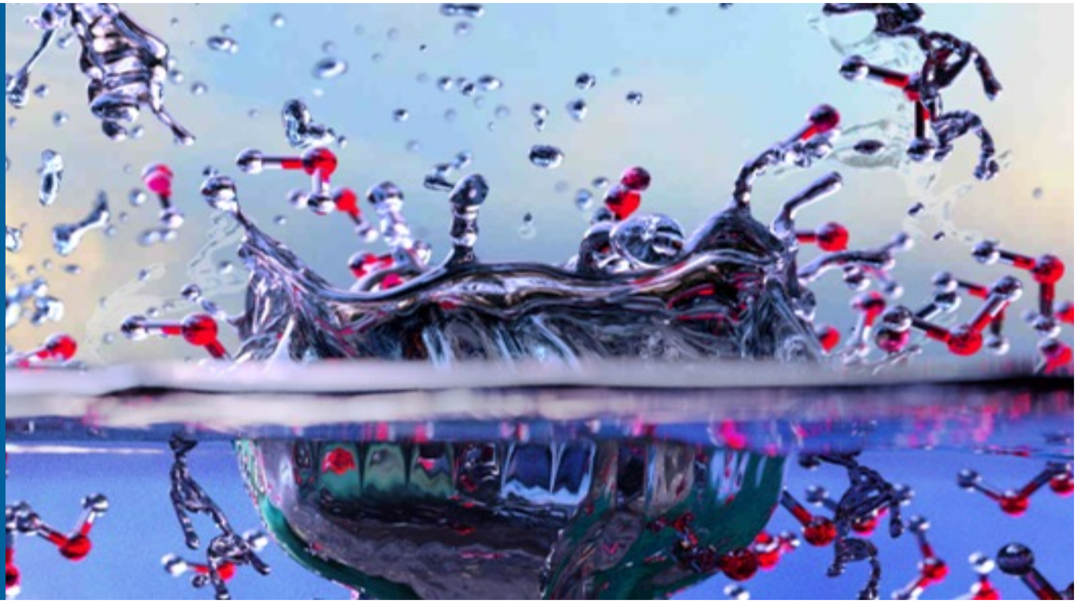
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
BIOENERGY TECHNOLOGIES OFFICE

Argonne NATIONAL LABORATORY

BIOENERGY TECHNOLOGIES OFFICE FY23 PEER REVIEW

Water Resource Management for Bioenergy and Bioproducts



May Wu
Argonne National Laboratory

DMA
April 7, 2023

PROJECT OVERVIEW

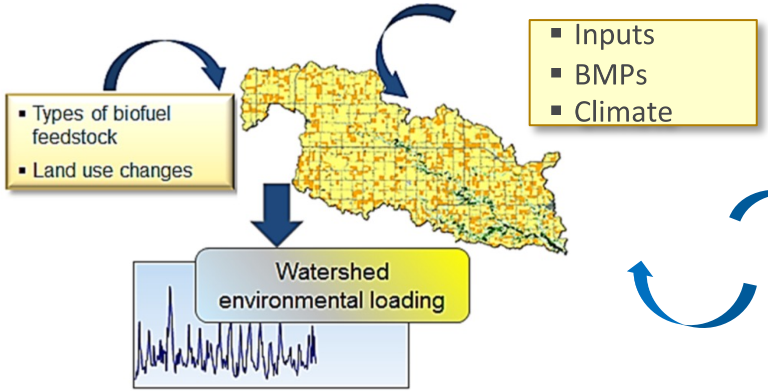
Research Question: How can we produce bioenergy in a manner that lowers impacts on regional water stress and water quality?

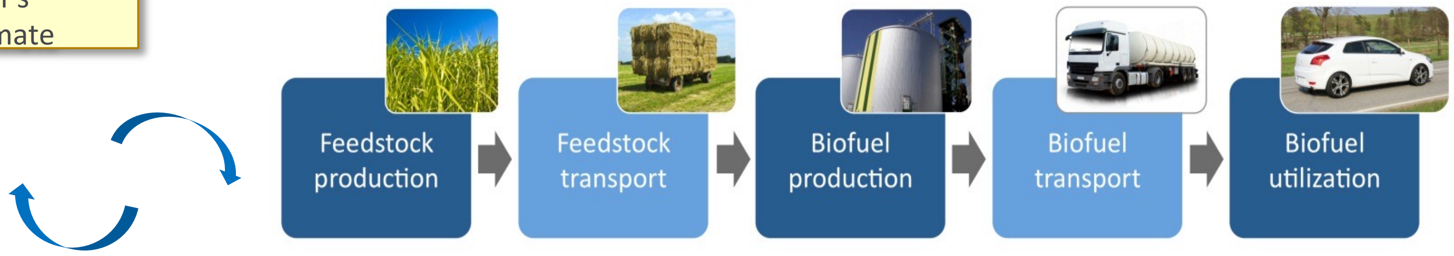
Goals: Deep understanding of water-land-feedstock-technology interactions to inform policy and strategy development toward a water-sustainable bio-economy.

Project Objectives

This project develops analyses and modeling tools to quantify the benefits and impacts of feedstock and production pathways on water resources and carbon trade-offs, and factor in non-traditional water resources to reduce the freshwater footprint of decarbonization technology deployment.

Water Use, Water Resource, and Water Quality





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APPROACH

- **Water Reuse**

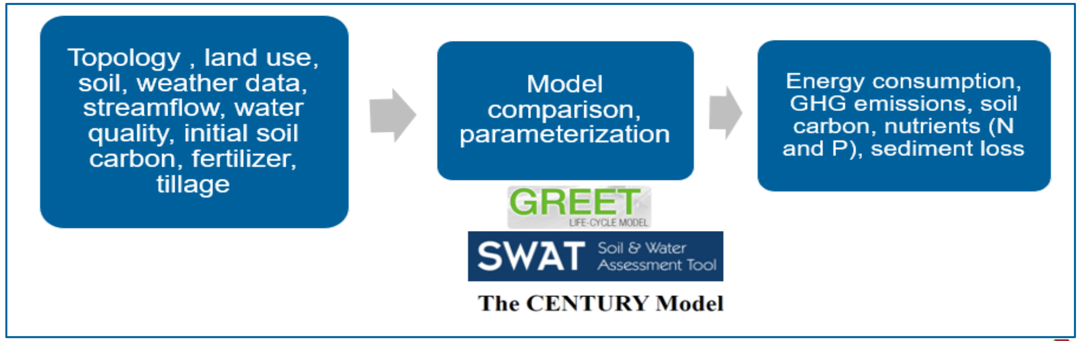
Survey current practices, identify challenges, and estimate the potential of adopting reclaimed municipal water resources for biofuel production.

- **Watershed LCA**

Integrated modeling and analysis to characterize interactions of carbon, nitrogen, phosphorus, and sediments in feedstock production with conservation practices for optimum environmental benefits.

Output

- **Water Reuse Potential** – Analysis of using reclaimed water for bioenergy at the county level to lower biofuel water footprint; a data inventory of current volume, reuse, regulation, and availability; and issues.
- **SWAT − C** – Hydrologic models characterize soil carbon, N_2O emissions, nutrients, and flow in feedstock production for LCA at the watershed scale.
- **WATER** – Spatial-explicit model with regional water resource platform and production stage water footprint for bioenergy; freshwater and reclaimed water database.



Key Features

- Use of traditional and non-traditional water resources for bioenergy.
- Platform to address nutrient, carbon, hydrology, and climate with geospatial resolution.

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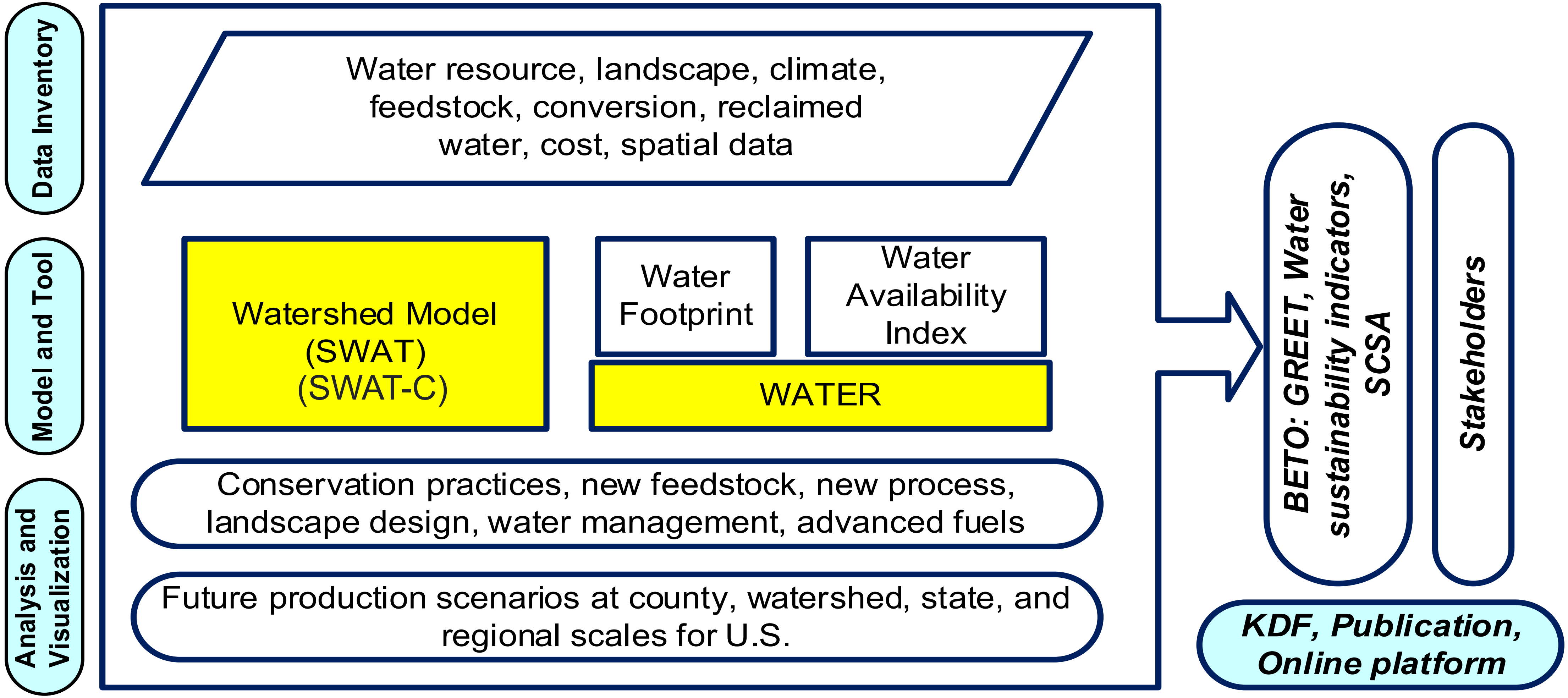
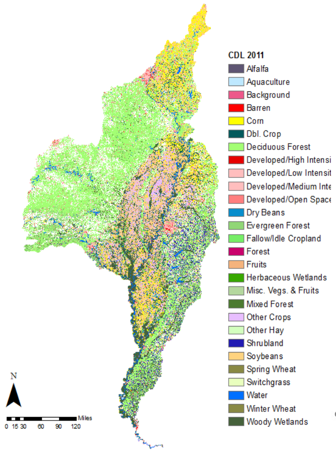
APPROACH

