THREE ESSAYS: RESERVOIR MANAGEMENT; SWITCHGRASS LAND LEASING; AND ITS ENVIRONMENTAL IMPACT

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ABSTRACT:

First essay determines the optimal lake levels for Lake Tenkiller that maximizes the total net economic benefits derived from both marketed and non-marketed uses under stochastic inflows. It was found that for Lake Tenkiller when recreational benefits are included, it is beneficial to maintain the lake level at around 634 feet above mean sea level until mid-August, and then start drawing down for hydropower generation.

Second essay assists the proposed biorefinery by determining if it can reduce the overall year-to-year variability in switchgrass biomass production by strategically selecting a portfolio of land to be leased to meet the required feedstock demand of the biorefinery. It was found that strategically selecting land to lease would reduce both the expected costs of switchgrass feedstock and the number of forced shutdown days.

Third essay estimates the farm-gate breakeven price of switchgrass relative to wheat production, which is the dominant crop in Oklahoma. The breakeven price of switchgrass is determined with (social) and without (private) considering selected external environmental consequences. Results suggest that the farm-gate breakeven price of switchgrass from the private landowners' perspective is higher than from the social planners' perspective when environmental consequences are considered.

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CHAPTER I

INTEGRATED RESERVOIR MANAGEMENT UNDER STOCHASTIC INFLOWS: A CASE STUDY OF LAKE TENKILLER

Abstract

This study is primarily concerned with the planning and management of a multipurpose reservoir. An economic optimization model using non-linear programming is developed and solved to maximize the net economic benefits derived from the different use of lake/reservoir water under uncertainty. Marketed urban and rural water supply and hydropower generation and non-marketed lake recreation uses are considered directly in the maximization problem, while flood control and downstream releases are incorporated as constraints. A mass balance equation is used to model the dynamics of lake hydrology. Unlike most studies including non-market benefits, both the value of a visitor day and the number of visitors are function of lake level. Results show that for Lake Tenkiller when recreational benefits are included, it is beneficial to maintain the lake level at around 634 feet above mean sea level (famsl) until mid-August, and then start drawing down for hydropower generation. A sensitivity analysis is also performed with different values of visitor day and peak electricity prices. However, the results show benefit to protecting recreational uses for all different scenarios making the conclusion robust. Although many reservoirs such as Tenkiller Ferry Dam were originally created for marketed uses such hydropower and flood control, these results illustrate the importance of considering non-market benefits in lake management.

Introduction

In the United States, and the southwest in particular, water supplies are intensively used and expected to experience increasing year long and seasonal pressures. In Oklahoma, seasonal and long-term droughts such as 2006 and 2011 highlighted the potential conflicts between the planned uses for reservoirs such as irrigation and increasingly popular recreational uses (OWRB 2011). Reservoirs in semi-arid areas such as Oklahoma are key to buffering the impacts of drought. Similar to many other semi-arid states, Oklahoma is currently updating its legislation, based on the findings of the 2011 comprehensive water management plan (OWRB 2011), to consider the impact of climate, demographic and economic changes. Unfortunately, the effects of management plans on recreational values are largely ignored (OWRB 2011). The water management problem is challenging for policy makers because water markets are absent or do not operate efficiently. Water managers face the question of how much water should be allocated among competing marketed uses such as hydroelectric power generation and municipal and industrial water uses versus how much water should be stored for non-marketed recreational uses. The optimization model employed in this study can aid water managers in efficiently allocating reservoir water among multiple uses so that the total net economic benefits to all sectors of society are maximized.

Optimization models that partially address the problem of surface water allocation have been employed for several decades. Ward and Lynch (1996) used an integrated optimal control model to evaluate the allocation of New Mexico's Rio Champa basin water between lake recreation, in-stream recreation, and hydroelectric power generation and found that water released for hydropower generation yielded higher benefits than managing lake volumes for recreational uses. Chatterjee et al. (1998) determined the optimal release pattern of reservoir water for irrigation and hydropower production in the western United States. They showed that water should be released if the value of releasing water for hydropower generation and irrigation is higher than the value of storing water for other purposes. Hanson et al. (2002), using contingent valuation, estimated the impact of water level changes on recreational values and found that during the summer, when the recreational benefits are valued most, a higher lake level should be maintained. Changchit and Terrell (1993) proposed a model for multipurpose reservoir operation systems under stochastic inflows and solved it using the chance-constrained goal programming (CCGP) methodology that allows the reservoir manager to rank and allocate water among various uses according to their relative values. However, economic benefits are not considered in their study.

These studies do not simultaneously consider both the marketed (hydropower generation, municipal and industrial water use, irrigation, and other uses) and non-marketed recreational values in reservoir management under uncertainty. The present study uniquely considers the economic benefits derived from hydropower generation; recreational, municipal and industrial use; flood control level; and downstream releases in a single model, while inflows are considered to be stochastic.

The main objectives of this study, given stochastic inflows to the reservoir, are to (1) determine the average monthly lake level and release pattern of water from the reservoir that would maximize the net total economic benefits, (2) compare the changes in the economic benefits and the lake level between cases when recreational values are directly included in the objective function as opposed to cases where recreational values are calculated after the optimization, and (3) determine the sensitivity of optimal lake levels to the changes in the value of electricity prices and the value of a visitor day.

Study Site

In 1953, the United States Army Corps of Engineers (USACE) completed the Tenkiller Ferry dam (Figure I-1) on the Illinois River in northeastern Oklahoma that was constructed for the purposes of flood control and hydropower generation. According to USACE (2009), Lake Tenkiller is one of the outstanding lakes in Oklahoma because of its clean water and abundant recreational facilities. It has water related recreational activities such as skiing, hiking, sailing, and fishing that attract a huge number of visitors every year. With a depth of 165 feet and clear water, it is also very popular among scuba divers, but the predominant use is swimming and boating. The lake has a shoreline of about 130 miles and a surface area of 12,650 acres. The total volume of water in the lake is 654,231 acre-feet (ac-ft) at the normal lake level of 632 famsl (feet above mean sea level). The maximum possible lake elevation is 667 famsl, and the maximum depth at the normal lake level is 165 feet (USACE 2010c). Lake levels have varied between 620 famsl and 653 famsl over the period from 1979 through 2010 (USACE 2010b, 2010c).

Methods

Both the hydrologic and economic characteristics of the model are shown in the schematic representation (Figure I-2). The total stochastic inflows of water was distributed among marketed (urban and rural water supply and hydropower) and non-marketed[1] (recreational) uses derived from a travel cost model. The economic benefits derived from recreational uses were obtained by multiplying the visitor day by the value of a visitor day. Economic benefits of hydropower production were obtained by multiplying the amount of hydropower produced based on the water released for this purpose and the head of the reservoir, that is, the average lake level above the turbine by price of electricity. Economic benefits arising from urban and rural water supply uses depend on consumer surplus plus producer surplus derived from monthly/weekly water demand (the area below the demand curve and above the supply curve).

Mathematical Model

A non-linear programming model developed for the Broken Bow reservoir in Oklahoma (Mckenzie 2003) was modified to allocate Lake Tenkiller water among competing uses given stochastic monthly or weekly inflows, on-peak and off-peak water demand for hydroelectricity, urban and rural water supply uses, and recreational uses for the year 2010. The Frontline Risk Solver (Fylstra 2010) was used to solve the model. Total net expected economic benefits were maximized over a year period by controlling monthly/weekly releases for hydroelectric power generation and urban and rural water supply uses. The limited capacity of the Risk Solver limited problem size. Therefore, stochastic inflows were modeled monthly except during June, July, and August, where they were modeled on a weekly basis. A mass balance equation was used to determine

[1] In this study, non-market valuation is limited to only "use values". A more extensive study could include "non-use values" such as existence value, bequest values and option values. Thus, restricting the study to "use values" suggests more conservative results.

the monthly/weekly level and volume of water in the lake given the inflows and outflows. The model was specified as:

Maximize:

$$\underset{r}{E(TB)} = \sum_{t=1}^{T} (E(HB_t) + E(RB_t) + URB_t) ; \quad (1)$$

where $E(TB)$ is the expected total economic benefits for the year 2010, $E(HB_t)$ is the expected hydroelectric power generation benefits in month/week t, $E(RB_t)$ is the expected recreational benefits in month/week t, r is the amount of water releases, and URB_t is the urban and rural water supply benefits in month/week t and T is the combinations of month and week for the year 2010.

According to USACE (2010c), the top of the flood pool for Lake Tenkiller is 667 famsl. Flood risk management in the model is implicitly considered by always maintaining the lake level below 645[2] famsl. An upper bound of 645 famsl was imposed on the lake level to maintain flood control capacity. The reservoir mass balance equation (Mckenzie 2003) determines the ending monthly/weekly reservoir volume from the beginning volume plus expected inflows (including precipitation); less outflows (hydropower generation releases and other releases), and evaporation:

$$V_{t+1} = V_t + E(I_t) - O_t - E_t \quad (2)$$

$$V_{min} \le V_t \le V_{max},\ O_{min} \le O_t \le O_{max},\ V_t,\ I_t,\ O_t \ge 0; \quad (3)$$

where V_{t+1} is the volume of water in the reservoir in month/week t+1, V_t is the volume of

[2] An 8 to 10 feet rise of lake level above the normal pool of 632 famsl results in the picnic area being under water. Therefore, in this study a conservatively maximum flood pool level was considered at 645 famsl.

water in the reservoir in month/week t, $E(I_t)$ is the expected inflow of water to the reservoir in month/week t, O_t is the outflows of water from the reservoir in month/week t, E_t is the evaporation of water from the reservoir in month/week t, V_{min} is the minimum volume of water in the reservoir, V_{max} is the maximum volume of water in the reservoir, O_{min} is the average minimum historical outflows of water from the reservoir, and O_{max} is the average maximum historical outflows of water from the reservoir. The bounds on the downstream releases are to protect minimum flows to the trout fishery on the lower Illinois River, which is maintained ten miles below the dam.

Monthly inflows were tested to determine if they could be modeled lognormal distributions (Wang et al. 2005). The acceptability of using the lognormal function to represent reservoir inflows over the October 1979 - May 2010 (USACE 2010a, 2010b) period was confirmed with the Kolmogorov-Smirnov goodness of fit test (Phillips 1972). Simulated average monthly/weekly inflows and their standard deviations were compared against the historical monthly/weekly inflows means and standard deviations (Table I-1).

Hydropower Generation Benefits

The economic benefits arising from hydroelectric power generation were obtained by multiplying the amount of electricity produced in each period by the price of electricity (USEIA 2010) for that particular period. Southwestern power administration (SWPA) delivered the total amount of hydroelectricity generated by Lake Tenkiller to the not-for-profit Oklahoma municipal electric systems at a rate of 2.8 cents per kilowatt-hour (SWPA 2007). However, in this study, both average wholesale and retail monthly electricity prices were used (USEIA 2010). The peak and normal average wholesale and retail hydroelectric prices were used in this study (Table I-2). Whether incremental amounts of electricity should be valued at the wholesale or retail price depends on the marginal costs of distribution. If the marginal distribution cost is very low, the retail price serves as an upper bound. If the marginal distribution cost is very high, the wholesale price serves as the lower bound for electricity values. The assumption was that all electricity generated between 3 pm through 7 pm during the summer of June, July and August was sold at a peak rate that was $0.02 per kilowatt hour (OEC 2010) above the wholesale or retail market price for that particular period.

The OLS regression method was used to estimate the hydroelectric power generation equation (ReVelle 1999) based on the daily water releases, lake level (effective head) data (USACE 2010a, 2010b), and the amount of electricity produced over the period of January 1995 through December 2000 (USACE 2000). The estimated equation was as follows:

$$MW_t = 0.232457(Head_t)(Qrel_t); \quad (1152) \qquad R^2 = 0.99. \tag{4}$$

where MW_t is the megawatt hour (MwH) of electricity generated in period t, $Qrel_t$ is the water (ac-ft) released in period t, and $Head_t$, is the head (famsl) in period t. The estimated coefficient above was significant at the 5% confidence level (t-value in parenthesis).

Urban and Rural Water Supply Benefits

The water demand model required monthly consumption values for a mixture of municipalities and rural water districts. Annual water consumption values are readily available for municipalities (OLM 2008). Attempts to survey rural water districts in the area were unsuccessful at the state level (OWRB 2011). However, monthly water treatment plant operation reports from 2001 through 2007 were obtained from the

Oklahoma department of environmental quality (ODEQ 2008). These reports were from Muskogee, Muldrow, Sallisaw, Gore, Eufaula, and Roland. The cities selected are those where water consumption by the population served by each city could be separated from the service area of rural water districts and matched with the quantity of water referenced in the water treatment reports. Then, a monthly per-capita water demand model (Borland, 1998) was estimated using SAS PROC MIXED (Littell et al. 2008). The city and annual variables were considered to be random.

The estimated monthly per capita water demand (gallons) equation based on the mean population was as follows:

$$\underset{}{Q_{m,c}} = \underset{(7.82)}{5.23\,Jan} + \underset{(6.71)}{4.49\,Feb} + \underset{(7.09)}{4.74\,Mar} + \underset{(6.76)}{4.52\,Apr} + \underset{(7.58)}{5.07\,May} + \underset{(8.1)}{5.41\,Jun} + \underset{(10.08)}{6.74\,Jul} +$$

$$\underset{(10.12)}{6.76\,Aug} + \underset{(8.78)}{5.86\,Sep} + \underset{(8.34)}{5.58\,Oct} + \underset{(7.41)}{4.96\,Nov} + \underset{(7.41)}{4.95\,Dec} + \underset{(4.15)}{1.24\,Pop_c}; \quad x^2 = 372.30. \qquad (5)$$

where $Q_{m,c}$ is the per capita water demand (in thousand gallons) in city *c* in a particular month *m*; *Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec* are the dummy variables (January through December), which took one for a particular month and zero for other months; and Pop_c is the relative population (*Pop/mean Pop*) of a particular city *c*. All of the estimated coefficients above were significant at the 10% confidence level (t-value in parenthesis).

The price of water (P_m) was rounded to $3 per thousand gallons, which was equal to pumping costs estimated from EPANET2 simulation model (EPA 2008); plus administrative costs (OML 2008). The summer and winter price elasticities (ρ_m) were considered as −0.25 and −0.04 respectively obtained from IWR Main (Davis et al. 1987). Monthly proposed water demand[3] by the 27 water districts, including urban areas of Tahlequah, Gore, Vian, Sequoyah, and Fort Gibson (USACE 2001), and in counties surrounding Lake Tenkiller was derived by multiplying the estimated monthly per capita water demand by the total population served under these water districts (Figure I-3). During the summer of June through September, the urban and rural water demand is at its peak mainly because of lawn irrigation. The combined demand was approximately five million gallons per day. The consumer surplus[4] derived from urban and rural water supply was calculated by integrating the price flexibility form of the demand function.

$$CS_t = \int_0^{Q_t} (\alpha_t + \delta_t Q_t) dQ_t; \tag{6}$$

where CS_t is the consumer surplus in month/week t, α_t is the $(P_t - \delta_t Q_t)$ intercept of the inverse demand function, and δ_t is the $(P_t / Q_t)(1/\rho_t)$ slope of the inverse demand function. The total welfare derived from urban and rural water supplies was obtained by subtracting the supply (pumping) cost from the consumer surplus to find the net consumer surplus.

Lake Recreational Benefits

In this study, the assumption that the number of monthly lake visitors was dependent on deviations of the lake from its normal level of 632 famsl was tested using monthly data from 1955 through 2010. Monthly visitor data from the period of 1975

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[3] The proposed water demand by the Lake Tenkiller and its surrounding area was much less than the supply reallocated using 1958 WSA (Water Supply Act) authority.
[4] Consumer surplus is the area under the demand curve.

through 2010 were obtained from USACE (2010a). Secondary data over the period of 1955 through 1974 published by Badger and Harper (1975) were also used. A quadratic relationship between the number of visitors and the deviations in the lake level above and below its normal level was estimated by regressing the number of monthly visitors against the deviation from the normal lake level for the same periods using maximum likelihood estimation. The estimated regression equation used in this study was:

$$\begin{aligned} V_{m,t} = {} & 86302 + \underset{(5.38)}{105821\,Apr} + \underset{(13.12)}{260192\,May} + \underset{(8.88)}{288535\,Jun} + \underset{(11)}{335015\,Jul} + \underset{(7.22)}{218473\,Aug} \\ & + \underset{(6.67)}{130746\,Sep} + \underset{(1.11)}{718\,ALkLv_m} + \underset{(2.07)}{13001\,LvJun} + \underset{(1.91)}{1401\,Tsumr_t} - \underset{(-1.22)}{236\,Lv_{Jn}^2} \\ & - \underset{(-2.99)}{1186\,Lv_{Jly}^2} - \underset{(-1.22)}{236\,Lv_{Aug}^2}; \qquad 2logLR = 17146.30. \end{aligned} \tag{7}$$

where $V_{m,t}$ was the number of visitors in a month *m* for a particular year *t*; *Apr, May, Jun, Jul, Aug* and *Sep* were the dummy variables which were one in the indicated month and zero otherwise; $Tsumr_t$ was the time trend for the summer June, July, and August (the number of visitors in other months did not vary significantly over time) for the year *t*, with 1955 as year one; $ALkLv_m$ was the difference between the actual and normal lake level (632 famsl) for the month *m*; *LvJun* was the discrete variable to test if visits to the lake in June were more sensitive to the lake level than in other months; Lv_{Jn}^2, Lv_{Jly}^2, Lv_{Aug}^2 was the squares of the difference between the actual and normal lake levels (632 famsl) for the months of June, July, and August respectively. The only significant trend in the number of visitors was during June, July, and August. The estimated coefficient for time trend variable $Tsumr_t$ 1401, allows for increased number of visitors by 1401 per year compared to reference year 1955. All of the estimated coefficients above were significant at the 10% confidence level (t-value in parenthesis).

The number of monthly visitors was found to increase with the lake level until it reached the normal level of 632 famsl in June, July, and August, mainly because the visitors were sensitive to the lake level for Lake Tenkiller when engaged in water based activities such as swimming, boating, and scuba diving because exposed shoreline is less attractive and hinders access. As implied by the quadratic lake level terms in equation 6, the number of visitors began to decline when the lake level increased above 632 famsl during the months of June, July and August. Any lake level below the normal pool would reduce boat accessibility and marinas, while any level above the normal pool might result in vulnerability to flash floods and increase navigational hazards. The effect of the lake level on visitors in July is stronger than in June or August (Figure I-4). The actual number of visitors had been adjusted upward to account the on average increase in number of visitors in the summer by year and compared it to the estimated number of visitors for the year 2010. Finally, monthly visits provided by the USACE were used as total single day visits in the value calculation. For Lake Tenkiller on average; each visitor spends a single day at the lake (USACE 2010a).

According to USACE economic guidance memorandum (Carlson, 2009) based on the unit day value method, the value of a visitor day ranges between $3.54 and $10.63 for general recreation. However, Gajanan et al. (1998) found that the economic value of lake recreation derived from motor boating and waterskiing ranges between $9.85 and $45.61, and it varies across different ecoregions in the United States. Boyer et al. (2008) estimated the recreational value of Lake Tenkiller as part of a larger random utility travel cost model for all lakes in Oklahoma and found the value of a visitor day to Lake

Tenkiller was around $191, the highest value for any Oklahoma lake. Badger and Harper (1975), using the travel cost method, found that the value of a visitor day at Lake Tenkiller was $4.67, which is equivalent to around $24 in 2010 prices. However in this study, conservatively two low values for a visitor day were used. The lower value used was $10 per visitor day (Carlson 2009) while the upper value used was $50 per visitor day about one-fourth the value estimated by Boyer et al. (2008).

An additional study by Roberts et al. (2008) had shown that the willingness to pay for a visitor day at Lake Tenkiller declined by $0.82 for each foot the lake was below the normal level. The value of a visitor day was decreased in the model from $50 and $10 (when the lake level was 632 famsl or more), to $43 and $3 per day (when the lake level was 624 famsl or less; Figure I-5 and Figure I-6). Total recreational benefits were calculated by multiplying the visitor day (obtained from the estimated number of visitors) by the value of a visitor day at the indicated lake level. Different recreational benefits are derived from different lake levels for the month of August 2010 (Table I-3). This study is also unique because both the number of visitors and the value of a visitor day vary with the level of the reservoir reflecting that both the quantity of visitors and the quality of those visits change with a decrease in recreational value due to lower than normal lake levels. Without this adjustment, most studies may overestimate recreational benefits.

Results

Effect of Including Recreation as an Optimizing Variable

The effect of explicitly including or not including recreational benefits in the lake management optimization function (objective 2) and its impact on the net economic benefits were measured by comparing two scenarios. In the first scenario, economic benefits were maximized with respect to releases for hydropower generation and public water supply uses only. Recreational benefits were calculated post optimization from resulting lake levels. In the second scenario, net economic benefits were maximized with respect to recreation, hydropower generation, and public water supply. Hydropower was assumed to be sold at the peak retail electricity prices (Table I-2), and the base visitor day was assumed to be worth $50 in both scenarios. Net annual economic benefits were $206.97 million when optimized with respect to hydropower and public water supply use, and recreational benefits were determined after the optimization (Table I-4). When recreational benefits were directly considered in the economic optimization model (scenario 2), the net annual economic benefits were $218.10 million. The estimated annual gain of $11.13 million from the lake resource was approximately 5.40 percent. Recreational benefits were increased by $11 million, or 10%, while the value of hydropower generation declined by $0.47 million (Figure I-6). The ratio of the increase in recreational benefits per dollar of hydropower loss was 23 to 1. Public water supply uses remained essentially unchanged between scenarios 1 and 2, because in the case of Lake Tenkiller, the proposed demand for domestic water use is much more inelastic than the demand for recreational and hydropower generation use.

When focusing on hydropower generation in scenario 1, the optimal strategy was to raise the lake level from the normal 632 to 645 famsl (Figure I-8) to increase head and power generation during the summer when both hydropower price and demand were at their peak. However, when recreational uses was considered (scenario 2) in the objective function, the optimal strategy was to maintain levels slightly above the normal pool of

632 famsl from May through mid-August and maximize visitor numbers during the summer. Of note is the fact that historical levels are very close to the scenario 2 level in May and June but are lower from July through October. These results indicate that the current management strategy does not strictly maximize hydropower production.

The model was then used to calculate the net economic benefits given the historical average lake levels (Figure I-8). The purpose was to estimate the net total economic benefits that would be obtained in the year 2010 if the lake level were constrained to average historical lake levels in the period from 1979-2010 with estimated 2010 visitor numbers and public water demands. The finding was that for the year 2010, total annual economic benefits derived from the average historical lake level would be around $216.39 million, which was about $2.6 million lower than in scenario 2, which explicitly considered recreational benefits in the objective function. That is, the historical (1979-2010) level was near optimal, (Figure I-8), except for July through October. One of the reasons for these levels is the early draw down to meet the peak electricity demand. Though not shown, a note-worthy fact is that optimal lake levels obtained under stochastic optimization are higher and much closer to the historical level than the level obtained under deterministic optimization. This result occurs because with lognormal inflows, the mean inflow is greater than the more likely median inflow. Releasing more water under the expectation of receiving a mean inflow would increase the number of years when the actual level was below normal. The optimal stochastic lake level from June through mid-July is almost identical to the average historical level.

Sensitivity of Optimal Lake Level to Recreational Values and Electricity Prices

In addition, the model was solved with three different combinations of values for a visitor day and peak electricity prices. These combinations were: (i) $50 value of a visitor day – peak retail hydroelectricity prices, (ii) $10 value of a visitor day – peak retail hydroelectricity prices and (iii) $10 value of a visitor day – peak wholesale hydroelectricity prices. These reflect scenarios 2, 3, and 4 respectively. The optimal number of visitors and the amount of hydropower produced under 2, 3, and 4 are around the same (Table I-5). Even when recreation is valued at $10 per day and electricity is priced at peak retail rates, little increase occurs in hydropower production when the electric prices were increased from wholesale to retail, and the value of a visitor day was decreased from $50 to $10. The optimal August lake level remains above the average historical August level for all three scenarios (Figure I-9). However, maintaining a normal lake level of around 632 famsl during the summer of June, July, and August for Lake Tenkiller was beneficial to maximize both the recreational and hydropower generation benefits, since any lake level above and below the normal lake level of 632 famsl would definitely reduce the number of visitors and their total value for the resource for those months. By contrast, in the model where hydroelectric power generation benefits were the main concern of the management (lake recreational benefits were not included in the objective function), then the regulator would maximize market benefits by increasing the lake level (head) above the turbine and releasing water during the summer when the electricity price was at its peak. The results show that during June, July, and August, when the number of visitors was at its peak, the lake level should be maintained two to three feet above the normal lake level of 632 famsl, and some of the releases for hydroelectric power generation should be shifted to the spring and fall periods. The scenario 2 results predict around 241,018 more visitors compared to scenario 1, if the lake level were maintained slightly above the normal level through mid-August (Figure I-10). The main increase of 188,118 visitors was predicted to occur in July.

As the level is lowered from 637 to 636 famsl, an additional 13.70 thousand ac-ft of water are released and $114.70 thousand dollars of electricity are generated. Also, as the lake level is lowered toward normal (from 637 to 636 famsl), the number of visitors increases, adding $28.70 thousand in recreational benefits for total economic benefits of $143.40 thousand, which is the change in the value of electricity produced plus the gain in the number of visitor days multiplied by $10 per day (Table I-6). The total value of economic benefits derived from the lake resource continues to increase though by smaller amounts until the lake level has reached 632 famsl. At this level, the predicted number of August visitor days is maximized at 392,260 (Table I-3). However, as the level is lowered below 632, the value of the visitor day declines (Figure I-6). While the decline from $10 per day at 632 famsl to $9.18 at 631 famsl seems small, the value of total recreational benefits at 631 famsl is obtained by multiplying 391,940 visitors by $9.18 (Table I-3). Thus, the value of recreational benefits declines by $333,036 for each one foot decline between 632 and 631 famsl, which is three times greater than the value of additional electricity generated. Thus for Lake Tenkiller, the finding is that total economic benefits derived from the lake resource are maximized by maintaining the lake level two to three feet above normal in June and July and reducing the level to the normal lake level of 632 famsl by mid-August. Including recreational values as a variable in the optimization indicates a higher than historical level should be maintained during July and August to increase recreational benefits.

Conclusion and Discussion

The results hold importance for rural communities dependent on tourism for increasing local income because although neither urban nor rural water supply use nor recreational use were considered to be the primary uses when the dam was constructed, the recreational values have become substantial (USACE 2009). The results show the value of electricity that could be generated by releasing more water and lowering the lake level below the normal level of 632 famsl in the summer period is more than offset by reduced recreational benefits. This result differs from the results obtained by Ward and Lynch (1996) for reservoirs in New Mexico. This difference is in part because the number of monthly summer visitors to Lake Tenkiller varies from 400 thousand to over 500 thousand and, in part, because the head above the turbines is lower for Lake Tenkiller than for the Rio Chama Basin of New Mexico. The optimal management plan is also influenced by the head of the reservoir. If the reservoir had higher elevation (head) over the turbine, then the value of hydroelectric power generation would increase relative to lake recreational benefits. The results indicate that the average lake level maintained over the years 1979-2010 would provide near optimal benefits for 2010 except for mid-July through October. Therefore, the suggestion for Lake Tenkiller is that the releases for hydropower generation should be delayed until mid-August.

The economic optimization model developed and used in this study is able to test several different management policies. This type of model could be used to identify the economic impacts of different types of allocation patterns by controlling the releases. The model's ability to allocate water among multiple uses over different time periods under stochastic inflows and to change the optimal usage pattern under different conditions makes it a unique and valuable tool for governmental policy analysis. The modeling approach used in this study may be useful for policy makers to compare different management scenarios and compare the impact of each strategy on the net economic benefits. This usemodel can help water managers and policy makers test different water management policies and implement them while managing a reservoir for multiple resource users.

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Table I-1. Simulated average monthly inflows and standard deviation compared with historical average inflows and standard deviation (1979-2010).

Historical	Inflow (ac-ft)		Simulated	Inflow (ac-ft)
Month	Average	Standard Deviation	Average	Standard Deviation
Jan	109,190	103,977	109,034	101,854
Feb	109,935	79,689	109,839	78,741
Mar	164,909	116,659	164,752	115,131
Apr	165,468	122,134	165,377	121,443
May	150,209	124,650	150,330	125,042
Jun week 1	26,041	20,695	26,021	20,510
Jun week 2	26,495	28,011	26,442	27,310
Jun week 3	33,492	55,420	33,534	54,739
Jun week 4	23,753	43,666	23,627	40,694
Jul week 1	18,046	26,716	17,966	25,274
Jul week 2	12,774	16,508	12,756	16,033
Jul week 3	8,484	6,621	8,494	6,748
Jul week 4	9,127	10,060	9,117	9,854
Aug week 1	7,366	10,104	7,521	12,792
Aug week 2	8,855	9,634	8,835	9,374
Aug week 3	6,753	5,829	6,760	5,876
Aug week 4	4,927	3,052	4,924	3,031
Sep	42,178	50,478	42,098	49,152
Oct	67,228	110,225	67,620	114,918
Nov	92,538	95,267	92,449	94,092
Dec	116,470	117,299	116,310	115,115

Table I-2. Wholesale and wholesale peak and retail and retail peak.

Month	Wholesale electricity price	Wholesale peak electricity price	Retail electricity price	Retail peak electricity price
Jan	$0.05	$0.05	$0.07	$0.07
Feb	$0.05	$0.05	$0.08	$0.08
Mar	$0.04	$0.04	$0.07	$0.07
Apr	$0.04	$0.04	$0.07	$0.07
May	$0.04	$0.04	$0.07	$0.07
Jun	$0.05	$0.07	$0.07	$0.07
Jul	$0.05	$0.07	$0.08	$0.10
Aug	$0.06	$0.08	$0.08	$0.10
Sep	$0.04	$0.04	$0.08	$0.10
Oct	$0.03	$0.03	$0.07	$0.07
Nov	$0.03	$0.03	$0.07	$0.07
Dec	$0.04	$0.04	$0.07	$0.07

Table I-3. Visitor day (number of visitors), value of a visitor day starting at $10, and recreational benefits for different lake levels for the month of August 2010.

Lake level (famsl)	Visitor day (number of visitors)	Value of a visitor day	Recreational benefits
638	380,770	10.00	$3,807,700
637	384,280	10.00	$3,842,800
636	387,150	10.00	$3,871,500
635	389,390	10.00	$3,893,900
634	390,990	10.00	$3,909,900
633	391,940	10.00	$3,919,400
632	392,260	10.00	$3,922,600
631	391,020	9.18	$3,589,564
630	389,150	8.36	$3,253,294
629	386,630	7.54	$2,915,190
628	383,480	6.72	$2,576,986

Table I-4. Comparison of total economic benefits from Lake Tenkiller when recreational values were, and were not, included in the objective function for 2010.

Recreational values in objective function***		Recreational values not in objective. function***	
Recreation* benefits $	126,902	Recreation* Benefits $	115,302
Hydropower** benefits $	6,679	Hydropower** benefits $	7,149
Rural water supply (RWS) $	84,518	Rural water supply (RWS) $	84,518
Total benefits (with recreation in objective function) $	218,099	Total benefits (without recreation in objective function) $	206,969

*Recreation valued at $50 per visitor day when lake level is 632 feet and above; **Hydropower valued at the average monthly retail peak electricity price; ***values in thousand US dollars

Table I-5. Sensitivity of the estimated number of monthly visitors and hydropower production to changes in the value of a visitor day from $50 per visitor day to $10 per visitor day from $50 per visitor day to $10 per visitor day when hydropower is valued at 2010 wholesale or retail peak electricity prices.

	Visitors			Hydropower-generation		
Scenario	2	3	4	2	3	4
Value of a visitor day	$50	$10	$10	$50	$10	$10
Monthly electricity price	Retail	Retail	Wholesale	Retail	Retail	Wholesale
Month		Number			MwH	
Jan	86,302	86,302	86,302	9,235	9,198	9,234
Feb	86,302	86,302	86,302	8,455	8,417	8,454
Mar	86,302	86,302	86,302	11,130	11,140	11,129
Apr	191,597	191,597	191,597	8,917	8,937	8,917
May	345,555	345,555	345,555	13,716	13,717	13,712
Jun week 1	104,851	104,839	104,840	3,144	3,165	3,143
Jun week 2	104,779	104,768	104,772	1,813	1,784	1,812
Jun week 3	105,595	105,583	105,591	2,797	2,818	2,794
Jun week 4	105,568	105,561	105,567	3,391	3,356	3,387
Jul week 1	123,920	123,932	123,916	1,459	1,551	1,458
Jul week 2	124,237	124,237	124,237	2,098	2,119	2,096
Jul week 3	124,180	124,175	124,181	614	618	613
Jul week 4	123,982	123,972	123,981	419	325	419
Aug week 1	92,913	92,910	92,913	385	386	385
Aug week 2	92,827	92,822	92,827	582	584	581
Aug week 3	93,009	93,008	93,009	127	116	127
Aug week 4	92,420	92,430	92,420	731	581	731
Sep	215,739	215,755	215,766	2,520	2,524	2,518
Oct	86,219	86,256	86,244	2,485	2,557	2,483
Nov	86,302	86,302	86,302	9,301	9,656	9,293
Dec	86,302	86,302	86,302	9,494	9,520	9,485
Total	2,558,899	2,558,909	2,558,926	92,812	93,068	92,769

Table I-6. Effect of releasing water to create a one foot decline in the lake level from 637 to 630 famsl on hydropower values and recreational benefits for August of 2010.

