Application of improved SWAT model for bioenergy production scenarios in Indiana Watersheds

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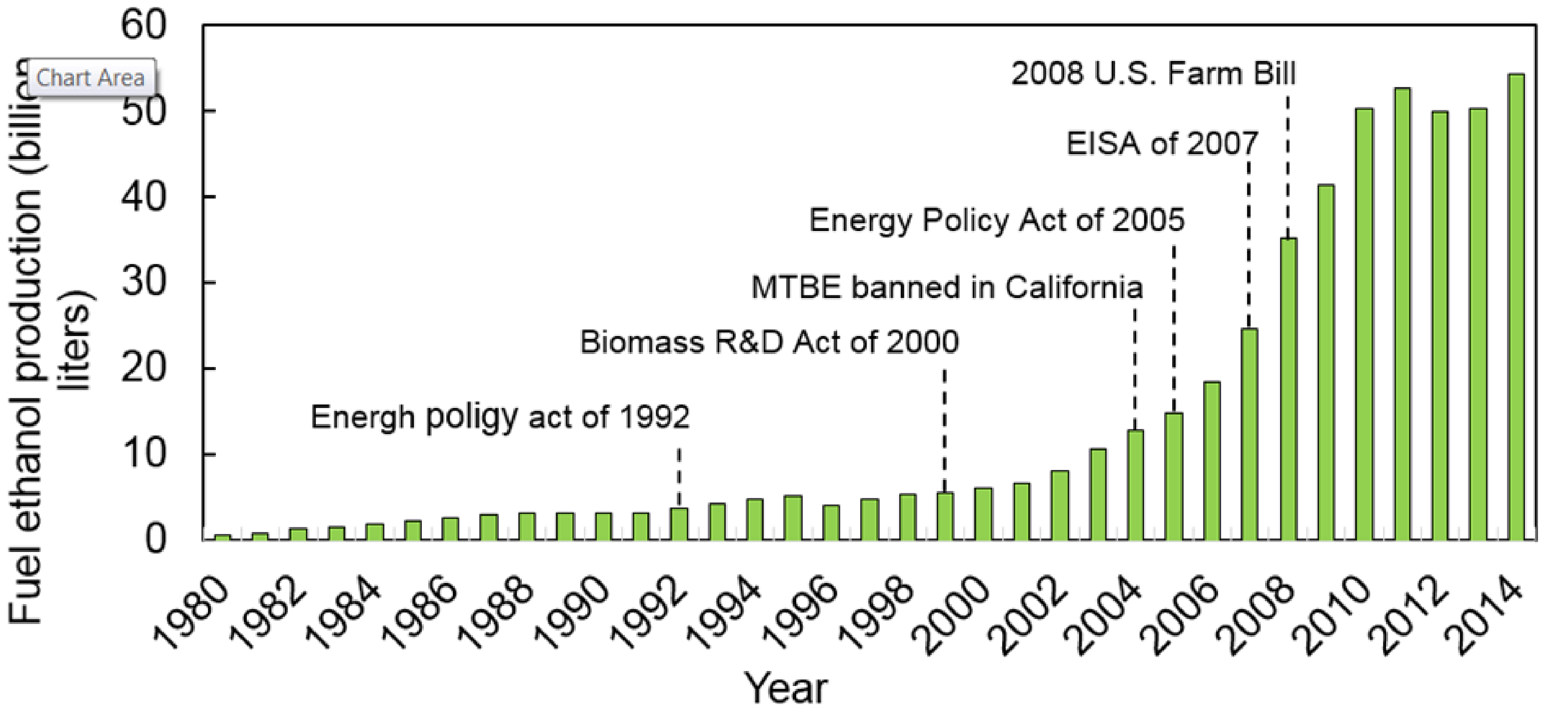
Introduction

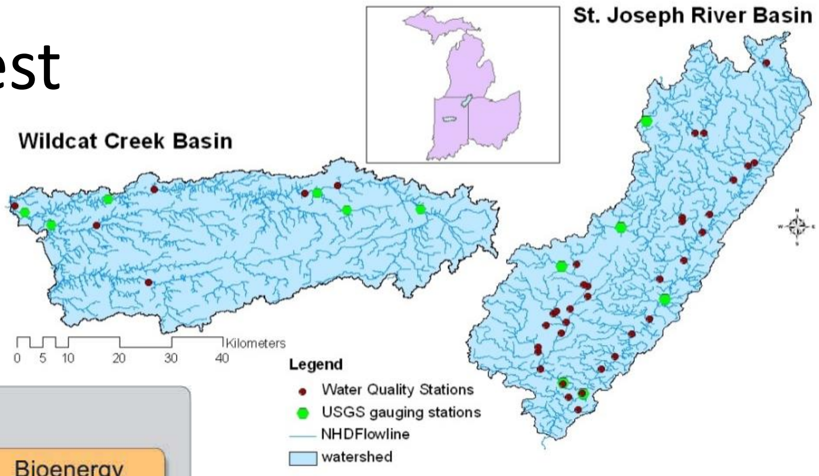
- Energy Independence and Security Act(EISA) of 2007
  - Renewable Fuels Standard:

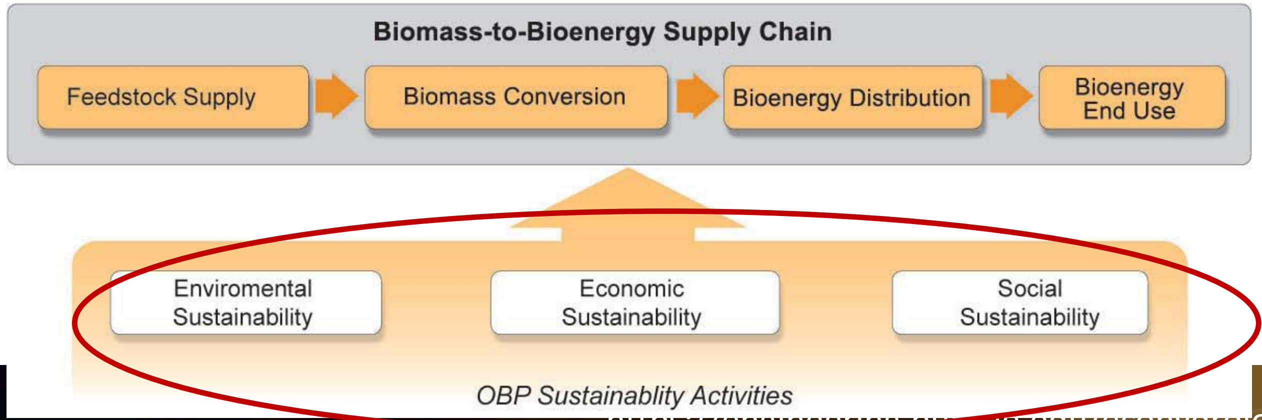
    136 billion liters of biofuel by 2022
  - Cellulosic ethanol and advanced biofuels: 79.5 billion liters

