Investigating Impacts of BMPs and Land Use Change on Water Quality for Sustainable Bioenergy Production

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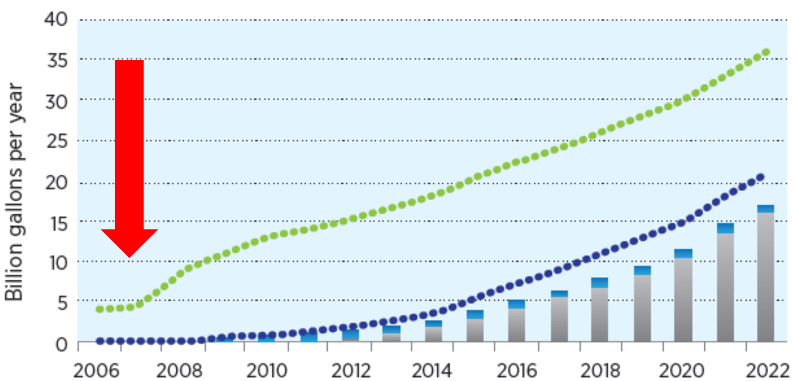
Bioenergy Future

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

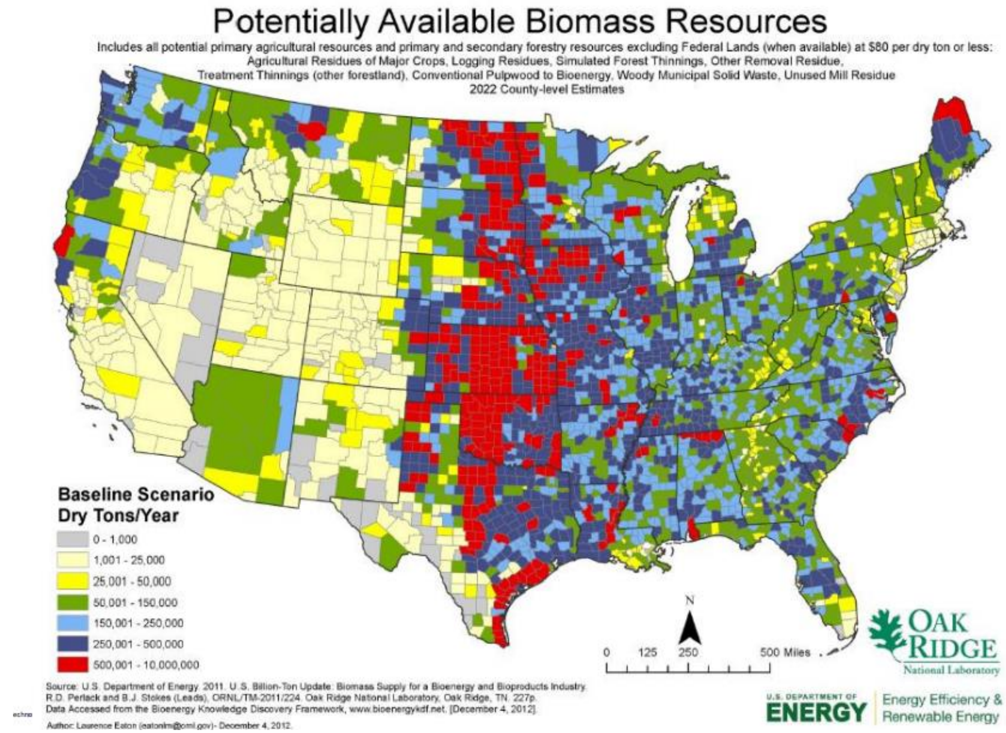
Estimate of U.S. Cellulosic Biomass by 2020 (NAS, 2009)

Feedstock	Millions of dry tons
Corn stover	112
Wheat and grass straw	18
Hay	18
Dedicated energy crops	164
Woody	124
Animal manure	12
MSW	100
Total	**548**



Cellulosic Biofuel Component (BGY)
Advanced Biofuel Total (BGY)
Biomass-based Diesel Component (BGY)
Renewable Fuel Total (BGY)

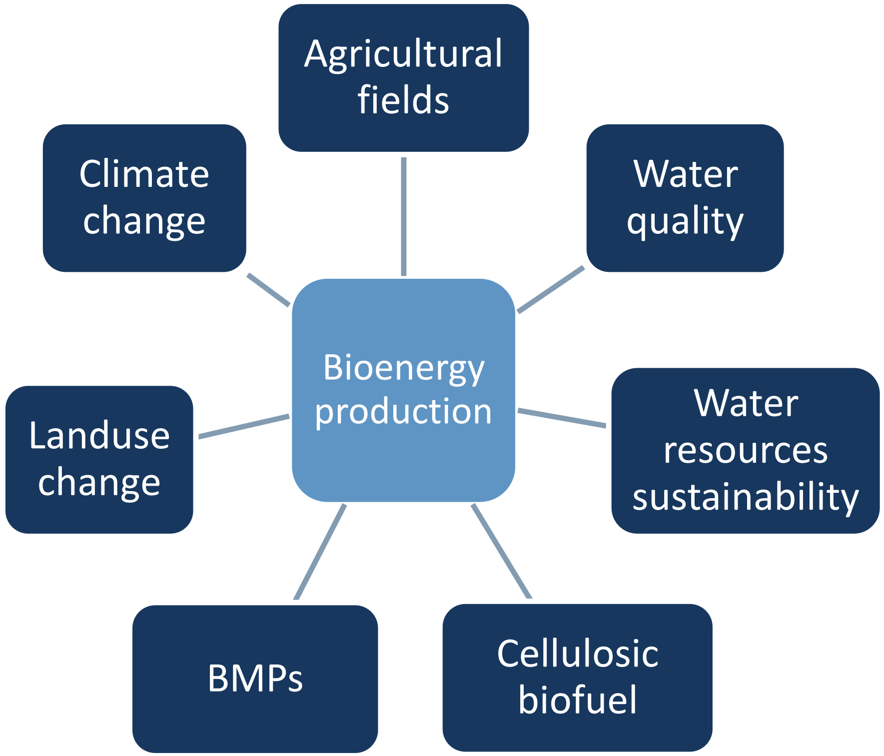
Map Results from BT2: 2022 Baseline, $60/dry ton



