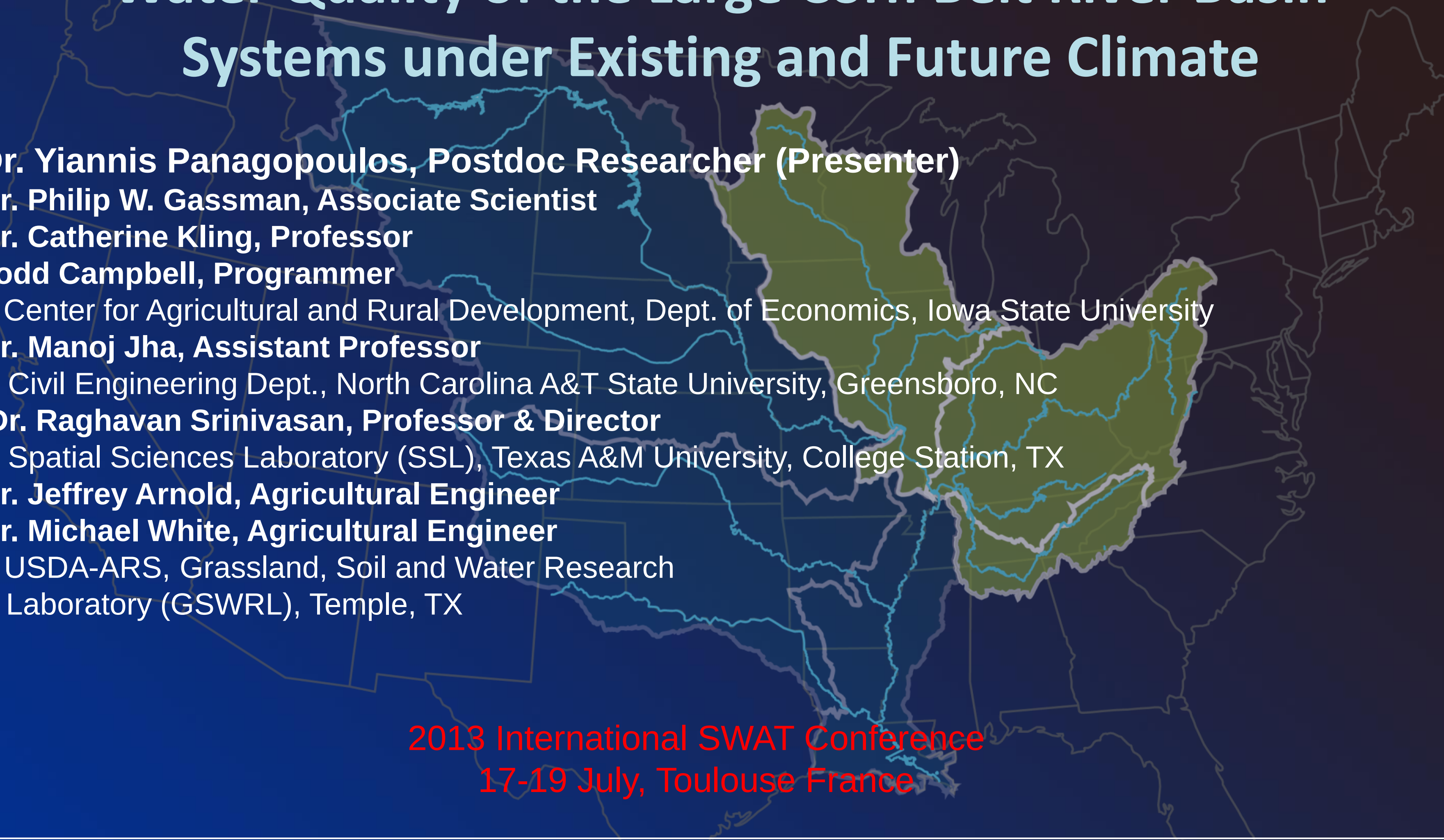
The Effect of Nutrient Reduction Practices on Water Quality of the Large Corn Belt River Basin Systems under Existing and Future Climate



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Presentation Overview

- NPS Pollution from the Upper Mississippi (UMRB) and Ohio-Tennessee (OTRB) River Basins
- Parameterization/Calibration of SWAT UMRB and OTRB models
- Climate change and agricultural management scenarios impact on water pollution and crop productivity in UMRB

Study Regions (UMRB & OTRB)

Primary source regions of nutrients to the Gulf of Mexico

UMRB

Area: 492,000 km^2
Crops: 50%
<5% Slopes: 75%
Prec: 900 mm/y

Loads at Grafton IL
(447,000 km^2)

Flow: 3500 m^3/s
NO_3-N: 360,000 t/y
TN: 500,000 t/y
TP: 30,000 t/y

OTRB

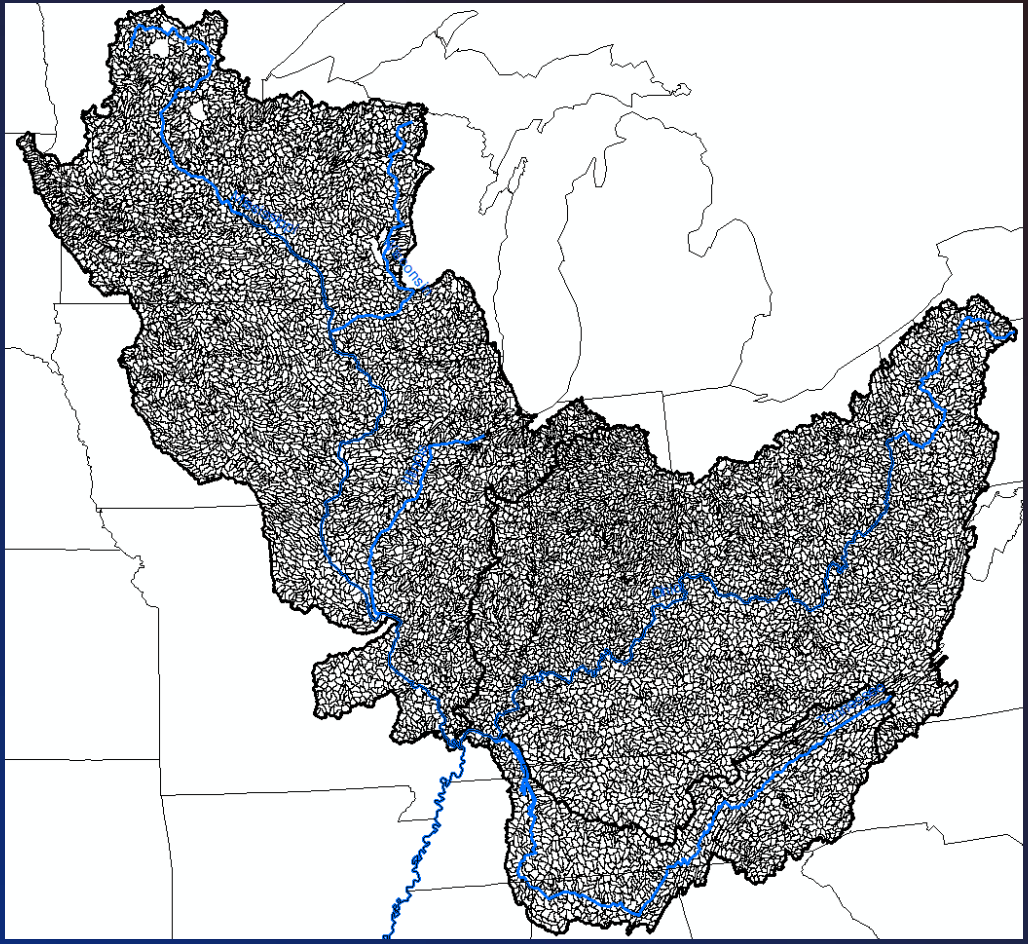
Area: 528,000 km^2
Crops: 20%
<5% Slopes: 35%
Prec: 1200 mm/y

