Watershed-scale assessment of stacked drainage practices in the Western Lake Erie Basin to improve water quality

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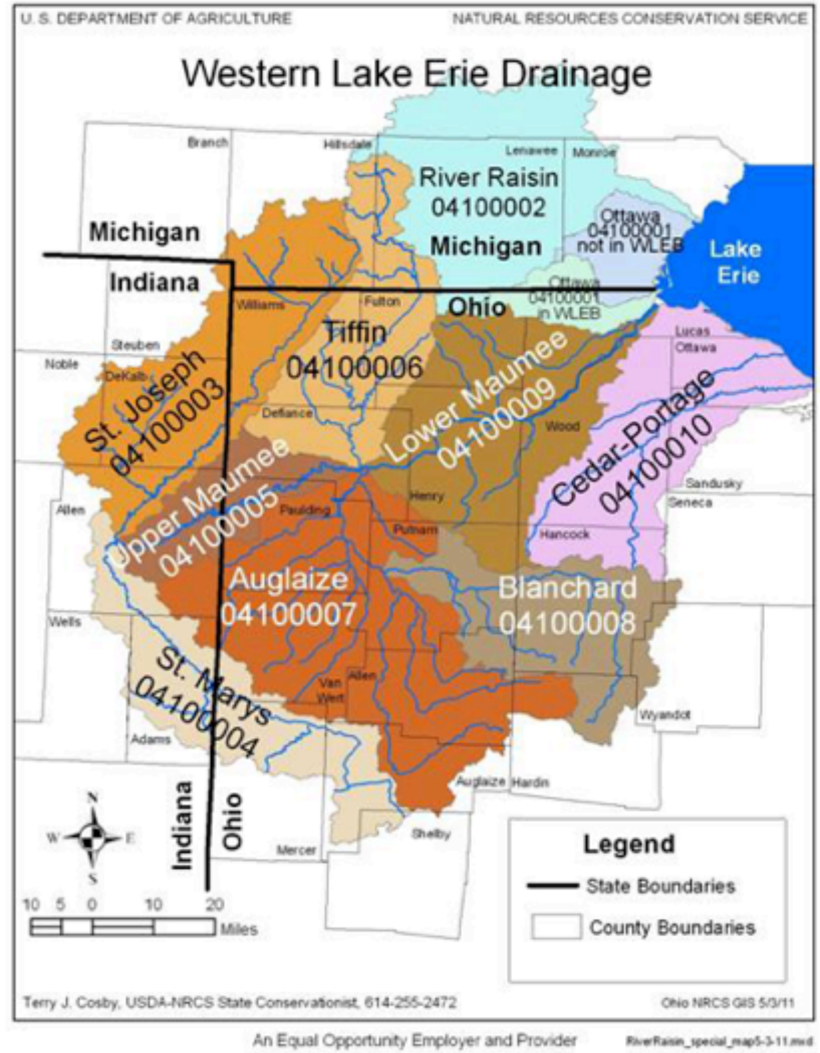
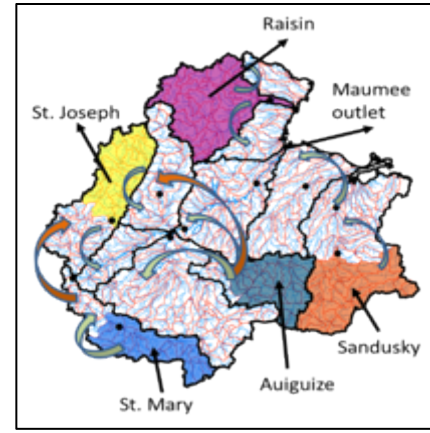
Goal

- Piggyback on WLEB CEAP project
- Assess novel conservation practices: <u>two-stage ditch</u> and <u>tile drain management</u> at the watershed scale.
- Use WLEB-CEAP SWAT
- Evaluate the <u>*effectiveness*</u> of these novel practices on water quality, including comparing them to traditional practices



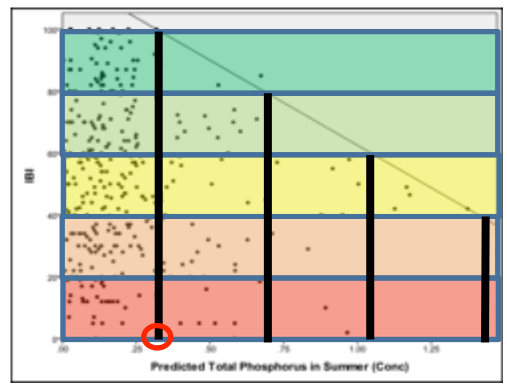
An Overview of Western Lake Erie CEAP Project & SWAT Model



Scott Sowa[1] and Jeff Arnold[2]

[1] The Nature Conservancy

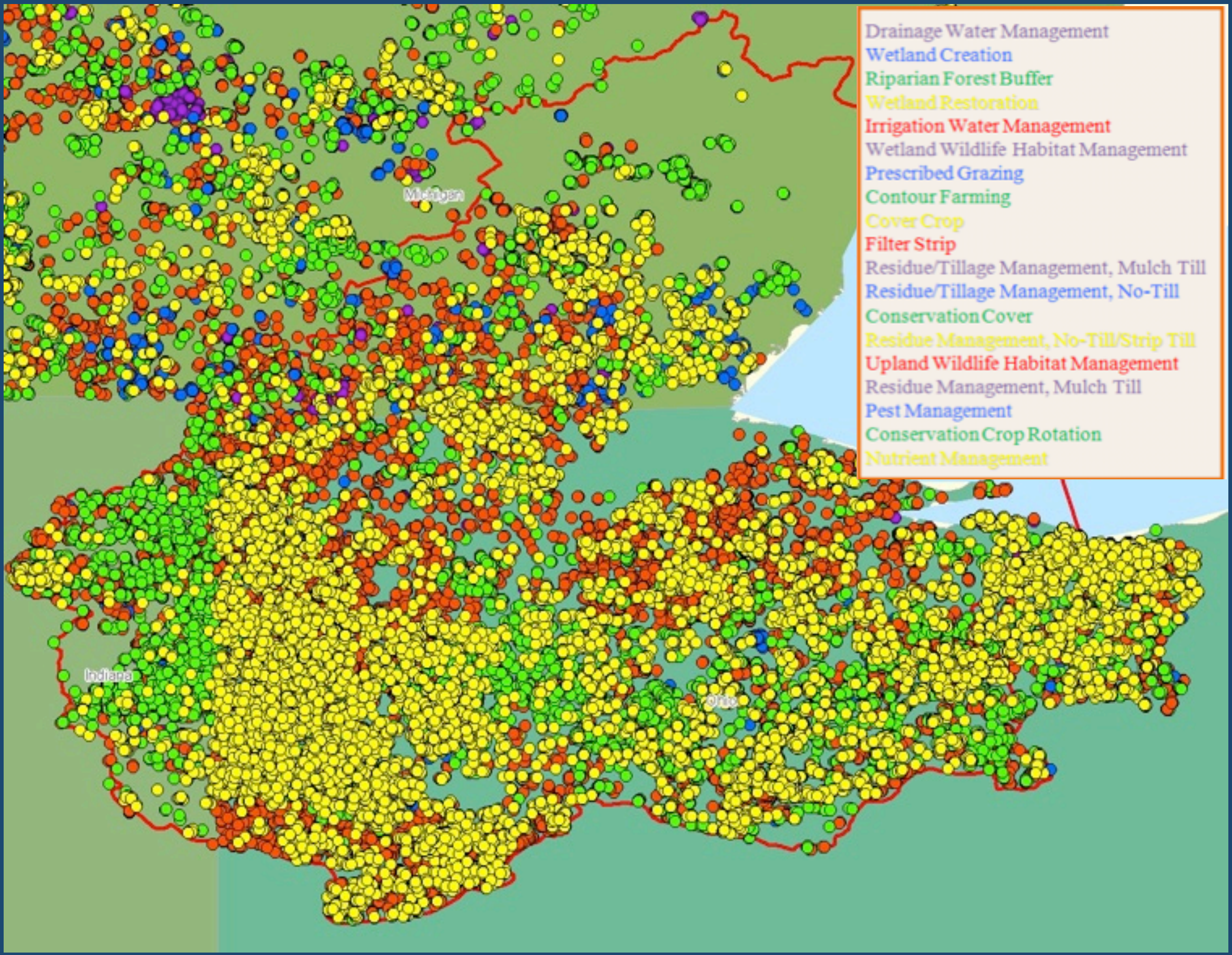
[2] USDA-ARS



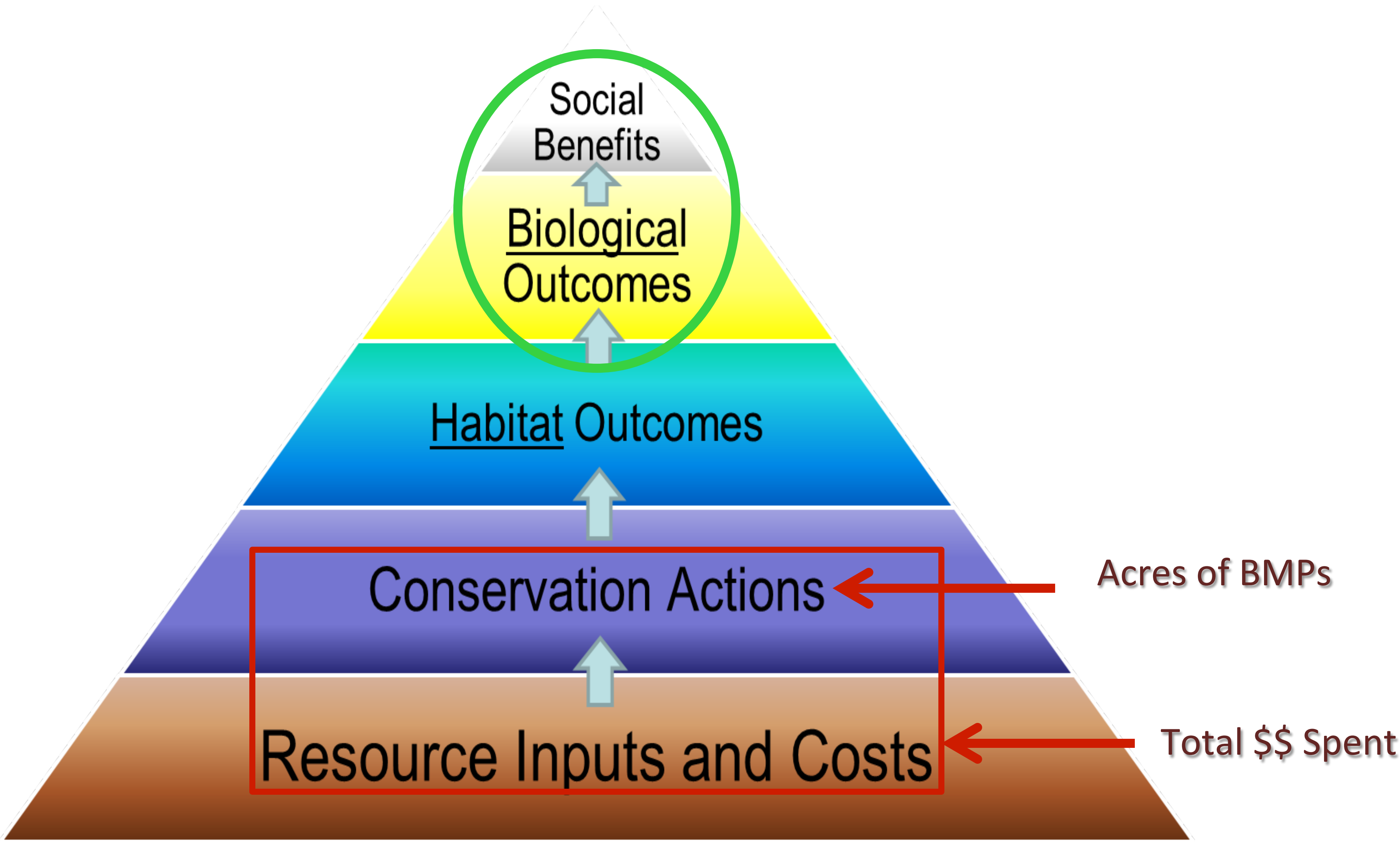
Great Lakes
SWAT Modeling Workshop

March 18, 2014

How Much Is Enough?