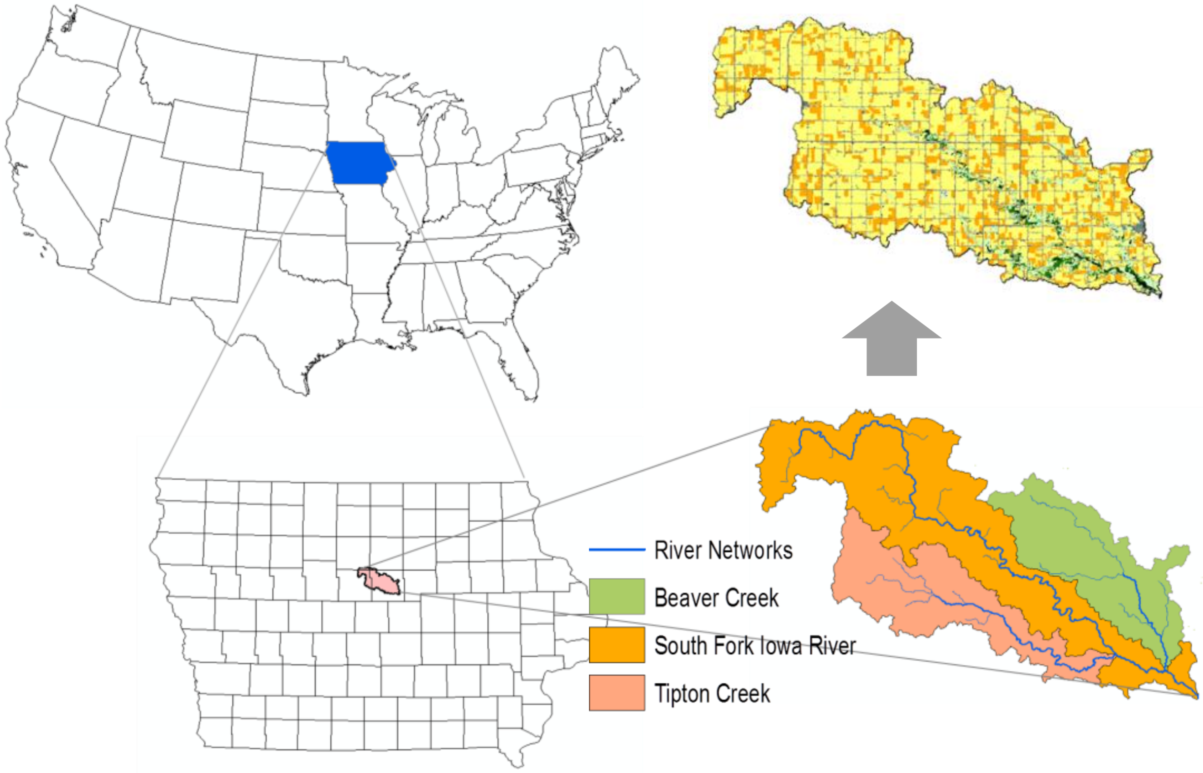
(Reference) U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry, available at http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf

Introduction

- Nonpoint source pollution is an issue for agricultural fields due to nitrogen and phosphorus from fertilizer and livestock in the Midwest.
- Biofuel production requires land and water resources and is significantly impacted by climate changes.
- Cellulosic biofuel feedstock production in a landscape design incorporating low productivity land was converted to high biomass production crop. The selective feedstock is switchgrass in this study.
- This study examines potential impacts of current and proposed landscape design and Best Management Practices (BMPs) on water quality under historical and future climate scenarios, supporting sustainable bioenergy production.



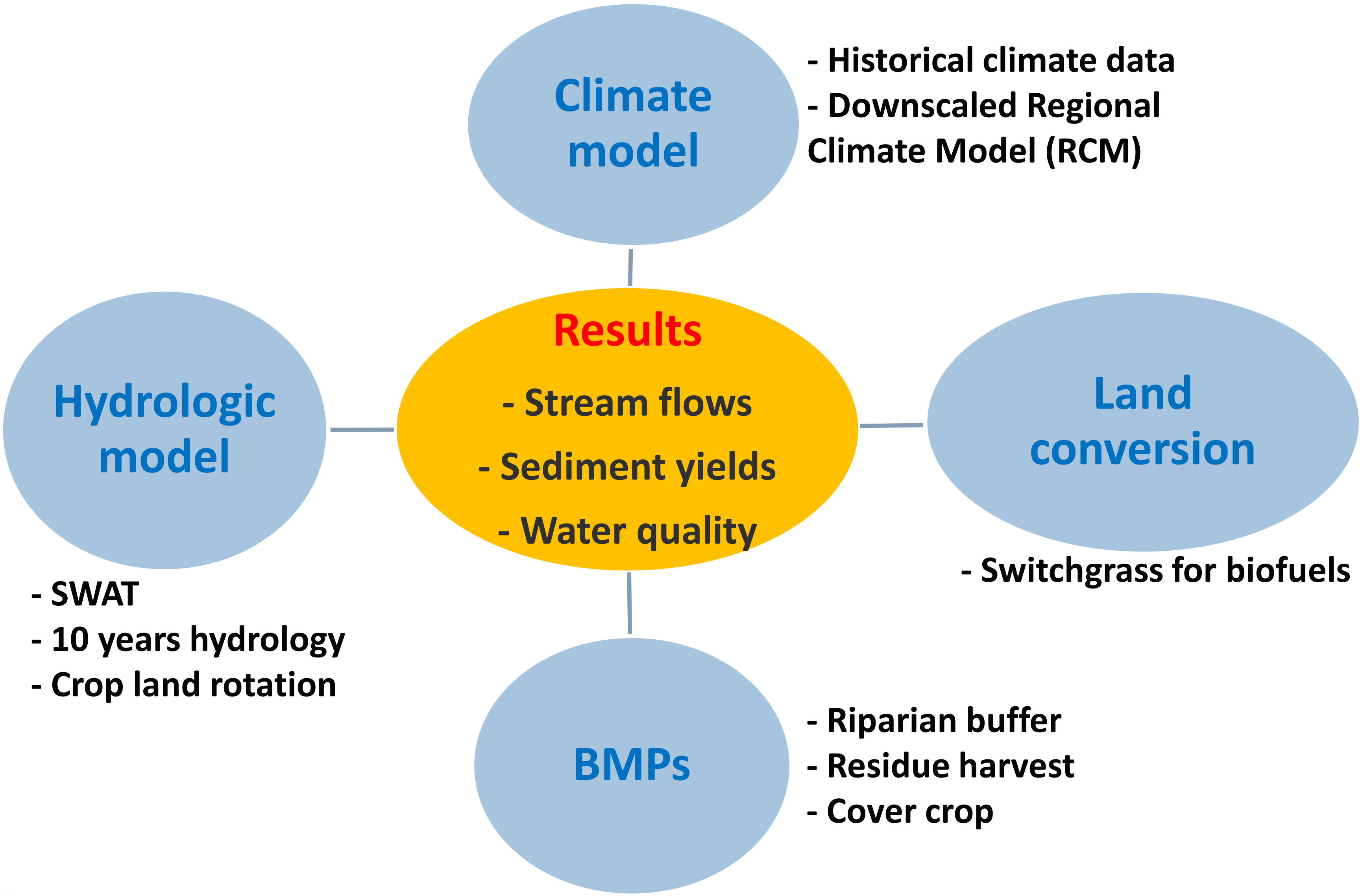
Study Area – South Fork Watershed



South Fork of the Iowa River Basin, IA

- Located in Hardin and Hamilton Counties in Iowa with drainage area approximately 800 km^2
- Includes the tributaries of Tipton and Beaver Creeks
- Corn and soybean are dominant crops: about 78.6% of the watershed area
- 3 main tributaries at the 10-digit hydrologic units (Beaver creek, the South Fork of the Iowa River, and Tipton creek)
- Historically, groundwater contamination is an issue because of nitrogen.

