Biofuel Expansion in the Ivinhema Basin: Model Development

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Project: Integrated Modeling of the Land Use, Water, and Energy Nexus of Brazilian Biofuels Expansion under Climate Change

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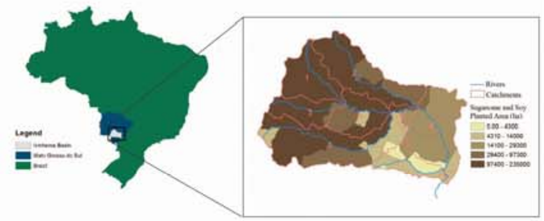
Background

Brazil is a global leader in biofuel production, accounting for approximately a quarter of the world's ethanol supply. The repercussions for local water resources in new areas of intensive biofuel expansion, however, remain uncertain. To assess the effects of various land-use change scenarios on water sustainability in Brazil, this study models a small basin currently experiencing soybean and sugarcane expansion. This effort is part of a larger study modeling land use, water and the energy nexus of Brazilian biofuels expansion under climate change.

Purpose

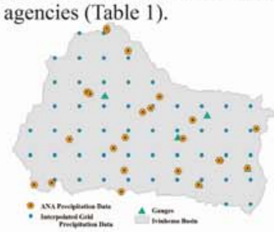
The purpose of this study is to determine the most accurate method for modeling water resources in a basin experiencing expanding biofuel production. Ivinhema basin in Southern Mato Grosso do Sul (Map 1) has experienced extensive sugarcane and soybean expansion since the mid-1990s. While the effect on water resources needs to be evaluated, the precipitation data currently available is not adequate for long-term modeling. This study compares model accuracy when using two different precipitation data inputs: rain gauge data from Brazil's National Water Agency (ANA), and interpolated grid data produced by the Energy Institute at the University of Texas at Austin.



Map 1: Ivinhema basin, rivers, catchments, and 2012 soy and sugarcane cultivation

Data

Most of the data used in this study was sourced from Brazilian governmental agencies (Table 1).



Map 2: Data Points throughout the Ivinhema Basin

Description	Data Source	Time Span
Stream Flow Data	Brazil's National Water Agency (ANA)	1990 - 2013, daily
Precipitation Data	Brazil's National Water Agency (ANA)	1990 - 2013, daily
Precipitation Data	Interpolated Grid	1990 - 2013, daily
Land Use Data	Brazilian Institute of Geography and Statistics (IBGE)	1990, 2000, 2008, 2012
Crop Coefficients and Stage Duration	Brazil's National Agricultural Supply Company (CONAB)	------------

Table 1: Data used in study

Precipitation Data

Both sets of precipitation data were averaged across watersheds (Map 1) and entered as daily time series data.

The two precipitation datasets show the same trend when mapped against one another; however, the UT Energy Institute Grid has fewer extremes -- fewer days with zero precipitation and lower maximum precipitation values -- than the ANA precipitation data.

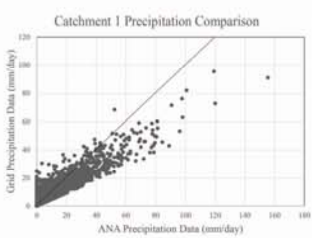


Figure 1: Data points in Invinhema basin

Land Use Data

Land use was evaluated for each catchment using three main crops: corn, soybeans, and sugarcane. Land use data by municipality were aggregated to each catchment. The remaining land area in each catchment was assumed to be grass. These values were calculated for 1990, 2000, 2008, and 2012. These data and crop coefficients and growth durations from CONAB were input.

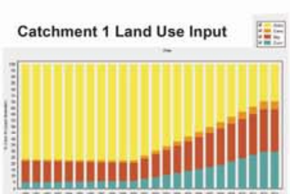


Figure 2: Data points in Invinhema basin

Methods

These data were entered into a model using WEAP software (described below). Four different input scenarios were run to test the validity of the UT Gridded dataset and the sensitivity of the model to land use and precipitation inputs (Table 2).

