Optimal Allocation of Agricultural Water Use in the Southeastern U.S Using Hydro-Economic Modeling

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Introduction

Conflict over water use in the southeastern US is increasingly common as communities and industries find themselves without adequate water supplies. However, agricultural water use in the southeastern states has received relatively little attention despite rapid growth in the use of irrigation by the region's farmers. For example, from 1997 to 2012, the number of irrigated acres in Tennessee increased by more than 200%. The base in 1997 was comparatively small, but the trend is remarkable. Given the increasing use and dependence on irrigation, is important to have a better understanding of what water scarcity could mean to agriculture in the southeastern region, and what cost-effective adaptations can be pursued by agricultural producers to increase the sector's resiliency.

Objective

The primary objective for this project is to estimate the economic value of water in the row crop and livestock sectors, given temporal and spatial variation in water availability across the study region. This report summarizes progress towards the objective.

Research Methods

Hydrologic Modeling – generate temporally- and spatially-explicit estimates of water availability and scarcity across the study region, using the Variable Infiltration Capacity (VIC) water balance model under current and projected economic and environmental conditions.

Economic Modeling – develop and apply a multi-sector partial equilibrium (PE) model to determine the economic value of water among different use categories, given VIC simulations.

Impacts of water use and value determined by the PE mode are linked with the IMPLAN model to estimate downstream impacts on changes in water use and agricultural output. Industry-specific water use coefficients determine per gallon values according to sector accounts (Blackhurst et al., 2010).

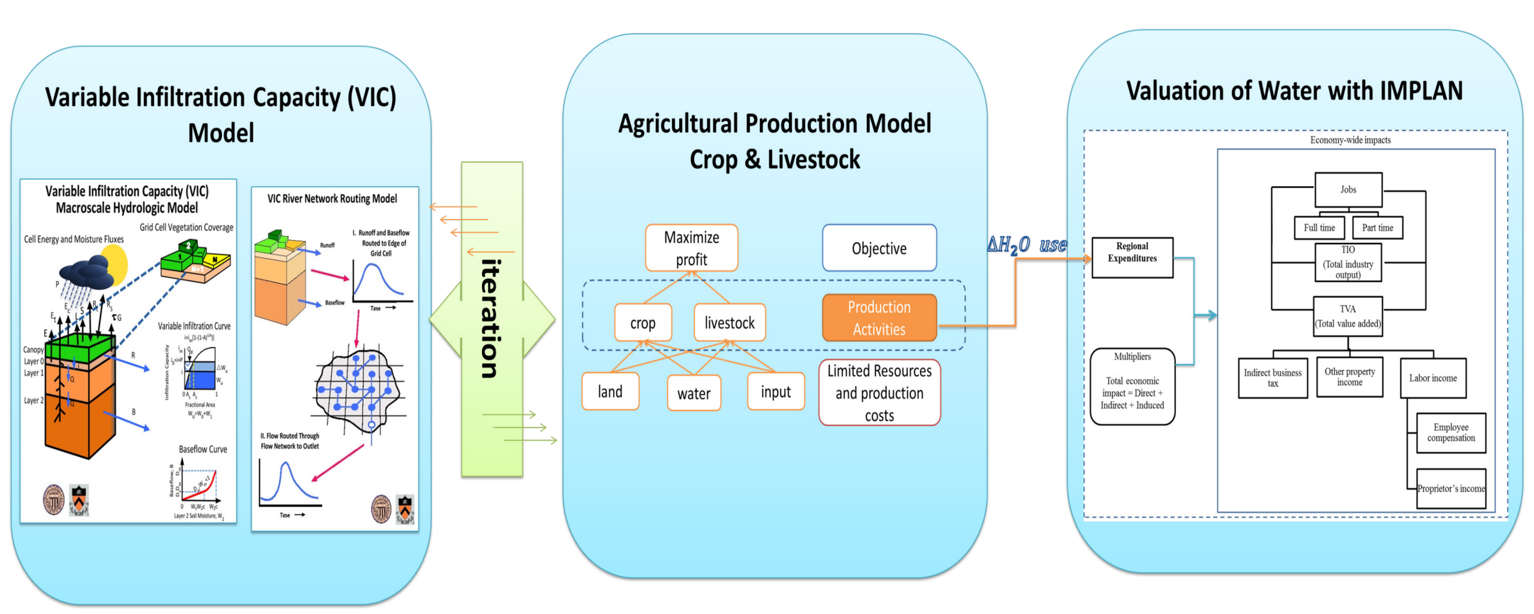

Figure 1. Model system

TN Agricultural Production Model (TNAP)

