Impact of Projected Biofuel Production on Water Use and Water Quality

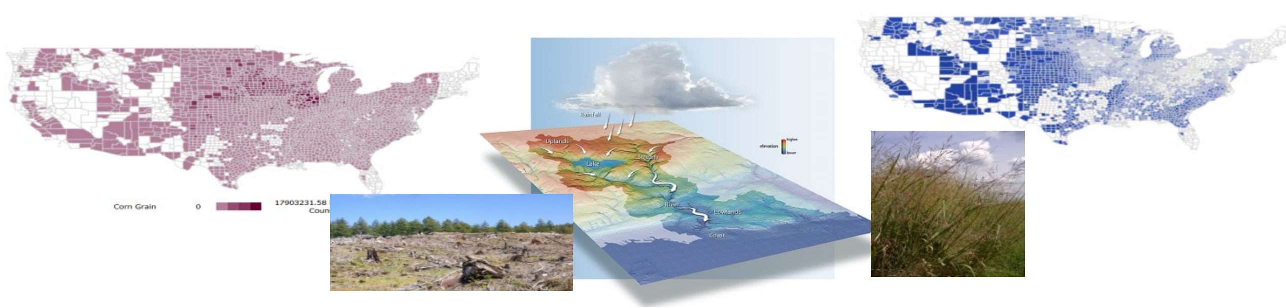
March 27-29, 2015

Analysis and Sustainability
WBS:4.2.1.10

May Wu
Argonne National Laboratory

Goal Statement

- Develop analyses on the water use associated with U.S. bioenergy and bio-products production
- Provide tools to quantify impacts on water quality and resources at multiple scales
- Support programmatic decisions by establishing quantitative metrics for enabling sustainable industry growth that reduces U.S. reliance on petroleum oil



Quad Chart Overview

Timeline

- Project start date: FY09
- Project end date: Project continuation and direction determined by DOE annually
- Percent complete: On going

Budget

	Total Costs FY 10 - 12	FY 13 Costs	FY 14 Costs	FY15 Planned Funding
DOE Funded	$1295K	$550K	$710K	$625K
Project Cost Share	N/A	N/A	N/A	N/A

Barriers

- **St.-B**. Consistent and science-based message on bioenergy sustainability
- **St.-D**. Implementing indicators and methodology for evaluating and improving sustainability
- **St.-E**. Best practices and systems for sustainable bioenergy production

Partners

- Collaborations/interactions:
  - INL (J. Jacobson; I. Bonner), ORNL (N. Griffith; Y. Jager; M. Langholtz), PNNL (L. Snowden-Swan), NREL (R. Davis).
  - U.S. Army Corp. Engineers, Purdue University (I. Chaubey)
  - USDA NRCS

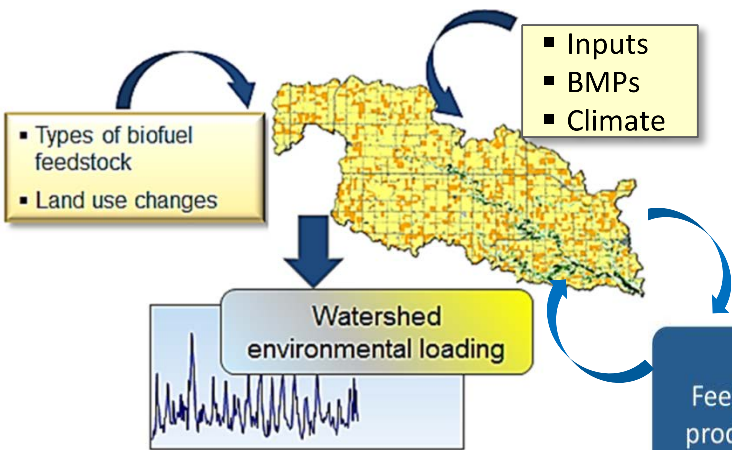
Definitions

- **Water footprint (WF) –** Net water loss to evapotranspiration and evaporation; incorporation of water into products or solids by a production process or activity
- **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
- **Water withdrawal –** Water uptake from surface or groundwater
- **Water consumption or Water use –** Water loss (accounted for in WF)
- **Blue water –** Surface and ground water
- **Green water –** Soil moisture from rainfall that used by vegetation
- **Grey water footprint –** Volume of wastewater and water required to dilute the chemicals in the wastewater to an acceptable level of concentration for the water body (specific to the WF methodology)
- **SWAT –** Soil Water Analysis Tool, a hydrologic watershed model
- **BMPs –** Best management practices
- **BOD –** Biochemical Oxygen Demand. The amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. It is used as an indicator of the degree of organic pollution in water

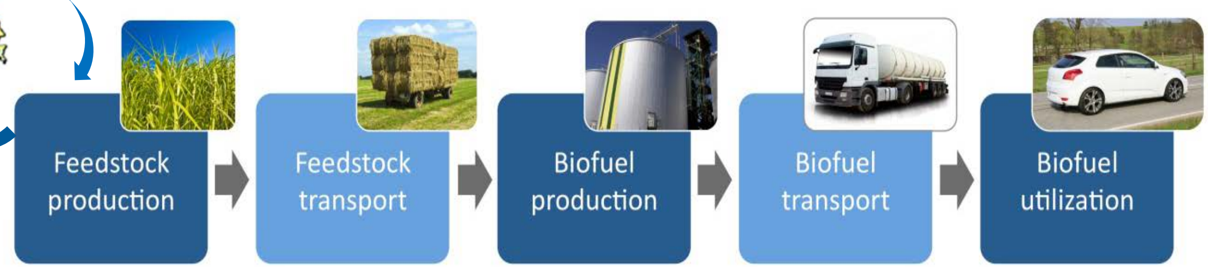
Project Overview

Objectives

- Develop analytical framework and tool to quantify the relationships between bioenergy production across various stages and **water use**, **water quality,** and **water resource** availability with spatial resolution
- Evaluate management practices in bioenergy landscapes that protect water resources and increase water-use efficiency
- Identify scenarios that are able to improve water sustainability of advanced bioenergy



Characteristics – ***Approach***
Region-specific – Watershed modeling
Production stage – Water footprint



Project Overview – Cont.

1 – Water Footprint Assessment

- Estimate water footprint of biofuels
  - Focus on freshwater use in production stages (feedstock and conversion)
  - Develop water quantity assessment across pathways: starch, oil seeds, algae, agricultural residue, perennials, forest resources, and new feedstock
  - Explore alternative water resource use
- Analyze water consumption in the production of baseline fuels
  - Petroleum, electricity, natural gas
  - Develop power-water tool

2 – Watershed Modeling

- Model water quality and hydrology for the bioenergy feedstock producing regions
  - Best management practices
  - Integrated landscape design
  - Future production scenarios
  - Climate impact

Key Aspects

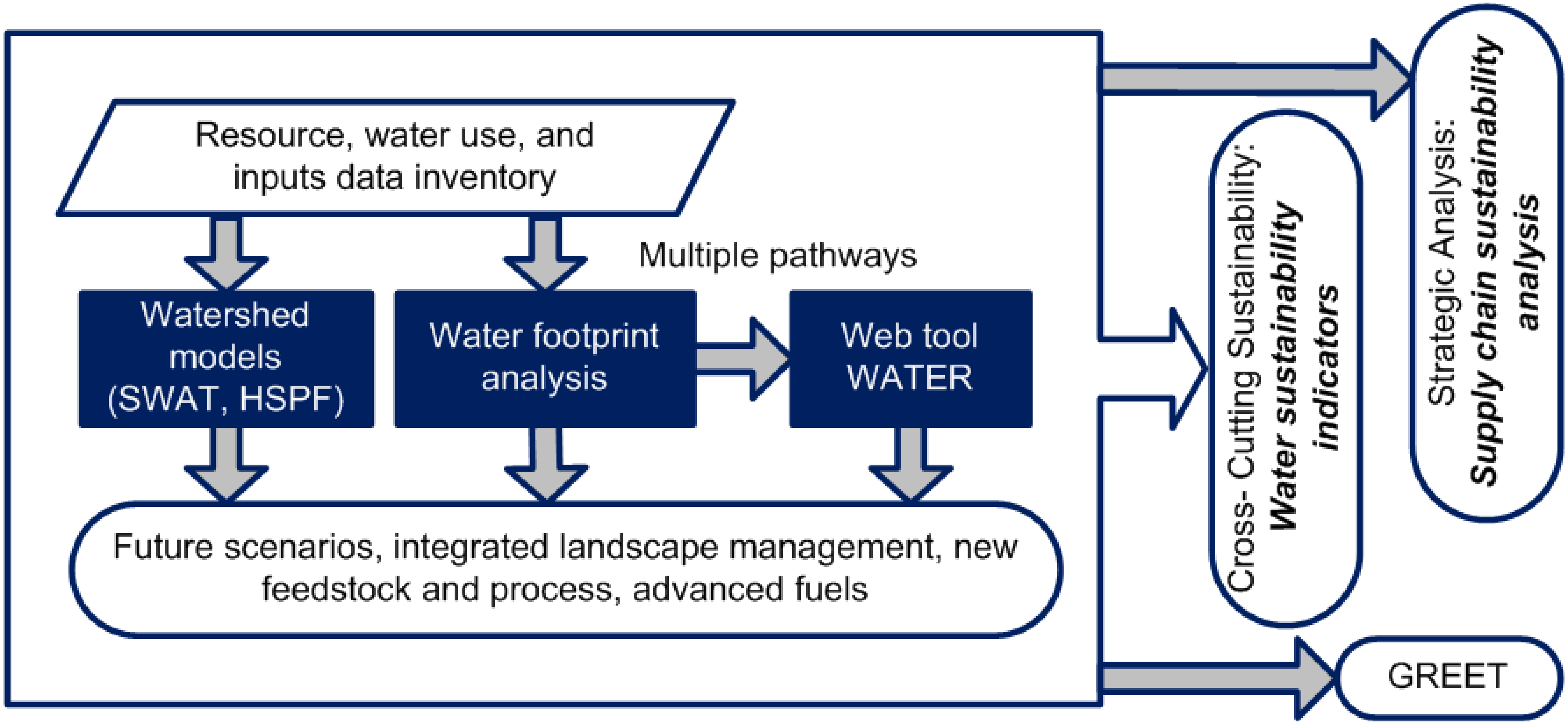
- **WATER** - Spatial-explicit water modeling and analyzing tool for various biofuel pathways at **county level** to address spatial heterogeneity
- Comprehensive **energy-water data inventory** across feedstock production and refining stages
- A suite of multi-scale **hydrologic models** characterize baseline water quality and quantity and simulate impacts of future scenarios
  - UMRB, ORB, MoRB, LMRB (see notes)
  - Iowa River watershed, South Fork watershed
  - **SWAT**, HSPF

