Development and Application of an Integrated Modeling System to Evaluate Adoption of Table Food Production in the Iowa UrbanFEWS Project

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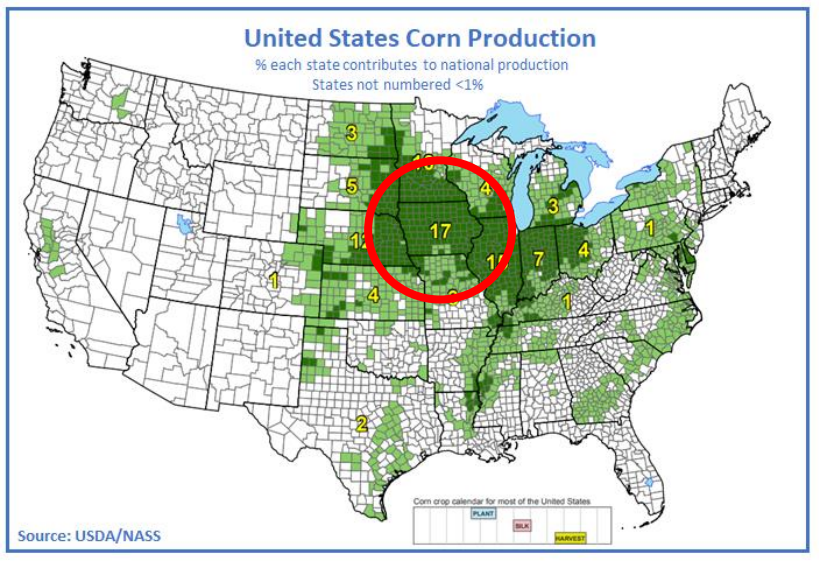
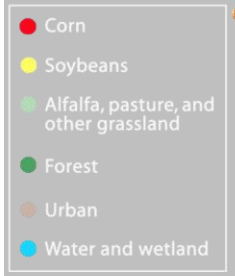
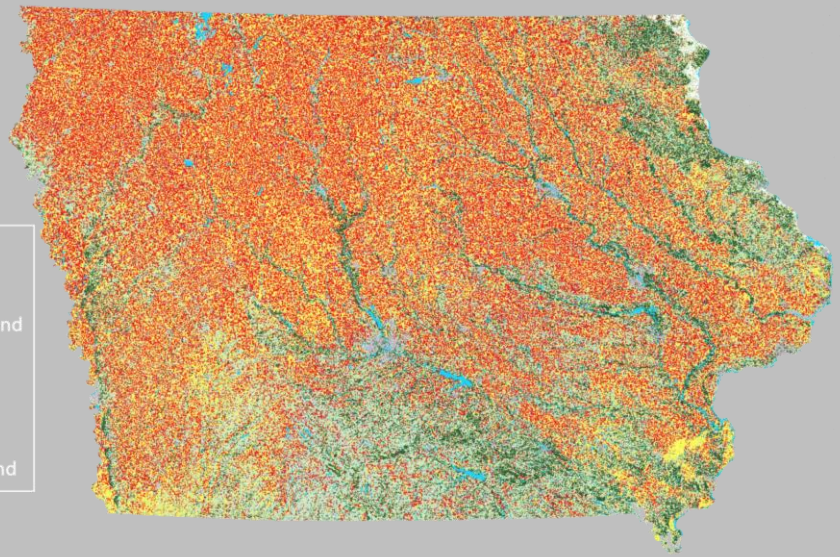
Overview of Presentation

- Iowa agriculture & water quality problems
- Overview of Iowa UrbanFEWS project
- Description of integrated modeling system
- Descriptions of models used in modeling system
- Initial scenario analysis with SWAT and LCA model
- Future directions

Location of Iowa in the Corn Belt Region; 2002 Iowa Land Use Map (Still the Same)







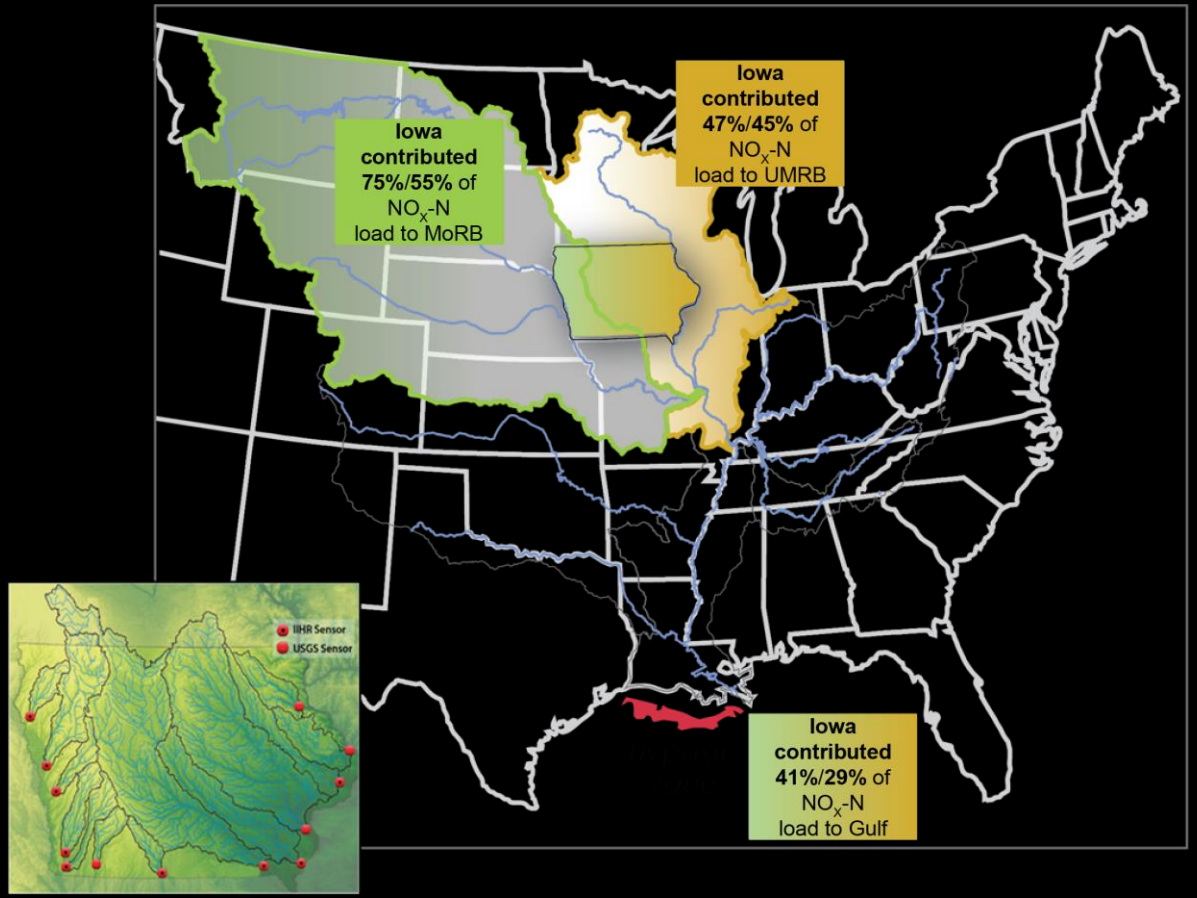
Source for U.S. map: Maps on the Web. 2017. Created by the USDA National Agricultural Statistic Service. https://mapsontheweb.zoom-maps.com/post/167277601486/us-corn-production-by-malleebull-as-the.