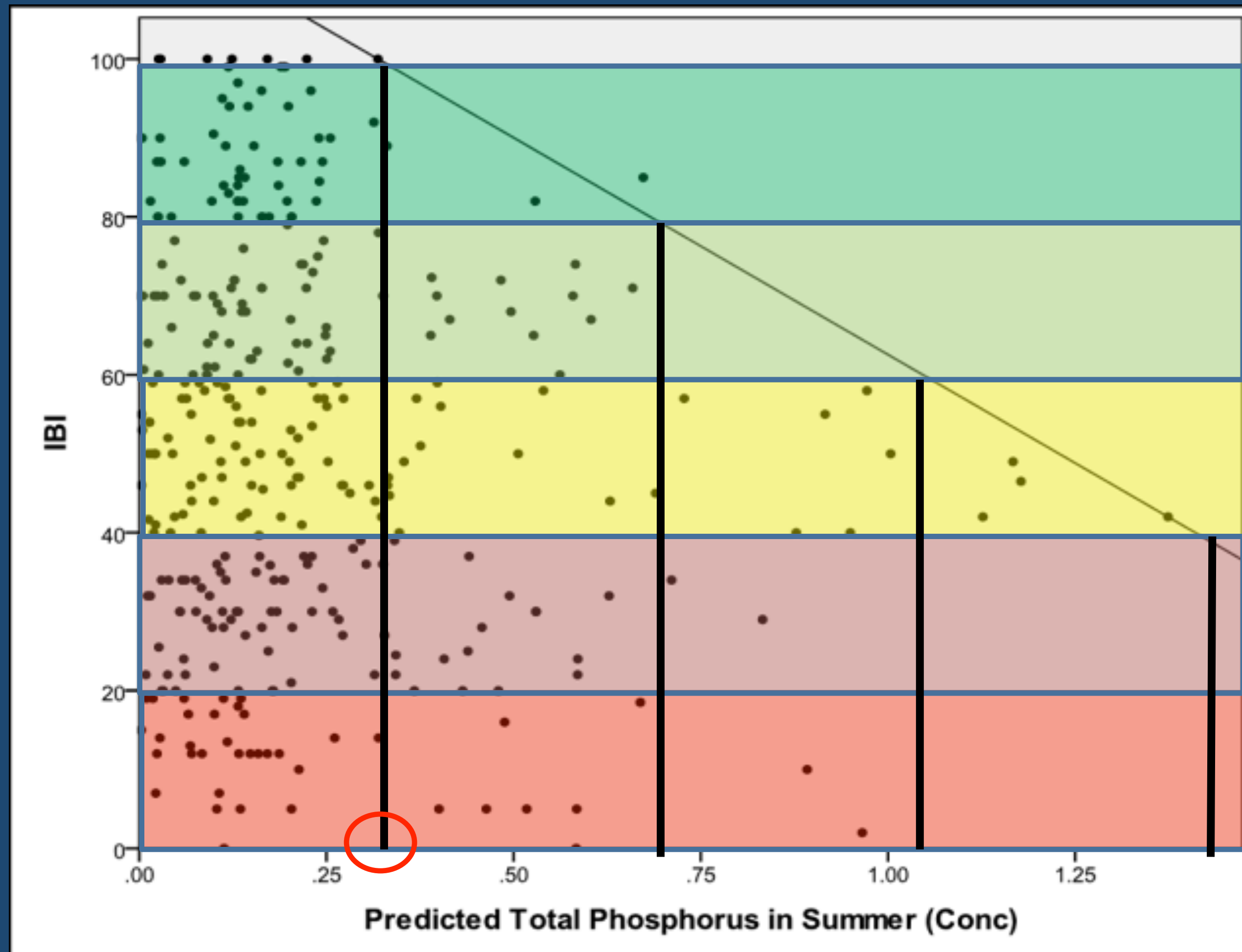
It Depends on Your Goal

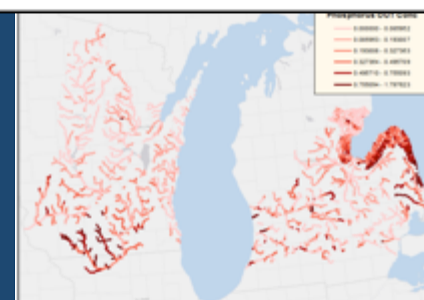


Phases of Work

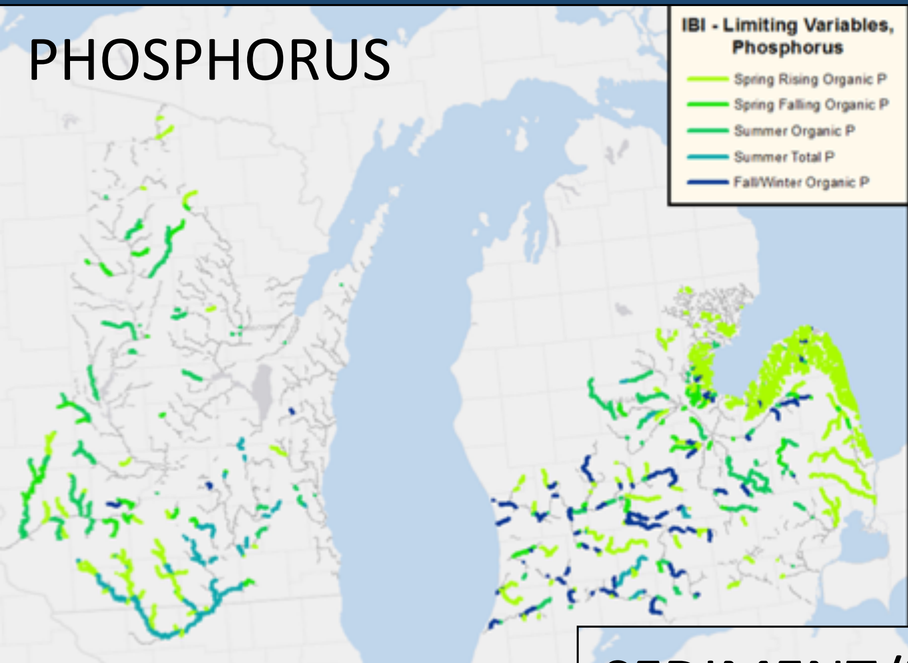
- Phase 1 – Identify and map limiting factors
  - Relate biological endpoints to SWAT parameters to identify and map limiting factor
- Phase 2 – Assess costs and benefits of scenarios
  - Use SWAT to forecast changes in water quality, flow, and biological endpoints
- Phase 3 – Decision tools to target and track
  - Develop online decision tools that allow us to target and track cumulative benefits of conservation practices
- Phase 4 – Goals and innovative strategies
  - Work with partners to set realistic goals and develop, test, and implement innovative strategies to achieve them