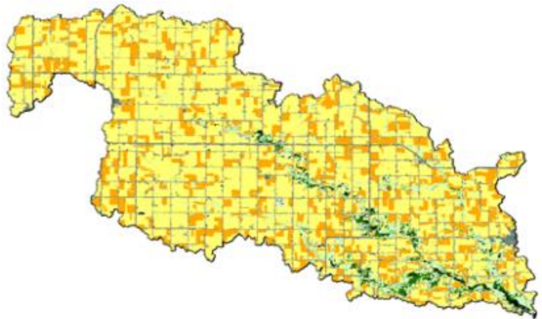
Methodology Framework

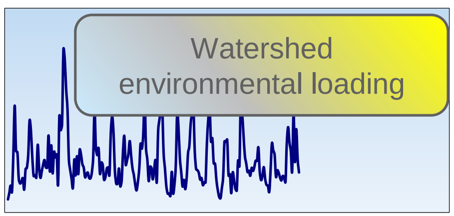


Application of SWAT to evaluate impacts of bioenergy production on water quality

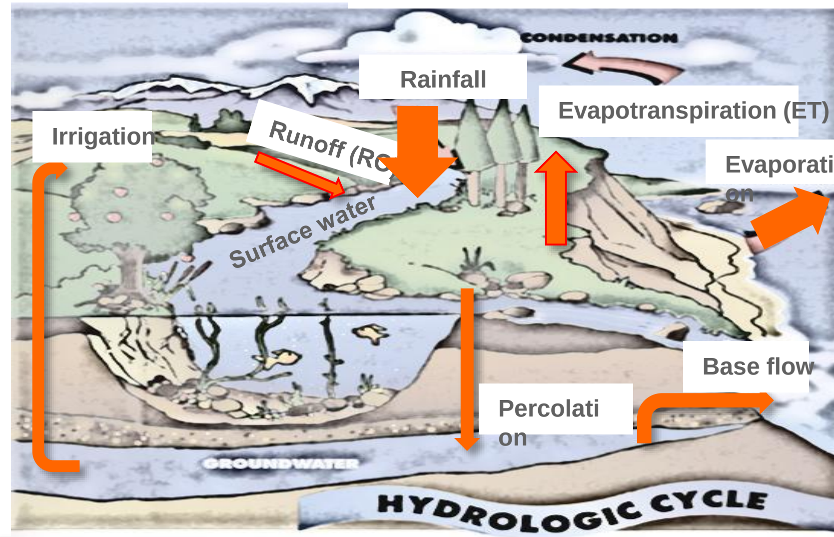
Soil & Water Assessment Tool | SWAT

- Types of biofuel feedstock
- Land use changes





Nitrogen, phosphorus, suspended sediments, flow



- Advance understanding of the relation of increased feedstock production to natural processes that affect spatial variations in
  - ***Water quality***
  - ***Water resource availability***
- Assist in a variety of management decisions and protection strategies to meet regulatory limit and sustainability criteria

SWAT model for the South Fork of Iowa River watershed includes 39 sub basins and 1,517 Hydrologic response units (HRUs).

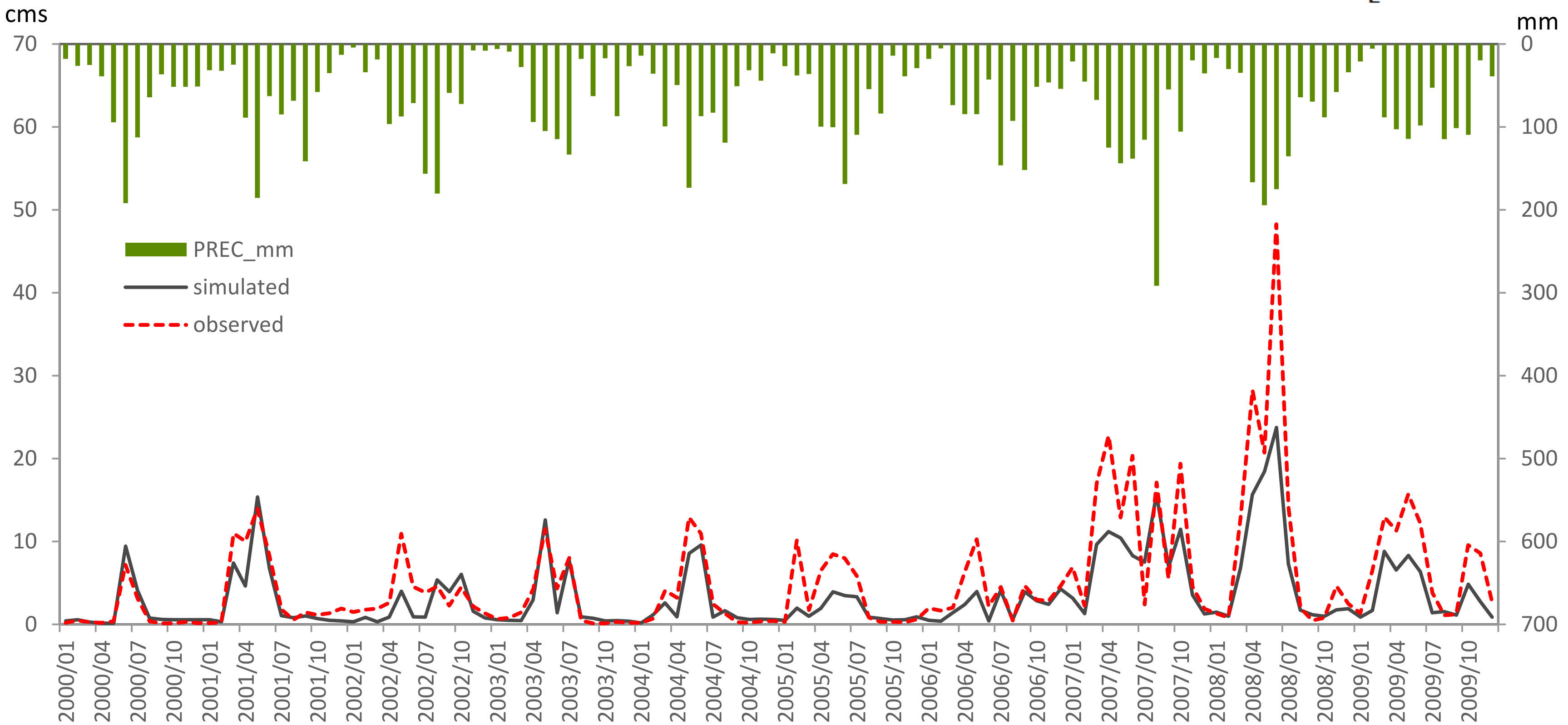
Input data

- DEM (30 m)
- HRU: 5% (land use), 10% (soil), 10% (slope)
- Land use map: Crop Data Layer (CDL) from NASS
  - Four-year crop rotations (mainly corn and soybean, 78.6%)
  - Corn and soybean combinations based on years 2007, 2008, 2009, and 2010: Eight different groups (e.g. corn-corn-corn-corn [CCCC], corn-soybean-corn-soybean [CSCS], soybean-corn-soybean-corn [SCSC])
  - Low-density residential area (10.6%) and pasture (8.5%)
- SSURGO soil data base
- Climate data (precipitation and max/min temperature) from NOAA's National Climate Data Center
- USGS gauging station