Level	Volume of release (ac-ft)	Changes in hydro-electric value*	Change in number of visitors	Changes in recreational benefits**	Total change in net economic benefits
637-636	13,722	$114,723	2,870	$28,700	$143,423
636-635	13,524	$113,905	2,240	$22,400	$136,305
635-634	13,335	$113,139	1,600	$16,000	$129,139
634-633	13,153	$112,410	950	$9,500	$121,910
633-632	12,979	$111,726	320	$3,200	$114,926
632-631	12,811	$111,074	-1,240	-$333,036	-$221,962
631-630	12,650	$110,461	-1,870	-$336,270	-$225,809

*electricity is valued at $0.10 per kilowatt hour; ** value of a visitor day at $10

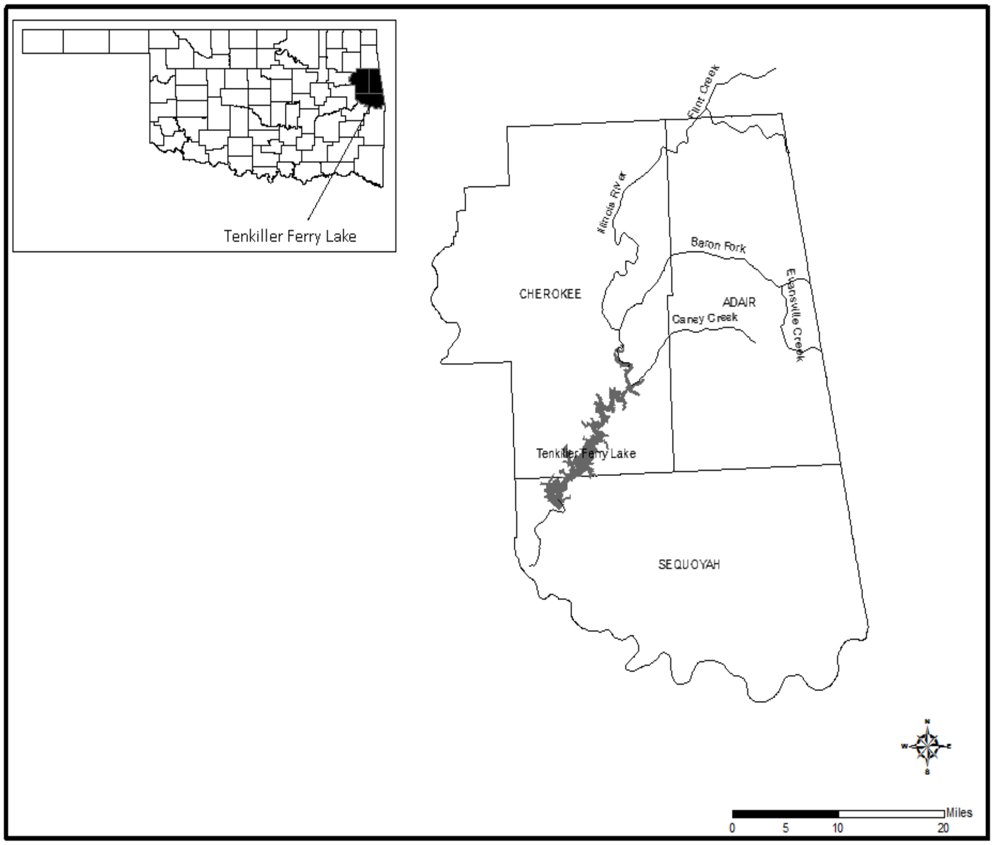

Figure I-1. Lake Tenkiller and its surrounding areas in northeast Oklahoma.

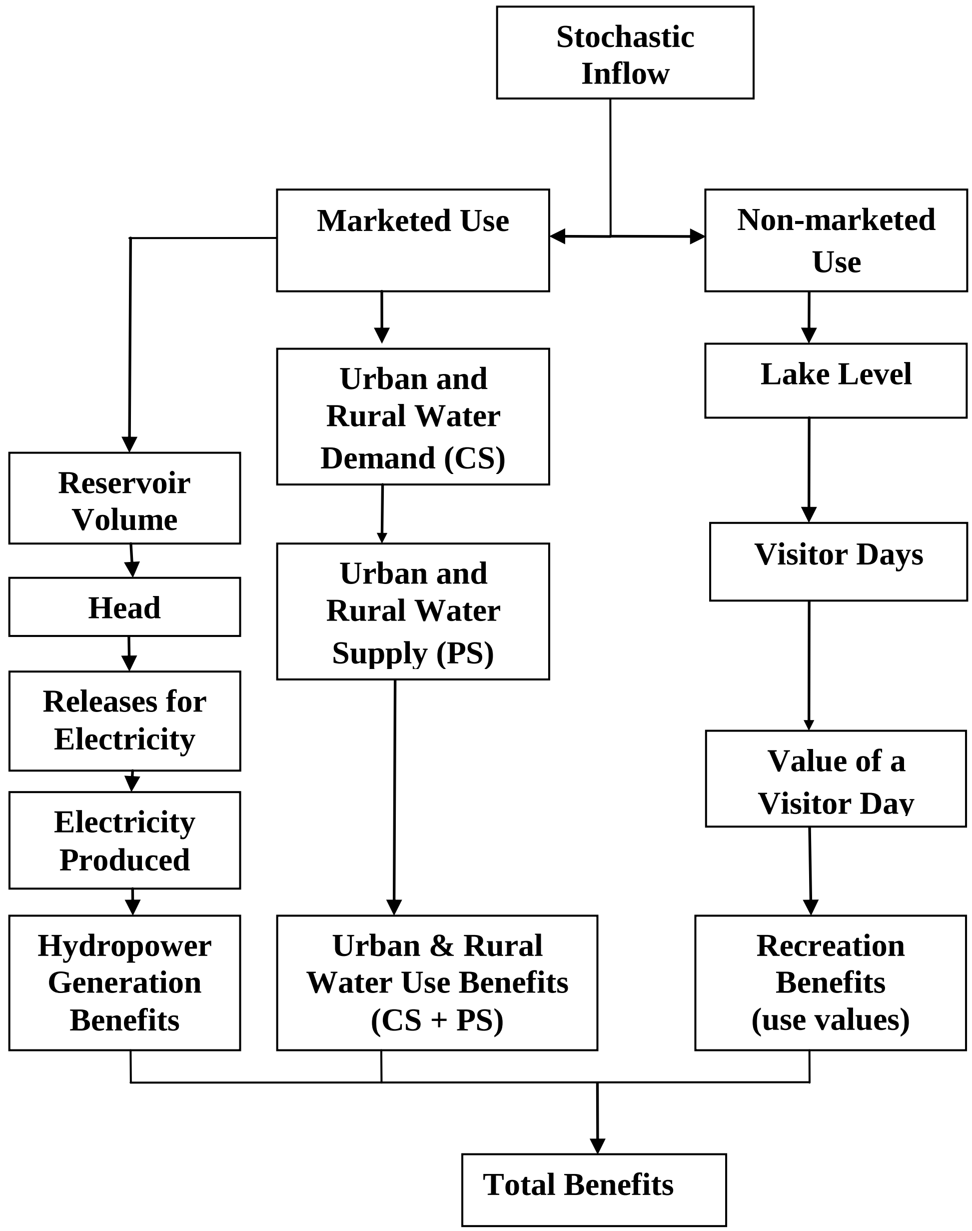

Figure I-2. Schemetic representation of the optimization model.

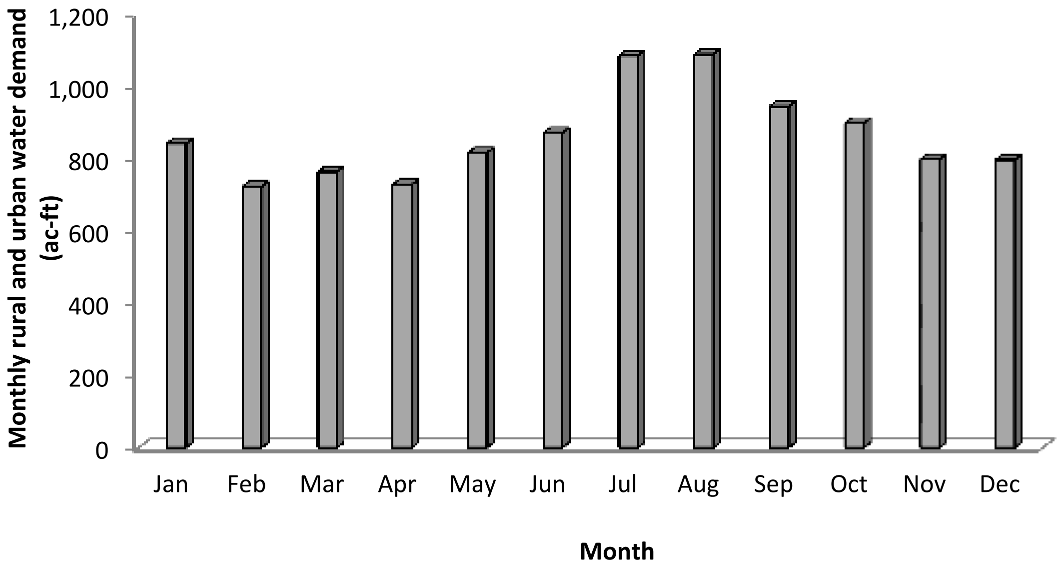

Figure I-3. Predicted urban and rural water demand (ac-ft) for each month for Lake Tenkiller and its surrounding area for the year 2010.

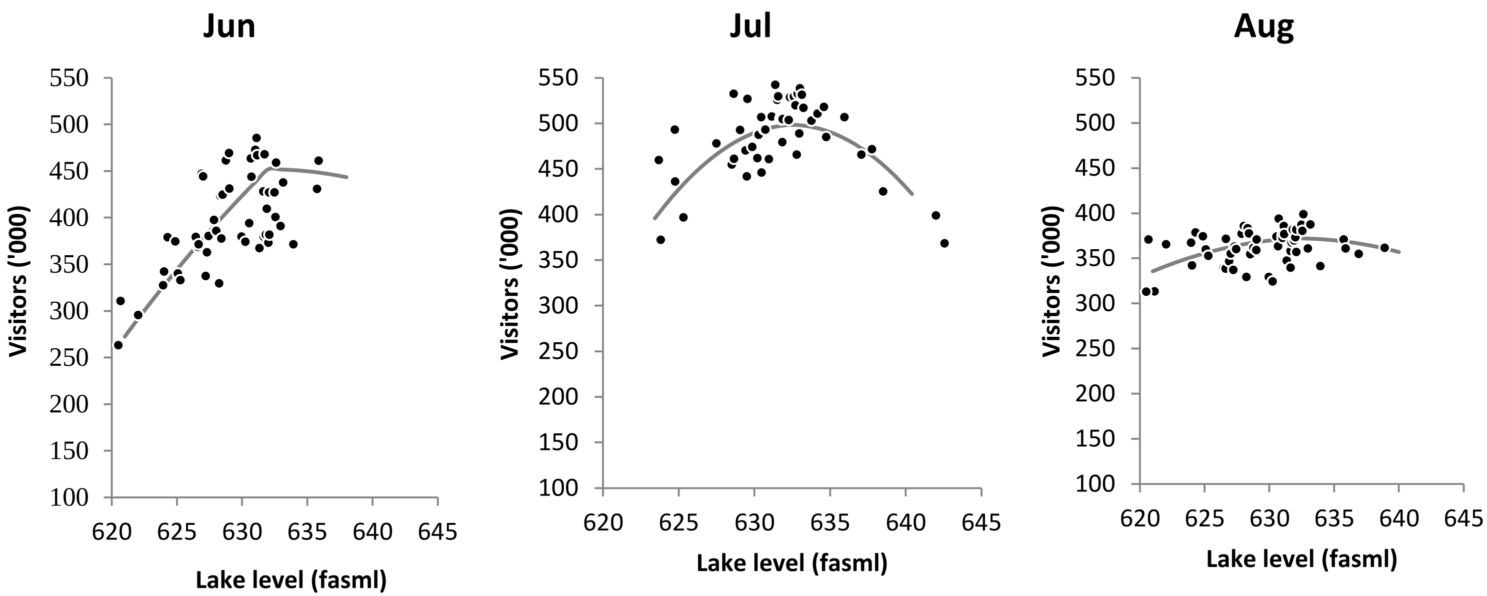

Figure I-4. Number of predicted versus actual visitors adjusted to 2010 visitors by adding (2010-year reported)*1401 to the reported number of visitors (in thousands) to Lake Tenkiller by lake level for the months of Jun, Jul, and Aug in 2010.

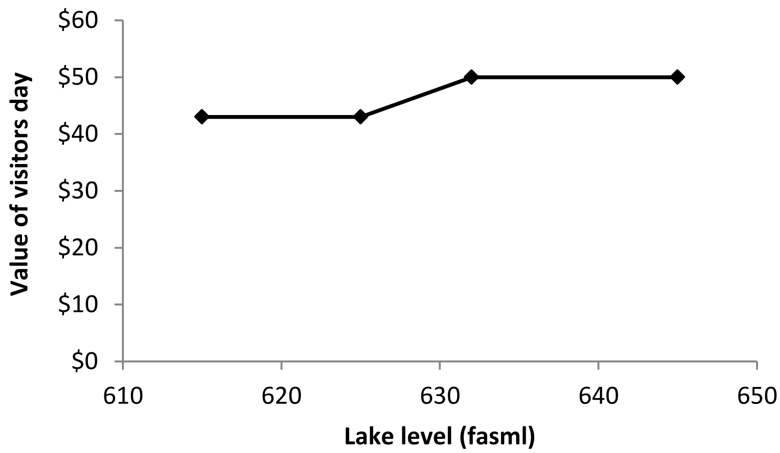

Figure I-5. $50 value of a visitor day at Lake Tenkiller adjusted as a function of lake level.

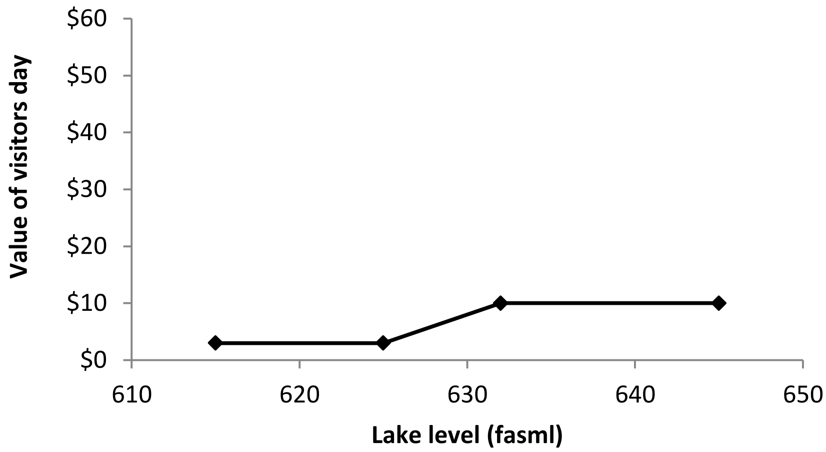

Figure I-6. $10 value of a visitor day at Lake Tenkiller adjusted as a function of lake level.

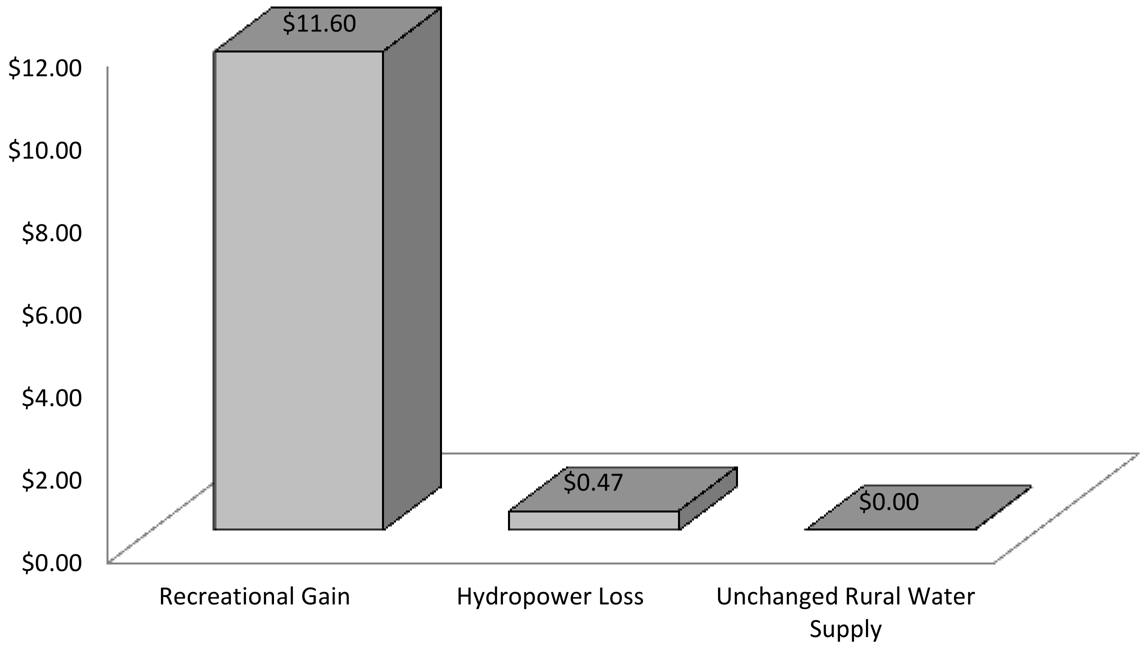

Figure I-7. Tradeoff between the loss in hydroelectric power generation values versus gain in lake recreational values when recreational values were included in the objective function for year 2010 (in million US dollars).

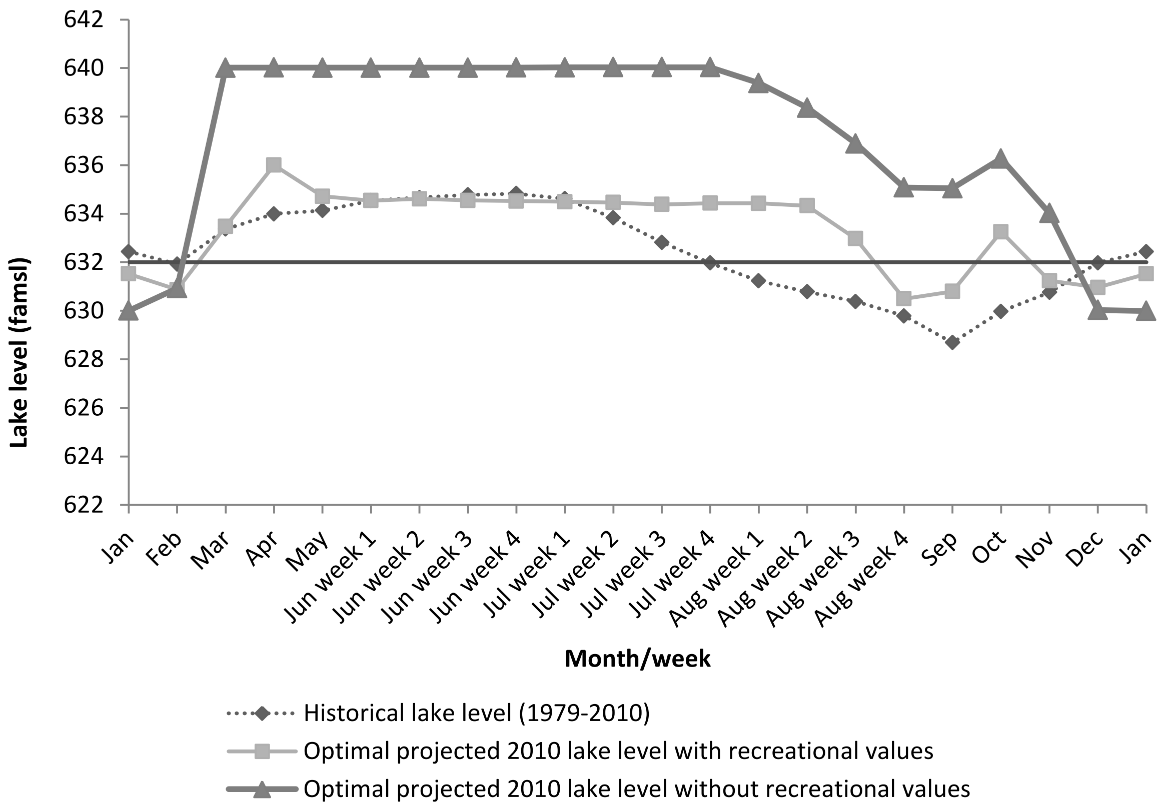

Figure I-8. Comparison between average historical monthly/weekly lake levels for Lake Tenkiller from 1979-2010 with the optimal lake levels for 2010 when recreational values were and were not included in the optimization model.

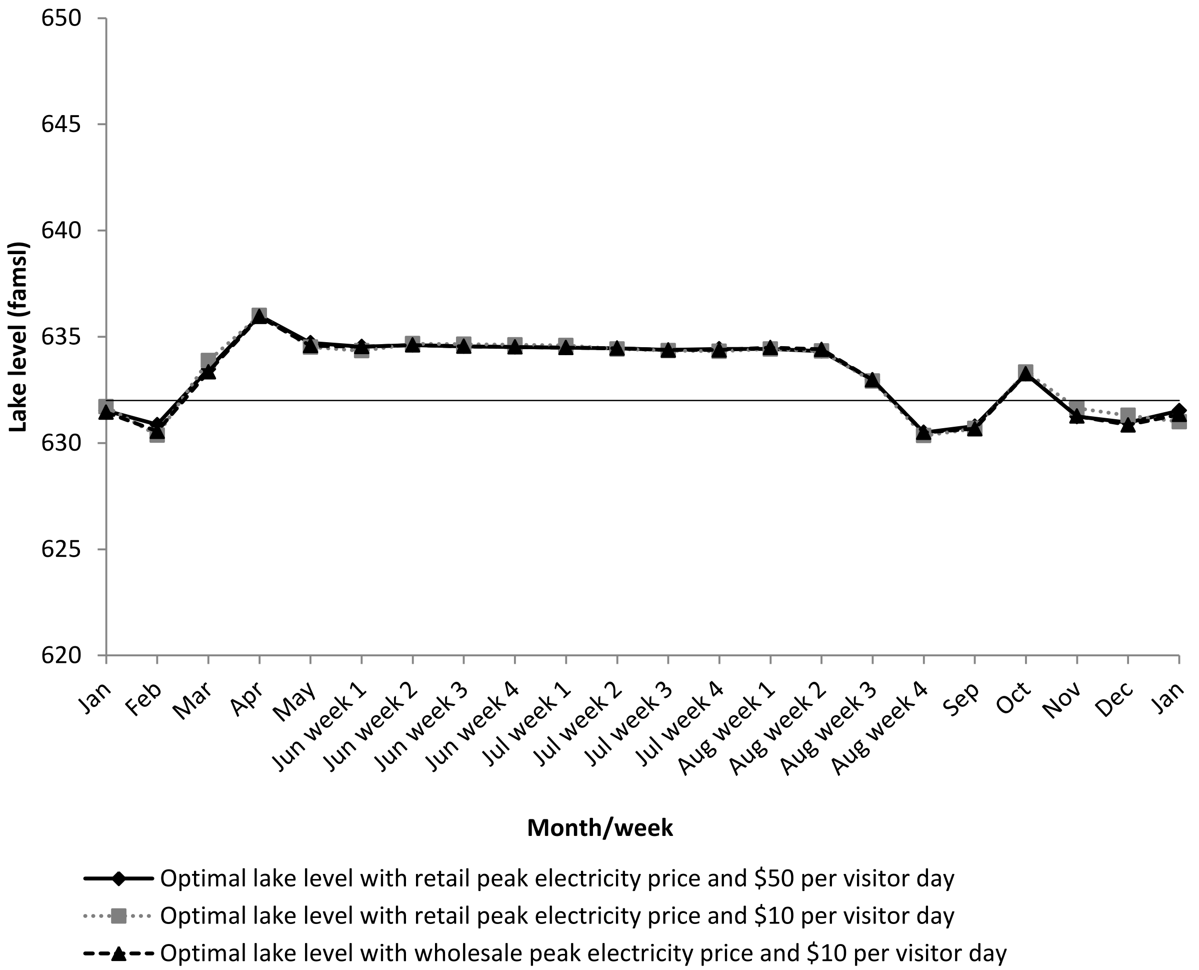

Figure I-9. Optimal lake level with recreational values included in the model for the year 2010 when (i) value of a visitor day is $50 and retail peak price of hydropower; (ii) value of a visitor day is $10 and retail peak price of hydropower; and (iii) value of a visitor day is $10 and wholesale peak price of electricity.

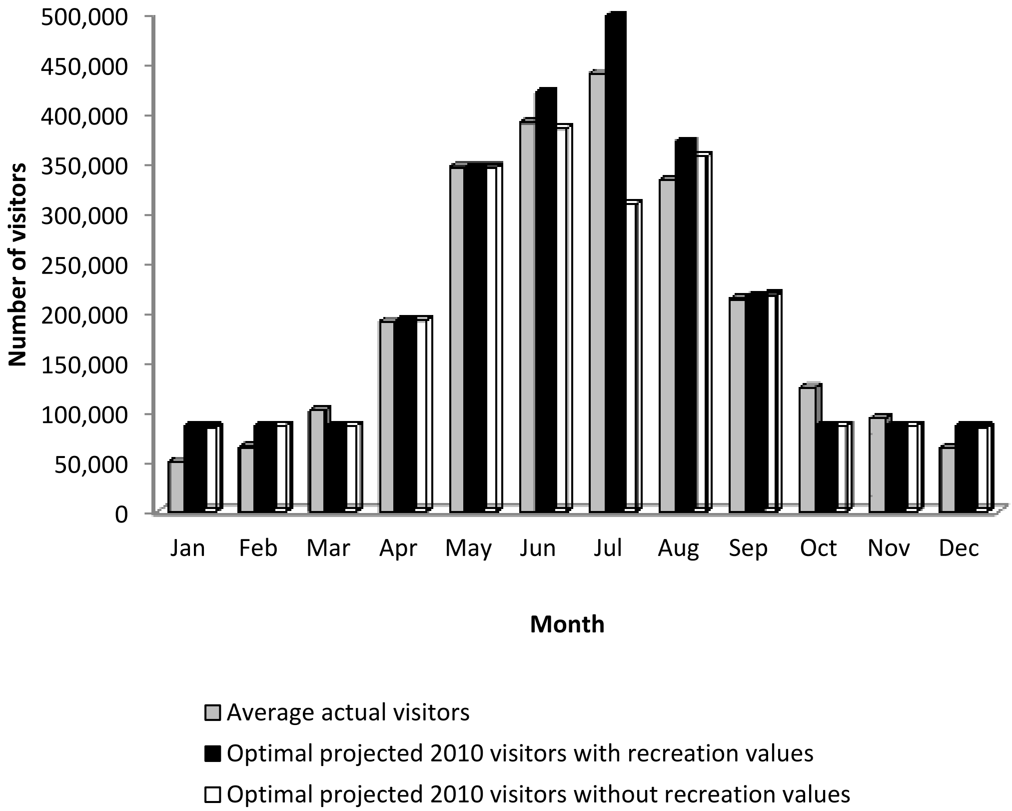

Figure I-10. Comparison of optimal number of monthly visitors for Lake Tenkiller when recreational benefits were, and were not, included in the objective function for the year 2010 with the average historical monthly visitor.

CHAPTER II

MANAGING EXPECTED SWITCHGRASS BIOMASS YIELD VARIABILITY BY STRATEGICALLY SELECTING LAND TO LEASE

Abstract

Cellulosic biorefineries that plan to use switchgrass exclusively will encounter year-to-year variability in feedstock production. The objective of this research is to determine the optimal quality, quantity, and location of land to contract while considering the spatial and temporal variability of switchgrass biomass yield. A model is developed and used to determine the land to contract for several levels of the opportunity cost of idling the biorefinery for lack of feedstock. In the region the expected net present value of considering switchgrass yield variability when selecting land to contract for a 2,000 Mg/day biorefinery is over $11 million for ten year contracts discounted at 10%.

Introduction

In anticipation of an economically viable feedstock production and conversion system, the U.S. Energy Independence and Security Act of 2007 included a provision that by 2022, that if produced, 16 billion gallons of cellulosic biofuels be marketed (USDA 2011). The U.S. Department of Energy's (2011) billion ton update estimates that for a price of $55 to $66 per Mg, 5 to 13 million hectares (ha) could be bid into production of perennial grasses for biorefinery feedstock by 2022. To-date the standard paradigm for evaluating the economics of cellulosic biofuels has followed the pattern used to evaluate grain ethanol. However, producing, harvesting, storing, and delivering cellulosic biomass from a dedicated perennial energy crop such as switchgrass and converting it to biofuel is fundamentally different than producing and marketing corn grain, and producing ethanol from grain. The infrastructure for corn grain was well developed prior to implementation of public policies designed to increase the production of fuel ethanol. Initially, the quantity of corn used by ethanol plants relative to total global corn production was relatively small. In bumper crop years as well as short crop years, corn ethanol biorefinery managers could bid corn grain from alternative uses. When the proportion of the corn crop that they required to meet their capacity requirements was relatively small, except for having to pay a higher price for feedstock, they did not have to be overly concerned about the risk of idling the biorefinery due to a short crop. A similar feedstock production and delivery infrastructure does not exist for the anticipated cellulosic biomass biorefineries.

Prior to investing in a cellulosic biorefinery, prudent investors would expect assurance that a flow of feedstock that meets the quality standards of the facility will be available at a cost that provides a high probability of a good investment. The first biorefinery in a region will not be able to rely on spot markets to procure feedstock since spot markets do not exist. One potential strategy would be for the biorefinery to engage in long term contracts with growers or land owners. Since switchgrass is a perennial and the annual harvestable biomass yield is uncertain, land owners are much more likely to be willing to contract for land area to seed to switchgrass than for delivering a prespecified quantity every year. Another alternative would be for the biorefinery to engage in long term land leases with land owners and for the biorefinery to manage the harvest and delivery of feedstock. In either case biorefinery management would be required to identify and contract for a sufficient quantity of land or production in the vicinity of the biorefinery to provide for the planned feedstock needs.

Prior studies have ignored the potential consequences of biomass spatial and temporal yield variability on cellulosic biorefinery economics (Brechbill and Tyner 2008; Duffy 2007; Epplin et al. 2007; Kaylen et al. 2000; Kazi et al. 2010; Khanna, Dhungana and Brown 2008; Mapemba et al. 2007; Mapemba et al. 2008; Mondzozo et al. 2011; Nienow et al. 1999; Perrin et al. 2008; Tembo et al. 2003; U.S. Department of Energy 2011; Wright et al. 2010; Wu, Sperow and Wang 2010). Switchgrass yields vary from year-to-year. If all land that is contracted for production is in close proximity to the biorefinery, in bad weather years, yields across the region may be low and insufficient to meet the needs of the biorefinery. In this case the biorefinery will be forced to shut down for a period of time. Each idled day for lack of feedstock will have economic consequences. The net opportunity cost of a forced idle day will depend on the lost revenue as well as on production costs that cannot be avoided.

In good weather years, yields may be greater than expected and more biomass may be produced than can be processed. In most regions mature biomass switchgrass would have limited alternative uses and the cost to bale is likely to exceed its value except for biorefinery feedstock. In years of excess production, the best strategy for fields distant from the biorefinery may be to mow the switchgrass and to leave the material in the field to build organic matter. If yields across fields within the potential biorefinery supply shed are not highly correlated, a biorefinery might attempt to reduce overall year-to-year variability in feedstock production by strategically selecting a portfolio of land to contract. The optimal land contracting strategy will depend on the cost of idling the plant relative to the cost of contracting for more land than required for an average production year.

The biorefinery could plan to maintain a storage reserve from which biomass may be retrieved in low production years. However, there are a number of issues associated with maintaining the quality of switchgrass biomass for an extended period of time. Larson et al. (2010), using data from a switchgrass storage experiment, found storage dry matter losses of 30% for a rectangular solid bale of switchgrass that was covered with a tarp and stored for 360 days. The cost and efficiency of conversion for systems such as enzymatic hydrolysis depend on the characteristics of the feedstock. Maintenance of feedstock quality over an extended period of time would require expensive storage facilities, added handling costs, and carry a substantial risk of loss from fire. Additionally, managing consecutive bad weather years could be challenging and require a large investment.

This study is designed to address both year-to-year switchgrass yield variability and within year yield variability across the supply shed of a potential cellulosic biomass biorefinery. It is designed to establish an initial baseline under the assumption that maintenance of a strategic storage reserve would be impractical. The objective is to determine the quantity, location, and class of land to contract (a) for an average switchgrass production year; (b) to ensure that in each production year the area under contract will produce sufficient feedstock to fully provide for the needs of the biorefinery even in the worst case (based on historical weather data) year; (c) to determine the tradeoff between the quantity of contracted land and the daily cost of idling the biorefinery; and (d) to determine the value of considering spatial and temporal switchgrass biomass yield variability when selecting land for contracting.

The remainder of this paper is organized as follows. First, we present conceptual models constructed to address the objectives. Second, we present data sources and data necessary to solve the models along with the steps and data used to validate and calibrate a biophysical simulation model. The simulation model is used to generate empirical switchgrass biomass yield distributions based on historical weather and soils for each of three land classes for thirty counties. Third, the empirical yield distributions based on fifty years of historical weather data and other data are incorporated into the models which are solved to fulfill the study objectives.

Conceptual Models for Economic Optimization

Three models are presented. First, a traditional model designed to minimize the cost to meet the expected annual biorefinery requirements based on average switchgrass yields (model 1) is described. Second, an enhanced model designed to identify the optimal quantity, quality, and location of land to contract to ensure that a sufficient quantity of feedstock can be delivered even in the worst expected production state of nature (based on historical weather) is presented (model 2). Third, a model is developed that enables determination of the tradeoff between the opportunity costs of closing the biorefinery as a result of insufficient feedstock and the quantity of contracted land considering the yield variability (model 3). The second and third models encompass both spatial (across land class and across counties within each year) and temporal (across years) biomass yield variability.

Model 1 – Identifying Land to Contract Based on Average Switchgrass Yields

In model 1, the objective function is optimized subject to available land, average switchgrass biomass yields, and the annual biorefinery requirements. The objective is:

$$\min_{XL,XB,\,XT} C = \sum_{i}^{I}\sum_{j}^{J}\lambda_{ij} XL_{ij} + \beta\sum_{i}^{I}\sum_{j}^{J} XB_{ij} + \sum_{i}^{I}\sum_{j}^{J}\tau_{ij} XT_{ij} \qquad (1)$$

where, C is the average costs ($) per year of contracting land, producing, harvesting, and transporting a fixed quantity of biomass to a predetermined location to meet the biorefinery demand; λ_{ij} is the production cost ($/ha/year) for amortized establishment costs, land rent, fertilizer, mowing, and raking costs in county *i* for land class *j*; XL_{ij} is the quantity (ha) of land class *j* leased for switchgrass production in county *i*; β is the cost ($/Mg) of baling and stacking switchgrass biomass; XB_{ij} is the quantity (Mg) of switchgrass baled and stacked in county *i* from land class *j*; τ_{ij} is the cost ($/Mg) of loading and transporting switchgrass biomass from county *i* and land class *j* to the biorefinery; XT_{ij} is the quantity (Mg) of switchgrass biomass transported from county *i* and land class *j* to the biorefinery.