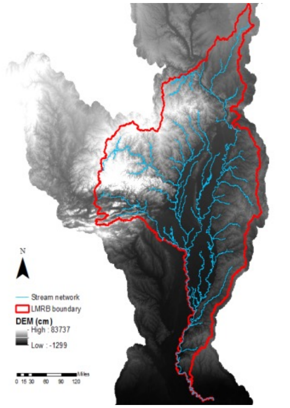
Analysis Framework *Data-driven, science-based, multi-scale*



Land, Feedstock, Water Resource, and Climate in a Single Framework

APPROACH: MODELS AND TOOLS



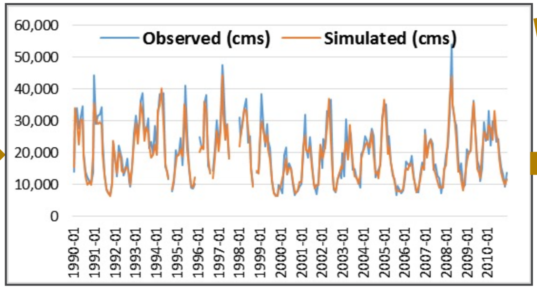


Model setup

Land use, climate, carbon, CH4, and N_2O flux, stream network, soil, crop management, geospatial datasets

Hydrologic Model
SWAT, SWAT-C

Model calibration



Simulation

- Landscape design
- Feedstock production
- Climate

Conservation practices

Carbon, Nitrogen, Phosphorus
Sediments, Flow

Analysis of ecosystem and economic value

Farming community

Drinking water supply

Watershed LCA

- SWAT modeling capability has been developed with the support of BETO to address water quality issues.
- Recently developed capability SWAT-C includes carbon cycles in addition to nitrogen, phosphorous, and hydrologic cycles with 70-80% newly incorporated coding, and was validated by field soil data from four midwestern watersheds.
- The new feature is capable of simulating soil organic carbon, and carbon flux for various land use and land covers at the watershed scale, and in-stream water quality.
- Beta testing in collaboration with SWAT team.

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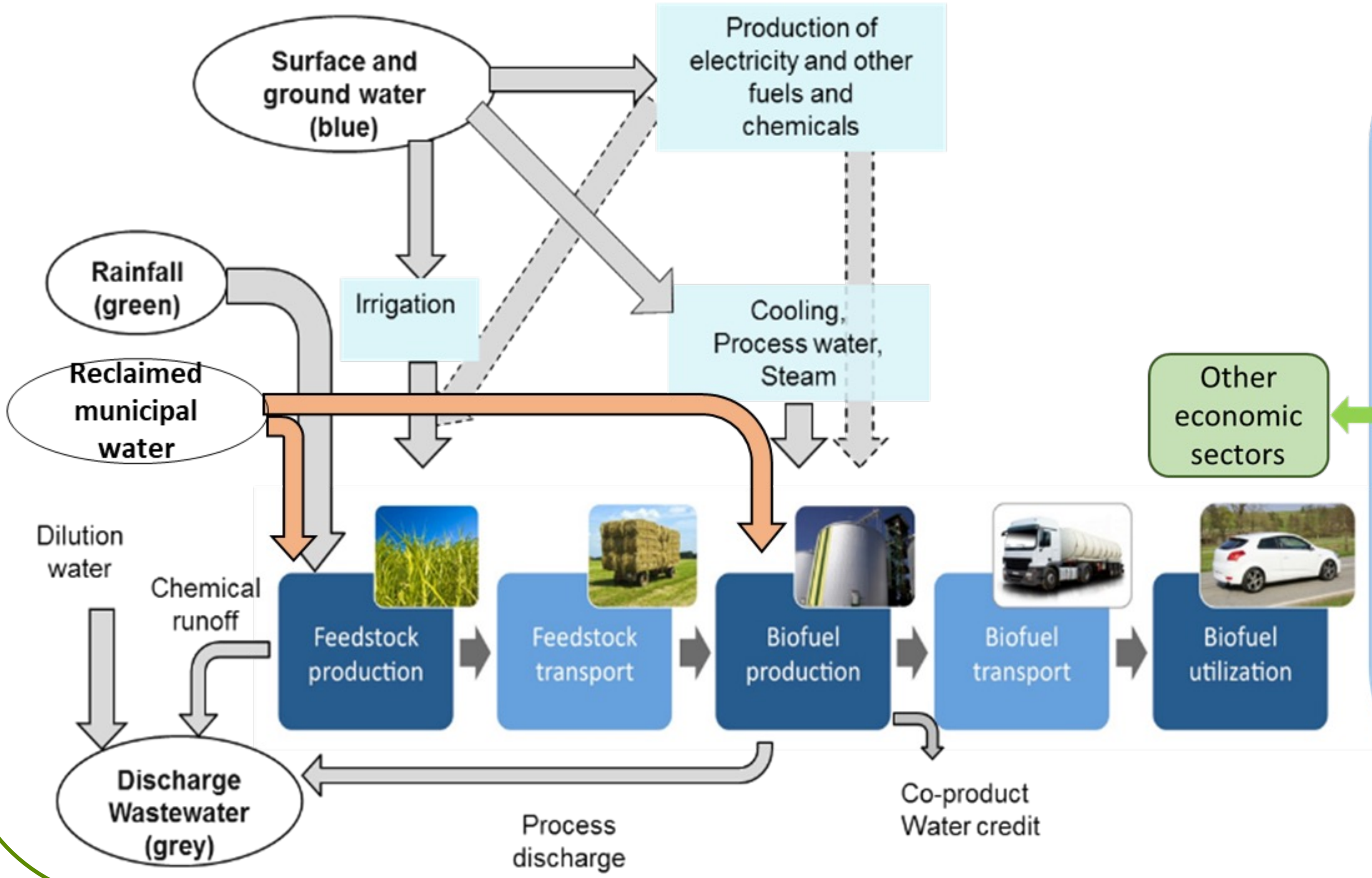
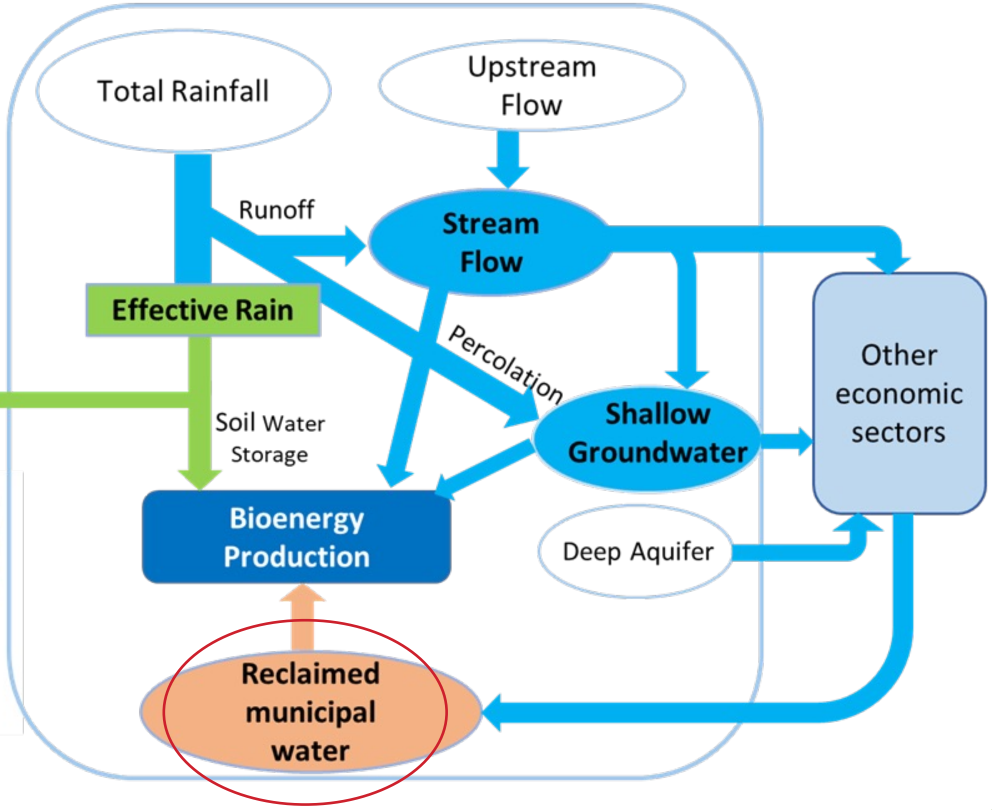
APPROACH: MODELS AND TOOLS

https://WATER.es.anl.gov

Water Footprint



Water Availability



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APPROACH: COLLABORATION AND PARTNERSHIP