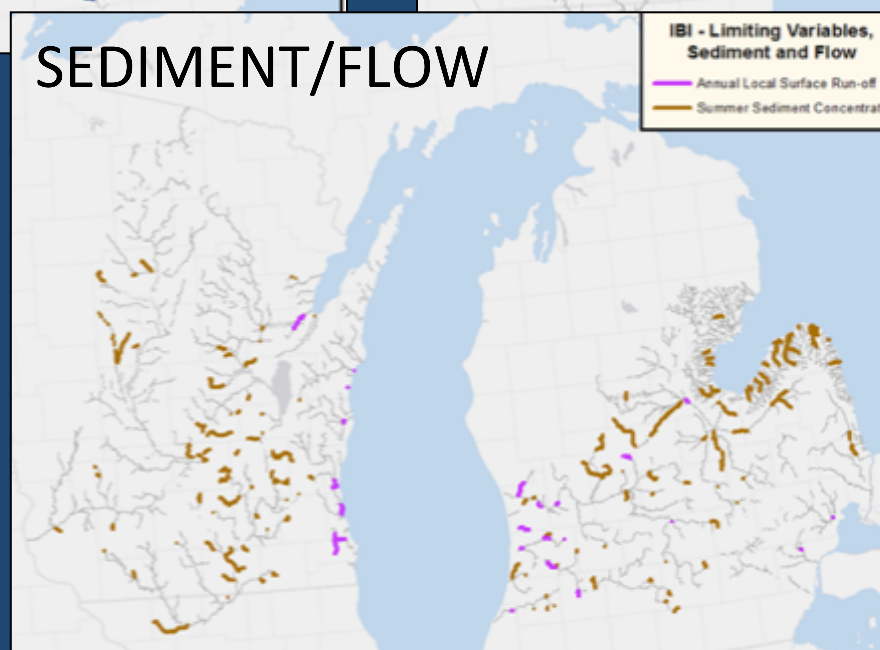
Phase 1 – Relate IBI to SWAT Parameters



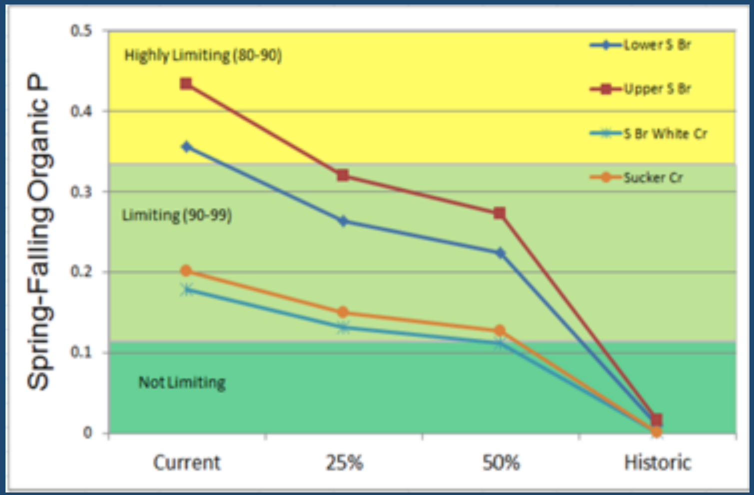


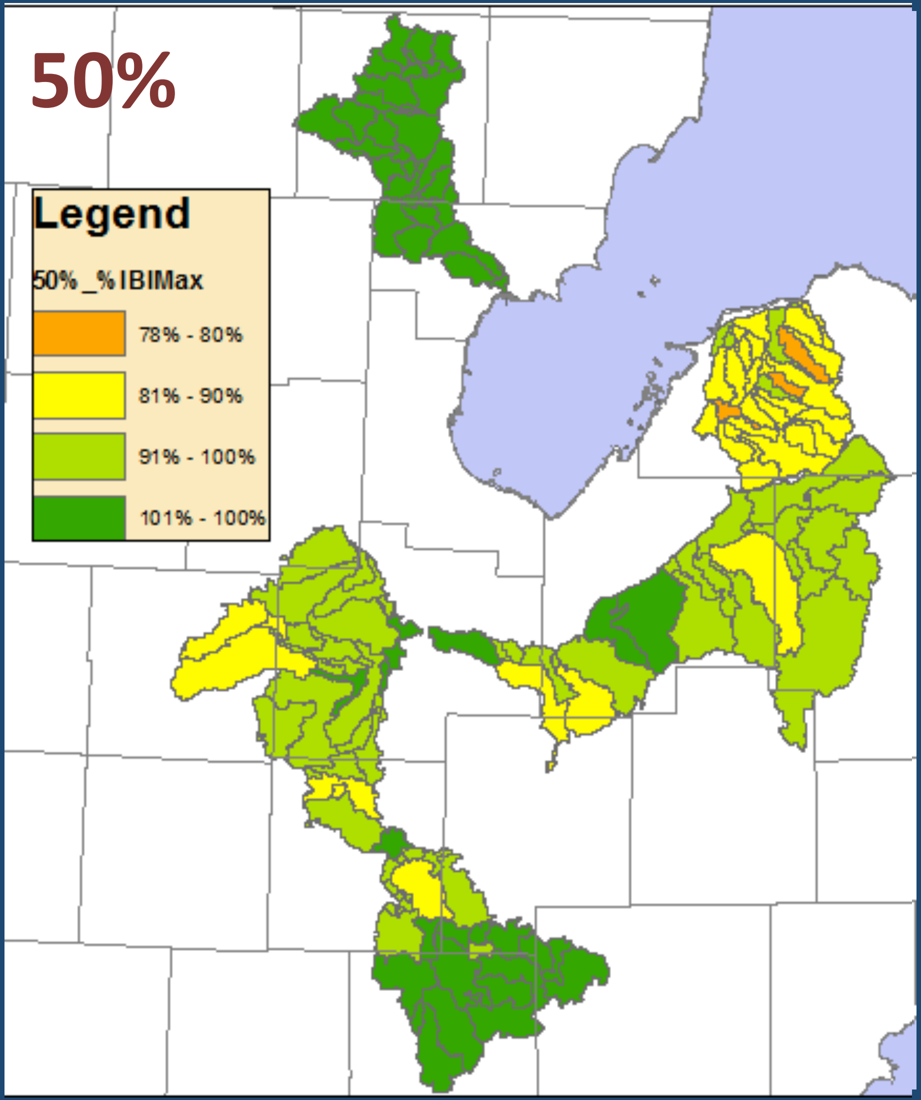
Phase 1: Identify and Map Limiting Variables

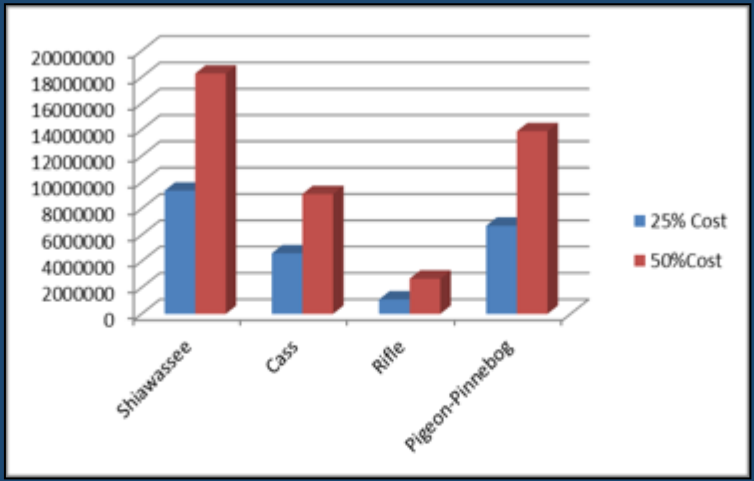




Phase 2: Assess Costs and Benefits of Scenarios

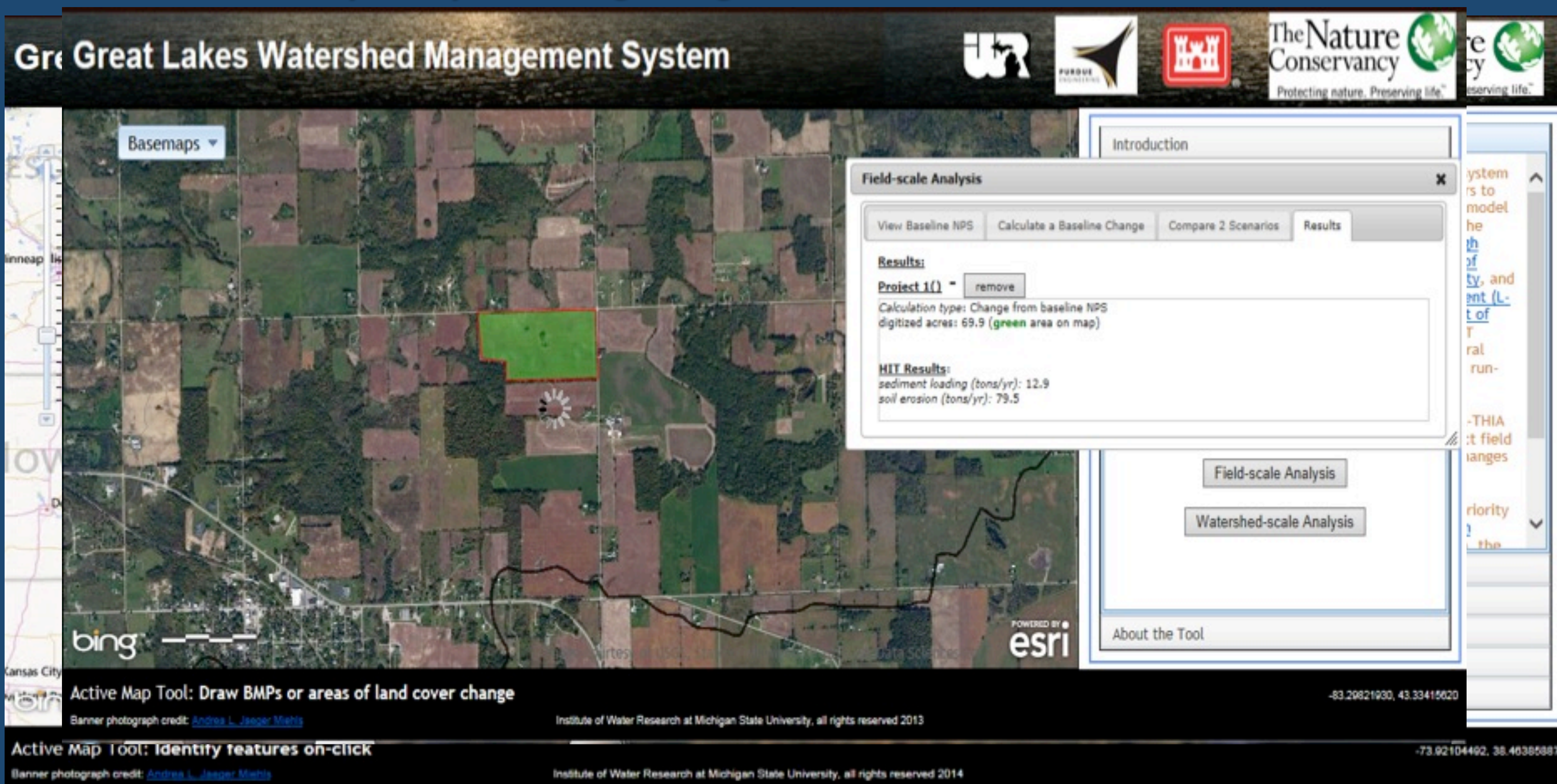






Phase 3: Decision Tools to Support Targeting and Tracking

Field-Scale Analysis and Planning



WLEB CEAP Objectives

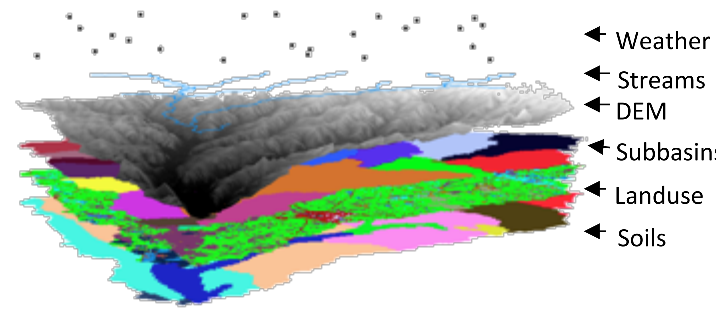
- Develop a downscaled SWAT model for WLEB

HUC 12: 391 subwatersheds
Area: 72 sqkm (range: 25 to 191)

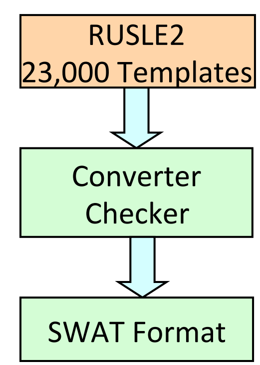
NHD plus: 11335 subwatersheds
Area: 2.61 sqkm (range: 0.001 to 80)

Data inputs and SWAT model setup

- ArcSWAT 2012 interface used
  - Rev 593 (latest)
- Watershed characterization
  - Predefined Subwatersheds and streams
    - 30m DEM, 12 digit HUCs, NHD streams – HUC12 setup
    - 30m DEM, NHD plus watersheds, NHD plus streams - NHD plus setup
      - Post processing to get predefined streams and subbasin in SWAT format
- Landuse landcover
  - 30m Landuse land cover
    - crop rotations
      - 2010 and 2011 CDLs and MODIS



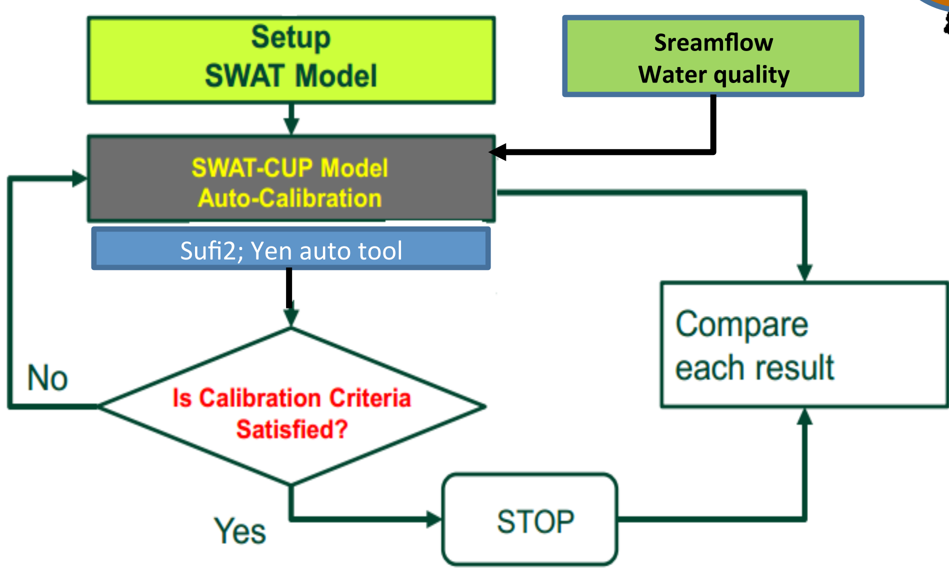
- Soils
  - STATSGO soils at 1: 250,000 scale
- Weather
  - Daily temperature and precipitation data from 1960 to 2010
- Tile drains
  - All agricultural area in flat areas were given tile drain
- Management
  - Fertilizer application rates : Derived from Agricultural Census Yield and Fertilizer use data
  - Tillage: USGS -Conservation Technology Information Center (CTIC) Survey Data
    - Conventional, Ridge, Reduced, Mulch, No-Till
  - Planting and harvesting, Tillage implements etc.: RUSLE2 Management