Loads at Metropolis IL
(526,000 km^2)

Flow: 8400 m^3/s
NO_3-N : 330,000 t/y
TN: 500,000 t/y
TP: 48,000 t/y

Delineation of Subwatersheds

- A “12-digit watershed” scale modelling system
- A major refinement, which can improve:
  - Input data accuracy (precipitation – management)
  - Water and pollutant routing
  - Scenarios targeting



- UMRB: 5729 12digits
- OTRB: 6350 12digits
- Average 12digit area: ~ 85 km^2
- Average 8digit area: ~ 4000 km^2
- <u>A 50 times finer discretization</u>

Input Data

Fertilizers:

- 117-156 kgN/ha/y and 25-34 kgP/ha/y. Statewide averages based on estimates from the Nutrient Geographic Information System

Tillage types:

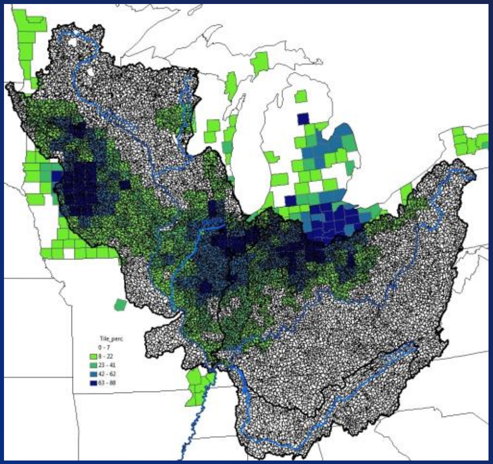
- Incorporated based on survey data collected by the Conservation Technology Information Center (CTIC) (conventional, reduced, mulch, and no-till)

Existing conservation practices:

- A proxy approach based on information provided in the CEAP UMRB study

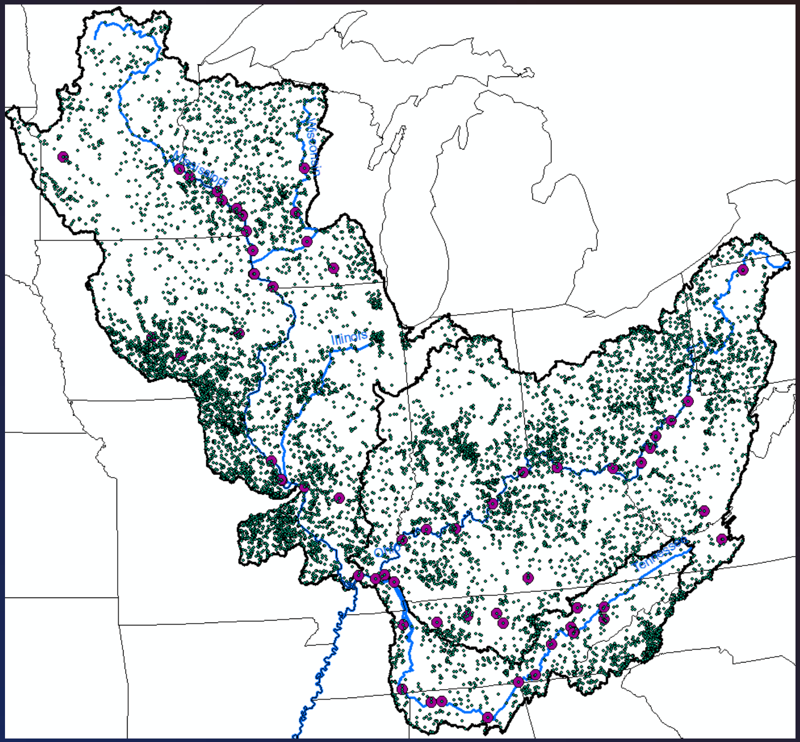
Tile drains:

- Assigned to the agricultural land with slopes lower than 2% and with poorly drained soils



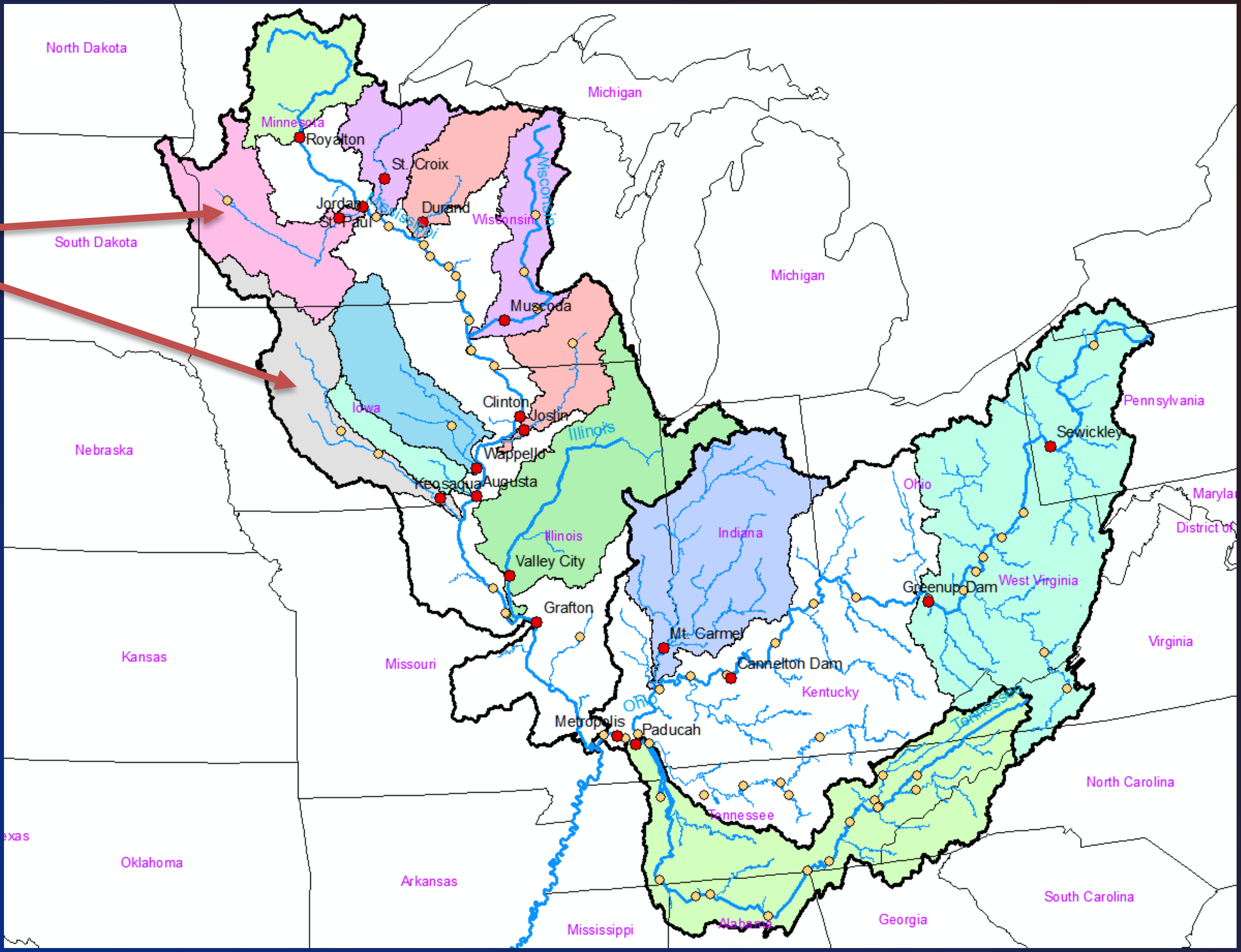
Dams and Reservoirs

- Army Corps of Engineers
- More than 10,000 Dams and Reservoirs
- The largest that are believed to have impact on sediments and nutrient transport have been incorporated
- SWAT parameters: Maximum storage and area, Normal Storage and area – No operational rules
- Trapping efficiency: Good simulation is needed, although no evidence