Equation (1) is minimized subject to the following set of constraints.

$$XL_{ij} \leq \eta_{ij} \qquad \forall i, j \tag{2}$$

Equation (2) imposes land constraints where η_{ij} is the quantity (ha) of land class *j* in county *i* available for contracting from current use for conversion to switchgrass production.

$$XB_{ij} \leq \bar{\alpha}_{ij} XL_{ij} \qquad \forall i, j \tag{3}$$

Equation (3) balances the quantity baled with the quantity produced; $\bar{\alpha}_{ij}$ is the mean switchgrass biomass yield (Mg/ha/year) in county *i* from land class *j* over *T* years.

$$XT_{ij} \leq XB_{ij} \qquad \forall i, j \tag{4}$$

Equation (4) balances the quantity transported with the quantity baled.

$$\sum_i \sum_j XT_{ij} \geq \delta \tag{5}$$

Equation (5) imposes the requirement that the quantity transported to the biorefinery fulfills the annual switchgrass feedstock requirement, denoted by the scalar δ (Mg/year).

$$XL_{ij}, XB_{ij}, XT_{ij} \geq 0 \tag{6}$$

Equation (6) is included to restrict the choice variables to be nonnegative.

Model 1 is designed to select the optimal (least-cost) location (county), quality (land class), and quantity of land on which to establish switchgrass to fulfill the biorefinery's annual requirement under the restrictive assumption that the average yield will be obtained on each land class in each county and each year. If yields are normally distributed and perfectly correlated across the land classes and counties in the supply shed, in half of the years the land identified by the model for contracting would produce more than the biorefinery could process. Alternatively, in the other half of the years, production from the contracted land would be insufficient to meet the annual needs and the biorefinery would have insufficient feedstock to operate at full capacity throughout the processing season (year).

Rather than contract land based on average yields, the biorefinery could choose to contract sufficient land so that even in the expected worst case production situation, adequate feedstock would be produced to enable the biorefinery to operate at full capacity in each year. While the true worst case production situation cannot be known, historical data may be used to generate yield distributions. To the extent that the generated yield distributions capture future yield variability and are available for each land class and county in the supply shed, a model may be formulated to identify which land to contract to ensure that the biorefinery could operate at full capacity even in poor feedstock production years. Model 2 includes constraints that require biorefinery requirements to be fulfilled for each possible state of nature based on available historical yield distributions and to determine which land should be contracted to minimize the cost to deliver feedstock.

Model 2 – Identifying Land to Contract to Fulfill Requirements in all States of Nature

Model 2 recognizes that yield from each land class in each county will differ in each state of nature but that for each state of nature the fixed demands of the biorefinery must be met. The model is designed to identify the location (county), quality (class), and quantity of land to contract. Every parcel that is contracted must be mowed in every year. However, for each year, depending on production, a unique combination of the contracted hectares may be optimally raked and baled. Thus, transportation flows may differ every year. The model is designed to compute the minimum expected cost over the *T* states of nature. The *T* states of nature are assumed to represent the complete yield distribution for each land class and each county. The objective function follows:

$$\min_{XL,XR,XB,XT} EC = \sum_{i}^{I}\sum_{j}^{J}\gamma_{ij}XL_{ij} + \rho\left(\sum_{t}^{T}\sum_{i}^{I}\sum_{j}^{J}XR_{tij}\right)/T + \beta\left(\sum_{t}^{T}\sum_{i}^{I}\sum_{j}^{J}XB_{tij}\right)/T + \left(\sum_{t}^{T}\sum_{i}^{I}\sum_{j}^{J}\tau_{tij}XT_{tij}\right)/T \quad (7)$$

where, *EC* is the expected costs ($) per year of renting land, producing, harvesting, and transporting biomass to a predetermined location to meet the biorefinery demand in each of the *T* states of nature; γ_{ij} is the production cost ($/ha/year) including amortized establishment costs, land rent, fertilizer, and mowing costs in county *i* for land class *j*; ρ is the cost ($/ha) to rake mowed biomass into a windrow for baling ($\gamma_{ij} = \lambda_{ij} - \rho$); XR_{tij} is the quantity (ha) of land class *j* raked in year *t* in county *i*. A choice variable for raking is introduced, since by assumption all of the land that is contracted must be mowed once per year. However, raking is required only for biomass that must be baled to fulfill the annual requirements. In years when production exceeds requirements, the excess production is mowed and left in the field to decompose. Since the cost of raking depends on the area (ha) of land raked while the cost to bale is a function of yield (Mg), raking and baling activities are considered separately.

T is the number of states of nature (years) for which historical yields are available; XB_{tij} is the quantity (Mg) of switchgrass baled and stacked in year *t* in county *i* from land class *j*; XT_{tij} is the quantity (Mg) of switchgrass biomass transported from county *i* and land class *j* to the biorefinery in year *t*.

Equation (7) is minimized subject to the following constraints:

$$XL_{ij} \leq \eta_{ij} \qquad \forall i, j \tag{8}$$

$$XR_{tij} \leq XL_{ij} \qquad \forall i, j \tag{9}$$

Equation (9) restricts the area (ha) raked to be less than or equal to the area under contract. In a given year, only the quantity of biomass required to fulfill the needs of the biorefinery will optimally be raked. The area raked may differ in each state of nature.

$$XB_{tij} \leq \alpha_{tij} XR_{tij} \qquad \forall t, i, j \tag{10}$$

Equation (10) restricts the quantity to be baled in year *t* from land class *j* in county *i* to be no more than the yield (α_{tij}) in year *t* from land class *j* in county *i* times the area raked.

$$XT_{tij} \leq XB_{tij} \qquad \forall t, i, j \tag{11}$$

Equation (11) balances the quantity baled with the quantity transported to the biorefinery from land class *j* in county *i* for each year *t*.

$$\sum_i \sum_j XT_{tij} \geq \delta \quad \forall t \tag{12}$$

Equation (12) imposes the constraint that the quantity transported to the biorefinery fulfills the annual switchgrass feedstock requirement in every year.

$$XL_{ij}, XR_{tij}, XB_{tij}, XT_{tij} \geq 0 \tag{13}$$

Equation (13) restricts the choice variables to be nonnegative.

Model 2 imposes the requirement that a sufficient quantity of land be contracted so that even in the most unfavorable weather production situation biomass will be produced to enable the biorefinery to operate at full capacity for the entire year. This requires contracting for and paying for more land than would be required in all except the most extreme bad weather year. An alternative would be to contract for less land and in years when production was less than sufficient, to idle the plant when feedstock is not available. The net cost of a forced idle day will depend on the lost revenue as well as on unavoidable production costs. However, this strategy would reduce the quantity and cost of land that is contracted for switchgrass production.

Model 3 – Identifying Tradeoff Between Contracting for Too Much Land versus Producing Too Little Feedstock

Model 3 is designed to determine the economic tradeoffs that result from contracting for less land resulting in some forced idle days in some years. The objective function follows:

$$\min_{XL,XR,XB,XT,XS} EAC = \sum_{i}^{I}\sum_{j}^{J} \gamma_{ij} XL_{ij} + \rho\left(\sum_{t}^{T}\sum_{i}^{I}\sum_{j}^{J} XR_{tij}\right)/T + \beta\left(\sum_{t}^{T}\sum_{i}^{I}\sum_{j}^{J} XB_{tij}\right)/T + \left(\sum_{t}^{T}\sum_{i}^{I}\sum_{j}^{J} \tau_{ij} XT_{tij}\right)/T + v\left(\sum_{t}^{T} XS_{t}\right)/T \tag{14}$$

EAC includes the expected annual cost ($) of not meeting the biorefinery demand as well as the average costs per year of contracting land, producing, harvesting, and transporting biomass to the biorefinery; v is the penalty (opportunity cost) ($/Mg) of not delivering sufficient feedstock to meet biorefinery requirements; XS_t is the quantity (Mg) of switchgrass less than the biorefinery capacity that is not available for processing in year t (shortage). Other variables are as previously defined.

The model includes the following constraints:

$$XL_{ij} \le \eta_{ij} \qquad \forall i, j \tag{15}$$

$$XR_{tij} \le XL_{ij} \qquad \forall i, j \tag{16}$$

$$XB_{tij} \le \alpha_{tij} XR_{tij} \qquad \forall t, i, j \tag{17}$$

$$XT_{tij} \leq XB_{tij} \qquad \forall t, i, j \tag{18}$$

Equations (15-18) are as previously defined.

$$\sum_i \sum_j XT_{tij} \geq \delta - XS_t \quad \forall t \tag{19}$$

For a given year, equation (19) permits the annual biorefinery capacity to be relaxed by the quantity XS_t (Mg).

$$\sum_t XS_t \leq \varphi \tag{20}$$

The total shortage quantity (Mg) across all years that may be permitted is constrained to a level, φ, as shown in equation (20). If the value of φ is set equal to zero, the model will identify sufficient land to be contracted to deliver δ Mg of feedstock in every year and Model 3 will provide the same solution as Model 2. To allow for average feedstock shortages that would result in one shutdown day per year, the value of φ may be set equal to one times the daily capacity times the number of states of nature that make up the empirical switchgrass yield distributions. The value of φ may be changed in combination with the value of v in equation (14) to trace out the tradeoff between land area contracted and the cost to idle the biorefinery.

$$\sum_i \sum_j \alpha_{tij} XR_{tij} + XS_t - XE_t = \delta \quad \forall t \tag{21}$$

Equation (21) balances the yield in each year. In years when production exceeds biorefinery requirements, XE_t tracks the quantity (Mg) of excess production and will be greater than zero. In years when production is short of biorefinery requirements, XS_t tracks the shortage quantity (Mg) and will be greater than zero.

$$XL_{ij}, XR_{tij}, XB_{tij}, XT_{tij}, XS_t, XE_t \geq 0 \tag{22}$$

Equation (22) restricts the choice variables to be nonnegative.

Study Area and Data Requirement

A number of sources were used to obtain parameter values required by the models. A biorefinery was assumed to be located near Okemah in Okfuskee County, Oklahoma (Figure II-1). Based on estimates provided by Kazi et al. (2010) and Wright et al. (2010), the biorefinery daily requirement of feedstock was set equal to 2,000 Mg. Assuming down time required for maintenance and allowing for 350 days of operation per year, the annual feedstock requirement (δ) was set at 700,000 Mg.

Production practices budgeted to estimate the cost of switchgrass establishment, maintenance, and harvest were based on a no-till establishment system (Turhollow and Epplin 2012). Switchgrass was assumed to be seeded, established, but not harvested, in year one. From years two onward it was assumed to be fertilized with 78 kg of nitrogen per hectare per year and harvested once per year. It was assumed that one condition of the land contract is that the land owner would be responsible for the cost of any phosphorus and potassium fertilizer and lime necessary for adequate pH, and adequate soil levels of phosphorus and potassium prior to switchgrass establishment (Haque, Epplin, and Taliaferro 2009). The switchgrass biomass is assumed to be harvested (baled) once per year. Table II-1 includes estimates of switchgrass production and harvest costs.

The quantity of available land with soil suitability ratings of class I, II, and III in each county was determined from the USDA NRCS Land Survey Geographic (SSURGO) database. The study was limited to land classes I-III based on the assumption that other land classes would not be suitable for economically viable production and harvest of switchgrass biomass. The quantity of land (XL_{ij}) assumed to be available for contracting by the biorefinery was set equal to

10% of the total quantity of each land class in each county. In the 30 county region 9% of the class I-III land is class I, 28% is class II, and 63% is class III. The USDA (2011) cash rental rate which is a market based estimate of the opportunity cost of land was used as the land rental cost. The estimated land cost for each land class (I, II, and III) for each county was obtained by extrapolating the USDA cropland rental values using equation (23). Land rent cost for each land class in each county was estimated to be:

$$\omega_{ij} = \mu_{ij}\left(\frac{\sum_j X_{ij}\chi_i}{\sum_j \mu_{ij} X_{ij}}\right) \qquad (23)$$

where, ω_{ij} is the rental cost of a hectare of land in county *i* and land class *j*; μ_{ij} is the potential wheat yield in county *i* and land class *j* as reported in the SSURGO data base, and; X_{ij} is the available hectares of land in county *i* and land class *j*; χ_i is the USDA reported cropland rental rate for the county *i*.

Transportation costs (τ_{ij}) were calculated based on an equation modified from data reported by Wang (2009).

$$\tau_{ij} = 0.8796 + 0.1983 D_{ij} \qquad (24)$$

where τ_{ij} is the estimated costs ($/Mg) for loading and transporting a Mg of switchgrass dry matter from land class *j* of county *i* to the biorefinery. D_{ij} is the one way distance (km) between the centroid of land class *j* of county *i* and the biorefinery. The centroid of each land class in each county was determined and the nearest town to the corresponding land class centroid was obtained via GIS (Figure II-2). Road distance between the town and the biorefinery was obtained from Google maps (maps.google.com).

Estimating Switchgrass Biomass Yield Distributions

Switchgrass historical yields are not available. However, a proxy for historical yields may be simulated by a calibrated and validated biophysical plant growth simulation model if field trial yield data and historical weather data are available. The Environmental Policy Integrated Climate (EPIC) model (Williams, Jones, and Dyke 1984; Mondzozo et al., 2010) was calibrated for switchgrass yields using EPIC v 0509 and validated against switchgrass biomass field trial yield data obtained from three locations in the region: Chickasha, Haskell, and Stillwater (Fuentes and Taliaferro 2002; Haque, Epplin, and Taliaferro 2009). Calibration and validation of switchgrass yields were performed for each of three different soil types: McLain silt loam, Taloka silt loam and Kirkland silt loam on which the field experiments were conducted. Soil related information for these land types including bulk density, water, clay, sand and silt content, organic carbon concentration, calcium carbonate content, saturated conductivity, and cation exchange capacity were obtained from the SSURGO land database. The field trial data used to validate the calibrated results were obtained from a single annual harvest. Daily weather data of solar radiation, maximum temperature, minimum temperature, relative humidity, wind velocity, and precipitation for each of the three sites for each year for which data were available were obtained from the MESONET (2011) and NOAA (2011) weather data archives.

The calibrated EPIC model was used to simulate switchgrass biomass yields (α_{tij}) for 50 states of nature (1962-2011) (t = 1..50) for three land classes (class I, II, and III) (j = 1..3) for each of 30 counties (i = 1..30). The soil classification within each land class with the most hectares in the county was used in the EPIC simulation to represent the specific land class. In other words, it was assumed that all soil types in the county within a particular class produced identical yields in each simulated year. Historical weather data for each county were obtained from the NOAA (2011) for years 1962 through 2011 and supplemented with data from local weather stations (MESONET, 2011). Thus, proxies for empirical yield distributions that contained 50 observations were produced for each county and each land class.

Cost of Idling the Biorefinery

The net amount of revenue lost due to not delivering a Mg of feedstock that could be processed will depend on the lost revenue as well as on the variable production costs that can be avoided. If it is assumed that none of the biorefinery operating costs can be avoided, lost revenue from not producing biofuel will depend on the net market price of biofuel. From January of 2010 through December of 2011, the Iowa weekly average ethanol price ranged from $0.38 to $0.78 per liter (Agricultural Marketing Resource Center 2012). These prices were influenced to some extent by public policies that provided subsidies and mandates. Ethanol contains less energy (75,700 Btu) per gallon than unleaded gasoline (115,000 Btu) (U.S. Department of Energy 2009). When relatively low volumes of ethanol are blended with gasoline, it has value as an oxygenate in addition to its energy value. However, when used in greater proportions in engines with compression ratios designed for unleaded gasoline, the lower Btu content results in a proportionately lower mileage. If direct subsidies for ethanol are eliminated, and if ethanol production exceeds the quantity required for ten percent blends, the marginal value of ethanol could be expected to be based on its energy content relative to gasoline. Based on the reference case for crude oil price for 2016 of $120 per barrel, as projected by the U.S. Energy Information Administration (2012), an ethanol price based on energy equivalence would be $0.55 per liter. For a conversion rate of 375 liters per Mg, and a wholesale biofuel price of $0.55 per liter the penalty charges for not processing feedstock derived from the lost revenue would be $206 per Mg. This provides an estimate of the value of v in equation (14). Since some of the operating costs may be avoided if the biorefinery is idled, this can be interpreted as an upper bound estimate of the penalty for not processing one Mg of feedstock.

EPIC Model Calibration and Validation

Productivity, growth, longevity, and adaptation traits of switchgrass primarily depend on the geographical location of their origin. Based on the latitude and longitude of origin, switchgrass is broadly classified into two ecotypes, upland and lowland. Lowland ecotype varieties are more compatible to the southern latitude or southern part of the U.S. due to their ability to adapt to the longer growing season and warmer climatic conditions. Upland varieties are widely adapted in the northern part of the U.S. due to their greater potential to survive in the colder conditions of northern latitudes (Casler et al. 2007).

Lowland ecotype switchgrass yields were calibrated using EPIC v 0509 and validated against switchgrass biomass field trial yield data obtained from three locations: Chickasha, Haskell, and Stillwater (Fuentes and Taliaferro 2002; Haque, Epplin, and Taliaferro 2009). Calibration and validation of switchgrass yields were performed for each of the three different soil types: McLain silt loam, Taloka silt loam and Kirkland silt loam on which the field experiments at Chickasha, Haskell and Stillwater were conducted. Soil related information for these land types including bulk density, water, sand and silt content, organic carbon concentration, calcium carbonate content, saturated conductivity and cation exchange capacity were obtained from the SSURGO land database. The field trial data used to validate the calibrated results obtained from a single annual harvest. Single harvest management practices starting from the second year, as conducted in the field experiments, were used to calibrate the EPIC model. Daily weather data of maximum temperature, minimum temperature, precipitation, solar radiation, relative humidity and wind speed for each location were obtained from MESONET (2011) and NOAA (2011).

Calibration required adjustments to the EPIC crop parameter (CROPCOM crop file in EPIC v 0509). Timing of leaf decline (DLAI, EPIC v 0509 crop parameter acronyms), and maximum leaf area index (DMLA) were adjusted to 0.75 and 6, respectively. Leaf area decline after anthesis (RLAD), rate of decline in biomass energy after anthesis (RBMD) and plant maturity (RWPC2) were adjusted to 0.1, 0.1 and 0.3, respectively (Thomson et al. 2009).
The Chickasha and Haskell field trials included three lowland ecotype switchgrass cultivars: Alamo, Kanlow and PMT 279. Measured yields of these cultivars were averaged and compared to the simulated yields. The Stillwater trials included only Alamo. EPIC simulated switchgrass yields were compared against the actual switchgrass yields (Figure II-3). The simulated yields explained 67% of the variation in the measured yields for the 10 years (1994-2000 and 2003-2005). However, the model did not closely predict the Chickasha yields recorded for 1995. When the 1995 Chickasha observation was dropped, the R^2 increased to 0.84. By this measure, the model was assumed to have successfully captured the switchgrass biomass yield response and yield variation and was assumed to be calibrated (Table II-2 and Table II-3).

Results

Model 1 was solved under the assumption that the average of the 50 simulated yields is produced in each state of nature on each land class in each county. Results obtained from the optimization model find that a biorefinery located near Okemah with an annual switchgrass feedstock requirement of 700,000 Mg will require 50,128 ha with an estimated delivered switchgrass feedstock cost of \$60.07 Mg^{-1} (Table II-4). Total annual feedstock cost is estimated to be \$42,049,000. However, if these 50,128 ha were contracted, based on the simulated yield distributions, in 24 of the 50 states of nature, the total yearly biomass demand would not be met. In the worst state of nature from a switchgrass biomass yield perspective, the plant would be forced to idle for 85.4 days. On average the plant would be shut down for 29.5 days during those 24 of 50 years when the contracted land produced insufficient feedstock. The average number of shut down days across the entire distribution of 50 years is 14.2.

The results of Model 1 also provide insight regarding the potential for consecutive "bad" and "good" production seasons. Based on the 50 years of simulated distributions, there was one period extending over five years during which production from the land identified for contracting land would not have been sufficient to meet the biorefinery's annual requirements. This finding suggests that maintaining a storage reserve is not likely to be practical for this region. Table II-5, shows that the biorefinery would optimally contract for land class I, II, and III in Creek, Hughes, McIntosh, Okfuskee, Okmulgee, Pittsburg, and Seminole counties, while land class I and II would be contracted in Lincoln County, and only land class I in Pottawatomie County (Figure II-4)**.** These findings follow from the assumption that the 50 years of data appropriately represents the entire switchgrass yield distribution.

Model 2 is designed to locate the optimal (least-cost) quantity of land from each land class and county to contract to ensure that 700,000 Mg be produced and delivered in each state of nature. If the biorefinery management chose to attempt to lease sufficient land so that the required feedstock would be available for each year, then 60,492 ha would be contracted, resulting in an increase relative to model 1 in the average cost of delivered feedstock from \$60.07 to \$64.17 Mg^{-1}. The total average annual feedstock cost would increase by 6.8% from \$42,049,000 to \$44,919,000. The difference in estimated average annual cost between model 1 and model 2 of \$2,870,000 (\$4.10/Mg of biorefinery capacity) could be interpreted as the annual cost of a self insurance policy to attempt to prevent idling the biorefinery due to insufficient feedstock.

Table II-4 also shows the annual cost for the "best" and the "worst" switchgrass biomass production year from among the 50 years in the distributions. Based on model 2, 60,492 ha would be contracted. However, in the most favorable weather year, only 42,485 ha would be required to produce the 700,000 Mg required. By assumption, production from the remaining 18,007 contracted hectares would be mowed but not raked and baled. Since less land is required to be raked and total transportation distance is reduced, average estimated cost to deliver feedstock in this "best" weather year is $62.80/Mg. In the "worst" weather state of nature all 60,492 contracted ha must be harvested and the estimated cost to deliver is $67.18/Mg. Figure II-5 shows that harvesting costs (including mowing, raking and baling activities) drives the entire production activity.

Table II-6 provides a listing of the optimal quantity of land to contract for each county and land class to ensure that 700,000 Mg can be delivered for each state of nature (model 2). Column 2 of table II-6 shows the proportion of years based on the yield distributions during which some biomass from each county that contains contracted land is baled and transported. By this measure, production from the contracted Johnston county land would be required only 2% of the time.

Table II-7 shows the relative change in quantity and location of land contracted if the model is solved to meet the 700,000 Mg requirement in each state of nature rather than an average of 700,000 Mg. The same quantity and quality of land is optimally contracted in Creek, Hughes, Okfuskee, Okmulgee, Pittsburg, Pottawatomie, and Seminole counties for both models 1 and 2. Additional land would be leased in Coal (999 ha), Haskell (65 ha), Johnston (107 ha), Latimer (740 ha), Muskogee (4,623 ha), Oklahoma (3,472 ha), and Wagoner (5,218 ha) counties. However, less land would be contracted in Lincoln (2,895 ha) and McIntosh (1,965 ha) counties (Figure II-4). The net additional hectares of land are required to ensure that in the worst case situation, the biorefinery can operate at capacity. As noted, for those states of nature in which production from the total contracted hectares exceeds biorefinery requirements, it is assumed that excess production would be mowed and left in the field to decompose and build organic matter. The total quantity of switchgrass baled and transported is constant (700,000 Mg) across years. However, the location of fields to bale and biomass to transport varies from year-to-year.

Table II-8 includes a correlation matrix for switchgrass yields in the counties and for those land classes for which optimally contracted land is different between model 1 and model 2. As expected, the highest yield correlations are across land classes within county: 0.95 between land class I and II in Oklahoma County; 0.79 between land class I and III in Wagoner County; 0.65 between land class II and III in McIntosh. Also, as might be expected the lowest correlation (-0.10) is between the most distant counties, Latimer and Oklahoma. When yield variability is ignored (model 1), land is not optimally contracted in either Latimer or Oklahoma County. Differences in yield across space provide an opportunity for a biorefinery to strategically contract land to manage spatial variability.

In model 3, the value of v in equation (14) is a measure of the cost of not processing one Mg of switchgrass due to insufficient feedstock production on the contracted land. An idled plant relinquishes the opportunity to process. The total cost for not processing depends on the value of the products not produced and sold minus the variable production costs that can be avoided if the biorefinery is idled. For a conversion rate of 375 liters per Mg for each $0.25 per liter biofuel value the penalty from the lost revenue would be $93.75 per Mg. Since there are other costs associated with processing that can be avoided, this can be interpreted as an upper bound estimate of the revenue lost for not processing.

Results from model 1 can be used to compute an upper value for the parameter φ in equation (20). Based on model 1, if the biorefinery elected to contract for land based on average yields it would average 14.2 days per year of required idling due to insufficient feedstock. For a 2,000 Mg/day biorefinery this would be an average annual shortage of 28,400 Mg. This value can be multiplied by the number of states of nature in the yield data set (in this case 50) to obtain an upper value for φ (1,420,000 Mg).

For a given level of φ the level of v can be parameterized to determine the tradeoff between the cost of not processing a Mg of switchgrass and the optimal quantity of land to contract. Results are reported in table II-9 and shown in figure II-6. For a biofuel price of $0.50 per liter and a conversion rate of 375 liters per Mg, every Mg not processed represents a lost opportunity to gain $187.5 in revenue. For this situation the biorefinery would optimally lease 53,379 ha. This would result in an average of 2.97 days per year during which the biorefinery would be idled due to insufficient feedstock. The average annual cost of leasing the land and producing, harvesting, and delivering the feedstock would be $43,057,150. The average annual opportunity cost of the lost revenue from insufficient feedstock would be $694,013. Dividing the delivered feedstock costs by the average processed quantity of 694,013 Mg, results in a cost estimate for the delivered switchgrass feedstock of $62.04 per Mg. This 53,379 ha can be compared to the 60,492 ha that would be required to ensure that adequate feedstock be produced in every year to prevent any shut down time. The opportunity cost of closing the biorefinery would have to increase to $960 per Mg before it would be optimal to contract for the 60,492 ha that would be required to insure against a feedstock shortage shutdown.

An estimate of the value of identifying and strategically contracting land can be determined by comparing the findings of model 1 with those of model 3. Model 1 identified 50,128 ha for contracting. However, as noted, if these 50,128 ha were contracted, based on the simulated yield distributions, in 24 of the 50 states of nature, yield would be less than sufficient to meet the needs of the biorefinery. The total annual feedstock cost estimate for model 1 of $42,049,000 follows from the assumption that the yield would be the same from each hectare in each year and that exactly 700,000 Mg would be delivered to the biorefinery in each state of nature. However, if the 50,128 ha were contracted, in years when production exceeded biorefinery requirements, the excess amount would not be raked, baled, or transported. The actual transportation flows and costs would be different in each year. In years when production on the 50,128 contracted ha is less than 700,000 Mg, all contracted hacteres would be harvested. Based on the simulated yield distributions, on average, only 671,694 Mg would be produced on the contracted ha. The average cost to deliver the feedstock would be $40,671,330 (table II-10) rather than $42,051,000 (table II-4) because in high yield years fewer hectares need to be raked and total transportation distances are less, and in low yield years, fewer Mg are available for baling and less total feedstock is available for transportation.

If the net cost of idling the biorefinery as a result of insufficient feedstock were $0.50 per liter not produced, then the estimated annual cost of downtime that would result from contracting the 50,128 ha would be $5,307,375. The average annual cost of feedstock plus downtime cost would be $45,978,705 (table II-10). If, on the other hand, the biorefinery elected to take account of switchgrass yield variability (model 3) when identifying and contracting for land, the average annual cost of feedstock plus downtime would be $44,170,359. The difference between these two values ($1,808,346) is an estimate of the annual value of considering spatial and temporal yield variability when selecting land to contract. Since the useful life of a biorefinery is expected to exceed 10 years, land contracts to produce feedstock could also be expected to be for at least 10 years, similar to 10-15 year Conservation Reserve Program land contracts (Osborn, Llacuna and Linsenbigler 1995). For a 10 year contract and a discount rate of 10% the present value of considering spatial and temporal yield variability when selecting land to lease for a single 2,000 Mg per day biorefinery in the region exceeds $11 million (Table II-10). There is a clear tradeoff between the biorefinery downtime costs and the optimal quantity of land to lease (Figure II-7). As more land is leased, the average number of days per year that the plant will be idled declines (Figure II-7).

Conclusion and Discussion

Much has been made about the anticipated cost reductions expected to be achievable with the n^{th} relative to the first cellulosic biorefinery with a specific technology (Kazi et al. 2010; Wright et al. 2010). However, these analyses have failed to consider that unlike cookie cutter corn ethanol plants that can procure a flow of feedstock by simply offering a price premium for corn grain relative to the local elevator, each cellulosic biorefinery will need to pay careful attention to feedstock procurement. Transportation costs can be expected to limit the procurement region for a biorefinery. Biomass yield from perennial grasses varies considerably across regions and across years (Sala et al. 1988). Based on the findings presented for the region evaluated, failure to consider spatial and temporal yield variability could be quite costly. If the initial biorefineries locate in regions with less biomass yield variability the n^{th} biorefinery may be located in a region with more yield variability and greater feedstock cost. The modeling system presented herein is generalizable to other regions and to other perennial dedicated energy crops such as miscanthus and short rotations woody crops. The value of strategically selecting land to contract will vary across regions and across species.

For the region of the study the optimal strategy resulted in contracting for more land than would be required in most years. Since it was assumed that the value of excess feedstock would be less than the cost of harvest, it was assumed to be mowed and the sequestered carbon left in the field. However, no value was assigned to the environmental benefit of producing this biomass.

If the provisions of the 2007 U.S. Energy Independence and Security Act are to be fulfilled, the production of dedicated energy crops such as switchgrass may be required. Development of feedstock production could be expected to develop simultaneously with biorefinery construction. A biorefinery designed to process switchgrass feedstock could engage in long term contracts designed to fulfill its feedstock needs. The models presented in this paper address the spatial and temporal variability of switchgrass biomass yield, issues which prior studies of dedicated energy crop production have not considered.

Models based on average production do not account for the opportunity cost incurred by the biorefinery for not producing and selling products in those years when biomass production from contracted land is not sufficient to enable the biorefinery to operate at production capacity. A fully vertically integrated system may reduce the variability of feedstock cost but cannot eliminate it.

The simulated yield distributions reveal that for the region of the study it would be difficult to manage a storage reserve from which biomass may be retrieved in low production years. Based on the 50 years of historical weather used to simulate yields, there was one period extending over five years during which production from the land identified for contracting would not have been sufficient to meet the biorefinery's annual requirements. Given the expense required to maintain switchgrass biomass quality while in storage, maintaining and using a feedstock storage reserve is not likely to be practical for this region.

Results of the model suggest that (in the absence of government imposed distortions) a cost-efficient switchgrass feedstock biorefinery system could engage in long term contracts with land owners to lease a sufficient quantity of land to provide for feedstock needs prior to, or simultaneously with, construction of a biorefinery.

Land could be leased in a manner similar to what occurred when millions of hectares were converted from cropland and enrolled in the Conservation Reserve Program (CRP). The difference being that the biorefinery rather than the government would be the lessee and would be responsible for paying the leasing cost. The CRP was established in 1985. USDA provided CRP participants with an annual per hectare rent and half the cost of establishing a permanent land cover (usually grass or trees) in exchange for 10 or 15 year leases. During the first three enrollment periods in 1986, more than three million ha were contracted. Within two years after the 1985 legislation, nine million U.S. ha were under contract (Osborn, Llacuna and Linsenbigler 1995). If an economically competitive biorefinery technology is developed, entrepreneurs could prepare a field-to-fuel business model and contract and convert millions of ha from current use to the production of a perennial dedicated energy crop in a relatively short period of time.

Companies may be reluctant to contract for sufficient quantities of land to provide for feedstock needs. Public opinion may not support conversion of 50,000 ha in a region from existing use to the production of a dedicated energy crop. The probability of successful rent seeking behavior on behalf of the biorefinery may be reduced if it becomes clear that production of perennial grass feedstock is more akin to harvesting CRP lands than farming conventional annual crops. Public officials may place impediments limiting the ability of biorefineries to lease large tracts of land. However, ambiguities as to what determines feedstock quality and how to provide a flow of feedstock throughout the year are likely to be resolved much more quickly if the annual payment to the land owner is set. Leased land would enable the biorefinery to manage feedstock quality and to manage harvest and transportation to optimize the field to biofuel system.

Public policy could be implemented to facilitate contracting between land owners and biorefineries by enabling the use of the USDA Farm Service Agency and USDA Natural Resources and Conservation Service infrastructure to identify suitable land for contract. Since land owners may be skeptical of contracting with a startup, given the history of bankruptcies in ethanol businesses, additional policies could be implemented to enable the USDA to provide an insurance mechanism to facilitate contract insurance. Experts from USDA's Risk Management Agency could contribute to designing insurance to mitigate moral hazard issues.

If an economically viable system for converting biomass from dedicated perennial species to biofuels is developed, in the absence of government intervention, because of the potential efficiencies from coordinated harvest, storage, and delivery, market forces are likely to drive the system toward vertical integration. The structure of the industry is more likely to resemble U.S. timber production and harvest and delivery than the atomistic U.S. grain production system.

An innovative model was introduced that enables determination of the tradeoff between the opportunity costs of closing the biorefinery as a result of insufficient feedstock and the quantity of contracted land considering both spatial and temporal switchgrass biomass yield variability. The model was used to determine the optimal quantity of land to lease as a function of the net cost of closing the biorefinery due to insufficient feedstock. For a 10 year land contract and a discount rate of 10% the present value of considering spatial and temporal yield variability when selecting land to lease for a single 2,000 Mg per day biorefinery in the region exceeds $11 million.

The value of considering spatial and temporal switchgrass yield variability when selecting land to lease will differ across regions. The models may be used to determine the value for other regions.