1 – Management Approach

- Success factors
  - WATER Tool: online, user-friendly, and open access, meeting the needs of bioenergy industry and policy makers so they can address water sustainability
  - Well-defined technical approach, transparent analysis
  - **Integrated with field test** and **R&D**
  - Strong collaboration with expertise
- Potential challenges
  - Uncertainty associated with early process R&D and field testing
  - Incomplete data coverage at state level or county level

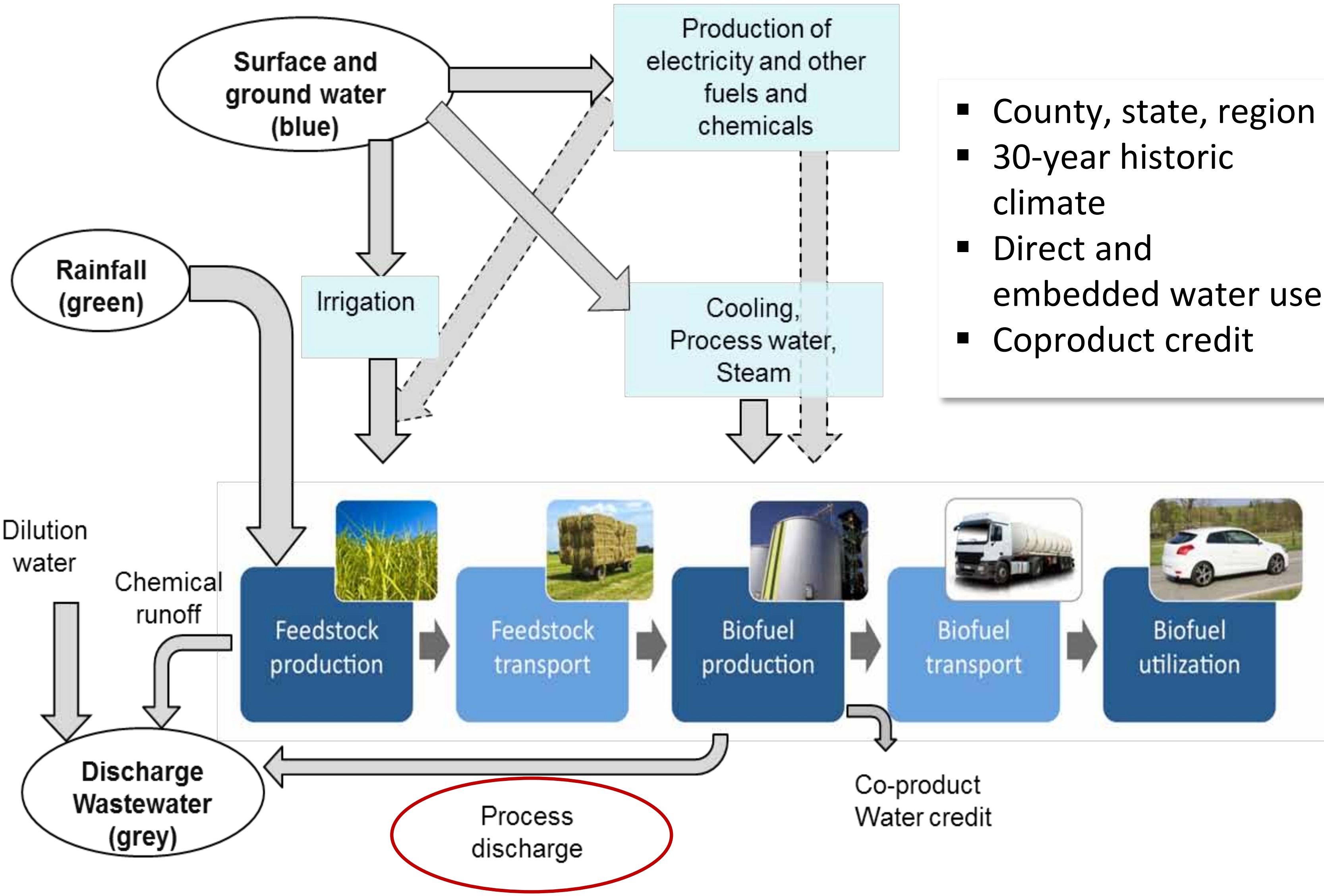
- Set quarterly milestones and deliverables, monitor monthly progress and expenditure, and conduct quarterly briefings
- Join **BETO Sustainability Hydrology monthly call** for *Water modeling and analysis*
- Join **BETO TEA-Sustainability Coordination monthly call** for *Pathway analysis*
- Integrate with feedstock and pathway development: *feedstock study* (Griffith, ORNL; USDA; Bonner, INL); *process R&D* (Snowden-Swan, PNNL); *process simulation* (Davis, NREL)
- Employ interdisciplinary team: hydrologist, computer engineer, environmental engineer

2 – Technical Approach



- Adopt WF methodology (UNESCO, ISO)
- Develop major assumptions in consultation with USDA, USGS, USFS, Army Corp. Eng., and biofuel industry
- Calibrate and verify assessment results with field observations
- Reach out to tool users or potential users to seek feedback

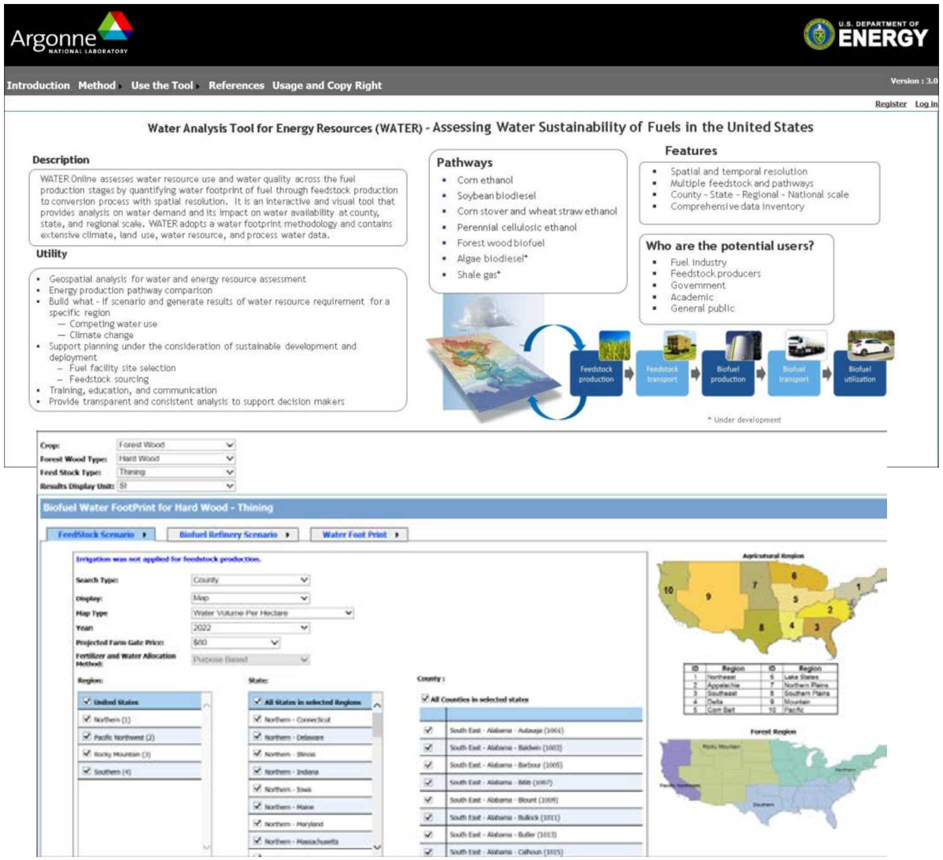
3 – 1. Water Footprint Accounting



- County, state, region
- 30-year historic climate
- Direct and embedded water use
- Coproduct credit