Current research focuses on the development and calibration of an agricultural production PE model for Tennessee (TN). The model structure builds on the California SWAP model (Howitt et al. ,2012). The TNAP model operates at a sub-regional level delineated at the Hydrological Unit Code 4 (HUC-4) resolution (Fig. 2). The dominant row crops most likely to be irrigated are corn, soybeans, wheat, and cotton (Table 1). Pastureland proxies the distribution of beef cattle operations typical to the eastern region of the state.

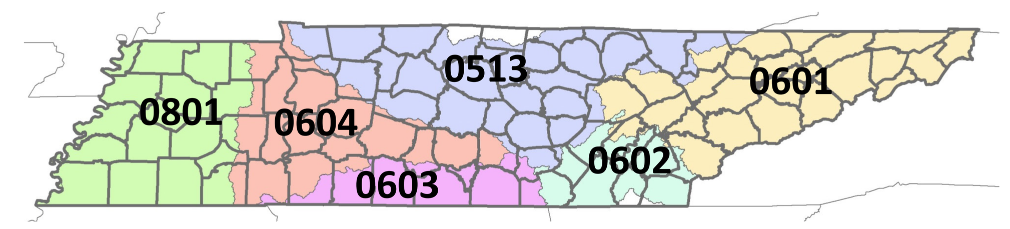

Figure 2. Research regions at HUC-4

Table 1: Current irrigated and rain-fed row crop acreage (000 acres)

	Corn		Cotton		Soybean		Sorghum		Wheat	
HUC-4	irrigated	rain-fed	irrigated	rain-fed	irrigated	rain-fed	irrigated	rain-fed	irrigated	rain-fed
0513	0.06	53.9	176.34	0	193.7	0	0	0	0	0
0601	33.7	0	29.2	0	10.5	0	0	0	0	0
0602	20.5	0	24.7	0	17.4	0	0	0	0	0
0603	4.42	156.85	1.15	38.4	145.78	0	0	0	0	0
0604	8.61	292.29	0.28	83.63	1.47	320.23	0	0	0	0
0801	48.58	608.72	20.07	269.13	22.08	850.92	0	1.3	0	85.8

The TNAP model is calibrated using Positive Mathematical Programming (PMP) (Howitt et al., 2012). For each activity, key data needs are: (1) per acre budgets (e.g., water, labor, land rent, chemicals) for each HUC region; (2) irrigation water availability; and (3) crop acreage supply elasticities.

Calibration entails maximizing producer surplus subject to land (L) and water availability (WL) constraints. Crops substitute according to a constant elasticity of substitution (CES) production function:

$$\max_{x_{ijk}} \sum_{i=1}^{6}\sum_{j=1}^{12} p_i\,\tau_{ij}\left[\sum_{k=1}^{5}\beta_{ijk}x_{ijk}\right]^{-\frac{1}{\rho}} - \sum_{i=1}^{6}\sum_{j=1}^{12}\sum_{k=1}^{1}\delta_{ij}exp\left(\gamma_{ij}x_{ijk}\right)$$
$$- \sum_{i=1}^{6}\sum_{j=1}^{12}\sum_{k=2}^{5}\theta_{ijk}x_{ijk} - \sum_{i=1}^{6}\sum_{j=1}^{12}\sum_{k=1}^{1}\omega_i q_{ij}x_{ijk}$$

$$subject\ to\!: \sum_{j=1}^{12}\sum_{k=1}^{1}x_{ijk} \le L_i$$
$$\sum_{j=1}^{12}\sum_{k=1}^{1}x_{ijk}q_{ij} \le WL_i$$

where i indexes regions (Fig. 2), j indexes crop activities (Table 1), k indexes inputs (water, land, labor, fertilizer, and chemicals), x are activity levels, β are cost shares, ρ is a substitution parameter, τ is a scaling factor, p is commodity price, q is water consumption, ω is water price, and θ are calibrated cost coefficients for non-land inputs.

