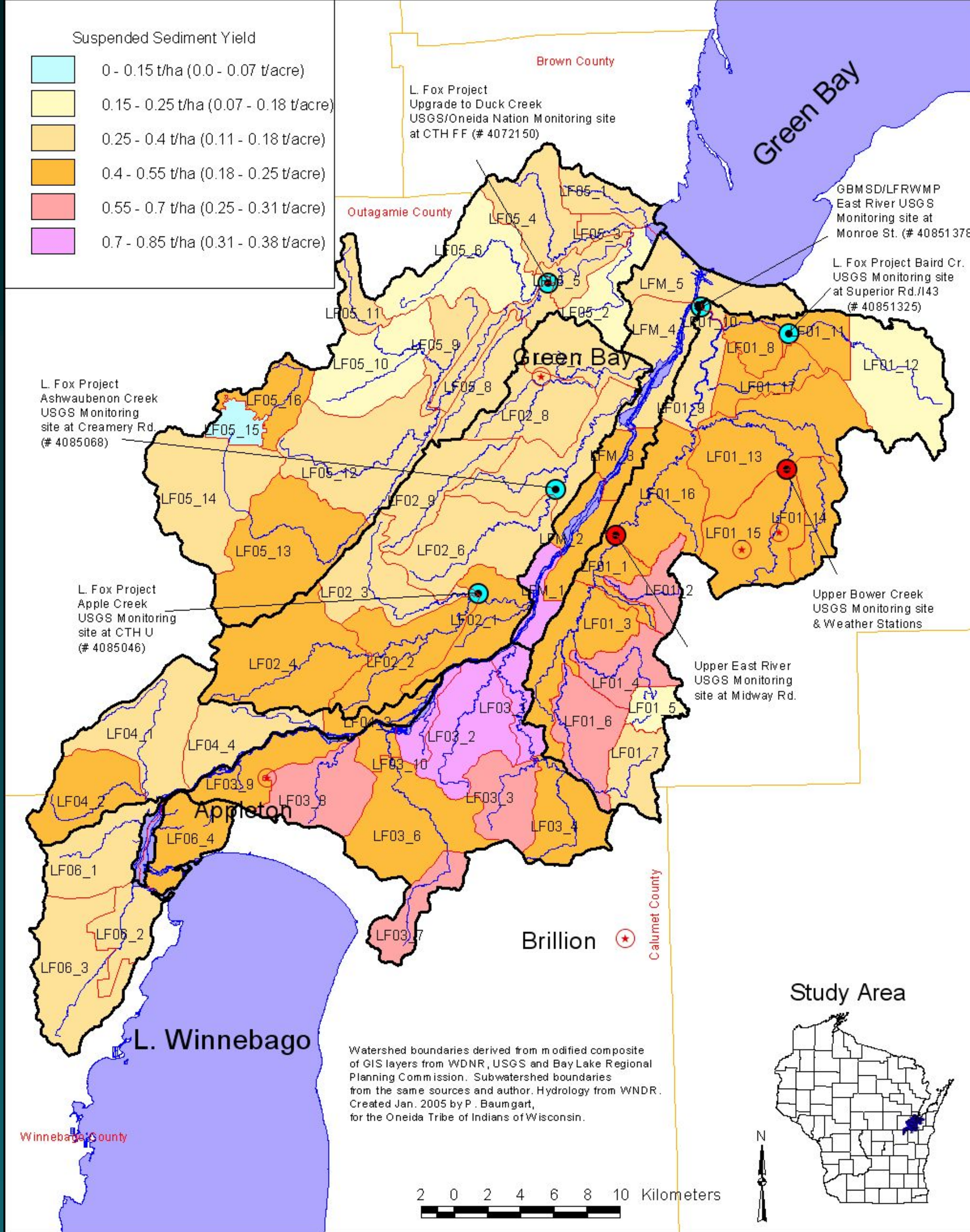
Baseline 2000 conditions



Lower Fox River Watershed

Simulated Subwatershed Suspended Sediment Yield (t/ha)

Baseline 2000 conditions



Output Example: non-point export to watershed outlets and lower Green Bay

Table 10-1. Simulated average annual suspended sediment and phosphorus non-point source loads from watersheds in the Lower Fox River Subbasin.