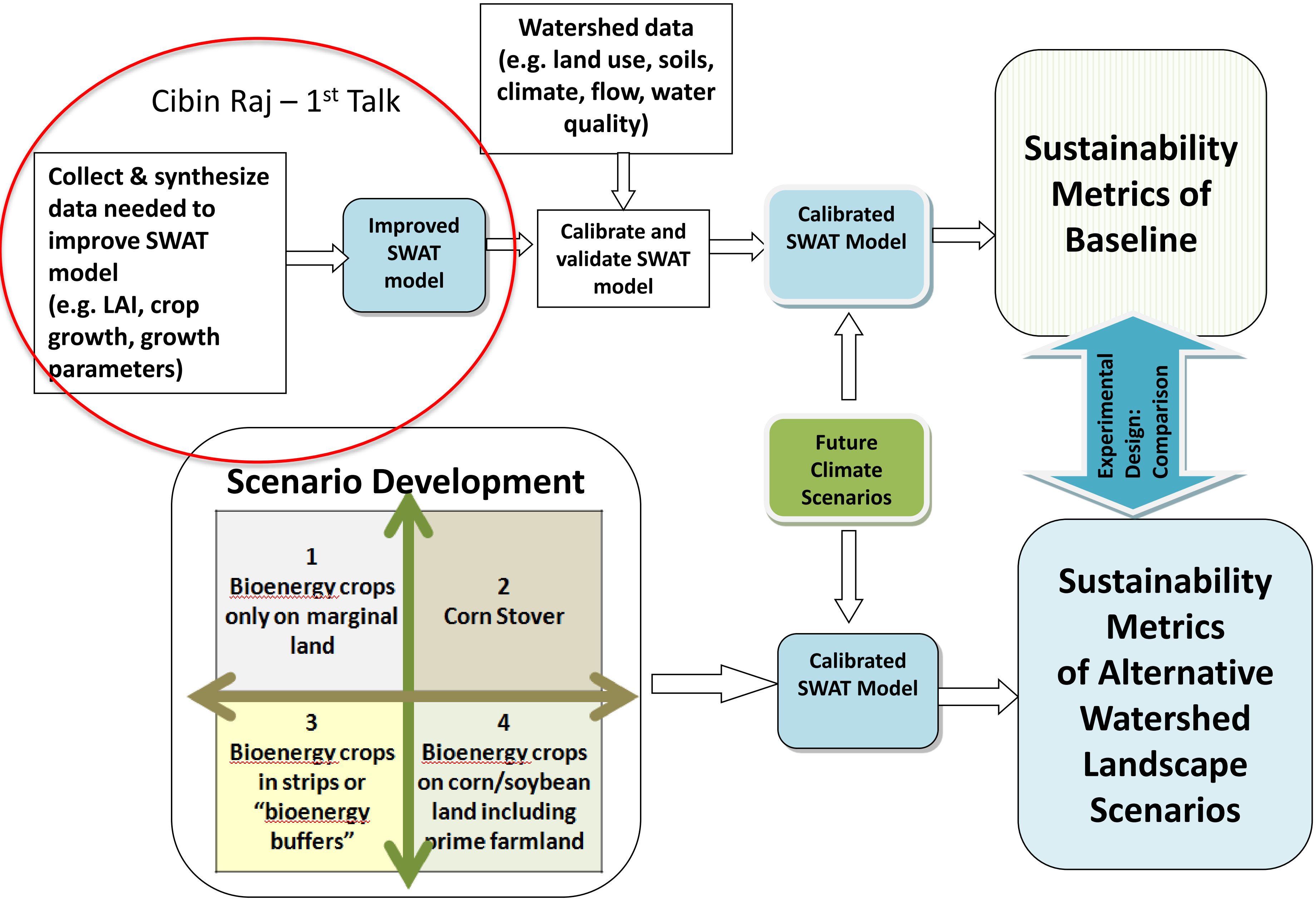


Project Goal

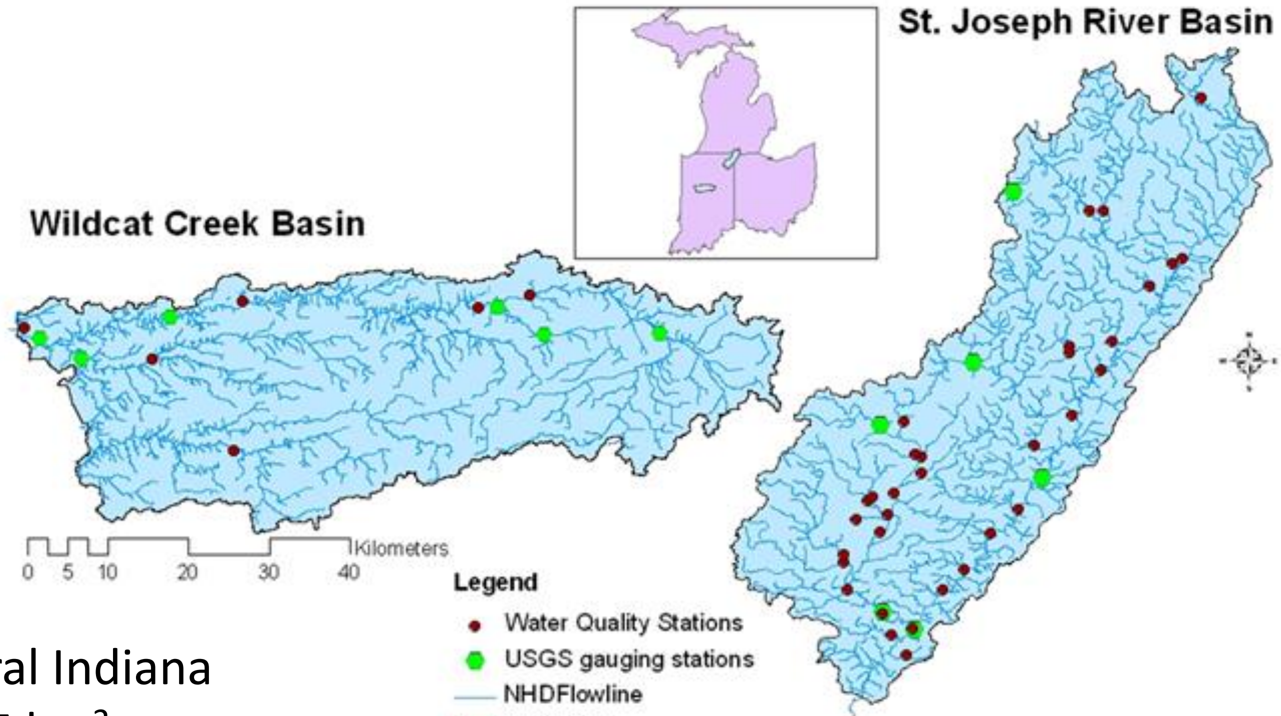
- Overall goal is to conduct a watershed-scale sustainability assessment of multiple energy crops and removal of crop residues
- Assessment conducted in two watersheds representative of Upper Midwest
  - Wildcat Creek watershed
  - St. Joseph River watershed






Cibin Raj – 1st Talk
Collect & synthesize data needed to improve SWAT model (e.g. LAI, crop growth, growth parameters)
Improved SWAT model
Watershed data (e.g. land use, soils, climate, flow, water quality)
Calibrate and validate SWAT model
Calibrated SWAT Model
Sustainability Metrics of Baseline
Experimental Design: Comparison
Future Climate Scenarios
Scenario Development
1 Bioenergy crops only on marginal land
2 Corn Stover
3 Bioenergy crops in strips or "bioenergy buffers"
4 Bioenergy crops on corn/soybean land including prime farmland
Calibrated SWAT Model
Sustainability Metrics of Alternative Watershed Landscape Scenarios

Study Watersheds



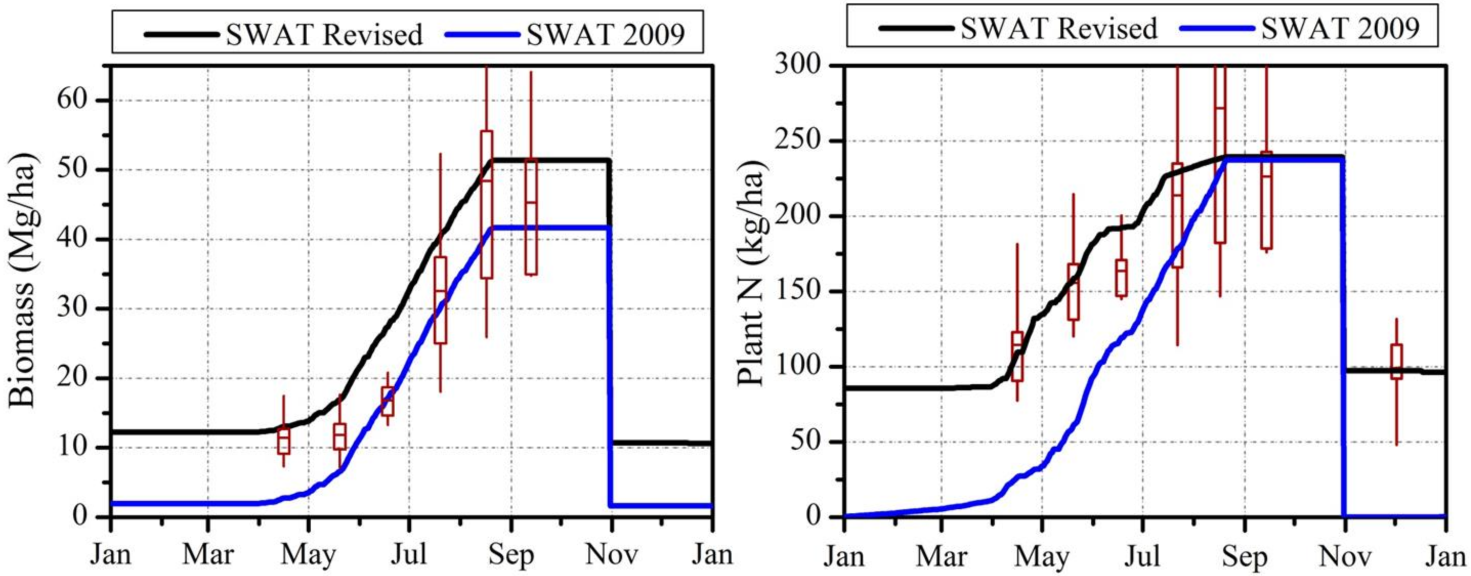
- North-Central Indiana
- Area – 2,045 km^2
- Agricultural watershed: 70% Corn /soyb