Hydrologic calibration approach

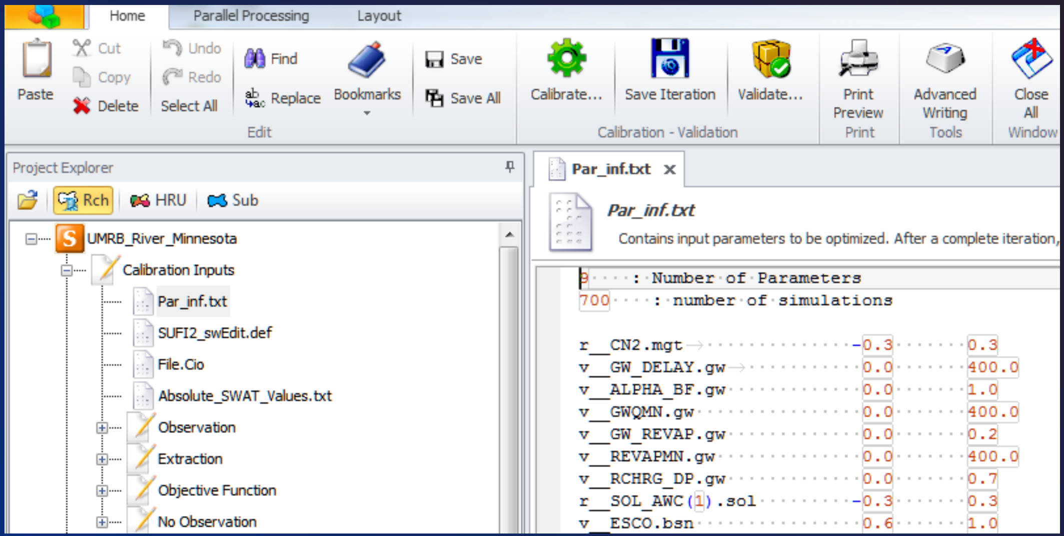
- 13 Individual projects created in SWAT
- Hydrologically independent watersheds within UMRB and OTRB



Calibration with SWAT-CUP

- A computer program for calibration of SWAT models
- The program links SUFI2, PSO, GLUE, ParaSol, and MCMC procedures to SWAT.
- It enables sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models.
- Parameters can range by absolute values or percentage
- SUFI2: Latin Hypercube sampling is carried out; leading to *n* parameter combinations, where *n* is the number of desired simulations.
- The objective function is then evaluated (NS, R^2, etc…)

SWAT-CUP available at:
http://www.eawag.ch/forschung/siam/software/swat/index



Auto-calibration and uncertainty with SUFI2

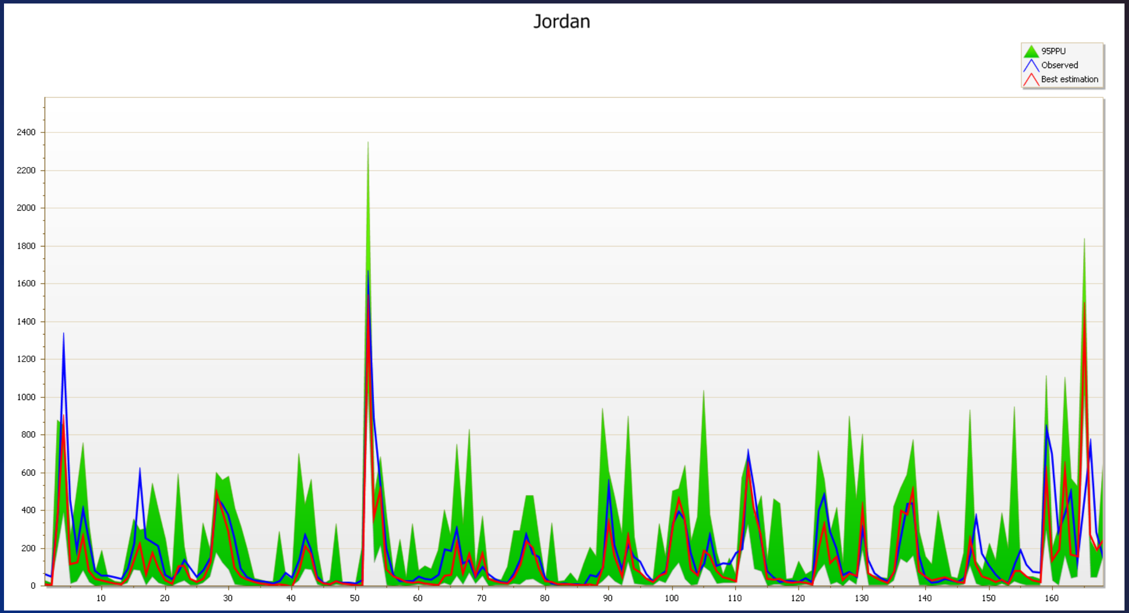
- The goodness of fit is assessed by the uncertainty measures calculated as:
  - The percentage *P* of measured data bracketed by the 95PPU band and
  - the average distance between the upper and the lower 95PPU (or the degree of uncertainty), which is expressed by a measure *Q*

- Red line: best simulation
- Blue line: observed data
- Green areas: 95 ppu uncertainty bounds

Desirable:

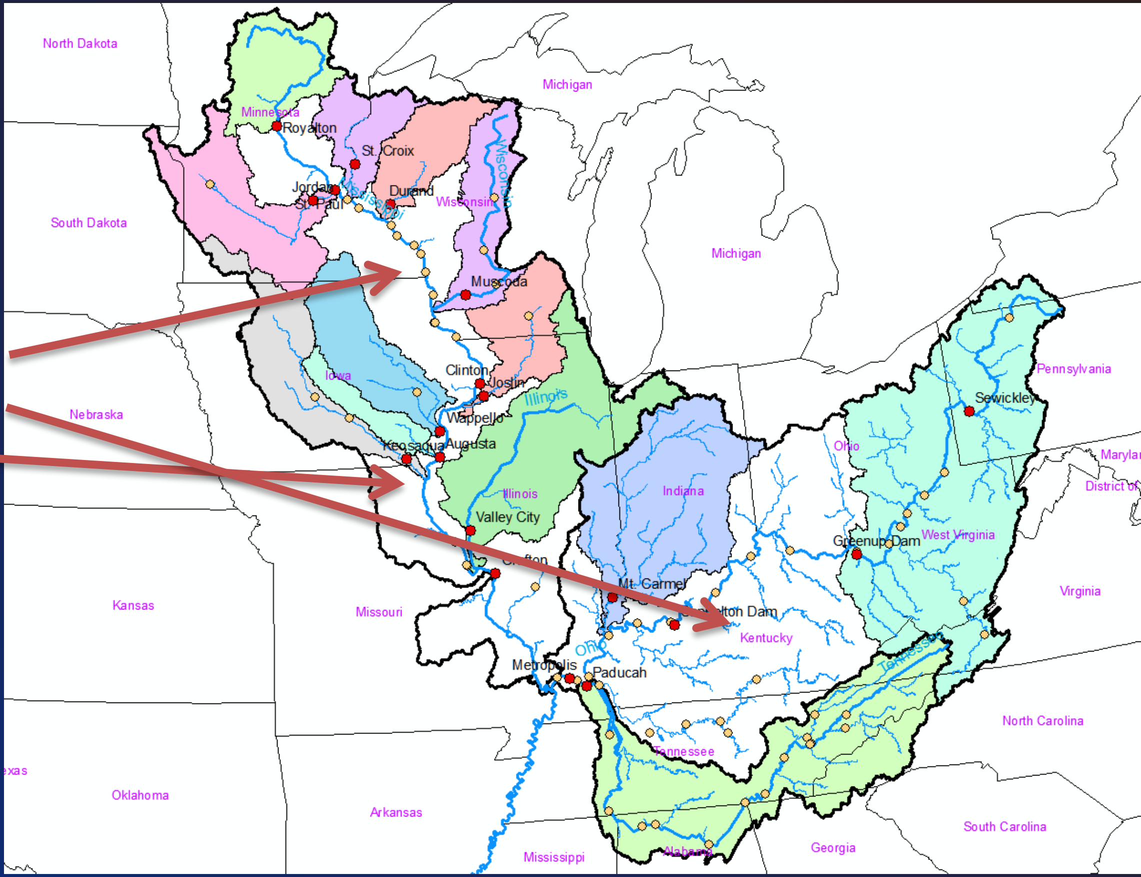
P ⟹ 1 (100%)