2022 Iowa Agricultural Rankings

Crop/livestock	Rank	% of U.S. total
Corn (grain)	1	17
Soybean	1	14
Total cropped area	1	8
All hogs	1	32
Cattle & calves on feed	4	8
Egg layers	1	13

Source: USDA-NASS. 2022 Iowa agricultural Statistics. USDA, National Agricultural Statistics Service Upper Midwest Regional Office, Des Moines, Iowa. https://publications.iowa.gov/43215/1/2022-Iowa-Annual-Bulletin.pdf

Iowa Nitrate Export to the Gulf of Mexico

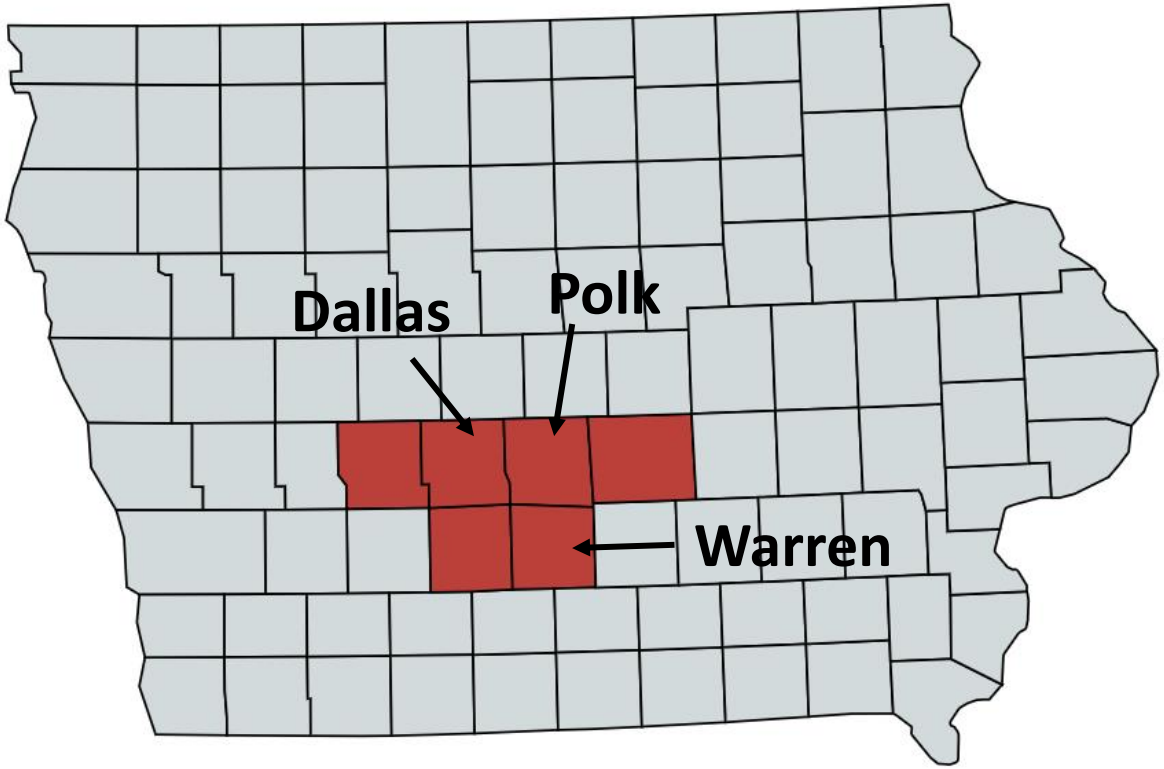


Sources: Jones et al. 2018. Iowa stream nitrate and the Gulf of Mexico PLoS ONE 13(4): e0195930. ttps://doi.org/10.1371/journal.pone.0195930; Jones et al. 2018. Iowa Statewide Stream Nitrate Load Calculated Using In Situ Sensor Network. JAWRA. 54(2): 471–486. https://doi.org/ 10.1111/1752-1688.12618

Iowa UrbanFEWS Project Area

Six-County Des Moines–West Des Moines, IA Metropolitan Statistical Area (DMSSA)

99 Counties in Iowa



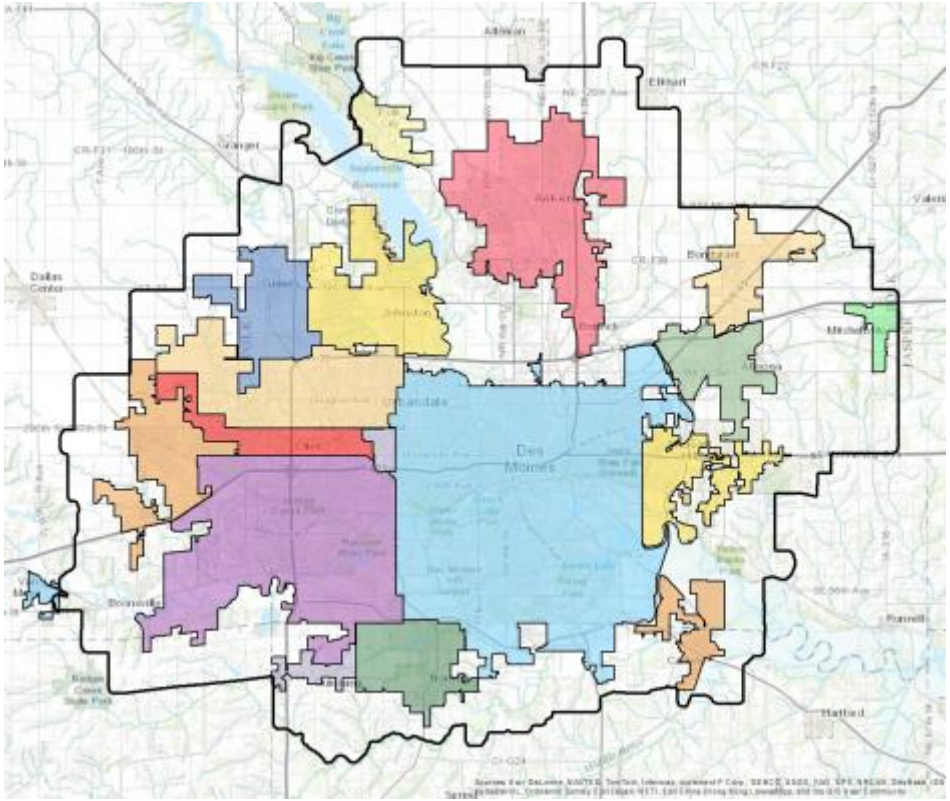
Source: Wikipedia. 2023. Des Moines metropolitan area. https://en.wikipedia.org/wiki/Des_Moines_metropolitan_area