- North Indiana
- Area – 2,800 km^2
- Agricultural watershed: 37% Corn /soyb, 25% pasture

SWAT model development

1. Model developed using 30m DEM, NASS land use data, SSURGO soil data and NCDC weather data
2. Calibrated model for crop growth, stream flow and water quality: a minimal calibration using only basin level parameters
3. The crop/land management practices were identified with the extensive stakeholder discussions

Miscanthus growth simulation



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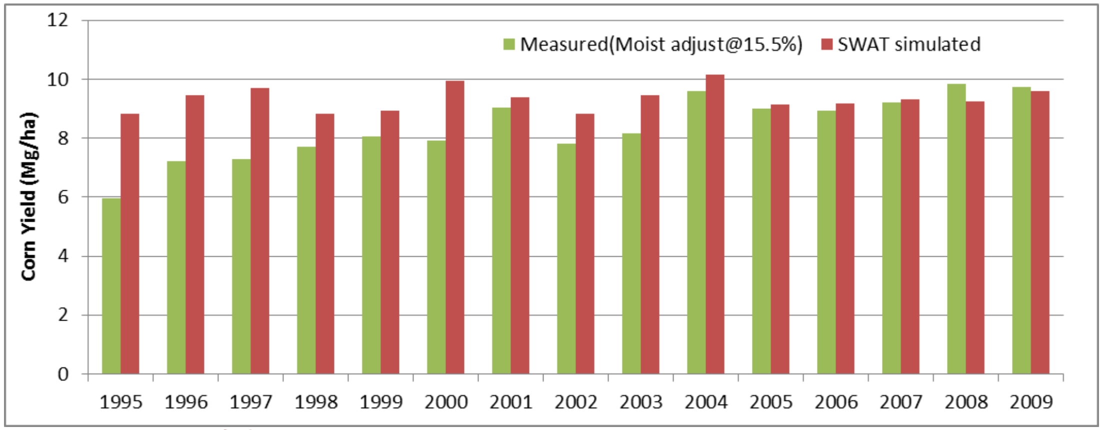
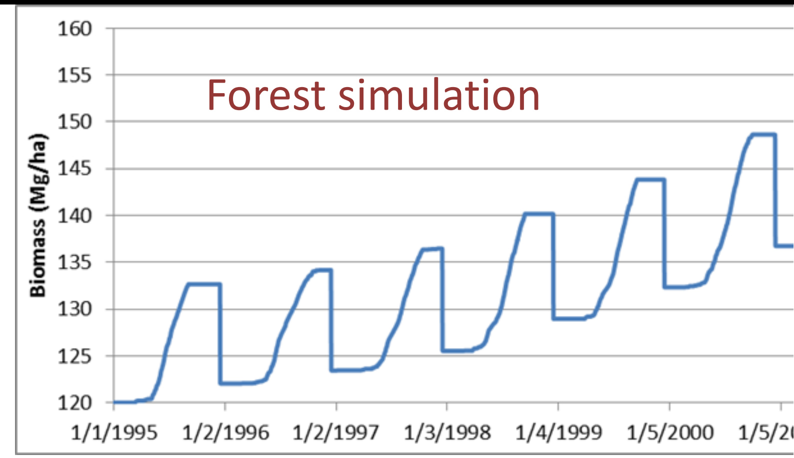
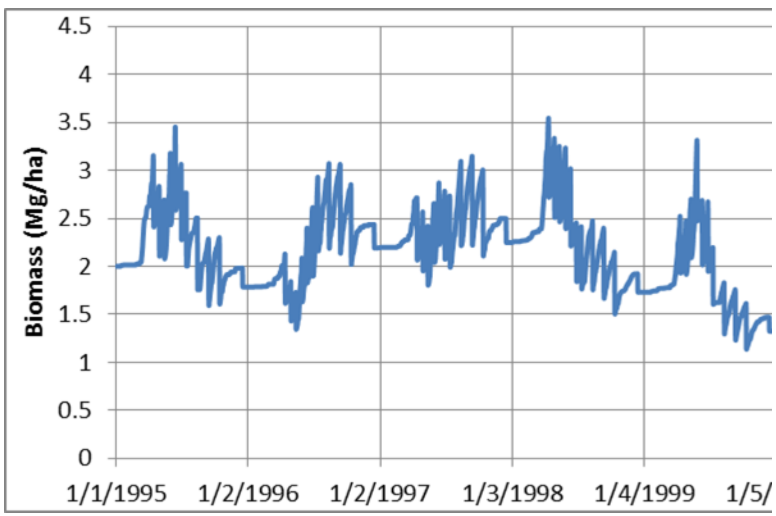
Crop growth and management