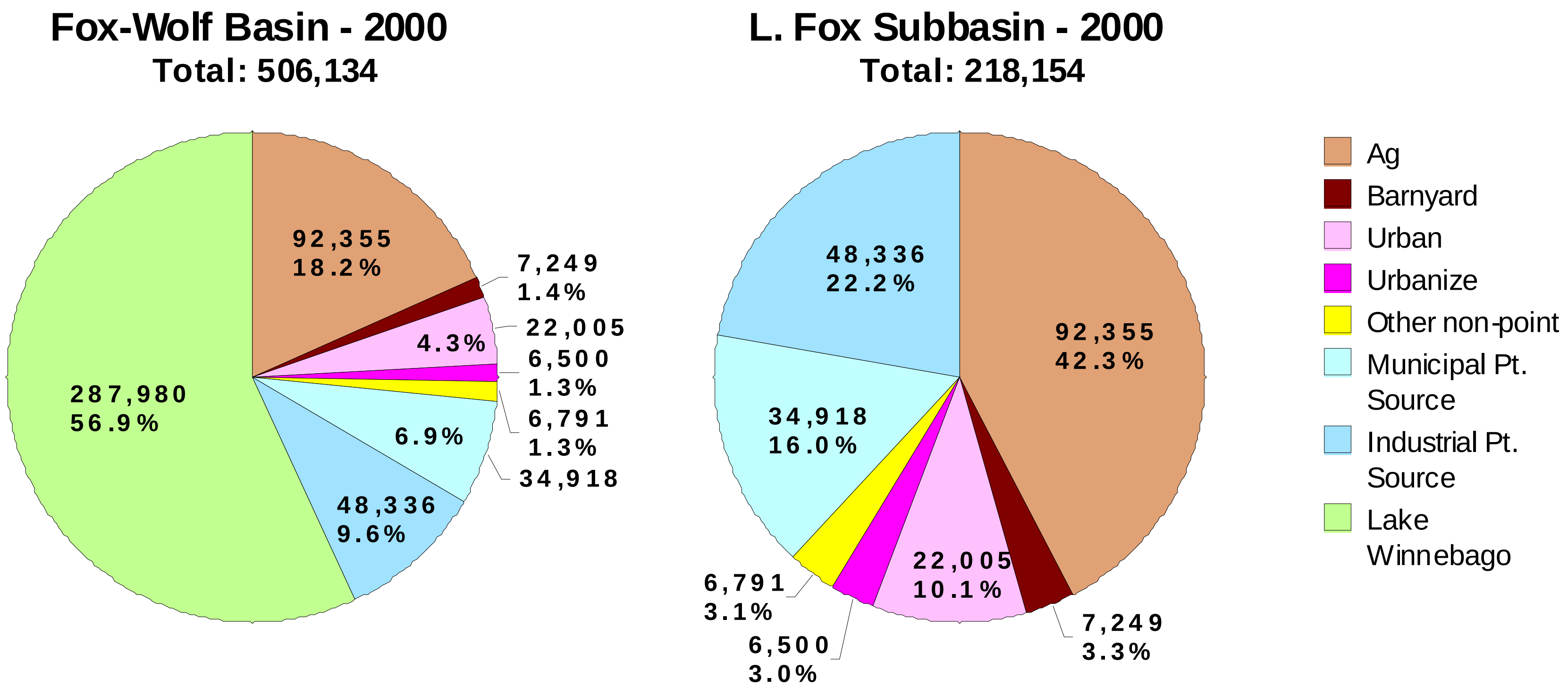
		Routed to Watershed Outlet				Routed to Lower Green Bay			
		TSS	Sed-P	Sol-P	Total P	TSS	Sed-P	Sol-P	Total P
	Area	(ton)	(kg)	(kg)	(kg)	(ton)	(kg)	(kg)	(kg)
	(sq. km)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)
1977-2000 Annual Average - Baseline 2000 Scenario									
LF01	**372.9**	14,500	14,600	20,200	34,900	14,500	14,600	20,200	34,900
East River		(0.39)	(0.39)	(0.54)	(0.94)	(0.39)	(0.39)	(0.54)	(0.94)
LF02	**291.0**	9,700	12,300	15,500	27,900	9,000	11,400	15,500	26,900
Apple, Dutchman, Ash.		(0.33)	(0.42)	(0.53)	(0.96)	(0.31)	(0.39)	(0.53)	(0.92)
LF03	**213.5**	12,000	14,500	14,100	28,600	10,900	13,100	14,100	27,200
Plum, Kankapot, Garners		(0.56)	(0.68)	(0.66)	(1.34)	(0.51)	(0.61)	(0.66)	(1.27)
LF04	**98.0**	3,800	3,800	3,600	7,400	3,500	3,400	3,600	7,000
Fox River, Mud Cr.		(0.39)	(0.39)	(0.37)	(0.76)	(0.36)	(0.35)	(0.37)	(0.71)
LF05	**389.2**	7,800	7,600	18,300	26,000	7,800	7,600	18,300	26,000
Duck Creek		(0.20)	(0.20)	(0.47)	(0.67)	(0.20)	(0.20)	(0.47)	(0.67)
LF06	**106.6**	4,000	3,900	4,600	8,600	3,600	3,500	4,600	8,100
LLBDM, Neenah Slough		(0.38)	(0.37)	(0.43)	(0.81)	(0.34)	(0.33)	(0.43)	(0.76)
LFM	**83.4**	3,600	3,300	3,200	6,500	3,400	3,100	3,200	6,300
L. Fox Main Channel		(0.43)	(0.40)	(0.38)	(0.78)	(0.41)	(0.37)	(0.38)	(0.76)
Lower Fox	**1554.6**	55,400	60,000	79,500	139,900	52,700	56,700	79,500	136,400
Subbasin		(0.36)	(0.39)	(0.51)	(0.90)	(0.34)	(0.36)	(0.51)	(0.88)