Map Showing Primary Urban Area in DMSSA

Des Moines: light blue

2022 census: 729,053
(Des Moines: 214,452)

Fastest growing metro area in Upper Midwest



Map source: Des Moines Area Metropolitan Planning Organization. 2023. https://dmampo.org/maps/; Other sources: CISION PR Newswire. DSM population continues to outpace peers. https://www.prnewswire.com/news-releases/dsm-population-growth-continues-to-outpace-midwest-peers-301840351.html

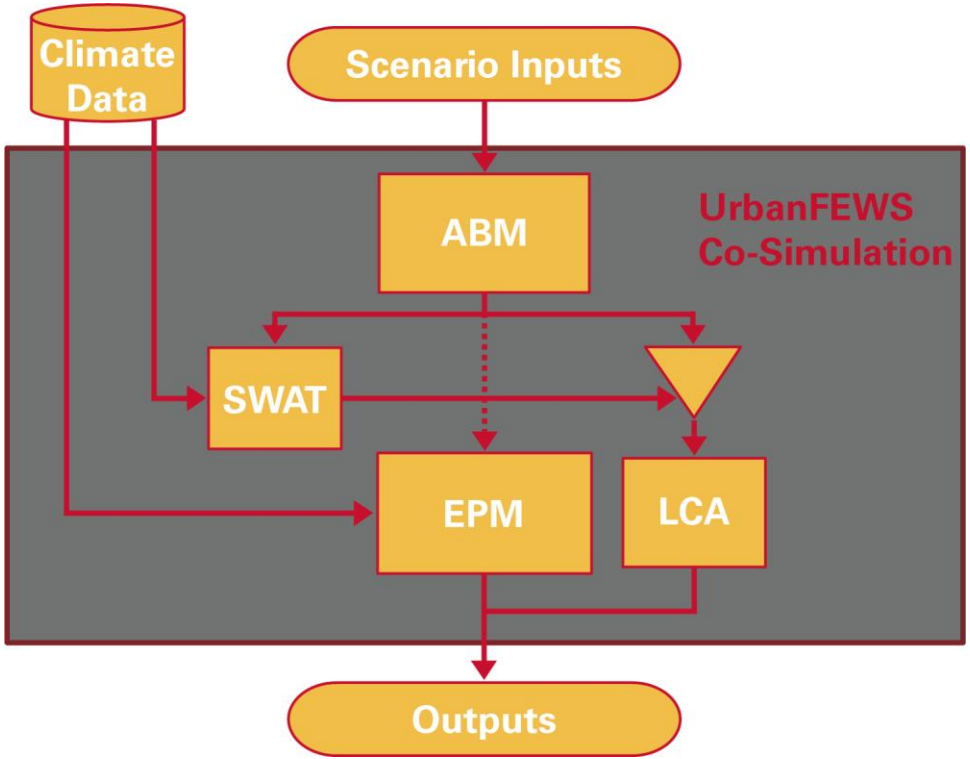
Iowa UrbanFEWS Project

- Funded by the National Science Foundation
- UrbanFEWS: urban food-energy-water nexus
- Promote increased table food production in DMSSA
  - Current local production = 5% of total dietary needs
- Table food: fruit, vegetables, grains, protein, dairy
- Develop integrated modeling system to capture:
  - Broader DMSSA including urban & peri-urban landscapes
  - Within the city of Des Moines only

Models Included in the Integrated System

Model name	Acronym	Role/Outputs
Agent Based Model	ABM	determine scenario land use change on an annual basis at a county level
Energy Plus Model	EPM	estimates building energy consumption due to climate, vegetation, etc. (Des Moines only)
Life Cycle Assessment	LCA	land use, energy use & global warming potential based on dietary consumption patterns
Soil and Water Assessment Tool	SWAT	streamflow, hydrologic balance, crop yields, nutrient & sediment transport

Schematic of Integrated Modeling System



Agent Based Model Description

- Agents represent heterogeneous real-life actors
- Agents are capable of autonomous decision-making, actions, and interactions
- Agents can be programmed to acquire new knowledge, change their behaviors, and adapt to other factors affecting their environment (population change, policy shifts, etc.)

