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

Argonne NATIONAL LABORATORY

## BIOENERGY TECHNOLOGIES OFFICE FY19 PEER REVIEW

# Water Resource Management for Bioenergy and Bioproducts


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Argonne National Laboratory


March 4–8, 2019
**Analysis and Sustainability**

## GOAL STATEMENT

Assess bioenergy feedstock production and conversion from water resource perspectives by

- *Establishing quantitative metrics*.
- *Developing hydrologic model and analysis* to evaluate water resource use and water quality in production stages.
- *Identifying production scenarios* that *increase water use efficiency, lower regional water stress, and reduce nutrient and sediment loss*.

## RELEVANCE

Addresses BETO technical barriers and challenges of the need for

- *High-quality analytical tools and models* with improved utility, consistency, and reliability.
- *Science-based, multi-stakeholder strategies* to integrate bioenergy with agricultural systems to maintain production while support ecosystem services.
- *Quantifying environmental benefits and economic cost*.

**Outcome:** Improves understanding of *trade-offs* between production targets and water sustainability and supports *science-based data driven* production strategies that protect regional water resource in a growing bio-economy.

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# QUAD CHART OVERVIEW

## Timeline and Funding

- Project start date: Oct. 2015
- Current merit review cycle: Oct. 2017 – Sept. 2020
- Project end date: Sept. 2020
- Percent complete: 40%

| | FY18 Costs | FY19 Costs | Total Planned Funding (FY19 - Project End Date) |
|---|---|---|---|
| **DOE Funded (k)** | $350 | $500 | $400 |

## Partners

– USDA ARS (M. Tomer)
– Antares (K. Comer, B. Belden)
– Des Moines Waterworks
– ORNL (Y. Jager), PNNL (M. Wigmosta), ANL (C. Negri, M. Wang)

## Barriers addressed

- **At.-B.** Analytical tools and capabilities for system-level analysis.
- **At.-E.** Quantification of economic, environmental, and other benefits and costs.
- **At.-H.** Consensus, data, and proactive strategies for improving land-use management.

## Objective

- Develop tools that illustrate annual available water resources and resulting stress for bioenergy production at the county level in the United States.
- Simulate water quality in feedstock production by using SWAT models and analyze value proposition of reducing nutrient loss at watershed scale.

## End-of-Project Goal

Provide spatial-explicit water quality and quantity analyses for bioenergy production by developing water availability indices and SWAT models available to stakeholders.

# PROJECT OVERVIEW

## Challenge

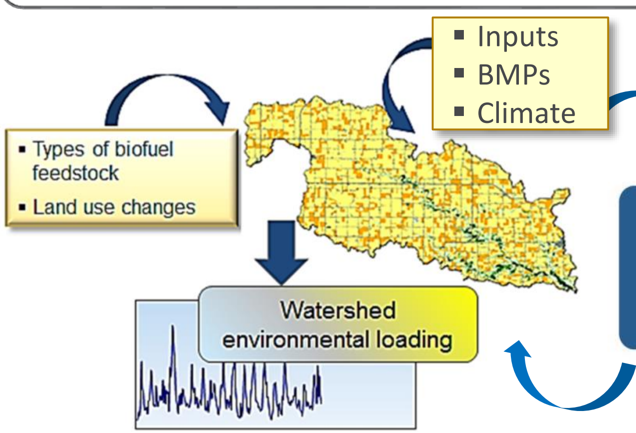
- The sustainable production of bioenergy and bio-product is constrained by regional water resource availability, water use intensity for production, and the resulting changes in water quality.

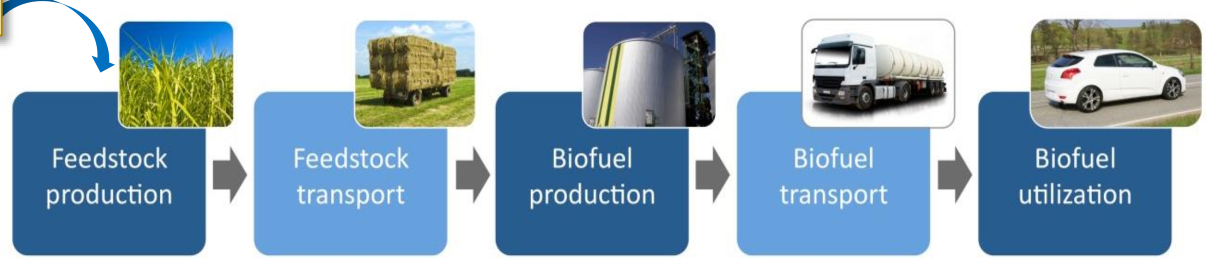
## Question

- How can we quantify and select production scenarios that potentially improve water quality and increase water use efficiency?

## Technical Objectives

- Design and develop tools that (1) illustrate annual available water resources and water footprint for bioenergy production at the county level in the United States and (2) determine such production's impact on regional water resource availability to non-bioenergy sectors with spatial resolution in an online platform.
- Simulate nutrients and sediment loadings associated with feedstock production, evaluate water quality effect of landscape design integrated with conservation practices for biomass production, and analyze the value proposition of reducing nutrient loss in biomass production.

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# PROJECT OVERVIEW (CONT.)

*The objectives will be achieved by*

**1. Water Resource Analysis**

- Assemble a water resource inventory for renewable surface water, groundwater, rain water, and reclaimed water at the county scale.
- Design and develop water availability index (WAI) for feedstock production (BT16) scenario; estimate the effect of production on regional water use stress.

**2. Water Footprint Analysis**

- Survey water consumption intensity of biofuel produced from multiple pathways and baseline industry.

**3. Hydrologic Modeling**

- Develop and calibrate SWAT model applications at watershed and river basin scales and establish historical water quality baseline.
- Simulate potential production landscape and BMP scenarios and identify region-specific production scenarios that reduce nutrient and sediment loss while increasing biomass production.

**4. Value Proposition Analysis**

- Assess county-level economic benefits of implementing multi-purpose buffer for feedstock.

## *Output*

- **WATER** - Spatial-explicit model with regional water resource platform and production stage water footprint for bioenergy; *available online.*
- **SWAT** modeling and analysis of multiple river basins and watersheds.
- **A set of analysis of water resource use and economic benefits** of reducing nutrients by biomass production in the watershed and river basin scale.

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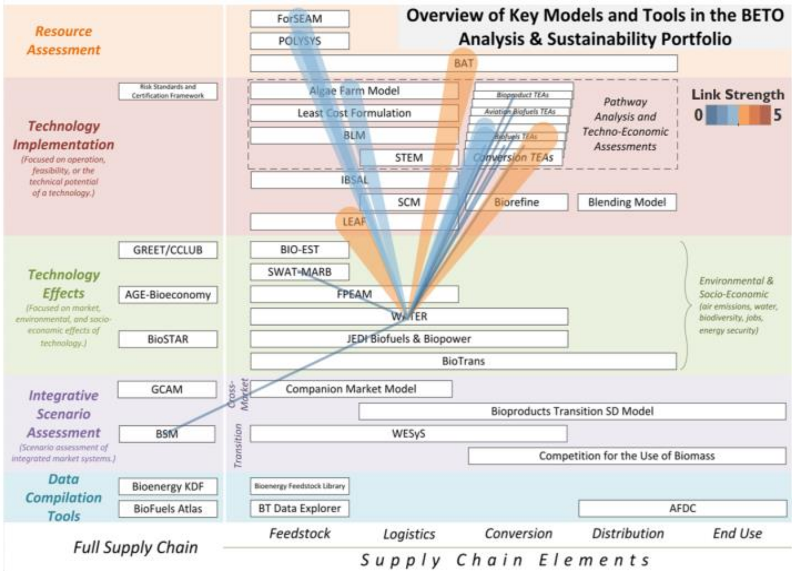
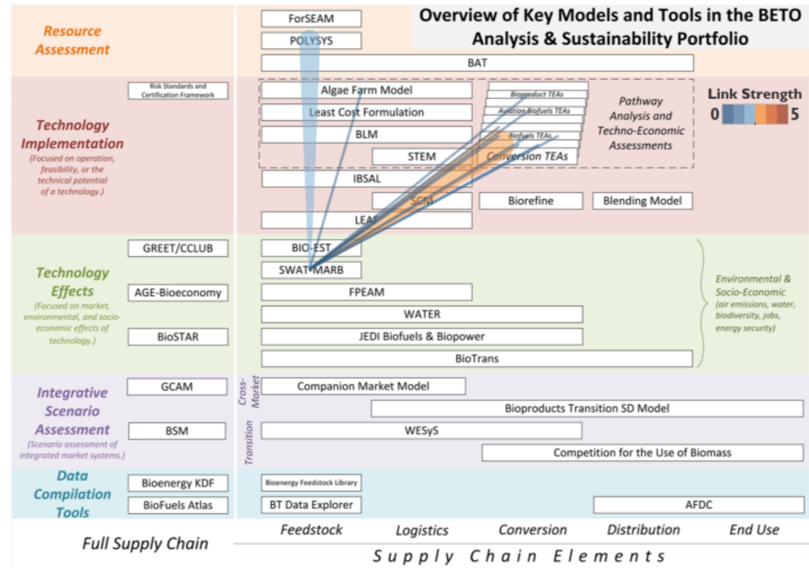
# WHERE THIS PROJECT FITS INTO BETO A&S PORTFOLIO

## WATER

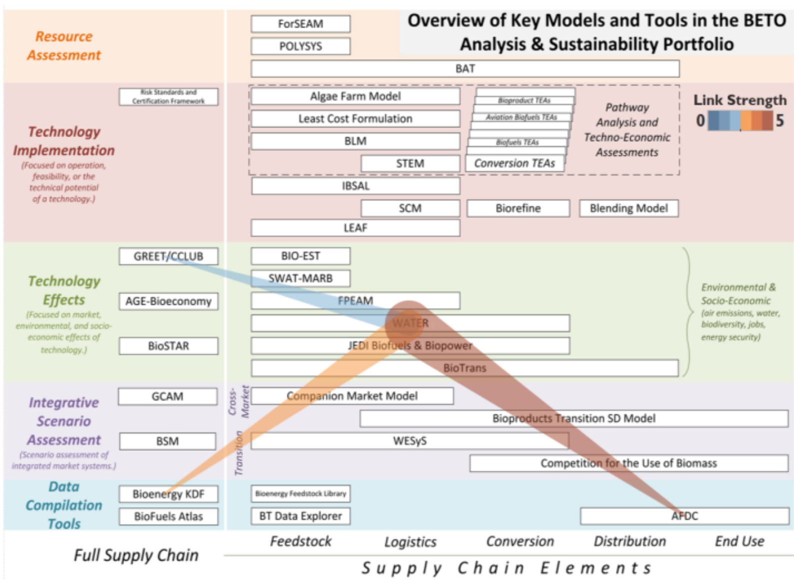
## SWAT - MARB

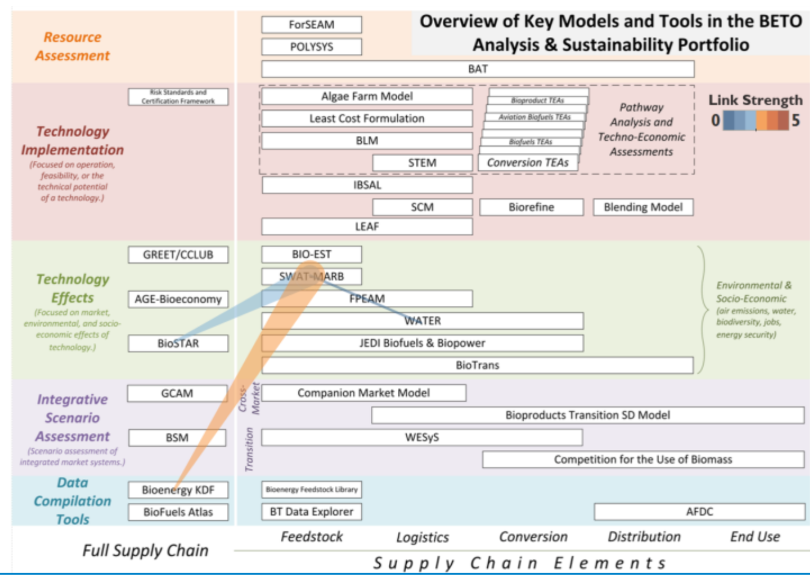
INPUT




OUTPUT



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# APPROACH (Management)

## Major Tasks

I. WAI analysis and WATER development

II. Water quality modeling and analysis using SWAT

## Identify Potential Challenges

– Incomplete temporal and spatial water resource data, poor data quality.
– Inconsistent estimates of water data by different data sources, and uncertainties in these estimates.
– Consumption efficiency changes as technology/management advances.