Table 10-4. Lower Fox River Subbasin simulated phosphorus loads by subwatershed for each landuse type (kg/year). Baseline 2000 Scenario - as routed to subwatershed outlet.

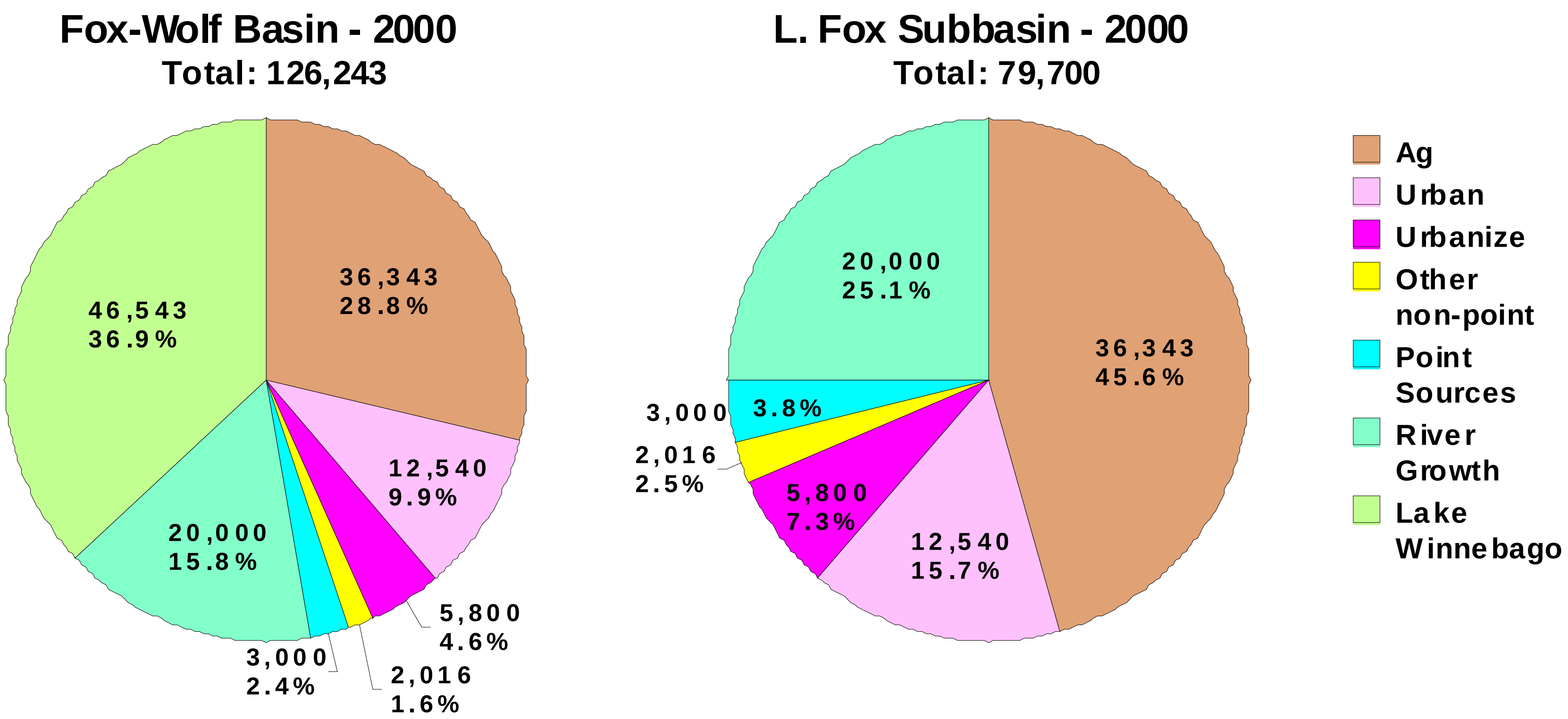
Subwatershed	Ag	Barnyard	Urban	Grassland	Forest	Wetland	Barren	Golf	Urbanize	TOTAL	Yield (kg/ha)
LF01-1	1,102	104	89	44	15	5	7	16	37	1,418	1.15
LF01-2	1,402	96	81	48	35	1	4	75	28	1,770	1.44
LF01-3	3,451	294	97	38	41	3	18	0	46	3,988	1.25
LF01-4	1,858	152	88	18	22	5	111	0	34	2,290	1.28
LF01-5	471	37	8	7	7	24	7	0	3	562	0.68
LF01-6	2,675	212	72	37	55	2	22	0	24	3,098	1.26
LF01-7	1,505	151	18	27	17	31	42	0	7	1,798	1.07
LF01-8	21	0	588	1	6	0	0	0	64	680	0.67
LF01-9	122	15	701	3	14	8	1	13	121	998	0.57
LF01-10	0	0	55	0	0	0	0	0	0	55	0.44
LF01-11	998	59	158	8	42	2	28	52	61	1,409	0.97
LF01-12	3,029	289	154	71	31	54	20	11	86	3,747	0.87
LF01-13	3,368	305	891	26	58	9	311	140	400	5,508	1.00
LF01-14	2,131	165	33	22	10	3	20	0	14	2,399	1.36
LF01-15	4,207	569	104	49	26	7	59	0	45	5,067	1.41
LF01-16	2,486	219	583	42	63	8	221	0	294	3,917	1.05
LF01-17	489	43	608	5	15	1	9	0	201	1,371	0.85
LF02-1	2,001	199	172	24	16	3	12	82	80	2,589	1.17
LF02-2	2,834	261	518	12	31	9	10	0	200	3,875	1.13
LF02-3	2,625	258	136	26	12	4	18	66	77	3,222	1.14
LF02-4	3,942	220	953	33	35	10	93	0	416	5,701	1.07
LF02-5	1,598	105	732	79	32	5	3	0	230	2,784	0.81
LF02-6	3,371	235	224	36	31	2	14	1	121	4,035	0.98
LF02-7	171	17	1,024	35	22	8	4	0	170	1,452	0.62
LF02-8	1,506	160	461	59	21	4	12	53	190	2,466	0.89
LF02-9	2,155	193	39	20	18	4	83	0	22	2,534	0.96
LF03-1	1,380	73	78	9	59	0	14	0	45	1,658	1.36
LF03-2	5,283	338	108	25	30	1	87	63	41	5,977	1.78
LF03-3	2,801	208	62	14	15	2	84	0	28	3,214	1.51
LF03-4	3,083	262	13	37	24	3	74	0	6	3,502	1.39