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Table II-1. Estimated annual production and harvesting costs of switchgrass.

Item	Unit	Quantity	Price unit	Costs
			$	$/ ha
Establishment costs	ha	1.00		394.45
Land rental	ha	1.00	variable	variable
Establishment costs, amortized for 10 years at 6.5%	$		0.065	variable
Nitrogen	kg	78.00	1.23	95.94
Annual Maintenance costs	$	1.00		9.63
Mowing	ha	1.00		30.97
Raking	ha	1.00		18.89
Baling, 681 kg dry biomass rectangular bale	kg	variable	28.89	variable
Total costs	$			variable

Source: Turhollow, A.F. and F.M. Epplin. "Estimating Region Specific Costs to Produce and Deliver Switchgrass." Chapter 8 in *Switchgrass: A Valuable Biomass Crop for Energy*. ed. Andrea Monti, New York: Springer Publishing Co. 2012.

Table I-2. Comparison between measured and simulated lowland ecotype switchgrass yields.

	Measured Yields	Simulated Yields
Mean (Mg ha^{-1})	14.68	14.41
St. Dev.	4.29	4.16
Maximum (Mg ha^{-1})	23.10	21.81
Minimum (Mg ha^{-1})	7.28	7.57

Table II-3. EPIC model switchgrass validation results.

Mean absolute percentage error (MAPE)	12.23%
Coefficient of determination (R^2)	0.66
Relative Error (Rel. Error)	0.02

Table II-4. Total annual feedstock costs (land contracted, production, fertilization, harvest, and transportation), average cost to deliver switchgrass, area leased, and average area harvested to deliver switchgrass.

	Total Feedstock Costs ($/yr)	Average Cost to Deliver Switchgrass ($/Mg))	Land Contracted (ha)	Area Harvested (ha)
Result from model 1				
Average Yield	42,051,000	60.07	50,128	[a]
Results from model 2: Insure 700,000 Mg in Every State of Nature				
Average	44,919,000	64.17	60,492	50,023
Best yield year	43,960,000	62.80	60,492	42,485
Worst yield year	47,026,000	67.18	60,492	60,492

[a] In years with average or below average yields the entire contracted area would be harvested. However, in years with above average yields, if the biomass has no alternative use, some contracted area would not be harvested.

Table II-5. Land contracted by county and by land class assuming average yield is achieved and ignoring year-to-year switchgrass yield variability (model 1).

County	Land Class I	Land Class II	Land Class III
		hectares	
Creek	1,337	3,647	3,842
Hughes	329	2,645	6,348
Lincoln	251	2,895	
McIntosh	14	1,413	552
Okfuskee	774	1,057	3,154
Okmulgee	544	3,003	5,139
Pittsburg	142	2,744	5,938
Pottawatomie	669		
Seminole	120	1,329	2,242
Total	4,180	18,733	27,215

Note: Area contracted for a specific land class and county was restricted to be no more than 10% of the existing quantity.

Table II-6. Land contracted by county and by land class to ensure that 700,000 Mg can be delivered for each state of nature (model 2). [a]

County	Proportion of years when biomass is raked, baled and transported	Land Class I	Land Class II	Land Class III
		hectares		
Coal	0.14		999	
Creek	1.00	1,337	3,647	3,842
Haskell	0.38	65		
Hughes	1.00	329	2,645	6,348
Johnston	0.02	107		
Latimer	1.00		740	
Lincoln	0.90	251		
McIntosh	1.00	14		
Muskogee	0.82			4,623
Okfuskee	1.00	774	1,057	3,154
Oklahoma	0.36	590	2,882	
Okmulgee	1.00	544	3,003	5,139
Pittsburg	1.00	142	2,774	5,938
Pottawatomie	1.00	669		
Seminole	1.00	120	1,329	2,242
Wagoner	0.46	773		4,445
Total		5,715	19,076	35,731

[a] For those counties and land classes for which land is optimally contracted, all available land is contracted except that only 46% of Muskogee County class III land is contracted.

Table II-7. Change in quantity of land optimally contracted as determined by model 1 and model 2 (model 2 value minus model 1 value).

County	Land Class I (ha)	Land Class II (ha)	Land Class III (ha)
Coal		999	
Creek	* [a]	*	*
Haskell	65		
Hughes	*	*	*
Johnston	107		
Latimer		740	
Lincoln	*	-2,895	
McIntosh	*	-1,413	-552
Muskogee			4,623
Okfuskee	*	*	*
Oklahoma	590	2,882	
Okmulgee	*	*	*
Pittsburg	*	*	*
Pottawatomie	*		
Seminole	*	*	*
Wagoner	773		4,445

[a] An * indicates that the same quantity of land was selected for contracting by both models 1 and 2.

Table II-8. Correlation matrix for switchgrass yield for counties and land classes for which a different quantity of land is optimally contracted between models 1 and 2.

County	Land Class	County											
		Coal	Haskell	Johnston	Latimer	Lincoln	McIntosh	McIntosh	Muskogee	Oklahoma	Oklahoma	Wagoner	Wagoner
		II	I	I	II	II	II	III	III	I	II	I	III
Coal	II	1.00											
Haskell	I	0.24[a]	1.00										
Johnston	I	0.45	0.42	1.00									
Latimer	II	0.14	0.13	0.19	1.00								
Lincoln	II	0.17	0.52	0.12	0.13	1.00							
McIntosh	II	0.37	0.22	0.36	0.20	0.33	1.00						
McIntosh	III	0.22	0.19	0.18	0.36	0.42	0.65	1.00					
Muskogee	III	0.39	0.41	0.17	0.17	0.25	0.30	0.23	1.00				
Oklahoma	I	0.06	0.46	0.31	-0.02	0.26	0.30	0.23	0.04	1.00			
Oklahoma	II	0.08	0.47	0.27	-0.10	0.24	0.27	0.19	0.09	0.95	1.00		
Wagoner	I	0.11	0.51	0.07	0.27	0.31	0.25	0.15	0.30	0.32	0.29	1.00	
Wagoner	III	0.16	0.58	0.11	0.13	0.34	0.20	0.12	0.50	0.26	0.28	0.79	1.00

[a] The correlation coefficient of switchgrass yield between land class II of Coal County and land class I of Haskell County is 0.24.

Table II-9. Biofuel price, corresponding revenue lost for not processing switchgrass feedstock, the number of days in an average year the biorefiney is forced to be idle, average cost to deliver switchgrass, and quantity of contracted land.

Net Biofuel Price ($/liter)	Lost Net Revenue (v) ($/Mg not processed)[a]	Forced downtime (average days/year)	Land Contracted (ha)	Average Annual Shortage (Mg)[b]	Average Annual Delivered Feedstock (Mg)	Annual cost of Forced Downtime ($/yr)	Annual Cost of Delivering Feedstock ($/yr)	Cost / Mg Delivered
				φ =1,420,000[b]				
0.1	37.5	14.15	49,464	28,306	671,694	1,061,475	40,511,170	60.32
0.2	75	14.15	49,464	28,306	671,694	2,122,950	40,511,170	60.32
0.3	112.5	6.86	51,465	13,727	686,273	1,544,288	41,953,190	61.13
0.4	150	4.24	52,198	8,488	691,512	1,273,200	42,611,090	61.62
0.5	187.5	2.97	53,379	5,987	694,013	1,122,563	43,057,150	62.04
0.6	225	1.94	54,212	3,879	696,122	872,775	43,470,000	62.45
1.2	450	0.32	55,813	631	699,369	283,950	44,445,260	63.55
2.56	960	0	60,492	0	700,000	0	44,919,930	64.17
				φ =1,000,000				
0.1	37.5	10	51,092	20,000	680,000	750,000	41,287,740	60.72
0.2	75	10	51,092	20,000	680,000	1,500,000	41,287,740	60.72
0.3	112.5	6.86	51,465	13,727	686,273	1,544,288	41,953,190	61.13
				φ =500,000				
0.1	37.5	5	51,923	10,000	690,000	375,000	42,402,630	61.45
0.2	75	5	51,923	10,000	690,000	375,000	42,402,630	61.45
0.3	112.5	5	51,923	10,000	690,000	375,000	42,402,630	61.45
0.4	150	4.24	52,198	8,488	691,512	1,273,200	42,611,090	61.62

[a] Here v from model 3 (equation 14) is assumed to be equal to the lost sales revenue from not processing as a result of insufficient feedstock.

[b] Constraint equation (20) from model 3 limits total biomass shortage across all years to a level, φ. The average annual shortage is φ/T. The initial level of φ was set equal to the average shortage per year as computed by model 1 times T.

Table II-10. Estimated value of strategically selecting land to lease if the net cost of failure to deliver feedstock is $187.50 per Mg.

Forced downtime (average days/year)	Land Contracted (ha)	Average Annual Shortage (Mg)[b]	Average Annual Delivered Feedstock (Mg)	Estimated Annual cost of Forced Downtime ($/yr)	Annual Cost of Delivering Feedstock ($/yr)	Average Annual Cost of Feedstock Plus Downtime ($/yr)
			Model 1			
14.15	50,128	28,306	671,694	5,307,375	40,671,330	45,978,705
			Model 3			
2.97	53,379	5,987	694,013	1,113,209	43,057,150	44,170,359
			Model 1 Value Minus Model 3 Value			
11.18	-3,251	22,319	-22,319	4,194,166	-2,385,820	1,808,346
		Value of Strategically Selecting Land to Contract				
		Discount Rate		Contract Length (yr)		Present Value
		0.10		10		$11,111,505
		0.10		15		$13,754,426
		0.15		10		$9,075,672
		0.15		15		$10,574,070

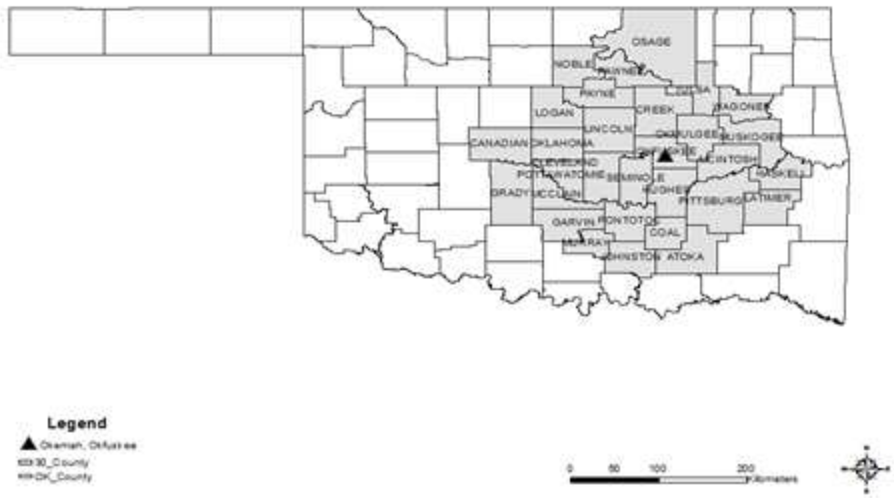


Figure II-1. Map showing the Oklahoma counties selected for potential switchgrass production

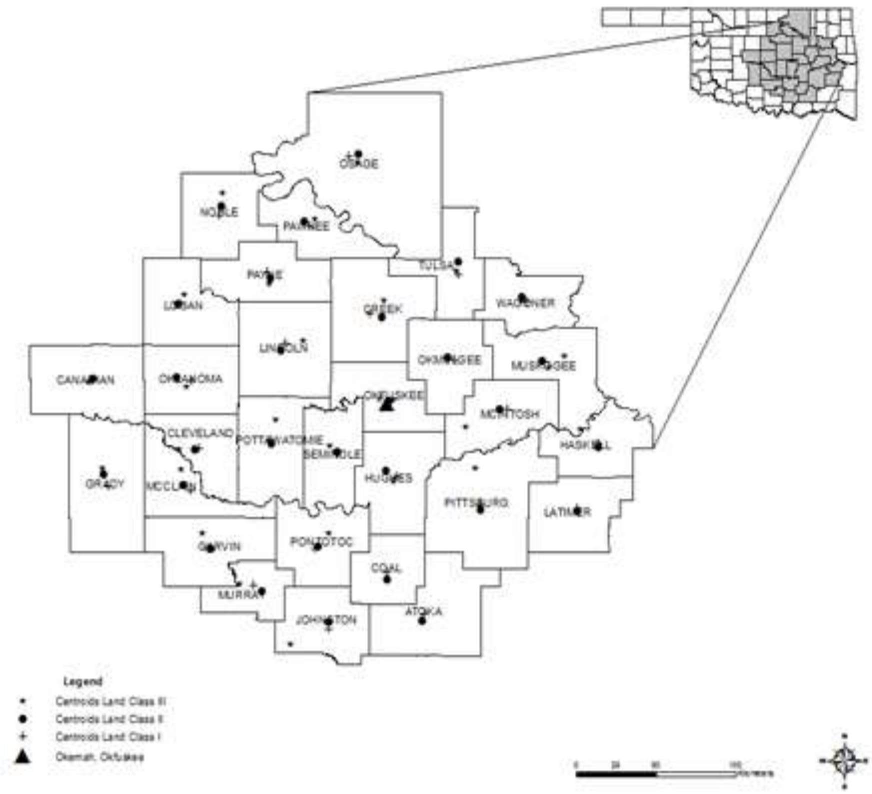


Figure II-2. Map of the centroids of land class I, II, and III in each of the thirty Oklahoma counties. Potential biorefinery location is indicated by ▲.

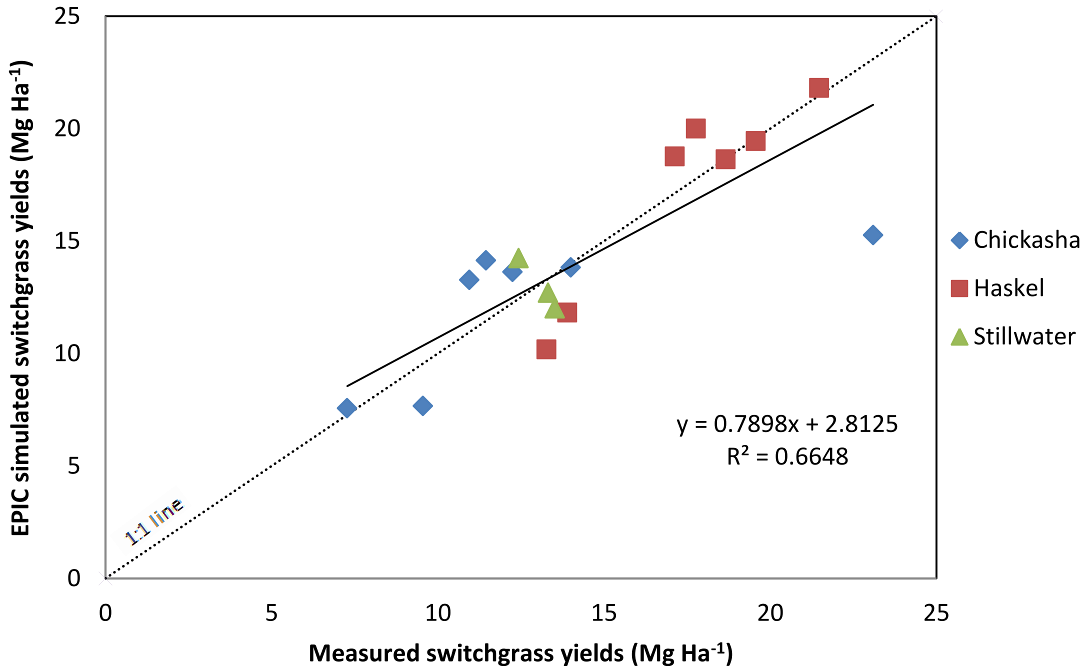
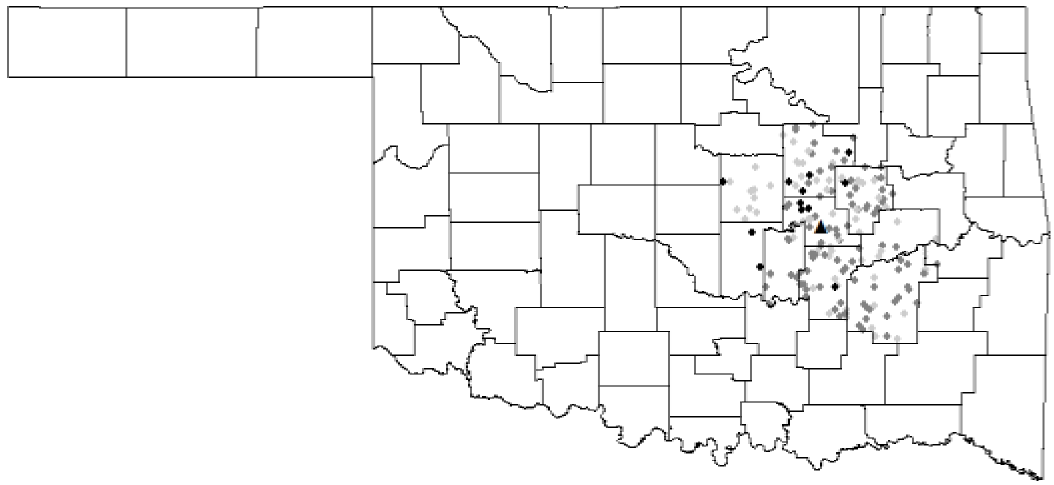


Figure II-3. Simulated and measured lowland ecotype switchgrass yields for the three location of Oklahoma over the year 1994 through 2000 and 2003-2005.

Land Leased Under Average Switchgrass Yield (model 1)



Land Leased to Ensure Sufficient Feedstock in Each Production Year (model 2)

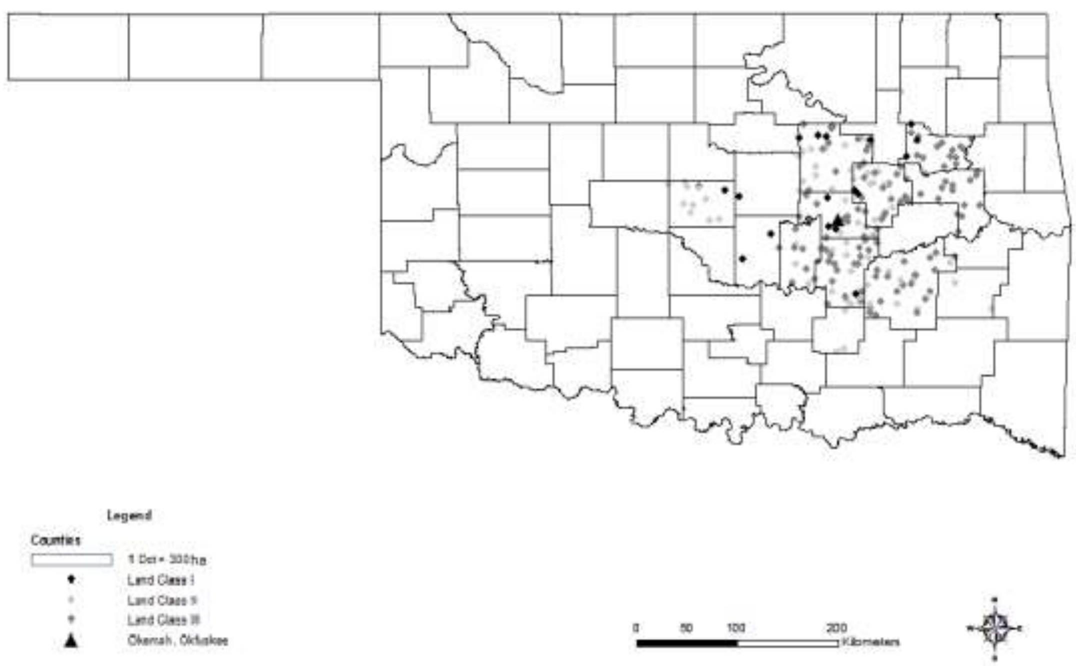


Figure II-4. Location and land class optimally contracted by county. (Symbols randomly assigned within counties.)

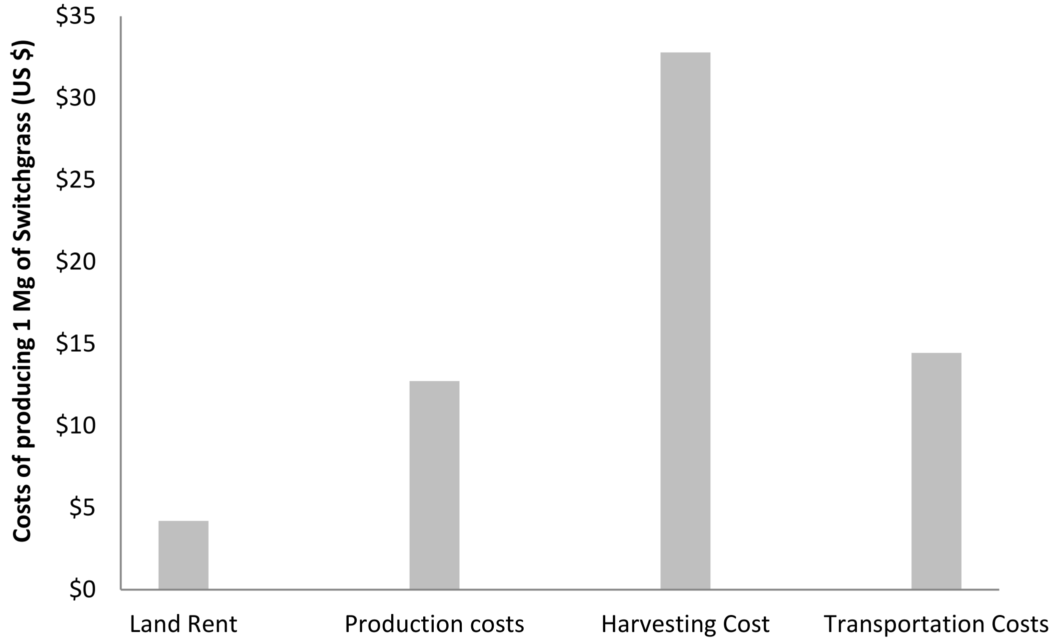


Figure II-5. Land rent, production costs, harvest costs, and transportation costs of one Mg of switchgrass
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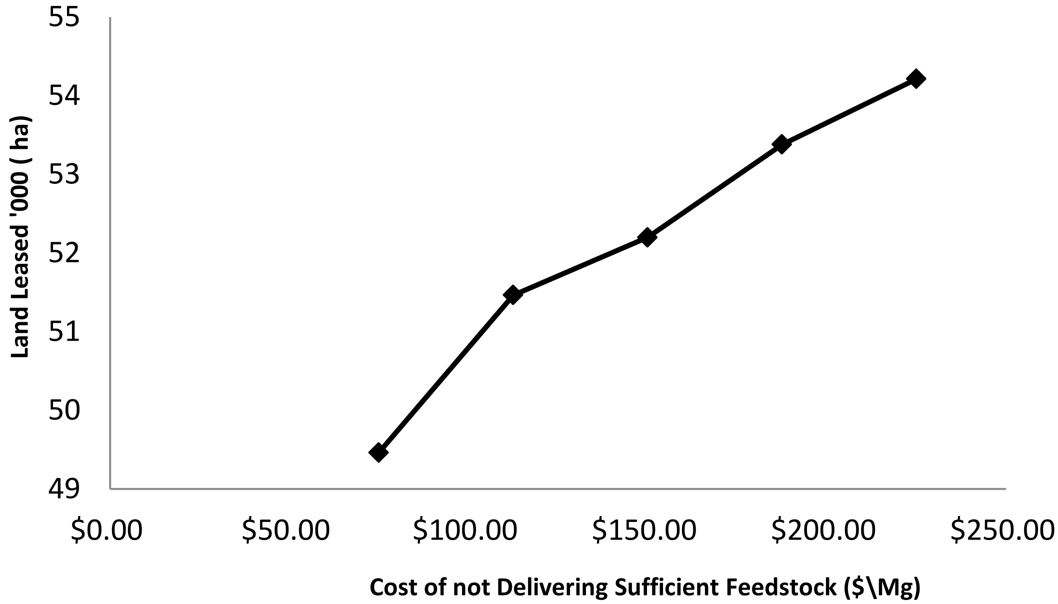

Figure II-6. Tradeoff between the cost ($/Mg) of downtime due to insufficient feedstock and the optimal quantity of land to lease

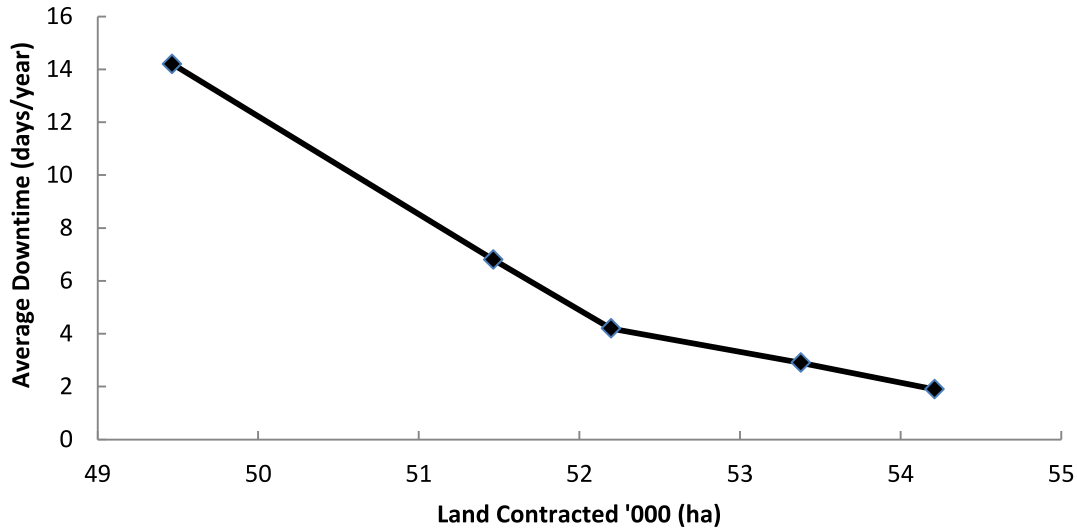

Figure II-7. Tradeoff between the average biorefinery forced downtime days per year for lack of feedstock and the quantity of contracted land.

CHAPTER III

IMPACT OF ENVIRONMENTAL VALUES ON THE BREAKEVEN PRICE OF SWITCHGRASS

Abstract

This study estimates the farm-gate breakeven price of switchgrass relative to wheat production, which is the dominant crop in Oklahoma. The breakeven price of switchgrass is determined both from the perspective of the private landowners' and from the social perspective where selected external environmental consequences are included. Results suggest that the farm-gate breakeven price of switchgrass from the private landowners' perspective is higher than from the social perspective when environmental consequences are considered. The environmental benefits (selective) derived from switching to bioenergy crop production are greatest on the most erodible land.

Introduction

With increased prices of fossil fuels and concern over environmental degradation there has been increased interest in finding alternative sources of energy. Part of this interest has focused on renewable bioenergy, which is expected to have fewer negative environmental consequences than hydrocarbon fuels. The U.S. Energy Independence and Security Act (EISA) of 2007 include a target level of 16 billion gallons of cellulosic ethanol by 2022. Among the many potential dedicated energy crops, switchgrass has promise due to its ability to grow on many different types of soil under diverse climatic conditions. The US-EPA (2010) used the Forestry and Agriculture Optimization Model (FASOM) to predict that by 2022, it would be economically feasible to produce around 0.9 billion gallons of ethanol from switchgrass biomass feedstock. The FASOM model also projected that most of the switchgrass used to produce the feedstock for the 0.9 billion gallons of ethanol would be grown in Oklahoma replacing wheat and hay production (U.S. EPA, p. 286-287).

Switchgrass can generate greater biomass yields with relatively less chemical fertilizer than annual non-legume crops. This is because in the fall, nutrients are translocated to its deep rhizomes. If the biomass harvest is delayed until the fall after the nutrients have translocated, they will not be removed. A perennial energy crop like switchgrass can also increase soil organic matter and provide a cover that reduces soil erosion relative to continuous cropping. There are additional environmental benefits from reduced nitrogen and phosphorous runoff and carbon sequestration.

The U.S. Conservation Reserve Program (CRP) was established in 1985. Under the CRP program highly erodible land was removed from agricultural production and trees or grasses were planted to reduce soil erosion (Mapemba et al., 2007). CRP participants were paid an annual land rental value and half the cost of establishing a permanent land cover (usually trees and grasses) in exchange for 10- or 15-year leases on land previously used to grow crops. One of the major goals of the CRP was to reduce soil erosion. As of January 2012, more than 12 million hectares were under USDA CRP contract at an average cost of $141/ha/year or a total cost of almost $1.7 billion per year (U.S. Department of Agriculture, Farm Service Agency, 2012). Allowing some of these lands to produce energy crops like switchgrass, would reduce the government CRP expenditure while maintaining at least some of the benefits such as reduced soil erosion, reduced nitrogen and phosphorous loss and sequester carbon. In anticipation of the establishment of a technology for converting cellulosic biomass into economically competitive bio-products, the CRP was amended by the 2002 Farm Bill to permit biomass harvesting of CRP grassland subject to restrictions (Farm Security and Rural Investment Act (FSRIA) of 2002, U.S. Department of Agriculture, 2003).

The projected potential for switchgrass production in Oklahoma raises several research questions. First, what net price for switchgrass would be required to bid land away from wheat production to switchgrass production? Second, what are the expected changes in soil erosion, fertilizer (nitrogen and phosphorous) runoff, and soil organic carbon from converting wheat production land into switchgrass production?

In this research study, the farm-gate price of switchgrass is estimated from the view of the private landowner and from the view of social planner by including selected environmental impacts. Specifically, the long-term environmental consequences resulting from replacing no-till wheat production by switchgrass production can be obtained through the reduction in soil erosion, nitrogen and phosphorous runoff and through changes in soil organic carbon (SOC). The monetary values to these environmental consequences are added to consider the abatement costs associated with the reduction of agricultural runoff caused from wheat and switchgrass production. This study will also estimate the potential environmental benefits derived from replacing no-till wheat production to switchgrass production and discuss the importance of a program such as conservation reserve program to incentivize switchgrass production from the soil planners' perspective.

Several studies have estimated the production costs of switchgrass feedstock. The production cost is used as the farm-gate breakeven price, which includes all the costs associated with the production of switchgrass. Mooney et al. (2009) determined the breakeven price of switchgrass for four different locations in Tennessee. They found that the farm-gate breakeven price of switchgrass based on 10-year production contracts was \$46 Mg^{-1} for an average yield of 17.7 $Mg\ ha^{-1}$ and \$69 Mg^{-1} for an average yield of 8.5 $Mg\ ha^{-1}$. Khanna, Dhungana and Brown (2008) estimated the Illinois farm-gate breakeven price of switchgrass to be \$98 Mg^{-1} with average yields of 9.42 $Mg\ ha^{-1}$. Epplin et al. (2007) estimated the cost of producing switchgrass under two alternative scenarios: (1) the land-lease alternative and (2) the farmer-contract. Under the land-lease alternative, the cost of switchgrass production including the cost of land lease, harvest and storage for the 55 counties of Oklahoma was \$40.65 Mg^{-1}. The study assumed an eight-month harvest system. The cost increased to \$58.15 Mg^{-1} when the harvest window was restricted to two months per year. In Tennessee, based on farmer bids to produce switchgrass, the cost of producing switchgrass ranged from \$39.67 Mg^{-1} to \$60.30 Mg^{-1} assuming that an average yield of 15.70 $Mg\ ha^{-1}$ could be obtained. McLaughlin and Kszos (2005) estimated U.S. farm-gate prices of switchgrass of \$30.31 Mg^{-1}, and \$44.00 Mg^{-1} for average yields of 11.4 $Mg\ ha^{-1}$, and 9.4 $Mg\ ha^{-1}$ respectively. The agricultural sector model POLYSIS was used in the study. However, these studies did not consider the environmental consequences of producing switchgrass relative to existing land use and also did not place any monetary value on those consequences while estimating the farm-gate breakeven price of switchgrass.

Nelson, Ascough II, and Langemeier (2005) discussed the environmental consequences of converting conventional crop land to switchgrass. They used the soil and water assessment tool (SWAT) to determine the environmental outcomes of switchgrass production. They simulated switchgrass yields and other commodity crop yields and estimated the farm-gate breakeven price of switchgrass. Graham, Downing and Walsh (1996) used the environmental policy integrated climate (EPIC) model to predict switchgrass and other alternative crop yields and their associated environmental outcomes. They determined the farm-gate breakeven price of switchgrass by comparing it to the production of other alternative crops. Both of these studies found that switchgrass production reduced soil erosion and nutrient loss compared to annual crops. King, Hannifan, and Nelson (1998) also found that switchgrass production reducted soil erosion and nutrient loss. However, these studies did not attach any monetary value to the environmental benefits derived from converting to switchgrass production while estimating the farm-gate breakeven price of switchgrass.

The primary objective of this study is to determine the site-specific farm-gate breakeven price of switchgrass under two scenarios: (1) from the profit maximizing private landowners' perspective where environmental issues are not considered; and (2) from social planner's perspective where selected environmental variables (soil loss, nitrogen and phosphorous loss, and changes in SOC) are valued. The secondary objective was to estimate the expected yield of switchgrass and wheat (major alternative crop) and the environmental outcomes including nitrogen loss, phosphorous loss, soil loss and changes in soil organic carbon (SOC) on alternative soil classes over a multi-county area. Furthermore, this study will also estimate the selective site-specific environmental benefits derived from producing switchgrass.

Conceptual Framework

This study integrates the environmental consequences and economic feasibility of producing switchgrass. The landowners' decision regarding shifting into a long-term investment such as switchgrass by replacing an existing annual crop mainly depends on the relative expected returns per hectare. Factors like the expected yield of switchgrass, production costs, agricultural policy program (subsidy) and the price of the switchgrass determine the profitability. The objective of the landowners/ farmers is assumed to be maximization of the net expected returns subject to availability of land, and is as follows:

$$\max_i E(\pi) = R_i A_i ; \; i \in (w, s) \tag{1}$$

$$s.t. \quad A_i \leq \bar{L} \tag{2}$$

$$A_i \geq 0 \tag{3}$$

where, $E(\pi)$ is the expected net returns derived from either producing wheat (w) or producing switchgrass (s); A_i is the acreage of crop i (wheat or switchgrass); R_i is the expected net returns per hectare, after incurring the abatement costs associated with the removing of agricultural runoff derived from producing crop i; $\bar{L}$ is the quantity of land available for switchgrass production. However, in the case of switchgrass, no formal market exists for the product. Therefore, the price of switchgrass is estimated from the returns of the best alternative crop, which in this case is assumed to be wheat.