## Success Factors

- Capturing regional variabilities of water resource and feedstock.
- Timely analysis for new technologies/management strategies to address technology viability from natural resource perspective.

- **Develop Collaborations**
  - NOAA and USGS: Surface and groundwater flow data and uncertainty analysis.
  - US Army Corp. Engineers: SWAT
  - USDA ARS: Watershed site-specific long term intensive water quality monitoring data and conservation practices tool ACPF.
  - Water industry: develop value proposition of nutrient loss reduction to water supply.
  - Biofuel industry: Biorefinery water use survey.
- **Assemble Interdisciplinary Team**
  - Consists of environmental engineer, hydrologist, and computer engineer.
- **Stakeholder Engagement**
  - Seek inputs and feedbacks from agriculture sector, conservation groups, biofuel industry.
- **Track Budget and Spending**
- **Well-defined Milestones** [1]

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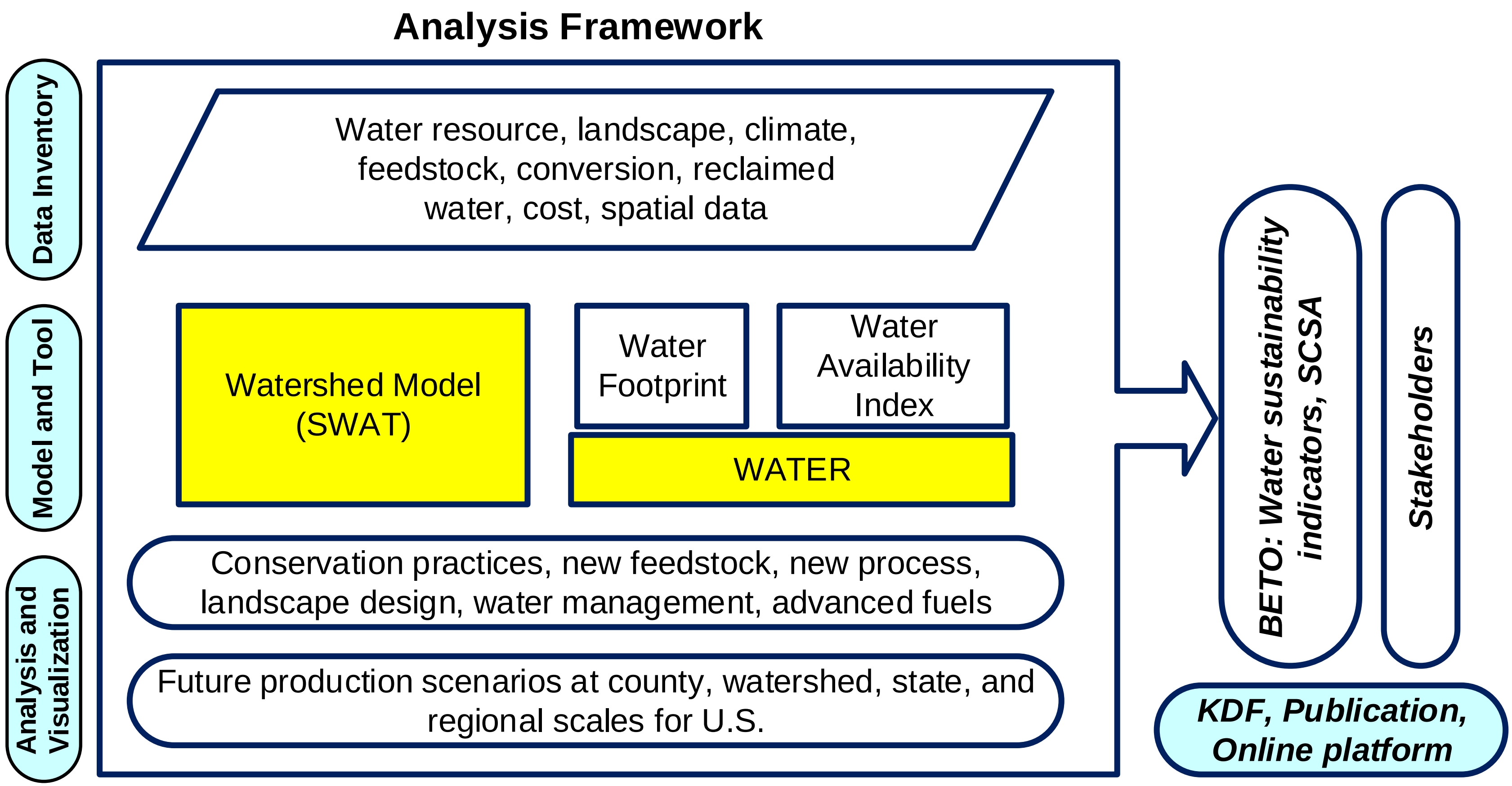
# APPROACH (Technical)




- Consistent methodology - Adopt WF methodology (UNESCO, ISO), physical process-based approach with rigorous calibration with historical observations.
- Develop major assumptions in consultation with USDA, USGS, USFS, US Army Corp., and biofuel industry.

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

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# TECHNICAL ACCOMPLISHMENTS: *OVERVIEW*

★ – milestone

***Since 2017 Peer Review***

- Completed ***mapping*** for surface water, renewable groundwater and soil moisture;★ Analyzed **freshwater *WAI*** for six BT16 agriculture and forestry scenarios at county, state, and regional scales for the United States. ★
- Developed **reclaimed wastewater *WAI methodology*** and assembled a county-level, technology-specific resource ***data inventory***.★
- Delivered EERE BETO ***webinars*** on 1) water resource availability analysis for bioenergy ★ and 2) water quality modeling and assessment in Mississippi River Basin tributaries.★
- Modeled effects of growing biomass as multi-purpose buffer in Lower Mississippi River Basin on ***nutrient reduction in*** the Gulf of Mexico ★ and estimated ***cost and benefits*** under future scenarios.★
- Analyzed ***value proposition*** of reducing agricultural land nitrogen loss to downstream municipal water supply at watershed scale.★
- Developed, calibrated a ***SWAT model*** for Raccoon River watershed and simulated water quality changes under multipurpose buffer.
- Released an update of a comparative study for ***water consumption intensity*** in the production of biofuels and baseline fuel. ★

**8** peer-reviewed journal publications, **2** webinars, and **1** National Lab Technical Report

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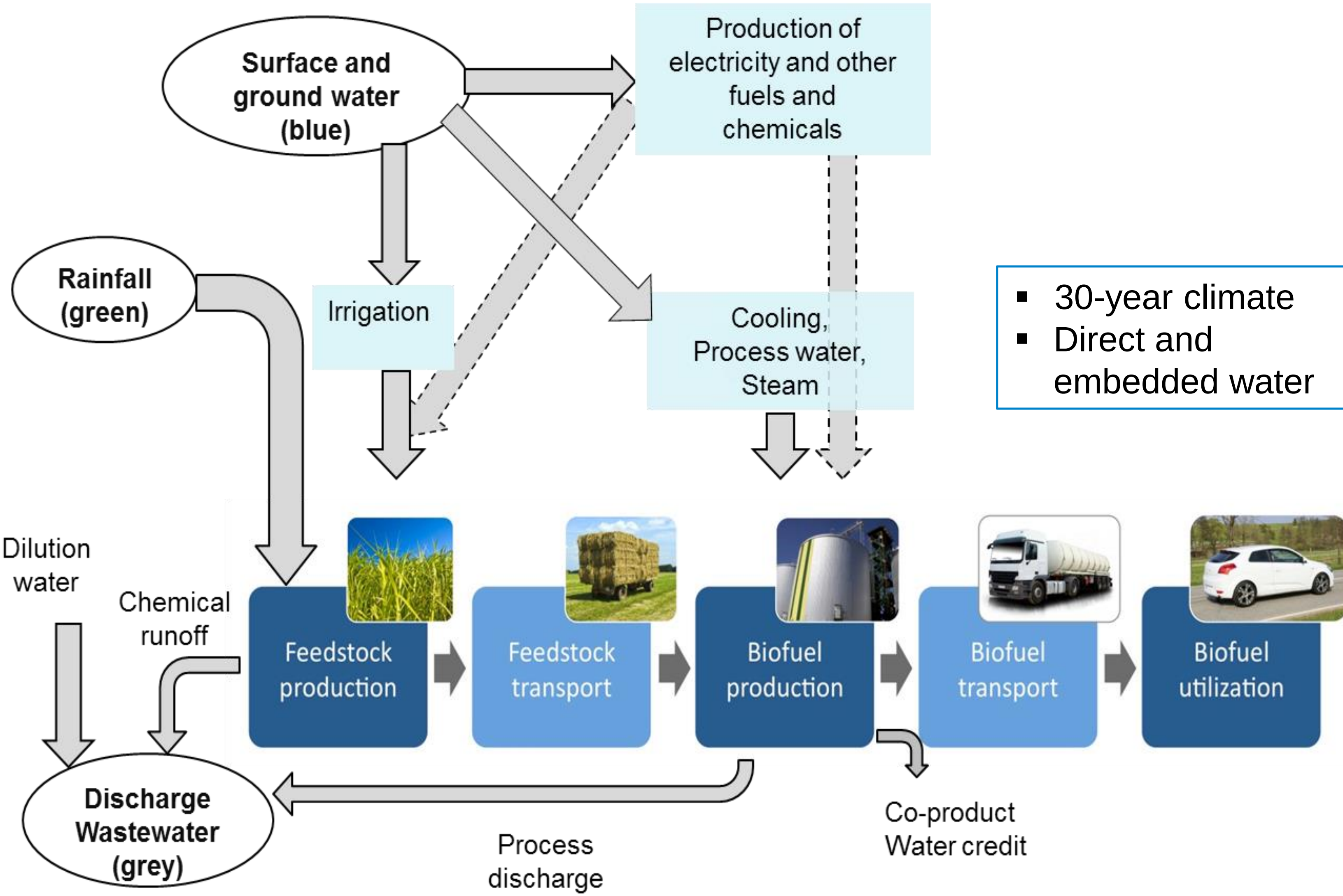
# TASK I. WAI analysis and WATER development