WATER (Water Analysis Tool for Energy Resources)

http://WATER.es.anl.gov

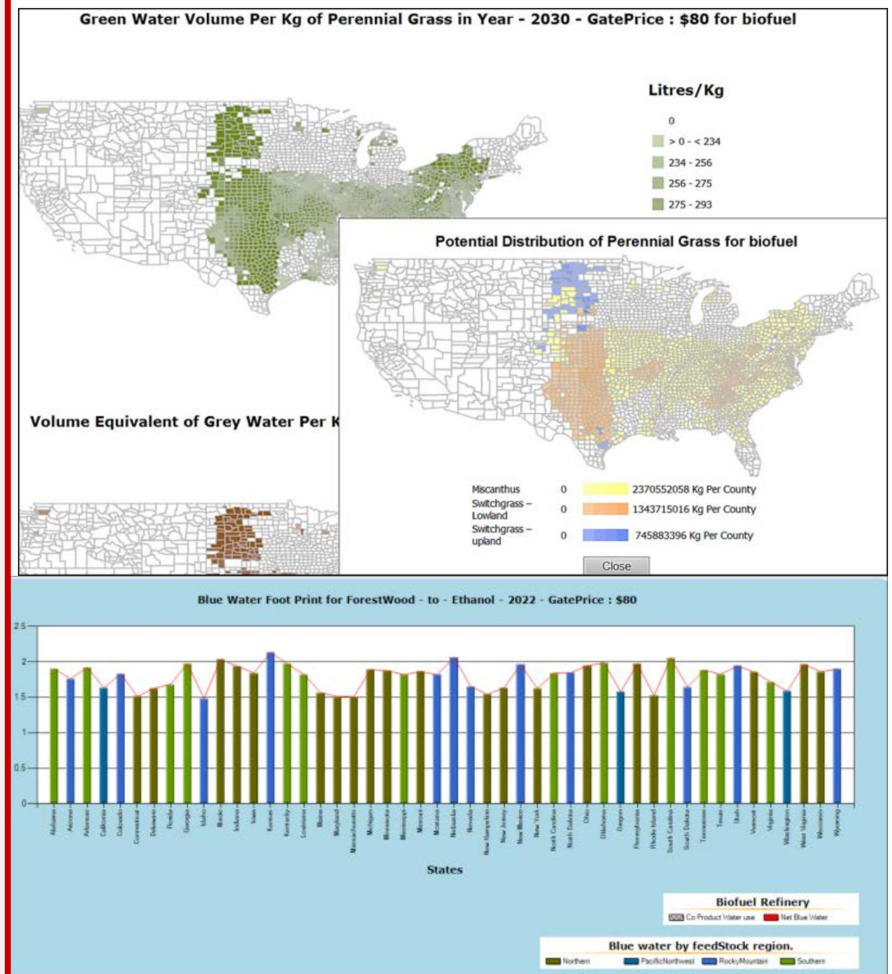


- Launched May, 2013
- Blue, green, and grey water footprint analysis
- Current pathways
  - Corn ethanol, soybean biodiesel, corn stover ethanol, wheat straw ethanol, switchgrass and miscanthus ethanol, forest wood ethanol, forest wood gasoline blend
- Feedstock production and conversion stages; biomass production volume distribution
- Resolution: region, state, county
- Metric: product, feedstock, land use

Database | WF spreadsheet modeling → Architecture design | Programming for model pathways | Web feature interface | SQL database

WATER Application

- Enables **compatible spatial resolution with POLYSYS and LEAF**, which allows for regional environmental sustainability assessment for a defined biofuel production scenario (multi-lab collaboration yielded 2 publications).
- Provides flexible structure for simulating multiple feedstock production in a region. Process plug-in available.
- Enables potential analysis of the interplay of policy, economics, social factor, and their impacts on water quality/quantity when used in conjunction with other models.
- Provide support to bioenergy industry, government, academia, and community for informed decision making.



Key Milestones and Progress

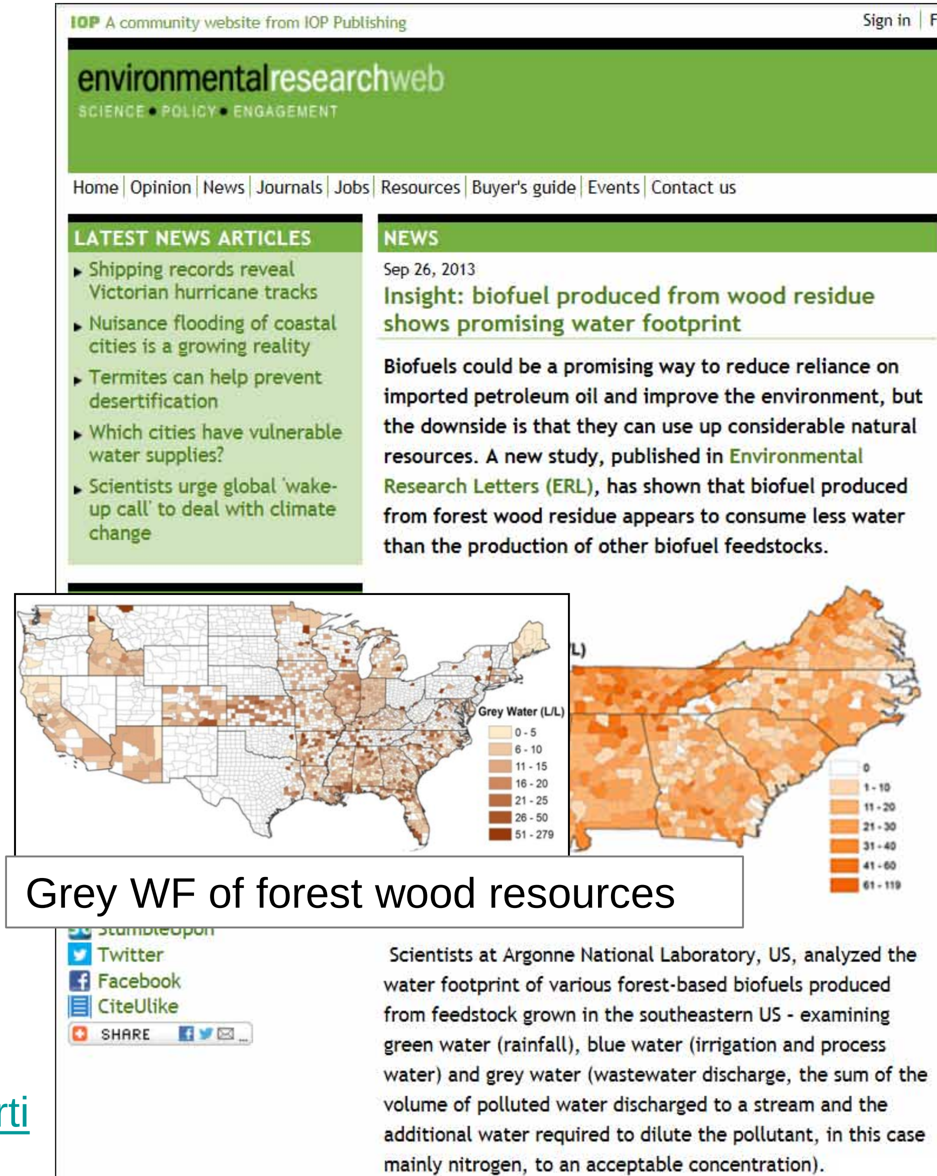
(Since 2013 peer review)

- Develop WF of **forest resource-based biofuels** by wood types (hardwood, softwood) and by feedstock (Short rotation woody crop (SRWC), thinning, and residue) in the U.S. at county, state, and forest region levels (100%)
- Release **WATER v. 2.0** containing perennial (two switchgrass ecotypes and miscanthus) pathways (Mar. 2014); deliver a PMM milestone report to BETO (100%)
- Release **WATER v. 3.0** containing forest wood pathway (Jan. 2015) (100%)
- Assess WF of corn stover ethanol under a sustainable harvest scenario for the U.S. (100%)
- Estimate **grey WF** for biofuels produced via **fast pyrolysis/hydrotreating**: initial analysis (100%), update (10%)
- Estimate grey WF analysis for biofuels produced via biological sugar-to-hydrocarbon pathway (10%)
- **Validate SRWC grey water** at southeast forest regions (30%)
- Update **energy-water database for WATER**: electricity generation (40%), natural gas production (conventional and shale gas) (40%)