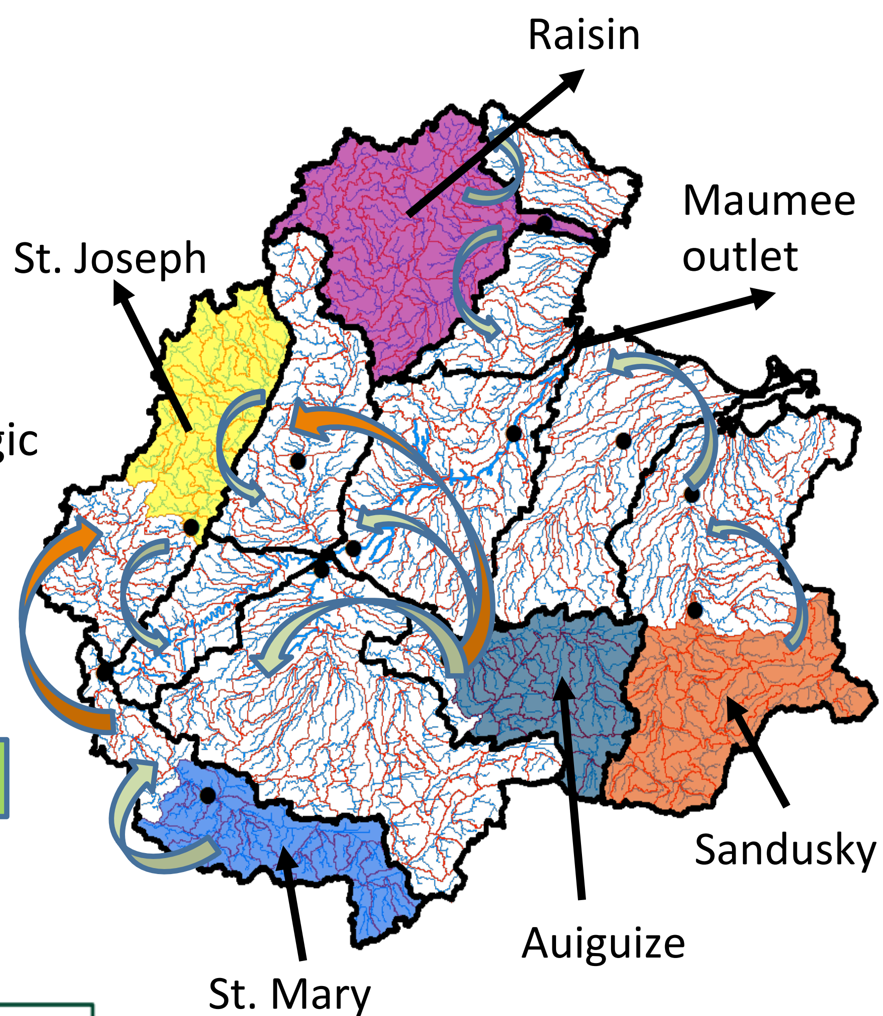


Calibration Strategy

- Calibrate for HUC12 setup and transfer parameters to NHD plus setup

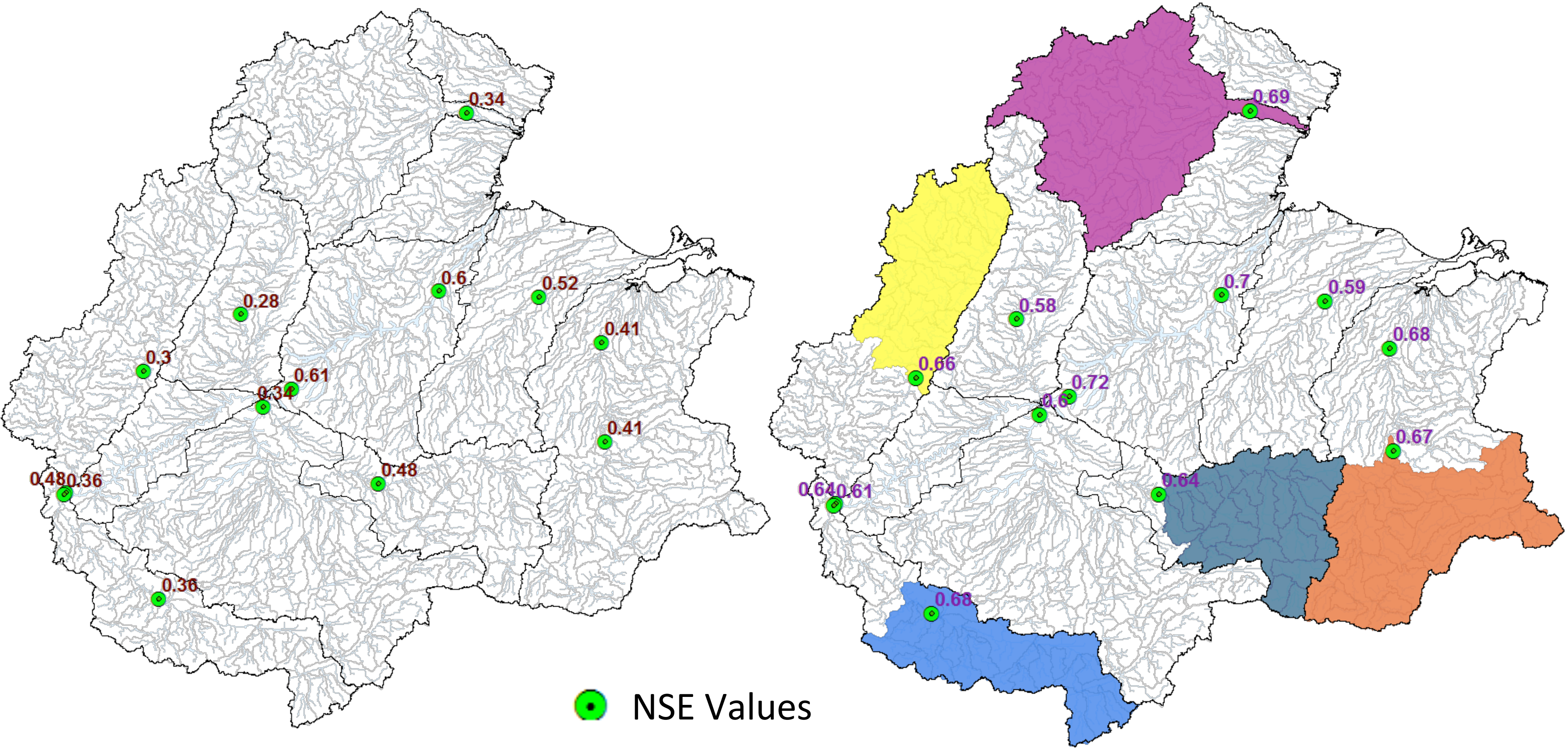
- Calibration Procedure
  - Calibrate at multiple locations
    - To capture spatio-temporal hydrologic variability within watershed
  - Compare with calibration at outlet
- Calibration Flow Chart





Outlet calibration

Regional calibration



- NSE values ranges from – infinity to 1
- Close to 1 means good fit between observed and predicted
- **NSE above 0.5 :** **very good model prediction**

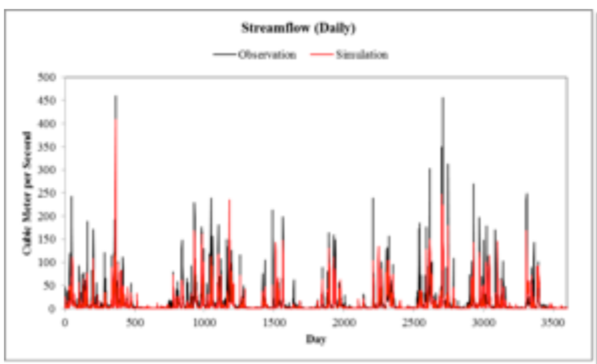
- Regional calibration validation period
  - 2000 to 2006

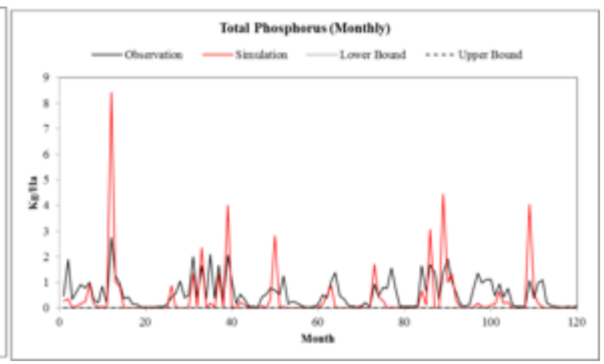
Watershed outlet			1990 -- 1999				
			R2	NS	Pbias	RMSE	RSR
Auiguize Outlet	Default before tile	Daily	0.44	0.44	5.11	87.39	0.75
	Default after tile		0.43	0.21	-40.55	105.14	0.89
	Outlet calibration		0.37	0.34	12.48	94.89	0.81
	regional calibration		0.63	**0.60**	-0.38	74.28	0.64
	Default before tile	Monthly	0.59	0.58	5.19	38.74	0.64
	Default after tile		0.66	0.47	-40.45	43.95	0.73
	Outlet calibration		0.61	0.58	12.57	38.80	0.64
	regional calibration		0.83	**0.83**	-0.49	3.12	0.15

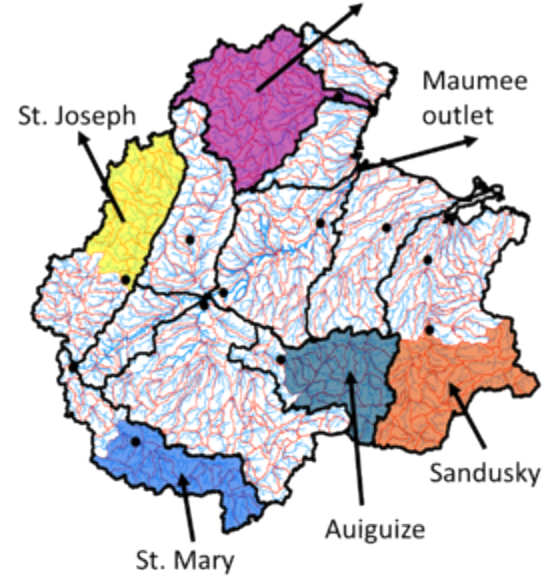
Watershed outlet			2000 -- 2006				
			R2	NS	Pbias	RMSE	RSR
Auiguize Outlet	Default before tile	**Daily**	0.54	0.52	7.11	86.12	0.70
	Default after tile		0.48	0.35	-36.33	99.66	0.80
	Outlet calibration		0.38	0.33	17.45	101.24	0.82
	regional calibration		**0.67**	**0.67**	**3.52**	**71.51**	**0.58**
	Default before tile	Monthly	0.74	0.72	7.11	34.40	0.53
	Default after tile		0.60	0.45	-36.04	48.14	0.74
	Outlet calibration		0.68	0.62	17.59	39.93	0.61
	regional calibration		0.84	**0.84**	3.51	26.31	0.40