- Government agencies, industry, NGO, Academia
- Water Quality and Carbon Modeling
  - USDA ARS/Texas A&M SWAT Team
  - Portland State University
  - U of IL Champaign
- Water Quality Impact
  - Des Moines Water Works
- Water Quantity
  - US EPA Office of Water
  - Water Reuse Association
  - Wastewater Treatment Facilities (Various)
  - State water agencies (Various)
  - Purdue University Northwest
- Interactions with USDA, USGS, ORNL (KDF)

SWAT Soil & Water Assessment Tool

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Des Moines Water Works Water You Can Trust for Life

PNW

National Water Reuse Action Plan WRAP

Portland State UNIVERSITY

I ILLINOIS

WATEREUSE

Visiting water reclamation plants and water supply infrastructure

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PROGRESS AND OUTCOMES: OVERVIEW

Since 2021 Peer Review

- Developed a framework that encompasses watershed modeling, field-scale feedstock simulation, and GREET to estimate watershed scale LCA and water quality. ★
- Completed the development SWAT-C model for Raccoon River watershed; calibrated the model with 20-year climate and water quality; performed preliminary simulation of three conservation practices. ★
- Submitted a manuscript of analysis of environmental and cost benefits of riparian buffer to drinking water supply in the Raccoon River watershed for publication in a peer-reviewed journal (under revision). ★
- Worked with SWAT development team to evaluate and test SWAT-C, providing inputs to improve the carbon module and intermediate data extraction, contributing to the model release.
- Coauthored a publication “Retrospective analysis of the U.S. corn ethanol industry for 2005–2019: implications for greenhouse gas emission reductions” in *Biofuels, Bioproducts, and Biorefining*.
- Completed state-level survey for municipal reclaimed water volume and reuse in the United States. Report under review. ★
- Conducted facility level survey of reclaimed municipal water use and analysis of county level availability for nine prominent bioenergy feedstock and reclaimed water states. ★
- Expanded the reclaimed municipal water database to include recent data years (2008, 2012, 2019-2021) in WATER. ★
- Developed analysis assessing the potential of using untapped reclaimed municipal water for bioenergy feedstock and agricultural crops in six states at the county level. ★
- Developed and implemented 3D visualization of water availability for six BT-16 scenarios in WATER. ★

★ Milestones

Watershed LCA Framework (*WALCAF*)

FD-CIC Farm Scale

Farming inputs
- Farm size
- Yield

Energy inputs
- Diesel
- Gasoline
- Natural gas
- LPG
- Electricity

Fertilizer input
- NPK fertilizer

SOC
- Location
- Farming practices

SWAT-C Watershed Scale

Topology
Soil profile
Climate
CO2, CH4, N2O flux
Streamflow
Water nutrients, sediments, TOC
Fertilizer use
Manure use
Tillage
Land cover and land use
Management and practices

Biomass

SOC Emissions

GREET

Fertilizer production
Chemical production
Energy production
LC inventory

Water Quality and Quantity

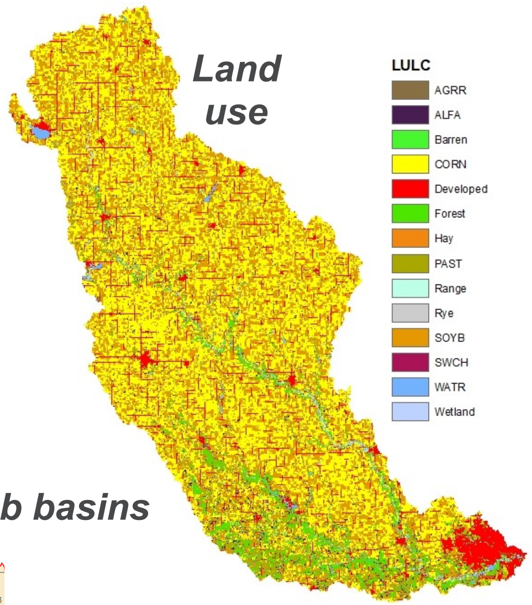
Energy Intensities
GHG Emissions

- A framework consists of SWAT-C, GREET, and FD-CIC.
- Simulate the C cycle at the watershed scale under conservation practices. Understand the interactions among N, P, C, water, and land.
- Established computation flow and defined inputs and outputs among the three models.
- Designed to address the challenges:
  - System boundary
  - Model calibration
  - Spatial resolution
  - Temporal scale
- Watershed application is under development.

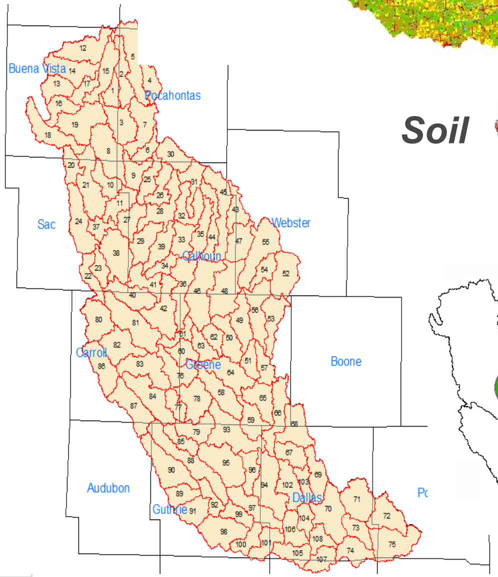
View the Power Point “notes” Page for Additional Info.

RACCOON RIVER WATERSHED SWAT-C

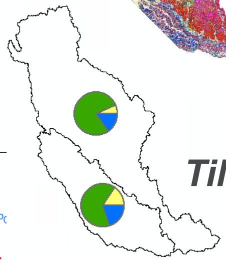
- Applied SWAT-C model to the corn and soybean dominant (74.5% of the area) Raccoon River watershed in Iowa.
- Calibrated model showed *satisfactory performance*.
- Evaluated three practices:
  - No till
  - Riparian buffer
  - Stover harvest with cover crops.