Q ⟹ 0

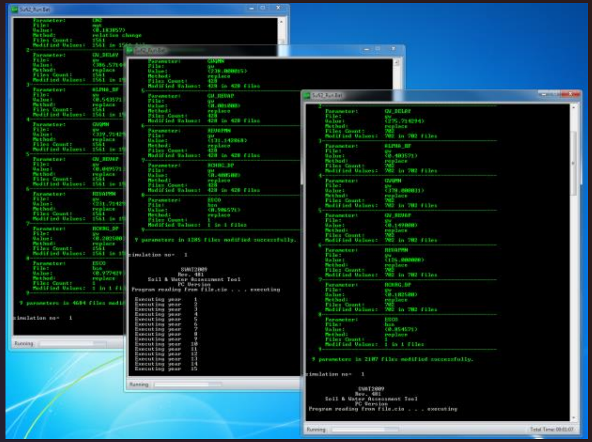


Hydrologic Calibration for intermediate areas

- Calibrated parameters of Individual projects remain stable
- SUFI2 optimizes the hydrological parameters of the 'white areas' within the river basins
- Evaluate fitness based on observed data at Clinton and Grafton (Mississippi) and Cannelton Dam and Metropolis (Ohio river)



Calibration Performance



- 14 years of monthly flows from each station (1997-2010)
- 400 iterations (model runs) – 8 parameters for flow calibration
- A few days time to calibrate all models at once
- Work undertaken in a 32 processors computer

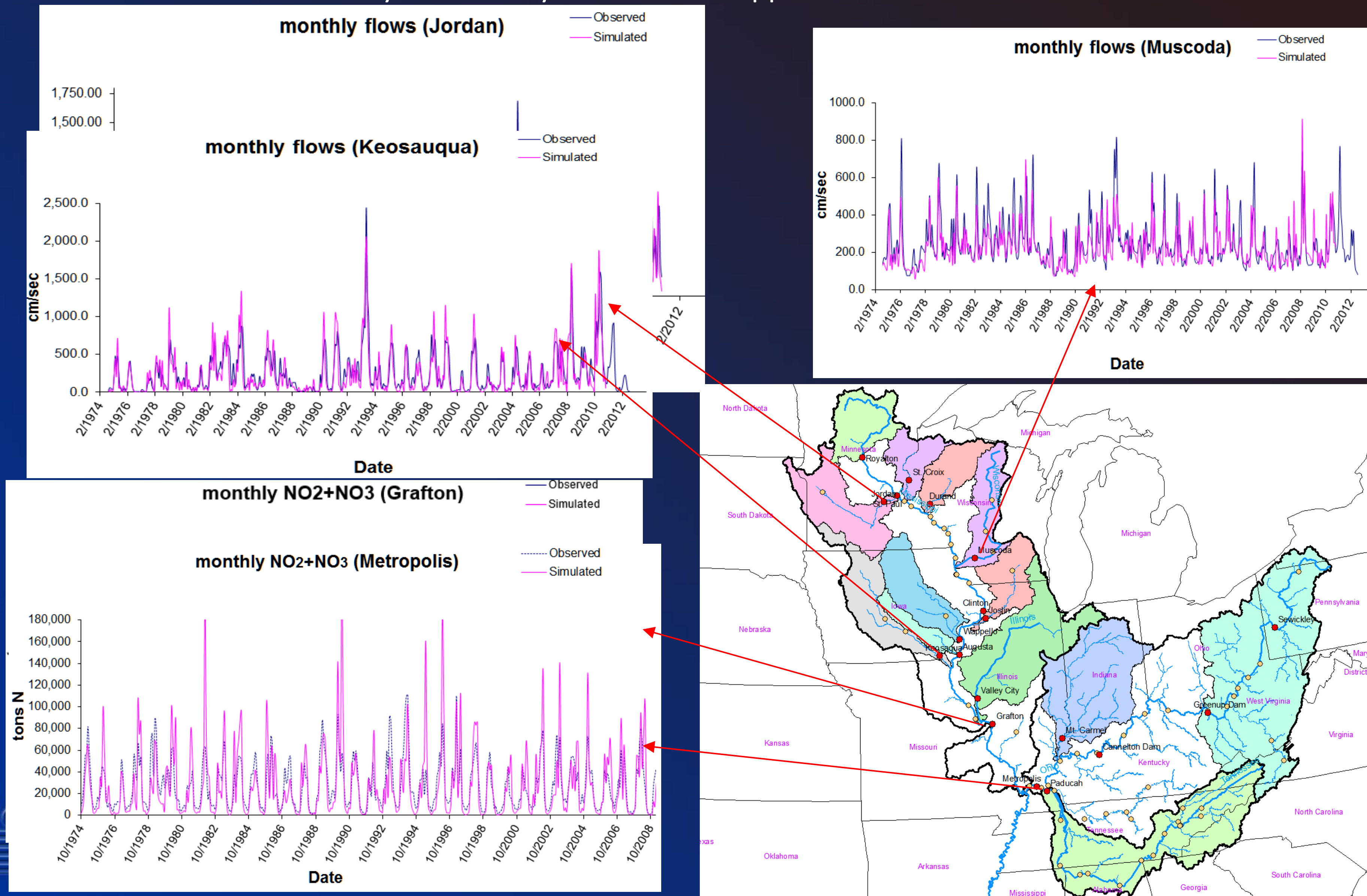
Results:

	SWAT Parameters								Uncertainty & Goodness of fit			
Location	GW_DELAY	ALPHA_BF	GWQMN	GW_REVAP	RCHRG_DP	CN2	ESCO	SOL_AWC1	p	r	R2	NS
Minnesota	28	0.63	0.7	0.02	0.005	-0.13	0.94	-0.1	0.51	0.72	0.77	0.67
St.Croix	27	0.79	55	0.02	0.33	-0.16	0.96	-0.06	0.65	1.13	0.82	0.67
Chippewa	259	0.54	50	0.02	0.21	-0.17	0.83	-0.05	0.77	1.24	0.71	0.7
Wisconsin	323	0.53	14	0.03	0.15	-0.12	0.94	0.18	0.76	1.81	0.62	0.59
Skunk	39	0.48	15	0.02	0.21	0.02	0.97	-0.1	0.57	0.56	0.89	0.88
Des Moines	86	0.49	204	0.04	0.05	-0.17	0.9	0.18	0.54	0.62	0.69	0.58
Illinois	49	0.65	56	0.02	0.04	-0.14	0.95	-0.2	0.48	0.76	0.69	0.52
Iowa	114	0.63	118	0.03	0.07	-0.12	0.95	-0.18	0.43	0.66	0.82	0.74
Royalton	169	0.09	25	0.01	0.27	-0.13	0.98	-0.05	0.67	1.44	0.5	0.48
Rock	180	0.85	188	0.01	0.08	-0.13	0.92	-0.15	0.38	1.04	0.68	0.52
Clinton	68	0.42	61	0.02	0.02	-0.15	0.89	0.04	0.43	0.50	0.64	0.53
Cannelton	13.5	0.137	59.5	0.03	0.02	-0.10	0.91	-0.05	0.52	0.30	0.92	0.91
Metropolis	58.5	0.75	155	0.05	0.03	0.00	0.99	0.05	0.44	0.18	0.90	0.89
Greenup	16	0.51	161	0.02	0.02	-0.07	0.89	0.09	0.71	0.80	0.90	0.89
Tennessee	6.2	0.169	119	0.18	0.24	-0.17	0.83	0.07	0.85	1.05	0.81	0.75
Wabash	33	0.579	19.7	0.07	0.10	-0.19	0.93	-0.14	0.77	0.89	0.89	0.88
Cannelton	13.5	0.137	59.5	0.03	0.02	-0.10	0.91	-0.05	0.52	0.30	0.92	0.91
Metropolis	58.5	0.75	155	0.05	0.03	0.00	0.99	0.05	0.44	0.18	0.90	0.89