## WATER FOOTPRINT ACCOUNTING




- 30-year climate
- Direct and embedded water

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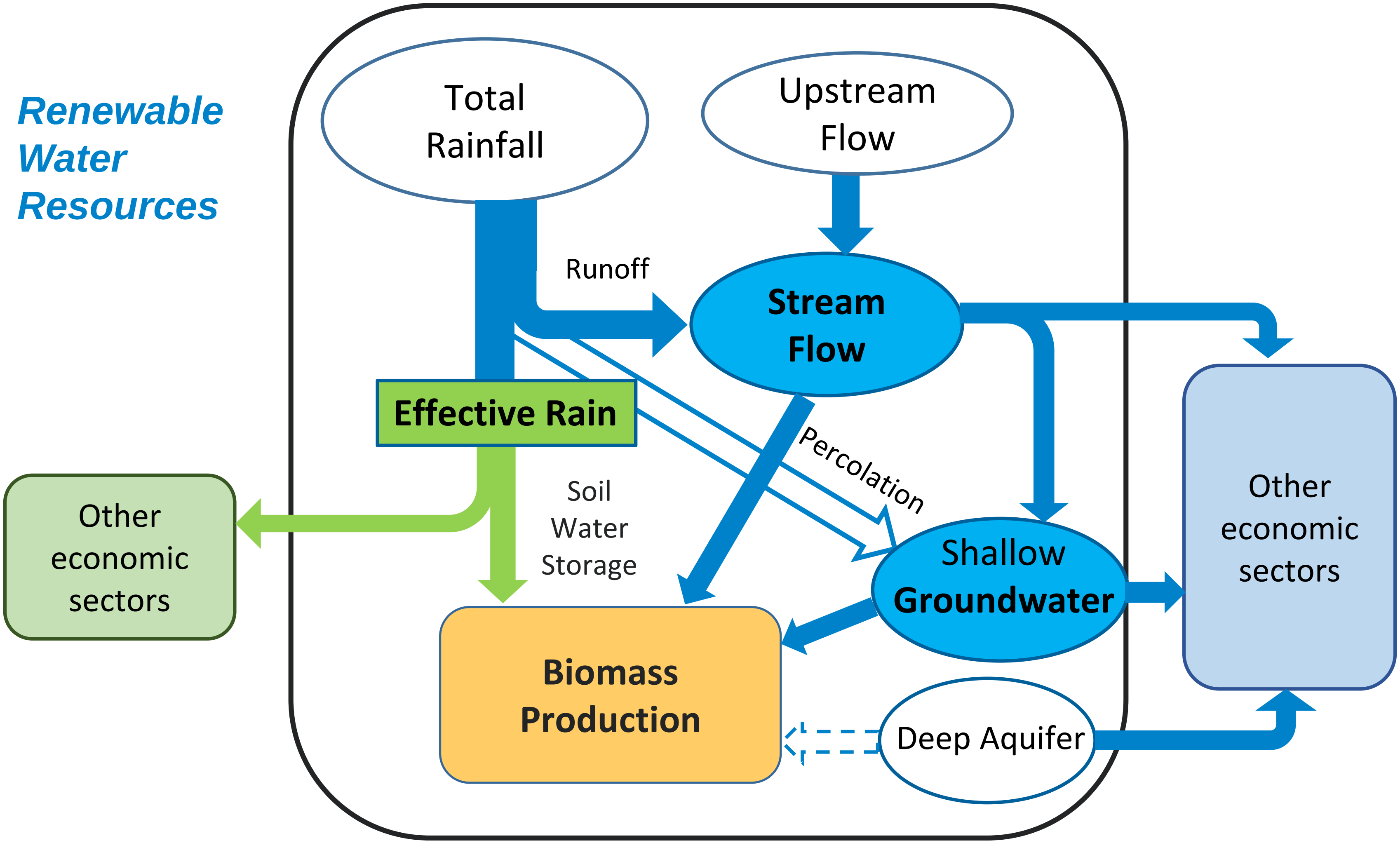
# TASK I. WAI analysis and WATER development

## WATER AVAILABILITY

***Renewable Water Resources***

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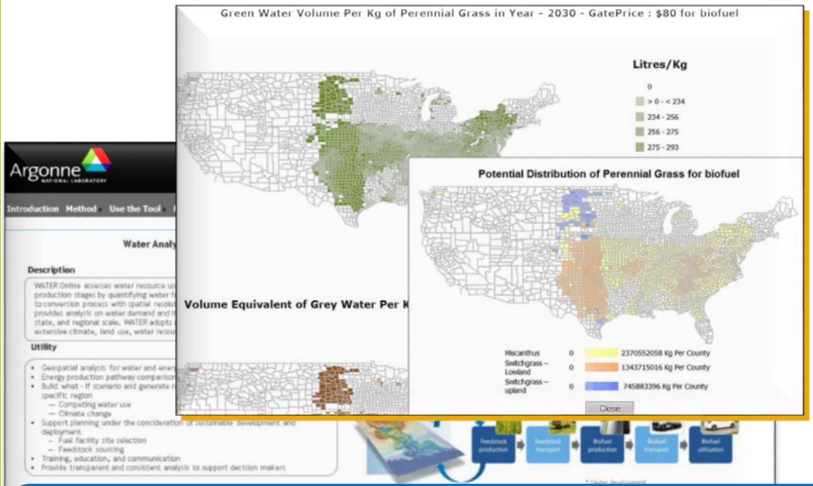
# WATER (Water Analysis Tool for Energy Resources)




## Fuel pathways

- Ethanol, biodiesel, renewable diesel blend, mixed alcohol blend
  - Corn (grain, fiber, stover), soy bean, wheat straw
  - Switchgrass and Miscanthus
  - Forest wood (hard, soft, mixed) residue
  - SRWC (willow, hybrid poplar)
- Petroleum
  - Conventional
  - Oil sands
- Electricity
  - Fossil, renewable, nuclear

## Application

- Assess water impact of future scenarios
- Evaluate production pathways
- Enable compatible spatial resolution with POLYSYS, LEAF, FAPRI, and other models/tools
- Support BETO with spatial-explicit water analysis, allowing analysis of the interplay among policy, economics, and environmental factors

## Features

- Water footprint at county level for the United States
- Feedstock production and conversion stages
- Agriculture and forestry
- Surface water, renewable groundwater, rain
- Metric: water consumption intensity, water availability indices

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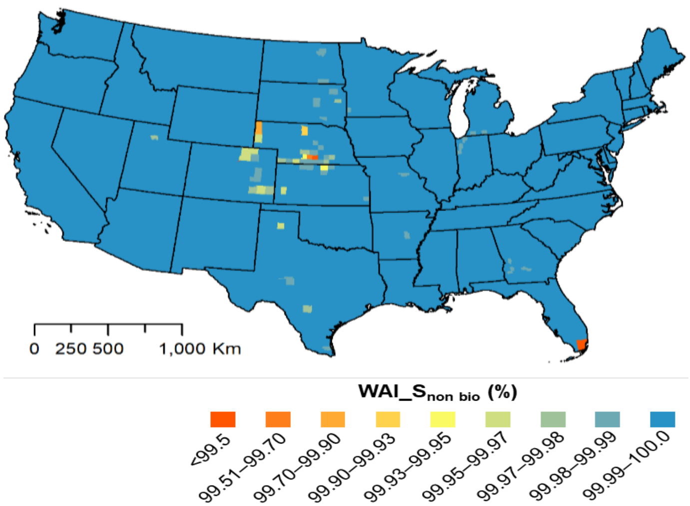
# TASK I. WAI analysis and WATER development

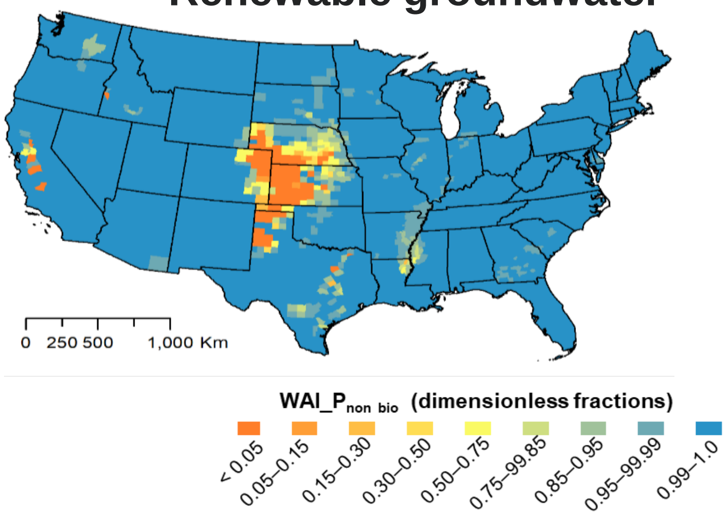
## BLUE WATER WAI

*Water Availability After Meeting Feedstock Demand*

**Surface water**




**Renewable groundwater**




- Surface water use for irrigating bioenergy crops accounts for less than 0.1% of total flow at county level nationally.
- Renewable groundwater use for irrigation varies significantly in geographical regions; some regions could require up to full capacity of annual renewable groundwater resource (high stress) if
  - Groundwater from *deep aquifer* is not used for irrigation and
  - Crop water demand is fully met.

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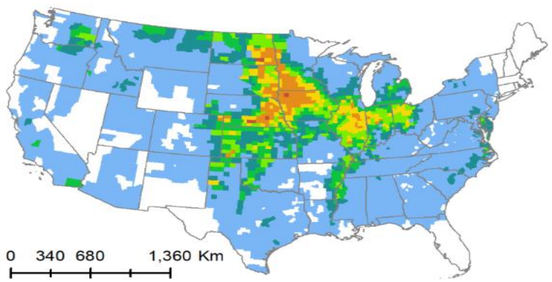
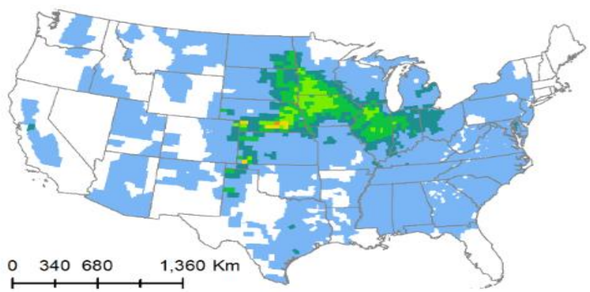
# TASK I. WAI analysis and WATER development

## GREEN WATER WAI

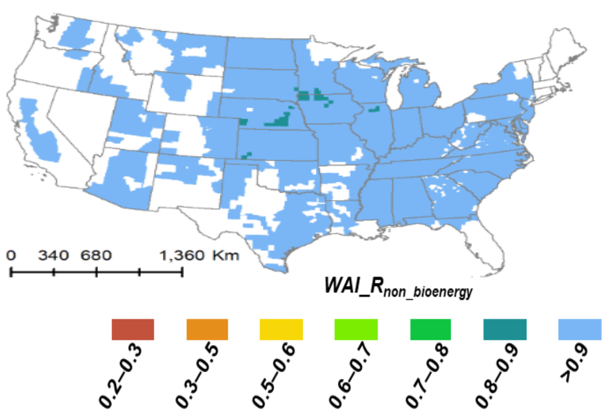
*Water Availability Comparison*




- When crop water demand of total *corn, soybeans, and wheat* production for **agriculture and bioenergy** is met.




- When crop water demand of total *corn* production for **agriculture and bioenergy** is met.




- When crop water demand of total *corn* production for **bioenergy** is met. On average, >90% of green water resources are available most counties in IA, NE, MN, and IL.