108 sub basins

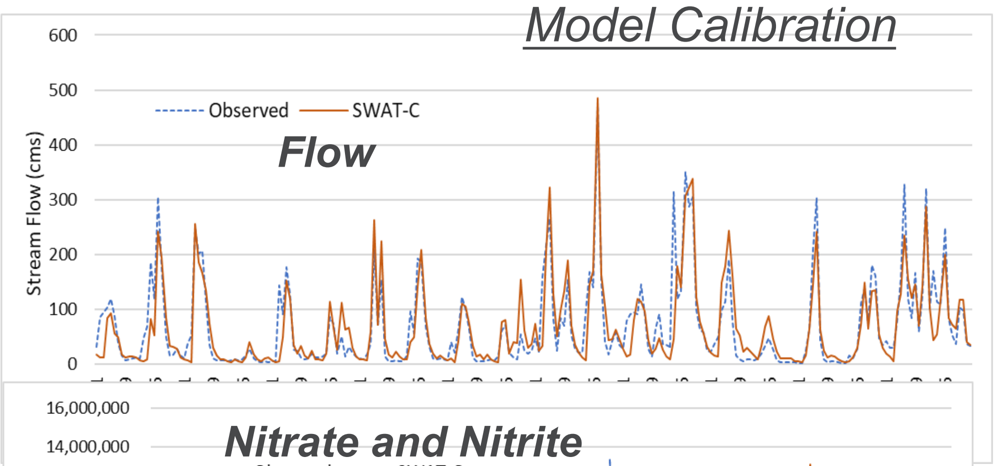


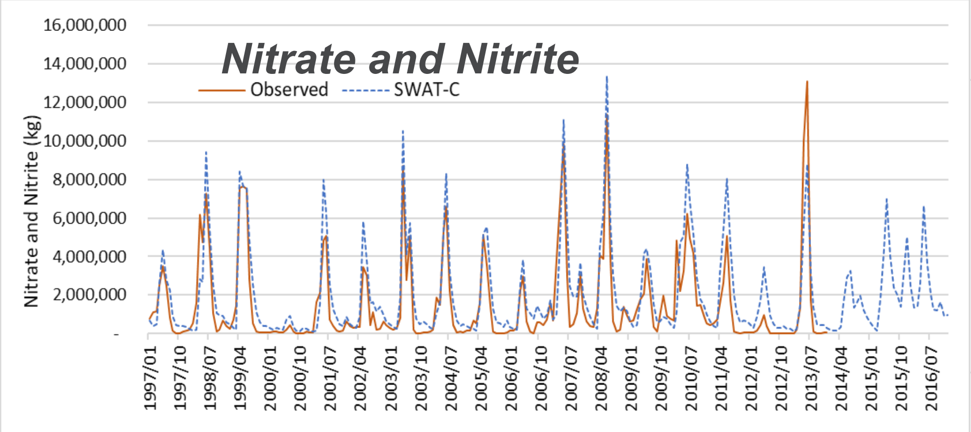
Soil

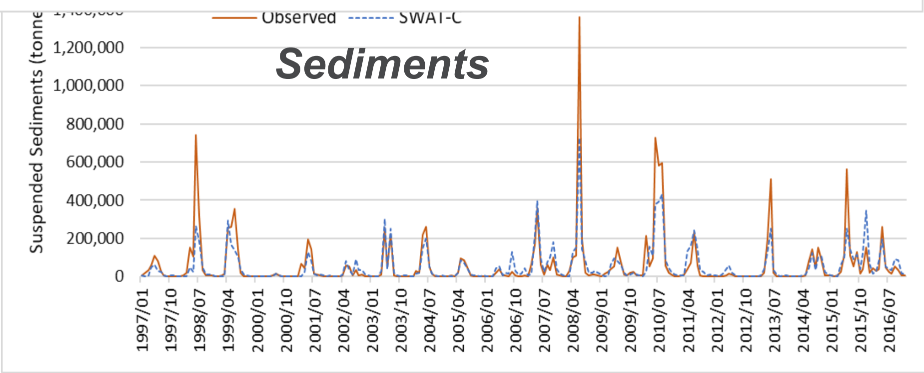


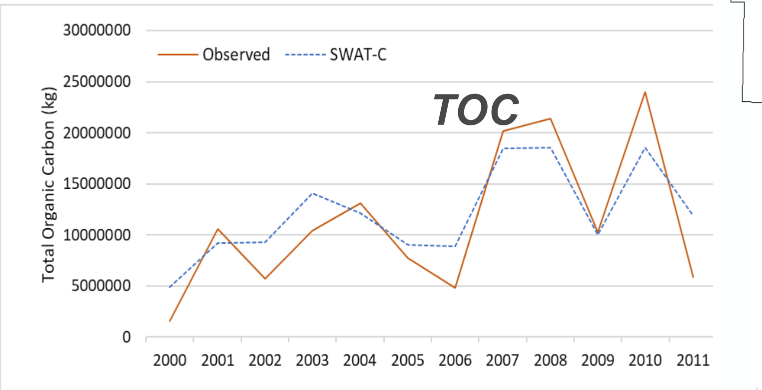
Tillage

Model Calibration









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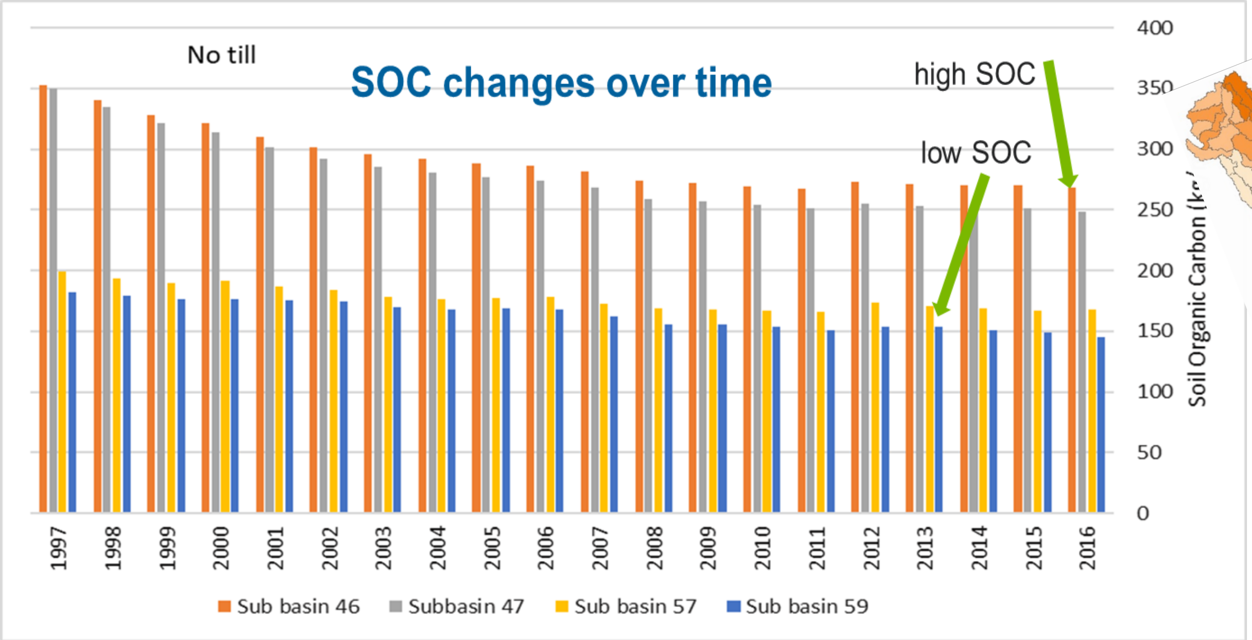
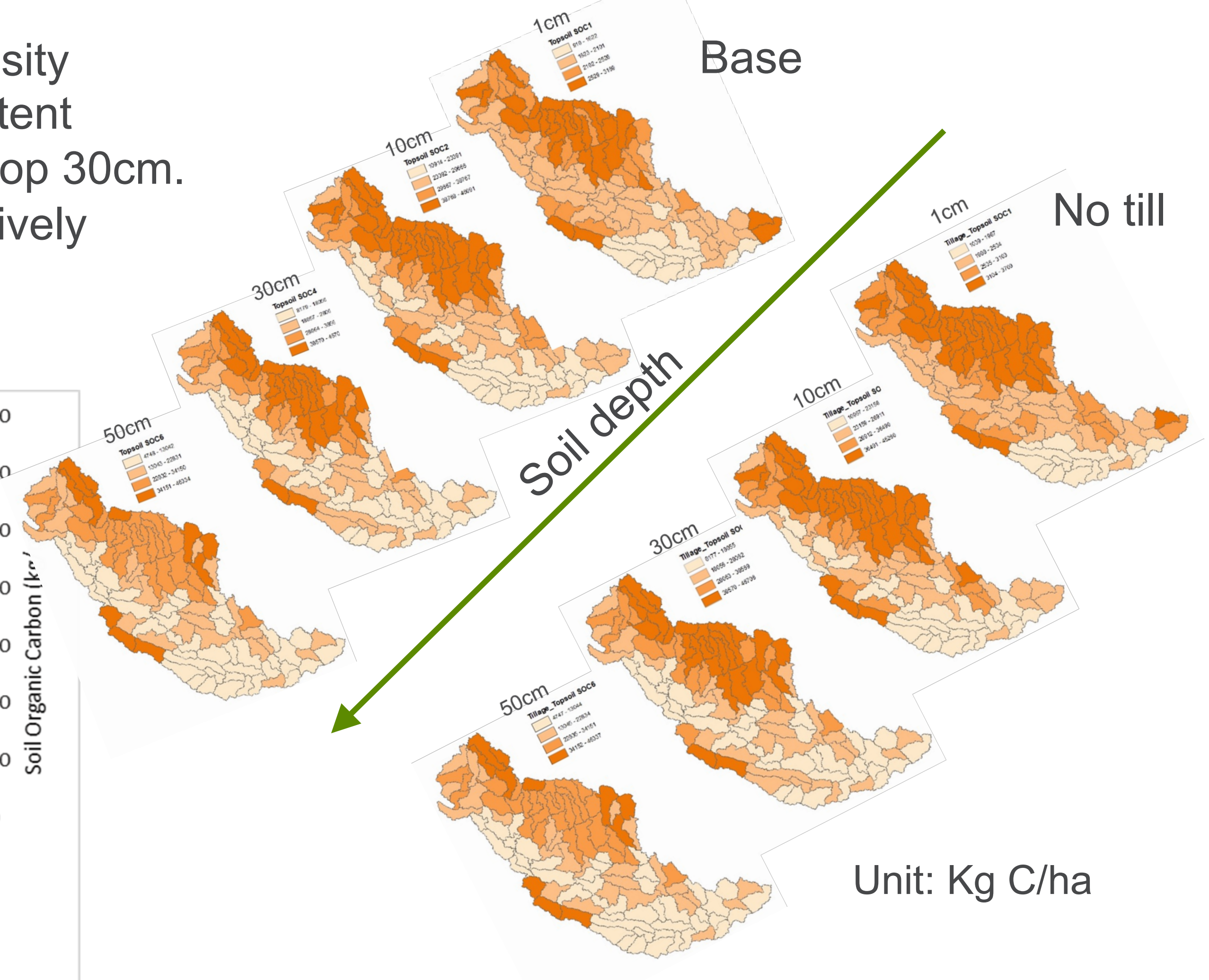
RRW SWAT-C PRELIMINARY RESULTS: NO-TILL

- Simulated SOC profile at 1cm-80cm across the watershed in base and conservation practice scenarios.
- No-till results in a significant increase in SOC intensity compared with the baseline, the increase is consistent across the watershed; most changes occur at the top 30cm.
- SOC declined slightly from 1997 and became relatively stable since 2008.
- Small reduction in N_2O emission.