WF of Biofuels Produced from Forest Resource

- Expanded analysis from SE region to entire U.S. based on BT2: sweet gum, loblolly pine, hybrid poplar, willow, and others.
- Identified low grey water and blue water footprint for forest-wood-based biofuel.
- Identified regional variability: lower WF in NC, GA, VA, MS, and portions of TN.
- Determined WF is highly dependent on feedstock mix and yield assumptions.
- Determined that results can be used to estimate other conversion processes and bio-power.
- Featured ERL publication in IOP Environmental Research Web.

http://environmentalresearchweb.org/cws/article/news/54777

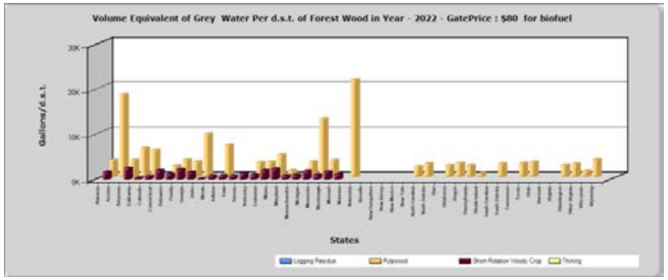


Grey WF of forest wood resources

WATER New Features *Since Last Review*

- Forest wood:
  - Six feedstock type, 13 feedstock scenario combinations in model
  - One biomass resource projection (2022, farm gate price $80 per d.s.t.)
- Perennial:
  - Three feedstock types (SWG upland and lowland, Miscanthus), 24 feedstock scenario combinations in model
  - Six biomass resource projections: (2022, 2030; farm gate prices: $40, $60, $80 per d.s.t.)
- Pyrolysis/hydrotreating and gasification, plug-in for conversion process fed with forest wood
- Biomass production and distribution by type of feedstock.

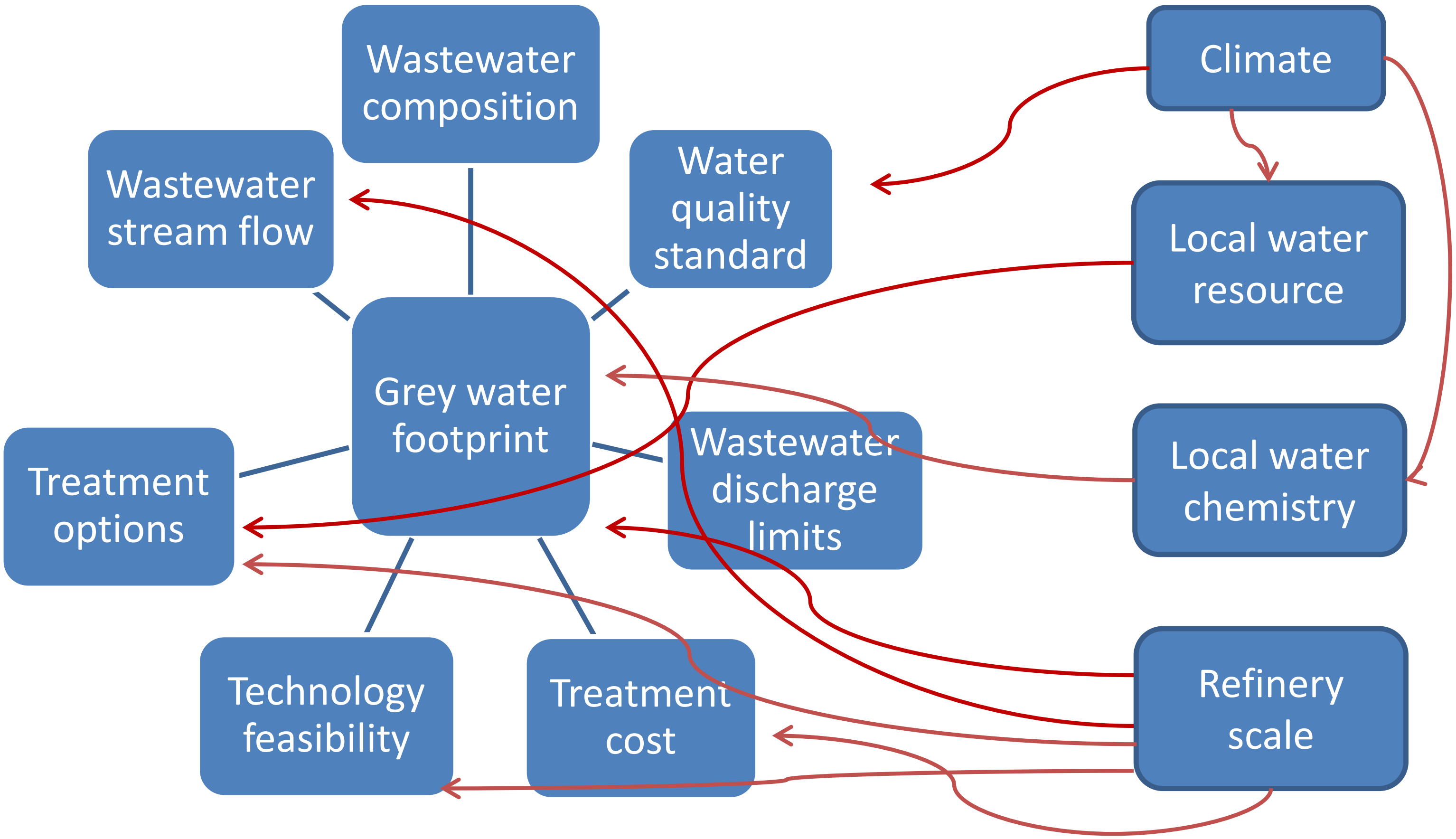
- Selection of feedstock and biorefinery location at state level
  - Single state
  - Multiple states: single-state feedstock supplies to multiple refineries; single refinery receives feedstock from farms from multiple states
- Water and fertilizer allocation for feedstock - consistent with LCA
  - Mass based
  - Production purpose based
- Co-product water displacement credits
- Results exportable/downloadable for maps, graphic charts, and table.



WATER 3.0 Release in 2015

- Argonne National Laboratory *press release* in early Jan., along with a feature story; WATER announcement sent to biofuel and water experts
- Broad media coverage and ripple effects resulted in more than 200 reports/stories in multimedia outlets in two weeks
- Coverage spread from biofuel producers and growers, biorefinery process developers, and forest industry network to academia, NGOs, consultants; coverage extended from U.S. to Europe and Asia. Examples:
  - DOE: BETO, EERE monthly blast, Bioenergy KDF, AFDC, Clean Cities
  - NARA, EESI, Sustainable City Network, Science New Daily, NWEEI, CBD (conversion on biodiversity), Dallas Dumpster News
  - Biofuel Ind. Today (EIN), Biofuel Digest, Biomass Digest, Lab Manager, Biofuels.dbio.eu, CPUC.Int, gracelinks, ipbiz, incbio, among others
- Positive responses to the release reflected bioenergy industry needs
  - Forest industry expressed interest and approached Argonne team; communication is ongoing
  - Industry request incorporation of HTL (hydrothermal liquefaction) and other processes, as well as forest wood logistics, manual.
  - Refinery siting/planning featured in WATER received attention.

Grey WF Analysis - Biorefinery



- Wastewater treatment is often the last factor to be considered in process R&D.
- Stringent regulation can affect the cost because of complex treatment options.
- Developing a grey WF estimate along with R&D progress can provide a quick representation of the wastewater for the techno-economic assessment (TEA).
- Process grey WF is a gap in WF assessment