Calibration-Validation graphs (1)

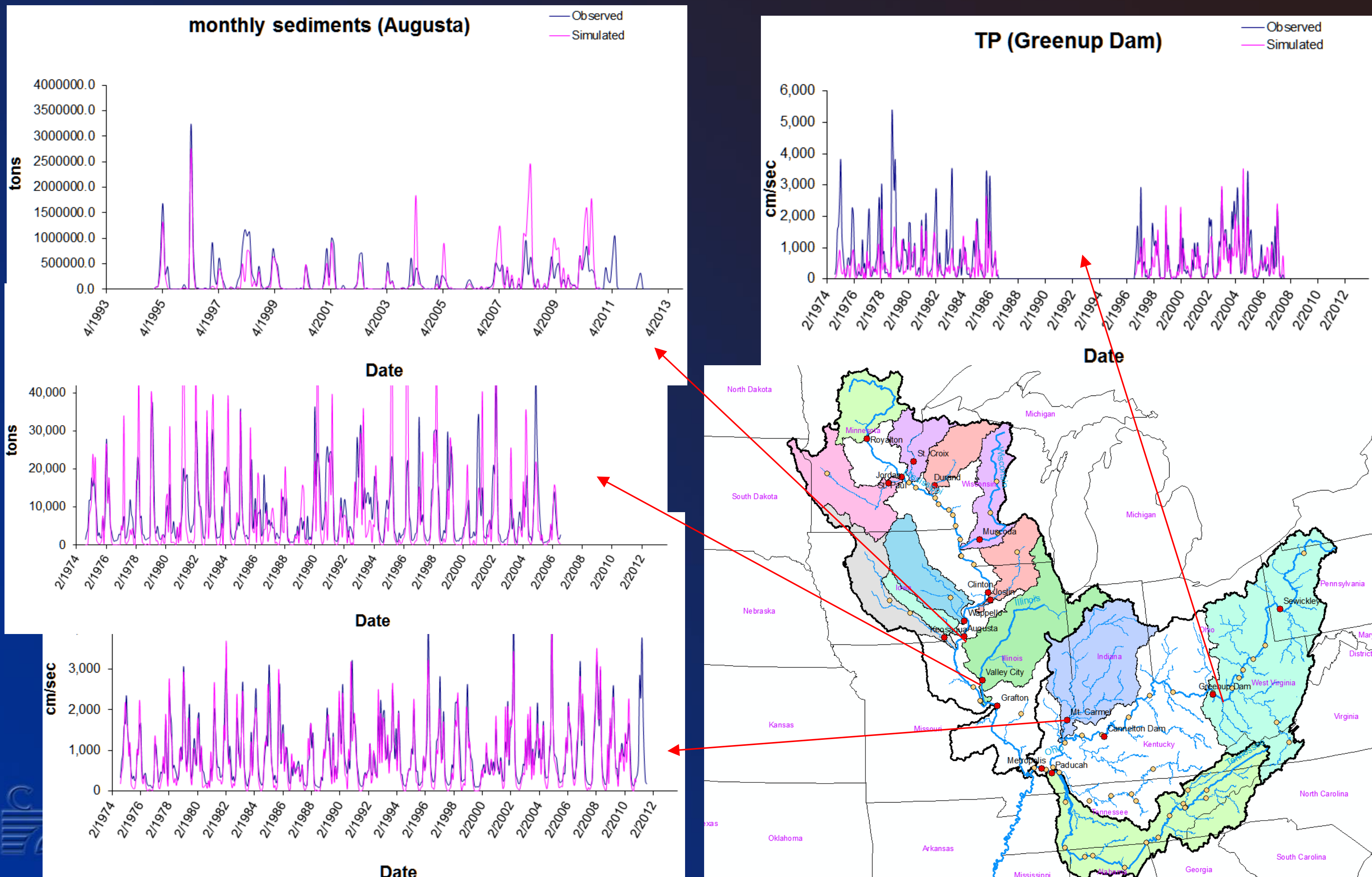
Validation: SWAT execution with the calibrated parameters for a past 20-year period

Sediments-Nutrients: Not fully calibrated yet – a manual approach is followed



Calibration-Validation graphs (2)

Validation: SWAT execution with the calibrated parameters for a past 20-year period
Sediments-Nutrients: Not fully calibrated yet – a manual approach is followed

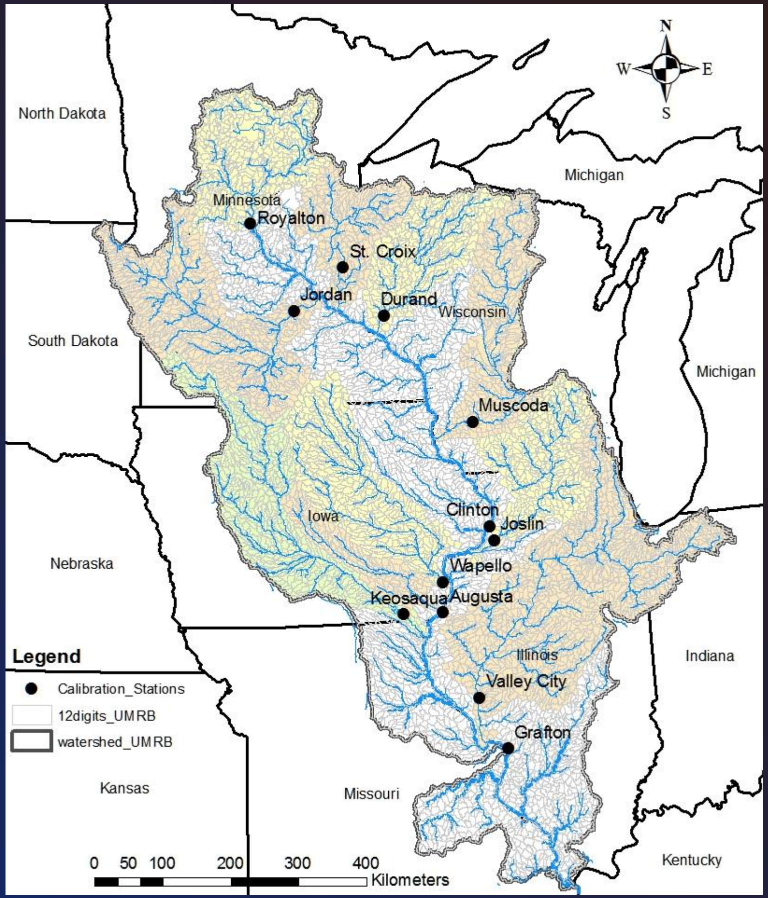


Agricultural management scenarios in UMRB

Baseline: C-S and C-C in 50% of UMRB area

Scenarios:

1. Conversion of corn-soybean (C-S) rotations to continuous corn rotation (C-C),
2. Apply No-tillage to all agricultural land
3. Apply an extended rotation of the typical C-S and C-C rotations with alfalfa (C-S-A-A-A)
4. Planting rye as a winter cover crop (COC) between the growing dates of the productive crops (C and S).