Soil organic carbon distribution



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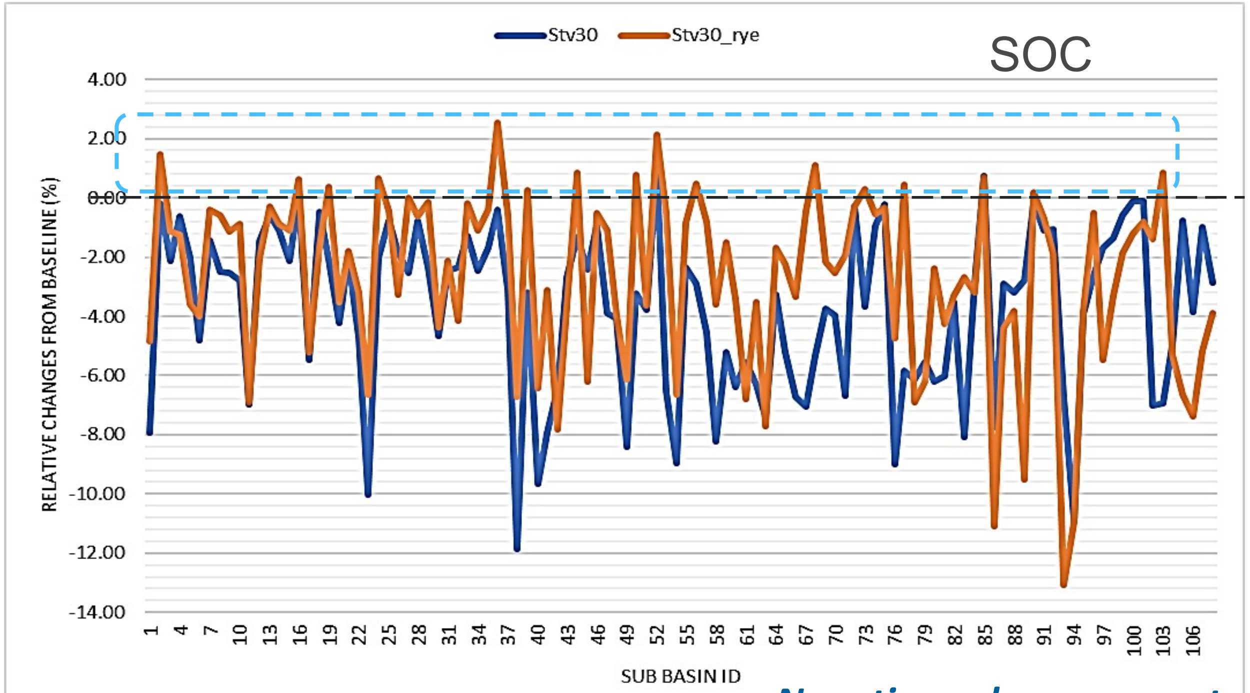
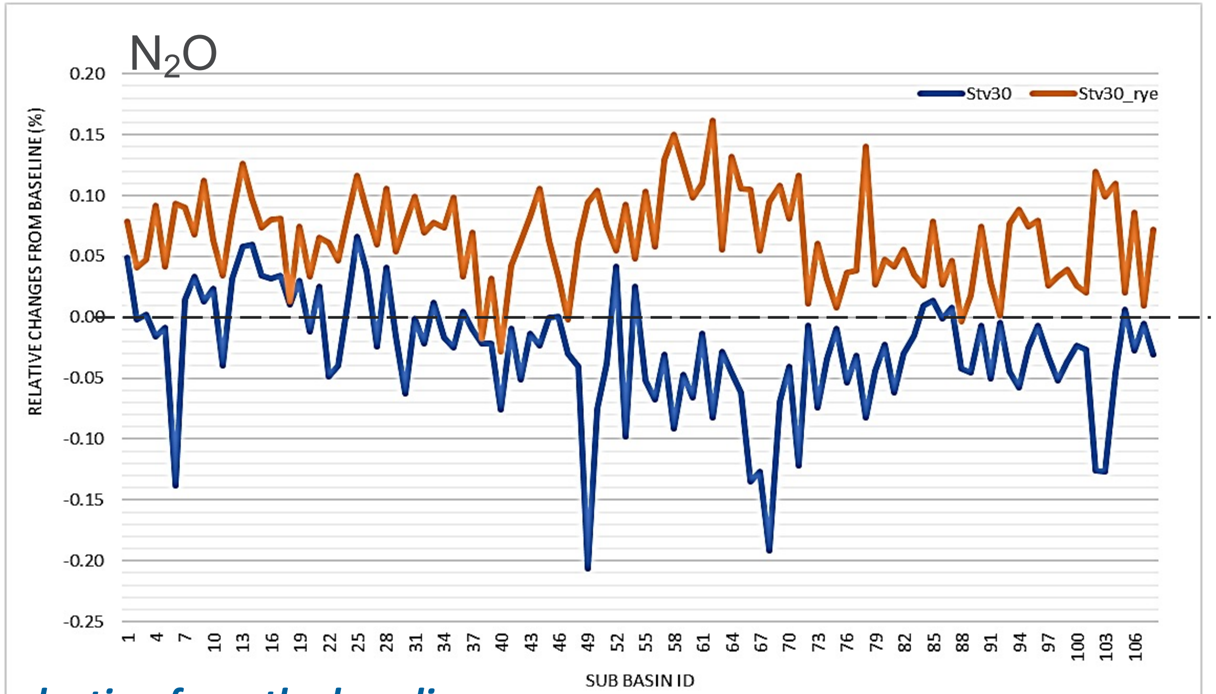
PRELIMINARY RESULTS : STOVER HARVEST

Changes in 20-years average value relative to the base across RRW





Negative value represent a reduction from the baseline.

- Results confirmed previous reports that stover harvests at a 30% rate would lead to a decrease in SOC in RRW. The reduction could be up to 12% in this watershed. Growing cover crops would recover SOC to certain degree.
- Identified sub-basins with a net increase in SOC with cover crop, to support implementation of the practice.
- Effect of stover removal on N_2O emission is minimal at less than $\pm$ 0.2%.

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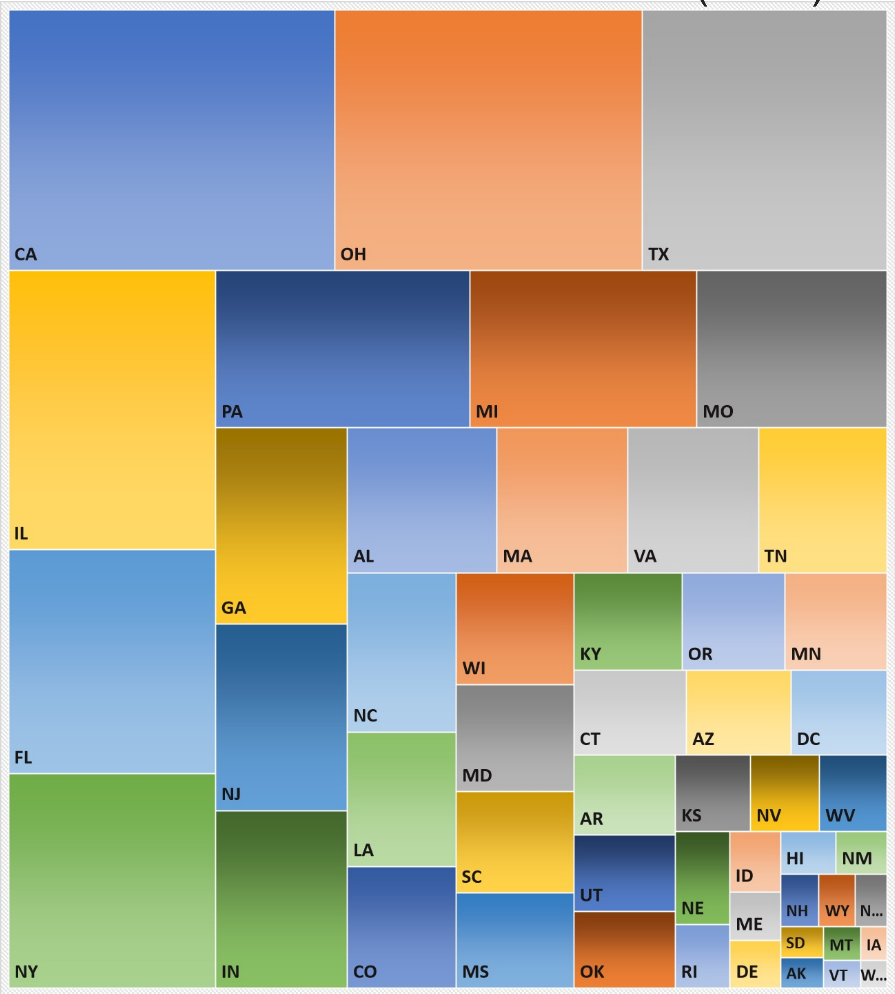
Progress and Outcomes

RECLAIMED WATER RESOURCE IN THE U.S.

Reclaimed Water Volume (2020)

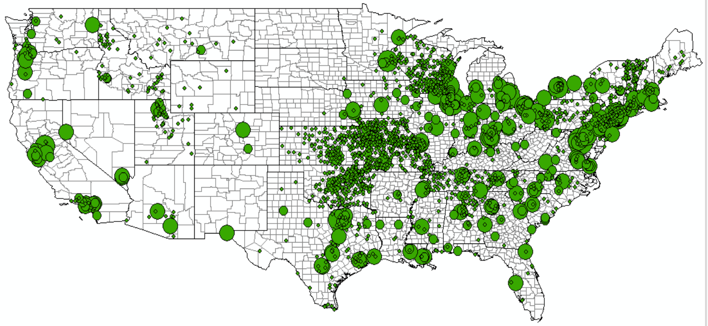


Data source: US EPA

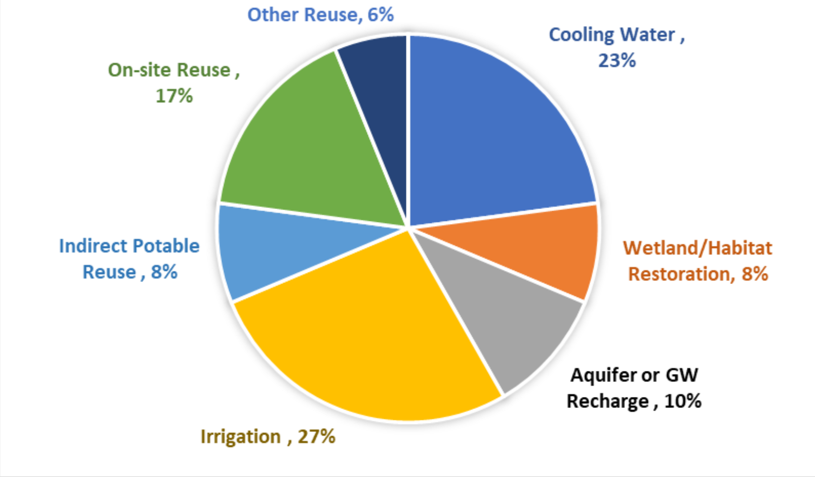
- On average, 32 billion gallons of municipal wastewater are treated daily in 2020, of which a majority goes through tertiary treatment. 90% of the effluent is discharged to the surface stream or ocean.
- Top ten reclaimed water resource states by volume:

  CA > OH > TX > IL > FL > NY > PA > MI > Mo > GA
- Irrigation and cooling are the major use of the reclaimed water; the largest use by volume is irrigation.
- Wide variations in reuse regulation:
  - 47 states allow for irrigation; 2 states do not allow for agriculture irrigation; 4 states have no regulation; and several states distinguish edible and non-edible crops irrigation.