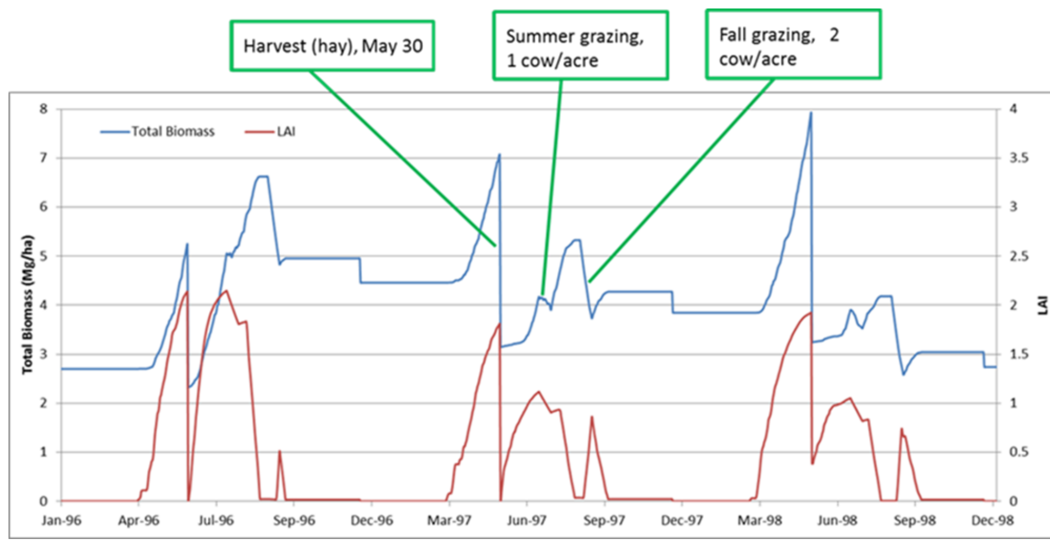


Corn yield



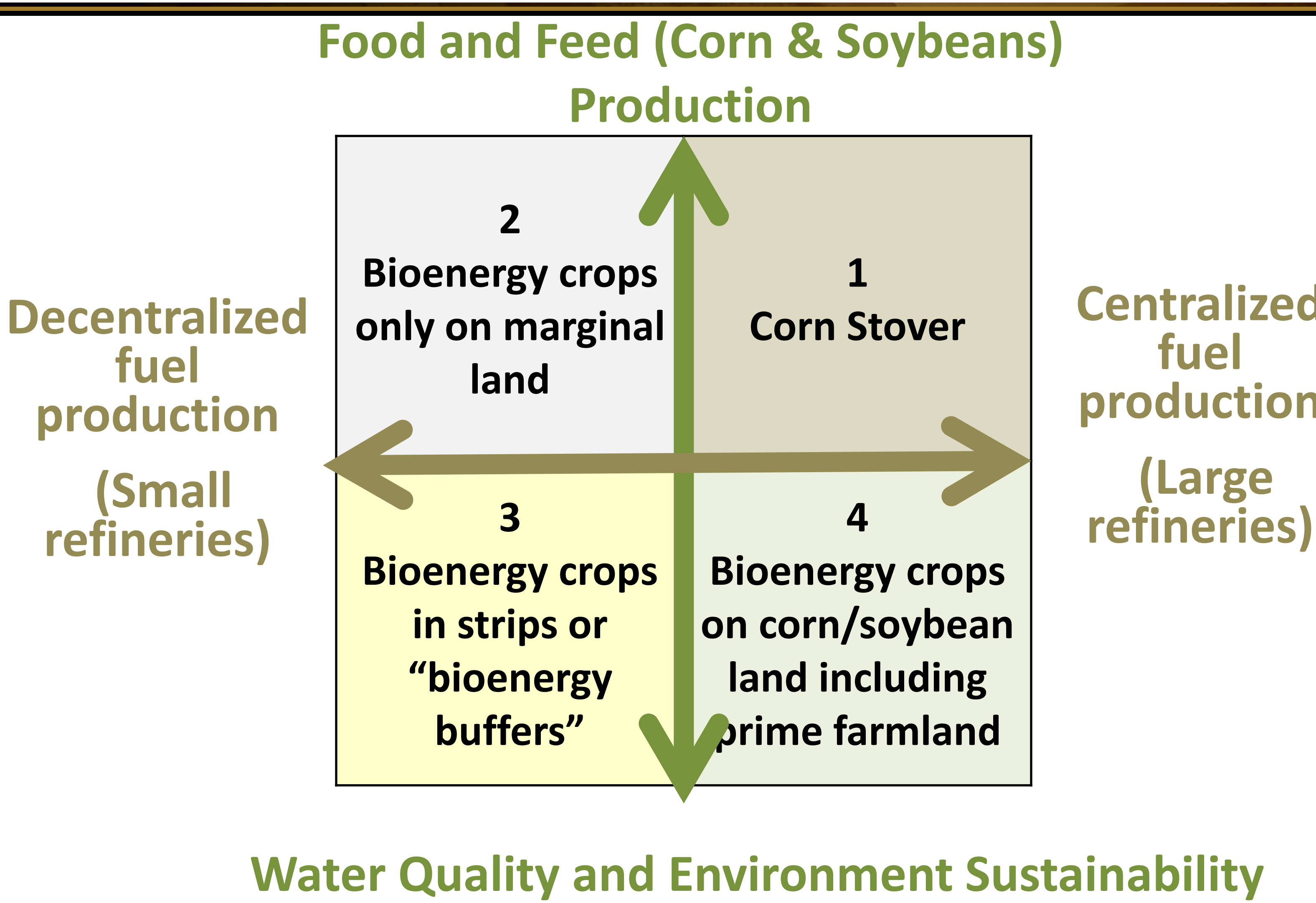


Kentucky bluegrass urban (lawns)



Tall Fescue Pasture

Bioenergy Scenario Development Principles



Bioenergy Scenarios

1. Corn stover removal– 20%, 30% and 50% (consistent with contracts that are emerging between farmers and cellulosic biorefineries), with and without nutrient replacement

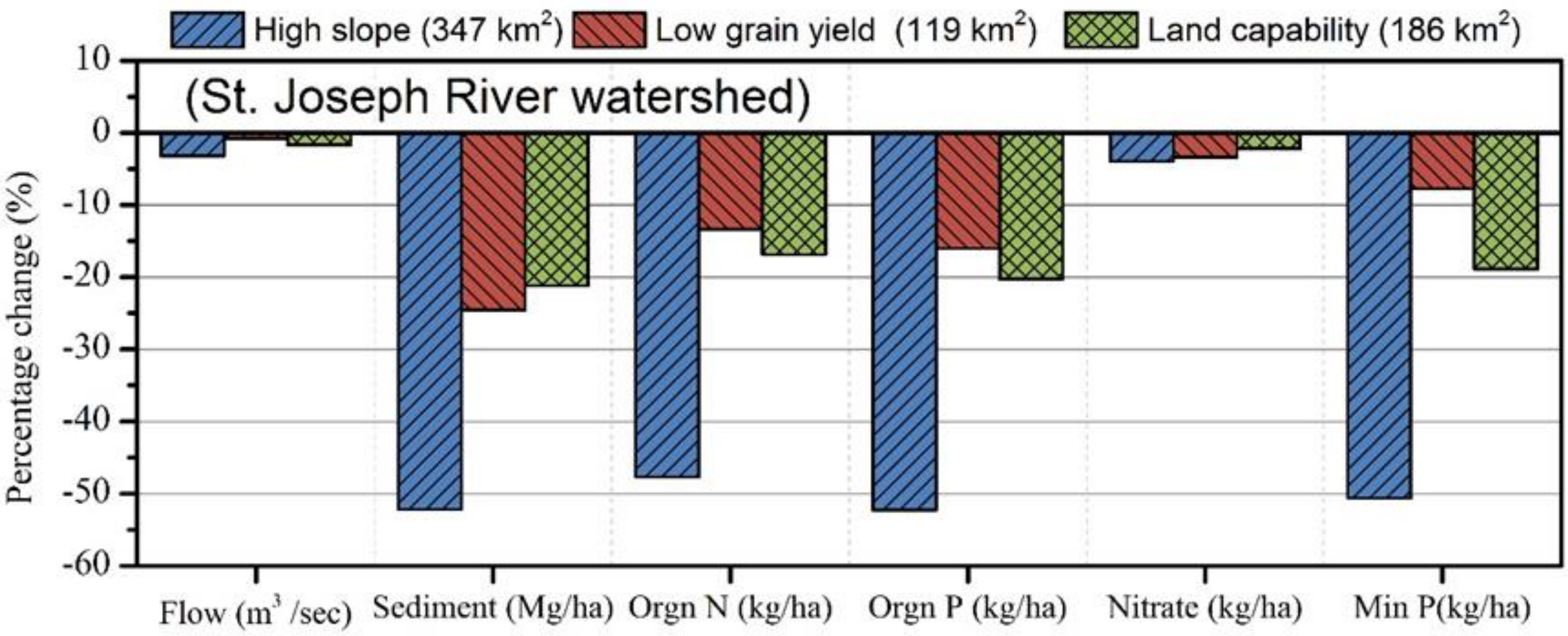
2. Perennial bioenergy crops on marginal lands – environmental (>2% slope), agricultural (low grain yield), land quality (LCC>2)

3. Perennial bioenergy crops in buffers around corn/soybean fields

4. Bioenergy crops in all agricultural areas
    - 100% of watershed
    - 50% of watershed, randomly selected
    - 50% of watershed, selected with plausibility criteria of marginal land, high slope area, pasture area, crop productivity, etc.

Bioenergy crops improve water quality

- Marginal Lands for bioenergy crops?