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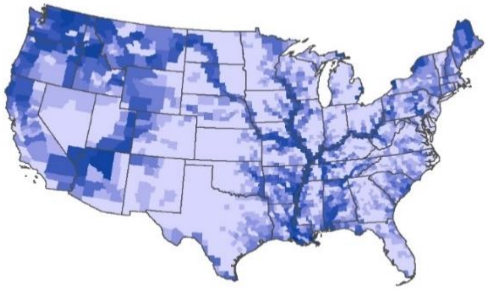
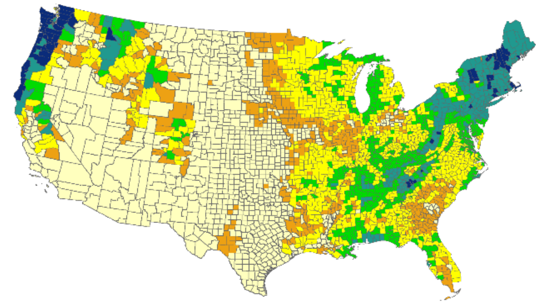
# WATER RESOURCE MAPPING

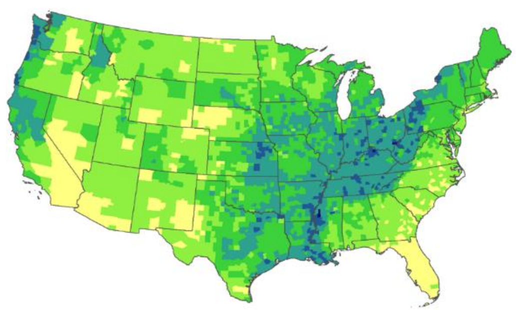
Annual Streamflow



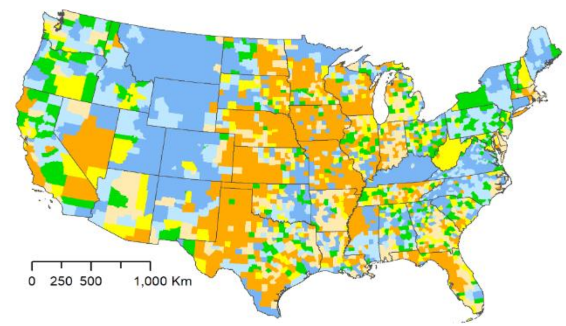
Annual Renewable Groundwater Flow



Monthly Soil Moisture Content



Irrigation Sourced from Groundwater




- Sustainable production of bioenergy and bioproducts can be achieved by planning feedstock and biorefinery production in areas with rich renewable groundwater and/or stream flow.
- Resource mapping provides a base for developing a management strategy that optimizes renewable water use, thereby preserving and protecting deep freshwater aquifer.

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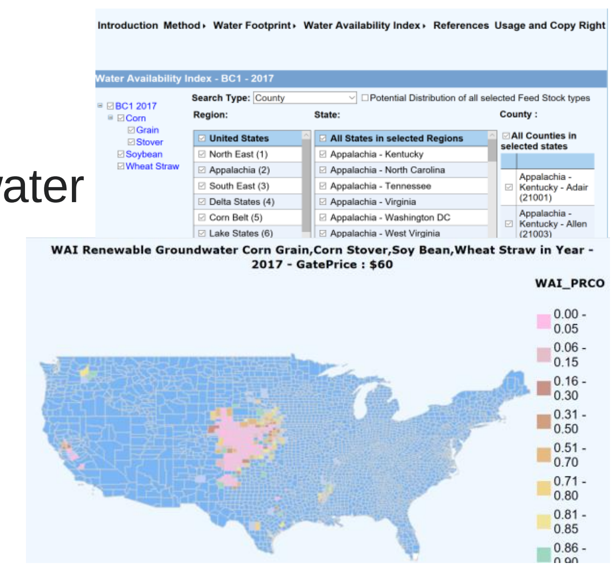
# WATER MODEL NEW ADDITIONS

- Major structural design to implement parallel platforms for integrated water analysis
  - Pathway platform: Water Footprint
  - Regional platform: Water Footprint, Water Availability Index (WAI)
- WAI module
  - Three WAIs (rainwater, surface water, and renewable groundwater)
  - Six BT16 agriculture and forestry scenarios
  - County, state, region
- Corn fiber biofuel pathway (50%)
- Water resource data inventory
  - Soil moisture, surface stream, renewable groundwater
- Database searching feature
  - Open to all stakeholders
- WATER link in KDF
- Biorefinery water use update (60%)




WAI module

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# TASK II. Water quality modeling and analysis

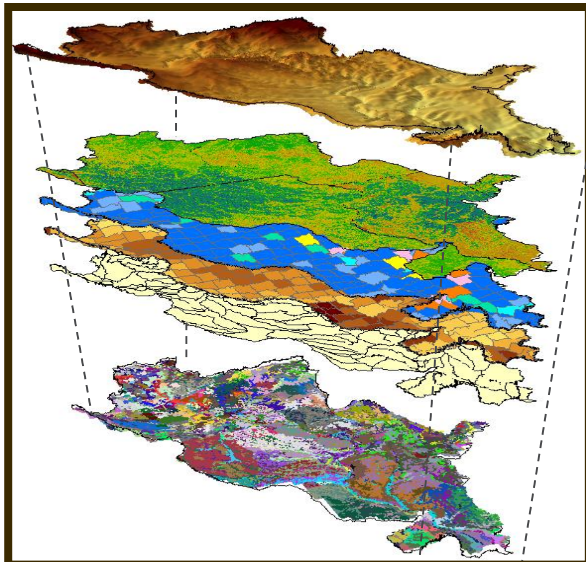
# SWAT MODELING

*Physical process-based model with empirical components derived from field data*

Topography

Water use

Subbasin



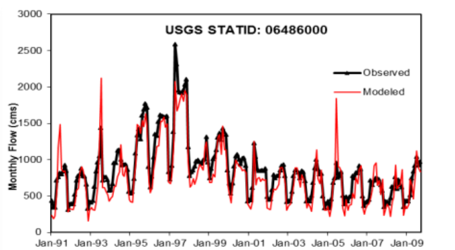
Land use, crop rotation

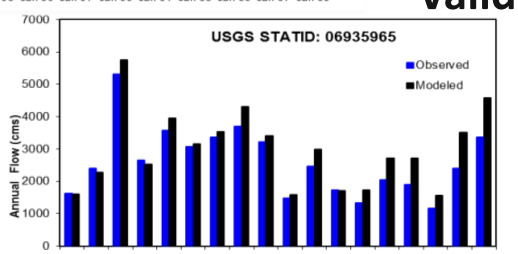
Fertilizer

Soil map

## Other Drivers and Input

- Climate
- Tile drainage
- Tillage
- Irrigation
- Point source
- Reservoirs




**Calibration and Validation**

## SWAT

**Hydrologic Cycle** ↔ **Crop Growth**

***Integrated Simulation***

**Nutrient Cycle** ↔ **Routing**

**Hydrology**
- Runoff
- Evapotranspiration
- Groundwater
- Soil moisture

**Water Quality**
- Nutrients
- Erosion
- Pesticides

**Biomass**
- Yield

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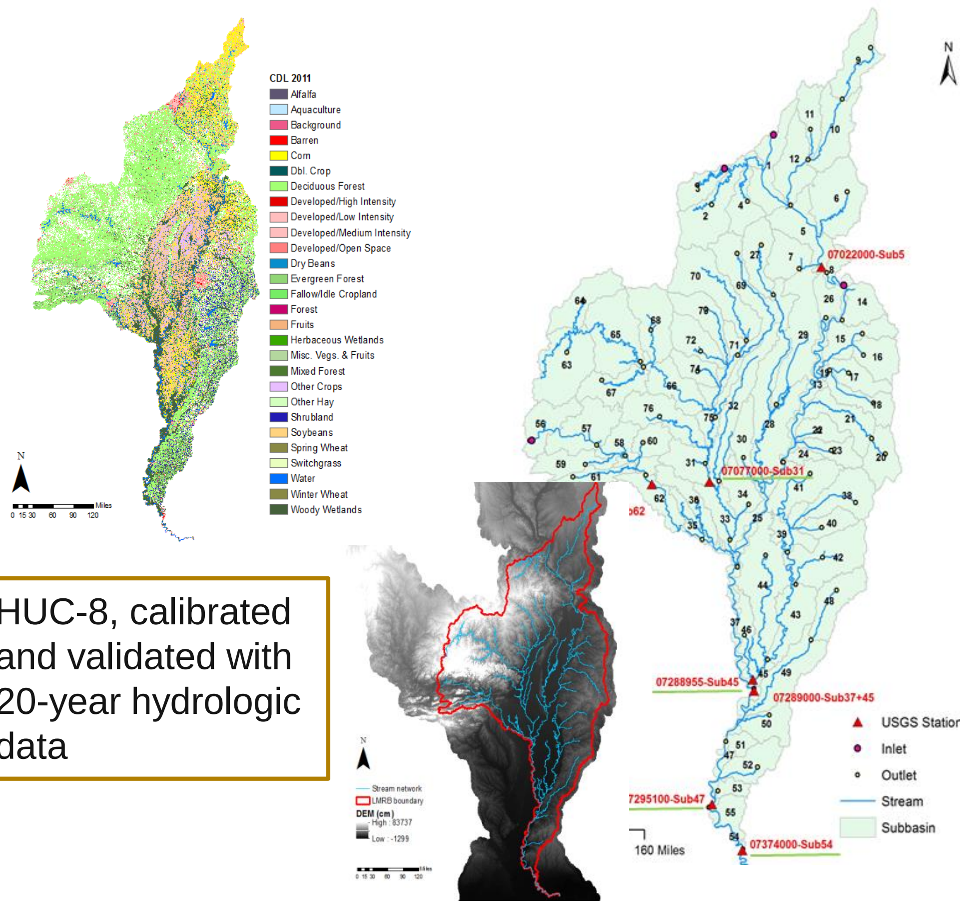
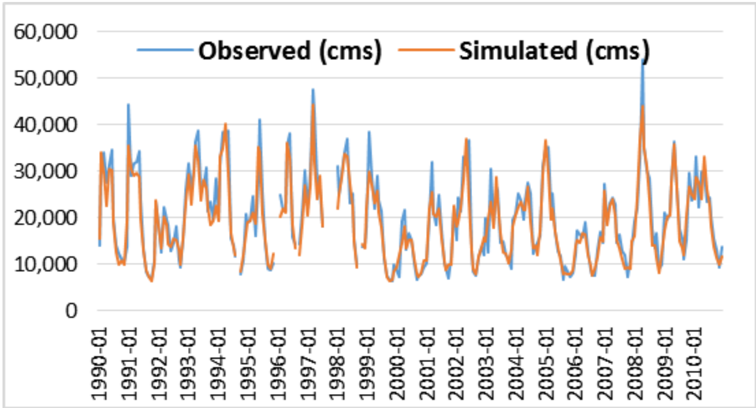
# TASK II. Water quality modeling and analysis