POTW Facilities



Water reuse type by number of states



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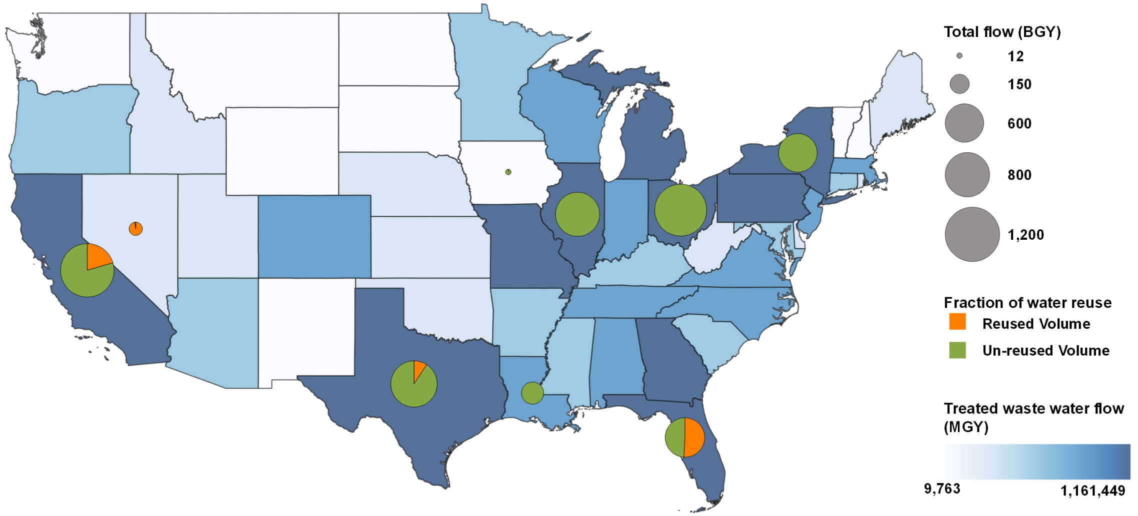
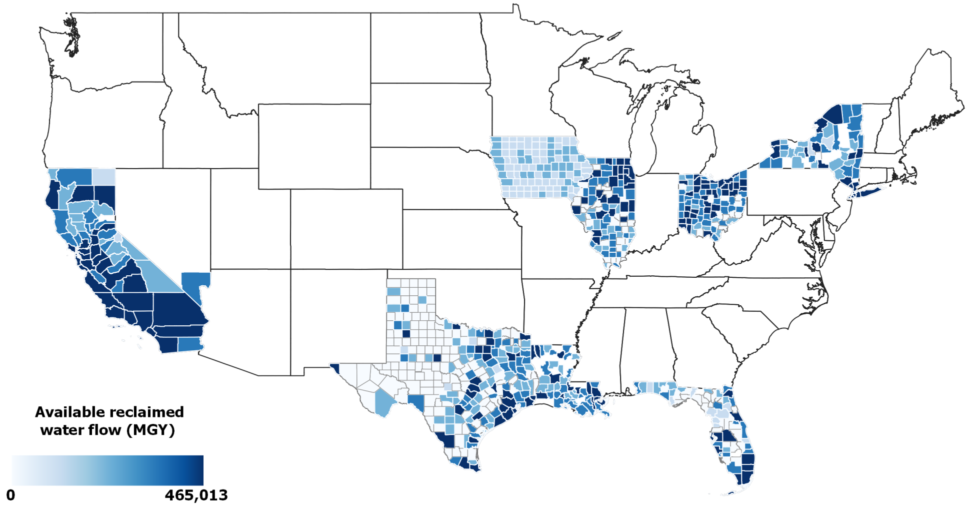
WATER REUSE SURVEY

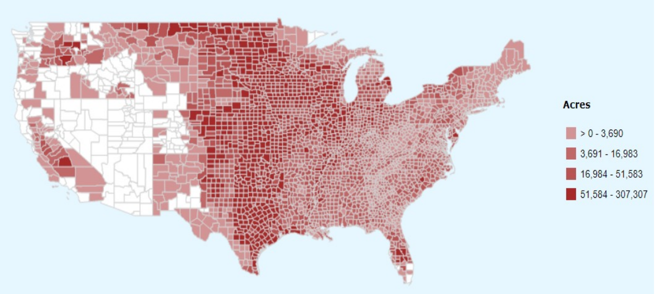
Reclaimed Water Volume and Reuse



County-Level Available Reclaimed Water in Select States



- Water reuse is more prevalent in western states; reuse data tracking varies significantly by states.
- Top water reuse states by reuse rate: Nevada (98%), Florida (50%), California (20%), and Texas (9%).
- States with large reclaimed water resources somewhat overlap with bioenergy feedstock.



Future feedstock scenario (BT16)

- Conducted county level survey and analysis for states with large volume of reclaimed water or high reuse:
  - CA, FL, TX, OH, IL, IA, NY, LA, and NV.
- Estimated potential of reclaimed water irrigation for feedstock and dominant agriculture crops in select states.
- Examined the water infrastructure needs.

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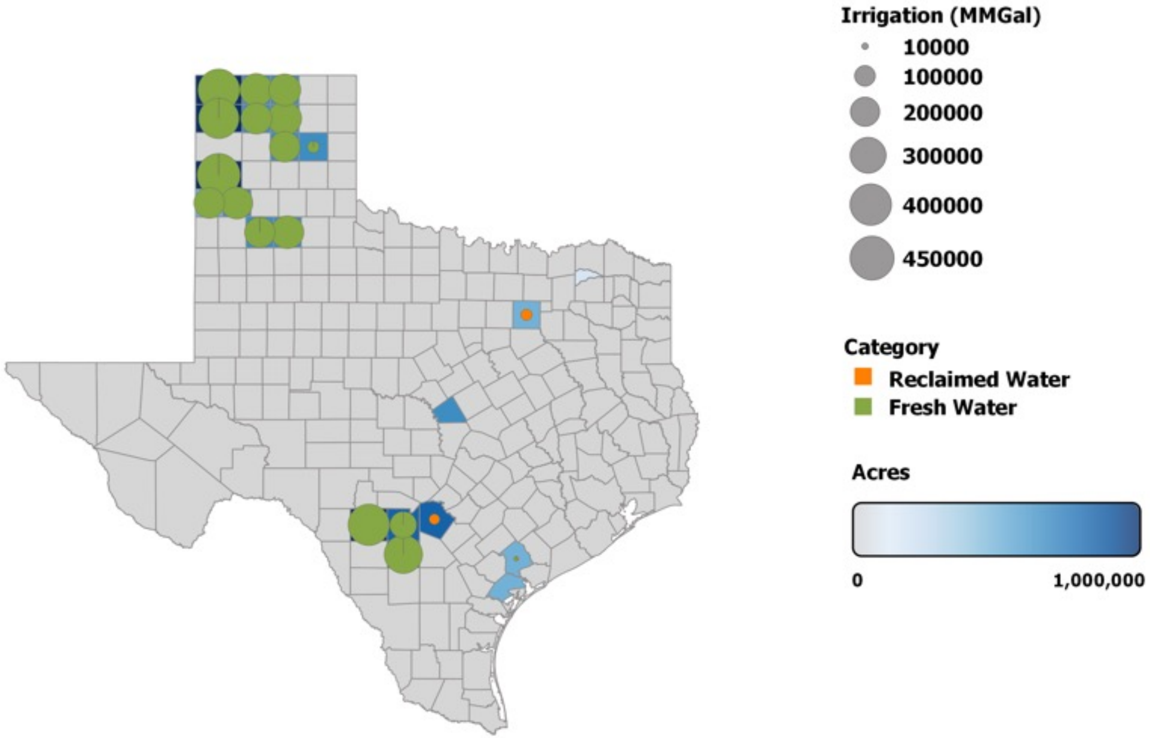
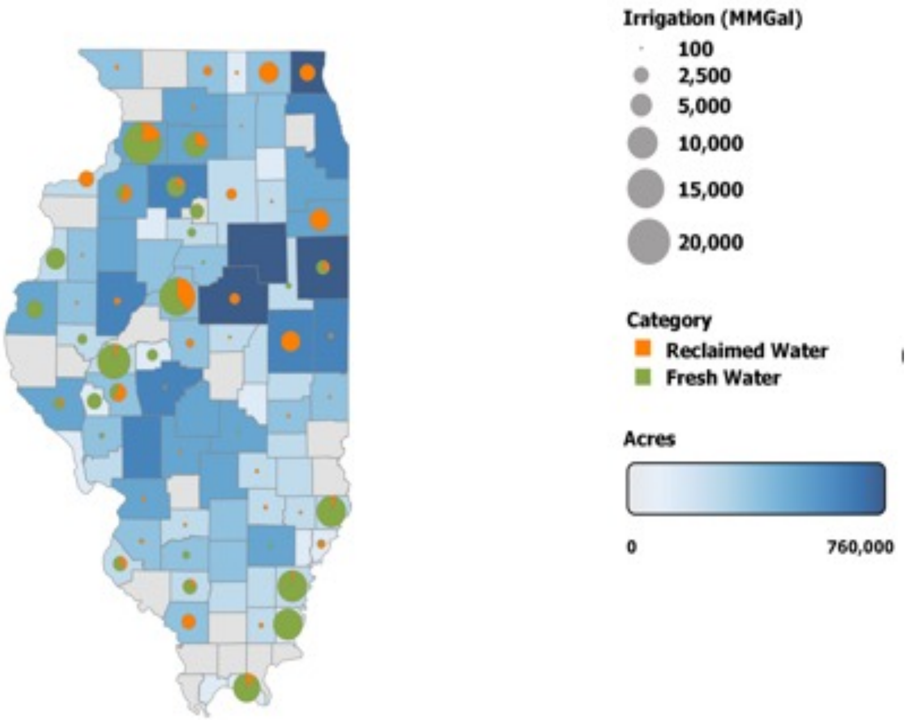
WATER REUSE FOR BIOENERGY





- Under the future scenario BC60-2040, 59,434 MGY of freshwater irrigation for **corn** can be substituted by reclaimed water in TX and 47,988 MGY in IL.
- Degree of reuse is affected by location of reclaimed water source and farm, irrigated land, crop-specific irrigation volume, and available reclaimed water volume.
- Water reuse benefits both water poor states and water rich states.