St Joseph River watershed

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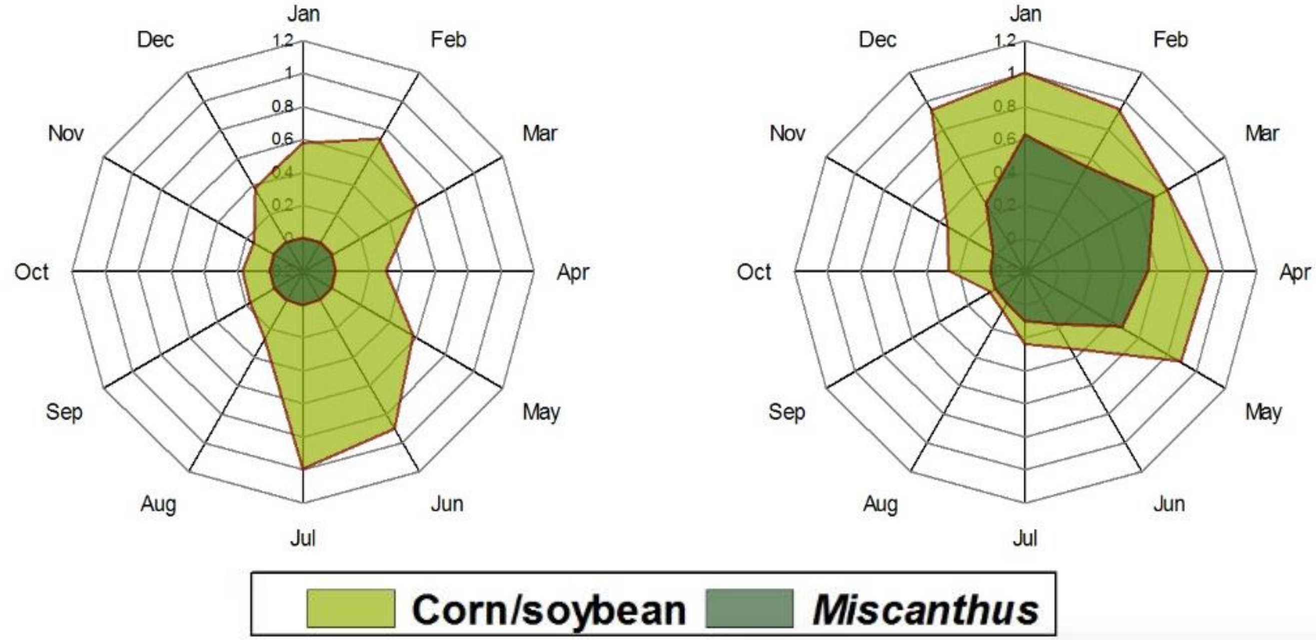
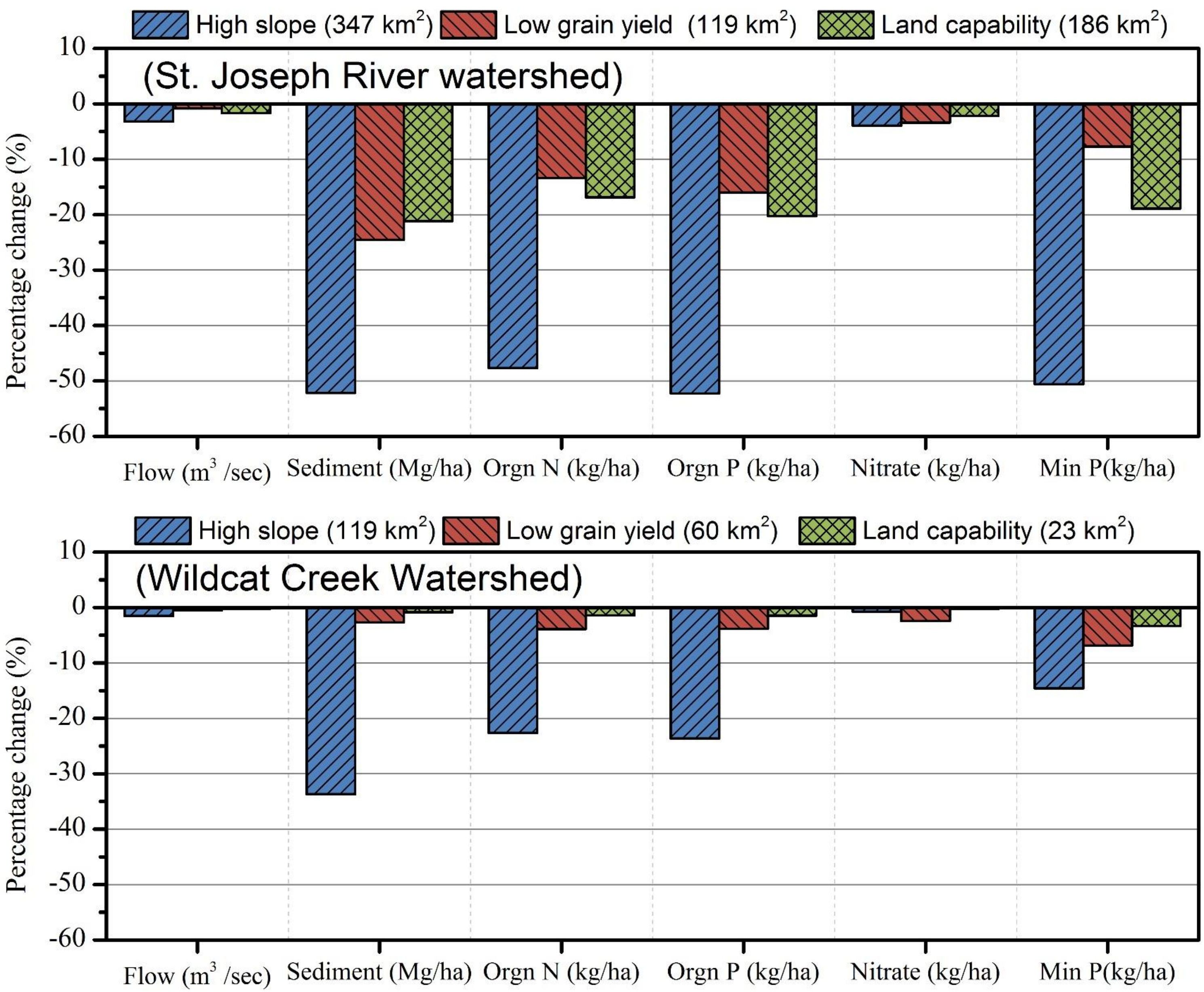
Bioenergy crops improve water quality

Erosion fraction **Nitrate loading fraction**



Impacts varied across watershed



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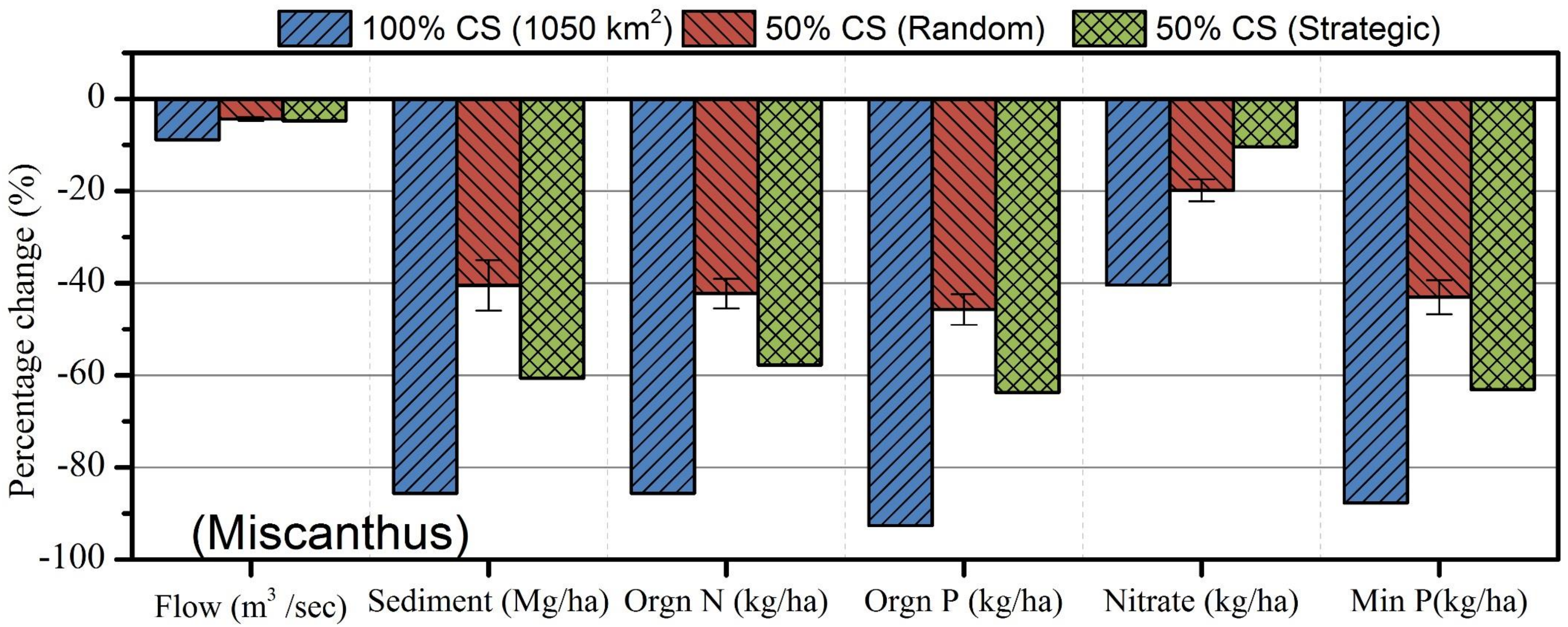
Bioenergy crops on prime farmland