- Regional calibration validation period
  - 2000 to 2006

Station	Iteration	Streamflow		Sediment	TP	TN
		NSE	PBIAS (%)	PBIAS (%)	PBIAS (%)	PBIAS (%)
54 - Raisin	190	0.30	28.47	27.14	-16.98	0.67
81 - St Joseph	213	0.34	17.44	31.94	-28.21	-1.56
123 - St Mary	85	0.49	11.82	-0.21	-4.43	-0.01
259 - Aguilla	206	0.52	24.17	-	29.66	-18.65
372 - Sandusky	97	0.56	13.41	-14.36	8.72	1.58



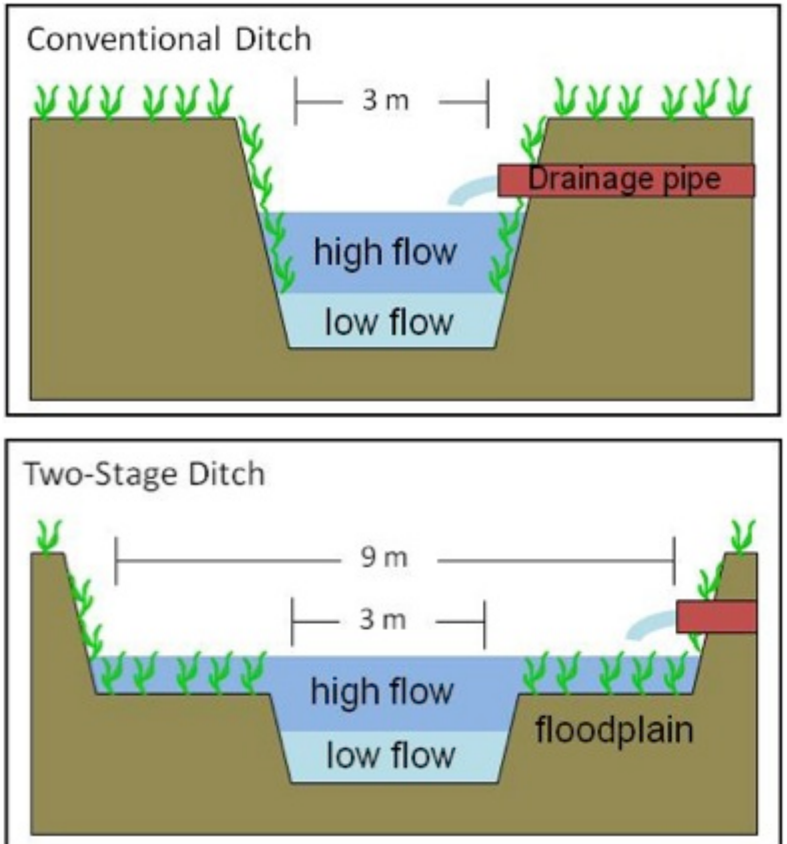




Process

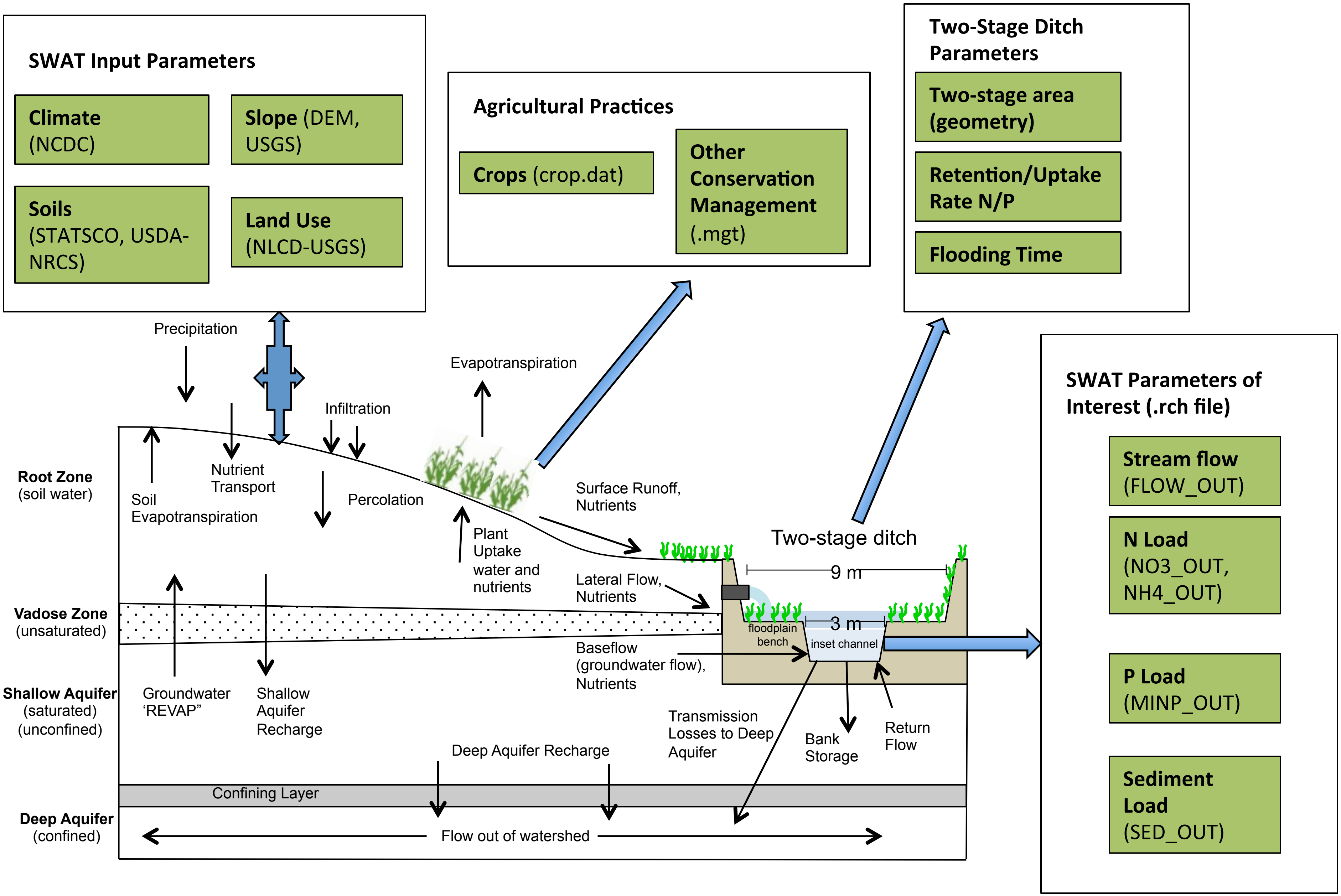
Task	**Proposed Dates**
Conduct extensive literature reviews/identify datasets to determine key parameters that influence practice performance	Year 1 ✔
Develop conceptual models summarizing understanding	Year 1 ✔
Generate algorithms to parameterize the practices in SWAT	Year 1-2
Evaluate management scenarios and their effects on water quality at a watershed scale	Year 2
Incorporate approach into the Conservation Practice Modeling Guide for SWAT.	End of Year 2

Two-stage ditch



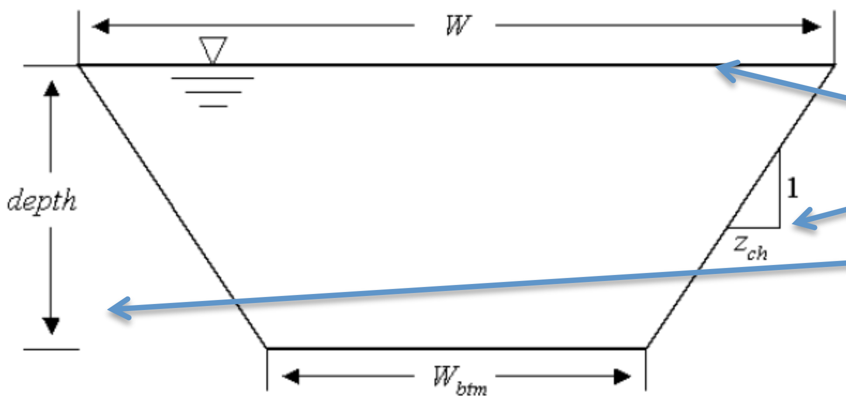
- Increase channel stability →when floodplain width 3 to 5 x bankfull width
- Increased sedimentation → particles settle out on floodplains
- Increased nutrient retention→ more time/space for removal
- Minimizes the retirement of land from agricultural production (= win-win)

General Conceptual Diagram of the Two-Stage Ditch



SWAT Modifications-Channel Geometry

Trapezoid channel

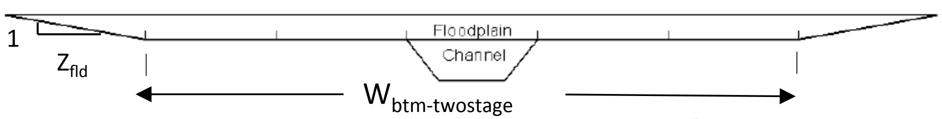


Bottom Width Trapezoid Channel (W_{btm})

1. **Top width -> New regional curves**
2. **Inverse side slope (Z_{ch}) –> 2/1**
3. **Bankfull depth-> New regional curves**

W_{btm} = Top Width – 2 x (Z_{ch} x Bankfull depth)

Two-stage + trapezoid channel



Bottom Width Two-Stage Ditch ($W_{btm\text{-}twostage}$)

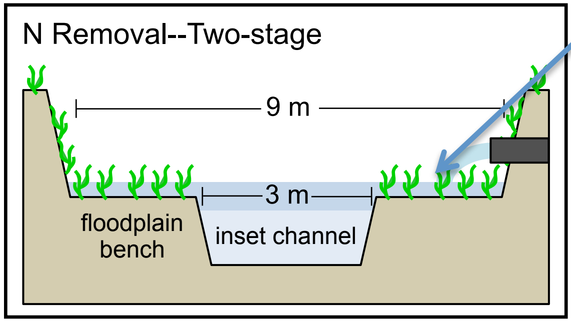
$W_{btm\text{-}twostage}$ = 3 to 5 x Top Width

Hydrology terms are then calculated

Conceptual Model: N Retention in Two-Stage Ditch (before water routing)

g N over time step of interest)