An integrated framework, which combines the economic model and environmental model, will be discussed. This study is divided into three sections: (1) a biophysical simulation model: the EPIC model was used to simulate the expected yield of switchgrass and wheat along with the environmental outcomes including (a) total soil loss (Mg ha^{-1}), (b) nitrogen loss (kg ha^{-1}), (c) phosphorous loss (kg ha^{-1}), and (d) changes in SOC (kg ha^{-1}); (2) an economic model is used to estimate the farm-gate breakeven price of switchgrass from the perspective of the profit maximizing landowners without valuing the environmental consequences based on the returns derived from the alternative crop, wheat; and (3) the farm-gate breakeven price of switchgrass is estimated from the social planner perspective valuing the environmental consequences. The schematic diagram in figure III-1 represents the integrated framework of the economic and environmental model.

Study Region and Data Requirement

This study examined switchgrass production in counties surrounding proposed potential biorefinery to be located near Okemah in Okfuskee County, Oklahoma. This plant is assumed to have an annual switchgrass feedstock requirement of 700,000 Mg. Models in chapter II, determined the location and land classes where land would optimally be leased: Coal (class II), Creek (class (I, II, III), Haskell (class I), Hughes (class I,II, III), Johnston (class I), Latimer (class II), Lincoln (class I, II), McIntosh (class I, II, III), Muskogee (class III), Okfuskee (class I, II, III), Oklahoma (class I, II), Okmulgee (class I, II, III), Pittsburg (class I, II, III), Pottawatomie (class I), Seminole (I, II, III), and Wagoner (class I, III). Therefore in this study, the farm-gate breakeven price of switchgrass with and without valuing the selected environmental consequences would be estimated for the identified counties and land classes (Figure III-2).

Data were obtained from several sources. Historical weather information was obtained from NOAA and Mesonet (2011). Soil information for each land class (I, II, and III) of each county was obtained from USDA, NRCS SSURGO soil database (2011). Table III-1 shows the Universal Soil Loss Equation (USLE) related attributes for each land class of each county (USDA-NRCS 2007). Production costs of switchgrass were obtained from table II-1 of chapter II, while cost of wheat production was taken from the Oklahoma State University (OSU), Agricultural Economics Enterprise Budget (2012) information (Table III-2). The price of wheat (in Mg) was obtained from the FAPRI baseline model (2012). The sources of the values of environmental outcomes were listed in table III-3.

Methodology

This study has three parts. In the first part, the EPIC model was used to simulate the biophysical plant growth process to obtain the expected yield, the amount of soil erosion, the effect of the soil erosion on crop yields, the amount of nitrogen lost through percolation, surface runoff and with sediment, the amount of phosphorous in surface runoff and with sedimentation, and changes in SOC for each class or soil type. In the second part budgeting was used to estimate the producers' profit from wheat production. The profit from wheat production was then used as the opportunity cost of land in switchgrass production. Net returns earned above the current wheat production plus fixed and variable costs associated with switchgrass production divided by the switchgrass yield gives the breakeven price. In the last section, the monetized value of the selected environmental variables was added to the private owner values considered in part two. An economic value was assigned to estimates of (a) off-site damage cost due to soil erosion, (b) nitrogen loss due to erosion, (c) phosphorous loss due to erosion, and (d) changes in the quantity of soil organic carbon. Comparing these two prices, the selected environmental consequences to the surrounding counties and land class types of the proposed biorefinery are estimated.

EPIC Model Yield Validation

The expected yields and the environmental outcomes including soil loss, nitrogen and phosphorous loss, and changes in SOC for wheat and switchgrass production is simulated using the Environmental Policy Integrated Climate (EPIC) model (Williams, Jones, and Dyke, 1984). However, prior to simulation the model was calibrated and validated. The detailed steps associated with the calibration and validation of switchgrass were explained in chapter II.

Wheat yields, using the daily weather at the experimental locations of Apache (2010-12), Kildare (2008-12), Homestead (2008-2011), and El Reno (2007-09) was simulated in EPIC and compared to experimental field trial data obtained from respective OSU experiment sites (2012). Calibration and validation of no-till grain only wheat yields were performed for each of the four different soil types. The Hollister silt loam, Tabler silt loam, Canadian fine sandy loam, and Pond creek silt loam were the respective soils on which the field experiments at Apache, Kildare, Homestead, and El Reno were conducted. Soil related information for these land types including bulk density, water, sand and silt content, organic carbon concentration, calcium carbonate content, saturated conductivity and cation exchange capacity were obtained from the SSURGO land database (2011). Daily weather values of maximum temperature, minimum temperature, precipitation, solar radiation, relative humidity and wind speed for each location were obtained from MESONET (2012). The management plan in the simulation (similar to that used in the field experiments that produced the empirical data), included planting in October and harvesting in June, and applying 47 kg/ha of ammonium polyphosphate solution (10-34-0) along with 57 kg/ha of urea (46-0-0) before planting was used in EPIC. The calibration and validation results for no-till grain only wheat yields are shown in Table III-4, Table III-5, and Figure III-3 respectively.

EPIC Model Soil Erosion Validation

Soil erosion may be estimated by the Universal Soil Loss Equation (USLE). The USLE (Wischmeier and Smith, 1978) equation is expressed as:

$$A=R*K*LS*C*P \qquad (4)$$

where, A represents average annual soil loss (tons per acre); R represents the potential of the rain in a particular area to produce erosion; K is the erodibility factor; LS represents the combined effect of slope length (L) and steepness (S); C represents the type of tillage and cropping system used; and P represents the reduction in erosion from the support practice factor including contour farming, cross-slope farming, buffer strips, strip cropping, and terraces.

In this study, site-specific annual soil loss is estimated based on the USLE equation and used to validate the EPIC simulated site-specific soil losses. Table III-1, includes the K and LS values used in this estimation. Based on the geographic location of the study region, an R-factor of 180 obtained from Cooper (2011) is used. The erodibility factor of each site-specific land class type (K) is obtained from the SURGO soil database

(2011). The LS factor is obtained based on the slope length (Storm et al., 1996) and the soil steepness gradient (%) from the LS table published by the Institute of Water Research, Michigan State University (2002). A *C* factor of 0.05 for no-till operation is obtained from the soil conservation manual published through the Agronomy Department of Purdue University (Franzmeier, and Steinhardt, 2009). The *P* factor is considered to be 1.0 assuming no special practices including contour farming are used (Franzmeier, and Steinhardt, 2009). Based on this information, an annual soil loss estimate was derived for no-till wheat production using the USLE equation for each county and each land class or soil type (Table III-1). Soil loss for no-till switchgrass production is estimated by revising the C-factor to 0.005 (Schwartz et al., 2012, Table III-1). The erodibility index (*EI*) based on the field office technical guide of NRCS, USDA, (1996) is estimated by dividing erodibility (*R***K***LS*) by the soil loss tolerance (*T*) and is expressed as:

$$EI = \frac{R*K*LS}{T} \qquad (5)$$

Soil loss derived for both no-till wheat and switchgrass production for each county and each soil type is simulated in EPIC based on the site-specific soil slope length and soil slope gradient information and validated against the estimated site-specific soil loss (Table III-6, Table III-7, Figure III-4, and Figure III-5).

EPIC Model Simulation

After the yields and the soil loss for both no-till wheat and switchgrass production are calibrated and validated, the calibrated models were used to simulate wheat and switchgrass yields and environmental outcomes based on 50 years of daily weather information. Each year’s data was considered as a state of nature. The EPIC simulation for switchgrass was performed with the assumption that wheat production land was converted to switchgrass production and on every tenth year switchgrass was replanted. Ten different 50 year random weather scenarios were generated based on a unique random number generator seed used in the EPIC control table (EPIC CONT) for each location. Each of these random weather scenarios was used to simulate a 50-year yield distribution along with the environmental outcomes derived from wheat and switchgrass production in each county and each land class type. After each of these 10 random distributions of wheat and switchgrass yields and environmental outcomes are simulated for each county and each land class, all the 10 observations for each of the 50 states of nature are averaged to estimate the expected switchgrass and wheat yields and environmental outcomes (soil loss, nitrogen loss, phosphorous loss, and changes in SOC) for each county and each land class type.

Economic Model

The farm-gate breakeven price of switchgrass is estimated based on the returns from the best alternative crop, which is wheat production. Site-specific enterprise budgets based on the detailed field operations for both crops were prepared for each county and each land class (Table II-1 and Table III-2). The foregone profit from the best alternative use, wheat production, was considered as the opportunity cost of the land for each land class (I, II, and III) and for each county. However, the rental rate above the net returns derived from wheat production would be paid (Fewell, Bergtold, and Williams, 2011) in order to encourage landowners to produce switchgrass. Therefore, in this study it is assumed that an additional extrapolated USDA (2011) cropland rental rate above the opportunity costs of the land derived from the forgone wheat production would be paid to the landowners/ farmers. Since the switchgrass and wheat production costs were not inflated, a real rate of interest was used as the discount rate with the assumption that all prices will change as per as the general inflation rate (Campbell and Brown, 2009). In the U.S., the average real rate of interest over the last 15 years was 4% (World Bank, 2012). Therefore, a discount rate of 4% was used in this study.

The farm-gate breakeven price of switchgrass to the profit maximizing landowner is the price of switchgrass that would at least ensure the landowner the equivalent return from the existing best alternative wheat production on the land. The net present value derived from wheat production in each county and in each soil type from the profit maximizing landowners' perspective is estimated using the following equation:

$$E(NPVP_{w,c,s}) = \sum_{i=1}^{n} \left(\frac{p_{i,w} E(Y_{i,w,c,s}) - VC_{i,w,c,s}}{(1+r)^i} \right) \tag{6}$$

where E($NPVP_{w,c,s}$) is the expected private profit maximizing land owners' net present value derived from wheat production for county c and land class type s; $P_{i,w}$ is the price of wheat w in year i; $E(Y_{i,w,c,s})$ is the expected wheat yield w for the i^{th} year and for county c and land class type s; $VC_{i,w,c,s}$ is the entire production cost including the establishment costs, fertilizer costs, and harvesting costs of wheat production w in i^{th} year for county c and land class type s; and r is the market discount rate.

The net present value derived from wheat production in each county and in each soil type from the social planners' perspective is estimated using the following equation:

$$E(NPVS_{w,c,s}) = \sum_{i=1}^{n} \left(\frac{p_{i,w} E(Y_{i,w,c,s}) - VC_{i,w,c,s} - \alpha N_{i,w,c,s} - \lambda SL_{i,w,c,s} - \beta P_{i,w,c,s}}{(1+r)^i} \right) \tag{7}$$

where E($NPVS_{w,c,s}$) is the expected social planners' net present value derived from wheat production *w* for county *c* and land class type *s*; the additional terms $N_{i,w,c,s}$ and $P_{i,w,c,s}$ are the quantity of nitrogen and phosphorous runoff in kg/ha derived from wheat production for the i^{th} year and for county *c* and land class type *s*; $SL_{i,w,c,s}$ is the quantity of soil loss in Mg/ha derived from wheat production for the i^{th} year and for county *c* and land class type *s*; α, β are the abatement costs of nitrogen and phosphorous runoff respectively; and λ is the damage costs associated with the soil loss.

The net present value derived from switchgrass production in each county and in each soil type from the profit maximizing landowners' perspective is estimated using the following equation:

$$E(NPVP_{g,c,s}) = \sum_{i=1}^{n} \left(\frac{BEP_{g,c,s} E(Y_{i,g,c,s}) - VC_{i,g,c,s} - LC_{c,s}}{(1+r)^i} \right) \tag{8}$$

where E($NPVP_{g,c,s}$) is the expected private profit maximizing land owners' net present value derived from wheat production for county *c* and land class type *s*; $BEP_{g,c,s}$ is the private profit maximizing land owners' farm-gate breakeven price of switchgrass *g* for county *c* and land class type *s*; $E(Y_{i,g,c,s})$ is the expected wheat yield *w* for the i^{th} year and for county *c* and land class type *s*; $VC_{i,g,c,s}$ is the entire production cost including the establishment costs, fertilizer costs, and harvesting costs of wheat production *w* in i^{th} year for county *c* and land class type *s*; $LC_{c,s}$.is the extrapolated USDA (2011) cropland rental rate for county *c* and land class type *s.*

The net present value derived from switchgrass production in each county and in each soil type from the social planners' perspective is estimated using the following equation:

$$E(NPVS_{g,c,s}) = \sum_{i=1}^{n} \left(\frac{BES_{g,c,s} E(Y_{i,g,c,s}) - VC_{i,g,c,s} - LC_{c,s} - \alpha N_{i,g,c,s} - \beta P_{i,g,c,s} - \lambda SL_{i,g,c,s} + \delta C_{i,g,c,s}}{(1+r)^i} \right) \quad (9)$$

where $E(NPVS_{g,c,s})$ is the expected social planners' net present value derived from switchgrass production for county *c* and land class type *s*; $BES_{g,c,s}$ is the social planners' farm-gate breakeven price of switchgrass *g* for county *c* and land class type *s*; $SL_{i,g,c,s}$ is the quantity of soil loss in Mg/ha derived from switchgrass production for the i^{th} year and for county *c* and land class type *s*; $C_{i,g,c,s}$ is the changes in the quantity of soil organic carbon Mg/ha derived from switchgrass production for the i^{th} year and for county *c* and land class type *s*; λ is the damage costs associated with the soil loss; δ is the assumed carbon credit given to the landowner/ farmer for sequestering carbon by producing switchgrass; and other variables are previously defined.

The landowner/farmer would be indifferent between producing either wheat or switchgrass only when the net present value derived from producing wheat would be identical to the net present value derived from producing switchgrass. Therefore, farm-gate breakeven price of switchgrass derived from private profit maximizing land owners' perspective is estimated by equating equation 6 and equation 8, and solving for $BEP_{g,c,s}$, and farm-gate breakeven price of switchgrass derived from social planners' perspective is estimated by equating equation 7 and equation 9, and solving for $BES_{g,c,s}$ respectively.

Environmental Analysis

The environmental analysis portion of this study deals with determining the differences in soil erosion, nitrogen and phosphorous runoff, and the changes in soil organic carbon that would occur from converting traditional wheat production land into energy crop (switchgrass) production. The EPIC model was used to simulate site-specific

50 states of nature distribution of environmental outcomes including nitrogen loss, phosphorous loss, off-site soil erosion and changes in SOC derived from switchgrass and wheat production for each of the ten different random weather scenerios for each location. Site-specific simulated expected environmental outcomes were then estimated for each county and each land class type surrounding the proposed hypothetical biorefinery location (mentioned in chapter II).

Now the most crucial part of this study is to estimate the societal benefits derived from the changes in the selected environmental outcomes derived from converting wheat production land into switchgrass production. Each of the environmental outcomes including soil loss, fertilizer runoff, and soil organic carbon loss would certainly cause environmental damages to the surrounding watershed and to the atmospheric carbon cycle. Therefore, these environmental outcomes have associated with some damage costs including both monetary costs and non-monetary costs such as loss in recreational values. On the other hand, in order to reduce the environmental damages, the government or the private individual could incur certain treatment costs. The optimal level of abatement occurs where the sum of the treatment and damage costs are minimum, that is, where the marginal damage costs equal marginal treatment costs.

Several previous studies have estimated the costs associated with the removal of agricultural runoff including nitrogen and phosphorous; and the off-site damage costs of soil erosion. Gerlach and DeSimone (2005) estimated the abatement costs of nitrogen in Maryland using enhanced nutrient technique and found the abatement was $13 kg/ha, Zivojinovich (2010) suggested that in case nitrogen is removed using the algal turf scrubber in Florida then the abatement costs was $55 kg/ha. Ribaudo et al. (2010) did a study for the entire United States and estimated the abatement costs of nitrogen of $6.37 using wetland restoration; Rabotyagov et al. (2010) focused their study on the upper Mississipi River basin, the major contributor of nutrients to the Gulf of Mexico hypoxic zone, estimated that in order to reduce the nitrogen loading by 30%, the abatement costs of $6.67 needs to be incurred through nutrient's reductions including nitrogen from agricultural fields.

Similarly, non-point sources phosphorous removals were estimated in several existing literature including Johansson and Randell (2003), Johansson et al. (2004), Keplinger et al. (2003). In another study, Ancev et al. (2006) estimated the shadow price where marginal phosphorous abatement costs and marginal damage costs from phosphorous pollution for the Eucha-Spavinaw, Oklahoma is equal, ranges from $14.16 to $70.17 kg/ha under different scenarios. In fact, visitors may be willing to pay more than the opportunity or abatement costs incurred in phosphorous runoffs (Roberts, Boyer, and Lusk, 2008). Off-site soil damage costs including the non-monetary recreational values were estimated in several previous studies (Pimentel et al., 1995; Ribaudo, 1986; and Huszer and Piper, 1986).

In this study, the cost of nitrogen abatement is assumed to be $6.37 per kg; phosphorous abatement costs is assumed at $25.83 per kg; and off-site damage costs of soil erosion is assumed at $3.15 per Mg (all these values are inflated by 2012 CPI, 2012). According to Bloomberg new energy finance (Doan, 2012), the carbon credits are auctioned between the ranges of $12 to $15 per Mg by California Air Resources Board; therefore, the value of carbon credit was assumed to be $15 per Mg of SOC for this study.

Each of the environmental outcomes was then multiplied by the abatement /damage costs of that particular environmental consequence. After the environmental consequences of switchgrass and wheat production were valued, then the budgeting technique was used to estimate the site-specific expected internal plus selected external returns and costs derived from switchgrass and wheat production over the 50 states of nature. Equating equation 7 and equation 9, and solving for $BES_{g,c,s}$ the site-specific farm-gate breakeven price of switchgrass was estimated for the social planners' perspective (on-farm plus selected environmental consequences).

Results

The EPIC model predicts that there will be a significant reduction in nitrogen loss, phosphorous loss and soil loss if no-till wheat production is replaced by switchgrass production. The site-specific reduction in nitrogen loss in average year ranges from 23.51 kg/ha at Hughes land class I to 68.54 kg/ha at Hughes land class III, the reduction in soil loss ranges from 0.40 Mg /ha on land class II in Lincoln County to 2.71 Mg /ha in Hughes County on lass III, and the reduction in phosphorous loss ranges from 0.02 kg/ha on land class II in Latimer County to 1.89 kg/ha in McIntosh County on land class III derived from replacing no-till wheat production with switchgrass production (Table III-8). These results confirm that potential for reducing soil, nitrogen, and phosphorus runoff when converting from no-till wheat to switchgrass is greater on land, which is more prone to erosion.

Beyond reducing the runoff, the production of switchgrass can also sequester more SOC, in an average year the site-specific SOC accumulation ranges from 122.10 kg/ha on land class III in Hughes County to 531.41 kg/ha also in Hughes County on land class I (Table III-8). However, the changes in SOC are greater on land class I compared to land class II and III, which increase with the plant biomass. The average reduction in soil loss, reduction in nitrogen loss, reduction in phosphorous loss, derived from switchgrass production on land class I is lower compared to the reduction in soil, nitrogen and phosphorous losses on land class II and III (Figure III-6). Land class III with slope gradient of 4% in Hughes County, McIntosh County, and Pittsburg County (Table-III-1) have the greatest environmental benefits derived from replacing no-till wheat production with switchgrass production. On the other hand, switchgrass produced on land class I sequesters more carbon than that produced on land class II and class III (Figure III-6). Therefore, converting land class III from wheat to switchgrass production is associated with greater reduction in runoff and thus more beneficial from the societal perspective compared to converting class I, and class II land.

The site-specific farm-gate breakeven price of switchgrass derived from the profit maximizing private landowner's (internal returns and cost) perspective ranges from $37 per Mg (Pottawatomie County land class I) to $66 per Mg (Johnston County land class I) (Table III-9). Switchgrass produced on land class III of each county has higher farm-gate breakeven price compare to the switchgrass produced on land class I and land class II, due to lower yields. However, when the selected environmental consequences are valued and considered (on-farm plus environmental benefits) in the estimation of the site-specific farm-gate breakeven price of switchgrass then the breakeven price reduces and ranges from $11 per Mg (Hughes County land class III) to $39 per Mg (Johnston County land class I). The average farm-gate breakeven price of switchgrass derived from private landowners' perspective increases as the average yields decrease from good quality soil to lower quality soil. However, when selected environmental outcomes are valued then the average farm-gate breakeven price of switchgrass decreases from good quality soil to lower quality soil. The selected environmental benefits derived from converting from wheat to switchgrass production on lower quality soil offsets the revenue loss due to lower yields on the lower quality soil.

Replacing no-till wheat production in Hughes County on land class III has the greatest reduction in runoff and at the same time has the lowest SOC accumulation (Table III-8). However, the benefits derived reducing runoff exceeded the benefits derived from lower accumulation of SOC in Hughes County land class III compared to land class I and land class II of the same county, resulting in the lowest farm-gate breakeven price of switchgrass in Hughes County land class III. As mentioned earlier, land class III of Hughes County, McIntosh County land class III and Pittsburg County land class III with slope gradient of 4% has the highest reduction of runoffs derived from replacing no-till wheat production by switchgrass production, also has the lowest farm-gate breakeven price of switchgrass $11 /Mg, $13 /Mg, and $13 /Mg, respectively (Table III-9) from the societal perspective. The changes in SOC is highest in land class I compared to land class II and III (Figure III-6) which increase with the plant biomass

The difference between the farm-gate breakeven prices of switchgrass derived from the private profit maximizing landowner's (internal returns and cost) perspective and derived from the societal (on-farm plus selected environmental benefits) perspective (Table III-9) range from $13 per Mg at Latimer County land class I to $46 per Mg at Pittsburg County land class III. As expected these differences are highest for land class III of Hughes County, McIntosh County land class III and Pittsburg County land class III.

When multiplied with the average yields of 11 Mg/ha, the environmental benefits derived from replacing no-till wheat to switchgrass on those erodible land would be on an average $495 /ha per year. The environmental benefits derived from leasing land for switchgrass production is estimated by multiplying these differences with the average yields per hectares and the hectares of land leased for each land class and in each county (Table III-9). The environmental benefit ranges from $5,652 for 14 ha of McIntosh County land class I to $3.47 million of Hughes County's 6,368 ha of land class III. In an average year, around $26 million environmental benefits could be derived to the society with the assumption that no more than 10% of the cropland converted from the production of no-till wheat to switchgrass on 65,382 ha used to produce feedstock for a biorefinery that required 700,000 Mg/year. On average, land class III has the highest environmental benefits (Figure III-7). Therefore, converting the most erodible land from wheat to the production of switchgrass has the greatest potential environmental benefits. Therefore, any public policies designed to incentivize feedstock production might best serve the interest of society by including land quality considerations.

A sensitivity analysis of the site-specific breakeven price of switchgrass is also performed (Table III-10). It is found that none of the results significantly change when (a) the discount rate is increased from 4% to 8%; (b) when the expected wheat price is doubled; (c) when the land rental values are doubled. Farm-gate breakeven price of switchgrass derived from the profit maximizing landowner perspective are higher than the farm-gate breakeven price of switchgrass derived from the societal perspective under all scenarios. In all scenarios, the difference between the farm-gate breakeven prices derived from private profit maximizing landowner perspective and societal perspective is greatest for the land class or soil type III, suggesting that more benefits would accrue to society from the conversion of the most erodible wheat production land into switchgrass production.

The farm-gate breakeven price of switchgrass derived from only internal costs is greater than the farm-gate breakeven price of switchgrass derived from on-farm plus environmental benefits. Converting land from no-till wheat production to switchgrass production would reduce nitrogen loss, phosphorous loss, and soil loss and increase soil organic carbon.

Conclusion and Discussion

This study finds that compared to no-till wheat production, perennial energy crop (switchgrass) production has the potential to reduce nitrogen and phosphorous runoff, reduce soil loss, and increase sequestration of SOC. This study finds that switchgrass production has environmental benefits over no-till wheat production. The economic differences in the environmental benefits between switchgrass production and no-till wheat production were determined by placing monetary values on the environmental benefits which included nitrogen loss, phosphorous loss, soil loss and changes in SOC. Valuing environmental benefits derived from switchgrass production reduces the site-specific farm-gate breakeven price of switchgrass. The difference between the farm-gate breakeven prices of switchgrass derived from the private profit maximizing landowner's (internal returns and cost) perspective and derived from the societal (on-farm plus selected environmental benefits) perspective has been highest at $46 per Mg at Pittsburg County land class III and lowest at $13 per Mg at Latimer County land class I. Switchgrass production results in relatively greater environmental benefits when it is used to replace wheat grown on the most highly erodible land (land class III). These differences in environmental consequences and potential benefits to society should be considered if public policies are used to incentivize switchgrass production. The sites with the slope gradient of 4% within the study area (Hughes County land class III, McIntosh County land class III and Pittsburg County land class III) have an average annual environmental benefit of $495/ ha derived for reducing the agricultural runoff by converting no-till wheat production into switchgrass production. Therefore, the policy maker may bid the erodible land form the existing no-till wheat production for switchgrass production with initializing a program similar to that of the conservation reserve program.

By public policy, land included in the CRP is required to have an erodibility index equal to or greater than eight (USDA-FSA, 2012). According to the estimated erodibility index using equation 2, Hughes County land class III, McIntosh County land class III, and Pittsburg County land class III would qualify for inclusion in the CRP. Interestingly, results show that when environmental benefits are considered the farm-gate breakeven price of switchgrass is lowest in those counties.

Accounting for the potential of planting wheat on some other land to offset the wheat production from the land converted to switchgrass further complicates the problem. The worldwide adjustment in land use in response to the conversion of the marginal land from its pre-switchgrass activity needs to be considered. Therefore, additional work will be required to consider the indirect land use issue.

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Table III-1. Site-specific USLE attributes and the estimated soil loss.

County LC	Slope (%)	Hydrologic group	Tolerance Factor (T)	Erodibility Factor (K)	Slope Length (m)	LS[§]	A* Wheat (Mg/ha)	A* Switchgrass (Mg/ha)
CREK LC-I	0.5	C	5	0.43	182.4	0.1	0.87	0.09
HASK LC-I	1	B	5	0.43	182.4	0.19	1.65	0.16
HUGH LC-I	1	B	5	0.37	182.4	0.19	1.42	0.14
JOHN LC-I	0.5	B	5	0.37	182.4	0.1	0.75	0.07
LINC LC-I	0.5	C	5	0.43	182.4	0.1	0.87	0.09
McIN LC-I	0.5	B	5	0.37	182.4	0.1	0.75	0.07
OKFU LC-I	0.5	C	5	0.43	182.4	0.1	0.87	0.09
OKLA LC-I	0.5	B	5	0.32	182.4	0.1	0.65	0.06
OKMU LC-I	1	B	5	0.37	182.4	0.19	1.42	0.14
PITS LC-I	1	B	5	0.37	182.4	0.19	1.42	0.14
POTT LC-I	0.5	C	5	0.43	182.4	0.1	0.87	0.09
SEMI LC-I	0.5	C	5	0.43	182.4	0.1	0.87	0.09
WAGN LC-I	1	B	5	0.32	182.4	0.19	1.23	0.12
COAL LC-II	2	B	5	0.37	152	0.39	2.91	0.29
CREK LC-II	2	B	5	0.32	152	0.39	2.52	0.25
HUGH LC-II	2	B	5	0.32	152	0.39	2.52	0.25
LATI LC-II	1	B	5	0.37	182.4	0.19	1.42	0.14
LINC LC-II	0.5	B	5	0.2	182.4	0.1	0.40	0.04
McIN LC-II	2	B	5	0.43	152	0.39	3.38	0.34
OKFU LC-II	0.5	B	5	0.32	182.4	0.1	0.65	0.06
OKLA LC-II	0.5	C	5	0.43	182.4	0.1	0.87	0.09
OKMU LC-II	2	B	5	0.37	152	0.39	2.91	0.29
PITS LC-II	2	C	5	0.43	152	0.39	3.38	0.34
SEMI LC-II	0.5	C	5	0.43	182.4	0.1	0.87	0.09
CREK LC-III	2.5	C	3	0.24	152	0.55	2.66	0.27
HUGH LC-III	4	C	5	0.43	121.6	0.86	7.46	0.75
McIN LC-III	4	B	3	0.28	152	0.86	4.85	0.49
MUSK LC-III	2	C	4	0.43	121.6	0.39	3.38	0.34
OKFU LC-III	0.5	B	5	0.20	182.4	0.1	0.40	0.04
OKMU LC-III	1	B	3	0.32	182.4	0.19	1.23	0.12
PITS LC-III	4	B	5	0.32	121.6	0.86	5.55	0.55
SEMI LC-III	2	B	3	0.24	152	0.39	1.89	0.19
WAGN LC-III	1	C	4	0.43	182.4	0.19	1.65	0.16

Source: USDA-NRCS SURGO soil database (2011).

[§] LS is the length-slope coefficient, *A is the soil erosion, A=R*K*LS*C*P

Table III-2. Estimated annual production and harvesting costs of wheat.

Item	Unit	Quantity	Price Unit	Cost
			$	$/ha
Seed	kg/ha	62	0.60	37
Fertilizer				
Nitrogen	kg/ha	62	1.23	76.26
Phosphorous	kg/ha	24	1.32	31.68
Pesticide				
Roundup ultra	l/ha	3.52	5.4	19.0
Maverick	l/ha	20.7	567.5	27.4
Insecticide				
Dimethoate	l/ha	0.88	12.47	10.94
Insurance	ha	1	17.28	17.28
Operating capital	$	6.50%	203.65	13.23
Spraying	ha	4	13.46	53.84
Dry fertilizer spreader	ha	1	10.42	10.42
No-till drill	ha	1	32.65	32.65
Combine	ha	1	52.91	52.91
Total costs				382.61

Source: OSU Enterprise Budget Software (2012)

Table III-3. Estimated costs of nitrogen, phosphorous abatement, off-site soil damage costs

Nitrogen abatement costs	Year	Location	Method	Costs ($/kg)
Zivojnovich	2010	Florida	Algal Turf Scrubber	$55.00
Gerlach, and DeSimone	2005	Maryland	Enhanced Nutrient Removal	$13.00
Ribaudo et al.	2010	USA	Wetlands Restoring	$6.37
Rabotyagov et al.	2010	Upper Mississipi river basin	Control of Nitrogen use in agricultural sector	$6.67
Phosphorous abatement costs				
Johansson, and Randall	2003	USA	Phosphorous Index Efficient Targeting	$20.63
Keplinger et al.	2003	Texas	TMDL	$31.00
Johansson et al.	2004	Minnesota	Frontier Approach	$26.80
Ancev et al.	2006	Oklahoma	Shadow price of marginal demage costs	$38.37
Off-site soil damage costs				
Pimental et al.	1995	USA		$2.94
Ribaudo	1986	US Southern Plains		$1.60
Huszer and Piper	1986	New Mexico		$1.45

Table III-4. Measured and simulated no-tillage grain only wheat yields.

	Measured Yields	Simulated Yields
Mean (Mg ha^{-1})	2.70	2.65
St. Dev.	0.96	0.70
Maximum (Mg ha^{-1})	4.71	4.18
Minimum (Mg ha^{-1})	1.35	1.59

Table III-5. EPIC model wheat yields validation results.

Mean absolute percentage error (MAPE)	24.46%
Coefficient of determination (R^2)	0.64
Relative Error (Rel. Error)	0.02

Table III-6. Estimated and simulated soil loss derived from no-till grain-only wheat production.

	Wheat		Switchgrass	
	USLE Estimated Soil Loss	EPIC Simulated Soil Loss	USLE Estimated Soil Loss	EPIC Simulated Soil Loss
Mean (Mg ha^{-1})	1.99	1.77	0.20	0.14
St. Dev.	1.62	1.23	0.16	0.10
Maximum (Mg ha^{-1})	7.46	5.81	0.75	0.51
Minimum (Mg ha^{-1})	0.42	0.40	0.04	0.02

Table III-7. EPIC model soil loss validation results.

	Wheat	Switchgrass
Mean absolute percentage error (MAPE)	34%	39%
Coefficient of determination (R^2)	0.83	0.88
Relative Error (Rel. Error)	0.10	0.27

Table III-8. Site-specific soil loss, nitrogen loss, phosphorous loss, reduction and changes in soil organic carbon (SOC) derived from replacing no-till wheat production with switchgrass production.