General Circulation Model (GCM) and Predicted Mid-Century Climate

- A1B scenario - greenhouse gases are assumed to increase through the middle of the 21st century - CO_2 concentrations stabilizing at 720 ppm

- A projected future climate from mid-century (2046-2065) results from the medium-resolution version of the Model for Interdisciplinary Research on Climate, version 3.2 (MIROC 3.2) Global Circulation Model (GCM)

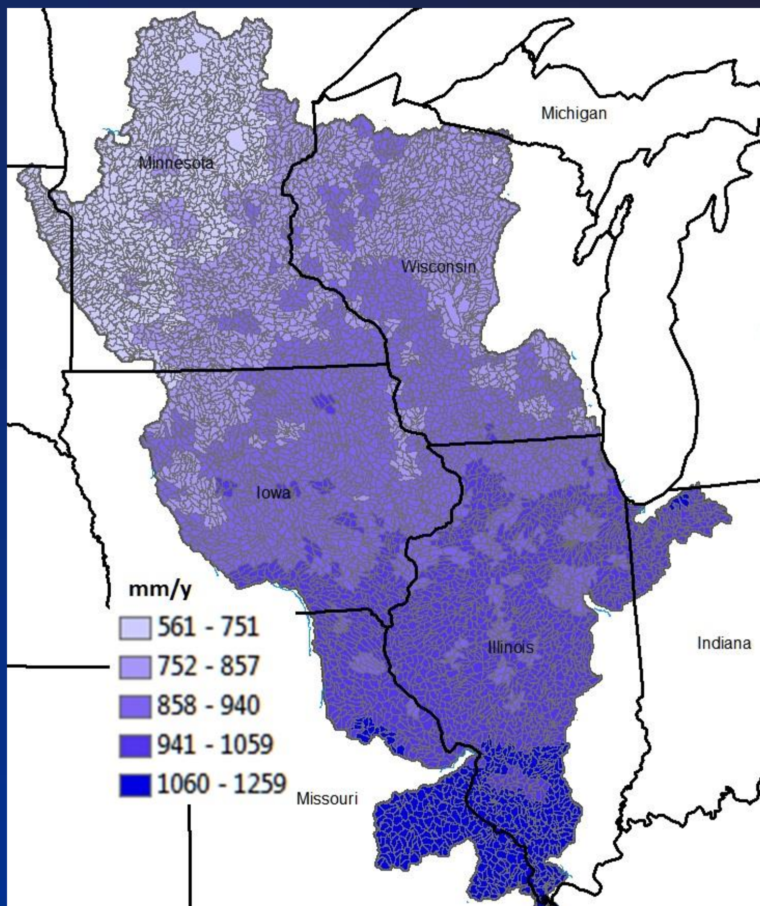
- Downscaling method: bias corrected with spatial disaggregation (BCSD)

- Interpolation to a 1/8 degree latitude-longitude grid. Adjustment of daily observed weather time-series (% changes in precipitation - absolute changes in T_{max}, T_{min}).

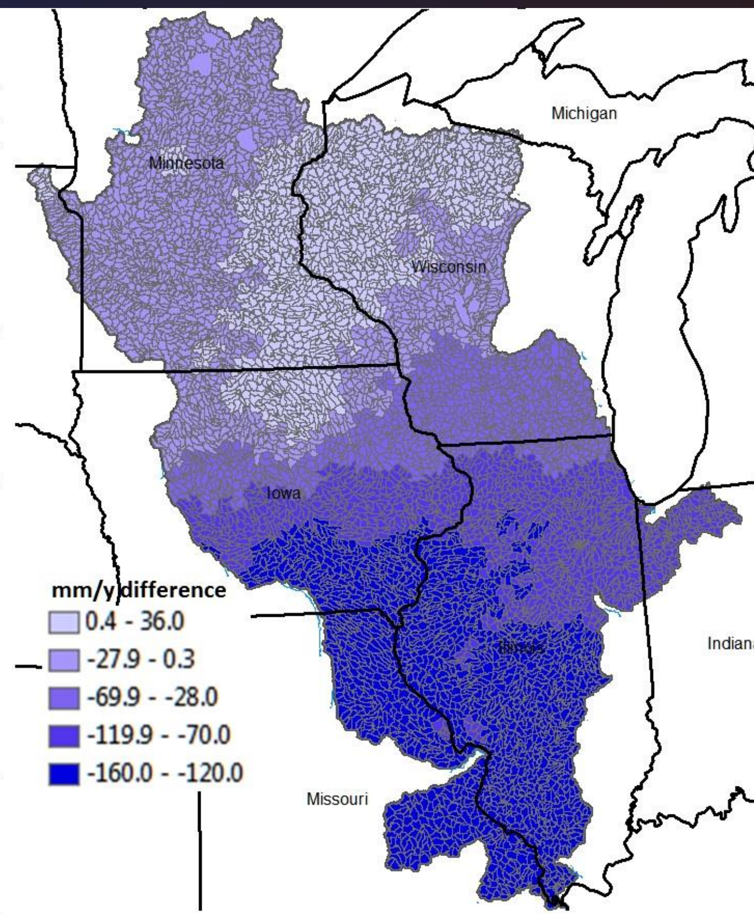
Changes in Precipitation across the UMRB

MIROC 3.2 (2046-2065)

Mean annual precipitation of the baseline (1981-2000)



Difference in mean annual precipitation between the baseline (1981-2000) and future (2046-2065) climate

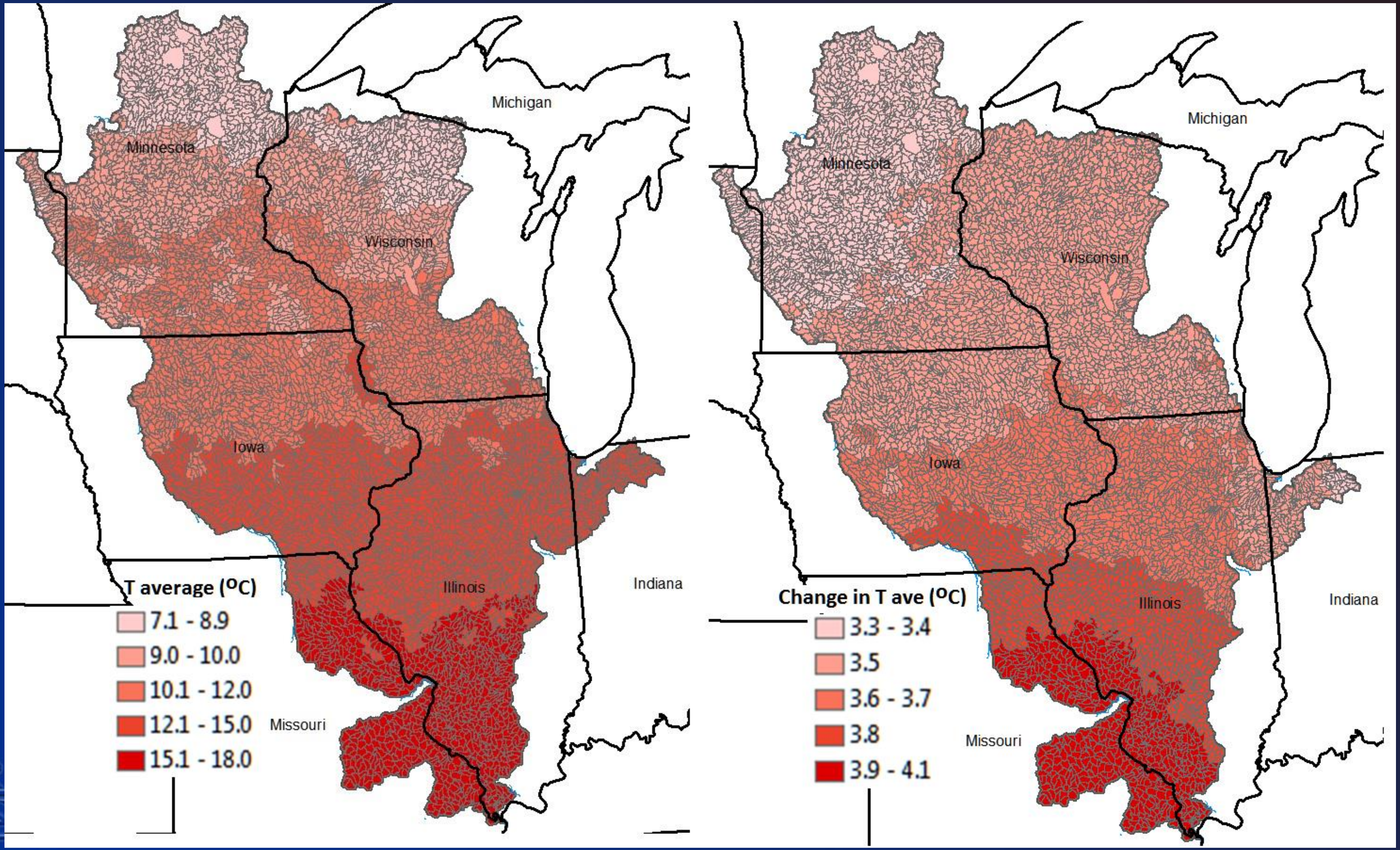


Changes in Temperature across the UMRB

MIROC 3.2 (2046-2065)