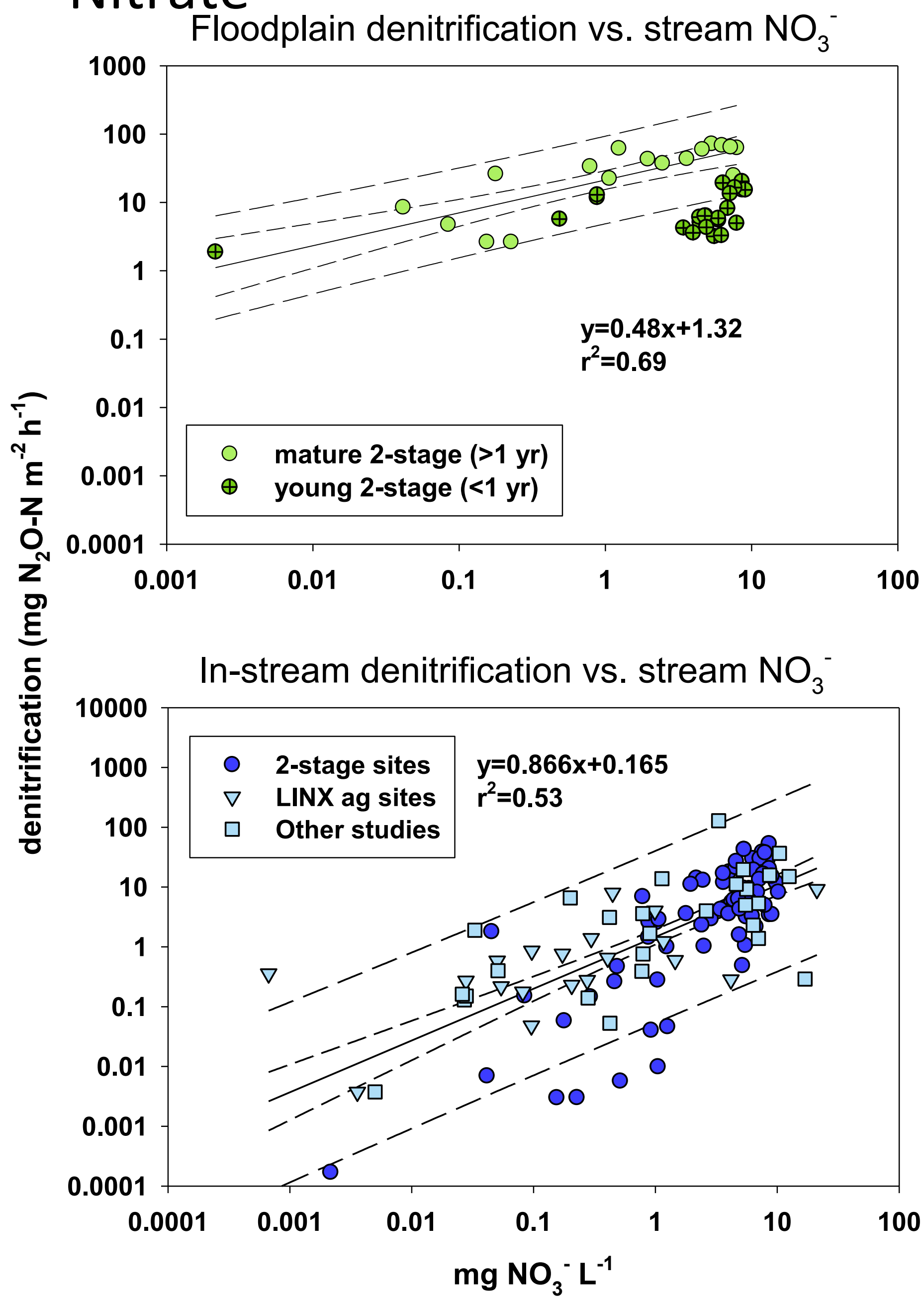
Two-stage area (m^2) X **Areal Uptake Rate** (Denitrification—> g N_2O-N m^{-2} $time^{-1}$) X **Flooding Time**



- **Two-stage area:** Top width at flood stage x reach length
- **Areal Uptake Rate:** User defined based on stream mean nitrate concentration. (see next slide).
- **Flooding Time:** Built into model (Time when volume of water in channel exceeds bankfull)

Two-stage and In-stream Denitrification Rates versus Stream Nitrate

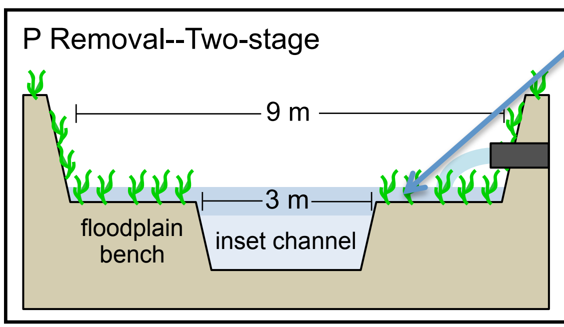
- Data are from ditches in the Midwest
- Positive correlation of stream NO3 and denitrifcation
- The user can choose a mean, max, or min condition in the model (based on the prediction intervals)



Conceptual Model: P Retention in Two-Stage Ditch (before water routing)

<u>g P over time step of interest)</u>

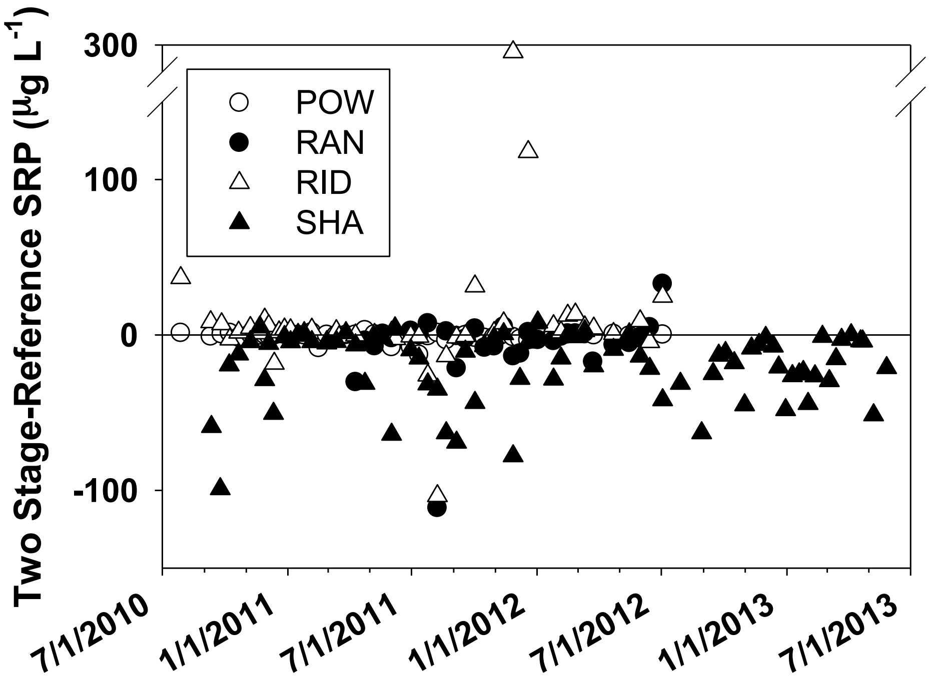
Two-stage Area (m^2) x **Phosphorus (TP and SRP) Reduction rate** ($kg\ m^{-2} time^{-1}$) x **Time**

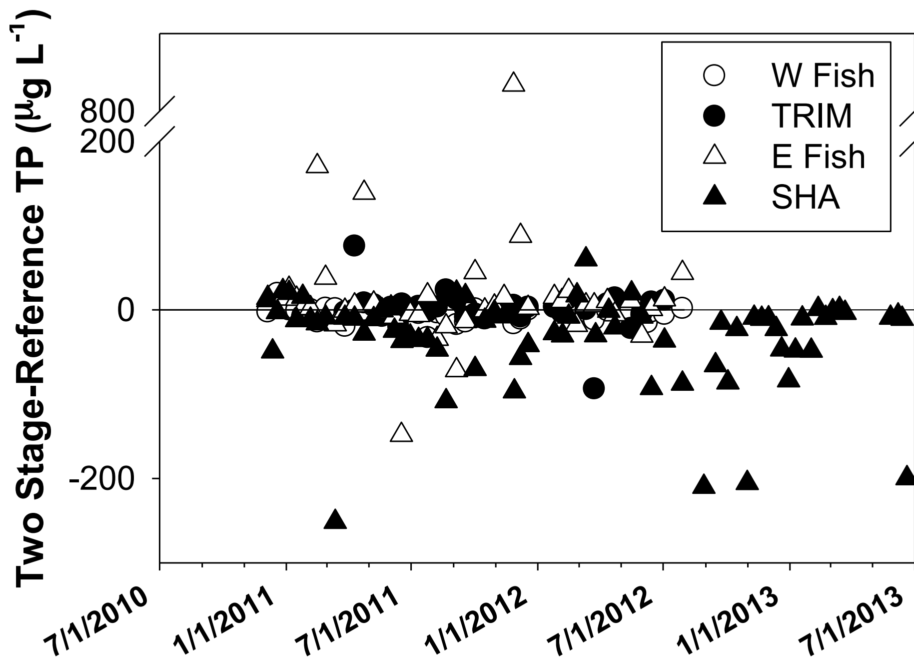


Two-stage Area → Top width at flood stage x reach length

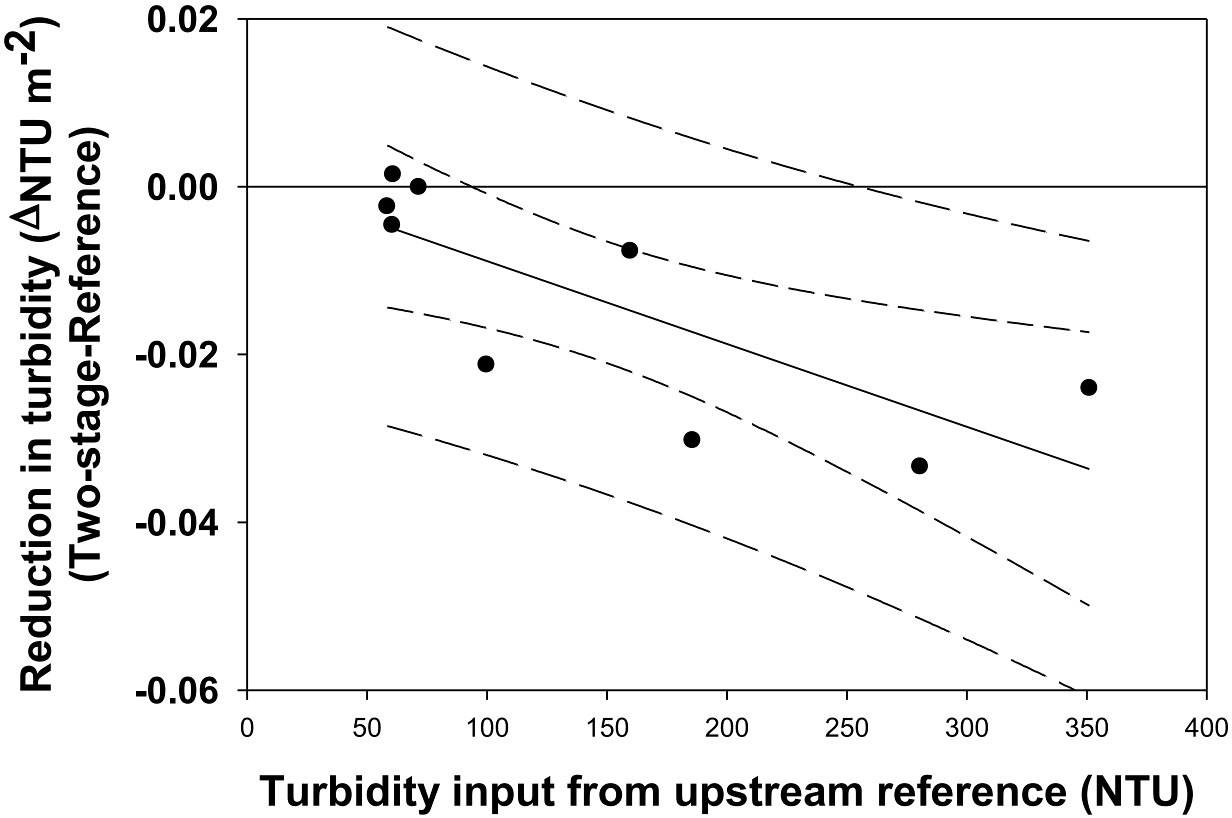
Phosphorus Reduction rate → User defined (see next slide)