St Joseph River watershed

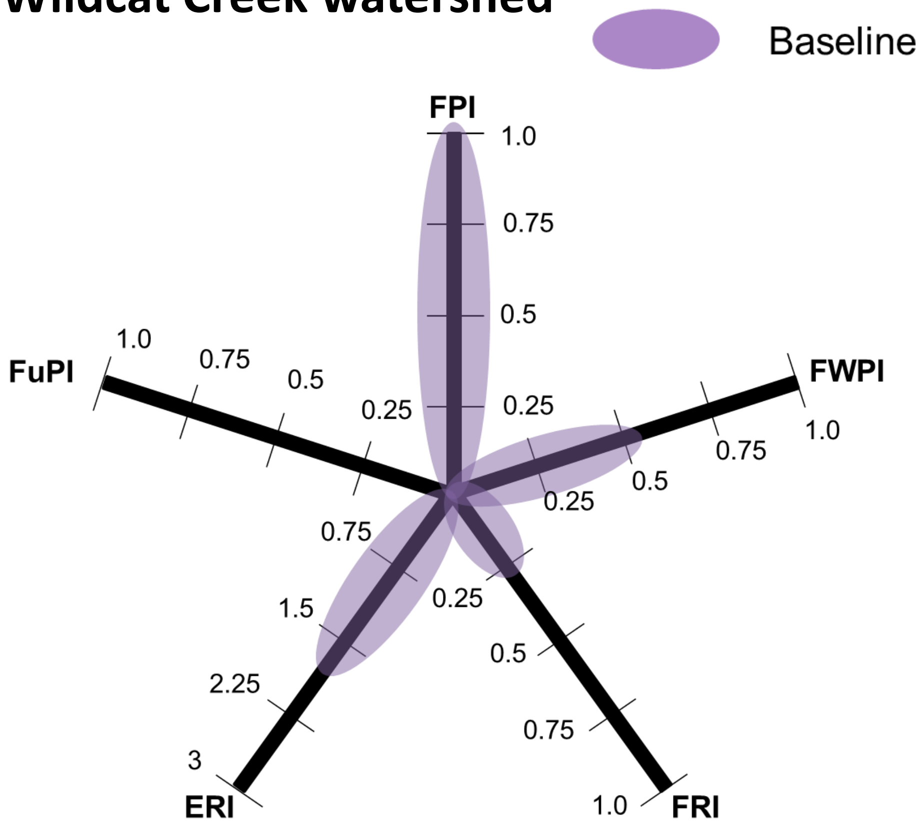


- Random and strategic selection: scope for optimal planning
- Strategic planning with one criteria may not be optimum for all water quality attributes

*Error bar for random selection scenario indicates the range of ensemble simulations from100 samples.

Bioenergy crops improve ecosystem services

Wildcat Creek watershed

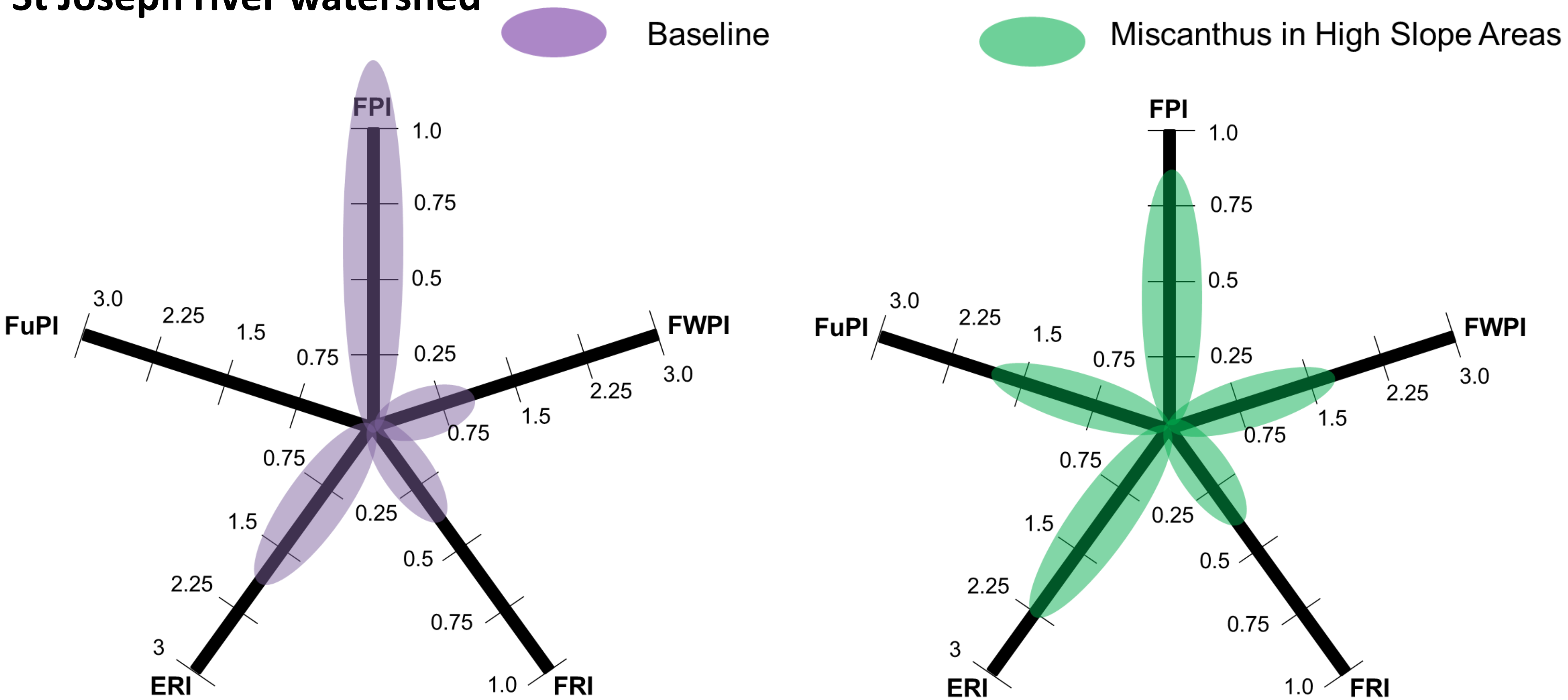


High slope area: 120 Km^2(8% of corn/soybean area and 6% of watershed area)

Fresh water provision (FWPI) , food (FPI) and fuel provision (FuPI), erosion regulation (ERI), and flood regulation (FRI)