	Precipitation Data		Land Use	
	Interpolated Grid Precipitation Data	ANA Precipitation Data	IBGE Land Use	100 percent grass cover
Scenario 1	x		x	
Scenario 2		x	x	
Scenario 3	x			x
Scenario 4		x		x

Table 2: Study scenarios

Metric of Model Accuracy

To assess the model's accuracy, Nash-Sutcliffe model efficiency coefficients (E) were calculated for each river using the following equation:

$$E = 1.0 - \frac{\sum_{i=0}^{N}(Qo_i - Qs_i)^2}{\sum_{i=0}^{N}(Qo_i - \overline{Q})^2}$$

Qo_i = observed flows
Qs_i = modeled flows
$\overline{Q}$ = mean of observed flows
N = 278 (monthly data, 1990 – 2013)

Nash-Sutcliffe values range from -∞ to 1, with 1 meaning that the model perfectly reflects reality, while values below zero indicate that the mean of the observed data is a better predictor than the model. E > 0.6 is considered very good.

WEAP Model

WEAP is water resources modeling and planning software developed by the Stockholm Environment Institute's U.S. Center. The model created for this study uses WEAP's Soil Moisture Method to predict flows for different land use and precipitation scenarios. This method allows users to input a variety of land use and soil parameters, including crop coefficients from CONAB, percent area under different crop regimes, and soil water capacity. The model was calibrated using Soil Water Capacity* and Preferred Flow Direction** as the primary calibration inputs (Table 3).

	Soil Water Capacity*	Preferred Flow Direction**
Catchment 1	1800	0.3
Catchment 2	2000	0.36
Catchment 3	1800	0.3
Catchment 4	1800	0.4
Catchment 5	2500	0.4
Catchment 6	2000	0.27
Catchment 7	5000	0.3
Catchment 8	2000	0.15
Catchment 9	590	0.25

Table 3: Primary callibration parameters

*Soil Water Capacity is the effective water holding capacity of the upper soil layer in mm.
**Preferred Flow Direction ranges between 0 and 1, with 0 representing 100 percent verticle flow and 1 representing 100 percent horizontal flow through soil.

Results

Nash-Sutcliffe Values by Gauge

Scenario		1	2	3	4
		IBGE Land Use values		Assuming 100% Grass Land Use	
River	Gauge	Grid Data	ANA Precipitation Data	Grid Data	ANA Precipitation Data
Dourados	64610000	0.74	0.48	0.31	0.65
Ivinhema	64617000	0.56	0.44	0.29	0.43
Brilhante	64601000	0.47	0.17	-0.24	0.37
Vacaria	64613800	-0.75	-0.82	-0.79	-0.73
Guirai	64618000	-5.93	-7.08	-6.94	-5.81

Table 4: Nash Coefficients, excluding missing ANA Precipitation Data.

A comparison of Nash-Sutcliffe coefficients for four different input scenarios shows that flows modeled using Scenario 1 is most accurate (Table 4); however, these results show that both the interpolated grid and the ANA precipitation values model the Dourados, Ivinhema, and Brilhante basins accurately. Vacaria and Gaurai have low Nash-Sutcliffe coefficients for all input scenarios, indicating that the physical parameters for these catchments may be inaccurate.

Conclusion

Both precipitation datasets result in relatively accurate results; however, the Grid data is preferred due to the high number of missing values in the ANA dataset. When included in analysis, these missing data result in lower Nash values and inaccurate flows. The IBGE Land Use data is favored because of its high levels of accuracy when combined with the Grid precipitation data, and generally better Nash values. As a result, Scenario 1 is preferred for future modeling.

Scenario 1 Results

Simulated vs. real flows are shown in Figure 3 for the Vacaria, Ivinhema, and Dourados Rivers. The Nash-Sutcliffe coefficents for these simulations are -0.75, 0.56 and 0.74 respectively.

Map 3: Flow Gauge locations in the Ivinhema basin.

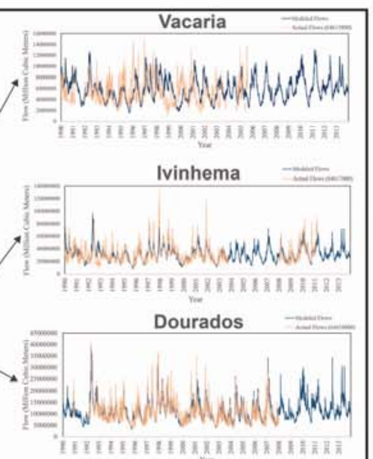


Figure 3: Data points in Invinhema basin