LF03-5	19	0	397	0	7	0	0	0	43	467	0.79
LF03-6	6,029	471	93	47	24	9	141	0	47	6,861	1.55
LF03-7	2,164	154	0	28	6	41	51	0	0	2,444	1.52
LF03-8	1,900	100	951	17	15	6	77	0	283	3,349	1.18
LF03-9	0	0	1,138	0	4	0	16	78	70	1,307	0.65
LF03-10	677	35	127	2	25	3	7	48	41	965	1.48
LF04-1	827	80	1,443	24	20	3	18	92	257	2,763	0.71
LF04-2	1,407	120	631	46	23	8	157	0	219	2,611	0.95
LF04-3	162	2	391	6	5	0	41	0	12	619	0.72
LF04-4	100	1	1,206	5	6	0	26	0	41	1,386	0.60
LF05-1	218	4	331	1	12	31	10	0	180	787	0.61
LF05-2	6	0	850	3	14	11	1	1	83	969	0.52
LF05-3	6	0	190	0	4	10	19	0	43	272	0.59
LF05-4	987	42	589	3	37	13	20	74	282	2,048	0.72
LF05-5	78	1	381	10	12	3	0	136	144	766	0.69
LF05-6	1,575	105	395	17	48	54	27	65	220	2,507	0.64
LF05-7	530	30	130	21	38	11	20	43	78	900	0.68
LF05-8	1,306	82	192	23	26	9	64	0	94	1,797	0.93
LF05-9	900	48	50	15	34	25	2	0	29	1,103	0.72
LF05-10	2,598	158	64	46	39	30	26	0	34	2,995	0.85
LF05-11	854	58	31	7	7	4	26	0	16	1,002	0.96
LF05-12	3,517	221	155	43	79	32	46	0	82	4,176	0.79
LF05-13	5,670	371	407	87	39	25	269	57	170	7,095	1.29
LF05-14	4,774	316	175	70	24	53	15	0	83	5,509	1.12
LF05-15	7	0	0	0	2	87	0	0	0	97	0.13
LF05-16	1,758	124	33	30	9	6	1	0	14	1,976	1.24
LF06-1	896	97	829	24	17	10	38	58	186	2,156	0.79
LF06-2	58	1	754	1	4	1	1	24	90	935	0.55
LF06-3	3,218	292	362	44	44	32	195	0	200	4,386	1.06
LF06-4	1	0	995	0	7	7	50	0	119	1,178	0.57
LFM1-1	968	165	256	5	7	0	4	0	70	1,477	1.57
LFM1-2	1,127	38	311	45	20	2	7	0	125	1,676	1.10
LFM1-3	179	8	501	13	5	0	1	0	70	776	0.76
LFM1-4	23	0	1,176	9	10	0	1	0	43	1,261	0.57
LFM1-5	16	0	1,026	0	32	23	0	0	216	1,314	0.50
TOTAL	**106,621**	**8,368**	**25,404**	**1,547**	**1,509**	**768**	**2,768**	**1,249**	**6,777**	**155,012**	**1.00**