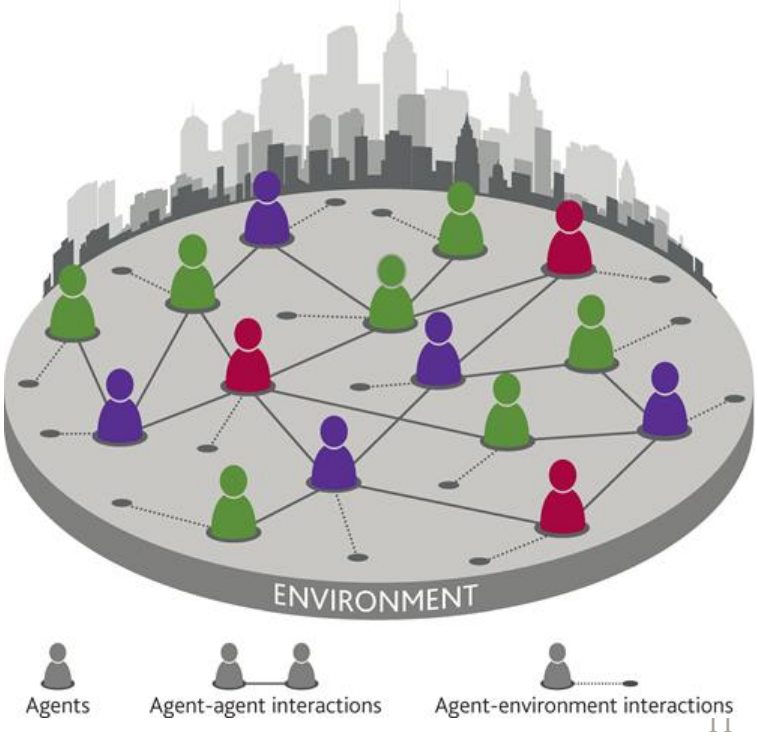
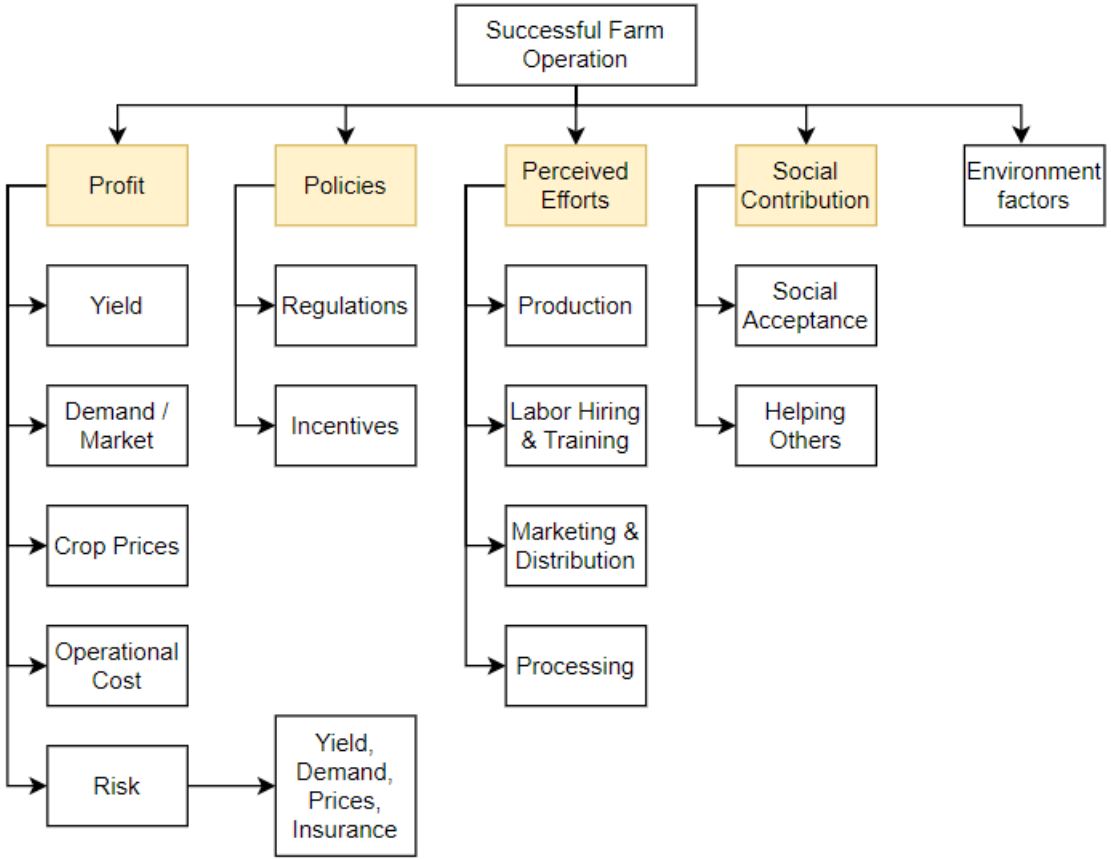


Figure Source: Turrell, A. 2016. Agent-based models: understanding the economy from the bottom up. Bank of England. https://www.bankofengland.co.uk/quarterly-bulletin/2016/q4/agent-based-models-understanding-the-economy-from-the-bottom-up

ABM Decision Making Hierarchy

- **Goal: Determine possibility of producer adopting a specialty crop**
- **Conducted survey of producers in central Iowa to support goal**
- **Developed 3 Commodity personas: Traditional, Maybe, Supportive, & one Specialty persona, based on the survey data results; personas do not change during a simulation**



Execution of the ABM

Farmer agents: traditional, maybe, supportive (commodity) & specialty personas

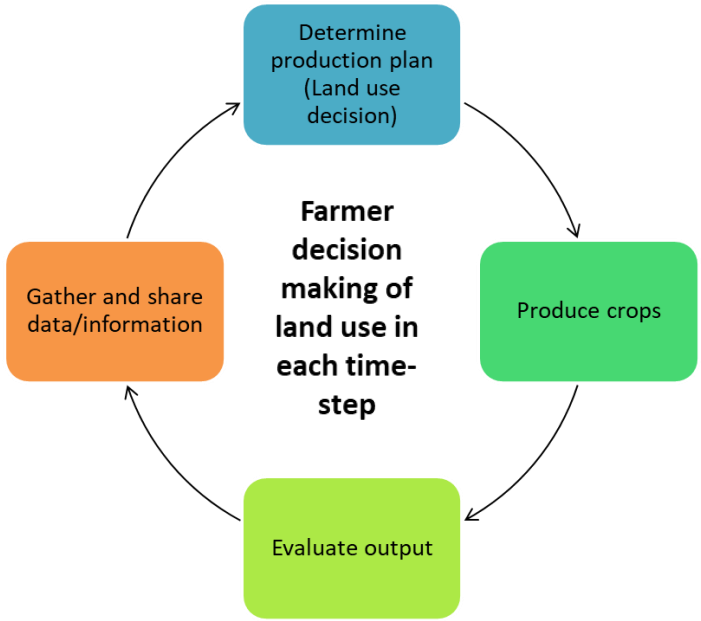
Extension agent: interventions in decision making

Production decision-making: land can be shifted from commodity crops to specialty crops (and vice versa)

Crop categories: commodity (corn & soybean), fruit 1 & 2, vegetable 1 & 2, small grain

Other categories: livestock, oil, sugar

Execute long-term annual time-step scenarios; land use decisions recalculated each year resulting in evolving changes in land use distributions