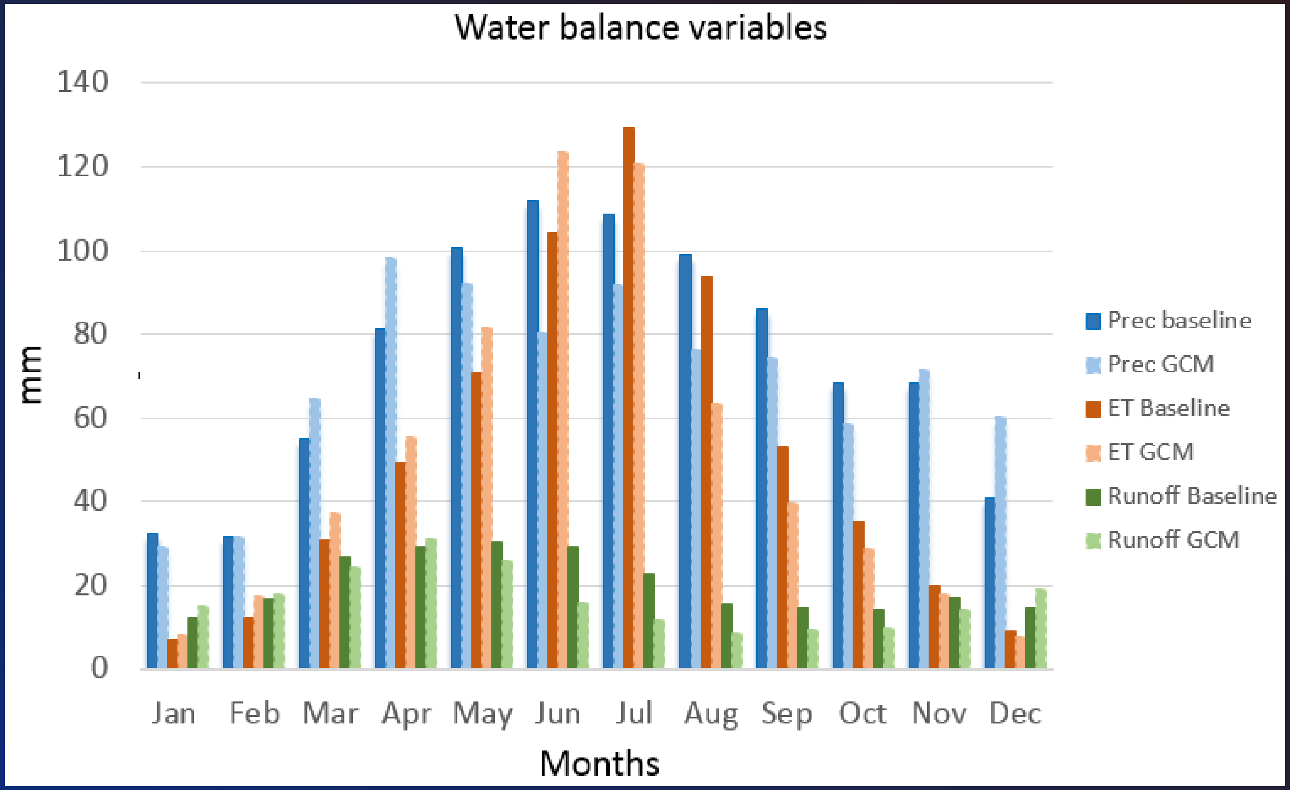
Mean annual temperature of the baseline (1981-2000)

Difference in mean annual temperature between the baseline (1981-2000) and future (2046-2065) climate



Water balance under the historic and future climate

- Annual precipitation reduced from 884 mm to 829 mm
- Greater reductions during the growth stages of the crops (May-Oct).
- Annual runoff reduced from 240 mm to 204 mm
- Reduced precipitation balanced the effect of increased temperature on ET, which remained at the same levels (600 mm/y)

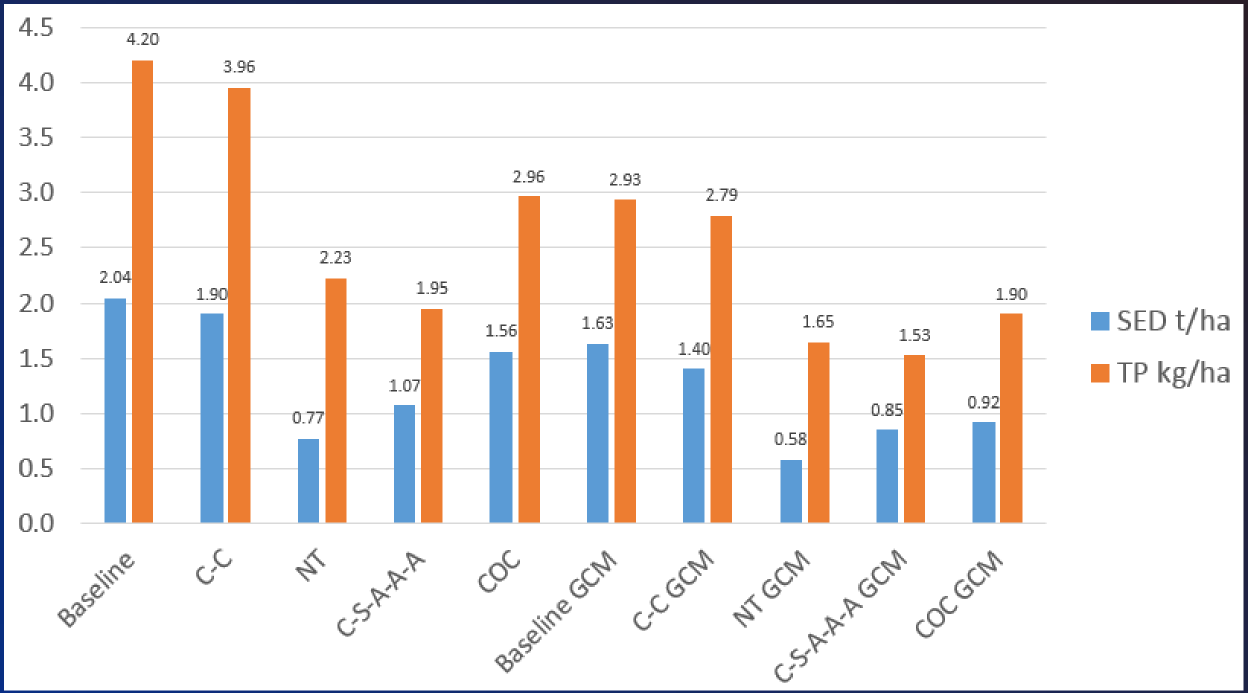


Scenarios implementation under existing and future climate

Impact on annual sediments and P loadings from UMRB cropland

- The replacement of soybean with corn in the C-C scenario leaves higher residue amounts on the ground reducing its erosion susceptibility, sediment transport and P losses.
- The expansion of NT reduces sediment and P load by 65% and 45% respectively
- Extended rotation (C-S-A-A-A) results in about 50% load reduction
- Rye used as cover crop (COC) causes a 25-30% reduction