SWAT Application for South Fork of Iowa River Watershed - Base scenario

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2} \right]$$

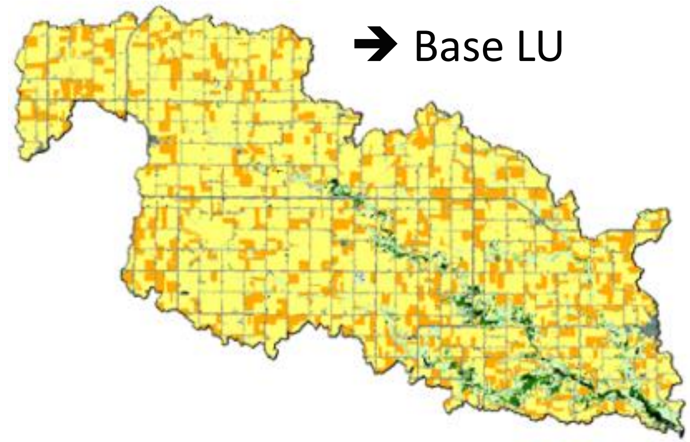
- Hydrograph



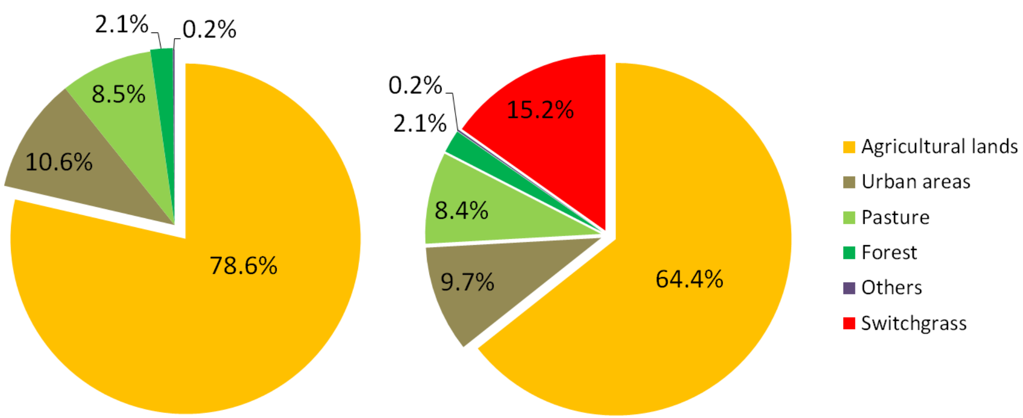
- Model performance (NSE: Moriasi et al. (2007) & R^2)
  - Calibration (2000-2005): [flow] 0.68 (NSE), 0.72 (R^2), [NO3] 0.65 (NSE), 0.77 (R^2)
  - Validation (2005-2009): [flow] 0.60 (NSE), 0.85 (R^2), [NO3] 0.58 (NSE), 0.71 (R^2)

Proposed Landscape Design

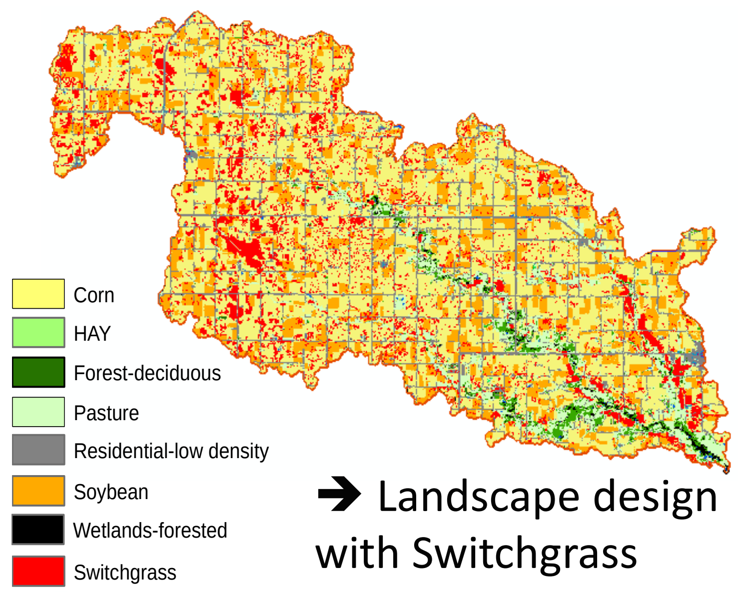
- Land use change for cellulosic biomass production in various sub basins across the watershed
  - Switchgrass
  - Stover
  - Corn grain
  - Soybean
- Collaborative project with INL and ORNL. Scenario developed by INL based on supply curve (ORNL) and soil erosion potential.



→ Base LU



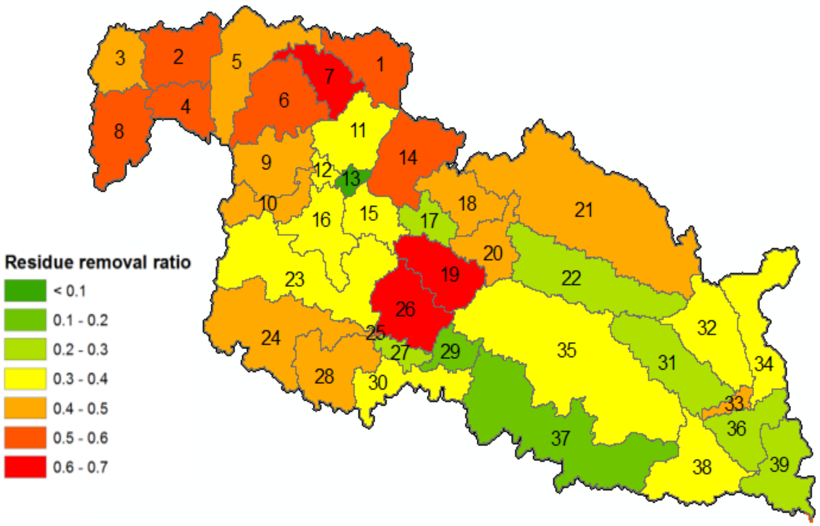
[Base LU] [SWG LU]



→ Landscape design with Switchgrass

Corn stover harvest + Cover crop application

- Residue harvest rates
  - total soil loss factor (T)
  - SCI values
  - annual maximum sustainable residue removal

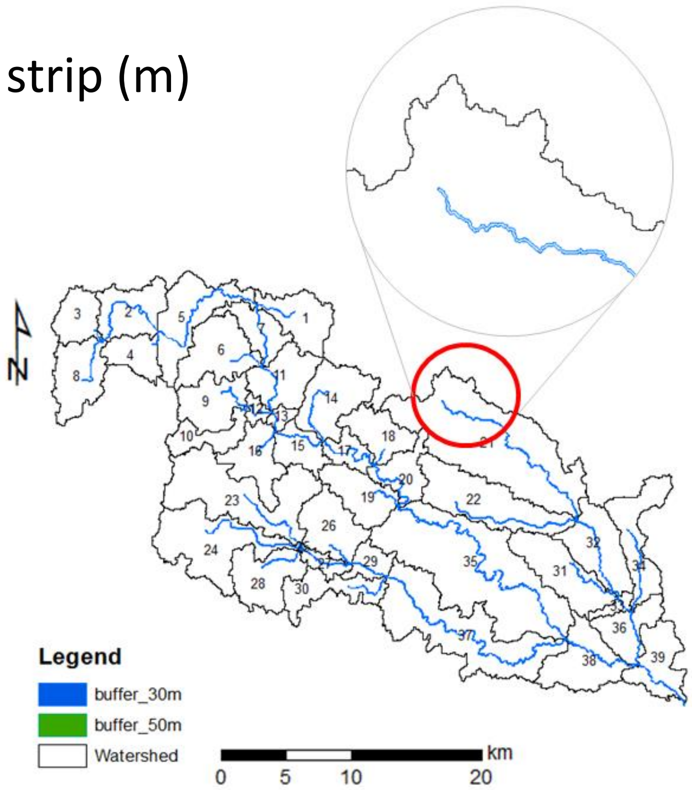


- Winter cover crop application
  - Rye was implemented to corn and soybean fields.
  - benefits; minimizing sediment erosion, nitrate, and phosphorous losses.