County Land Class (LC)	Slope (%)	Soil loss Reduction (Mg ha^{-1} yr^{-1})	Nitrogen loss Reduction (kg ha^{-1} yr^{-1})	Phosphorous loss Reduction (kg $ha^{-1}$$yr^{-1}$)	Changes in SOC (kg ha^{-1} yr^{-1})
Creek LC-I	0.5	1.4	43.6	0.8	158.2
Haskell LC-I	1	1.3	46.4	0.9	390.9
Hughes LC-I	1	0.8	23.5	1.3	531.4
Johnston LC-I	0.5	1.3	38.3	1.0	367.3
Lincoln LC-I	0.5	0.8	33.7	0.7	231.7
McIntosh LC-I	0.5	1.4	41.0	0.4	524.8
Okfuskee LC-I	0.5	1.2	37.8	0.7	156.0
Oklahoma LC-I	0.5	0.4	33.6	0.4	412.3
Okmulgee LC-I	1	1.2	31.4	1.2	467.8
Pittsburg LC-I	1	1.2	34.0	0.4	419.4
Pottawatomie LC-I	0.5	1.1	33.4	0.9	395.1
Seminole LC-I	0.5	2.0	41.0	1.3	241.2
Wagoner LC-I	1	0.8	29.1	0.7	157.8
Coal LC-II	2	2.0	39.8	0.9	302.4
Creek LC-II	2	1.2	43.6	1.0	151.9
Hughes LC-II	2	1.0	36.0	1.3	261.0
Latimer LC-II	1	0.5	25.7	0.0	294.5
Lincoln LC-II	0.5	0.4	25.1	0.6	336.6
McIntosh LC-II	2	3.0	59.5	1.4	404.8
Okfuskee LC-II	0.5	0.6	25.9	0.1	319.9
Oklahoma LC-II	0.5	0.9	44.4	0.7	309.6
Okmulgee LC-II	2	1.7	52.4	1.2	326.4
Pittsburg LC-II	2	2.3	47.7	0.7	209.0
Seminole LC-II	0.5	0.9	41.0	1.3	241.2
Creek LC-III	2.5	3.0	52.2	1.4	210.8
Hughes LC-III	4	5.5	68.5	1.3	122.1
McIntosh LC-III	4	3.4	66.0	1.9	290.2
Muskogee LC-III	2	3.3	29.1	0.7	194.2
Okfuskee LC-III	0.5	0.5	25.9	0.1	279.9
Okmulgee LC-III	1	1.5	31.1	0.5	432.9
Pittsburg LC-III	4	3.7	63.2	1.5	154.1
Seminole LC-III	2	1.9	55.2	1.5	135.9
Wagoner LC-III	1	1.3	56.2	1.1	137.8

Table III-9. Site-specific farm-gate breakeven price of switchgrass with (social) and without (private) valuing the environmental outcomes, the differences between them, hectares of land leased in each land class and each county, and the corresponding environmental benefits

County Land Class (LC)	Slope (%)	Private (/Mg)	Social (/Mg)	Diff. (/Mg)	Land (ha)	Env. Benefit
Creek LC-I	0.5	$48	$25	$23	1,337	$470,180
Haskell LC-I	1	$53	$28	$24	65	$28,472
Hughes LC-I	1	$49	$30	$19	329	$99,123
Johnston LC-I	0.5	$66	$39	$27	107	$51,403
Lincoln LC-I	0.5	$53	$36	$18	251	$75,644
McIntosh LC-I	0.5	$51	$24	$26	14	$5,652
Okfuskee LC-I	0.5	$50	$32	$18	774	$252,815
Oklahoma LC-I	0.5	$54	$36	$19	590	$200,654
Okmulgee LC-I	1	$49	$27	$22	544	$192,701
Pittsburg LC-I	1	$53	$33	$20	142	$49,768
Pottawatomie LC-I	0.5	$37	$20	$17	669	$211,861
Seminole LC-I	0.5	$54	$32	$22	120	$44,981
Wagoner LC-I	1	$52	$34	$18	773	$252,212
Coal LC-II	2	$51	$34	$16	999	$275,298
Creek LC-II	2	$51	$16	$34	3,647	$1,422,695
Hughes LC-II	2	$50	$28	$23	2,645	$934,153
Latimer LC-II	1	$50	$37	$13	740	$163,834
Lincoln LC-II	0.5	$55	$37	$18	2,895	$815,349
McIntosh LC-II	2	$56	$18	$38	1,413	$743,870
Okfuskee LC-II	0.5	$52	$38	$15	1,057	$253,309
Oklahoma LC-II	0.5	$56	$34	$22	2,882	$1,070,551
Okmulgee LC-II	2	$52	$19	$33	3,003	$1,467,664
Pittsburg LC-II	2	$55	$32	$24	2,774	$1,065,487
Seminole LC-II	0.5	$54	$32	$22	1,329	$498,166
Creek LC-III	2.5	$56	$12	$44	3,842	$1,757,661
Hughes LC-III	4	$56	$11	$45	6,348	$3,472,148
McIntosh LC-III	4	$58	$13	$45	552	$290,040
Muskogee LC-III	2	$54	$37	$17	4,623	$1,181,251
Okfuskee LC-III	0.5	$53	$39	$14	3,154	$715,647
Okmulgee LC-III	1	$54	$30	$24	5,139	$1,773,843
Pittsburg LC-III	4	$58	$13	$46	5,938	$3,056,363
Seminole LC-III	2	$57	$26	$31	2,242	$898,225
Wagoner LC-III	1	$55	$26	$29	4,445	$2,075,663
Total						$25,866,681

Table III-10. Sensitivity analysis of the site-specific breakeven price per Mg of switchgrass.

	Land Class I	Land Class II	Land Class III
Breakeven Price Private Landowners Perspective			
Discount rates 4%	$51.47	$52.96	$55.76
Discount rate double (8%)	$53.63	$55.22	$57.86
Wheat Price double	$107.65	$111.96	$118.41
Land rent double	$55.64	$57.34	$59.92
Breakeven Price Societal Perspective			
Discount rates 4%	$30.45	$29.54	$22.87
Discount rates double (8%)	$29.91	$29.03	$22.40
Wheat Price double	$88.28	$86.59	$85.58
Land rent double	$34.58	$33.65	$27.09
Differences b/w Private Landowner and Societal Perspective Breakeven Price			
Discount rates 4%	$21.03	$23.41	$32.89
Discount rates double (8%)	$23.72	$26.19	$35.46
Price double	$19.37	$25.37	$32.83
Land rent double	$21.06	$23.69	$32.83

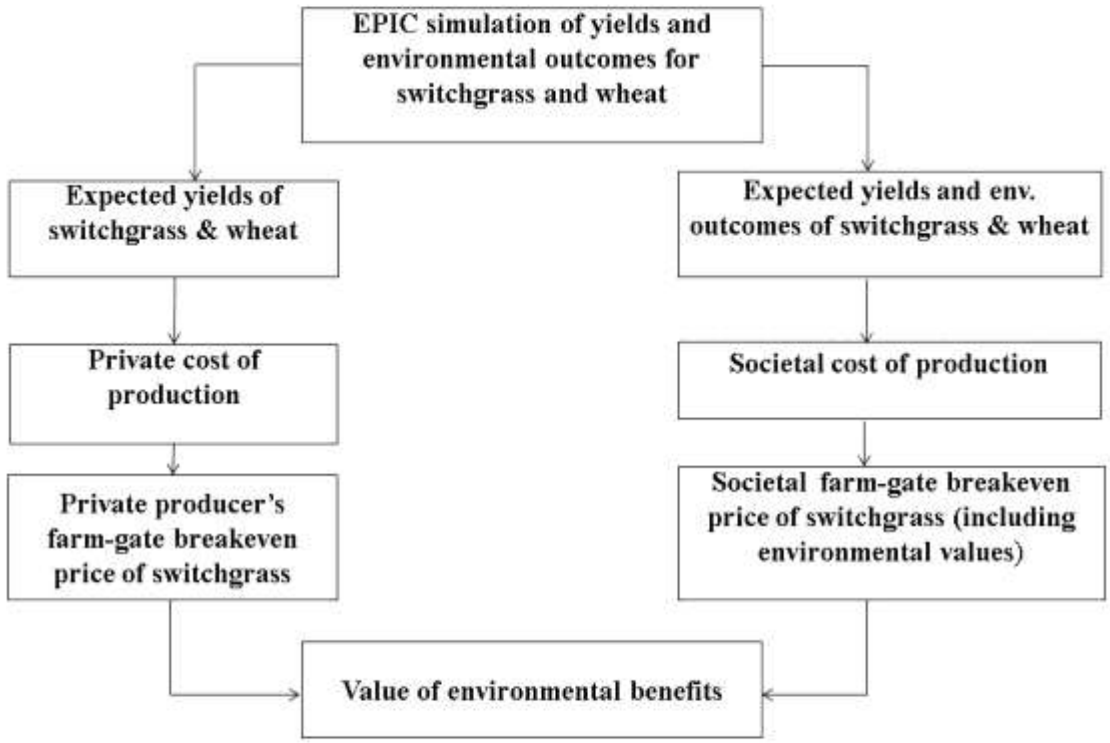

Figure III-1. Flowchart of the integrated economic and environmental model.

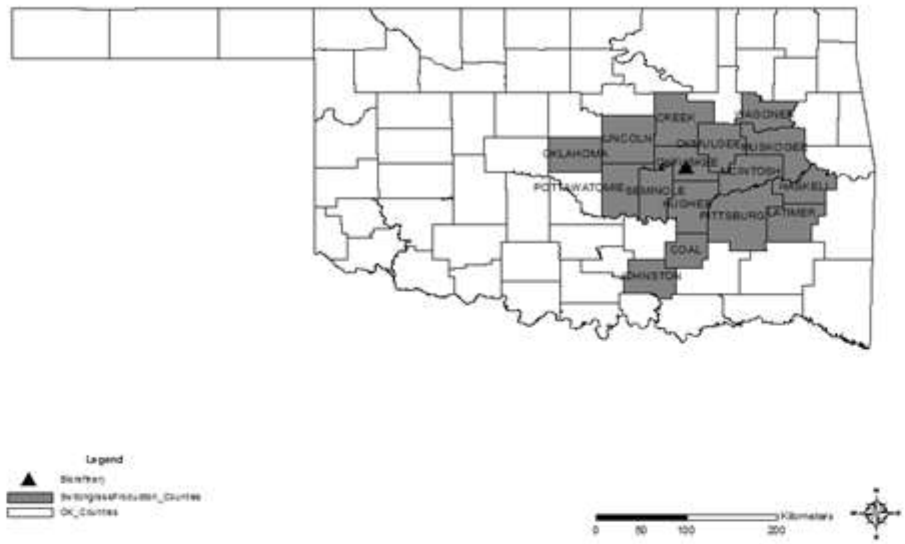

Figure III-2. Land to be converted to switchgrass to support a hypothetical biorefinery at Okemah, Oklahoma.

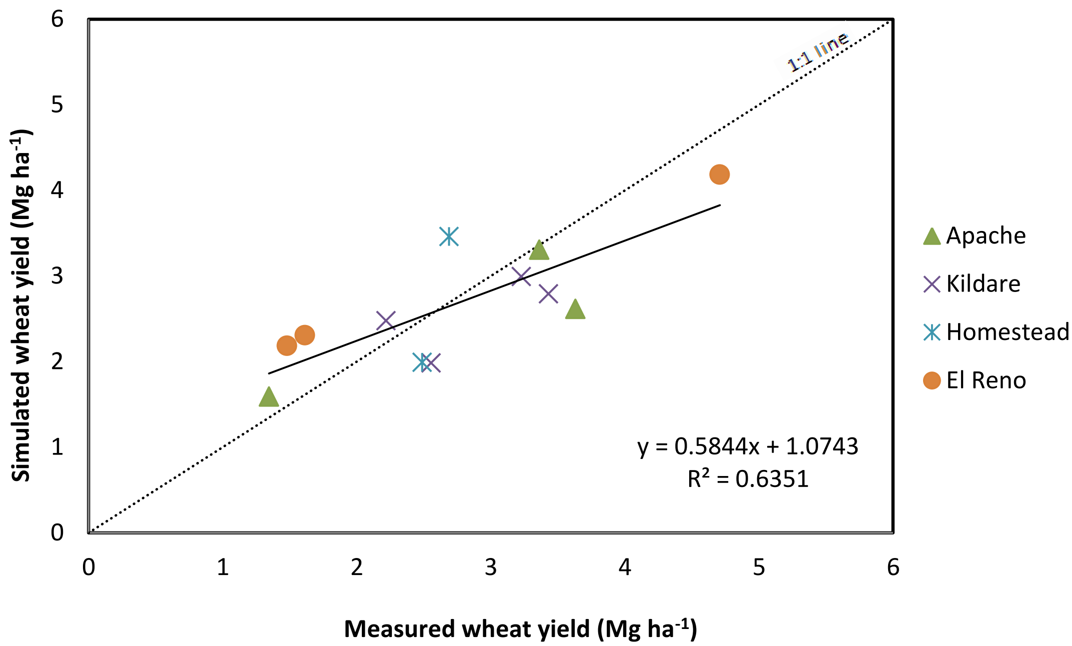

Figure III-3. Simulated and measured no-till grain-only wheat yields for four Oklahoma locations.

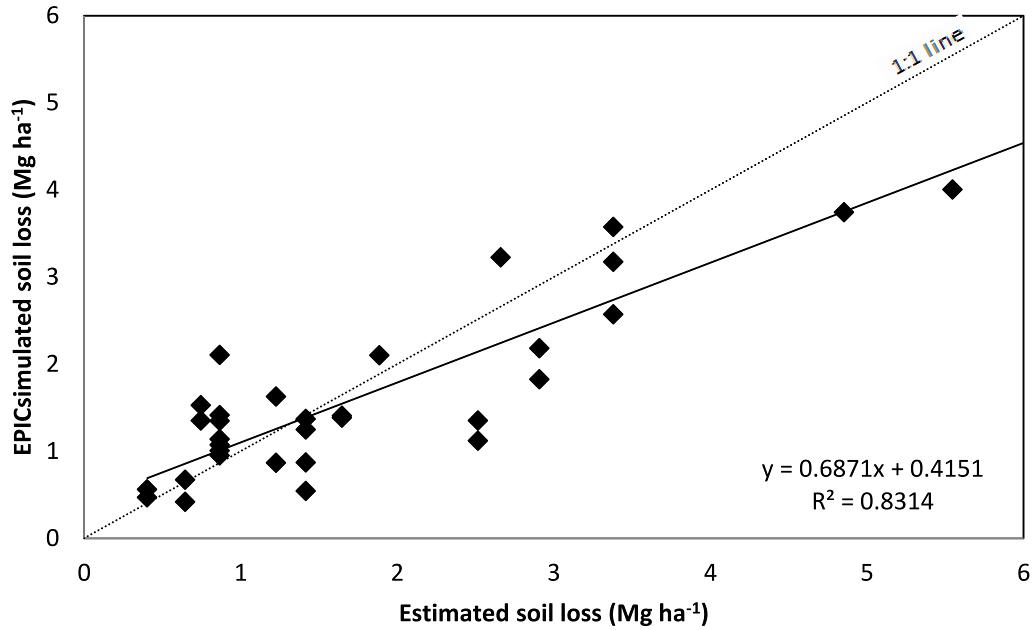

Figure III-4. Simulated and estimated soil loss derived from no-till wheat production.

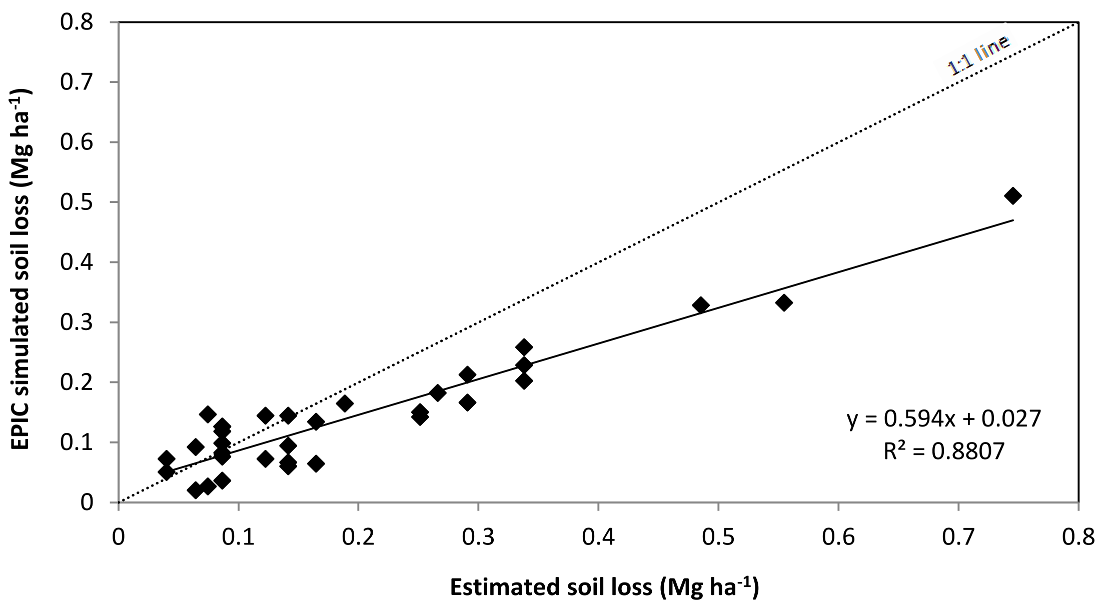

Figure III-5. Simulated and estimated soil loss derived from switchgrass production.

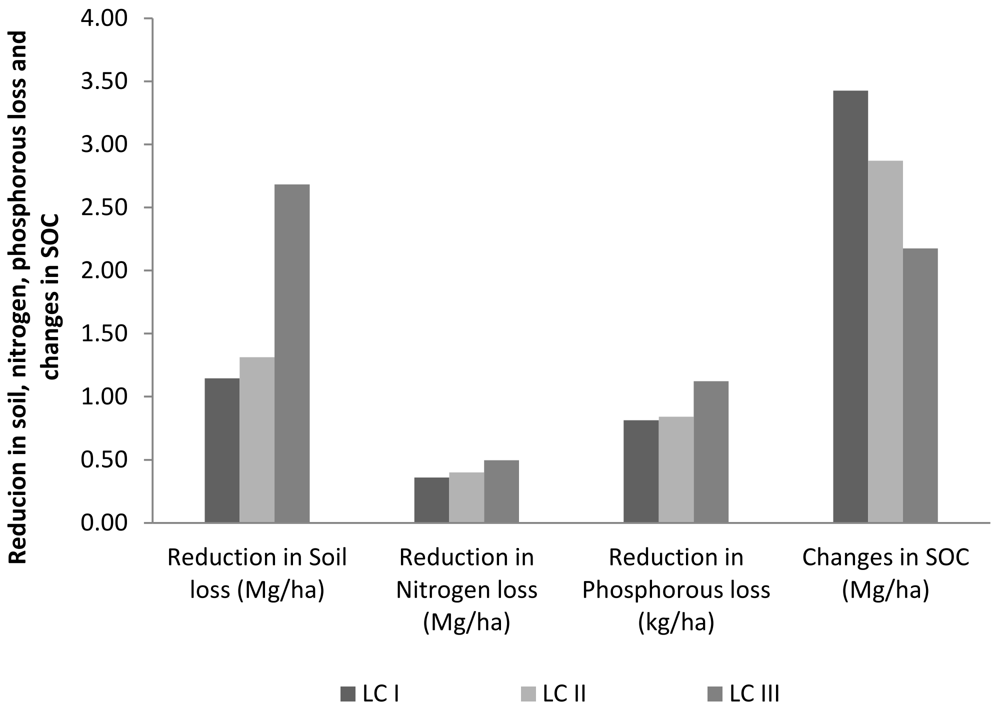

Figure III-6. Average per year reduction in soil loss, nitrogen loss, phosphorous loss, and changes in SOC between land class I (LC I), land class II (LC II), and land class III (LC III).

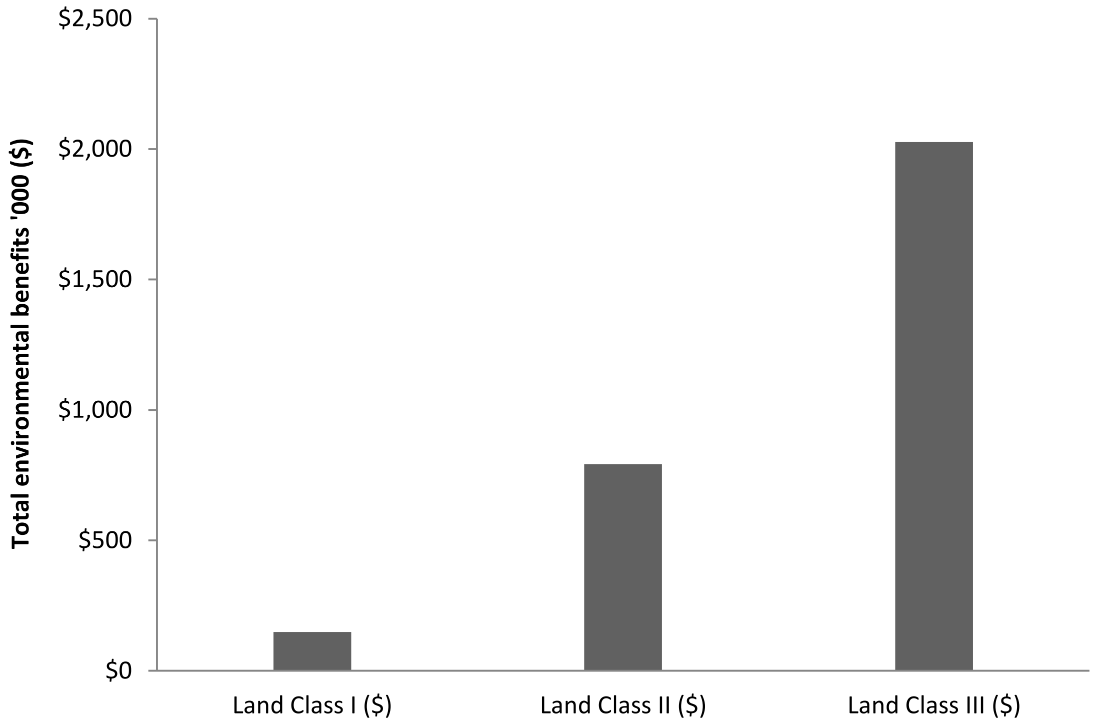

Figure III-7. Total environmental benefits derived to society from a potential biorefinery established at Okemah, Okfuskee, Oklahoma.

APPENDIX

GAMS Code for Chapter II Model 3

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OPTIONS LIMROW=0, LIMCOL=0;
OPTION OPTCR = 0.0000;
option lp=minos;
OPTION RESLIM=1000000;
OPTION ITERLIM=5000000;
SETS
C Counties
/ATOK, CANA, CLEV, COAL, CREK, GRAV, GRAD, HASK, HUGH, JOHN,
LOGN, LINC, McCL, McIN, MURR, MUSK, NOBL, OKFU, OKLA, OKMU
OSAG, PAWN, PYNE, PITS, PONT, POTT, LATI, SEMI, TULS, WAGN /
L land class
/CLS1, CLS2, CLS3/
T Time periods
/year1*year50/
Table LandRent(C,L) Rental costs of land $ per hectare 'No Class1 type soil for ATOK COAl
& LATI'
$ondelim
$include F:\PhD_Proposal\Rent.csv
$offdelim
;
Scalar  LF "Standard Life" /10/;
Scalar  ESTCST "Establishment costs without land rent"/394.45/;
*/Turhollow, A.F. and F.M. Epplin.  "Estimating Region Specific Costs to Produce and
*/Deliver Switchgrass."
*/Chapter 8 in Switchgrass: A Valuable Biomass Crop for Energy.  ed. Andrea Monti, New
*/York: Springer Publishing Co. 2012
Scalar R "Amortization Rate"/0.065/;
Parameter AMORTCOST(C,L) Total amortization costs of per hectare land;
AMORTCOST(C,L)=((LandRent(C,L)+ESTCST)*((1+R)**LF*R))/((1+R)**LF-1);
Scalar NIT "Nitrogen applied Kg per hectare"/78/;
Scalar PN "Price of Nitrogen $ per Kg"/1.23/;
Scalar AM "Annual maintainence cost per hectare" /9.63/
Scalar MOW "Cost of Mowing per hectare"/30.97/;
*/Turhollow, A.F. and F.M. Epplin.  "Estimating Region Specific Costs to Produce and
*/Deliver Switchgrass."
*/Chapter 8 in Switchgrass: A Valuable Biomass Crop for Energy.  ed. Andrea Monti, New
*/York: Springer Publishing Co. 2012
Parameter LNDCST(C,L) Total production costs per hectare;
LNDCST(C,L)=AMORTCOST(C,L)+LandRent(C,L)+PN*NIT+AM+MOW;
Parameter PRDCST(C,L) Total production costs per hectare EXCLUDING LAND RENT;
PRDCST(C,L)=AMORTCOST(C,L)+PN*NIT+AM;
Scalar RAK "Cost of Raking per hectare" /18.89/;
Scalar Bal "Cost of Baling per hectare"/28.89/;
Table DIS(T,C,L)
*/Distance form Centriod of Soil Class in County C Soil class L  to the biorefinery
*/location in Km 'No Class1 type soil for ATOK COAl & LATI'
      ATOK.CLS1      ATOK.CLS2     ATOK.CLS3     CANA.CLS1     CANA.CLS2     CANA.CLS3
Year1         0        145.85        145.85        167.76        167.76        167.76
Year2         0        145.85        145.85        167.76        167.76        167.76
Year3         0        145.85        145.85        167.76        167.76        167.76
Year4         0        145.85        145.85        167.76        167.76        167.76
Year5         0        145.85        145.85        167.76        167.76        167.76
Year6         0        145.85        145.85        167.76        167.76        167.76
Year7         0        145.85        145.85        167.76        167.76        167.76
Year8         0        145.85        145.85        167.76        167.76        167.76
Year9         0        145.85        145.85        167.76        167.76        167.7
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Year10	0	145.85	145.85	167.76	167.76	167.76
Year11	0	145.85	145.85	167.76	167.76	167.76
Year12	0	145.85	145.85	167.76	167.76	167.76
Year13	0	145.85	145.85	167.76	167.76	167.76
Year14	0	145.85	145.85	167.76	167.76	167.76
Year15	0	145.85	145.85	167.76	167.76	167.76
Year16	0	145.85	145.85	167.76	167.76	167.76
Year17	0	145.85	145.85	167.76	167.76	167.76
Year18	0	145.85	145.85	167.76	167.76	167.76
Year19	0	145.85	145.85	167.76	167.76	167.76
Year20	0	145.85	145.85	167.76	167.76	167.76
Year21	0	145.85	145.85	167.76	167.76	167.76
Year22	0	145.85	145.85	167.76	167.76	167.76
Year23	0	145.85	145.85	167.76	167.76	167.76
Year24	0	145.85	145.85	167.76	167.76	167.76
Year25	0	145.85	145.85	167.76	167.76	167.76
Year26	0	145.85	145.85	167.76	167.76	167.76
Year27	0	145.85	145.85	167.76	167.76	167.76
Year28	0	145.85	145.85	167.76	167.76	167.76
Year29	0	145.85	145.85	167.76	167.76	167.76
Year30	0	145.85	145.85	167.76	167.76	167.76
Year31	0	145.85	145.85	167.76	167.76	167.76
Year32	0	145.85	145.85	167.76	167.76	167.76
Year33	0	145.85	145.85	167.76	167.76	167.76
Year34	0	145.85	145.85	167.76	167.76	167.76
Year35	0	145.85	145.85	167.76	167.76	167.76
Year36	0	145.85	145.85	167.76	167.76	167.76
Year37	0	145.85	145.85	167.76	167.76	167.76
Year38	0	145.85	145.85	167.76	167.76	167.76
Year39	0	145.85	145.85	167.76	167.76	167.76
Year40	0	145.85	145.85	167.76	167.76	167.76
Year41	0	145.85	145.85	167.76	167.76	167.76
Year42	0	145.85	145.85	167.76	167.76	167.76
Year43	0	145.85	145.85	167.76	167.76	167.76
Year44	0	145.85	145.85	167.76	167.76	167.76
Year45	0	145.85	145.85	167.76	167.76	167.76
Year46	0	145.85	145.85	167.76	167.76	167.76
Year47	0	145.85	145.85	167.76	167.76	167.76
Year48	0	145.85	145.85	167.76	167.76	167.76
Year49	0	145.85	145.85	167.76	167.76	167.76
Year50	0	145.85	145.85	167.76	167.76	167.76

+

	CLEV.CLS1	CLEV.CLS2	CLEV.CLS3	COAL.CLS1	COAL.CLS2	COAL.CLS3
Year1	137.58	137.58	113.51	0	121.5	121.5
Year2	137.58	137.58	113.51	0	121.5	121.5
Year3	137.58	137.58	113.51	0	121.5	121.5
Year4	137.58	137.58	113.51	0	121.5	121.5
Year5	137.58	137.58	113.51	0	121.5	121.5
Year6	137.58	137.58	113.51	0	121.5	121.5
Year7	137.58	137.58	113.51	0	121.5	121.5
Year8	137.58	137.58	113.51	0	121.5	121.5
Year9	137.58	137.58	113.51	0	121.5	121.5
Year10	137.58	137.58	113.51	0	121.5	121.5
Year11	137.58	137.58	113.51	0	121.5	121.5
Year12	137.58	137.58	113.51	0	121.5	121.5
Year13	137.58	137.58	113.51	0	121.5	121.5
Year14	137.58	137.58	113.51	0	121.5	121.5
Year15	137.58	137.58	113.51	0	121.5	121.5
Year16	137.58	137.58	113.51	0	121.5	121.5
Year17	137.58	137.58	113.51	0	121.5	121.5
Year18	137.58	137.58	113.51	0	121.5	121.5
Year19	137.58	137.58	113.51	0	121.5	121.5
Year20	137.58	137.58	113.51	0	121.5	121.5
Year21	137.58	137.58	113.51	0	121.5	121.5
Year22	137.58	137.58	113.51	0	121.5	121.5
Year23	137.58	137.58	113.51	0	121.5	121.5
Year24	137.58	137.58	113.51	0	121.5	121.5
Year25	137.58	137.58	113.51	0	121.5	121.5
Year26	137.58	137.58	113.51	0	121.5	121.5
Year27	137.58	137.58	113.51	0	121.5	121.5

Year28	137.58	137.58	113.51	0	121.5	121.5
Year29	137.58	137.58	113.51	0	121.5	121.5
Year30	137.58	137.58	113.51	0	121.5	121.5
Year31	137.58	137.58	113.51	0	121.5	121.5
Year32	137.58	137.58	113.51	0	121.5	121.5
Year33	137.58	137.58	113.51	0	121.5	121.5
Year34	137.58	137.58	113.51	0	121.5	121.5
Year35	137.58	137.58	113.51	0	121.5	121.5
Year36	137.58	137.58	113.51	0	121.5	121.5
Year37	137.58	137.58	113.51	0	121.5	121.5
Year38	137.58	137.58	113.51	0	121.5	121.5
Year39	137.58	137.58	113.51	0	121.5	121.5
Year40	137.58	137.58	113.51	0	121.5	121.5
Year41	137.58	137.58	113.51	0	121.5	121.5
Year42	137.58	137.58	113.51	0	121.5	121.5
Year43	137.58	137.58	113.51	0	121.5	121.5
Year44	137.58	137.58	113.51	0	121.5	121.5
Year45	137.58	137.58	113.51	0	121.5	121.5
Year46	137.58	137.58	113.51	0	121.5	121.5
Year47	137.58	137.58	113.51	0	121.5	121.5
Year48	137.58	137.58	113.51	0	121.5	121.5
Year49	137.58	137.58	113.51	0	121.5	121.5
Year50	137.58	137.58	113.51	0	121.5	121.5

+

	CREK.CLS1	CREK.CLS2	CREK.CLS3	GRAV.CLS1	GRAV.CLS2	GRAV.CLS3
Year1	51.19	51.19	51.19	165.09	165.09	165.09
Year2	51.19	51.19	51.19	165.09	165.09	165.09
Year3	51.19	51.19	51.19	165.09	165.09	165.09
Year4	51.19	51.19	51.19	165.09	165.09	165.09
Year5	51.19	51.19	51.19	165.09	165.09	165.09
Year6	51.19	51.19	51.19	165.09	165.09	165.09
Year7	51.19	51.19	51.19	165.09	165.09	165.09
Year8	51.19	51.19	51.19	165.09	165.09	165.09
Year9	51.19	51.19	51.19	165.09	165.09	165.09
Year10	51.19	51.19	51.19	165.09	165.09	165.09
Year11	51.19	51.19	51.19	165.09	165.09	165.09
Year12	51.19	51.19	51.19	165.09	165.09	165.09
Year13	51.19	51.19	51.19	165.09	165.09	165.09
Year14	51.19	51.19	51.19	165.09	165.09	165.09
Year15	51.19	51.19	51.19	165.09	165.09	165.09
Year16	51.19	51.19	51.19	165.09	165.09	165.09
Year17	51.19	51.19	51.19	165.09	165.09	165.09
Year18	51.19	51.19	51.19	165.09	165.09	165.09
Year19	51.19	51.19	51.19	165.09	165.09	165.09
Year20	51.19	51.19	51.19	165.09	165.09	165.09
Year21	51.19	51.19	51.19	165.09	165.09	165.09
Year22	51.19	51.19	51.19	165.09	165.09	165.09
Year23	51.19	51.19	51.19	165.09	165.09	165.09
Year24	51.19	51.19	51.19	165.09	165.09	165.09
Year25	51.19	51.19	51.19	165.09	165.09	165.09
Year26	51.19	51.19	51.19	165.09	165.09	165.09
Year27	51.19	51.19	51.19	165.09	165.09	165.09
Year28	51.19	51.19	51.19	165.09	165.09	165.09
Year29	51.19	51.19	51.19	165.09	165.09	165.09
Year30	51.19	51.19	51.19	165.09	165.09	165.09
Year31	51.19	51.19	51.19	165.09	165.09	165.09
Year32	51.19	51.19	51.19	165.09	165.09	165.09
Year33	51.19	51.19	51.19	165.09	165.09	165.09
Year34	51.19	51.19	51.19	165.09	165.09	165.09
Year35	51.19	51.19	51.19	165.09	165.09	165.09
Year36	51.19	51.19	51.19	165.09	165.09	165.09
Year37	51.19	51.19	51.19	165.09	165.09	165.09
Year38	51.19	51.19	51.19	165.09	165.09	165.09
Year39	51.19	51.19	51.19	165.09	165.09	165.09
Year40	51.19	51.19	51.19	165.09	165.09	165.09
Year41	51.19	51.19	51.19	165.09	165.09	165.09
Year42	51.19	51.19	51.19	165.09	165.09	165.09
Year43	51.19	51.19	51.19	165.09	165.09	165.09
Year44	51.19	51.19	51.19	165.09	165.09	165.09
Year45	51.19	51.19	51.19	165.09	165.09	165.09
Year46	51.19	51.19	51.19	165.09	165.09	165.09

Year47	51.19	51.19	51.19	165.09	165.09	165.09
Year48	51.19	51.19	51.19	165.09	165.09	165.09
Year49	51.19	51.19	51.19	165.09	165.09	165.09
Year50	51.19	51.19	51.19	165.09	165.09	165.09