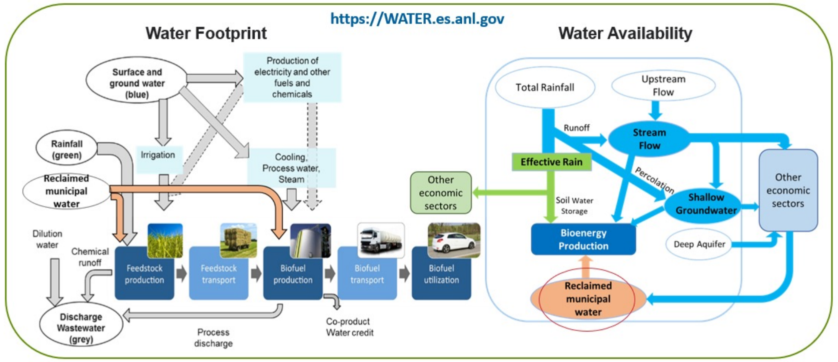
WATER REUSE BRINGS SUBSTANTIAL REDUCTION OF FEEDSTOCK WATER FOOTPRINT

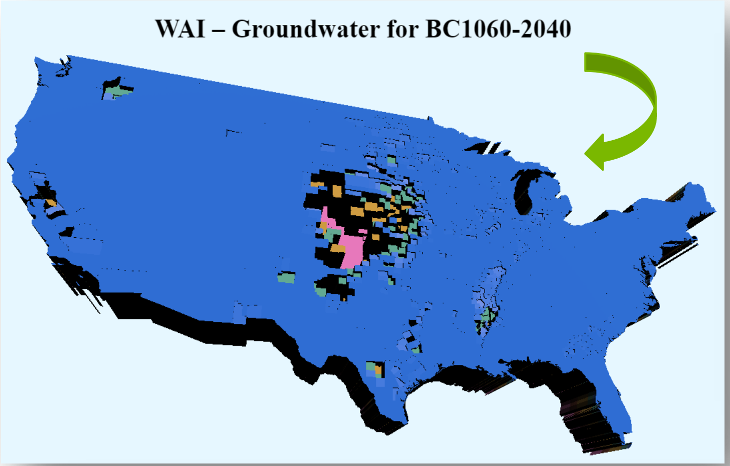
- Under the scenario BC60-2040, reclaimed water can provide a total of 224.9 billion gallons of irrigation water in the six states, 124 billion gallons in TX.
- Within a state, freshwater use can be reduced from 0-100% at the county level, affecting 209 counties.
- Similarly, reclaimed water irrigation for agricultural crop can meet irrigation needs of
  - 72% for oats, corn, and soybeans in NY.
  - 37.4% for corn and soybeans in IA.
  - 6.1% for corn, cotton, wheat, sorghum, and soybeans in TX.

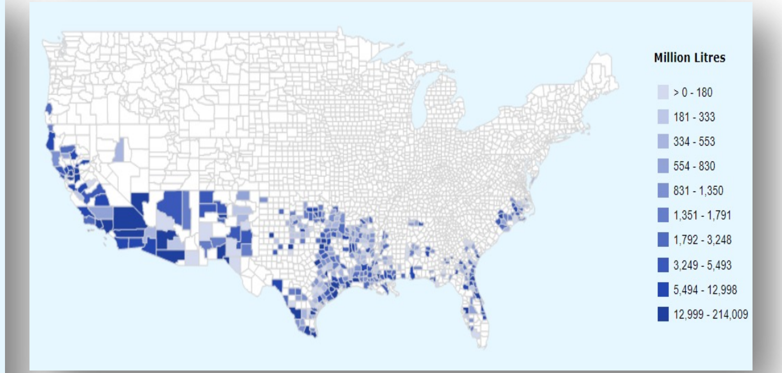
	RW irrigation (MGY)	Crops	Water demand reduction	# of Counties affected
TX	123,698	Corn, wheat, sorghum	2%	52
IL	48,092	Corn, wheat	32%	62
LA	40,138	Corn, rice	0.5%	31
OH	9,112	Corn	72%	25
IA	3,819	Corn	12%	32
NY	3	Corn	72%	7

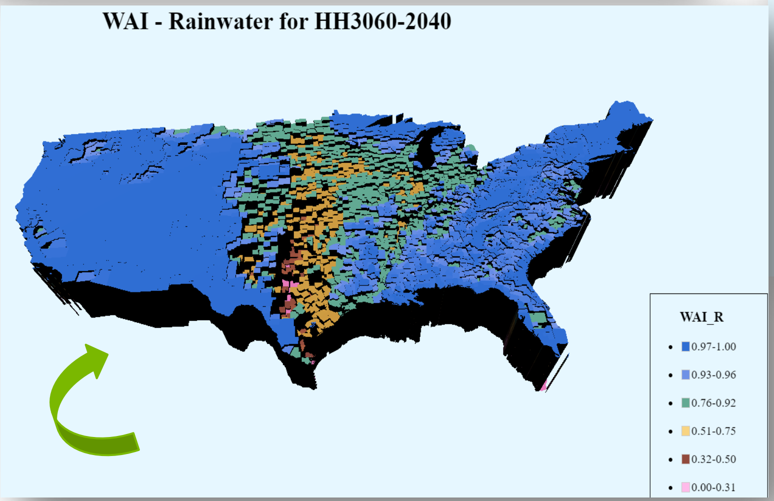
WATER 4.0 UPDATE

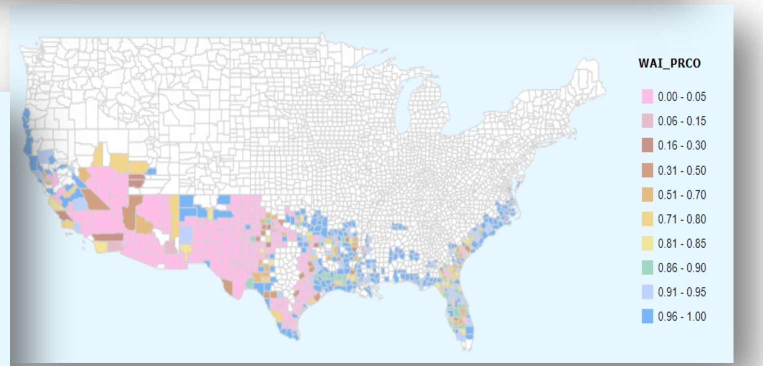
- Reclaimed water database is being updated to state and county level.
- Reclaimed water platform is updated with water footprint and water availability index for three algae scenarios.
- Developed 3D WAI module to enhance visualization for six BT16 scenarios.











Algae Scenarios

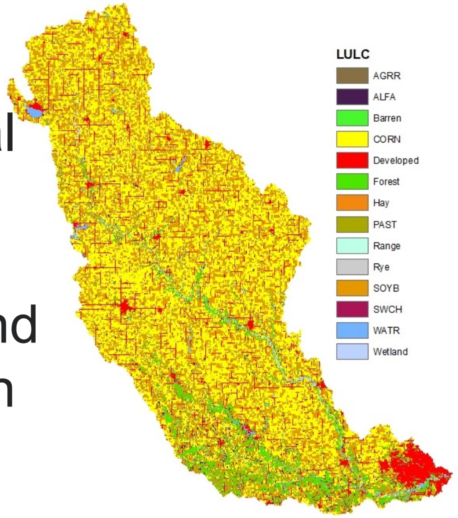
BT-16 Scenarios

IMPACTS

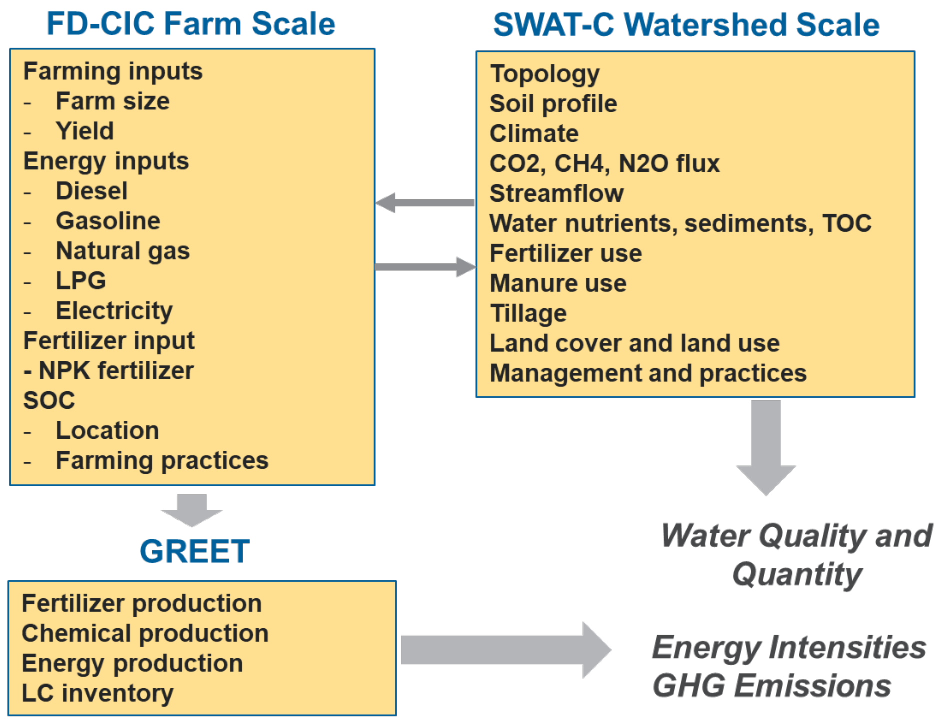
- This project connects to the decarbonization of the agriculture industry and feedstock production (I).
  - SWAT-C and Watershed LCA Framework (WALCAF) provide detailed modeling and analysis of water quality, carbon intensity, and carbon stock at the sub-basin scale and county level to address the water resource impacts and the tradeoffs between water quality and carbon in feedstock production.