Define Net Grey WF - Indicator for Process Wastewater

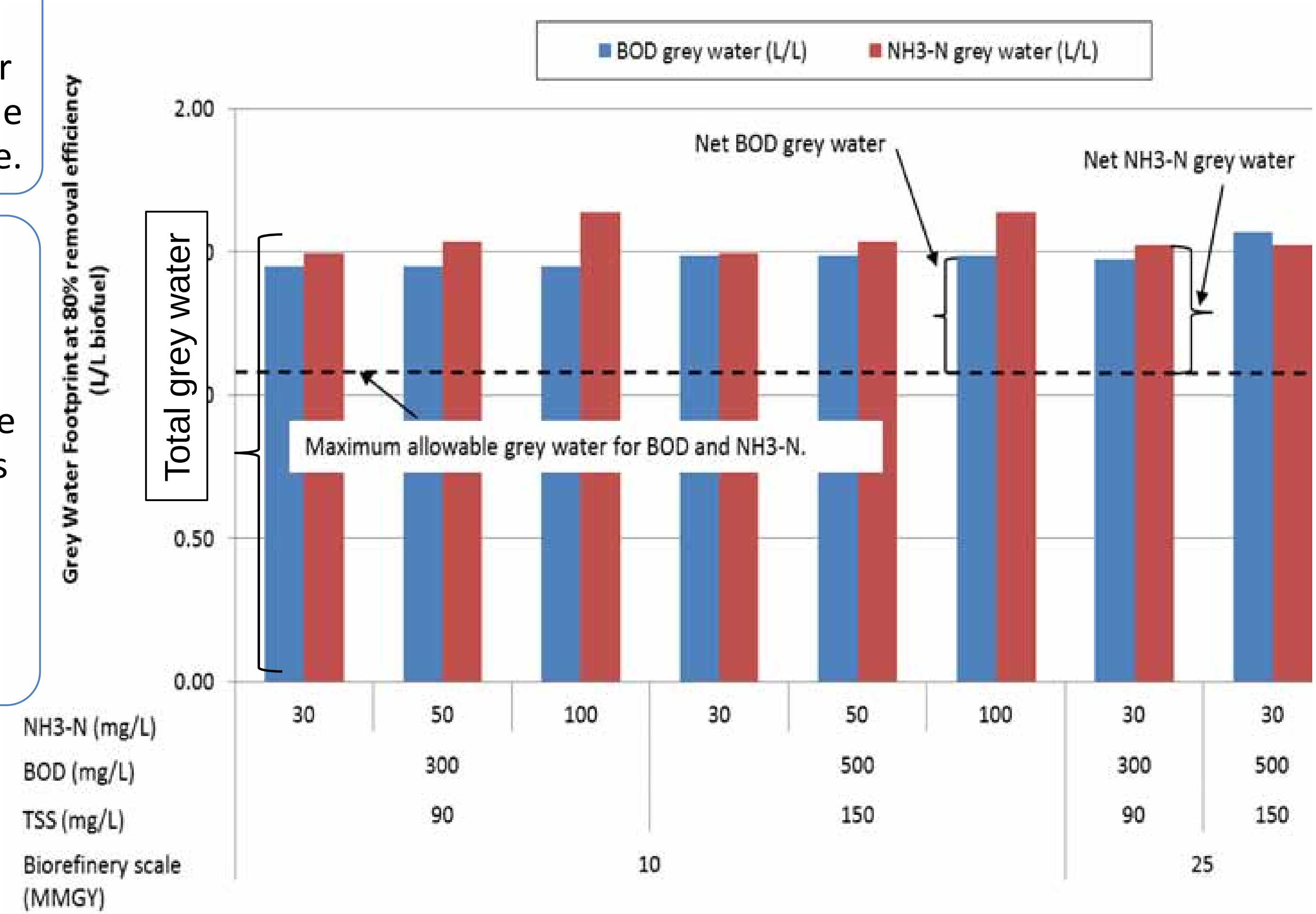
Total Grey Water

Net grey water

- Portion of the total grey water that exceeds the maximum value.

Maximum allowable grey water

- Below the value the discharge is considered acceptable to the natural water system



Grey WF Analysis: Fast Pyrolysis/Hydrotreating

- Wastewater stream characterization, technology and efficiency, and management options were analyzed on the basis of final treated water quality at refinery scale of 10-90 MGY.
- The analysis was tailored to the decision making criteria by WWTP professional and plant managers.
- Cost associated with off-site treatment were estimated to evaluate economic viability of the treatment regimes.
- Ammonia is dominant component
  - On-site pre-treatment is recommended and
  - Further technology evaluation is under way
- BOD_5 concentration governs the total treatment cost under the management option for the stream.

- Additional samples are being collected from process R&D, and characterization is in progress to evaluate the reproducibility, through collaboration with PNNL.
- Further WF and economic analysis is planned and results will feed to ***TEA.***


Argonne

ANL/ESD-13/7

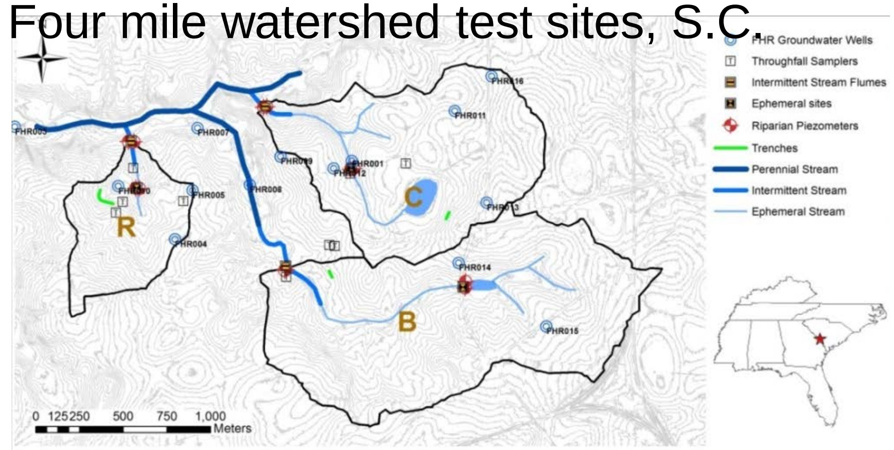
Investigating Grey Water Footprint for the Production of Gasoline and Diesel from Biomass via Fast Pyrolysis

Energy Systems Division

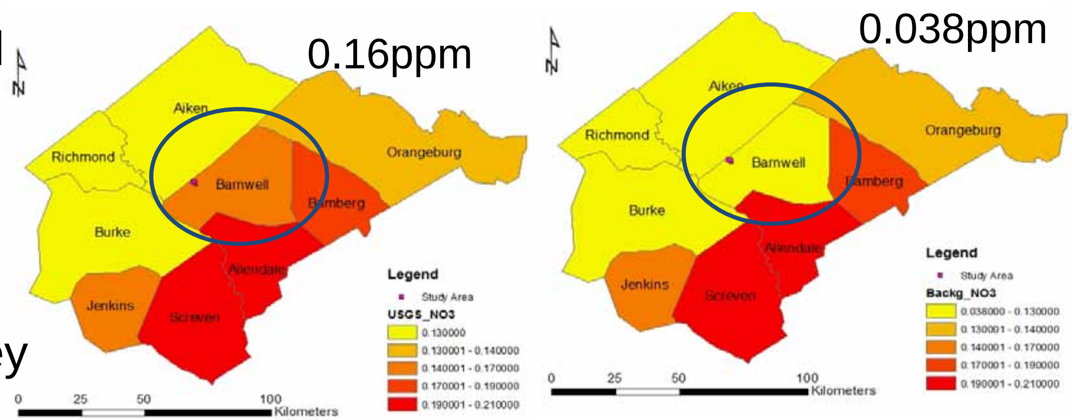
SRWC Production Grey WF Validation

- Analysis is integrated with field tests through collaboration with ORNL.
- Pre-land-conversion (2011-2012) water samples were collected from sites and compared with historical data.
- In-stream background nitrate (NO_3) decreased by 80% and total phosphorus (TP) by 78% in past 20 years.
- The background data were used to update grey WF; green WF was estimated.
- Post land conversion water sample is being collected/analyzed. Fertilizer grey WF will be determined.

Four mile watershed test sites, S.C.



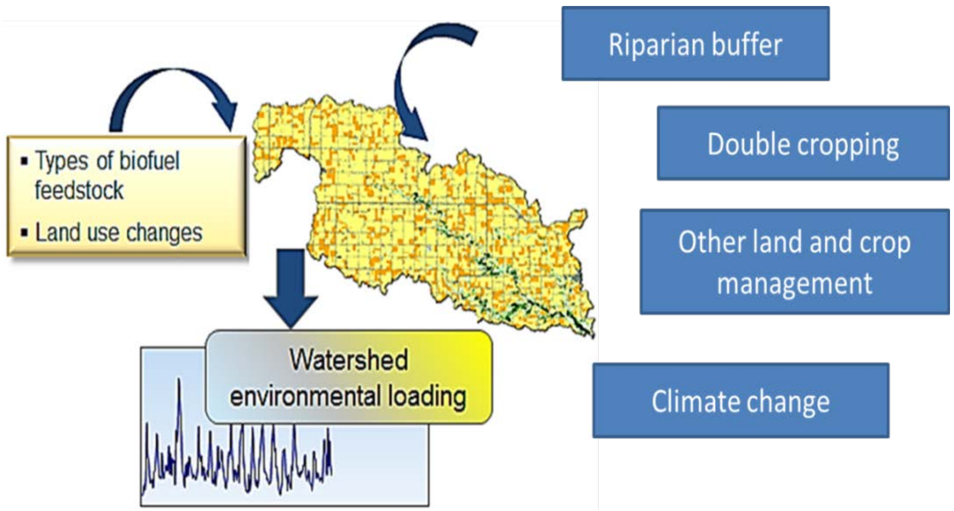
2002 2012



Watershed average nitrate concentration

3 – 2. Watershed Modeling

- This work examines the impact of bioenergy production on water by characterizing nutrients, stream flow, and suspended sediments
  - Identify key players/factors in integrated landscape design
  - Simulate management programs in landscape design; select effective watershed strategies to improve water quality and reduce impacts
  - Apply multiple-scale hydrologic modeling with a focus on finer scale
  - Analyze small watershed (South Fork of Iowa River) to tributaries of large river basin (Missouri River Basin)



  - Focus on Agricultural dominant regions where a majority of conventional biofuel is produced and potentially a significant portion of cellulosic will come be from
  - Develop SWAT model applications