Riparian buffer application

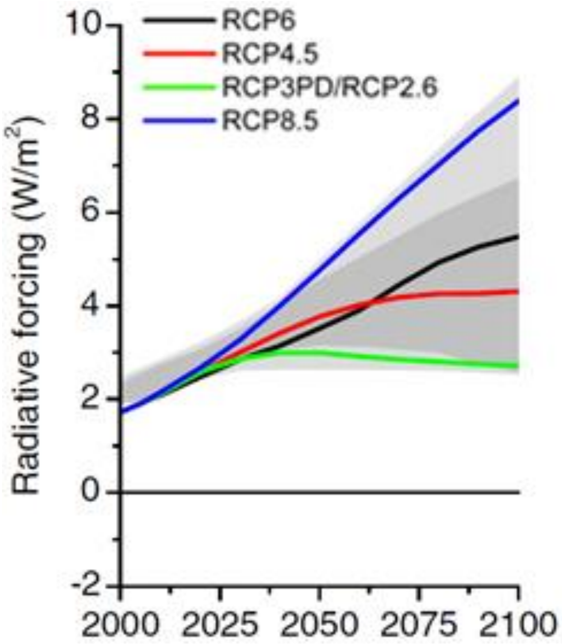
- Filter strip trapping efficiency
  - $Trap_{eff} = 0.367\ (FILTERW)^{0.2967}$

    where, FILTERW: width of the filter strip (m)
  - Buffer width 30m was applied.
  - Alamo switchgrass was selected.
  - 1.9% (watershed)
  - 2.4% (total agricultural croplands)



Climate model

- IPCC projected temperature increases between 1.5 and 4.5˚C from a doubling of equivalent carbon dioxide (CO2) concentrations, and extensive spatial variability in temperature and other climate changes
- Global Climate Models (GCM) have been downscaled to regional climate models (RCM) through various methods such as dynamic, statistic, and delta change.



Weather Research and Forecasting (WRF) model by Argonne National Laboratory

- Downscaling of 2.5-degree National Centers for Environmental Prediction-U.S. DOE reanalysis II (NCEP-R2) data
- Resolution: 12 km and RCP: 8.5
- Future model: 2085-2094

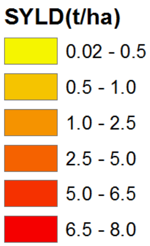
Bioenergy Production Scenarios of the Study

- Eight combinations of different land use and climate scenarios
  - Land conversion occurs from low productive land or idle land to switchgrass.
  - Riparian buffers were applied.
  - Proposed land conversion with residue harvest and winter cover crop application
  - Historical climate and future climate models.

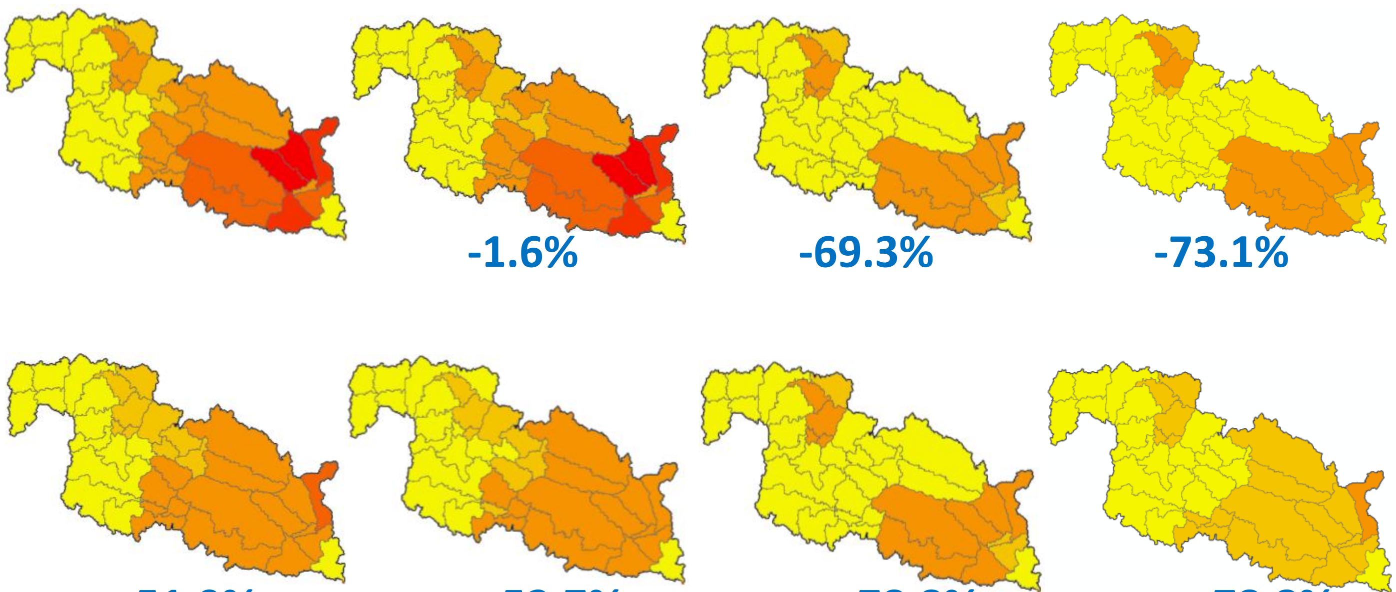
Historical Climate Model	BLU	BLU_RB	SWG	RH_CC_SWG
	Base landuse	Base Landuse + RB	LUC with SWG	Stover harvest + cover crop + LUC with SWG

Future Climate Model (WRF, RCP 8.5)	BLU_WRF	BLU_RB_WRF	SWG_WRF	RH_CC_SWG_WRF
	Base landuse	Base Landuse + RB	LUC with SWG	Stover harvest + cover crop + LUC with SWG