Bioenergy crops improve ecosystem services

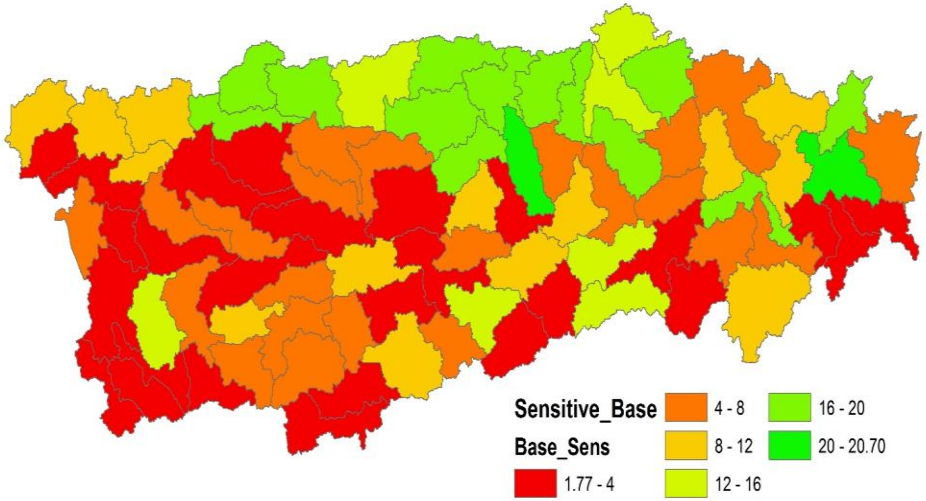
St Joseph river watershed



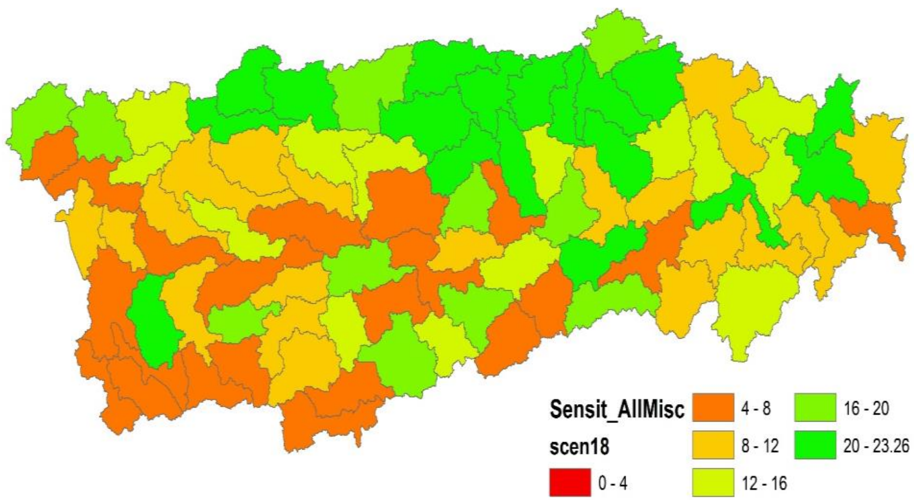
High slope area: 347 Km^2(33% of corn/soybean area and 12% of watershed area)

Fresh water provision (FWPI) , food (FPI) and fuel provision (FuPI), erosion regulation (ERI), and flood regulation (FRI)

Bioenergy crops improve fish species richness

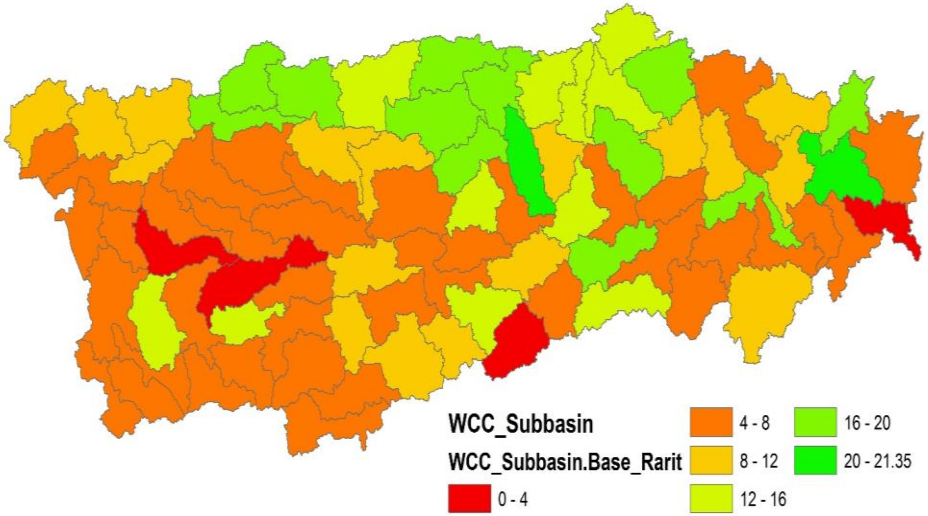


Baseline

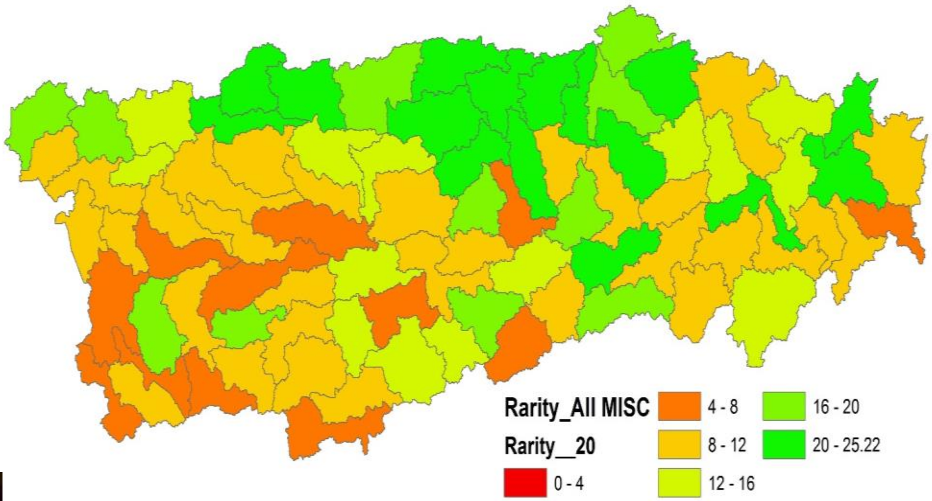


Miscanthus in all corn/soybean area

Bioenergy crops improve rarity weighted richness



Baseline



Miscanthus in all corn/soybean area

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Conclusions

- Average stream flow, annual peak flow and number of days over threshold reduced with all bioenergy scenarios
- Energy crop scenarios in general improved water quality with exceptions of stover removal that increased sediment load and switchgrass replacing pasture that increased nitrate load at watershed outlet
- Water quality benefits due to land use change is generally greater than the effects of climate change variability
- There is opportunity to maximize bioenergy crop benefits by optimum landscape planning
- Bioenergy crops in general improved ecosystem services

Additional Slides

Climate Projections

- Precipitation and temperature from **nine climate model simulations**: 3 models (GFDL CM2.0.1, UKMO HadCM3 3.1 and NCAR PCM 1.3) for each of three future emission scenarios (A1B, A2, B1)
- Bias corrected and statistically downscaled with resolution of 1/8^{o}
- climate data from 1950-2050: 10 years model warm up, **1960-1989(Past), 1990-2019 (present), and 2020-2049 (future)**

Accomplishment: Developed appropriate indicators of bioenergy crop impacts

Category	Indicator	Units	Indicator for
Soil erosion and its impact on long-term productivity	Erosion	Mg/ha/year	Soil loss
	Total nitrogen	Kg-N/ha	Soil productivity
	Extractable Phosphorus	Kg-P/ha	Soil productivity
Water Quantity	Annual maxima	m^3/sec	High flow
	Runoff index	-	Stream flow
	Richards-Baker Flashiness Index	-	Variability
	7 day average low flow for year	m^3/sec	Low flow
	Water Stress Index (WSI)		Water use
Water Quality	Sediment load or sediment concentration	Mg/ha/year or mg/L	Suspended sediment
	Nitrate and total nitrogen	Kg-N/ha	Nitrogen loading
	Organic phosphorus and total phosphorus	Kg-P/ha	Phosphorus loading
Biomass and crop production	Total biomass and harvested yield	t/ha	crop production
Profitability	Break-even feedstock price	$	
Aquatic Biodiversity			