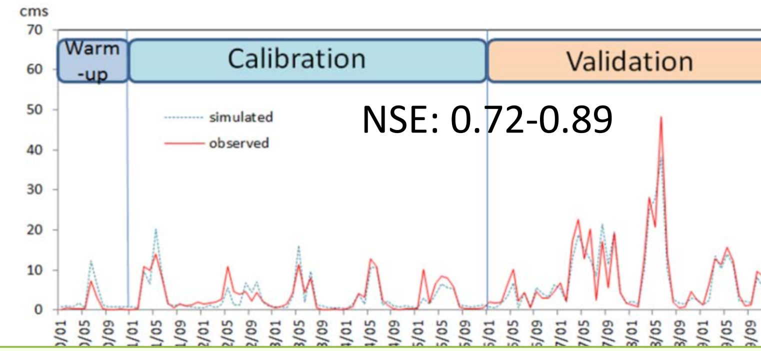
Key Milestones and Progress

(Since 2013 peer review)

- Develop a SWAT base model for **South Fork of Iowa River** (SFIR) **watershed** (100%)
- Evaluate modeling approach for the **representation of buffer strip** in SWAT (100%)
- Implement **riparian buffer** in SFIR and simulate water quality results (100%)
- Apply an integrated landscape design with **land conversion to switchgrass** scenario; develop comparisons under climate change for the SFIR watershed (100%)
- Simulate **cover crop** grown in stover harvest area in the integrated landscape management scenario for SFIR watershed (70%)
- Modeling integrated landscape scenario in a major watershed in IA (10%)
- Develop two SWAT base models for **Missouri River Basin** (MoRB): Upper MoRB and Lower MoRB (100%); implement **a future production scenario** (USDA baseline, $50 /d.s.t., 2022) on MoRB SWAT models and conduct tributary basin water quality analysis (100%)
- Conduct a water sustainability analysis for a **BT16 scenario** at watershed scale (10%)

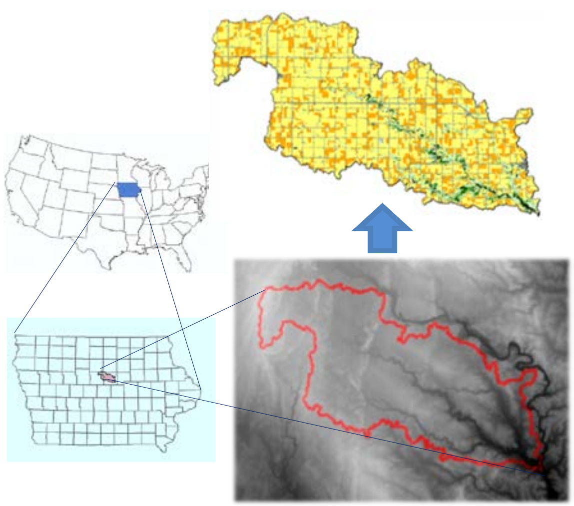
SWAT Application for Integrated Landscape Management

- Collaboration with INL, USDA CEAP
- A SWAT base model for SFIR was developed, calibrated, and validated at fine resolution
  - Ten years of meteorological data, land cover and soil data, and hydrological process monitoring data
  - 80,000-ha watershed; 39 sub basins
  - Applied a scenario which converts a portion of low productivity land to grow switchgrass (SWG)

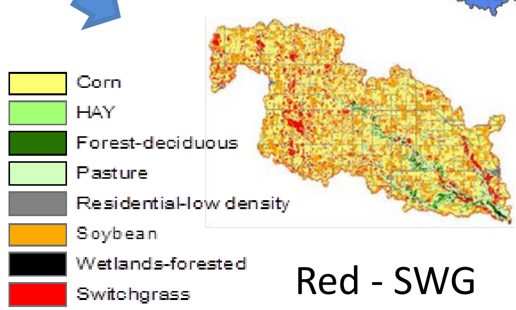


Converting a portion of cropland to SWG brings substantial reduction – 69% for sediments, 55% for total nitrogen, and 46% for total phosphorus – on weighted average

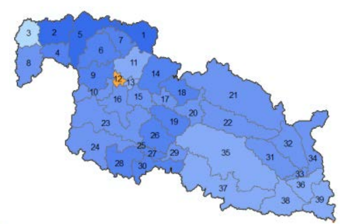
Changes in nutrients and sediments



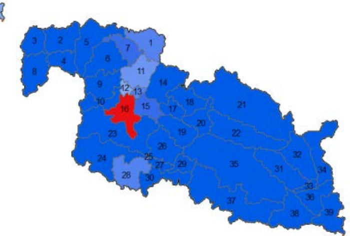
Land conversion to SWG



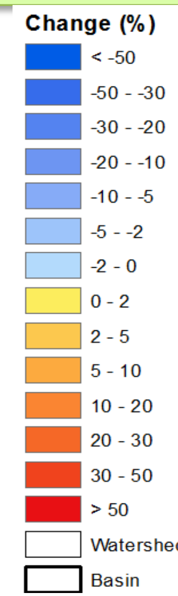
Red - SWG



Nitrate



Sediments

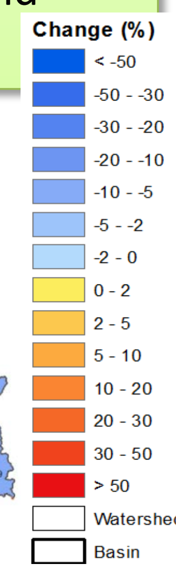


Representation of Buffer Strips in SWAT

Implementing buffer strip in agricultural land to capture nutrient and soil runoff

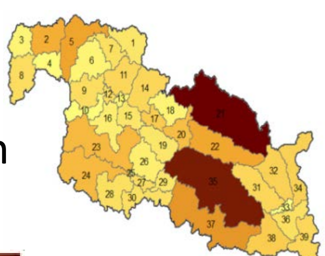
- Reviewed buffer modeling in SWAT:
  - Biomass growth in the buffer strip is not calculated by SWAT.
  - Current model for buffer is not location specific. Fine resolution is required to locate riparian buffer.
  - Modeling methods were compared.
- Developed approaches:
  - Characterize buffer at HRU level.
  - Develop selection criteria to identify buffer location.

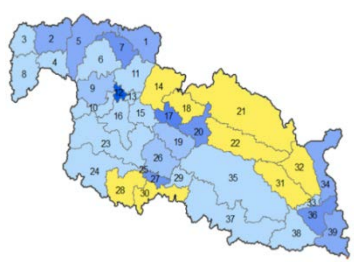
- Application
  - SWG buffer is planted along major stream in SFIR watershed.
  - 50% Biomass harvest: 11,497 d.s.t./yr, 920,000 gal. of biofuel.
  - Organic nitrogen contributes to half of the total nitrogen.
  - Riparian buffer is most effective in mitigating phosphorus, followed by nitrate and sediments. Water yield remains unchanged.