TP and SRP Reduction in two-stage

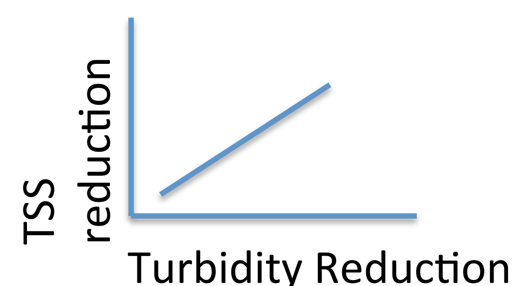




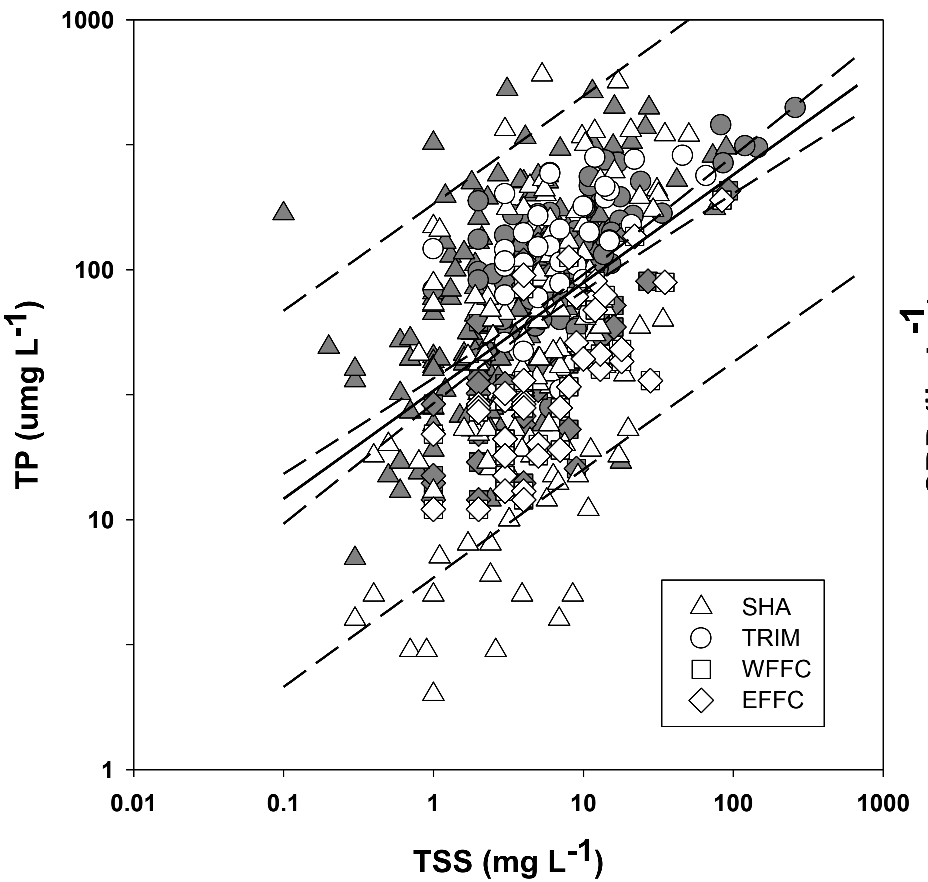
How do we predict this in a model?



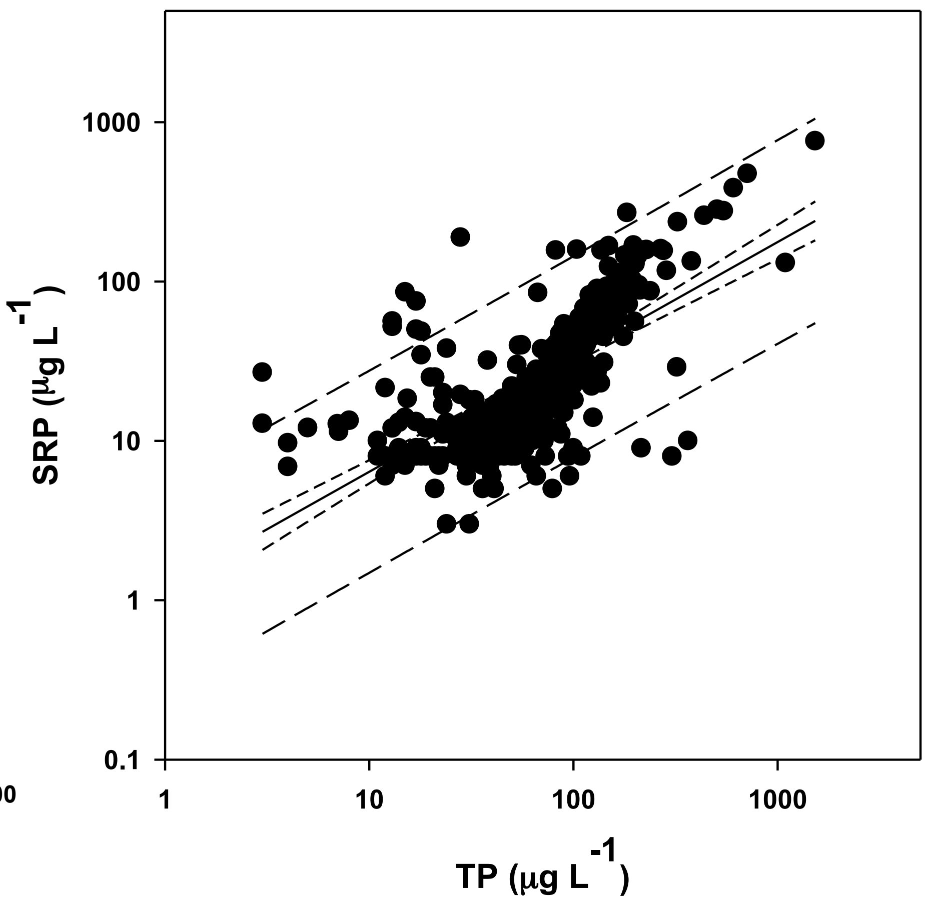
- Look at data from 9 two-stage ditches in the Midwest
- Reduction in turbidity per unit area of two-stage increases as turbidity input from upstream increases
- Positive correlation of turbidity versus TSS shown in > 40 studies