- Similar behavior of scenarios under climate change
- Reduction of sediments and P to even lower levels due to reduced runoff (especially surface runoff)

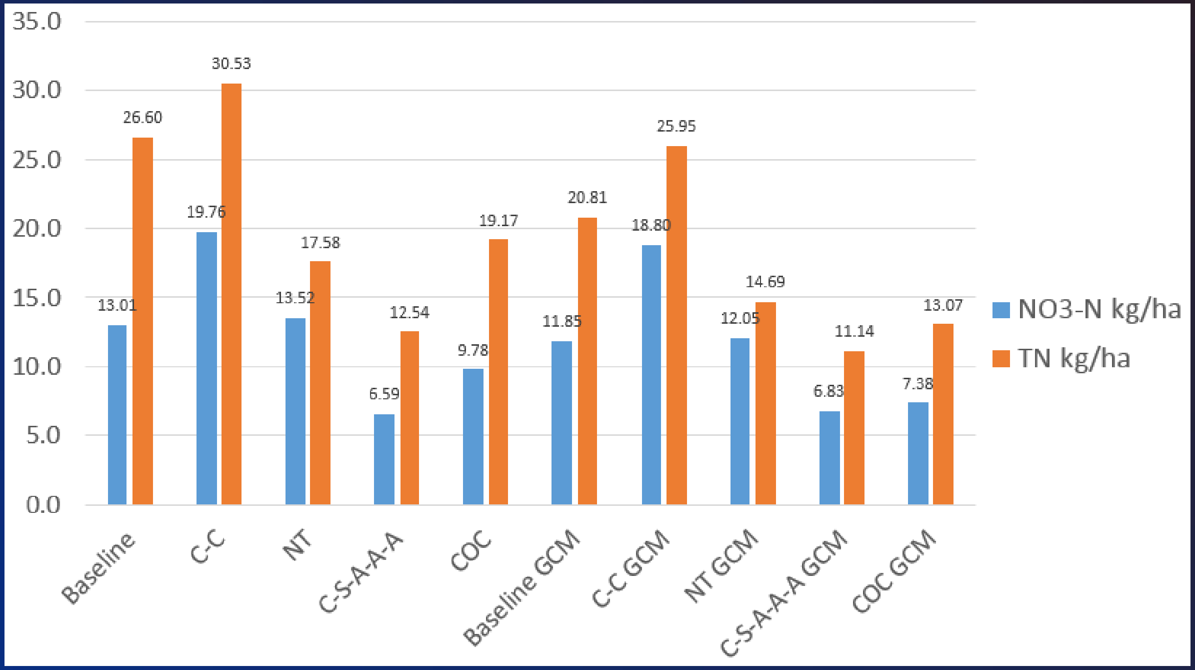


Scenarios implementation under existing and future climate

Impact on annual NO_3-N and TN loadings from UMRB cropland

- Increased N pollution was only predicted for the C-C scenario due to the increased N fertilization (50 kg/ha)
- Adoption of NT had little effect on NO_3-N losses but considerable on organic N and TN
- C-S-A-A-A is the most effective scenario - 50% N pollution reduction due to reduced erosion and no N fertilization in alfalfa (3 out of 5 years of the rotation)
- Cover crops reduced N pollution by 30% due to N uptake and erosion protection during a period when the ground was susceptible to pollutant transport

- Similar behavior of scenarios under climate change
- Reduction of NO_3-N and TN to even lower levels due to reduced runoff (both surface and subsurface)

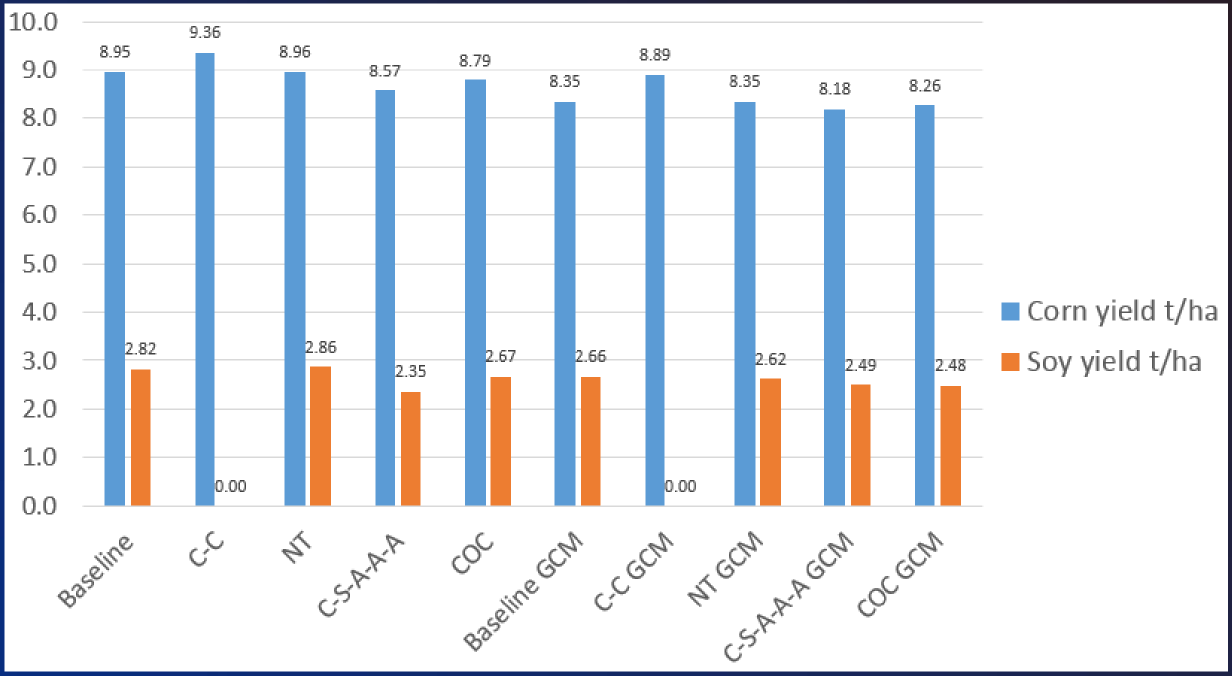


Scenarios implementation under existing and future climate

Impact on corn and soybean yields of the UMRB

- Mean annual simulated corn and soybean yields in the baseline scenario are 8.95 and 2.82 t/ha
- Continuous corn results in a slightly increased annual harvest yield of 9.36 t/ha
- NT applied in all C-S and C-C HRUs of UMRB does not practically have any impacts on yield
- C-S-A-A-A reduced yields by less than 5% for corn but close to 15% for soybean – climate variability may be important here (corn and soybean growing in certain years)
- The cover crop reduces slightly (2-6%) corn and soybean yields due to nutrients uptake by rye

- Similar behavior of scenarios under climate change
- Reduction of yields due to less water availability that may cause more water stress days



Conclusions

SWAT Performance

- Calibration of such large systems seems an endless task, continuous update with new data (reservoirs, point sources (now included), conservation practices)

- SWAT-CUP is an indispensible tool for such large systems to finalize hydrologic calibration in reasonable time

- Sediment and nutrient calibration still done manually

- Curve numbers are always reduced in both UMRB and OTRB (up to – 20%)

- Surface runoff highly responsible for sediment and organic nutrient predictions, subsurface for NO_3-N

- 12 digits lead to improved SWAT performance compared to old studies, although much remain to be tested

Conclusions

Climate change and scenarios

- The MIROC3.2 GCM predicts reduced precipitation during the crop-growth period in the most intensely cultivated areas of UMRB having a negative impact on crops

- At the same time, future climate has an assisting role in reducing pollutant losses from land to waters

- All scenarios behaved similarly under the current and future climate resulting in reduced erosion and nutrient loadings to surface water bodies

- No-till was the most environmentally effective scenario with the greatest pollution reduction sustaining crop production levels

- The potential SWAT contribution in developing a general decision support system for the Corn Belt agricultural systems is highlighted