# SWAT WATERSHED ANALYSIS




- Historical baseline
- Potential biomass production scenarios




HUC-8, calibrated and validated with 20-year hydrologic data

Nitrogen
Phosphorus
Sediments

**Conservation Practices**

**Value proposition of reducing nutrient loss**

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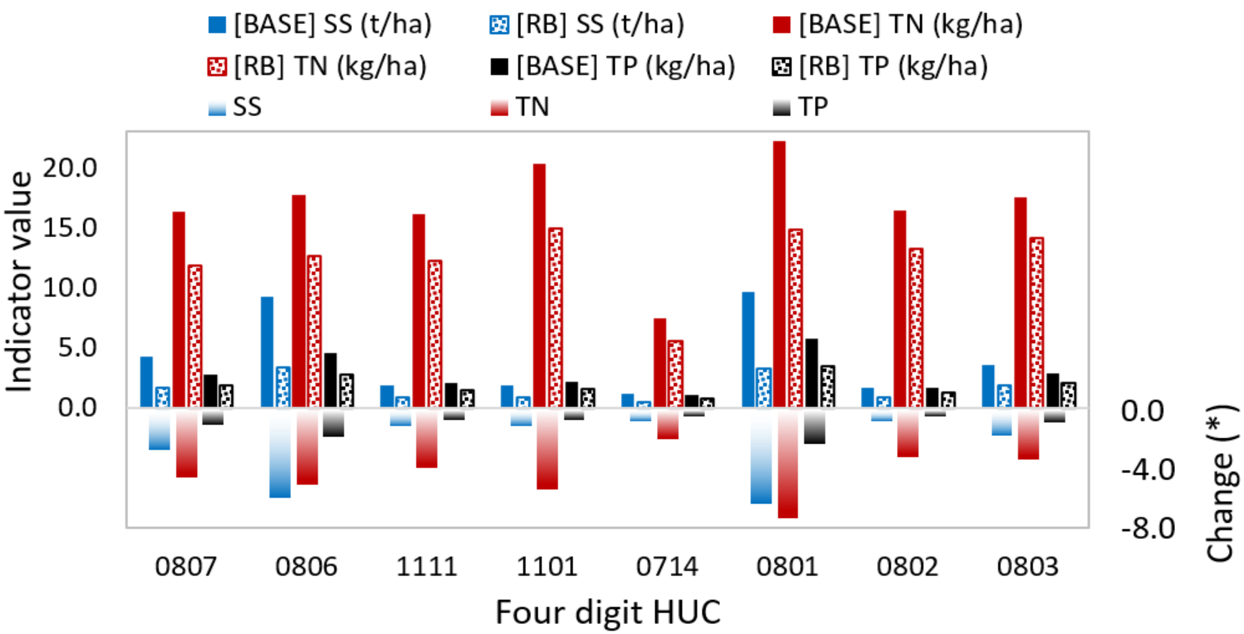
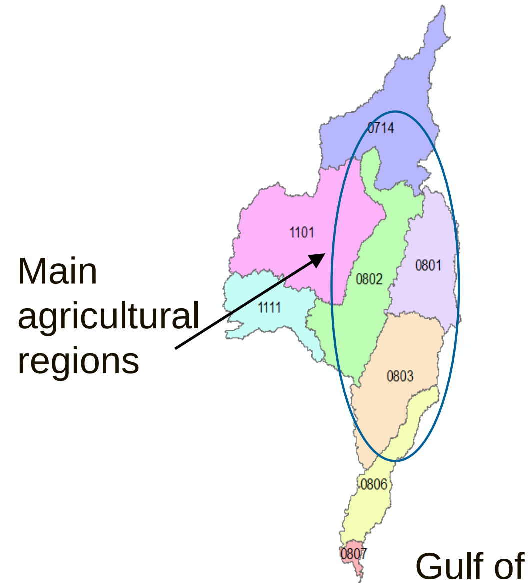
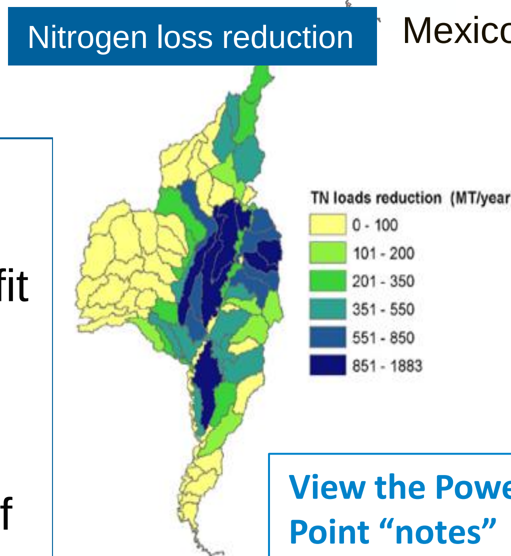
# WATER QUALITY BENEFITS OF MULTIPURPOSE BUFFER IN LOWER MRB




- Significant decrease in nitrogen and sediment loss across all regions when multipurpose buffer is installed in agriculture land. Water quality in Region 0801 would benefit most from the buffer per acre basis.
- Region 0807 is at the outlet to the Gulf of Mexico. If multipurpose buffer is installed in all riparian zones in LMRB, 30–60% of TN, TP, and SS loads output to the Gulf could be avoided.

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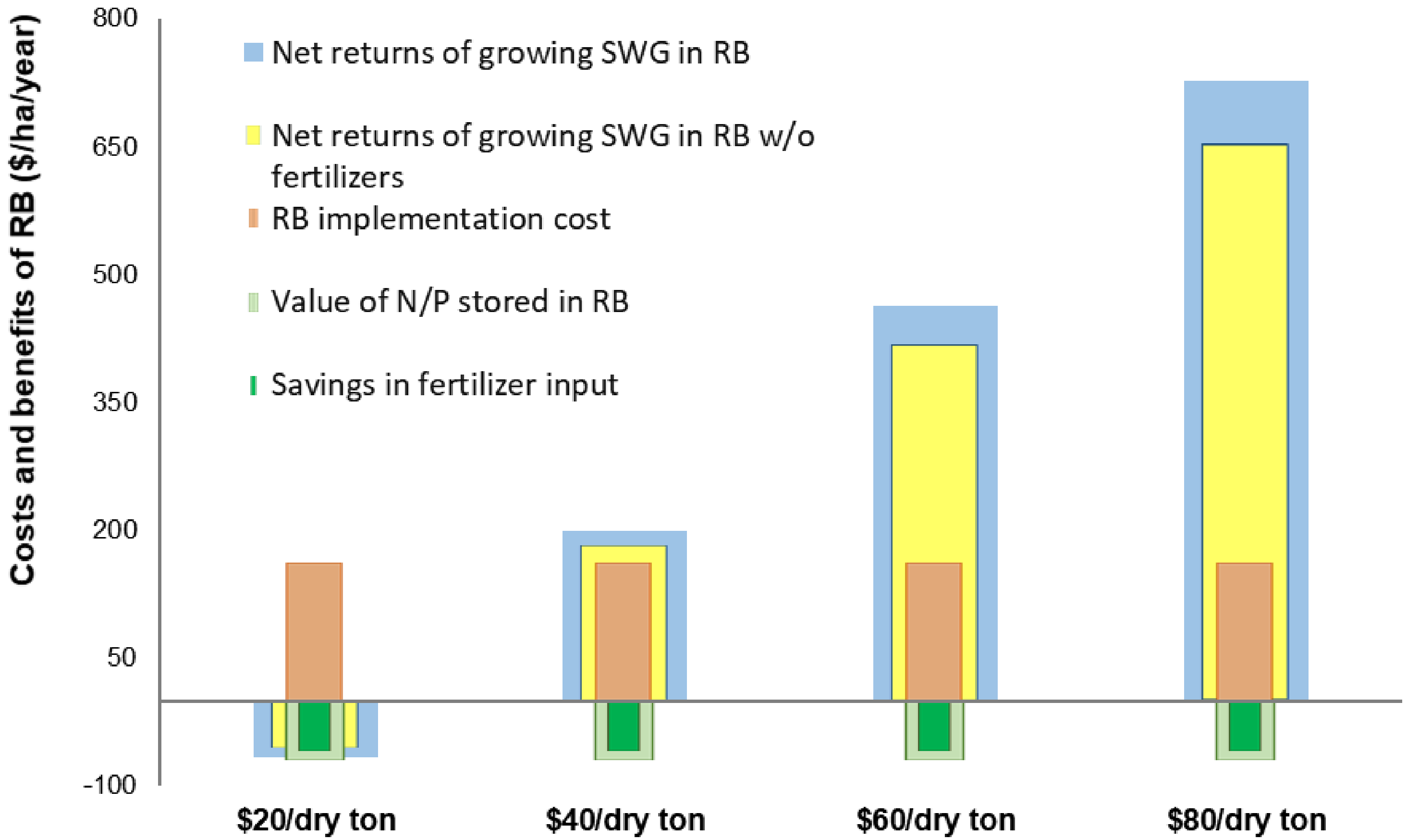
# ECONOMIC COSTS AND BENEFITS OF *MULTIPURPOSE BUFFER* IN LOWER MRB

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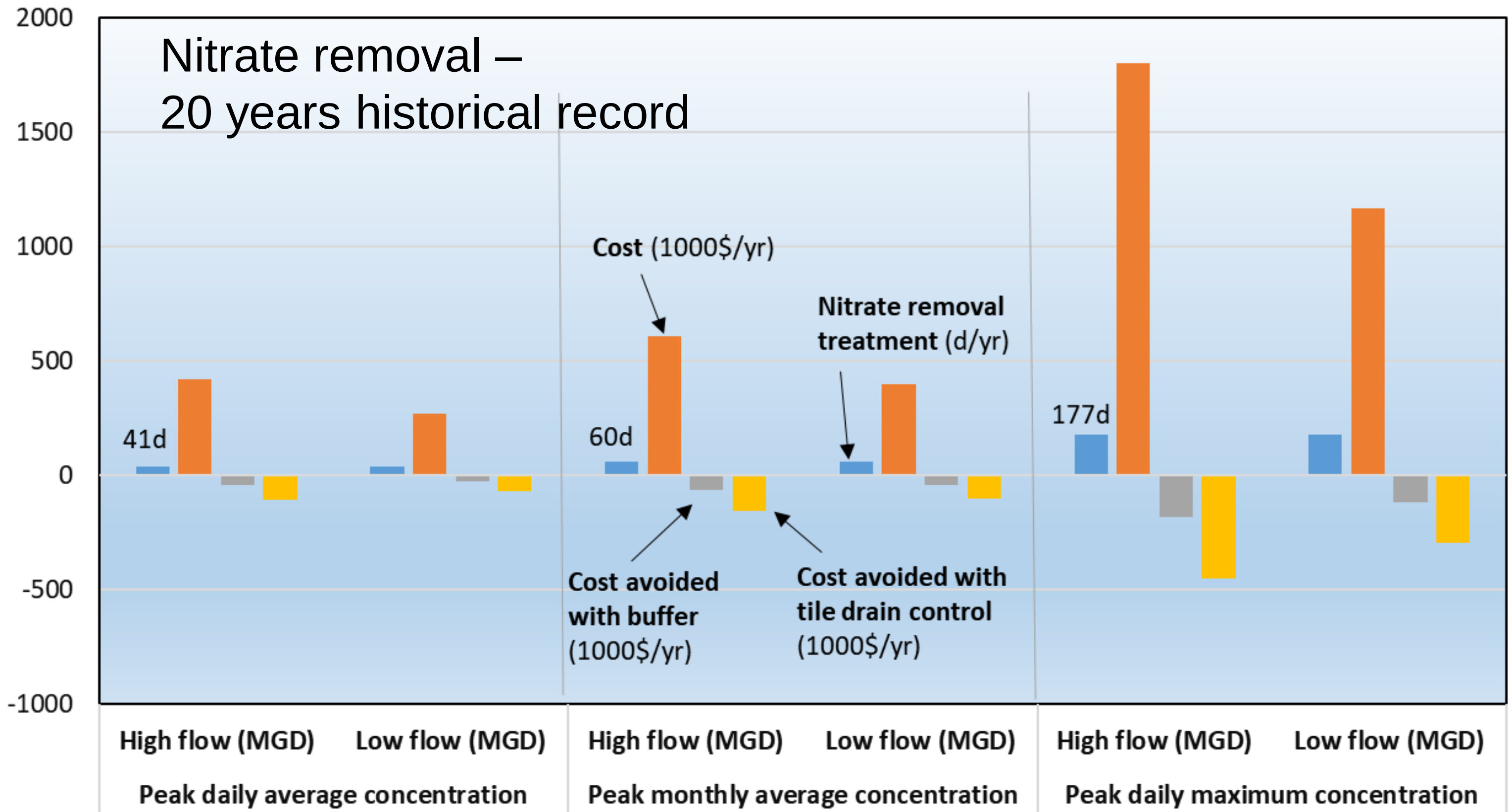
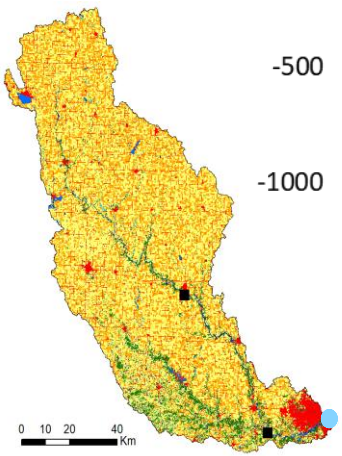
TASK II. Water quality modeling and analysis