Reductions of TP and SRP in two-stage

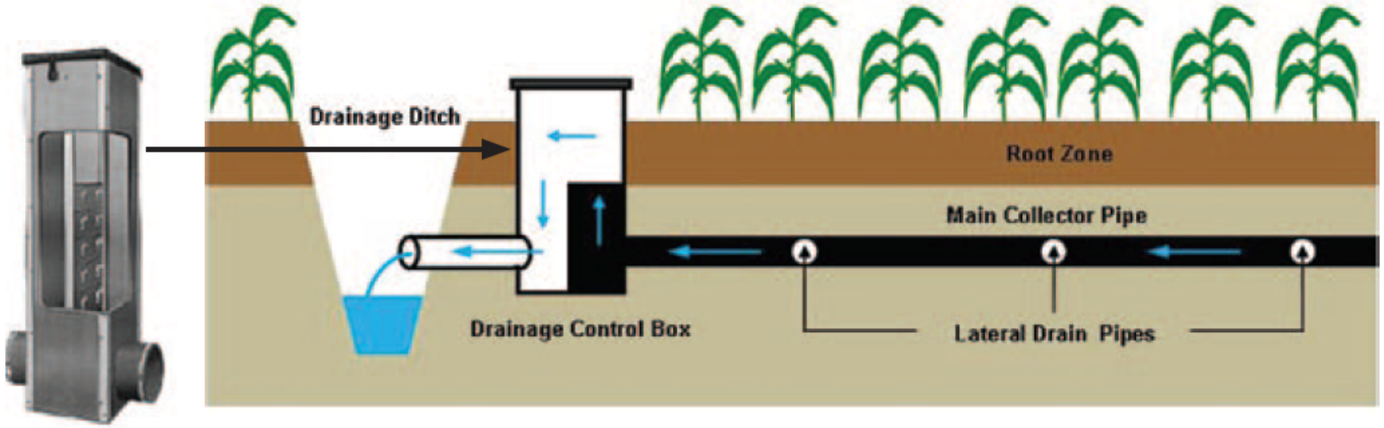


- Positive correlation of TSS and TP



- Positive correlation of TP and SRP

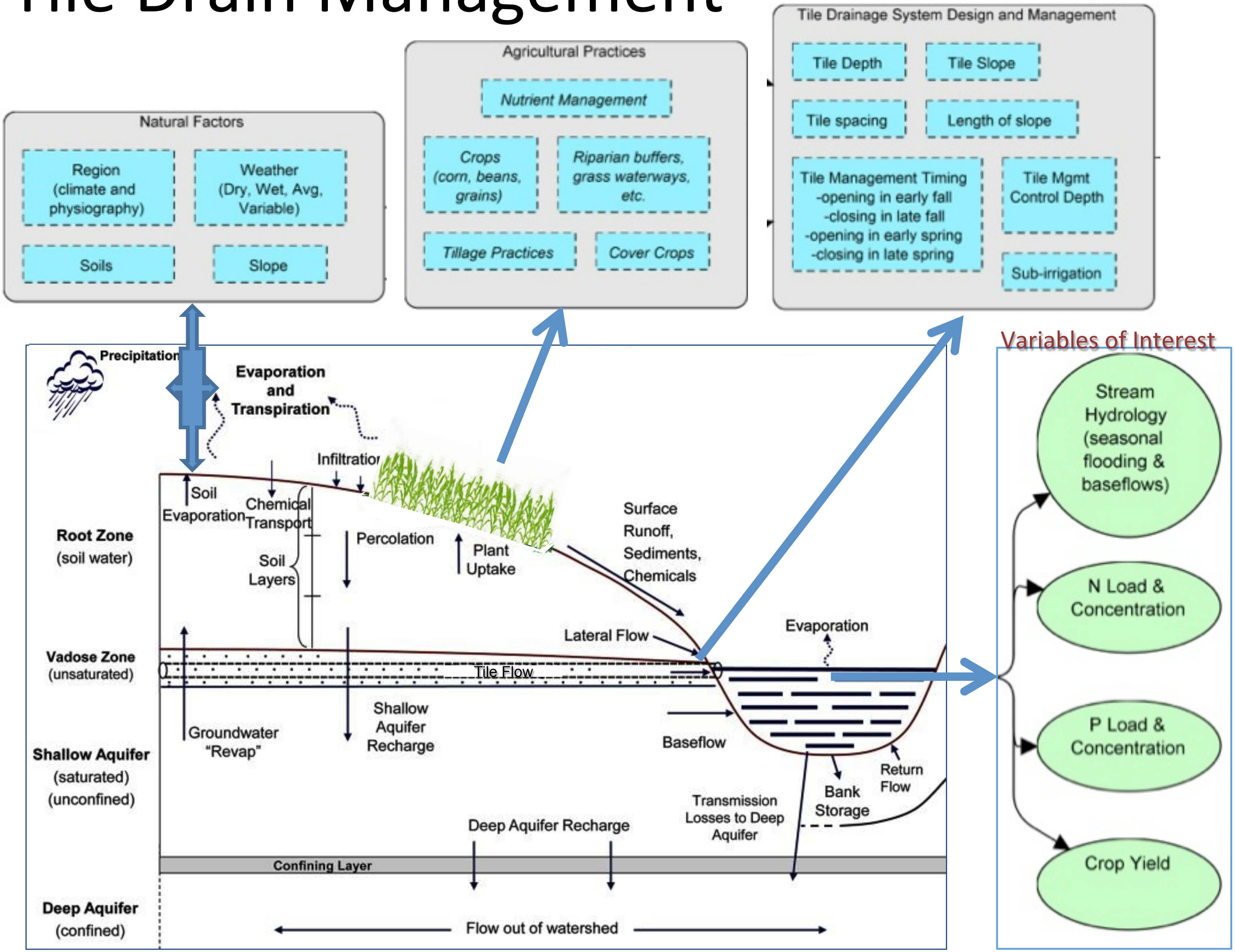
Tile drain management



Skaggs et al. 2012

- Manipulation of subsurface drains via water level control structures
- Hold back water to improve nutrient retention
- Significant N and potentially P reduction

Tile Drain Management



Meta-Analysis

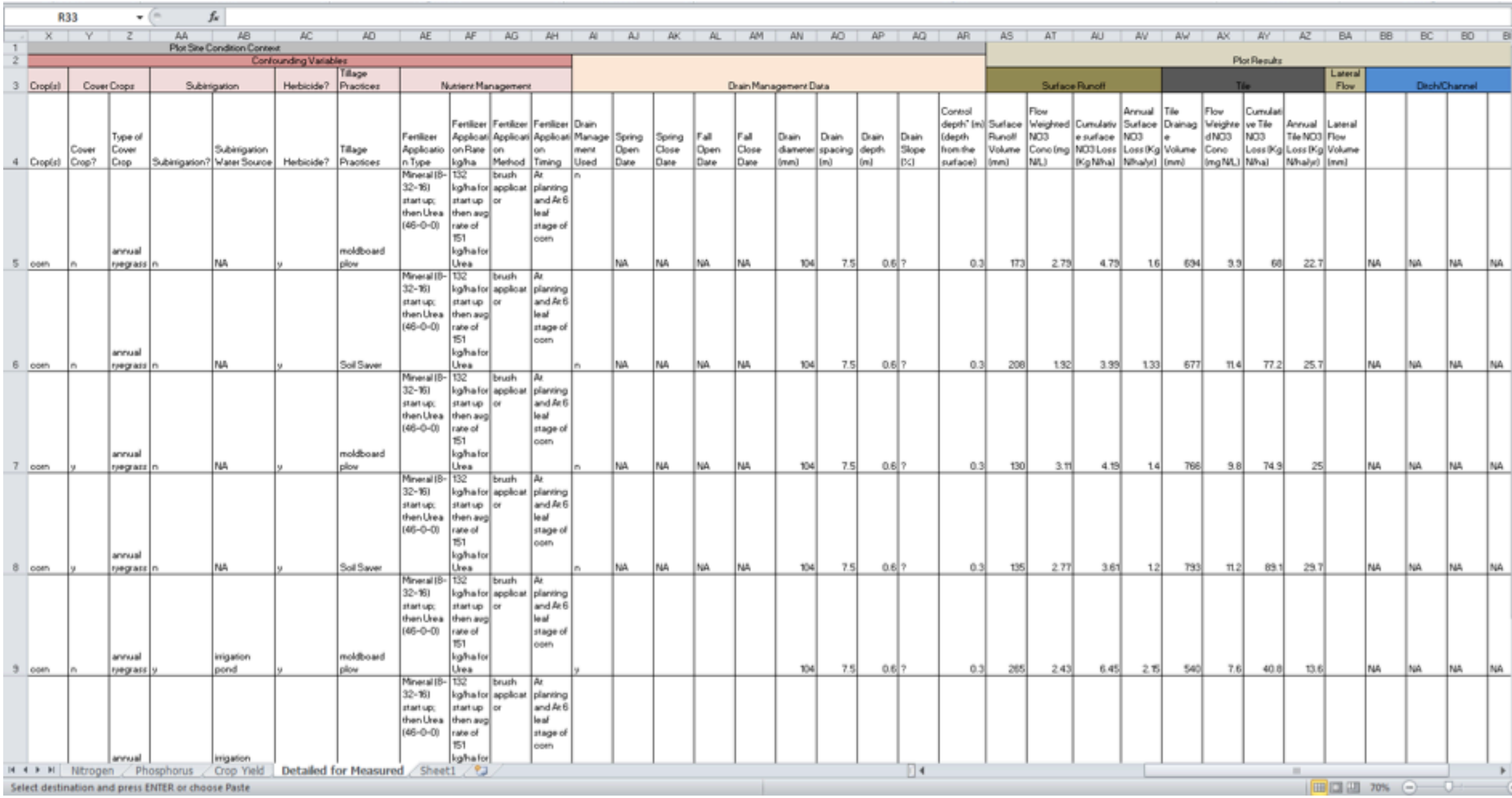
Drainage Responses

- Hydrology – tile flow, surface runoff, lateral flow
- Nutrients – concentrations, loads

Potential Predictor Variables

- Natural – soils, climate,
- Ag practices – crops, nutrient mgmt, cover crops, tillage
- Tile Management – drain spacing & depth, control depth, control timing

Drainage Management – Meta analysis



R33

	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE
1	Plot Site Condition Context																																	
2	Confounding Variables																					Plot Results												
3	Crop(s)	Cover Crops		Subirrigation		Herbicide?	Tillage Practices	Nutrient Management				Drain Management Data										Surface Runoff				Tile				Lateral Flow	Ditch/Channel			
4	Crop(s)	Cover Crop?	Type of Cover Crop	Subirrigation?	Subirrigation Water Source	Herbicide?	Tillage Practices	Fertilizer Application Type	Fertilizer Application Rate kg/ha	Fertilizer Application Method	Fertilizer Application Timing	Drain Management Used	Spring Open Date	Spring Close Date	Fall Open Date	Fall Close Date	Drain diameter (mm)	Drain spacing (m)	Drain depth (m)	Drain Slope (%)	Control depth" (m) (depth from the surface)	Surface Runoff Volume (mm)	Flow Weighted NO3 Conc (mg N/L)	Cumulative surface NO3 Loss (Kg N/ha)	Annual Surface NO3 Loss (Kg N/ha/yr)	Tile Drainage Volume (mm)	Flow Weighted NO3 Conc (mg N/L)	Cumulative Tile NO3 Loss (Kg N/ha)	Annual Tile NO3 Loss (Kg N/ha/yr)	Lateral Flow Volume (mm)				
5	corn	n	annual ryegrass	n	NA	y	moldboard plow	Mineral (8-32-16) start up; then Urea (46-0-0)	132 kg/ha for start up then avg rate of 151 kg/ha for Urea	brush applicator	At planting and At 6 leaf stage of corn	n	NA	NA	NA	NA	104	7.5	0.6	?	0.3	173	2.79	4.79	1.6	694	9.9	68	22.7		NA	NA	NA	NA
6	corn	n	annual ryegrass	n	NA	y	Soil Saver	Mineral (8-32-16) start up; then Urea (46-0-0)	132 kg/ha for start up then avg rate of 151 kg/ha for Urea	brush applicator	At planting and At 6 leaf stage of corn	n	NA	NA	NA	NA	104	7.5	0.6	?	0.3	208	1.92	3.99	1.33	677	11.4	77.2	25.7		NA	NA	NA	NA
7	corn	y	annual ryegrass	n	NA	y	moldboard plow	Mineral (8-32-16) start up; then Urea (46-0-0)	132 kg/ha for start up then avg rate of 151 kg/ha for Urea	brush applicator	At planting and At 6 leaf stage of corn	n	NA	NA	NA	NA	104	7.5	0.6	?	0.3	130	3.11	4.19	1.4	766	9.8	74.9	25		NA	NA	NA	NA
8	corn	y	annual ryegrass	n	NA	y	Soil Saver	Mineral (8-32-16) start up; then Urea (46-0-0)	132 kg/ha for start up then avg rate of 151 kg/ha for Urea	brush applicator	At planting and At 6 leaf stage of corn	n	NA	NA	NA	NA	104	7.5	0.6	?	0.3	135	2.77	3.61	1.2	793	11.2	89.1	29.7		NA	NA	NA	NA
9	corn	n	annual ryegrass	y	irrigation pond	y	moldboard plow	Mineral (8-32-16) start up; then Urea (46-0-0)	132 kg/ha for start up then avg rate of 151 kg/ha for Urea	brush applicator	At planting and At 6 leaf stage of corn	y					104	7.5	0.6	?	0.3	265	2.43	6.45	2.15	540	7.6	40.8	13.6		NA	NA	NA	NA
			annual		irrigation			Mineral (8-32-16) start up; then Urea (46-0-0)	132 kg/ha for start up then avg rate of 151 kg/ha for	brush applicator	At planting and At 6 leaf stage of corn																							

Nitrogen | Phosphorus | Crop Yield | Detailed for Measured | Sheet1

Select destination and press ENTER or choose Paste

70%

Drainage Management Literature Review/Meta-Analysis

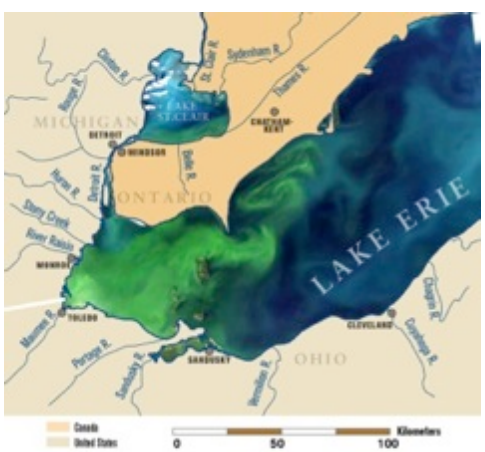
- 50+ papers - field studies, simulations, reviews
- Variety of geographies
- Lack of reporting of potential predictor variables
- Paucity of phosphorus research

Preliminary important drivers

- Local and regional climate
- Drain management
- Clearly more effective in combination w/ other practices, but not necessarily multiplicative
- Crop yield generally neutral, but benefits with cover crop and DWM

Moving Forward

- Quantitative evaluation of water quality benefits from new and innovative conservation practices through a combined effort: WLEB CEAP and UMWC project
- Widespread adoption and exposure—most effective combination of conservation practices utilizing a Large Advisory Panel (WLEB CEAP)
- Easy transfer (other agricultural watersheds)
  - SWAT is a widely-used tool
- Improved Great Lakes water quality protection



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By Tom Archer