Effect of Agricultural Activity on River Water Quality: A Case Study for the Lower Colorado River Basin

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Abstract

This case study investigates the effect of a change in cropping pattern involving expanded acres of crops for biofuel feedstock, on the discharge of nutrients to rivers. Annual data from 1968-2008 on stream flow, cropped acres, and precipitation for Wharton County, Texas are used. A positive impact of increased corn acreage over this period on river discharge is identified.

Keywords: Biofuels, Stream Flow, and Discharge

Introduction

Biofuel demand has the potential to impact cropping activities across United States. Continuous cropping of a single crop, removal of the majority of plant material, and increasing the application of irrigation and chemical inputs are just a few examples of changes that may be expected in production agriculture as a result of biofuel policies. Production activities that are focused on the continuous growth and removal of biomass can impact soil fertility, leading to an increase in removal of plant nutrients in runoff, affecting productivity and contributing to surface and ground water contamination (Office of Technology Assessment 1984). Moreover, agricultural practices that expose structurally-fragile soil to harsh environments and land uses leave little or no time for soil restoration and increase chemical losses in runoff and percolation (Lal and Stewart 1994). Basta, Huhnke, and Stiegler (1997) evaluated the impact of agricultural chemical runoff on water quality and found that application of chemical inputs to eroded soils is a significant contributor to surface and ground water contamination. Hamilton and Helsel (1995) also noted that the major factors affecting the amount of chemicals reaching water bodies from agricultural cropland are impacted by land use practices, hydrology, sediment composition, precipitation, and crop type.

In recent years, partly as a result of biofuel initiatives, there has been an increase in corn acres in the Lower Colorado River region of Texas (National Agricultural Statistics Service 2010). River discharge in this region has been increasing and associated water quality has been steadily declining. These phenomena suggest there may be unintended consequences related to the response of production agriculture to federal energy policy. This agriculture production region offers an opportunity to estimate the implications of cropping pattern changes on river discharge and associated water quality. It is also expected that corn acreage increases will offset

acreage devoted to other major crops in the region such as soybeans and grain sorghum, including acres enrolled in a conservation program (Tokgoz et al. 2007). Improved understanding of the effects of a cropping pattern change on discharge in this region is expected to be useful in predicting consequences in other regions.

Literature Review

The rapid expansion of agriculture over the past few centuries led to conversion of natural or native vegetation to cultivated agricultural systems. Such changes to land use and agricultural practices have significantly increased leaching of chemicals to surface and ground waters (Carpenter et al. 1998). Several studies also reported a strong relationship between cropping pattern changes and nutrient level enhancements in watersheds across the United States (Johnson et al. 1997; Liu et al. 2000).

U.S. federal bioenergy policy is directed toward ethanol, which leads to increased production of crop grains (high in starch). The expanded production of biofuels provides incentive for transforming cropping patterns more to feed grains such as corn. There is also emphasis for harvesting biomass to convert to ethanol. This can lead to elimination of crop residue at the soil surface and contribute to increased transport of chemicals in surface and groundwater (Johnston et al. 1981).

Increased fertilizer applications to croplands and runoff from soils with high nutrients are some of the major causes of eutrophication (McIsaac et al. 2001). Reports from United States Department of Agriculture (USDA) indicate that 60 percent of the soil that is lost from U.S. croplands is deposited in streams and rivers (U.S. Department of Agriculture 1989). National Research Council (2000) reported that over 60 percent of the coastal rivers in the United States moderately to severely degrade due to nutrient enrichment. These studies support the argument that increased discharge to rivers can be attributed to cropping pattern changes; specifically, increases in production of input-intensive crops. One of the other major challenges associated with agricultural-related water quality deterioration is the difficulty associated with its "hard-to-notice" initial impacts, and by the time the impacts are noticed, remedial strategies are difficult to implement (Sharpley 1999). Although, this paper does not specifically address the issue of non-point pollution characteristic of the agricultural activity, it is worthwhile mentioning that

most agricultural activities and their associated impact on water quality are a non-point pollution issue, where it is difficult to trace back the impact on water quality to a particular farm/producer.

Most of the nutrients transported to the water bodies through runoff result from application of nutrients to eroded soils. According to Young (1989), eroded soils contribute three times more nutrients in runoff than healthy soils. Pimentel et al. (1995) indicated soil erosion results in limited availability of basic nutrients such as nitrogen, phosphorous, and potassium for crop production. Scanlon et al. (2007) reported that degradation of water quality in irrigated agricultural regions is similar to that of rain-fed regions, which is a result of fertilizer leaching, salt mobilization, etc. Based on the above observations, the goal of this research is to estimate river water discharge levels in the Lower Colorado River region of Texas as a result of increased cropping activity and shift in cropping patterns, as a consequence of the policies aimed at increasing the biofuel crop production. It is assumed that in increased discharges from cropland to rivers, there are increased levels of nutrients since they are not specifically estimated in this study.