+

	GRAD.CLS1	GRAD.CLS2	GRAD.CLS3	HASK.CLS1	HASK.CLS2	HASK.CLS3
Year1	190.1	190.1	190.1	109.43	141.53	141.53
Year2	190.1	190.1	190.1	109.43	141.53	141.53
Year3	190.1	190.1	190.1	109.43	141.53	141.53
Year4	190.1	190.1	190.1	109.43	141.53	141.53
Year5	190.1	190.1	190.1	109.43	141.53	141.53
Year6	190.1	190.1	190.1	109.43	141.53	141.53
Year7	190.1	190.1	190.1	109.43	141.53	141.53
Year8	190.1	190.1	190.1	109.43	141.53	141.53
Year9	190.1	190.1	190.1	109.43	141.53	141.53
Year10	190.1	190.1	190.1	109.43	141.53	141.53
Year11	190.1	190.1	190.1	109.43	141.53	141.53
Year12	190.1	190.1	190.1	109.43	141.53	141.53
Year13	190.1	190.1	190.1	109.43	141.53	141.53
Year14	190.1	190.1	190.1	109.43	141.53	141.53
Year15	190.1	190.1	190.1	109.43	141.53	141.53
Year16	190.1	190.1	190.1	109.43	141.53	141.53
Year17	190.1	190.1	190.1	109.43	141.53	141.53
Year18	190.1	190.1	190.1	109.43	141.53	141.53
Year19	190.1	190.1	190.1	109.43	141.53	141.53
Year20	190.1	190.1	190.1	109.43	141.53	141.53
Year21	190.1	190.1	190.1	109.43	141.53	141.53
Year22	190.1	190.1	190.1	109.43	141.53	141.53
Year23	190.1	190.1	190.1	109.43	141.53	141.53
Year24	190.1	190.1	190.1	109.43	141.53	141.53
Year25	190.1	190.1	190.1	109.43	141.53	141.53
Year26	190.1	190.1	190.1	109.43	141.53	141.53
Year27	190.1	190.1	190.1	109.43	141.53	141.53
Year28	190.1	190.1	190.1	109.43	141.53	141.53
Year29	190.1	190.1	190.1	109.43	141.53	141.53
Year30	190.1	190.1	190.1	109.43	141.53	141.53
Year31	190.1	190.1	190.1	109.43	141.53	141.53
Year32	190.1	190.1	190.1	109.43	141.53	141.53
Year33	190.1	190.1	190.1	109.43	141.53	141.53
Year34	190.1	190.1	190.1	109.43	141.53	141.53
Year35	190.1	190.1	190.1	109.43	141.53	141.53
Year36	190.1	190.1	190.1	109.43	141.53	141.53
Year37	190.1	190.1	190.1	109.43	141.53	141.53
Year38	190.1	190.1	190.1	109.43	141.53	141.53
Year39	190.1	190.1	190.1	109.43	141.53	141.53
Year40	190.1	190.1	190.1	109.43	141.53	141.53
Year41	190.1	190.1	190.1	109.43	141.53	141.53
Year42	190.1	190.1	190.1	109.43	141.53	141.53
Year43	190.1	190.1	190.1	109.43	141.53	141.53
Year44	190.1	190.1	190.1	109.43	141.53	141.53
Year45	190.1	190.1	190.1	109.43	141.53	141.53
Year46	190.1	190.1	190.1	109.43	141.53	141.53
Year47	190.1	190.1	190.1	109.43	141.53	141.53
Year48	190.1	190.1	190.1	109.43	141.53	141.53
Year49	190.1	190.1	190.1	109.43	141.53	141.53
Year50	190.1	190.1	190.1	109.43	141.53	141.53

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	HUGH.CLS1	HUGH.CLS2	HUGH.CLS3	JOHN.CLS1	JOHN.CLS2	JOHN.CLS3
Year1	63.56	63.56	63.56	190.22	167.37	167.37
Year2	63.56	63.56	63.56	190.22	167.37	167.37
Year3	63.56	63.56	63.56	190.22	167.37	167.37
Year4	63.56	63.56	63.56	190.22	167.37	167.37
Year5	63.56	63.56	63.56	190.22	167.37	167.37
Year6	63.56	63.56	63.56	190.22	167.37	167.37
Year7	63.56	63.56	63.56	190.22	167.37	167.37
Year8	63.56	63.56	63.56	190.22	167.37	167.37
Year9	63.56	63.56	63.56	190.22	167.37	167.37
Year10	63.56	63.56	63.56	190.22	167.37	167.37
Year11	63.56	63.56	63.56	190.22	167.37	167.37
Year12	63.56	63.56	63.56	190.22	167.37	167.37
Year13	63.56	63.56	63.56	190.22	167.37	167.37

Year14	63.56	63.56	63.56	190.22	167.37	167.37
Year15	63.56	63.56	63.56	190.22	167.37	167.37
Year16	63.56	63.56	63.56	190.22	167.37	167.37
Year17	63.56	63.56	63.56	190.22	167.37	167.37
Year18	63.56	63.56	63.56	190.22	167.37	167.37
Year19	63.56	63.56	63.56	190.22	167.37	167.37
Year20	63.56	63.56	63.56	190.22	167.37	167.37
Year21	63.56	63.56	63.56	190.22	167.37	167.37
Year22	63.56	63.56	63.56	190.22	167.37	167.37
Year23	63.56	63.56	63.56	190.22	167.37	167.37
Year24	63.56	63.56	63.56	190.22	167.37	167.37
Year25	63.56	63.56	63.56	190.22	167.37	167.37
Year26	63.56	63.56	63.56	190.22	167.37	167.37
Year27	63.56	63.56	63.56	190.22	167.37	167.37
Year28	63.56	63.56	63.56	190.22	167.37	167.37
Year29	63.56	63.56	63.56	190.22	167.37	167.37
Year30	63.56	63.56	63.56	190.22	167.37	167.37
Year31	63.56	63.56	63.56	190.22	167.37	167.37
Year32	63.56	63.56	63.56	190.22	167.37	167.37
Year33	63.56	63.56	63.56	190.22	167.37	167.37
Year34	63.56	63.56	63.56	190.22	167.37	167.37
Year35	63.56	63.56	63.56	190.22	167.37	167.37
Year36	63.56	63.56	63.56	190.22	167.37	167.37
Year37	63.56	63.56	63.56	190.22	167.37	167.37
Year38	63.56	63.56	63.56	190.22	167.37	167.37
Year39	63.56	63.56	63.56	190.22	167.37	167.37
Year40	63.56	63.56	63.56	190.22	167.37	167.37
Year41	63.56	63.56	63.56	190.22	167.37	167.37
Year42	63.56	63.56	63.56	190.22	167.37	167.37
Year43	63.56	63.56	63.56	190.22	167.37	167.37
Year44	63.56	63.56	63.56	190.22	167.37	167.37
Year45	63.56	63.56	63.56	190.22	167.37	167.37
Year46	63.56	63.56	63.56	190.22	167.37	167.37
Year47	63.56	63.56	63.56	190.22	167.37	167.37
Year48	63.56	63.56	63.56	190.22	167.37	167.37
Year49	63.56	63.56	63.56	190.22	167.37	167.37
Year50	63.56	63.56	63.56	190.22	167.37	167.37

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	LOGN.CLS1	LOGN.CLS2	LOGN.CLS3	LINC.CLS1	LINC.CLS2	LINC.CLS3
Year1	169.68	169.68	169.68	78.79	91.02	91.02
Year2	169.68	169.68	169.68	78.79	91.02	91.02
Year3	169.68	169.68	169.68	78.79	91.02	91.02
Year4	169.68	169.68	169.68	78.79	91.02	91.02
Year5	169.68	169.68	169.68	78.79	91.02	91.02
Year6	169.68	169.68	169.68	78.79	91.02	91.02
Year7	169.68	169.68	169.68	78.79	91.02	91.02
Year8	169.68	169.68	169.68	78.79	91.02	91.02
Year9	169.68	169.68	169.68	78.79	91.02	91.02
Year10	169.68	169.68	169.68	78.79	91.02	91.02
Year11	169.68	169.68	169.68	78.79	91.02	91.02
Year12	169.68	169.68	169.68	78.79	91.02	91.02
Year13	169.68	169.68	169.68	78.79	91.02	91.02
Year14	169.68	169.68	169.68	78.79	91.02	91.02
Year15	169.68	169.68	169.68	78.79	91.02	91.02
Year16	169.68	169.68	169.68	78.79	91.02	91.02
Year17	169.68	169.68	169.68	78.79	91.02	91.02
Year18	169.68	169.68	169.68	78.79	91.02	91.02
Year19	169.68	169.68	169.68	78.79	91.02	91.02
Year20	169.68	169.68	169.68	78.79	91.02	91.02
Year21	169.68	169.68	169.68	78.79	91.02	91.02
Year22	169.68	169.68	169.68	78.79	91.02	91.02
Year23	169.68	169.68	169.68	78.79	91.02	91.02
Year24	169.68	169.68	169.68	78.79	91.02	91.02
Year25	169.68	169.68	169.68	78.79	91.02	91.02
Year26	169.68	169.68	169.68	78.79	91.02	91.02
Year27	169.68	169.68	169.68	78.79	91.02	91.02
Year28	169.68	169.68	169.68	78.79	91.02	91.02
Year29	169.68	169.68	169.68	78.79	91.02	91.02

Year30	169.68	169.68	169.68	78.79	91.02	91.02
Year31	169.68	169.68	169.68	78.79	91.02	91.02
Year32	169.68	169.68	169.68	78.79	91.02	91.02
Year33	169.68	169.68	169.68	78.79	91.02	91.02
Year34	169.68	169.68	169.68	78.79	91.02	91.02
Year35	169.68	169.68	169.68	78.79	91.02	91.02
Year36	169.68	169.68	169.68	78.79	91.02	91.02
Year37	169.68	169.68	169.68	78.79	91.02	91.02
Year38	169.68	169.68	169.68	78.79	91.02	91.02
Year39	169.68	169.68	169.68	78.79	91.02	91.02
Year40	169.68	169.68	169.68	78.79	91.02	91.02
Year41	169.68	169.68	169.68	78.79	91.02	91.02
Year42	169.68	169.68	169.68	78.79	91.02	91.02
Year43	169.68	169.68	169.68	78.79	91.02	91.02
Year44	169.68	169.68	169.68	78.79	91.02	91.02
Year45	169.68	169.68	169.68	78.79	91.02	91.02
Year46	169.68	169.68	169.68	78.79	91.02	91.02
Year47	169.68	169.68	169.68	78.79	91.02	91.02
Year48	169.68	169.68	169.68	78.79	91.02	91.02
Year49	169.68	169.68	169.68	78.79	91.02	91.02
Year50	169.68	169.68	169.68	78.79	91.02	91.02

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	McCL.CLS1	McCL.CLS2	McCL.CLS3	McIN.CLS1	McIN.CLS2	McIN.CLS3
Year1	149.09	166.47	166.47	64.59	85.77	85.77
Year2	149.09	166.47	166.47	64.59	85.77	85.77
Year3	149.09	166.47	166.47	64.59	85.77	85.77
Year4	149.09	166.47	166.47	64.59	85.77	85.77
Year5	149.09	166.47	166.47	64.59	85.77	85.77
Year6	149.09	166.47	166.47	64.59	85.77	85.77
Year7	149.09	166.47	166.47	64.59	85.77	85.77
Year8	149.09	166.47	166.47	64.59	85.77	85.77
Year9	149.09	166.47	166.47	64.59	85.77	85.77
Year10	149.09	166.47	166.47	64.59	85.77	85.77
Year11	149.09	166.47	166.47	64.59	85.77	85.77
Year12	149.09	166.47	166.47	64.59	85.77	85.77
Year13	149.09	166.47	166.47	64.59	85.77	85.77
Year14	149.09	166.47	166.47	64.59	85.77	85.77
Year15	149.09	166.47	166.47	64.59	85.77	85.77
Year16	149.09	166.47	166.47	64.59	85.77	85.77
Year17	149.09	166.47	166.47	64.59	85.77	85.77
Year18	149.09	166.47	166.47	64.59	85.77	85.77
Year19	149.09	166.47	166.47	64.59	85.77	85.77
Year20	149.09	166.47	166.47	64.59	85.77	85.77
Year21	149.09	166.47	166.47	64.59	85.77	85.77
Year22	149.09	166.47	166.47	64.59	85.77	85.77
Year23	149.09	166.47	166.47	64.59	85.77	85.77
Year24	149.09	166.47	166.47	64.59	85.77	85.77
Year25	149.09	166.47	166.47	64.59	85.77	85.77
Year26	149.09	166.47	166.47	64.59	85.77	85.77
Year27	149.09	166.47	166.47	64.59	85.77	85.77
Year28	149.09	166.47	166.47	64.59	85.77	85.77
Year29	149.09	166.47	166.47	64.59	85.77	85.77
Year30	149.09	166.47	166.47	64.59	85.77	85.77
Year31	149.09	166.47	166.47	64.59	85.77	85.77
Year32	149.09	166.47	166.47	64.59	85.77	85.77
Year33	149.09	166.47	166.47	64.59	85.77	85.77
Year34	149.09	166.47	166.47	64.59	85.77	85.77
Year35	149.09	166.47	166.47	64.59	85.77	85.77
Year36	149.09	166.47	166.47	64.59	85.77	85.77
Year37	149.09	166.47	166.47	64.59	85.77	85.77
Year38	149.09	166.47	166.47	64.59	85.77	85.77
Year39	149.09	166.47	166.47	64.59	85.77	85.77
Year40	149.09	166.47	166.47	64.59	85.77	85.77
Year41	149.09	166.47	166.47	64.59	85.77	85.77
Year42	149.09	166.47	166.47	64.59	85.77	85.77
Year43	149.09	166.47	166.47	64.59	85.77	85.77
Year44	149.09	166.47	166.47	64.59	85.77	85.77
Year45	149.09	166.47	166.47	64.59	85.77	85.77
Year46	149.09	166.47	166.47	64.59	85.77	85.77
Year47	149.09	166.47	166.47	64.59	85.77	85.77
Year48	149.09	166.47	166.47	64.59	85.77	85.77

Year49	149.09	166.47	166.47	64.59	85.77	85.77
Year50	149.09	166.47	166.47	64.59	85.77	85.77

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	MURR.CLS1	MURR.CLS2	MURR.CLS3	MUSK.CLS1	MUSK.CLS2	MUSK.CLS3
Year1	136.68	156.7	156.7	136.68	101.38	94.41
Year2	136.68	156.7	156.7	136.68	101.38	94.41
Year3	136.68	156.7	156.7	136.68	101.38	94.41
Year4	136.68	156.7	156.7	136.68	101.38	94.41
Year5	136.68	156.7	156.7	136.68	101.38	94.41
Year6	136.68	156.7	156.7	136.68	101.38	94.41
Year7	136.68	156.7	156.7	136.68	101.38	94.41
Year8	136.68	156.7	156.7	136.68	101.38	94.41
Year9	136.68	156.7	156.7	136.68	101.38	94.41
Year10	136.68	156.7	156.7	136.68	101.38	94.41
Year11	136.68	156.7	156.7	136.68	101.38	94.41
Year12	136.68	156.7	156.7	136.68	101.38	94.41
Year13	136.68	156.7	156.7	136.68	101.38	94.41
Year14	136.68	156.7	156.7	136.68	101.38	94.41
Year15	136.68	156.7	156.7	136.68	101.38	94.41
Year16	136.68	156.7	156.7	136.68	101.38	94.41
Year17	136.68	156.7	156.7	136.68	101.38	94.41
Year18	136.68	156.7	156.7	136.68	101.38	94.41
Year19	136.68	156.7	156.7	136.68	101.38	94.41
Year20	136.68	156.7	156.7	136.68	101.38	94.41
Year21	136.68	156.7	156.7	136.68	101.38	94.41
Year22	136.68	156.7	156.7	136.68	101.38	94.41
Year23	136.68	156.7	156.7	136.68	101.38	94.41
Year24	136.68	156.7	156.7	136.68	101.38	94.41
Year25	136.68	156.7	156.7	136.68	101.38	94.41
Year26	136.68	156.7	156.7	136.68	101.38	94.41
Year27	136.68	156.7	156.7	136.68	101.38	94.41
Year28	136.68	156.7	156.7	136.68	101.38	94.41
Year29	136.68	156.7	156.7	136.68	101.38	94.41
Year30	136.68	156.7	156.7	136.68	101.38	94.41
Year31	136.68	156.7	156.7	136.68	101.38	94.41
Year32	136.68	156.7	156.7	136.68	101.38	94.41
Year33	136.68	156.7	156.7	136.68	101.38	94.41
Year34	136.68	156.7	156.7	136.68	101.38	94.41
Year35	136.68	156.7	156.7	136.68	101.38	94.41
Year36	136.68	156.7	156.7	136.68	101.38	94.41
Year37	136.68	156.7	156.7	136.68	101.38	94.41
Year38	136.68	156.7	156.7	136.68	101.38	94.41
Year39	136.68	156.7	156.7	136.68	101.38	94.41
Year40	136.68	156.7	156.7	136.68	101.38	94.41
Year41	136.68	156.7	156.7	136.68	101.38	94.41
Year42	136.68	156.7	156.7	136.68	101.38	94.41
Year43	136.68	156.7	156.7	136.68	101.38	94.41
Year44	136.68	156.7	156.7	136.68	101.38	94.41
Year45	136.68	156.7	156.7	136.68	101.38	94.41
Year46	136.68	156.7	156.7	136.68	101.38	94.41
Year47	136.68	156.7	156.7	136.68	101.38	94.41
Year48	136.68	156.7	156.7	136.68	101.38	94.41
Year49	136.68	156.7	156.7	136.68	101.38	94.41
Year50	136.68	156.7	156.7	136.68	101.38	94.41

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	NOBL.CLS1	NOBL.CLS2	NOBL.CLS3	OKFU.CLS1	OKFU.CLS2	OKFU.CLS3
Year1	186.03	186.03	181.82	35.73	35.73	35.73
Year2	186.03	186.03	181.82	35.73	35.73	35.73
Year3	186.03	186.03	181.82	35.73	35.73	35.73
Year4	186.03	186.03	181.82	35.73	35.73	35.73
Year5	186.03	186.03	181.82	35.73	35.73	35.73
Year6	186.03	186.03	181.82	35.73	35.73	35.73
Year7	186.03	186.03	181.82	35.73	35.73	35.73
Year8	186.03	186.03	181.82	35.73	35.73	35.73
Year9	186.03	186.03	181.82	35.73	35.73	35.73
Year10	186.03	186.03	181.82	35.73	35.73	35.73
Year11	186.03	186.03	181.82	35.73	35.73	35.73
Year12	186.03	186.03	181.82	35.73	35.73	35.73
Year13	186.03	186.03	181.82	35.73	35.73	35.73
Year14	186.03	186.03	181.82	35.73	35.73	35.73
Year15	186.03	186.03	181.82	35.73	35.73	35.73

Year16	186.03	186.03	181.82	35.73	35.73	35.73
Year17	186.03	186.03	181.82	35.73	35.73	35.73
Year18	186.03	186.03	181.82	35.73	35.73	35.73
Year19	186.03	186.03	181.82	35.73	35.73	35.73
Year20	186.03	186.03	181.82	35.73	35.73	35.73
Year21	186.03	186.03	181.82	35.73	35.73	35.73
Year22	186.03	186.03	181.82	35.73	35.73	35.73
Year23	186.03	186.03	181.82	35.73	35.73	35.73
Year24	186.03	186.03	181.82	35.73	35.73	35.73
Year25	186.03	186.03	181.82	35.73	35.73	35.73
Year26	186.03	186.03	181.82	35.73	35.73	35.73
Year27	186.03	186.03	181.82	35.73	35.73	35.73
Year28	186.03	186.03	181.82	35.73	35.73	35.73
Year29	186.03	186.03	181.82	35.73	35.73	35.73
Year30	186.03	186.03	181.82	35.73	35.73	35.73
Year31	186.03	186.03	181.82	35.73	35.73	35.73
Year32	186.03	186.03	181.82	35.73	35.73	35.73
Year33	186.03	186.03	181.82	35.73	35.73	35.73
Year34	186.03	186.03	181.82	35.73	35.73	35.73
Year35	186.03	186.03	181.82	35.73	35.73	35.73
Year36	186.03	186.03	181.82	35.73	35.73	35.73
Year37	186.03	186.03	181.82	35.73	35.73	35.73
Year38	186.03	186.03	181.82	35.73	35.73	35.73
Year39	186.03	186.03	181.82	35.73	35.73	35.73
Year40	186.03	186.03	181.82	35.73	35.73	35.73
Year41	186.03	186.03	181.82	35.73	35.73	35.73
Year42	186.03	186.03	181.82	35.73	35.73	35.73
Year43	186.03	186.03	181.82	35.73	35.73	35.73
Year44	186.03	186.03	181.82	35.73	35.73	35.73
Year45	186.03	186.03	181.82	35.73	35.73	35.73
Year46	186.03	186.03	181.82	35.73	35.73	35.73
Year47	186.03	186.03	181.82	35.73	35.73	35.73
Year48	186.03	186.03	181.82	35.73	35.73	35.73
Year49	186.03	186.03	181.82	35.73	35.73	35.73
Year50	186.03	186.03	181.82	35.73	35.73	35.73

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	OKLA.CLS1	OKLA.CLS2	OKLA.CLS3	OKMU.CLS1	OKMU.CLS2	OKMU.CLS3
Year1	125.65	118.08	118.08	41.72	41.72	41.72
Year2	125.65	118.08	118.08	41.72	41.72	41.72
Year3	125.65	118.08	118.08	41.72	41.72	41.72
Year4	125.65	118.08	118.08	41.72	41.72	41.72
Year5	125.65	118.08	118.08	41.72	41.72	41.72
Year6	125.65	118.08	118.08	41.72	41.72	41.72
Year7	125.65	118.08	118.08	41.72	41.72	41.72
Year8	125.65	118.08	118.08	41.72	41.72	41.72
Year9	125.65	118.08	118.08	41.72	41.72	41.72
Year10	125.65	118.08	118.08	41.72	41.72	41.72
Year11	125.65	118.08	118.08	41.72	41.72	41.72
Year12	125.65	118.08	118.08	41.72	41.72	41.72
Year13	125.65	118.08	118.08	41.72	41.72	41.72
Year14	125.65	118.08	118.08	41.72	41.72	41.72
Year15	125.65	118.08	118.08	41.72	41.72	41.72
Year16	125.65	118.08	118.08	41.72	41.72	41.72
Year17	125.65	118.08	118.08	41.72	41.72	41.72
Year18	125.65	118.08	118.08	41.72	41.72	41.72
Year19	125.65	118.08	118.08	41.72	41.72	41.72
Year20	125.65	118.08	118.08	41.72	41.72	41.72
Year21	125.65	118.08	118.08	41.72	41.72	41.72
Year22	125.65	118.08	118.08	41.72	41.72	41.72
Year23	125.65	118.08	118.08	41.72	41.72	41.72
Year24	125.65	118.08	118.08	41.72	41.72	41.72
Year25	125.65	118.08	118.08	41.72	41.72	41.72
Year26	125.65	118.08	118.08	41.72	41.72	41.72
Year27	125.65	118.08	118.08	41.72	41.72	41.72
Year28	125.65	118.08	118.08	41.72	41.72	41.72
Year29	125.65	118.08	118.08	41.72	41.72	41.72
Year30	125.65	118.08	118.08	41.72	41.72	41.72
Year31	125.65	118.08	118.08	41.72	41.72	41.72
Year32	125.65	118.08	118.08	41.72	41.72	41.72
Year33	125.65	118.08	118.08	41.72	41.72	41.72
Year34	125.65	118.08	118.08	41.72	41.72	41.72

Year35	125.65	118.08	118.08	41.72	41.72	41.72
Year36	125.65	118.08	118.08	41.72	41.72	41.72
Year37	125.65	118.08	118.08	41.72	41.72	41.72
Year38	125.65	118.08	118.08	41.72	41.72	41.72
Year39	125.65	118.08	118.08	41.72	41.72	41.72
Year40	125.65	118.08	118.08	41.72	41.72	41.72
Year41	125.65	118.08	118.08	41.72	41.72	41.72
Year42	125.65	118.08	118.08	41.72	41.72	41.72
Year43	125.65	118.08	118.08	41.72	41.72	41.72
Year44	125.65	118.08	118.08	41.72	41.72	41.72
Year45	125.65	118.08	118.08	41.72	41.72	41.72
Year46	125.65	118.08	118.08	41.72	41.72	41.72
Year47	125.65	118.08	118.08	41.72	41.72	41.72
Year48	125.65	118.08	118.08	41.72	41.72	41.72
Year49	125.65	118.08	118.08	41.72	41.72	41.72
Year50	125.65	118.08	118.08	41.72	41.72	41.72

+

	OSAG.CLS1	OSAG.CLS2	OSAG.CLS3	PAWN.CLS1	PAWN.CLS2	PAWN.CLS3
Year1	171.56	171.56	171.56	144.79	144.79	144.79
Year2	171.56	171.56	171.56	144.79	144.79	144.79
Year3	171.56	171.56	171.56	144.79	144.79	144.79
Year4	171.56	171.56	171.56	144.79	144.79	144.79
Year5	171.56	171.56	171.56	144.79	144.79	144.79
Year6	171.56	171.56	171.56	144.79	144.79	144.79
Year7	171.56	171.56	171.56	144.79	144.79	144.79
Year8	171.56	171.56	171.56	144.79	144.79	144.79
Year9	171.56	171.56	171.56	144.79	144.79	144.79
Year10	171.56	171.56	171.56	144.79	144.79	144.79
Year11	171.56	171.56	171.56	144.79	144.79	144.79
Year12	171.56	171.56	171.56	144.79	144.79	144.79
Year13	171.56	171.56	171.56	144.79	144.79	144.79
Year14	171.56	171.56	171.56	144.79	144.79	144.79
Year15	171.56	171.56	171.56	144.79	144.79	144.79
Year16	171.56	171.56	171.56	144.79	144.79	144.79
Year17	171.56	171.56	171.56	144.79	144.79	144.79
Year18	171.56	171.56	171.56	144.79	144.79	144.79
Year19	171.56	171.56	171.56	144.79	144.79	144.79
Year20	171.56	171.56	171.56	144.79	144.79	144.79
Year21	171.56	171.56	171.56	144.79	144.79	144.79
Year22	171.56	171.56	171.56	144.79	144.79	144.79
Year23	171.56	171.56	171.56	144.79	144.79	144.79
Year24	171.56	171.56	171.56	144.79	144.79	144.79
Year25	171.56	171.56	171.56	144.79	144.79	144.79
Year26	171.56	171.56	171.56	144.79	144.79	144.79
Year27	171.56	171.56	171.56	144.79	144.79	144.79
Year28	171.56	171.56	171.56	144.79	144.79	144.79
Year29	171.56	171.56	171.56	144.79	144.79	144.79
Year30	171.56	171.56	171.56	144.79	144.79	144.79
Year31	171.56	171.56	171.56	144.79	144.79	144.79
Year32	171.56	171.56	171.56	144.79	144.79	144.79
Year33	171.56	171.56	171.56	144.79	144.79	144.79
Year34	171.56	171.56	171.56	144.79	144.79	144.79
Year35	171.56	171.56	171.56	144.79	144.79	144.79
Year36	171.56	171.56	171.56	144.79	144.79	144.79
Year37	171.56	171.56	171.56	144.79	144.79	144.79
Year38	171.56	171.56	171.56	144.79	144.79	144.79
Year39	171.56	171.56	171.56	144.79	144.79	144.79
Year40	171.56	171.56	171.56	144.79	144.79	144.79
Year41	171.56	171.56	171.56	144.79	144.79	144.79
Year42	171.56	171.56	171.56	144.79	144.79	144.79
Year43	171.56	171.56	171.56	144.79	144.79	144.79
Year44	171.56	171.56	171.56	144.79	144.79	144.79
Year45	171.56	171.56	171.56	144.79	144.79	144.79
Year46	171.56	171.56	171.56	144.79	144.79	144.79
Year47	171.56	171.56	171.56	144.79	144.79	144.79
Year48	171.56	171.56	171.56	144.79	144.79	144.79
Year49	171.56	171.56	171.56	144.79	144.79	144.79
Year50	171.56	171.56	171.56	144.79	144.79	144.79

+

	PYNE.CLS1	PYNE.CLS2	PYNE.CLS3	PITS.CLS1	PITS.CLS2	PITS.CLS3
Year1	120.07	120.07	143.12	89.39	75.34	75.34
Year2	120.07	120.07	143.12	89.39	75.34	75.34
Year3	120.07	120.07	143.12	89.39	75.34	75.34
Year4	120.07	120.07	143.12	89.39	75.34	75.34
Year5	120.07	120.07	143.12	89.39	75.34	75.34
Year6	120.07	120.07	143.12	89.39	75.34	75.34
Year7	120.07	120.07	143.12	89.39	75.34	75.34
Year8	120.07	120.07	143.12	89.39	75.34	75.34
Year9	120.07	120.07	143.12	89.39	75.34	75.34
Year10	120.07	120.07	143.12	89.39	75.34	75.34
Year11	120.07	120.07	143.12	89.39	75.34	75.34
Year12	120.07	120.07	143.12	89.39	75.34	75.34
Year13	120.07	120.07	143.12	89.39	75.34	75.34
Year14	120.07	120.07	143.12	89.39	75.34	75.34
Year15	120.07	120.07	143.12	89.39	75.34	75.34
Year16	120.07	120.07	143.12	89.39	75.34	75.34
Year17	120.07	120.07	143.12	89.39	75.34	75.34
Year18	120.07	120.07	143.12	89.39	75.34	75.34
Year19	120.07	120.07	143.12	89.39	75.34	75.34
Year20	120.07	120.07	143.12	89.39	75.34	75.34
Year21	120.07	120.07	143.12	89.39	75.34	75.34
Year22	120.07	120.07	143.12	89.39	75.34	75.34
Year23	120.07	120.07	143.12	89.39	75.34	75.34
Year24	120.07	120.07	143.12	89.39	75.34	75.34
Year25	120.07	120.07	143.12	89.39	75.34	75.34
Year26	120.07	120.07	143.12	89.39	75.34	75.34
Year27	120.07	120.07	143.12	89.39	75.34	75.34
Year28	120.07	120.07	143.12	89.39	75.34	75.34
Year29	120.07	120.07	143.12	89.39	75.34	75.34
Year30	120.07	120.07	143.12	89.39	75.34	75.34
Year31	120.07	120.07	143.12	89.39	75.34	75.34
Year32	120.07	120.07	143.12	89.39	75.34	75.34
Year33	120.07	120.07	143.12	89.39	75.34	75.34
Year34	120.07	120.07	143.12	89.39	75.34	75.34
Year35	120.07	120.07	143.12	89.39	75.34	75.34
Year36	120.07	120.07	143.12	89.39	75.34	75.34
Year37	120.07	120.07	143.12	89.39	75.34	75.34
Year38	120.07	120.07	143.12	89.39	75.34	75.34
Year39	120.07	120.07	143.12	89.39	75.34	75.34
Year40	120.07	120.07	143.12	89.39	75.34	75.34
Year41	120.07	120.07	143.12	89.39	75.34	75.34
Year42	120.07	120.07	143.12	89.39	75.34	75.34
Year43	120.07	120.07	143.12	89.39	75.34	75.34
Year44	120.07	120.07	143.12	89.39	75.34	75.34
Year45	120.07	120.07	143.12	89.39	75.34	75.34
Year46	120.07	120.07	143.12	89.39	75.34	75.34
Year47	120.07	120.07	143.12	89.39	75.34	75.34
Year48	120.07	120.07	143.12	89.39	75.34	75.34
Year49	120.07	120.07	143.12	89.39	75.34	75.34
Year50	120.07	120.07	143.12	89.39	75.34	75.34

+

	PONT.CLS1	PONT.CLS2	PONT.CLS3	POTT.CLS1	POTT.CLS2	POTT.CLS3
Year1	152.21	127.57	127.57	63.05	97.9	97.9
Year2	152.21	127.57	127.57	63.05	97.9	97.9
Year3	152.21	127.57	127.57	63.05	97.9	97.9
Year4	152.21	127.57	127.57	63.05	97.9	97.9
Year5	152.21	127.57	127.57	63.05	97.9	97.9
Year6	152.21	127.57	127.57	63.05	97.9	97.9
Year7	152.21	127.57	127.57	63.05	97.9	97.9
Year8	152.21	127.57	127.57	63.05	97.9	97.9
Year9	152.21	127.57	127.57	63.05	97.9	97.9
Year10	152.21	127.57	127.57	63.05	97.9	97.9
Year11	152.21	127.57	127.57	63.05	97.9	97.9
Year12	152.21	127.57	127.57	63.05	97.9	97.9
Year13	152.21	127.57	127.57	63.05	97.9	97.9
Year14	152.21	127.57	127.57	63.05	97.9	97.9
Year15	152.21	127.57	127.57	63.05	97.9	97.9
Year16	152.21	127.57	127.57	63.05	97.9	97.9
Year17	152.21	127.57	127.57	63.05	97.9	97.9
Year18	152.21	127.57	127.57	63.05	97.9	97.9

Year19	152.21	127.57	127.57	63.05	97.9	97.9
Year20	152.21	127.57	127.57	63.05	97.9	97.9
Year21	152.21	127.57	127.57	63.05	97.9	97.9
Year22	152.21	127.57	127.57	63.05	97.9	97.9
Year23	152.21	127.57	127.57	63.05	97.9	97.9
Year24	152.21	127.57	127.57	63.05	97.9	97.9
Year25	152.21	127.57	127.57	63.05	97.9	97.9
Year26	152.21	127.57	127.57	63.05	97.9	97.9
Year27	152.21	127.57	127.57	63.05	97.9	97.9
Year28	152.21	127.57	127.57	63.05	97.9	97.9
Year29	152.21	127.57	127.57	63.05	97.9	97.9
Year30	152.21	127.57	127.57	63.05	97.9	97.9
Year31	152.21	127.57	127.57	63.05	97.9	97.9
Year32	152.21	127.57	127.57	63.05	97.9	97.9
Year33	152.21	127.57	127.57	63.05	97.9	97.9
Year34	152.21	127.57	127.57	63.05	97.9	97.9
Year35	152.21	127.57	127.57	63.05	97.9	97.9
Year36	152.21	127.57	127.57	63.05	97.9	97.9
Year37	152.21	127.57	127.57	63.05	97.9	97.9
Year38	152.21	127.57	127.57	63.05	97.9	97.9
Year39	152.21	127.57	127.57	63.05	97.9	97.9
Year40	152.21	127.57	127.57	63.05	97.9	97.9
Year41	152.21	127.57	127.57	63.05	97.9	97.9
Year42	152.21	127.57	127.57	63.05	97.9	97.9
Year43	152.21	127.57	127.57	63.05	97.9	97.9
Year44	152.21	127.57	127.57	63.05	97.9	97.9
Year45	152.21	127.57	127.57	63.05	97.9	97.9
Year46	152.21	127.57	127.57	63.05	97.9	97.9
Year47	152.21	127.57	127.57	63.05	97.9	97.9
Year48	152.21	127.57	127.57	63.05	97.9	97.9
Year49	152.21	127.57	127.57	63.05	97.9	97.9
Year50	152.21	127.57	127.57	63.05	97.9	97.9