Energy Plus Model Execution

- Building energy simulation program: https://energyplus.net/
- Weather data and building data are key inputs
- Weather data augmented by WRF climate model temperature data
  - https://www.mmm.ucar.edu/models/wrf
- Executed on sub-hourly time step
- Established land surface temps. (LSTs) across entire DMSSA
  - Performed with WRF; used in Des Moines urban model
- Developed models to account for ET effects from trees and greenery on buildings, including a green facade component

Energy Plus City of Des Moines Model

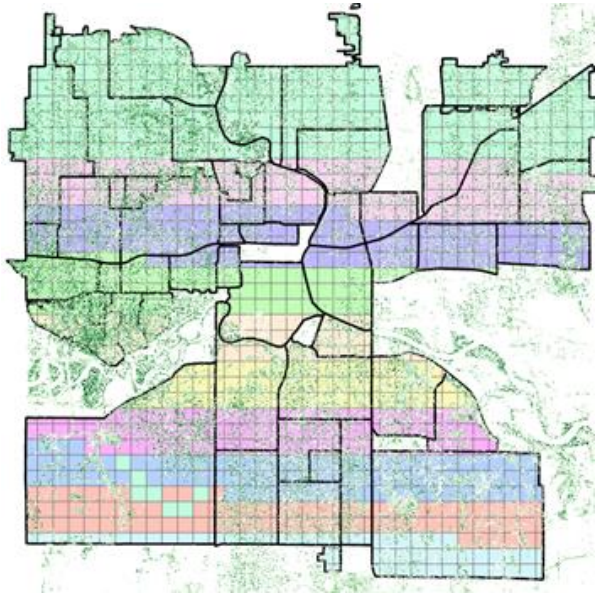
Defining cell sizes

400 x 400 m grid

Height of trees
Foliage cover ratio

Height of buildings
floor area ratio

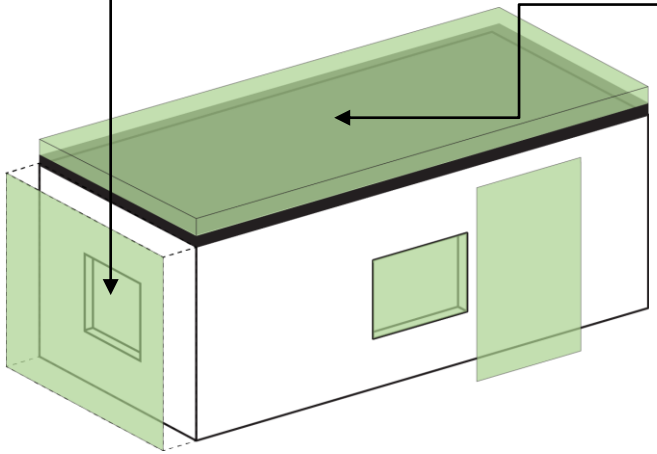
- Implemented a 400x400 meter grid system to upgrade the energy use simulation from neighborhood to city scale
- Efficiently organized; analyzed numerous buildings within city using the grid system
- Utilized multivariate clustering to identify similar cells based on factors and characteristics
- Clustered similar grids together, improving scalability for city-wide simulation



Energy Plus Modelling: A Green Facade Component for Building Energy Simulation

Green Facade Module

+ Air gap present
+ Buoyancy is accounted for
+ Applied to whole facade
+ greenery ET effects
- Solar radiation transmission to the underlying wall not captured



Green Roof Module

+ Based on established model
- Cannot be used vertically
- Soil Layer
- No air gap
- No buoyancy effect

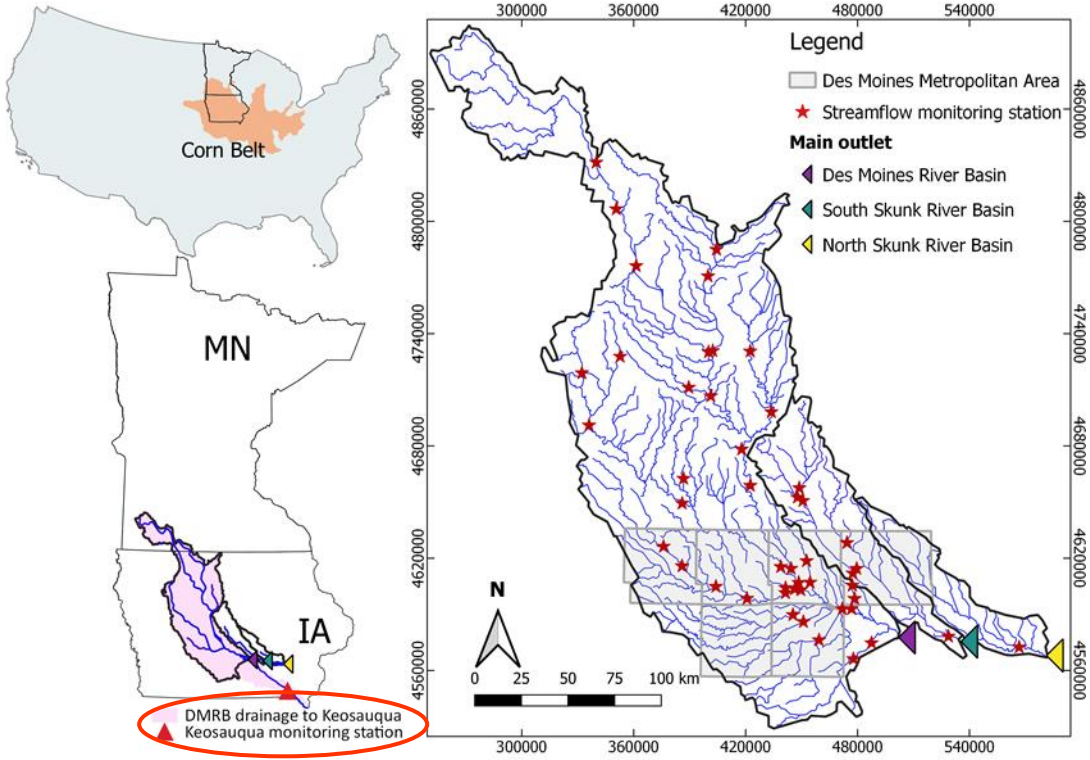
SWAT Study Areas for Iowa UrbanFEWS

Study area characteristics

Des Moines (DMRB) 31,892 km²
South Skunk (SSRB) 4,593 km²
North Skunk (NSRB) 2,259 km²

- **Land use**: soybean and corn fields representing together 70%, 71%, and 61% of the DMRB, SSRB, and NSRB.