To stakeholders

- Results support regional and local land development and water management strategy, support feedstock production planning, and inform agriculture decarbonization programs.



WALCAF application: Agricultural watersheds



Key takeaway:

- Contribute to tracking soil carbon change and soil GHG emissions at the watershed scale.

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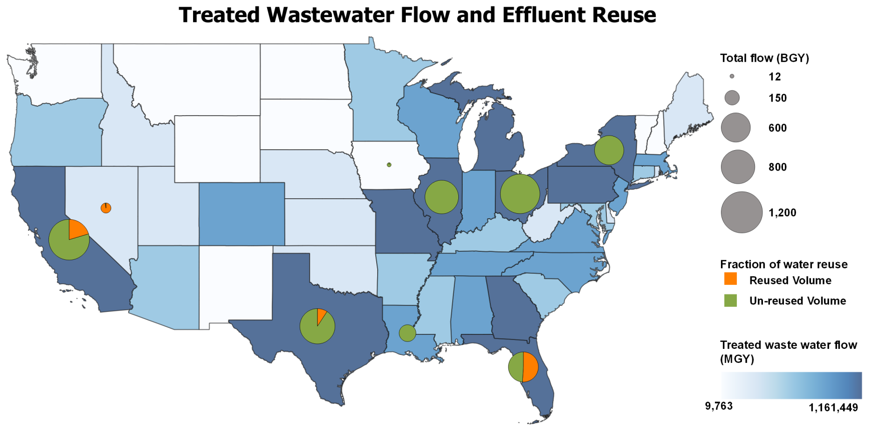
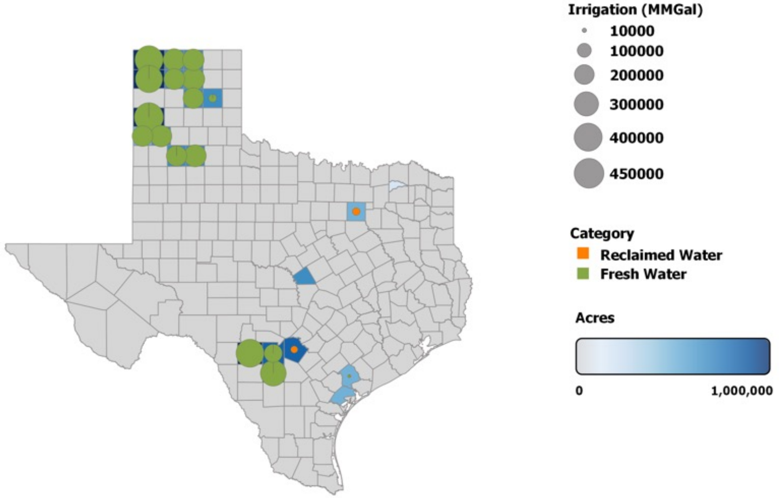
IMPACTS

- This project connects to the <u>decarbonization of the agriculture industry and feedstock production</u> (II).
  - Municipal reclaimed water analysis from this project provides the bioenergy industry most updated knowledge and data on non-traditional water resource distribution, availability, and the potential at the geospatial resolution to support sustainable production.

To stakeholders

- WATER with updated reclaimed water inventory supports data-driven decision-making for landowners and growers to select the land area for feedstock and source irrigation with reduced water footprint in various regions, especially those under water stress.





Key takeaway:

- Contribute to improve water sustainability of bioenergy.

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IMPACTS

To BETO

- Provide the analytical platforms/tools capable of addressing region-specific water quantity and water quality issues to meeting BETO's goal of decarbonization of transportation, industry and agriculture.

To broader communities

- This work provide water sustainable solutions to mitigate the risks on increased freshwater stress intensified by climate change; and approaches to minimize water quality impact in production to watershed community.

- *The reclaimed water data inventory is also being applied to other BETO projects, for siting of CO_2 refineries.**

View the Power Point "notes" Page for Additional Info.

SUMMARY

Approach

- Develop well-defined framework encompasses conventional and non-conventional water resource, water quality, carbon, nutrients, climate, land use, and conservation practices with rigorous calibration in geospatial and temporal resolution.
- Strong stakeholder engagement through collaboration with water and agriculture agencies, public and private sectors, NGOs, and academia.

Impacts

- The Results of this project and the platform are supporting BETO's CO_2U consortium's environmental analysis.
- This project is closely connected to decarbonization of transportation, industry, and agriculture.

Progress and Outcomes

- Developed a framework WALCAF to analyze watershed scale LCA and water quality; developed a calibrated SWAT-C model for Raccoon River watershed and evaluated the impact of three conservation practices on SOC change, nutrients release, and GHG emissions.
- Completed a state-level water reuse survey for municipal reclaimed water in the United States followed by a facility level survey for night states to determine the availability of reclaimed municipal water.
- Assessed the potential of using untapped reclaimed municipal water for bioenergy feedstock and agricultural crops in six states at the county level.

Water Use, Water Resource, and Water Quality

Quad Chart Overview

Timeline

- Project start date: Oct. 2021
- Project end date: Sept. 2023

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022) $500,000*	*$1,500,000*
Project Cost Share*	*(negotiated total federal share) 100%*	

Project Partners*

- Portland State University
- Des Moines Water Works
- USDA ARS

Project Goal

Develop analyses and modeling tools to quantify the benefits and impacts of feedstock and production pathways on water resources and carbon trade-offs, and factor in non-traditional water resources to reduce the freshwater footprint of decarbonization technology deployment.

End of Project Milestone

Watershed scale nutrient, carbon, sediments, and water resource tradeoffs. Simulation of carbon, nutrients, and water cycles at the watershed scale to analyze the implications and interactions of decarbonization in feedstock production integrated with conservation practices in the Raccoon River watershed.

Funding Mechanism

Annual Operational Plan

*Only fill out if applicable.

Acknowledgements

BETO: Andrea Bailey

- Argonne National Laboratory
  - Miae Ha, Hoyoung Kwon
  - Shawn Ho, Sophie Kochanek, Maille Bowerman, Griffin Stewart
- Des Moines Waterworks
- Portland State University
- Purdue University Northwest
- USDA ARS SWAT Team
- U.S. EPA WRAP
- University of Illinois at Urbana-Champaign
- Water Reuse Association
- Water Environmental Federation

ADDITIONAL SLIDES

DEFINITIONS

- **SWAT –** Soil Water Analysis Tool, a hydrologic watershed model.
- **WAI** – Water availability indices. Degree of water available to other economic sectors after meeting a specific need.
- **Water footprint (WF) –** Net water loss to evapotranspiration and evaporation; incorporation of water into products or solids by a production process or activity.
- **Water withdrawal –** Water uptake from surface or groundwater
- **Water consumption or Consumptive water use –** Water evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use (accounted for in WF analysis)
- **Water Reuse –** The practice of reclaiming water from a variety of sources, treating it, and reusing it for beneficial purposes**.** *Water reuse is often used interchangeably with water recycling***.**
- **Blue water –** Fresh surface and groundwater
- **Evapotranspiration (ET) –** Loss of water from the land cover both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it
- **Effective Rain (ER) –** The part of rainfall stored in the root zone and can be used by the plants (FAO)
- **Green water –** Soil moisture from rainfall that is consumed by vegetation; the use of effective rain
- **Grey water footprint –** Volume of water required to dilute the chemicals in the wastewater to an acceptable level of concentration for the water body (*specific to the WF methodology*).

RESPONSES TO PREVIOUS REVIEWERS' COMMENTS (2021)

Comments & Suggestions

- This group can provide key support for a range of other projects regarding water availability and quality. This project fills an important gap in many DOE BETO projects: water quality and water footprint tools that are clearly defined will help many tools improve their sustainability assessment. This project team has developed deep expertise in the water/bioenergy nexus. They appear to be a node for water impacts in the portfolio and should be leveraged to support other efforts.
- It would be good to see environmental NGOs added to the list of collaborations to facilitate public acceptance of bioenergy. It would be helpful to understand what current uses of reclaimed water are and competition for reclaimed water, or if there are barriers to using the reclaimed water. USDA ARS folks have many different water models can be collaborated. This analysis can be integrated with some efforts to assess bioenergy impacts on sustainability, such as the BioSTAR tool and GCAM.

Responses

We would like to express our appreciation for the reviewers' effort and input. Your compliments to the achievements, suggestions on potential water resource issues, gaps to be addressed in tools/models, and increased interactions with NGOs and additional projects in BETO's portfolio are extremely valuable. We took the advices and investigated water reuse issues and gaps, increased interactions with NGOs such as WaterReuse, and increased collaborations with USDA ARS. We contributed water footprint datasets to BioSTAR. We look forward to continue contribute to DMA and BETO's mission of building an economically viable and environmentally sustainable bioeconomy.