Establish baseline scenario – Future climate

- Future climate was simulated with 9 climate model simulations:
- 3 models
  - GFDL CM2.0.1,
  - UKMO HadCM3 3.1
  - NCAR PCM 1.3

for each of

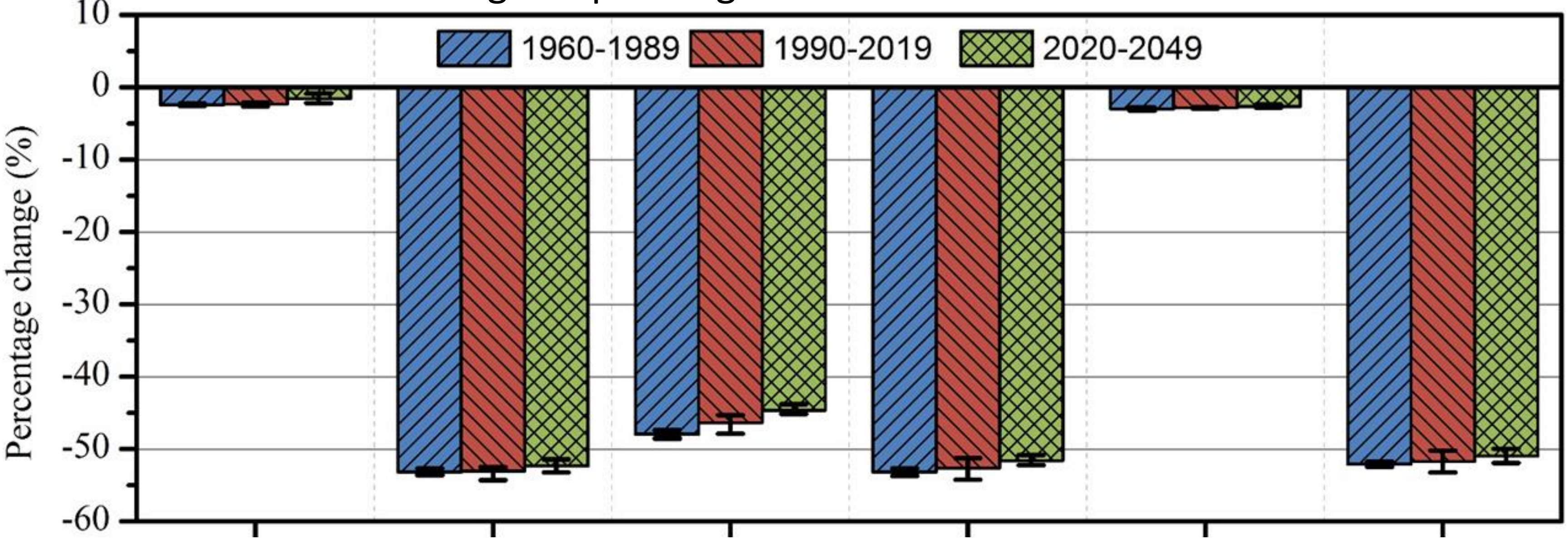
- 3 future emission scenarios (A1B, A2, B1)

	Unit	1960-1989	1990-2019	2020-2049
Erosion	Mg/ha	1.91	2.13	2.23
Final Org N (Init=13140)	kg/ha	12052	11345	10684
Final Nitrate (Init=64)	kg/ha	80	100	116
Final Org P (Init=1610)	kg/ha	1458	1363	1275
Final Min P (Init=287)	kg/ha	643	912	1187
Avg of Annual Peak flow	m^3/sec	185	201	198
Days over threshold	Days >300 m3/sec	3.9	6.6	8.3
Runoff Index	-	0.537	0.519	0.516
R-B Index	-	0.215	0.208	0.208
7day Avg low flow	-	0.039	0.095	0.11
Water Stress index	-	0.594	0.573	0.585
Sediment load (outlet)	Mg/ha	0.83	0.94	0.98
Nitrate load (outlet)	kg/ha	12.5	14.6	14.9
TN load (outlet)	kg/ha	18.9	21.0	20.9
Org P load (outlet)	kg/ha	1.1	1.4	1.5
TP load (outlet)	kg/ha	1.4	1.7	1.9

Sustainablility indicators of the baseline scenario with GCM data for three 30-year simulations; average values from 9 GCM model simulations are provided

Environmental impacts of energy crop scenarios with climate change

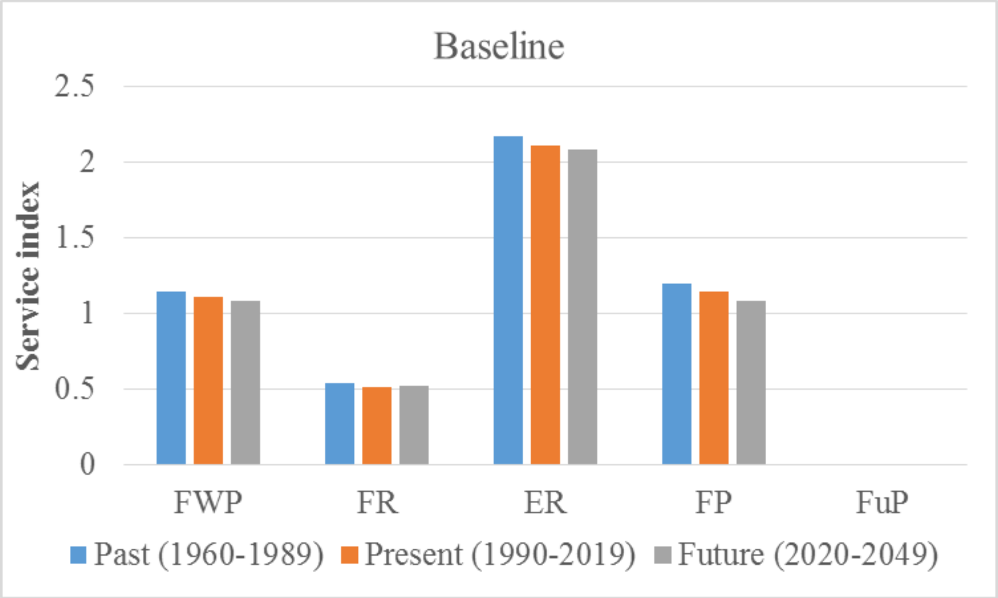
Miscanthus in high slope marginal land- SJR

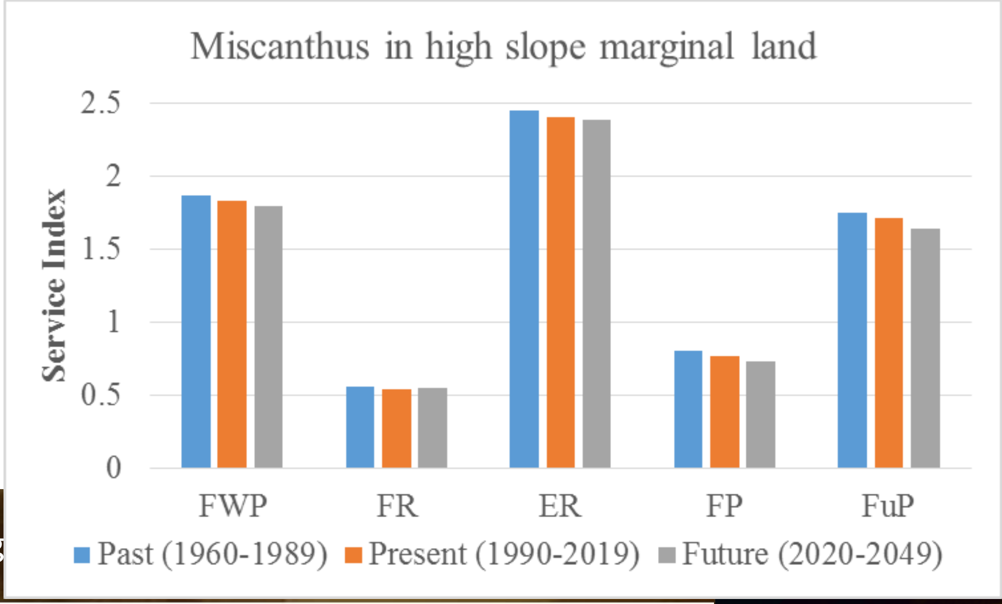


Flow (m^3/s) | Sediment (Mg/ha) | Org N (kg/ha) | Org P (kg/ha) | Nitrate-N (kg/ha) | Min P (kg/ha)

- Results that are similar under all climate periods and GCMs (error bars) show that water quality benefits due to **land use change** is generally greater than the effects of **climate change variability.**

Climate change + biofuel scenarios





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