- **Soil type**: Loamy Wisconsin Glacial Till (tile drainage represent 54%, 51% and 44% of the DMRB, SSRB and NSRB)



HAWQS calibration outlet

SWAT Progress for Iowa UrbanFEWS

- Initial hydrologic testing completed (Science Total Environment)
  - https://doi.org/10.1016/j.scitotenv.2022.156302
- Future hydrologic effects of using 2 GCMs/2 RCMs (Water)
  - https://doi.org/10.3390/w15040750
- Crop parameters for 24 fruits/vegetables (Water, submitted)
- Effects of using two tile drain options (J. ASABE, submitted)
- Initial future scenario in CARD Agricultural Policy Review
  - https://www.card.iastate.edu/ag_policy_review/article/?a=150

LCA Model Use in Iowa UrbanFEWS

- Initially used CleanMetrics LCA; More recently USE-EIO LCA
  - CleanMetrics: https://www.cleanmetrics.com/ToolsDatabases
  - USE-EIO: https://doi.org/10.1016/j.jclepro.2017.04.150
- Four DMSSA food system scenarios (Science Total Environment)
  - http://dx.doi.org/10.1016/j.scitotenv.2022.161095
- Large-, Mid-, and Small-Scale Food Systems (Sustainability)
  - https://doi.org/10.3390/su132011368
- Initial future scenario in CARD Agricultural Policy Review
  - https://www.card.iastate.edu/ag_policy_review/article/?a=150

Key Parameters to Define LCA Baseline Scenario

Food System Stage	BASE	LOCAL
Production	California vegetable producer scale (average) = 59 acres	Iowa vegetable producer scale (average) = 8 acres
Processing	37 % of fruits/vegetables processed	None available for fruits and vegetables
Packaging	96.6 % of food is packaged	67.5 % is sold with limited packaging
Transport	Average distance modeled = 1,740 km	Metropolitan distance modeled = 160 km
Wholesale/Retail	96.6 % sold through wholesale/retail	67.5 % sold direct-to-consumer
Waste	Average food waste = 33 %	Average local food waste = 22 %

LCA Food Groups: Foods that can be Produced in Iowa and are Regularly Eaten in DMSSA

Consumption by food group	BASE	
	%	servings/day
Protein (food items = 5)	**50.07%**	7.71
Dairy (foods = 2)	**50.34%**	1.51
Fruit (foods = 8)	**49.89%**	0.88
Vegetable (foods = 18)	**50.30%**	1.85
Grains (foods = 2)	**50.21%**	6.64
Oil (foods = 2)	**50.02%**	63.90
Sugar (foods = 2)	**50.33%**	22.40

Table 1. Description of Current Condition and Future Scenario

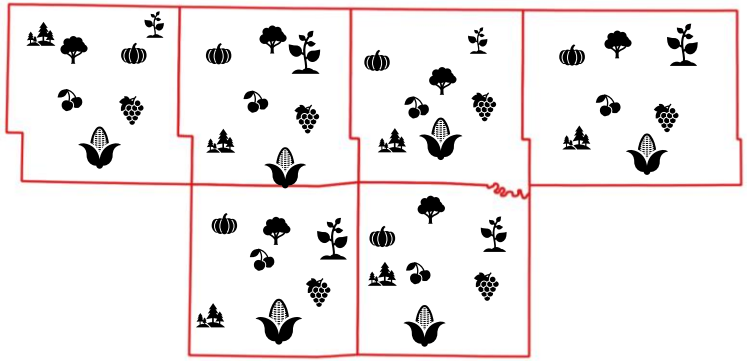
DMMSA Food System	Current amount of local food production	Increased local food production within the DMMSA
LCA	Current conditions: Models 50% of dietary requirements in 2020 with current production (about 5% local and 45% distant) based on consumption patterns	Future scenario: Models 50% of dietary requirements in 2040 with all local production based on current consumption patterns
SWAT	Current conditions: Models land use and yield conditions for 2020	Future scenario: Models future land use with 50% local production and future yield conditions for 2040

Land Needed for Future Scenario

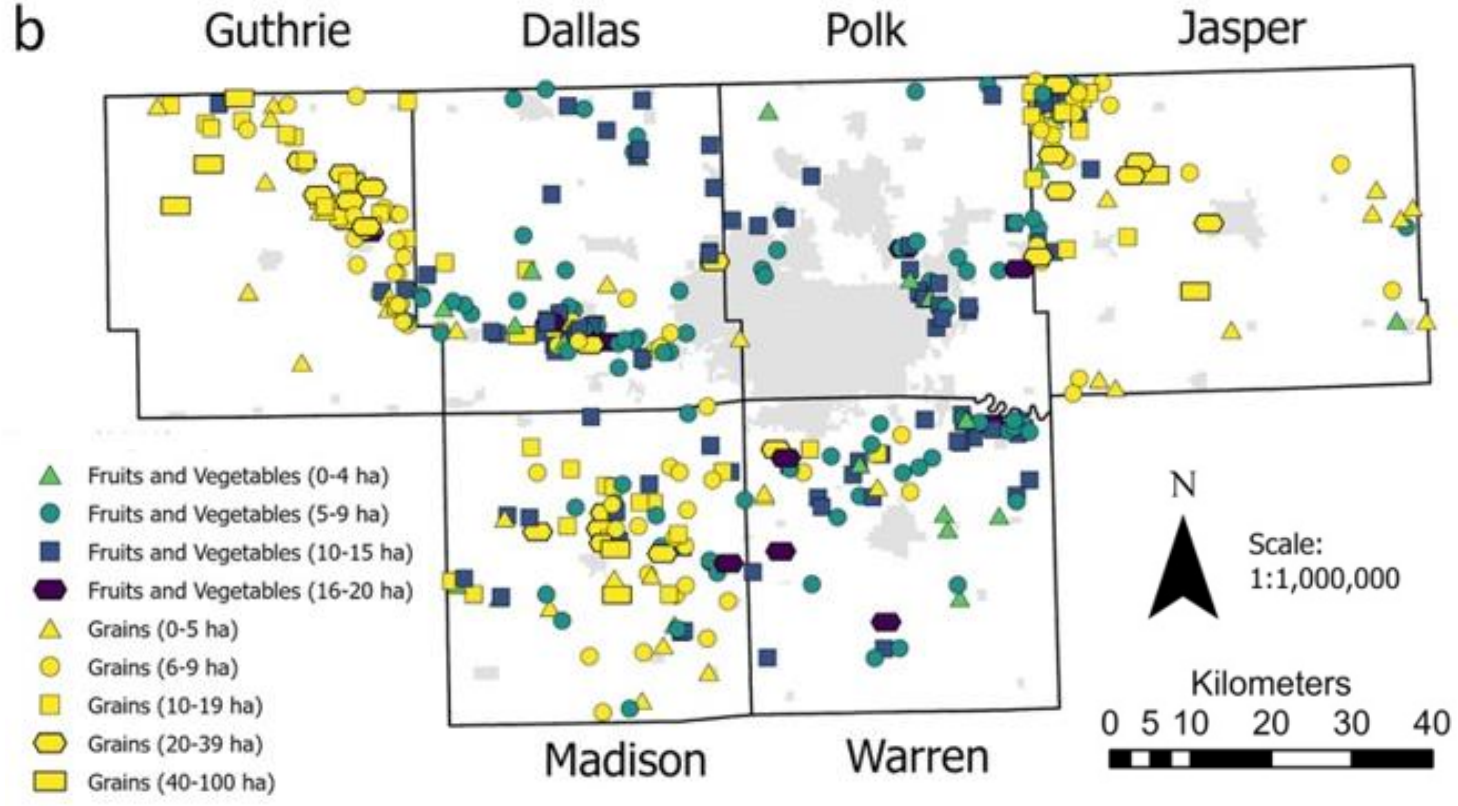
~18,000 ha required for 50% dietary scenario (2% of DMSSA area)