Data

Annual river water discharge into the Lower Colorado River Basin for the years 1968 to 2008 periods for Wharton County, Texas (Latitude 29 ° 18'32", Longitude 96 ° 06'13") were used in this study. The data were obtained from U.S. Geological Survey (USGS) surface water statistics (U.S. Geological Survey 2010). The drainage area for the study region extends over 42,003 square miles. Annual precipitation data for the region were obtained from the Texas Water Development Board (2010). Monthly data were averaged to obtain annual values for the analysis.

Annual county agricultural statistics for the period 1968 to 2008 were obtained from the National Agricultural Statistics Service (2010). The number of irrigated acres planted to corn, the primary biofuel crop, was used for this analysis. Federal mandates for biofuel production resulted in expansion of crop acreage and shifts in cropping patterns (Malcolm and Aillery 2009). Hence, a biofuel dummy was included to account for the biofuel policy effect. The Energy Policy Act of 1992 provided strong incentives for the use of renewable fuels in the United States; hence, a dummy variable, which captures the effect of a policy aimed to include renewable fuels, was included. The dummy variable takes on a zero value prior to 1992 and a

value of one in each year from 1992 onwards. Summary statistics of the variables constituting the data set are provided in Table 1.

Table 1 Selected Descriptive Annual Statistics for the Lower Colorado River Region, Wharton County, 1968-2008

Variable	Mean	Std. Dev.	Min	Max	Obs.
Precipitation (inches)	43.87	9.87	23.62	62.12	41
River discharge (cfs)	2,837.74	2,069.98	691.8	11,120	41
Corn acres	42,878.05	20,622.6	8,500	96,200	41
Log river discharge	7.72	0.68	6.54	9.32	41

cfs: cubic feet per second
Sources: National Agricultural Statistics Service (2010), Texas Water Development Board (2010), and U.S. Geological Survey (2010).

Methodology and Results

A model was formulated whereby discharge (q_t) is a function of area of planted irrigated corn (A_t), precipitation (P_t), and the biofuel dummy variable (B_t) :

$$q_t \ = \ f\left(P_t, A_{t,} B_t\right).$$

The distribution of discharge was found to be skewed; hence, a log transformation is used for the discharge variable. Therefore, the analysis is conducted by evaluating the logarithmically-transformed discharge, i.e., $q_t = lnQ_t$. Precipitation is divided by the discharge variable to evaluate changes in the discharge-precipitation relationship. Finally, a model is applied that allows for the discharge-precipitation relationship to be a function of planted irrigated corn area. The final relationship is estimated using a generalized additive model, with s(A_t) as a smoothing function of the acreage. The estimation of s(A_t) resulted in a straight line, indicating a linear relationship. Therefore the final model is a linear model, which has an interaction term $A_t P_t$.

Pimentel et al. (1995) notes that one-half of the amounts of nutrients applied and remaining in soil are lost following a heavy rainfall. Hence, a precipitation variable was included in the analysis. Linear and quadratic fits between log-discharge and precipitation were

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examined with Akaike information criteria (AIC) and Bayesian Information Criteria (BIC), where it was concluded the linear model was a better fit; hence, a linear precipitation term was subsequently used for the analysis.

Irrigated corn acres planted in the county increased by 350 percent from 1968 to 2008 (National Agricultural Statistics Service 2010). A similar procedure to that used for the precipitation variable was employed for the acreage variable. Again, the linear form performed best based on the above AIC and BIC criteria. Tests were also conducted to check for the presence of heteroskedasticity and autocorrelation. The LM test for autoregressive conditional heteroskedasticity and the Bruesch-Godfrey LM test for autocorrelation in time series data were performed. Both tests failed to reject the null, signifying absence of autocorrelation and heteroskedasticity.

Over time, several factors can contribute to the level of contaminants reaching water bodies. A time variable was included to capture the trend effects, such as improvements in conservation efforts, change in conservation policies, etc. Regression results from the analysis are presented in Table 2.