# ECONOMIC BENEFITS OF NUTRIENT LOSS REDUCTION TO REGIONAL WATER SUPPLY




Raccoon River Watershed




Des Moines Waterworks

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# STAKEHOLDER ENGAGEMENT – *EERE BETO WEBINARS*

- "*Freshwater Availability for Bioenergy Production in the United States – Assessment and Issues*"
  - Summarizes freshwater resources that are available to bioenergy, agriculture, and other economic sectors, including rainwater, surface water, and renewable groundwater at county level for the United States under historical and potential future scenarios and uncertainties.
  - Attracted 132 registrants from various federal, state, and local government agencies, NGOs, academic institutions, and industries in the United States and abroad.

- *"Simulating water quality and hydrology responses to growing biomass feedstock in the Mississippi River Basin (MRB)"*
  - Summarized MRB water quality modeling and assessment of bioenergy production under historical baseline, future scenarios, and conservation practices for Upper MRB, Ohio RB, Missouri RB, Arkansas RB, Tennessee RB, and Lower MRB and its impact on nutrient and sediment runoff to the Gulf of Mexico.
  - Jointly delivered by ANL and ORNL.

Key take-away:
- Broadcast findings, conclusion and uncertainties.
- Seek feedbacks, needs, and future directions.

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# STAKEHOLDER ENGAGEMENT –

- Close interaction with government agencies, reached out to state and local agencies and non-public sector entities.
  - American Water Resource Association meetings, USGS – *Water resource availability, water infrastructure, data and tools.*
  - Greeley & Hansen, Des Moines Waterworks, MWRDGC, WEF –*Monitoring, management, and technologies for freshwater and reclaimed water resources.*
  - NBF, RFA, Poet – *Water consumption assessment in biorefinery.*
  - IL Nutrient Loss Reduction Strategy (IEPA) bi-annual meetings – *Strategy development and implementation; conservation practices evaluation*
  - Chesapeake Bay Program STAC – *Implement conservation practices, water quality monitoring and modeling workshop*
  - USDA NRCS [1]
- Maintained collaboration with Antares – *landscape design*

Key take-away:

- Keep track of the development and issues in water resource monitoring, use and water technologies with water professionals and entities.
- Communication with water conservation community and agriculture stakeholders on approaches to improve water quality by using biomass.

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# RELEVANCE TO BETO

- Addresses several BETO **technical barriers** and challenges, including:
  - **At.-B.** High-quality analytical tools and models to enable informed decision-making.
  - **At.-H.** Science-based, multi-stakeholder strategies to integrate bioenergy with agricultural systems that can improve land-use management to maintain crop yields while supporting ecosystem services.
  - **At.-E.** Quantifying economic, environmental, and other benefits and cost to understand trade-offs and enhances synergies among various factors.
- Informs BETO's strategic thinking by evaluating the potential **degree of impact** of energy policies on natural resource using the system analysis and models.
- Provides **leverage** to other BETO projects:
  - Developing and simulating landscape design scenario for biomass production and evaluate water quality impact that supports Antare's Landscape design project (FY19).
  - Sharing SWAT Raccoon River watershed model for water modeling task in the landscape TEA with BETO *Integrated Landscape Management* project.
- Communicating water consumption and water resource availability with SCSA and other tools.

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# RELEVANCE TO THE BROADER COMMUNITY

- Reliable platform and models that examine water sustainability metrics:
  - WATER translates feedstock/pathway selection and biomass production scenarios into estimates of water demand, water footprint, and water availability/stress; and provides a water data inventory.
  - SWAT modeling permits multi-scale watershed analysis of water quality impacts of future feedstock production scenarios and evaluates approaches to reduce nutrient and sediment burdens. In conjunction with cost and benefits consideration, further analysis develops value proposition of reducing nutrient loss using biomass.
- Science-based consistent assessments on impacts of water resource management that support informed decision making for technologically viable commercial bioenergy applications.
- Journal publications, KDF, webinars, and presentations in major venues for water resource and bioenergy communities.

**Water resource use and water quality are key areas for sustainable bioeconomy**

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

# FUTURE WORK

*Key milestones are underlined*

- Complete regional platform design and configuration, update petroleum oil water consumption in WATER, and test WAI module and new features.
- Complete implementation of corn fiber pathway in WATER.
- Release of WATER 4.0, which is able to simulate WF and WAI for a given pathway and/or six BT16 scenarios at county, state, and regions, and contains updated water consumption in biofuel pathways.
- Design an algae pathway in WATER that accounts for reclaimed wastewater supplemented by freshwater for bio-oil production covering cultivation, harvesting, and conversion stages[1].
- Release of assessment for reclaimed municipal wastewater available (WAI_M) under BT16 production scenarios in the United States at the county level. The assessment is summarized in a manuscript for peer-reviewed journal publication.
- Complete a survey analysis that summarizes current practices and progress in water use and management in biorefinery at facility level, evaluate progress, and identify areas critical to continued improvement in water efficiency and wastewater/solids management.

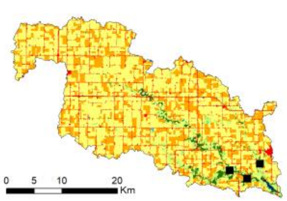
[1]View the PowerPoint "Notes" page for additional information.

# FUTURE WORK

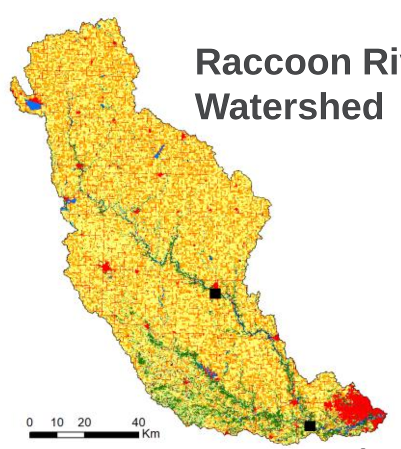
- Simulate biomass production through stover harvest, land conversion to switchgrass and cover crops by using SWAT model to demonstrate water quality benefits of bioenergy production based on landscape design in North Raccoon and South fork of Iowa River watersheds. This task will be completed in collaboration with Landscape Design project[1].
- Develop and submit a joint publication for the ACPF[2] - SWAT modeling work with USDA ARS, Iowa State University, and other participating institutes and organizations.
- Go/No Go decision point [3]
  - Review biorefinery water survey data, estimate response rate and the degree of industry representation to determine whether effort will be needed to reach out additional facilities for data collection.
  - Address uncertainties.

*Key milestones are underlined*

**SFIR Watershed**




**Raccoon River Watershed**




**[2, 3] (View the PowerPoint "Notes" page for additional information)**

# SUMMARY

## Geospatial Analytical Framework for Water Sustainability

### *Overview*

- Design and develop tools that illustrate annual available water resources and water footprint for bioenergy production.
- Simulate nutrients and sediment loadings associated with feedstock production; evaluate water quality effect by using hydrologic modeling.

### *Approach*

- Collaborate with water and agriculture agencies, partner with public and private sectors, seek input from stakeholders, and identify synergies.
- Develop well-defined framework, consistent methodology, and rigorous calibration; incorporate spatial and temporal resolution with national coverage.

### *Relevance*

- Provide BETO with models and tools (WATER, SWAT) and science-based analysis that is consistent, reliable, and high quality to address water issue.
- Provide DOE stakeholders with quantifiable economic and environmental value proposition analysis to inform decision-making.

### *Key Technical Accomplishments*

- WAI of 6 BT16 scenarios for 3 freshwater resources (green water, surface, groundwater).
- Water resource inventory of reclaimed municipal wastewater for United States.
- SWAT water quality simulation of multi-purpose buffer in Lower MRB.
- Cost and benefits of implementing multipurpose buffer biomass in agriculture land.
- Value proposition of reducing nitrogen loss to downstream municipal water supply.
- 8 peer-reviewed journal publications, 2 EERE BETO webinars, and 1 National Lab Technical Report.

### *Future work*

- Release of WATER 4.0
- Algae pathway in WATER, reclaimed water WAI
- SWAT model of marginal land for biomass
- Water consumption survey documentation

# Acknowledgements

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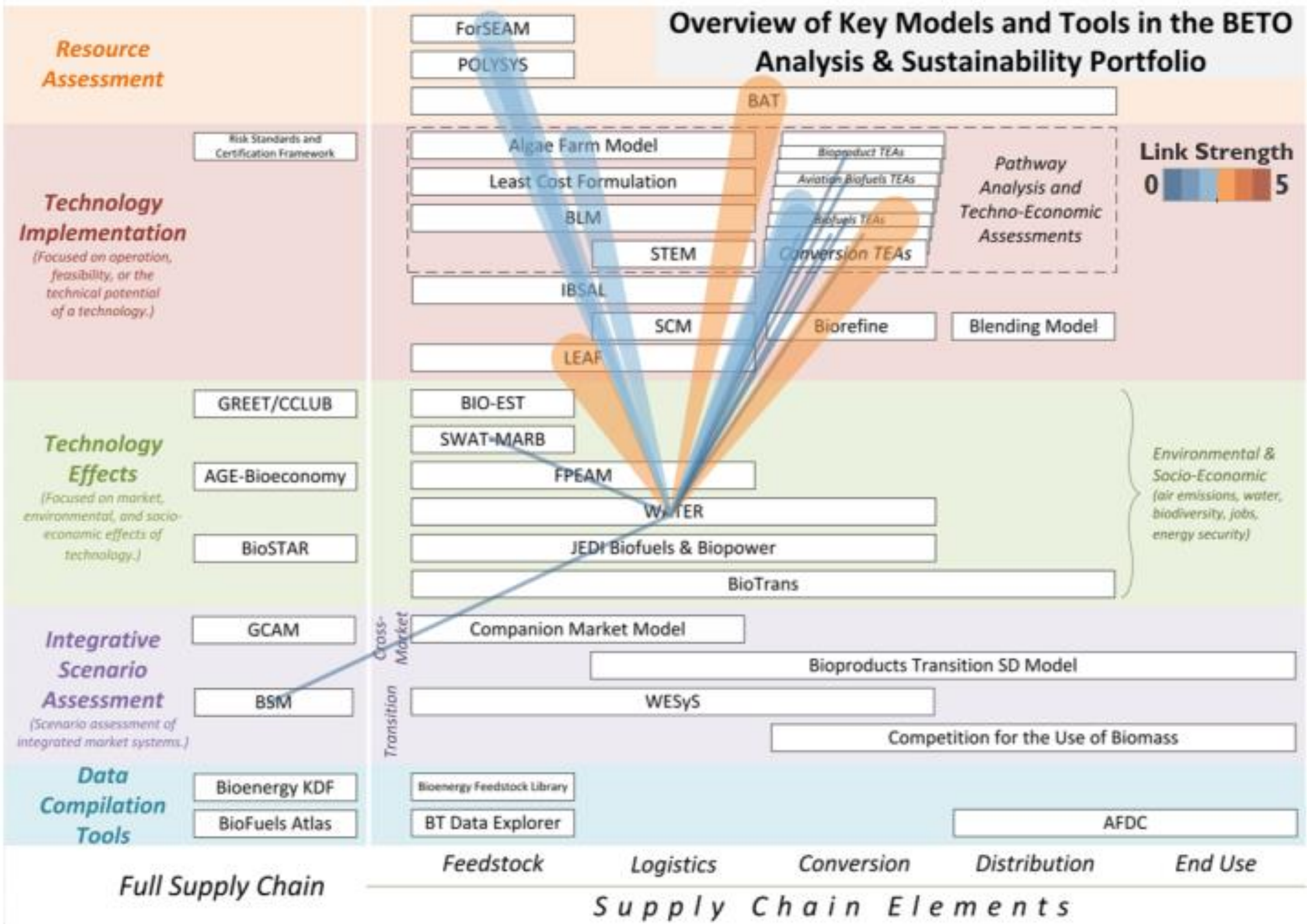
- Des Moines Waterworks
- Greeley & Hansen
- RFA, NBF
- ANL: Cristina Negri, Michael Wang