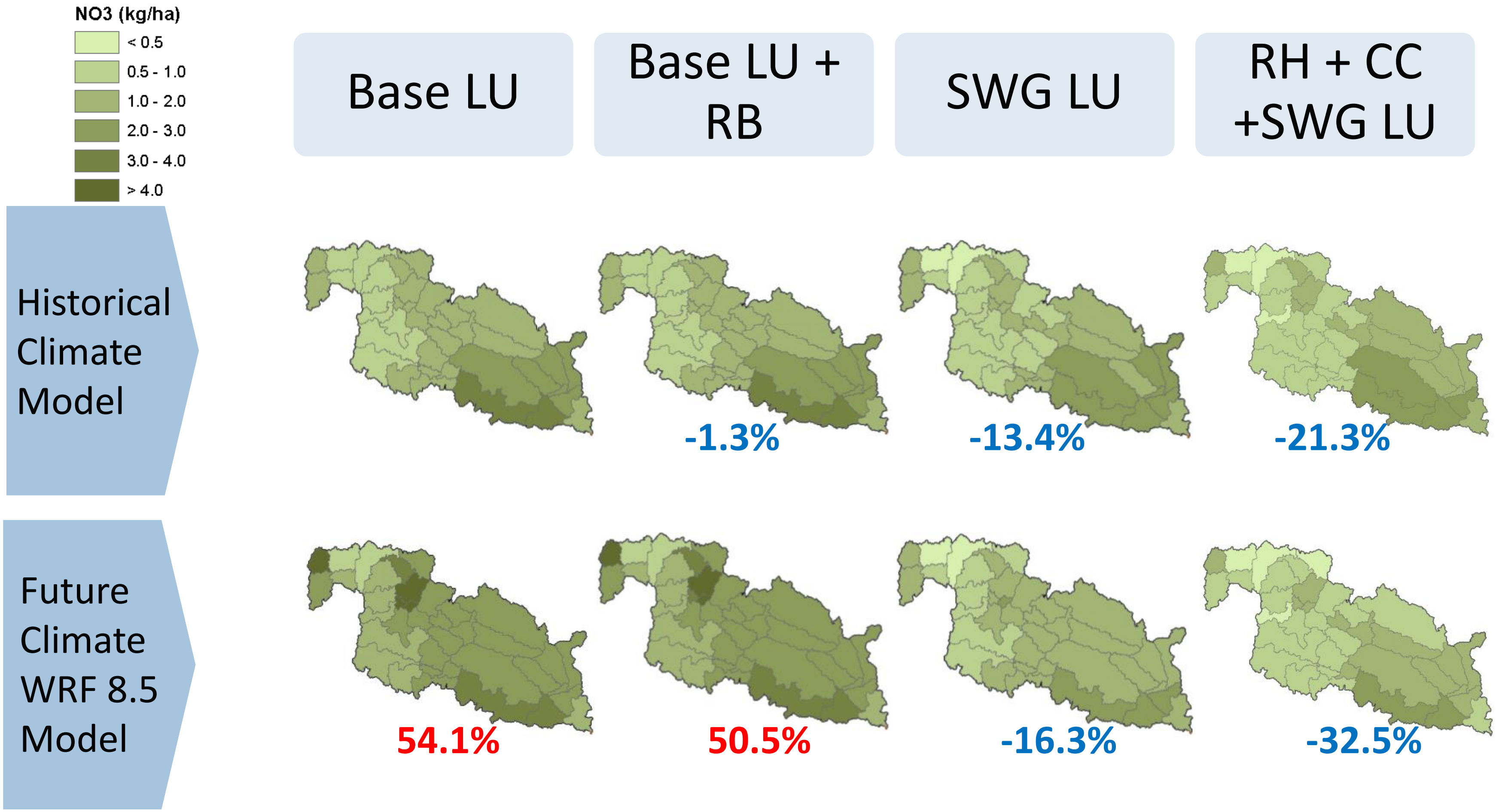
Change of Sediment Yield (t/ha) under various land use & climate scenarios



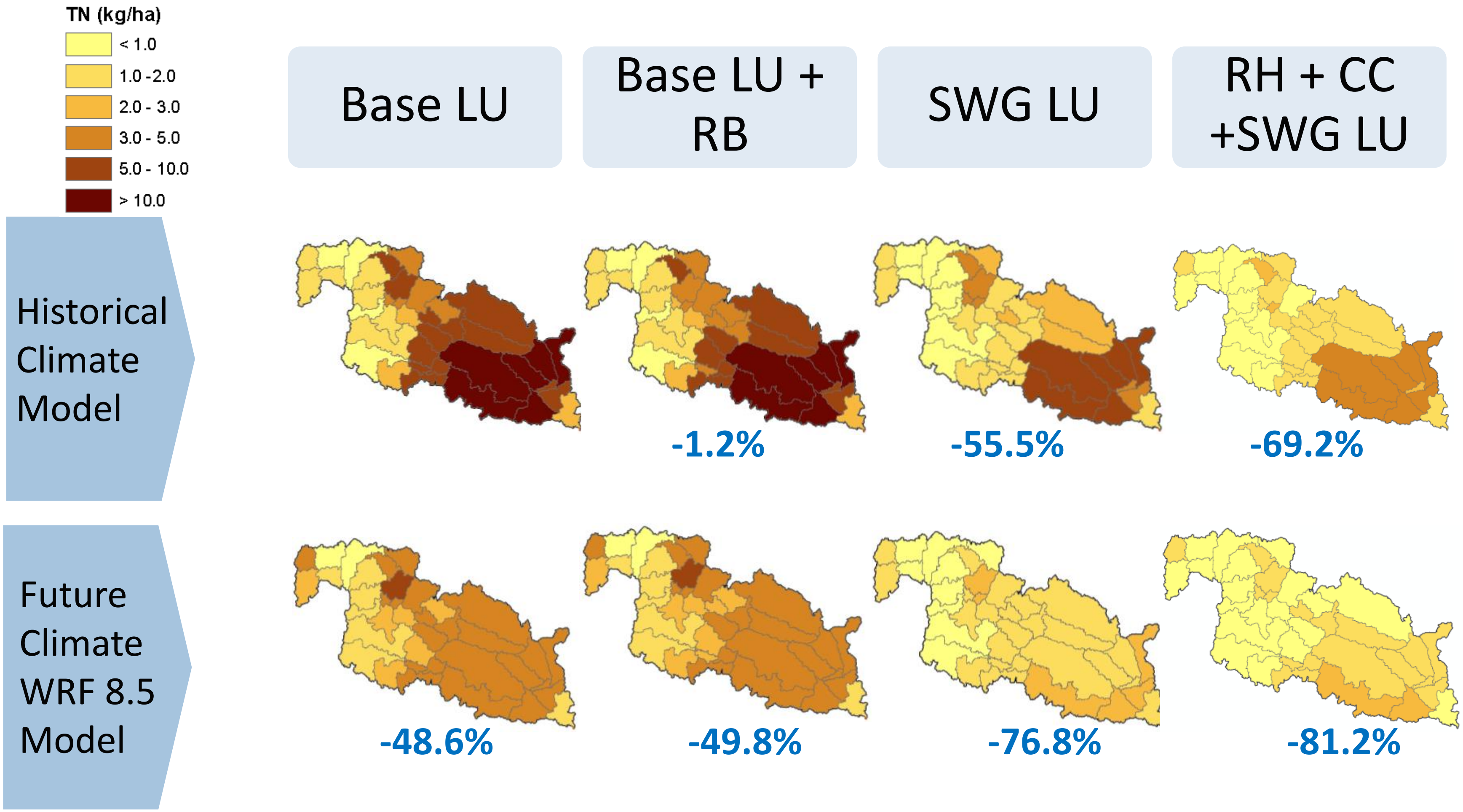
	Base LU	Base LU + RB	SWG LU	RH + CC +SWG LU
Historical Climate Model		-1.6%	-69.3%	-73.1%
Future Climate WRF 8.5 Model	-51.9%	-52.7%	-78.8%	-78.8%