Land use to meet 50 % consumption for DM-MSA population in 2050:
Fruits: 2,513 ha
Vegetables: 1,975 ha
Grains: 13,264 ha (includes livestock feed)
Table food total: 17,752 ha

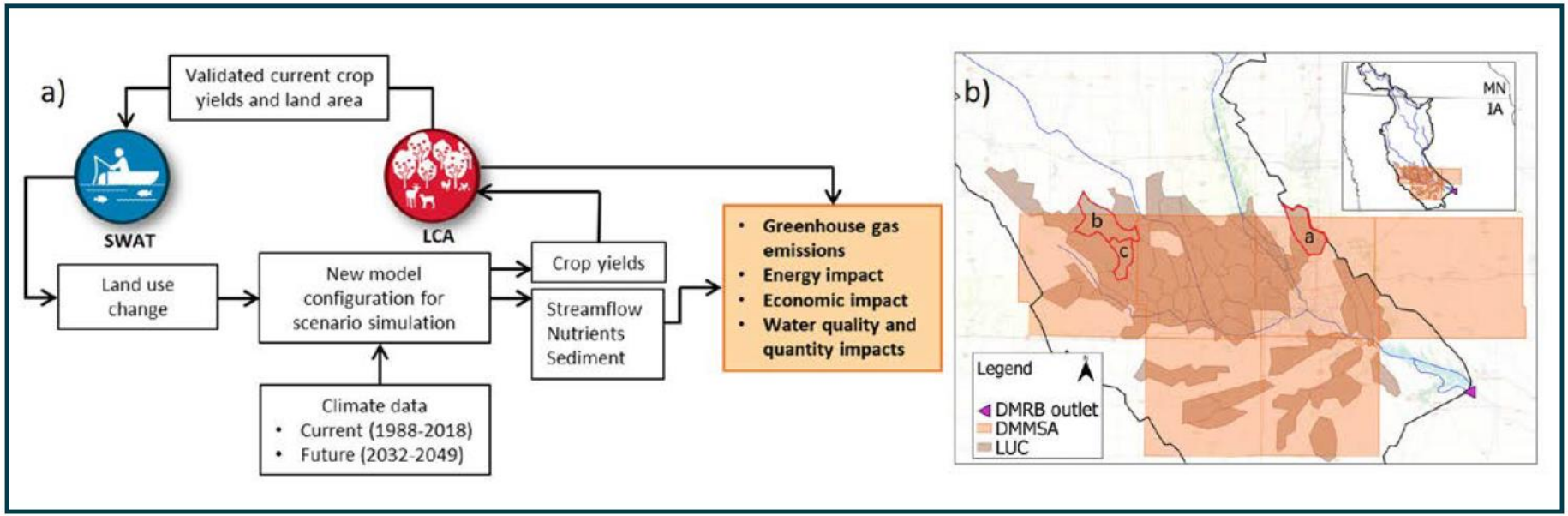
Future scenario



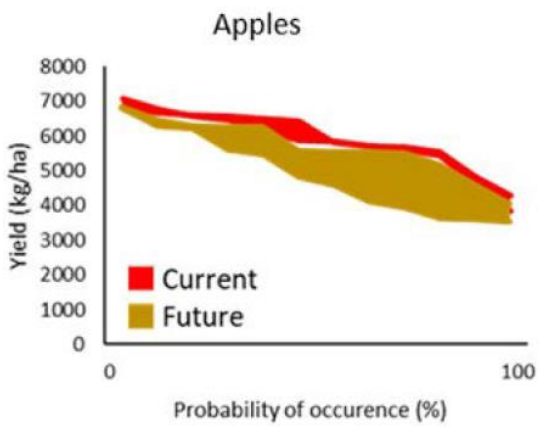
The future scenario for table food production included mid-scale production and spatial clustering

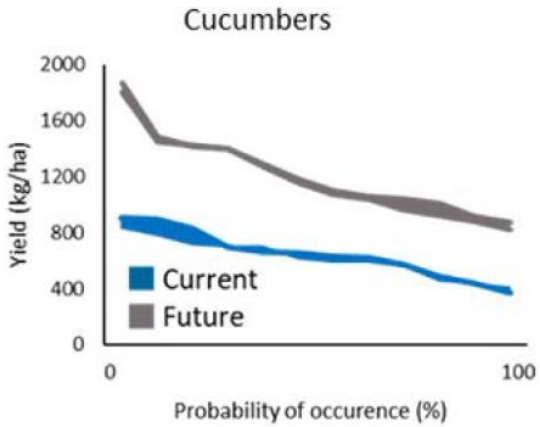


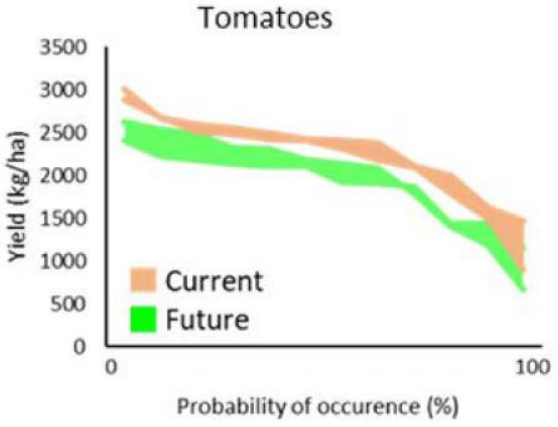
Methodological Flowchart (a), and DMMSA Study Area Location (b) Showing Subbasins Where Land Use Changes Were Modeled