# APPENDICES

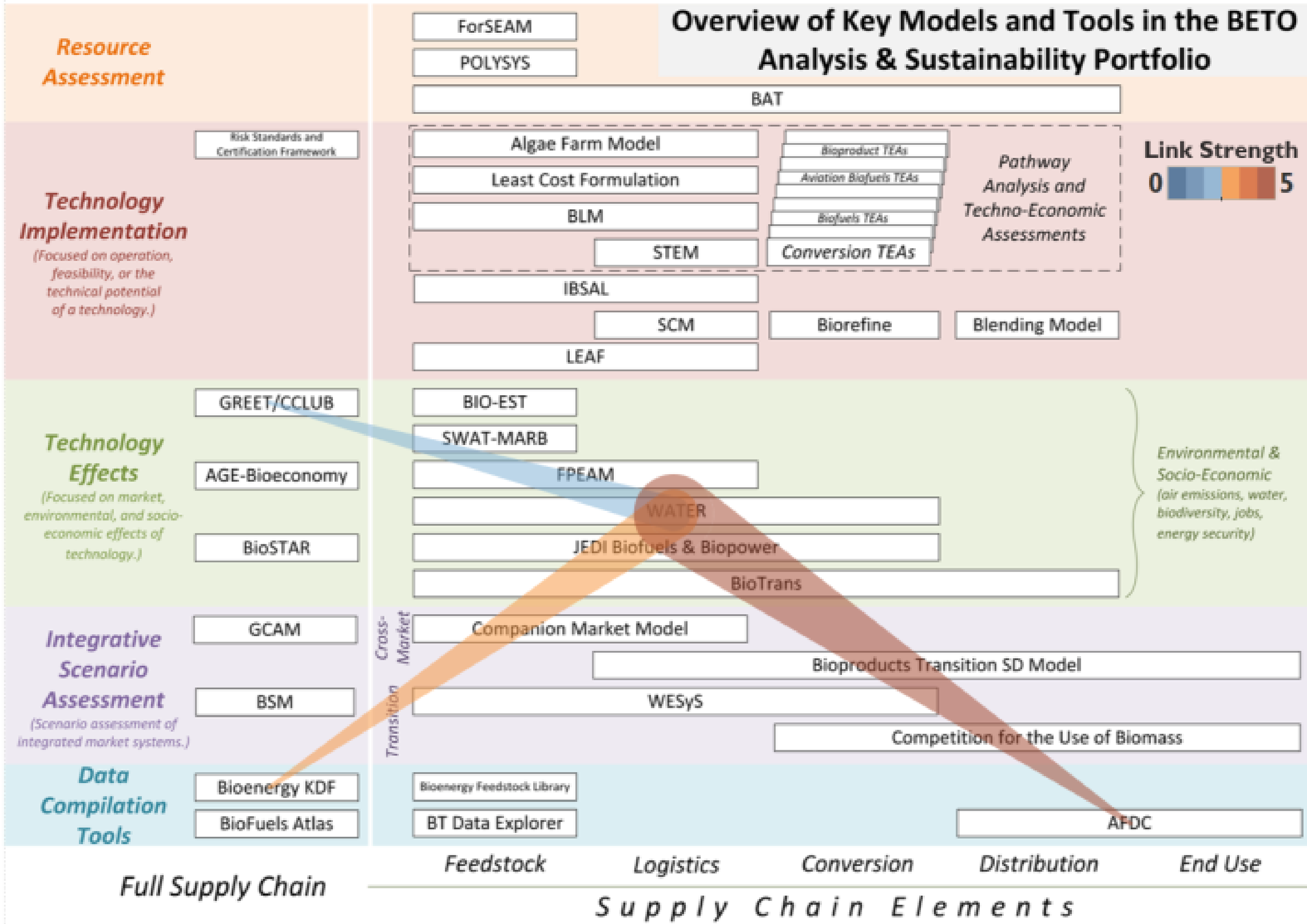
# APPENDIX 1

# WATER- INPUTS



# APPENDIX 2

# WATER - OUTPUTS



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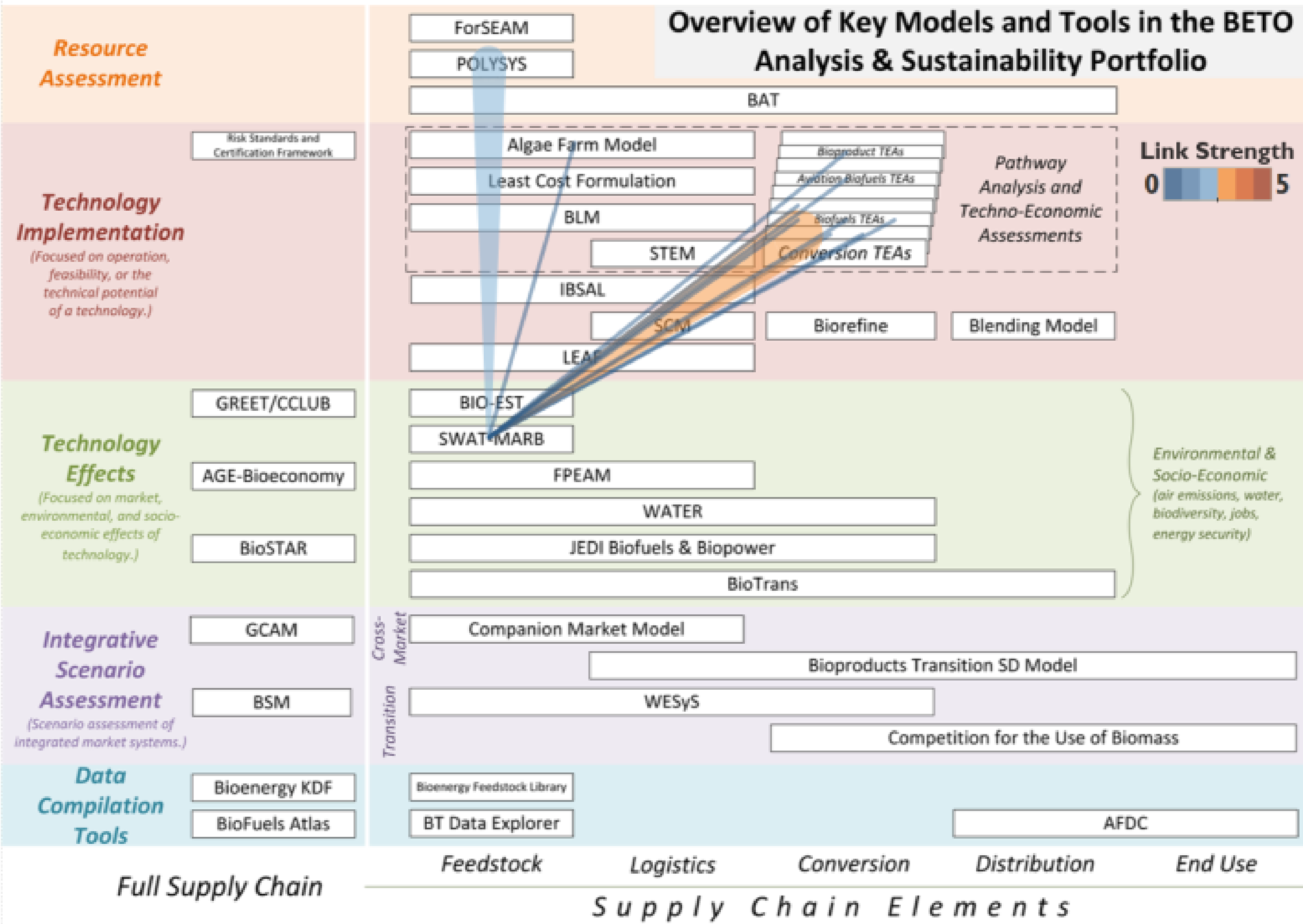
# APPENDIX 3

# SWAT-MARB - INPUTS



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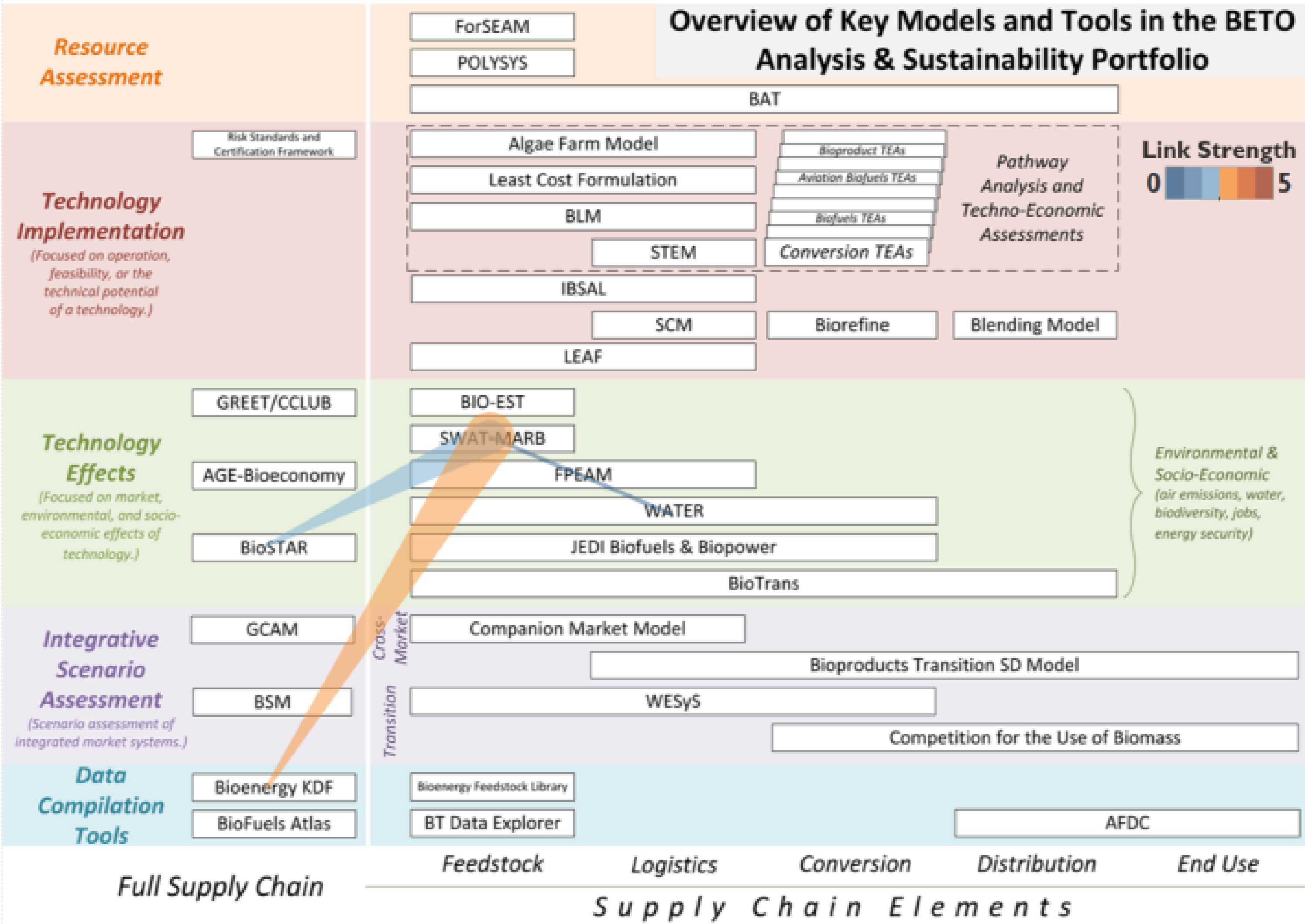
# APPENDIX 4