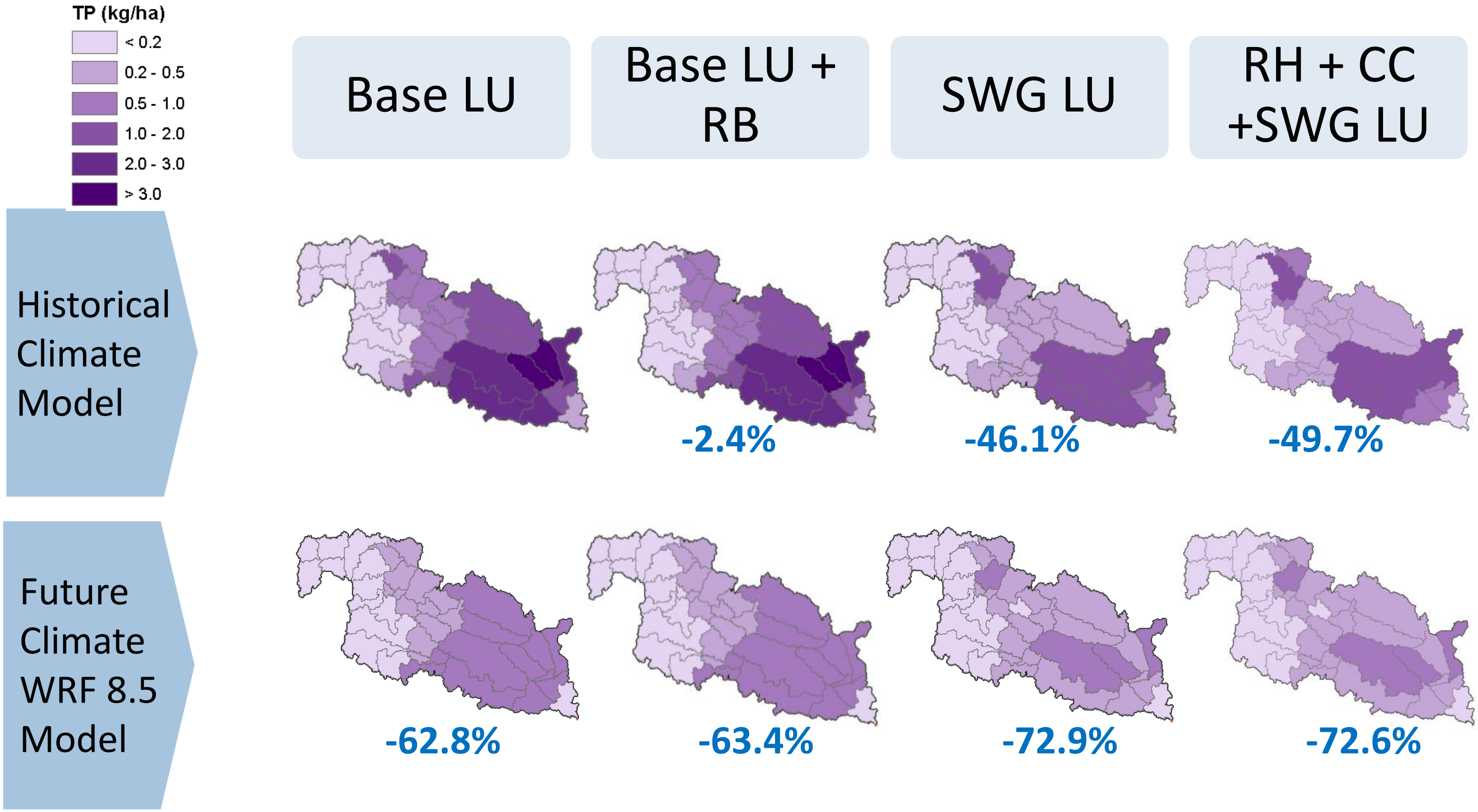
Change of nitrate loadings (kg/ha) under various land use & climate scenarios



Change of total nitrogen under various land use & climate scenarios



Change of total phosphorus under various land use & climate scenarios



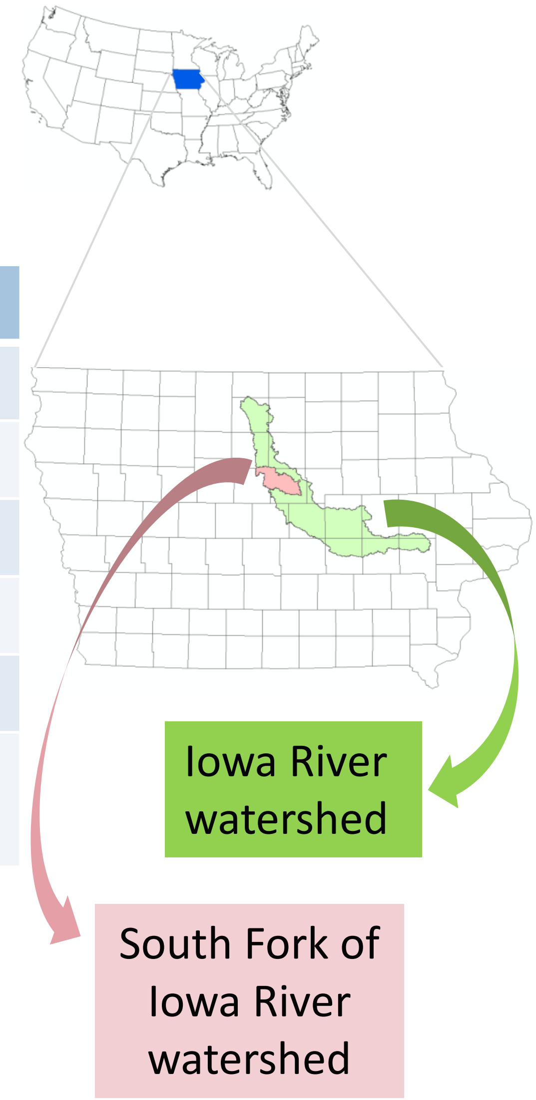
Concluding remarks

- Eight different scenarios with alternative land uses under current climate and future climate model were applied to calibrated hydrologic model to simulate flow, sediment, and water quality in the South Fork Iowa River watershed.
- Landscape design with switchgrass can effectively improve water quality, strengthen soil control, with minimal impact on water resource, while producing feedstock for bioenergy production.
- Under future climate scenarios, land converted to switchgrass shows significant improvement in sediment and nutrient loadings from current land use.
- Switchgrass – based bioenergy can provide a production system that is resilient to climate change scenarios investigated in this study.
- Best Management Practices (BMPs) such as riparian buffer strips and cover crop show positive effects on water quality and suspended sediment.
- Water quality benefits a proposed landscape design with switchgrass are greater than the effects of BMP applications.