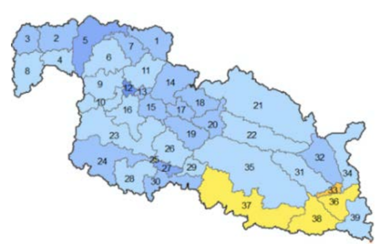
Changes in nutrients and sediments

Biomass production

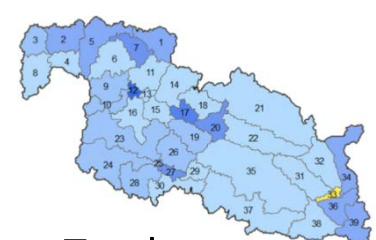




Sediments

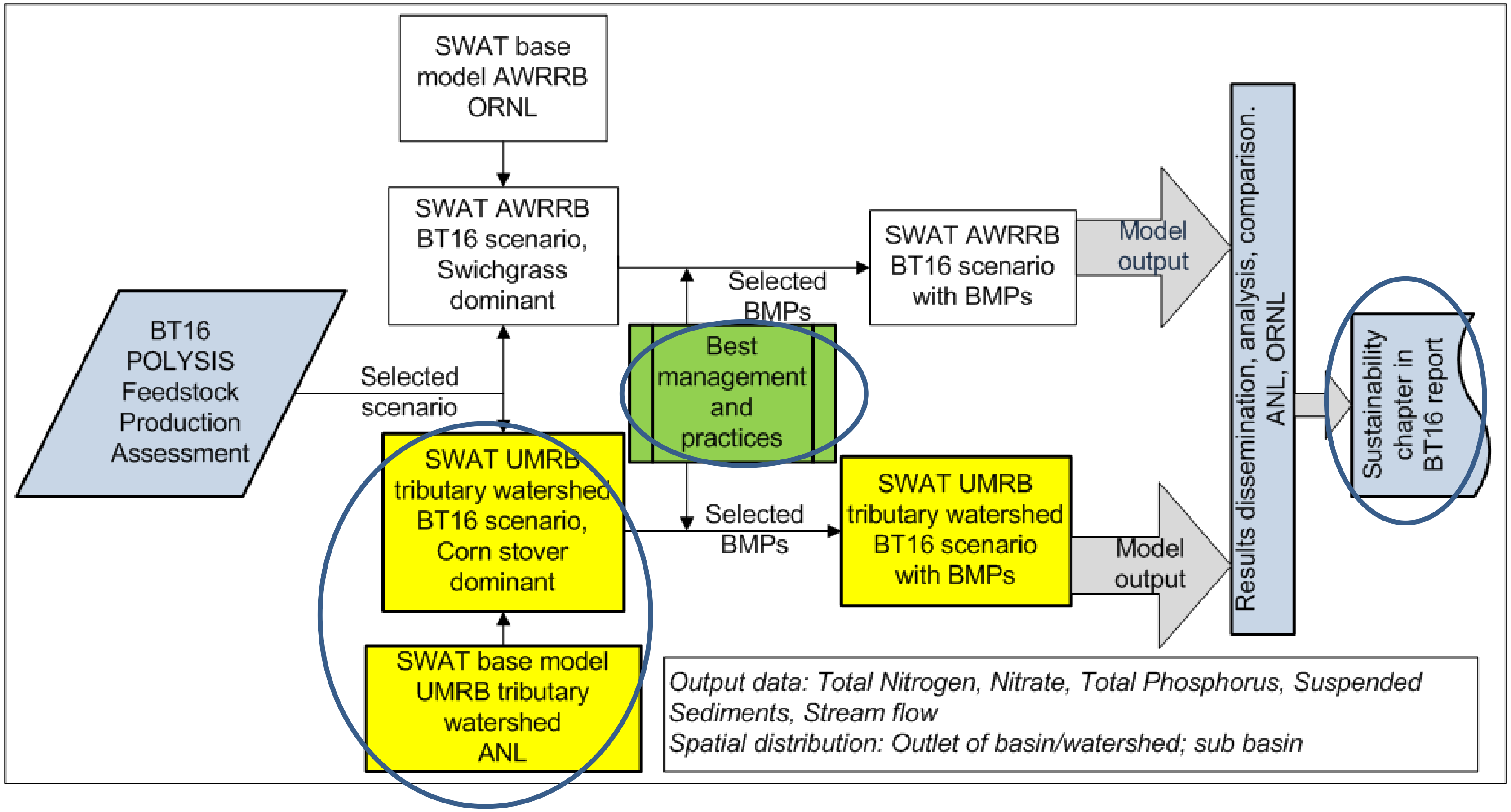


Nitrate



Total Phosphorus

Improving Water Sustainability for the Billion Ton 2016

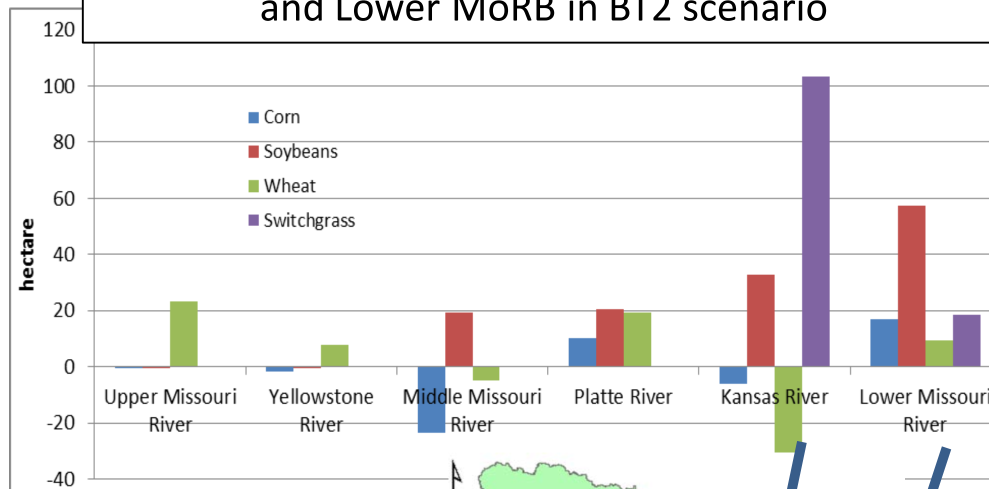


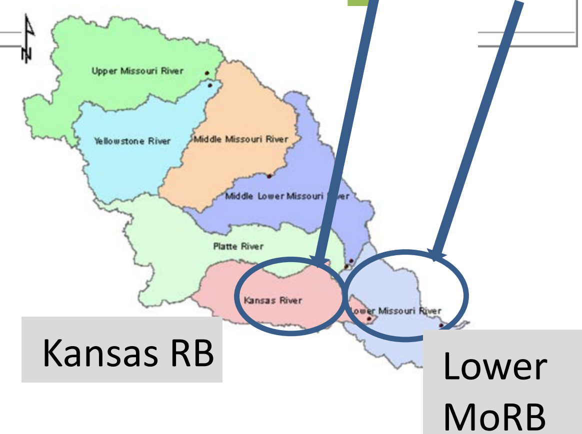
- Conduct joint effort with ORNL to determine water quality and quantity indicators
- Focus on fine-scale watershed in a corn-residue-dominant region in Midwest
- Focus on select management practices and other scenarios
- Expect receiving scenario data soon

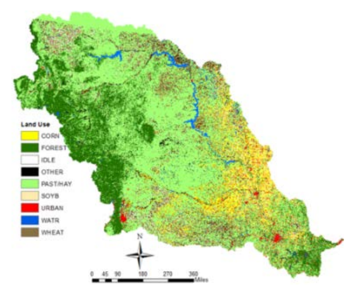
Missouri River Basin (MoRB): Regional Watershed Analysis

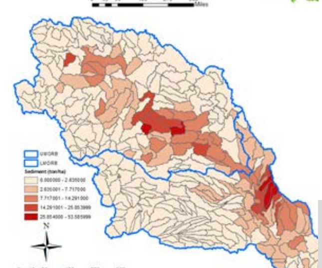
- Develop SWAT models to simulate 20-year hydrologic process.
- Identify water quality hot spots under future scenarios by applying regional watershed analysis.
- Conduct temporal and spatial analysis:
  - Phosphorus loadings are relatively small.
  - Lower MoRB constantly show the highest loadings for nitrate, sediments and phosphorus.

Land conversion to SWG is projected for Kansas RB and Lower MoRB in BT2 scenario

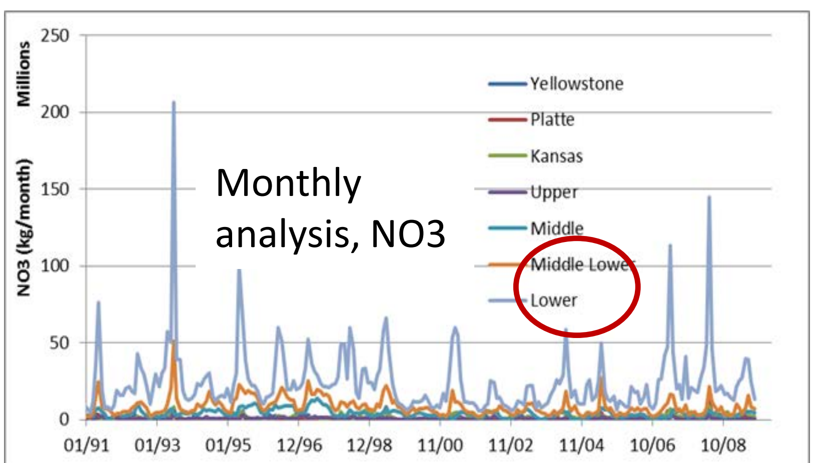






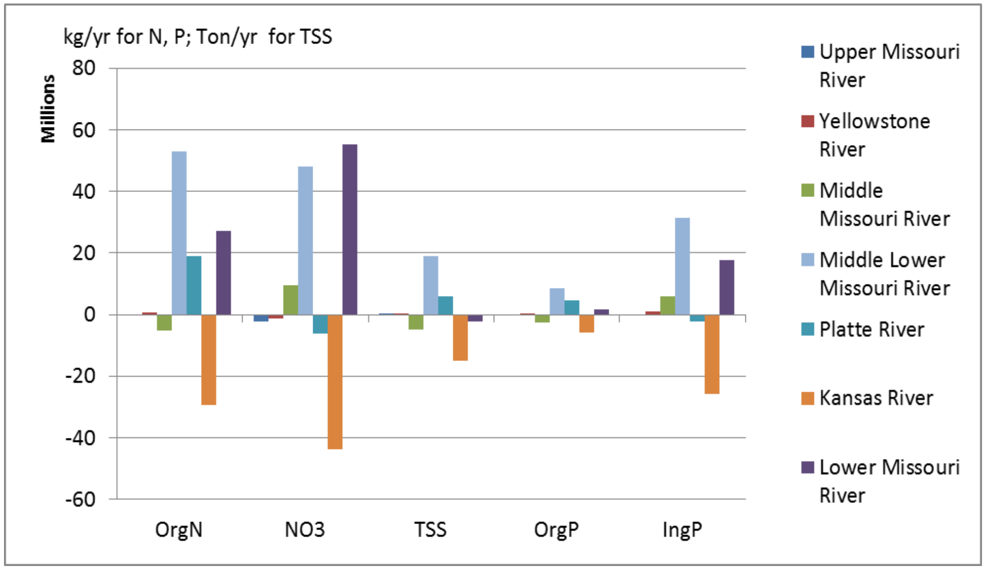


Sediments (TSS)



Model Water Quality for the MoRB: A BT2 Scenario

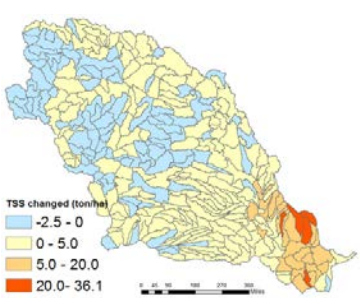
Changes of nutrients and TSS



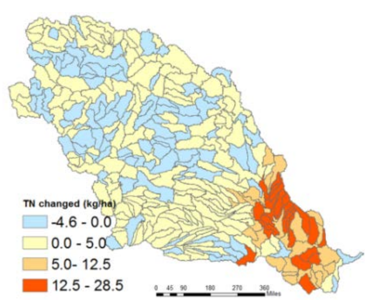
Percent changes in water quality (kg or ton per ha)

- Kansas RB can achieve substantial reduction in nutrients and sediments primarily benefited from large land conversion to SWG.
- Middle-lower MoRB and Lower MoRB may need more attention.
- Future investigation include finer scale analysis for the two regional watersheds, implementing riparian buffer and other BMPs to reduce loadings.