# SWAT-MARB - OUTPUTS



# APPENDIX 5: DEFINITIONS

- **BMPs –** Best management practices
- **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*)
- **LMRB** – Lower Mississippi River Basin
- **MRB** – Mississippi River Basin
- **Renewable Diesel Blend (RDB) –** Fuel produced from biological sugar-to-hydrocarbon process
- **SWAT –** Soil Water Analysis Tool, a hydrologic watershed model
- **WAI** – Water availability indices.
- **$WAI\_R_{non\ bio}$**: Rainwater (or green water) available for non-bioenergy sectors.
- **$WAI\_S_{non\ bio}$**: Surface water resource available for non-bioenergy sectors.
- **$WAI\_P_{non\ bio}$**: Renewable groundwater resource available for non-bioenergy sectors.
- **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)

# APPENDIX 6

# RESPONSES TO PREVIOUS REVIEWERS' COMMENTS (2017)

**Comments:**

This project is core to developing BETO's capacities on water impact side. It would be helpful to think about how the results can best be disseminated and made useful to stakeholders.

The project appears to be progressing well. Stakeholder engagement is strong. Consideration should be given to better engaging non-public sector entities such as private industry or NGOs.

It was suggested in the 2015 Peer Review that algae would be a great addition to the WATER model. I would like to encourage BETO to do this since water is such an integral part of algae system. It would complement BETO's ongoing work on algae and add a robustness to water modeling.

**Responses:**

We thank reviewers for recognizing our accomplishments and recommending future strategies. We are working on a plan to disseminate data and communicate results and tools as a result of this work to the scientific community and general public via various channels (e.g., webinars, journal publications). We will increase engagement with private sectors. We will also consider adding an algae pathway to WATER.

# APPENDIX 7

# PUBLICATIONS (*SINCE 2017 REVIEW*)


- Wu, M., M. Mintz, M. Wang, S. Arora, Y-W Chiu, and H. Xu, 2018. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline – 2018 Update*. Argonne National Laboratory Technical Report, **ANL/ESD-09/01 Rev.2**, Argonne National Laboratory, Lemont, IL, U.S.A.
- Xu, H., M. Wu, and M. Ha, 2018. *A county‐level estimation of renewable surface water and groundwater availability associated with potential large‐scale bioenergy feedstock production scenarios in the United States*. ***GCB Bioenergy***. 2018; 00:1–17. https://doi.org/10.1111/gcbb.12576.
- Ha, M., Z. Zhang, and M. Wu, 2018. Biomass production in the Lower Mississippi River Basin: Mitigating associated nutrient and sediment discharge to the Gulf of Mexico. ***Science of the Total Environment***, DOI: 10.1016/j.scitotenv.2018.03.184.
- Lampert, D., and M. Wu, 2018. Automated Approach for Construction of Long-Term, Data-Intensive Watershed Models, ***J. Comput. Civ. Eng***., 2018, 32(4): 06018001. DOI: 10.1061/(ASCE)CP.1943-5487.0000762.
- Xu, H., M. Wu, and M. Ha, 2018. The value proposition of reducing nutrient loss from agricultural fields by growing riparian buffers as bioenergy feedstock in the Lower Mississippi Basin. ***BioFPR.*** https://onlinelibrary.wiley.com/doi/abs/10.1002/bbb.1930
- Wang, M.-H., P.-C. Tseng, J.-C., Wen, C.-Y. Yu, P.-C. Chiang, and M. Wu. Sustainable water resource management for agriculture water use: A case study of Zhuoshui River Watershed, Taiwan. Under review.
- Xu, H., and M. Wu, 2018. A First Estimation of County-Based Green Water Availability and Its Implications for Agriculture and Bioenergy Production in the United States, ***Water*** Special Issue: Progress in Water Footprint Assessment, 10(2), 148; doi:10.3390/w10020148.
- Demissie, Y., E. Yan, and M. Wu, 2017. Hydrologic and Water Quality Impacts of Biofuel Feedstock Production in the Ohio River Basin, ***GCB Bioenergy*** (2017) 9, 1736–1750, doi: 10.1111/gcbb.12466.
- Liu, J., G. Mao, A.Y. Hoekstra, H. Wang, J. Wang, C. Zheng, M.T.H. van Vliet, M. Wu, B. Ruddel, and J. Yan. 2018. Managing the energy-water-food nexus for sustainable development, ***Applied Energy***, Special Issue on Energy-Water-Food Nexus, 210, 377-381. DOI:10.1016/j.apenergy.2017.10.064

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## APPENDIX 8

# PRESENTATIONS (*SINCE 2017 REVIEW*)

- Johnson, K., M. Wu, and Y. Jager, **EERE BETO Webinar***: Simulating Water Quality and Hydrology Responses to Growing Biomass Feedstock in the Mississippi River Basin,* Dec. 6, 2018.
- Wu, M., Project meeting: *Enabling Sustainable Landscape Design for Continual Improvement of Operating Bioenergy Supply Systems,* Dec. 11-12, 2018, Des Moines, IA.
- Ha, M., M. Wu, and H. Xu, *Harvestable Multipurpose Buffer: Evaluation Environmental Benefits and Cost,* Poster presented at **IL Nutrient Loss Reduction Strategy Workshop**, November 13, 2018, Champaign, IL.
- Ha, M., Z. Zhang, and M. Wu, *Biomass Production in the Lower Mississippi River Basin: Mitigating Associated Nutrient and Sediment Discharge to the Gulf of Mexico*, 2018 **AWRA Annual Water Resources** Conference, November 4-8, 2018, Baltimore, MD.
- Xu, H., M. Wu, and M. Ha. *Renewable Surface and Groundwater Water Availability for Future Production Scenarios: Impacts of Soil Moisture on Irrigation Demand Estimate*, 2018 **AWRA Annual Water Resources** Conference, November 4-8, 2018, Baltimore, MD.
- Wu, M., *Update on Incoming Water Crisis,* Nineteenth Century Charitable Association, Oak Park, IL, Nov. 19, 2018.
- Wu, M., *Water Use, Water Quality and Water Resource Availability*, **Environmental Engineering Seminar**, Northwestern University, Evanston, IL, Oct. 5, 2018.
- Wu, M., M. Ha, and Z. Zhang, *Water Quality: Nutrients and Sediment Runoff*, The National Biodiesel Foundation 2018 **Sustainability and LUC Workshop**, St. Louis, MO, Sept. 27, 2018.
- Wu, M., H. Xu, and M. Ha, **EERE BETO Webinar**: *Freshwater Availability for Bioenergy Production in the United States – Assessment and Issues,* Sept. 17, 2018.
- Darling, S., Y. Lin, D.J. Liu, J. Quinn, M. Urgun-Demirtas, and M. Wu. *Water Research at Argonne: Comprehensive Strategies*. **Current - Technion collaborative research workshop**, March 12, 2018, Chicago, IL.
- Wu, M., *Uncertainties in Energy – Water Landscape: Assessment and Attributes*, **Center for Innovation through Visualization and Simulation (CIVS)**, Purdue University Northwest, Feb. 24, 2018, Hammond, IN.

# APPENDIX 9
# PRESENTATIONS (CONTINUED)

- Wu, M., *Water Sustainable Energy Production through Integrated Land and Feedstock Resource Management – Tools and Assessment*, **WATER@Wayne Seminar Series**, Wayne State University, Detroit, MI, Jan. 11, 2018.
- Ha, M., and M. Wu, *How Can We Manage Future Bioenergy Production to Protect Water Quality ? An Evaluation for A Mississippi River Tributary Basin*. Poster presentation at Inaugural **NLRS Partnership** Conference, Nov. 29, 2017, Springfield, Illinois.
- Wu, M., M. Ha, and H. Xu, *Water – A Water Impact Assessment Model Framework for Bioenergy and Agriculture,* 2017 **AWRA** conference, Session 11: The Water-Energy Nexus. Nov. 5-9, 2017, Portland OR.
- Wang, M., P. Tseng, M. Wu, and P. Chiang, *Sustainable Water Resource Management for Agriculture Water Use: A Case Study of Zhuoshui River Watershed, Taiwan,* 2017 **AWRA** conference, Session 19: Integrated Water Resources Management Nov. 5-9, 2017, Portland OR.
- Ha, M., and M. Wu, *Water Quality Evaluation for Agricultural Management Practices on Producing Bioenergy in an Upper Mississippi River Tributary Basi*n, 2017 **AWRA** conference, Session 11: The Water-Energy Nexus. Nov. 5-9, 2017, Portland, OR.
- Wu, M., *Water Footprint of Biofuels*, Nexus Coordinating Group, **Department of State,** Nov. 8, 2017.
- Wu, M., *Water Sustainable Energy Production through Integrated Land and Feedstock Resource Management*, **Workshop on the Sustainable Water Environment in Megacities and Megaregions**, Oct. 5, 2017, Chicago, IL.
- Xu, H., and M. Wu, *Water Footprint Implication of Proposed Future Production Scenarios*, poster presentation at Northwestern **Water Security Workshop**, Aug. 1, 2017, Chicago, IL.
- Xu, H., and M. Wu, *Water Footprint Implication of Proposed Future Production Scenarios - Issues in Green Water Estimate*, 2017 Joint **Conference ISIE and ISSST**, June 25-29, 2017, Chicago.
- Wu, M., *Environment Sustainable Agriculture and BioEnergy Production through Integrated Landscape Design and Water Resource Planning*, Science Node Virtual **Workshop on Food-Energy-Water Nexus**, **Texas Water Research Network**, April 19, 2017.
- Wu, M., *Integrated Water - Land Resource Management for Sustainable Production, Workshop on Dragon-to-Gate Program*, Argonne-National Taiwan University, Argonne, April 6, 2017.