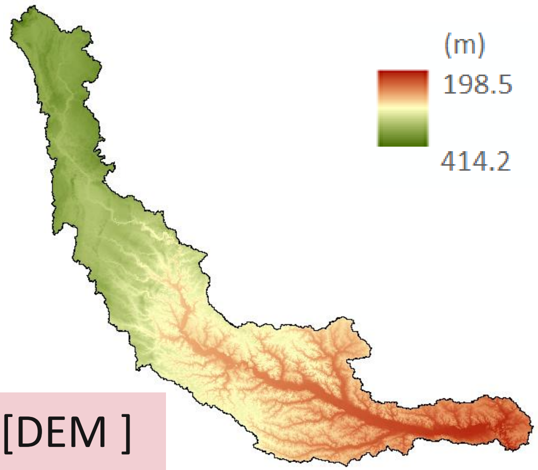
Ongoing project

	Iowa River watershed
Drainage area	8,061 km^2
Crop areas	63.5 %
Main crops	Corn and soybean
Tributaries	8-digit HUCs (Upper Iowa, Middle Iowa)
# of counties	16

- Historically, groundwater contamination is an issue because of nitrogen.

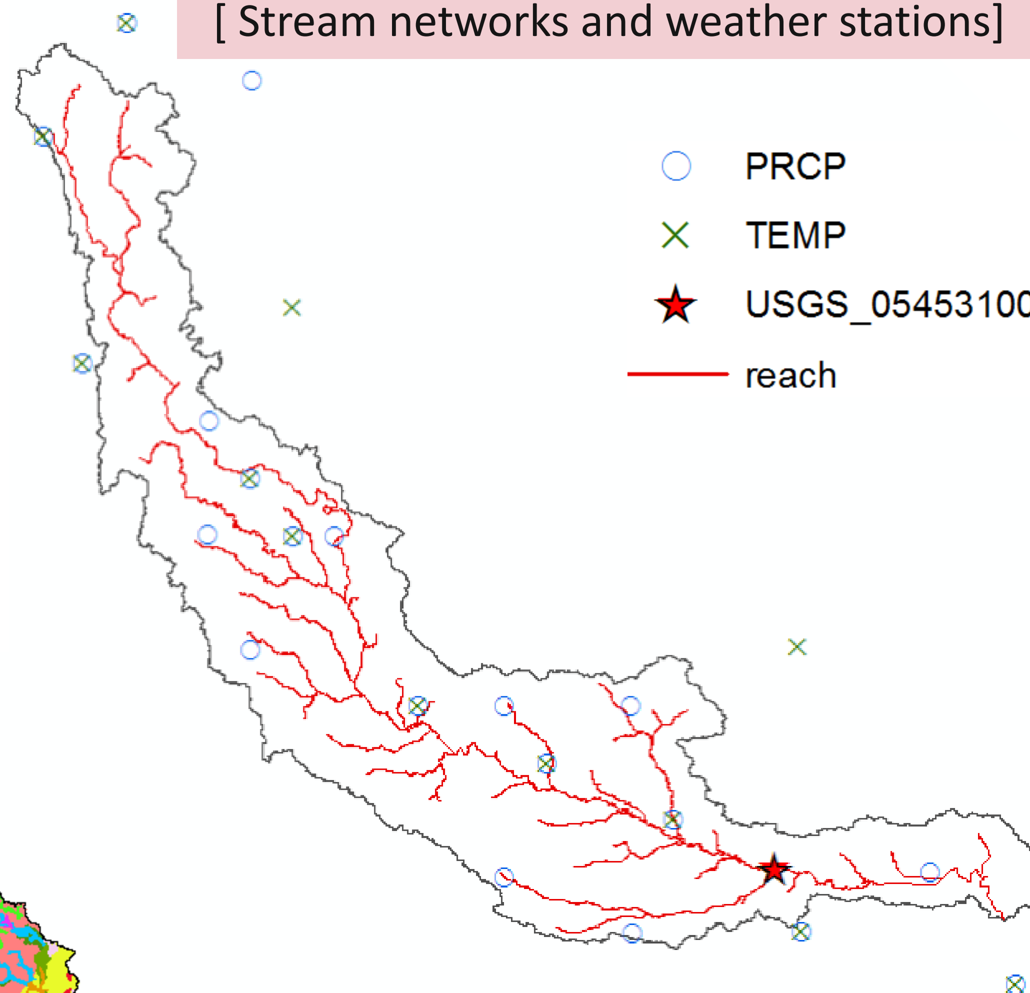


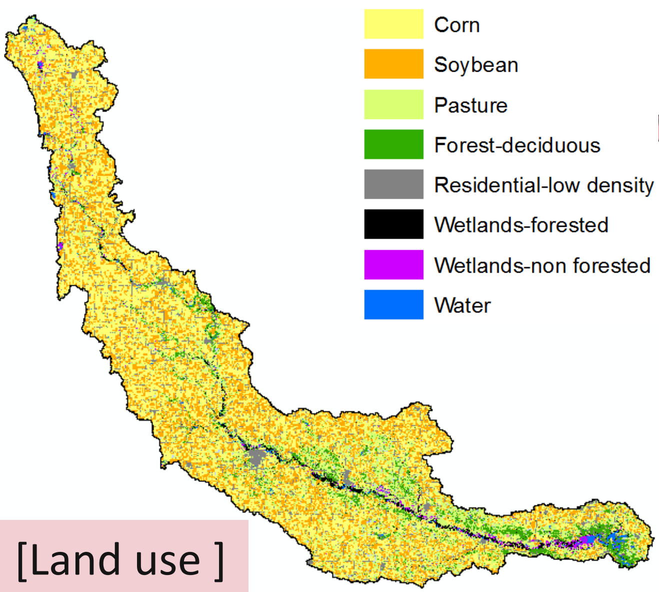
Iowa River Watershed



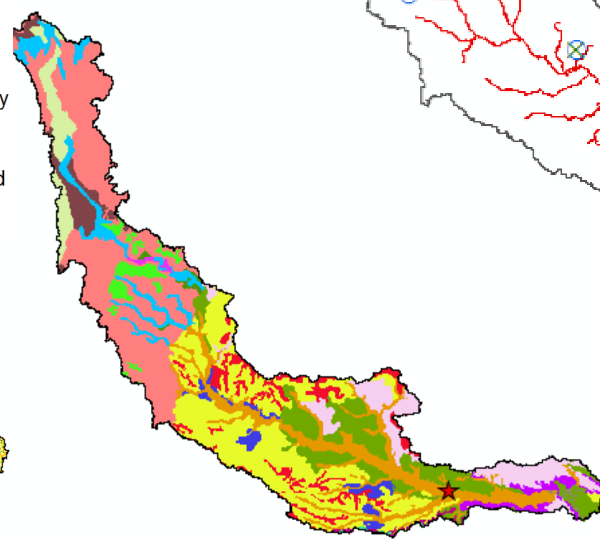
[DEM]

[Stream networks and weather stations]





[Land use]



[Soil – STATSGO]

Acknowledgement

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- Kara Cafferty, Ian Bonner, and Jacob Jacobson (Idaho National Laboratory) for developing the land use change scenario with economic and LEAF modeling.
- Climate modeling work was supported by Jia-Li Wang and V. R. Kotamarthi (Argonne National Laboratory).

Thank you !