Output Example: subwatershed phosphorus loads by source

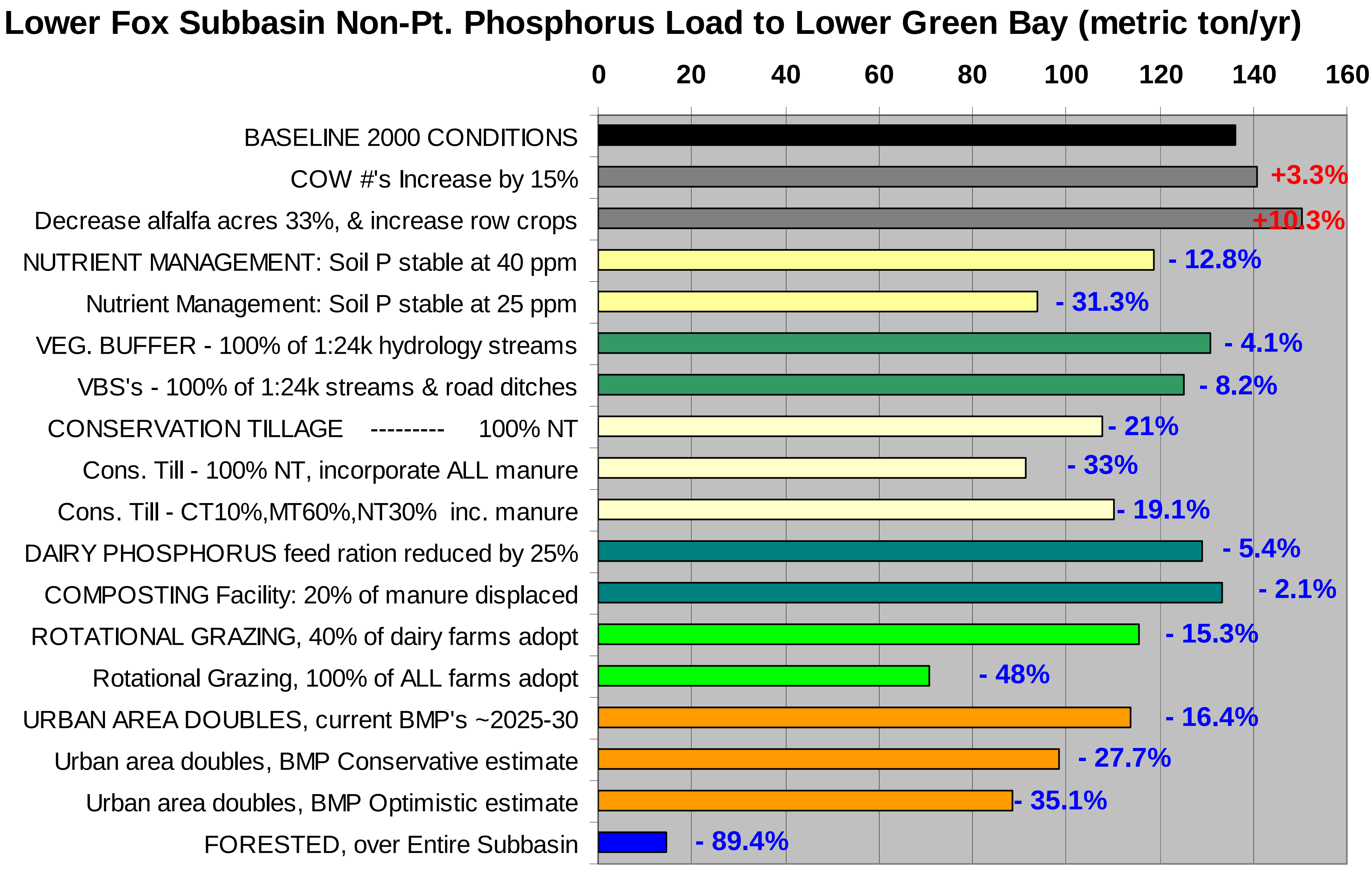
Phosphorus Load Allocation to Lower Green Bay (kg/year)



Suspended Sediment Allocation to Lower Green Bay (metric tons/year)



Alternative Management Scenarios



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
- Simulated reductions from urban area doubling highly dependent on assumed P and TSS export from urban areas

Questions?

Email: baumgarp@uwgb.edu

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