The exponential cost parameters (δ, γ) are functions of land supply elasticities. Land supply elasticities are econometrically estimated using a land use transition model (Miller and Plantinga, 1999).

Land supply elasticities – Land use transition probabilities were estimated as a function of revenue per acre for i = 1,…95 counties in Tennessee for t = 1997, 2002, 2007, and 2012. The share of land (y) in activity k (alias j) is:

$$y_{t,i,k} = \sum_{j=1}^{K}\pi_{t,i,j,k}\cdot y_{t,i,j} + u_{t,i,k}$$

where

$$\pi_{t,i,j,k} = \frac{\exp\left(y_{t-1,i,j}\sum_h \alpha_{h,k}\cdot z_{t,i,h}\right)}{\sum_k \exp\left(y_{t-1,i,j}\sum_h \alpha_{h,k}\cdot z_{t,i,h}\right)}$$

and z_h are per acre revenues, α parameters, and $u \sim iid(0,\Omega)$. Crop areas, yields, cattle inventory, and prices (in 2012 $'s) were collected from the USDA's National Agriculture Statistical Service to calculate annual per acre revenues from agricultural activities.

Preliminary Results

Given the maximum likelihood estimates of the transition probabilities and a covariance estimator robust to spatial and temporal dependence, land supply elasticities were simulated using a Monte Carlo procedure (Fig. 3). For r = 1,…10,000 iterations, own-price supply elasticities are estimated conditional on a new realization of α: $\alpha_r^* = \alpha^* + L\zeta_r$, where $\zeta_r \sim N(0,1)$ and L is the lower triangular Cholesky factorization of the covariance estimator.

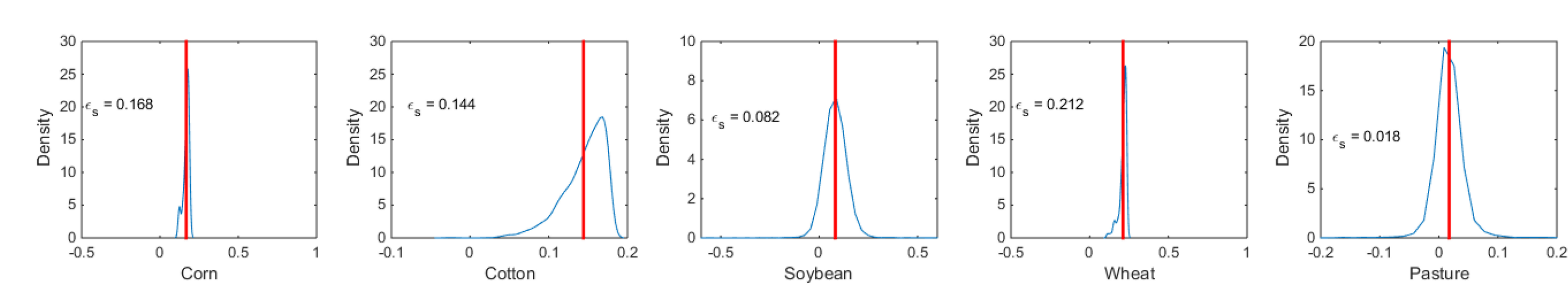

Figure 3. Land supply elasticity estimates

Challenges and Future Research

Regionalized crop budgets – Disaggregating input costs by sub-region provides additional variation. Minimum, maximum, and most likely observed costs admit a range of scenarios for sensitivity analyses.

Irrigation water availability – Variations in water availability will be determined by the VIC model (Fig. 1). These data will impact water availability constraints (WL), thereby determining water values under different stress scenarios.

TNAP integration with IMPLAN – Modifying the Life Cycle Assessment procedures developed by Blackhurst et al. (2010) to the regional hydro-economic model. The procedure maps agricultural sector impacts into the regional economy.

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