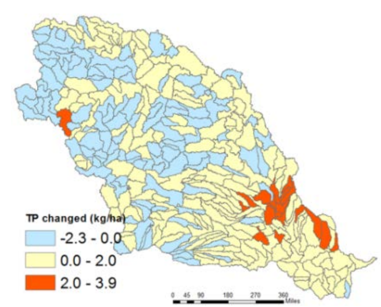
Provide feedback to BT16 projection on land use change



TSS



Total Nitrate



Total Phosphorus

Red:
Yellow: minimal or no change
Blue:

3 Relevance

- Water use and wastewater release are two key issues associated with water sustainability in bioenergy development. Availability and sufficiency of water resource and meeting tightened regulations can become a barrier in financing and siting of refinery and limit deployment
- This project provides consistent platform to examine water sustainability metrics for bioenergy production, to meet BETO A&S's strategic goal of integrating water quantity and quality assessments into biomass and bioenergy production analyses (MYPP 2014)
  - Water Footprint translates feedstock/pathway selection into estimates of water resource demand and water quality impact
  - SWAT modeling permits multi-scale watershed analysis of water quality impacts of future feedstock production scenarios
- This project analyzes water consumption cross biofuel production stages
  - Evaluate integrated landscape management to reduce nutrient and sediments burdens
  - Identify regional-specific low-water-intensity feedstock mix
  - Analyze key factors in process water and wastewater management, supporting TEA.
- This project supports stakeholders
  - Provides a robust, on-line, user-friendly tool with appropriate functionality
  - Facilitates incorporation of local water resource constraints in site selection for new projects, in addition to economic and infrastructure considerations
  - Supports policy makers to compare and evaluate potential impacts of energy policies on natural resource

5 – Future Work

Water Footprint / WATER

- Update **water - energy database** for electricity generation and natural gas (Q2 milestone), and for oil sands
- Conduct WF assessment for **biological sugar-to-hydrocarbon** pathway
- Validate SRWC grey water footprint
- Prepare pyrolysis/hydrotreating grey water update (Q4 milestone)
- Analyze national-scale county level **WF of** mixed feedstock for future bioenergy feedstock production scenario **(BT16**)
- Develop projection component in **WATER architect** for increased future scenarios

SWAT modeling

- Quantify **double cropping** system for the areas where stover is harvested at watershed scale for SFIR
- Develop a SWAT base model for Iowa River watershed and apply an integrated landscape design scenario (Q3 milestone); evaluate BMPs
- Assess water sustainability of a **BT16** scenario on a **stover-dominant watershed**; evaluate approaches to improve water quality (Q4 milestone)
- Collect agricultural management and practices data and point source data for **LMRB SWAT** base model development

Go/No-go: A plan for integrating MRB tributary SWAT models (joint effort by ANL and ORNL) will be developed to identify technical issues associated with model integration.

Possible abatement actions: Consult with US EPA and Army Corp for approaches in model integration in the region.

(View the PowerPoint "Notes" page for additional information)

Summary

Approach

- Well defined framework, consistent methodology, multi-lab collaboration; multi-agency consultation
- Apply watershed modeling of LUC and BMPs at fine scales; spatial temporal analysis

Technical Accomplishments

- Major release of WATER 3.0 in multi-media; broad coverage reached key audiences
- WATER on-line tool with new addition of perennial and forest feedstock and thermochemical pathways
- Developed SWAT modeling method for representing riparian buffer; developed SWAT modeling of an integrated landscape management scenario in SF.
- Conducted regional watershed analysis for MoRB identifying hot spot for BMP application.

Relevance

- Provide a platform to analyze water use and wastewater release along the production stages to address potential barriers limiting deployment
- Assist DOE stake holders with data acquisition/validation and analysis to estimate water sustainability of various bioenergy pathways

Critical Success factors

- Developed WATER tool - online, user friendly, multiple pathways, and spatial resolution
- Integrated with field tests and R&D

Technology Transfer and *Future work*

- WF results feed to TEA, Sust. indicators and GREET; support GBEP; BT16
- *Grey WF of multiple pathways prioritized by BETO*; *WF database update*; *SWAT for future LU and BMPs in IR*

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- PNNL: Lesley Snowden-Swan, Sue Jones

Additional Slides

Responses to Previous Reviewers' Comments

Comments:

This project can be viewed as a fundamental or framing project for Sustainability and Analysis water quality projects focused on finer scales …. It is not clear that this project is well **integrated in real time** with others that are exploring **finer scales**…Need to **validate model** predictions across scales with field data.

Responses:

The project addressed the above comments by emphasizing the integration and validation of modeling through collaboration with other BETO supported projects:

1. SRWC grey water validation task collaborated with SRWC project team (ORNL), which is exploring **field-scale** long-term tests. Field data collected since the inception of the project (2011- current) were transferred to ANL and used to estimate and **validate** grey WF for SRWC over time.
2. Grey WF for pyrolysis/hydrotreating task is **integrated** well with R&D in PNNL. Process wastewater sample characterization provides a basis for developing WF estimates. As the R&D progresses, samples are collected from 2013 to 2015 and estimate is updated. Similar approach is taken for sugar-to-hydrocarbon pathways.
3. SWAT development for SFIR is based on 10 years USDA CEAP monitoring data and **sub-field** analysis by INL.

Publications

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- Muth, D. J. Jr, M. H Langholtz, E. C D Tan, J. J. Jacobson, A. Schwab, M. Wu, A. Argo, C. C Brandt, K. Y.-W. Chiu, A. Dutta, L. M Eaton, E. M Searcy, 2014. Investigation of thermochemical biorefinery sizing and environmental sustainability impacts for conventional supply system and distributed preprocessing supply system designs, Biofuels, Bioprod. Bioref. (2014) DOI: 10.1002/bbb.1483.
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- Chiu, Y., M. Wu. 2013. Considering water availability and wastewater resources in the development of algal bio-oil, Biofuels, Bioprod. Bioref. (2013) Vol. 7 (4), p406-415. DOI: 10.1002/bbb.1397.

Presentations

Presentation

- Wu, M., Yalamanchili, S., Chiu, Y., Ha, M., WATER, 15th National Conference and Global Forum on Science Policy and the Environment, Jan. 26-29, 2015. Washington DC.
- Ha, M., Wu, M., Wang, J., Mitigating Impact of Climate Change on Water Quality by Landscape Design Incorporating BMPs in Biofuel Production, 15th National Conference and Global Forum on Science Policy and the Environment, Jan. 26-29, 2015. Washington DC.
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- Wu, M. Sustainability of Renewable and Advanced Fuel Production, 2014 International Symposium on Adaptation to Climate Change for Energy Sustainability: Education Aspect, April 17, 2014. Taipei, Taiwan
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- Wu, M., Water Footprint of Biofuels: Current Understanding and Challenges, ASABE international symposium, Evapotranspiration: Challenges in Measurement and Modeling from Leaf to the Landscape Scale and Beyond. April 7-11, 2014. Raleigh, NC.
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- Lampert, D. and M. Wu, Modeling biofuel feedstock and its watershed impacts at UMRB. American Water Resource Association Conference 2013, Nov. 4-7, Portland, Oregon.
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- Lampert, D., M. Wu, Development of a Watershed Modeling Approach to Assess the Impacts of Biofuel Feedstock on Water Quality in the Upper Mississippi River Basin, Energy and Sustainability 2013, 4th International Conference on Energy and Sustainability, 19 - 21 June 2013, Bucharest, Romania.

Software

- A hydrologic modeling software PyHSPF developed with BETO support in last two years has obtained BSD open source license and been posted at an open source software host. *https://github.com/drduffman/PyHSPF* with a link to KDF. A link of the software site is being submitted to Aaron Myers at KDF to be included in KDF site.