Table 2 Estimates of the Model Fitted by Generalized Additive Model Function for the Lower Colorado River Region, Wharton County, 1968-2008

Intercept	Precipitation	Acres x precipitation	Biofuel dummy	Year	#Adj. R-sq
7.778*	0.021**	7.54e-07**	0.040	0.006	0.192
(0.231)	(0.012)	(1.46e-07)	(0.220)	(0.020)	(0.105)

* and ** indicates variable significant at one and five percent level, respectively.
Standard errors in parentheses, #f-value in parentheses

The coefficient on precipitation is positive and significant at the five percent level, indicating a positive effect of annual rainfall on the discharge to the river. The estimate on the acres-precipitation interaction term equals 7.54×10^{-7} and is also significant at five percent level, showing that the discharge is significantly affected by the area of planted irrigated corn. Coefficients on the biofuel dummy and year are not statistically significant. Higher-order polynomials for the trend variable were also tested and found to be insignificant. Figure 1 is an illustration of the fitted values of log discharge.
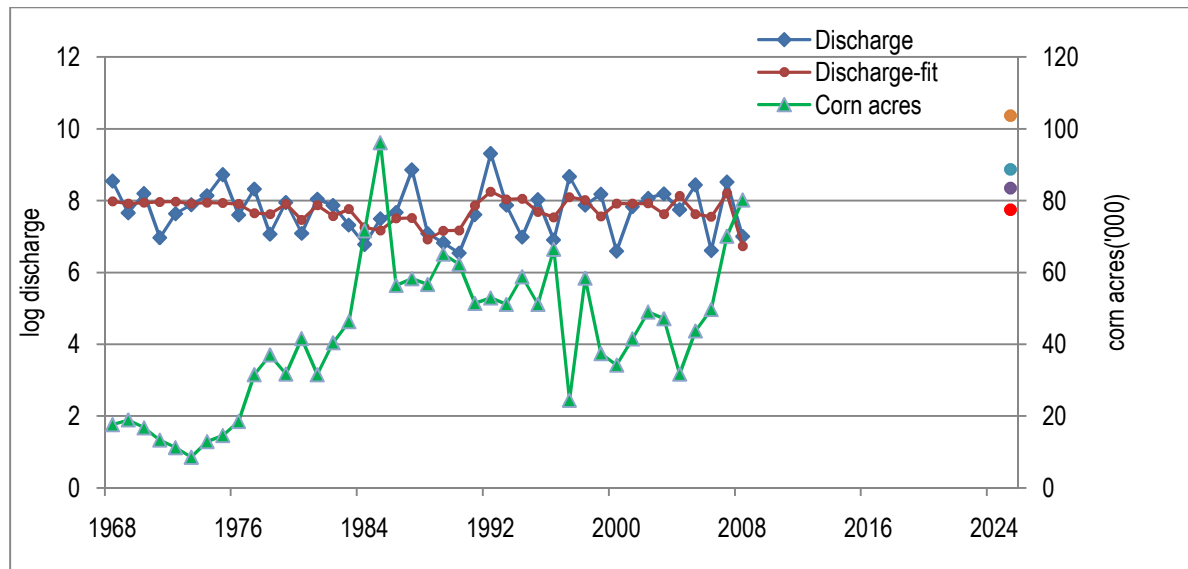
Figure 1: Log-discharge for the Lower Colorado River for years 1968-2008. Also shown are the corn acres for the region during the same time period. Projected river discharge levels for 25, 50, 75, and 100 percent increases in irrigated corn crop acres are also shown on the graph as dots for 2025.

With future assumed changes in crop acreages resulting from ethanol feedstock production expansion, the model is applied to project changes in discharges to the Lower Colorado River, specifically with respect to increasing irrigated corn acreage. The projections of discharge were done with expansion of irrigated corn acres by 25 percent, 50 percent, 75 percent, and 100 percent. By the year 2025, utilizing the simulated precipitation values, an increase in irrigated corn acreage by 100 percent is estimated to increase discharge to the river by 34.3 percent. This increase in acres is anticipated to represent a major increase in irrigation water use and, ultimately, result in increased nutrient export into the Lower Colorado River. Table 3 is a summary of the discharge levels to the river at the assumed respective level of crop acres.

Table 3 Projected River Discharge Levels due to Increased Corn Crop Acreages in the Lower Colorado River Region, Wharton County, for 2025.

	Increase in river discharge by increasing percentage of corn acres by				
	Present acres	25%	50%	75%	100%
River Discharge (cfs)	7.725	7.754	8.356	8.878	10.376

Summary and Conclusions

Statistical analysis of annual discharge and precipitation in the Texas Lower Colorado River basin for 1968 to 2008 suggests that increasing irrigated corn acreage increased the discharge to the river. This result is consistent with the work of Schilling et al. (2010) who suggested cropping activities were more important than climate change in affecting discharge to a river. Quantifying the magnitude of crop acreage influence, irrigated corn acreage in this case, on increasing river flow is an important benchmark for assessing the significance of cropping patterns change on regional water patterns. This case is based on the Lower Colorado River basin. A purpose of this exercise was to emphasize that energy (or other) policy can have unintended consequences, suggesting a need for broader analysis before implementation. All regions are unique with specific characteristics, making a generalized conclusion invalid.

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