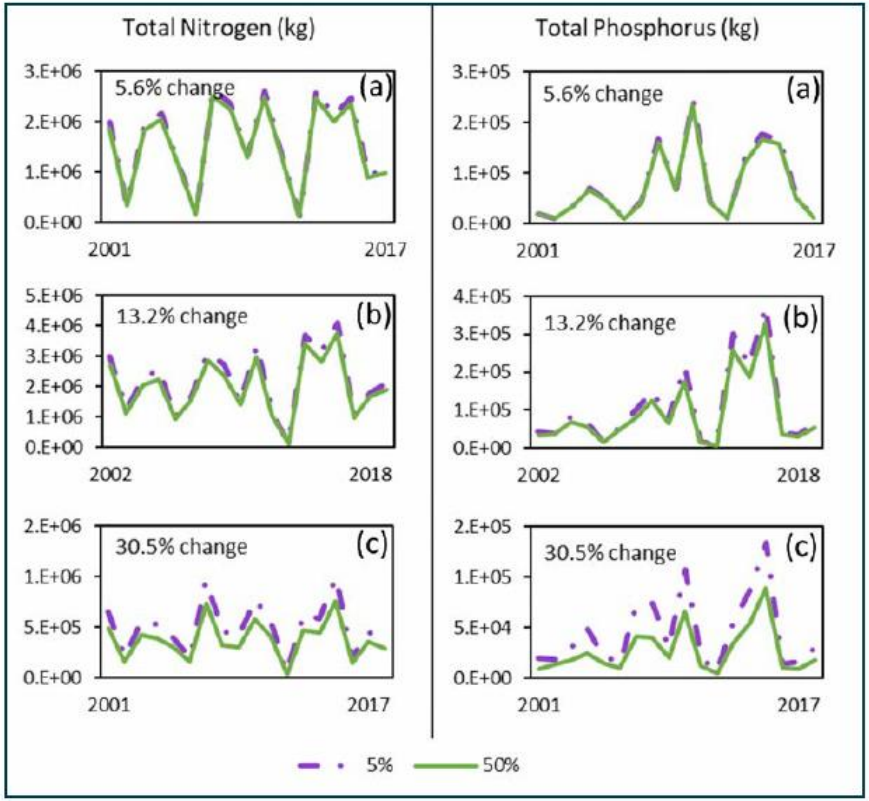
SWAT-Predicted Crop Yield (kg/ha) Trends for Current Versus Future Climate Projections



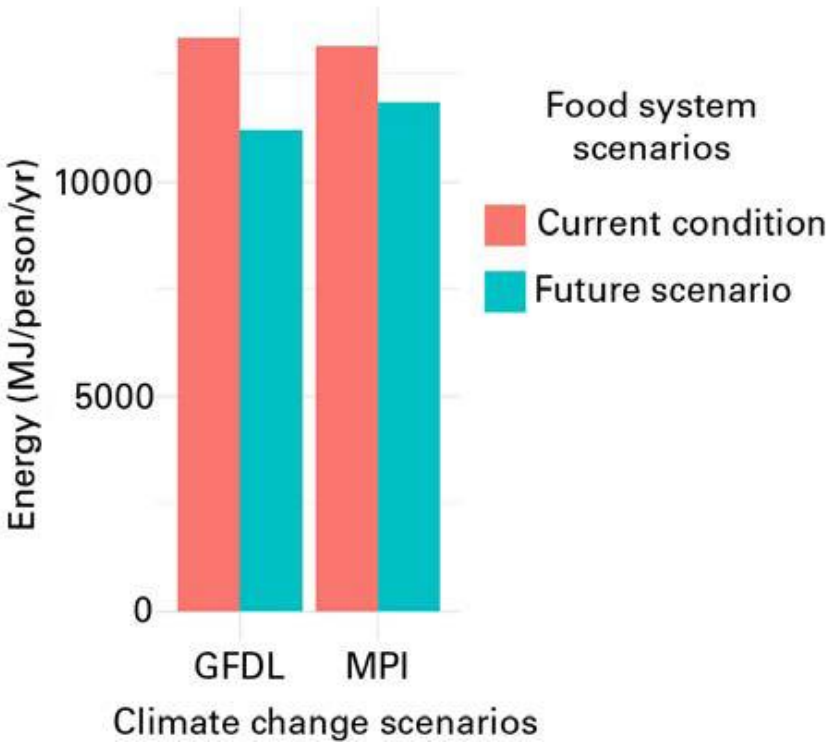


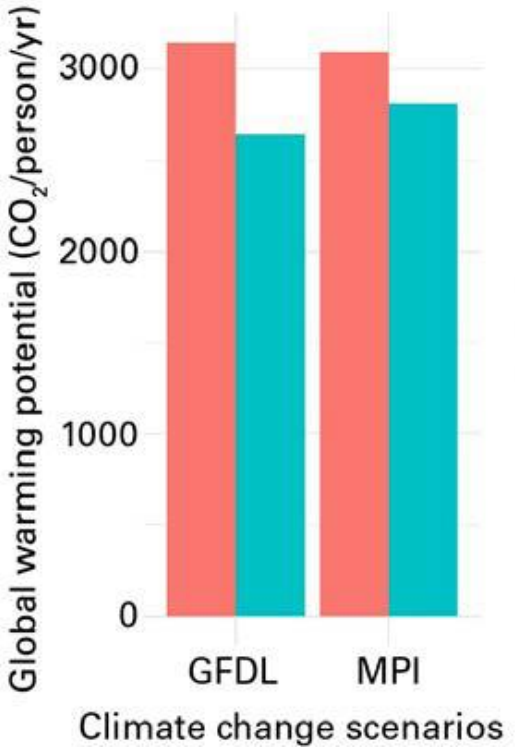


Results of Total Nitrogen and Phosphorus Loads for Three Subbasins (a, b and c in spatial map) in Response to Converting Land Use to Fruit and Vegetable Production



Per person energy and global warming potential to meet 50% of dietary requirements given GFDL and MPI climate projections





Future Directions

- Complete execution of modeling system
  - ABM model should be completed
- SWAT: Continued testing and applications
  - Nutrient and sediment load testing
  - Multiple applications within integrated system
  - Additional BMP assessments