+

	LATI.CLS1	LATI.CLS2	LATI.CLS3	SEMI.CLS1	SEMI.CLS2	SEMI.CLS3
Year1	0	43.38	143.38	55.59	55.59	47.51
Year2	0	43.38	143.38	55.59	55.59	47.51
Year3	0	43.38	143.38	55.59	55.59	47.51
Year4	0	43.38	143.38	55.59	55.59	47.51
Year5	0	43.38	143.38	55.59	55.59	47.51
Year6	0	43.38	143.38	55.59	55.59	47.51
Year7	0	43.38	143.38	55.59	55.59	47.51
Year8	0	43.38	143.38	55.59	55.59	47.51
Year9	0	43.38	143.38	55.59	55.59	47.51
Year10	0	43.38	143.38	55.59	55.59	47.51
Year11	0	43.38	143.38	55.59	55.59	47.51
Year12	0	43.38	143.38	55.59	55.59	47.51
Year13	0	43.38	143.38	55.59	55.59	47.51
Year14	0	43.38	143.38	55.59	55.59	47.51
Year15	0	43.38	143.38	55.59	55.59	47.51
Year16	0	43.38	143.38	55.59	55.59	47.51
Year17	0	43.38	143.38	55.59	55.59	47.51
Year18	0	43.38	143.38	55.59	55.59	47.51
Year19	0	43.38	143.38	55.59	55.59	47.51
Year20	0	43.38	143.38	55.59	55.59	47.51
Year21	0	43.38	143.38	55.59	55.59	47.51
Year22	0	43.38	143.38	55.59	55.59	47.51
Year23	0	43.38	143.38	55.59	55.59	47.51
Year24	0	43.38	143.38	55.59	55.59	47.51
Year25	0	43.38	143.38	55.59	55.59	47.51
Year26	0	43.38	143.38	55.59	55.59	47.51
Year27	0	43.38	143.38	55.59	55.59	47.51
Year28	0	43.38	143.38	55.59	55.59	47.51
Year29	0	43.38	143.38	55.59	55.59	47.51
Year30	0	43.38	143.38	55.59	55.59	47.51
Year31	0	43.38	143.38	55.59	55.59	47.51
Year32	0	43.38	143.38	55.59	55.59	47.51
Year33	0	43.38	143.38	55.59	55.59	47.51
Year34	0	43.38	143.38	55.59	55.59	47.51
Year35	0	43.38	143.38	55.59	55.59	47.51
Year36	0	43.38	143.38	55.59	55.59	47.51
Year37	0	43.38	143.38	55.59	55.59	47.51

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Year38        0        43.38        143.38        55.59        55.59        47.51
Year39        0        43.38        143.38        55.59        55.59        47.51
Year40        0        43.38        143.38        55.59        55.59        47.51
Year41        0        43.38        143.38        55.59        55.59        47.51
Year42        0        43.38        143.38        55.59        55.59        47.51
Year43        0        43.38        143.38        55.59        55.59        47.51
Year44        0        43.38        143.38        55.59        55.59        47.51
Year45        0        43.38        143.38        55.59        55.59        47.51
Year46        0        43.38        143.38        55.59        55.59        47.51
Year47        0        43.38        143.38        55.59        55.59        47.51
Year48        0        43.38        143.38        55.59        55.59        47.51
Year49        0        43.38        143.38        55.59        55.59        47.51
Year50        0        43.38        143.38        55.59        55.59        47.51
+
            TULS.CLS1    TULS.CLS2    TULS.CLS3    WAGN.CLS1    WAGN.CLS2    WAGN.CLS3
Year1         107.91       115.19       113.79       102.84       127.79       127.79
Year2         107.91       115.19       113.79       102.84       127.79       127.79
Year3         107.91       115.19       113.79       102.84       127.79       127.79
Year4         107.91       115.19       113.79       102.84       127.79       127.79
Year5         107.91       115.19       113.79       102.84       127.79       127.79
Year6         107.91       115.19       113.79       102.84       127.79       127.79
Year7         107.91       115.19       113.79       102.84       127.79       127.79
Year8         107.91       115.19       113.79       102.84       127.79       127.79
Year9         107.91       115.19       113.79       102.84       127.79       127.79
Year10        107.91       115.19       113.79       102.84       127.79       127.79
Year11        107.91       115.19       113.79       102.84       127.79       127.79
Year12        107.91       115.19       113.79       102.84       127.79       127.79
Year13        107.91       115.19       113.79       102.84       127.79       127.79
Year14        107.91       115.19       113.79       102.84       127.79       127.79
Year15        107.91       115.19       113.79       102.84       127.79       127.79
Year16        107.91       115.19       113.79       102.84       127.79       127.79
Year17        107.91       115.19       113.79       102.84       127.79       127.79
Year18        107.91       115.19       113.79       102.84       127.79       127.79
Year19        107.91       115.19       113.79       102.84       127.79       127.79
Year20        107.91       115.19       113.79       102.84       127.79       127.79
Year21        107.91       115.19       113.79       102.84       127.79       127.79
Year22        107.91       115.19       113.79       102.84       127.79       127.79
Year23        107.91       115.19       113.79       102.84       127.79       127.79
Year24        107.91       115.19       113.79       102.84       127.79       127.79
Year25        107.91       115.19       113.79       102.84       127.79       127.79
Year26        107.91       115.19       113.79       102.84       127.79       127.79
Year27        107.91       115.19       113.79       102.84       127.79       127.79
Year28        107.91       115.19       113.79       102.84       127.79       127.79
Year29        107.91       115.19       113.79       102.84       127.79       127.79
Year30        107.91       115.19       113.79       102.84       127.79       127.79
Year31        107.91       115.19       113.79       102.84       127.79       127.79
Year32        107.91       115.19       113.79       102.84       127.79       127.79
Year33        107.91       115.19       113.79       102.84       127.79       127.79
Year34        107.91       115.19       113.79       102.84       127.79       127.79
Year35        107.91       115.19       113.79       102.84       127.79       127.79
Year36        107.91       115.19       113.79       102.84       127.79       127.79
Year37        107.91       115.19       113.79       102.84       127.79       127.79
Year38        107.91       115.19       113.79       102.84       127.79       127.79
Year39        107.91       115.19       113.79       102.84       127.79       127.79
Year40        107.91       115.19       113.79       102.84       127.79       127.79
Year41        107.91       115.19       113.79       102.84       127.79       127.79
Year42        107.91       115.19       113.79       102.84       127.79       127.79
Year43        107.91       115.19       113.79       102.84       127.79       127.79
Year44        107.91       115.19       113.79       102.84       127.79       127.79
Year45        107.91       115.19       113.79       102.84       127.79       127.79
Year46        107.91       115.19       113.79       102.84       127.79       127.79
Year47        107.91       115.19       113.79       102.84       127.79       127.79
Year48        107.91       115.19       113.79       102.84       127.79       127.79
Year49        107.91       115.19       113.79       102.84       127.79       127.79
Year50        107.91       115.19       113.79       102.84       127.79       127.79
;
Scalar FXCT "Fixed cost of transportation $ per Mg"/0.8796/;
Scalar VRCT "Variable cost of transportation $ per Mg"/0.1983/;
PARAMETER TRNSCST(T,C,L) "Transportation cost in $ per dry Mg truck";
TRNSCST(T,C,L) = (FXCT + VRCT*DIS(T,C,L));
Table TOTLAND(C,L) Hectare of land by county and land class
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*/10 percent of the total land in each soil class type is used
$ondelim
$include F:\PhD_Proposal\Land.csv
$offdelim
;
Table AnYld(T,C,L) Annual EPIC simulated biomass yield by county land class (Mg per ha)
         ATOK.CLS1  ATOK.CLS2     ATOK.CLS3  CANA.CLS1     CANA.CLS2     CANA.CLS3
Year1        0        19.2         16.08       18.58         17.59         11.52
Year2        0        15.67        12.66       13.31         10.12          9.85
Year3        0        17.03        15.72       15.75         15.12         12.94
Year4        0        19.38        17.1        17.53         16.47         14.8
Year5        0        20.78        16.3        16.95         16.64         12.95
Year6        0        15.89        13.47       17.34         14.92         14.5
Year7        0        16.2         12.29       17.87         16.57         14.25
Year8        0        18.33        11.73       14.12         13.03         10.11
Year9        0        15.94        13.98       14.14         12.28         12.24
Year10       0        20.19        17.44       15.75         13.33         11.39
Year11       0        17.02        13.92       11.47         10.58         10.07
Year12       0        20.15        14.21       17.5          17.48         12.51
Year13       0        19.15        16.44       17.77         15.52         12.66
Year14       0        20.2         14.46       18.11         16.52         12.5
Year15       0        17.2         14.51       17.71         10.96          9.76
Year16       0        12.56        11.18       16.81         15.22         13.11
Year17       0        12.57        11.87       12.97         11.21          9.75
Year18       0        18.66        14.62       16.74         15.71         12.76
Year19       0        11.66        10.21       12.65         11.13          7.92
Year20       0        16.73        15.69       16.6          15.44         13.56
Year21       0        15.86        13.2        17.42         15.68         11.04
Year22       0        13.54        12.5        14.9          14.67         10.59
Year23       0        15.74        12.16       17.33         13.37          8.75
Year24       0        15.83        11.03       18.77         16.14         10.6
Year25       0        16.05        12.39       18.4          16.89         13.18
Year26       0        17.47        13.21       18.06         16.36         12.49
Year27       0        11.76         8.64       17.4          12.5           7.08
Year28       0        20.82        14.14       19.31         18.31         16.89
Year29       0        14.35         8.14       16.77         14.06          7.91
Year30       0        18.15        10.63       18.97         16.84         14.43
Year31       0        19.2         12.85       18.25         18.16         14.02
Year32       0        18.15        14.7        16.96         16.1          13.69
Year33       0        19.57        12.03       18.07         16.81          9.59
Year34       0        15.49        10.93       14.44         14.09         13.48
Year35       0        19.22        12.63       16.8          16.8          13.19
Year36       0        16.85         8.4        14.48         13.36         12.34
Year37       0        11.26         6.85       15.99         11.15          5.93
Year38       0        16.67        12.99       16.6          16.18         10.61
Year39       0        13.13        11.79       16.27         13.4           9.2
Year40       0        18.7         11.95       18.46         16.56         12.06
Year41       0        18.77        11.06       13.02         11.12         10.08
Year42       0        17.2         15.37       14.25         12.82          9.82
Year43       0        19.98        15.79       13.47         12.57         10.35
Year44       0        15.84        11.46       17.16         17.14         14.75
Year45       0        13.4          9.62       17.4          14.36          9.9
Year46       0        17.66        11.32       18.25         18.06         13.97
Year47       0        21.12        12.86       19.53         18.12         12.53
Year48       0        18.22        11.99       14.79         14.69         11.96
Year49       0        17.63        16.57       18.41         15.52         10.46
Year50       0        12.91        11.05       11.66          7.68          7.4
+
          CLEV.CLS1     CLEV.CLS2    CLEV.CLS3  COAL.CLS1  COAL.CLS2     COAL.CLS3
Year1       17.91         17.56        14.74        0        16.83         11.63
Year2       14.61         12.36         9.78        0        18.01          9.96
Year3       16.67         15.79        13.52        0        16.59         11.87
Year4       19.07         18.83        16.46        0        17.66          9.82
Year5       20.83         19.77        17.23        0        19.78         11.88
Year6       20.03         17.6         15.35        0        14.32         13.11
Year7       19.52         19.48        17.64        0        14.97         14.01
Year8       18.9          17.97        15.22        0        15.63         12.21
Year9       16.87         15.36        12.98        0        16.29         11.72
Year10      18.19         16.77        13.95        0        18.5          15
Year11      14.9          13.36        11.2         0        18.23         11.19
Year12      20.68         20.57        18.51        0        12.88         11.53
```

Year13	19.48	18.51	15.45	0	17.58	15.68
Year14	19.76	19.74	14.99	0	18.02	15.73
Year15	19.55	17.14	13.66	0	17.72	13.04
Year16	20.01	13.51	10.65	0	16.69	11.1
Year17	19.75	17.36	14.79	0	19.58	9.55
Year18	18.16	18.12	13.43	0	17.6	12.45
Year19	19.98	17.25	13.38	0	19.13	12.85
Year20	16.32	15.65	12.51	0	14.58	11.6
Year21	18.04	16.81	10.48	0	12.98	11.76
Year22	17.25	17.2	13.71	0	18.89	10.29
Year23	19.29	18.55	15.18	0	17.4	9.92
Year24	19.18	18.87	16.74	0	18.36	14.02
Year25	18.41	17.48	15.64	0	14.87	13.54
Year26	18.1	17.09	15.36	0	15.05	12.37
Year27	18.92	16.38	12.32	0	18.47	8.1
Year28	17.29	16.82	14.09	0	15.01	13.4
Year29	17.03	16.78	12.67	0	12.84	8.9
Year30	17.32	16.4	15.49	0	12.97	10.18
Year31	19.4	18.28	17.9	0	13.3	12.55
Year32	16.89	16.39	15.46	0	13.87	13.36
Year33	18.62	17.25	14.9	0	13.5	12.69
Year34	15.54	12.11	11.72	0	16.63	13.44
Year35	18.74	18.62	17.65	0	15.9	14.22
Year36	16.26	15.63	14.41	0	17.02	11.58
Year37	16.7	11.62	9.01	0	14.92	7.04
Year38	19.36	18.13	14.93	0	17.32	13.38
Year39	17.84	12.73	11.84	0	15.45	9.7
Year40	19.92	18.29	16.75	0	18.89	12.38
Year41	19.91	16.8	16.13	0	17.97	11.59
Year42	19.53	13.63	10.56	0	18	13.03
Year43	20.67	13.43	10.79	0	17.67	11.75
Year44	20.03	13.66	12.94	0	18.95	12.2
Year45	16.14	14.65	12.27	0	14.33	8.3
Year46	18.15	17.55	13.77	0	18.23	13.28
Year47	19.15	16.3	14.78	0	19.77	13.81
Year48	17.29	13.5	11.21	0	12.86	12.21
Year49	18.91	12.9	10.39	0	15.72	12.56
Year50	15.13	9.51	7.8	0	14.66	9.48

+

	CREK.CLS1	CREK.CLS2	CREK.CLS3	GRAV.CLS1	GRAV.CLS	GRAV.CLS3
Year1	14.99	11.89	8.89	14.7	14.7	14.54
Year2	16.22	10.44	9.95	13.41	13.41	12.71
Year3	16.52	12.42	12.1	12.04	12.04	11.59
Year4	17.92	11.07	10.8	14.1	14.1	13.63
Year5	18.67	13.5	13.04	13.13	13.13	12.77
Year6	18.68	13.91	12.45	13.79	13.79	12.66
Year7	17.35	12.65	11.17	17.21	17.21	17.16
Year8	17.82	10.58	10.25	16.94	16.94	16.82
Year9	13.57	10.15	9.61	13.65	13.65	12.36
Year10	19.09	14.86	11.13	17.23	17.23	16.68
Year11	16.9	8.04	7.62	16.18	16.18	13.1
Year12	14.69	12.14	11.61	16.71	16.71	16.01
Year13	15.3	14.58	13.27	16.23	16.23	16.21
Year14	16.41	13.93	13.9	13.67	13.67	12.35
Year15	17.42	11.2	10.71	17.27	17.27	17.27
Year16	15.23	9.28	7.73	15.67	15.67	15.5
Year17	14.46	8.8	7.7	12.73	12.73	11.86
Year18	18.61	11.77	11.42	16.38	16.38	15.13
Year19	12.6	9.33	9.01	13.54	13.54	12.63
Year20	14.11	10.54	10	16.67	16.67	16.49
Year21	16.7	10.58	8.92	16.4	16.4	15.41
Year22	15.92	8.55	8.16	16.2	16.2	14.01
Year23	17.03	10.43	9.81	16.96	16.96	15.19
Year24	15.92	9.89	9.45	14.62	14.62	14.3
Year25	15.34	10.55	10.38	14.38	14.38	13.55
Year26	15.53	10.5	9.98	15.3	15.3	14.69
Year27	16.52	6.32	6.21	14.86	14.86	14.31
Year28	17.83	14.38	14.06	17.46	17.46	17.42
Year29	14.23	6.25	5.66	13.87	13.87	12.05
Year30	17.22	13.37	12.41	16.79	16.79	15.83
Year31	14.91	14.11	13.31	17.71	17.71	16.9

Year32	15.78	10.58	8.93	16.49	16.49	16
Year33	18.98	15.16	14.89	17.52	17.52	15.66
Year34	13.64	13.19	9.41	11.85	11.85	10.47
Year35	17.88	11.72	10.52	15.69	15.69	15.36
Year36	17.34	12.42	12.37	16.42	16.42	15.51
Year37	12.64	5.77	4.73	12.31	12.31	11.71
Year38	16.73	13.13	11.57	17.92	17.92	17.86
Year39	15.35	10.17	9.74	13.14	13.14	13.02
Year40	16.28	11.31	10.94	17.72	17.72	17.61
Year41	16.18	11.76	11.09	17.05	17.05	16.98
Year42	18.4	16.52	14.68	17.14	17.14	17.09
Year43	18.09	10.65	10.11	19.51	19.51	19.51
Year44	17.44	15.58	11.23	17.13	17.13	15
Year45	17.09	9.8	9.07	13.06	13.06	12.24
Year46	15.73	15.47	13.66	16.06	16.06	13.24
Year47	15.45	12.86	12.04	16.88	16.88	16.46
Year48	14.21	10.99	10.27	16.49	16.49	16.24
Year49	16.87	14.72	14.37	16.19	16.19	15.57
Year50	14.14	8.46	7.86	12.05	12.05	10.24

+

	GRAD.CLS1	GRAD.CLS2	GRAD.CLS3	HASK.CLS1	HASK.CLS2	HASK.CLS3
Year1	18.76	18.76	18.16	19.16	17.95	17.95
Year2	14.04	14.04	9.32	17.34	8.71	8.71
Year3	13.98	13.98	12.81	18.11	12.56	12.56
Year4	17.56	17.56	16.23	20.76	15.82	15.82
Year5	17.04	17.04	15.71	19.92	14.49	14.49
Year6	15.46	15.46	13.46	20.95	17.87	17.87
Year7	13.7	13.7	12.69	17.38	16.09	16.09
Year8	13.98	13.98	12.88	18.91	12.53	12.53
Year9	7.59	7.59	6.12	15.54	13.87	13.87
Year10	10.86	10.86	9.31	19.16	18.4	18.4
Year11	12.17	12.17	10.79	18.77	13.73	11.13
Year12	17.39	17.39	15.84	18.68	13.48	13.48
Year13	16.08	16.08	13.61	17.09	14.87	14.87
Year14	17.34	17.34	17.22	17.71	16.54	16.54
Year15	18.53	18.53	13.16	19.06	17.21	17.21
Year16	14.36	14.36	12.44	17.64	14.02	14.02
Year17	13.66	13.66	12.14	17.47	11.7	11.7
Year18	16.11	16.11	14.54	17.1	14.97	14.97
Year19	11.41	11.41	10.32	15.71	12.37	12.37
Year20	15.87	15.87	14.49	15.94	15.64	15.64
Year21	18.77	18.77	17.83	17.82	17.07	17.07
Year22	14.46	14.46	11.6	16.81	13.64	12.09
Year23	17.05	17.05	12.52	18.61	17.59	17.59
Year24	15.13	15.13	14.8	17.3	15.99	15.99
Year25	15.5	15.5	13.92	16.31	13.49	13.49
Year26	16.9	16.9	15.31	16.95	15.82	15.82
Year27	18.17	18.17	12.7	18.52	14.42	14.42
Year28	16.45	16.45	16.41	18.16	16.33	16.33
Year29	14.8	14.8	14.54	14.36	10.83	10.83
Year30	17.12	17.12	15.38	18.55	14.73	14.73
Year31	16.99	16.99	13	19.75	18.16	18.16
Year32	15.17	15.17	12.04	15.06	14.8	14.8
Year33	17.76	17.76	13.27	19.86	19.01	18.17
Year34	12.71	12.71	10.35	12.31	10.68	10.68
Year35	16.18	16.18	15.77	19.2	14.17	14.17
Year36	16.25	16.25	14.35	18.37	16.1	16.1
Year37	14.4	14.4	10.86	16.89	13.06	13.06
Year38	16.04	16.04	13.84	16.53	16.16	16.16
Year39	12.05	12.05	9.48	18	14.11	14.11
Year40	16.65	16.65	13.01	18.42	15.47	15.47
Year41	14.49	14.49	11.13	18.73	15.84	15.84
Year42	15.87	15.87	13.82	18.34	16.38	16.38
Year43	14.83	14.83	12.75	18.35	16.09	16.09
Year44	15.83	15.83	14.46	18.67	16.71	15.02
Year45	13.64	13.64	12.21	17.67	14.37	14.37
Year46	17.13	17.13	15.99	18.74	17.82	17.82
Year47	19.08	19.08	18.47	17.8	17.26	17.26

Year48	16.56	16.56	15.58	16.12	11.8	11.8
Year49	16.04	16.04	14.12	18.31	16.62	16.62
Year50	11.38	11.38	8.31	15.53	10.06	10.06

+

	HUGH.CLS1	HUGH.CLS2	HUGH.CLS3	JOHN.CLS1	JOHN.CLS2	JOHN.CLS3
Year1	16.54	16.37	15.29	17.06	16.35	10.49
Year2	16.5	16.07	11.77	18.52	12.01	7.88
Year3	15.47	15.26	13.01	15.52	13.79	11.18
Year4	16.27	16.16	14.15	16.87	15.69	11.71
Year5	16.04	15.93	13.18	18.64	17.12	11.41
Year6	16.86	16.01	14.28	18.22	16.16	10.25
Year7	16.57	15.45	13.17	16.58	14.6	13.8
Year8	18.26	17.74	16.08	19.1	17.82	12.14
Year9	16.54	16.38	14.85	17.34	15.41	10.48
Year10	18.47	18.17	16.65	19.25	18.91	13.73
Year11	17.15	17.13	13.22	18.53	15.35	11.49
Year12	17	16.36	14.39	16.11	14.42	13.59
Year13	15.17	14.57	13.64	16.93	16.9	14.01
Year14	14.88	12.58	10.61	20.05	18.08	15.03
Year15	19.21	17.07	11.8	16.34	14.61	10.7
Year16	17.26	17	15.46	17.55	14.71	11.04
Year17	14.94	14.61	12.57	21.02	15.15	13.1
Year18	15.13	14.92	13.15	19.56	19.03	12.36
Year19	9.88	9.67	8.97	19.55	12.16	9.72
Year20	15.75	15.41	14.46	15.27	15.21	14.06
Year21	13.71	12.75	10.16	19.99	16.88	11.85
Year22	16.76	16.47	15.13	18.55	13.76	10.95
Year23	17.65	17.61	14.99	18.25	15.7	11.3
Year24	14.54	14.53	12.86	17.37	14.2	12.68
Year25	16.42	16.28	14.48	17.3	16.95	12.86
Year26	17.15	16.92	15.52	17.16	16.24	13.97
Year27	17.07	17.06	12.44	19.43	15.11	8.91
Year28	17.82	17.63	17.6	17.58	15.61	12.01
Year29	12.79	11.24	10.35	13.83	13.23	6.34
Year30	14.09	13.48	12.07	17.53	16.06	13.56
Year31	12.63	11.66	10.08	20.79	17.33	11.1
Year32	14.33	13.58	12.42	16.88	15.34	13.26
Year33	19	18.82	16.19	17.57	17.37	11.92
Year34	16.02	15.37	13.15	16.41	13.28	12.36
Year35	15.43	14.32	12.6	20.76	15.23	11.51
Year36	17.36	17.27	15.88	18.59	15.05	9.7
Year37	15.79	15.22	9.67	16.35	11.4	7.06
Year38	16	14.45	12.21	17.87	14.59	11.79
Year39	16.43	16.03	12.83	16.86	11.19	10.06
Year40	16.4	16.02	13.48	19.16	17.76	12.89
Year41	16.63	16.61	15.3	17.79	16.59	15.23
Year42	17.72	17.71	15.36	19.05	16.68	11.62
Year43	16.86	15.01	12.77	21.14	18.38	14.29
Year44	16.62	16.55	16.18	18.89	17.4	13.52
Year45	13.48	13.38	11.11	15.52	13.32	8.01
Year46	16.38	16.29	11.5	18.86	18.32	11.84
Year47	17.32	16.97	15.01	20.05	17.54	14.44
Year48	15.76	14.65	12.63	15.38	13.95	11.67
Year49	16.2	15.78	15.09	17.39	16.57	12.42
Year50	12.14	10.48	9.84	15.66	11.89	10.1

+

	LOGN.CLS1	LOGN.CLS2	LOGN.CLS3	LINC.CLS1	LINC.CLS2	LINC.CLS3
Year1	18.38	17.95	15.95	18.49	16.96	11.26
Year2	15.88	15.04	14.86	15.38	10.9	9.77
Year3	16.9	13.64	10.8	18.68	18.41	15.55
Year4	15.94	12.6	10.36	19.9	18.9	13.73
Year5	17.99	15.73	13.03	17.58	13.82	10.8
Year6	19.24	18.16	17.96	19.99	18.85	13.85
Year7	14.14	12.98	12.86	18.2	15	12.11
Year8	17.91	16.95	15.91	17.71	15.52	11.66
Year9	13.08	10.58	10.01	13.17	12.44	10.77
Year10	15.84	14.85	14.42	18.83	17.98	12.58
Year11	12.96	12.52	12.18	15.21	12.37	7.84
Year12	19.37	18.44	16.32	17.24	15.57	13.52
Year13	18.88	18.69	18.07	19.35	16.2	15.24
Year14	18.85	18.39	15.7	19.52	17	11.36

Year15	15.77	10.84	10.08	20.22	15.11	12.23
Year16	14.76	12.53	11.6	14.65	12.78	10.77
Year17	13.85	12.66	12.03	15.96	14.74	12.22
Year18	17.64	15.7	14.74	18.91	16.91	14
Year19	12.62	11.71	10.12	12.7	11.64	9.2
Year20	14.65	12.04	11.05	14.67	13.74	12.17
Year21	16.66	14.86	10.63	9.62	9.61	8.58
Year22	11.8	11	10.81	17.54	16.95	11.28
Year23	16.05	11.34	9.37	17.18	16.88	11.72
Year24	17.07	16.89	15.3	15.75	12.58	11.15
Year25	15.63	14.9	11.9	17.85	17.21	13.87
Year26	16.67	16.03	14.63	19.95	18.4	13.86
Year27	14.88	10.81	8.95	19.55	12.06	7.15
Year28	19.64	19.6	18.54	20.06	20.04	17.97
Year29	15.1	13.51	8.93	14.99	12.52	8.35
Year30	13.33	11.63	11.46	19.44	18.58	16.57
Year31	19.62	17.32	15.15	15.04	14.36	13.59
Year32	16.27	15.52	12.65	13.47	12.78	12.71
Year33	17.78	14.69	13.72	18.74	16.16	15.32
Year34	13.48	10.49	9.07	11.85	10.87	10.2
Year35	18.68	18.38	17.35	19.49	19.4	13.61
Year36	17.87	15.02	14.7	18.46	18.37	13.99
Year37	14.55	12.84	10.45	15.66	14.56	7.79
Year38	17.47	15.1	15.01	18.68	16.68	12.83
Year39	16.87	14.14	12.32	18.61	14.44	9.95
Year40	17.15	16.58	14.06	18.89	16.32	15.3
Year41	18.49	17.37	16.58	19.43	18.16	14.21
Year42	18.59	16.18	15.16	18.65	17.95	16.17
Year43	18.93	17.9	17.34	18.76	16.8	11.34
Year44	18.44	17.46	17.18	20.11	19.53	13.84
Year45	15.71	14.51	13.94	16.71	14.56	10.22
Year46	15.52	14.91	12.91	16.27	12.23	10.41
Year47	19.79	19.68	16.45	18.87	17.54	12.18
Year48	17.17	16.5	15.75	16.32	16.09	13.01
Year49	17.24	13.31	12.51	18.69	17.21	13.05
Year50	12.56	8.87	8.14	13.02	8.65	8.35

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	McCL.CLS1	McCL.CLS2	McCL.CLS3	McIN.CLS1	McIN.CLS2	McIN.CLS3
Year1	17.68	15.66	11.84	16.32	16.32	14.01
Year2	16.91	11.89	8.79	16.7	16.7	10.67
Year3	15.58	13.98	12.01	14.53	14.53	13.4
Year4	18.4	17.59	12.72	15.15	15.15	13.48
Year5	17.38	13.65	12.16	17.42	17.42	16.06
Year6	17.29	16.8	15.28	15.37	15.37	14.83
Year7	19.67	19.58	16.51	14.65	14.65	12.05
Year8	18.02	17.74	12.67	16.4	16.4	14.32
Year9	16.17	13.45	10.58	15.28	15.28	10.97
Year10	18.29	16.85	13.18	15.8	15.8	14.96
Year11	17.62	11.92	7.72	15.69	15.69	10.51
Year12	18.92	17.22	14.93	16.23	16.23	14.64
Year13	18.02	17.94	13.66	15.58	15.58	15.14
Year14	14.75	12.77	12.1	16.57	16.57	15.98
Year15	19.65	15.92	11.63	16.73	16.73	14.84
Year16	14.74	10.22	9.67	15.77	15.77	15.27
Year17	13.58	12.97	10.73	15.7	15.7	11.93
Year18	12.85	12.29	9.29	18.93	18.93	15.58
Year19	12.53	10.46	7.53	15.48	15.48	12.83
Year20	16.68	15.04	12.47	15.93	15.93	13.14
Year21	19.43	18.89	13.8	14.38	14.38	13.46
Year22	14.51	11.6	9.23	15.75	15.75	13.97
Year23	10.45	10.27	7.76	14.24	14.24	12.44
Year24	14.11	12.74	10.72	18.36	18.36	14.61
Year25	16.52	14.2	12.54	15.43	15.43	15.03
Year26	16.7	15.78	12.89	16.9	16.9	16.21
Year27	16.78	11.28	5.33	17.66	17.66	12.19
Year28	20.55	20.24	18.12	17.86	17.86	14.57
Year29	17.49	16.64	8.87	13.43	13.43	12.79
Year30	19.46	17.45	14.35	15.85	15.85	13.35
Year31	20.2	18.44	13.74	13.07	13.07	10.53
Year32	17.78	15.18	14.68	16.21	16.21	13.25
Year33	12.77	12.72	10.46	15.45	15.45	13.39

Year34	13.94	12.71	10.03	14.22	14.22	14.11
Year35	18.26	18.24	14.29	17.12	17.12	15.15
Year36	17.4	16.44	13.67	18.35	18.35	17.77
Year37	14.83	10.96	6.98	14.59	14.59	10.79
Year38	18.63	16.68	12.87	13.32	13.32	12.37
Year39	15.54	12.91	9.29	13.86	13.86	13.75
Year40	19.67	18.6	13.1	13.31	13.31	13.03
Year41	19.12	18.8	15.02	16.11	16.11	12.48
Year42	19.48	17.99	14.72	18.09	18.09	16.34
Year43	19.24	17.92	13.55	17.96	17.96	14.22
Year44	19.45	15.11	10.87	17.85	17.85	14.36
Year45	16.73	14.06	10.49	11.83	11.83	9.79
Year46	14.59	12.4	11.08	16.54	16.54	15.31
Year47	20.67	18.81	14.44	16.34	16.34	16.07
Year48	16.77	15.27	12.8	16.43	16.43	16.29
Year49	17.68	17	11.65	14.79	14.79	11.92
Year50	14.29	8.59	8.5	11.4	11.4	10.65

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	MURR.CLS1	MURR.CLS2	MURR.CLS3	MUSK.CLS1	MUSK.CLS2	MUSK.CLS3
Year1	17.75	17.68	12.37	15.9	15.89	15.83
Year2	17.47	11.79	8.28	14.94	14.64	14.02
Year3	15.52	14.86	12.96	16.27	16.1	16.04
Year4	16.98	15.14	10.64	17.31	17.31	17.3
Year5	18.06	14.75	13.17	18.3	16.89	16.13
Year6	19.23	17.32	11.88	18.77	18.24	17.37
Year7	18.1	17.36	14.7	16.4	14.82	13.7
Year8	18.18	16.09	10.78	17.62	17.53	17.43
Year9	17.22	14.39	10.53	17.47	17.29	16.95
Year10	19.64	18.77	12.69	17.97	17.95	17.59
Year11	18.85	15.79	11.63	18.48	17.85	17.79
Year12	17.81	16.72	16.28	13.83	12.47	11.45
Year13	18	16.22	14.25	15.26	15.04	13.73
Year14	19.51	16.54	14.46	17.84	17.58	17.16
Year15	18.28	13.25	11.07	16.18	15.88	14.91
Year16	16.44	13.28	11.51	17.76	17.58	17.41
Year17	16.53	15.14	12.71	18.31	17.66	17.66
Year18	20.32	17.56	14.49	16.48	15.87	15.77
Year19	12.83	11.59	9.85	15.21	13.35	13.04
Year20	17.46	16.31	13.56	16.94	16.33	14.71
Year21	14.49	14.06	12.17	15.07	14.66	14.15
Year22	15.65	13.13	11.74	8.75	8.46	8.04
Year23	18.79	15.83	10.72	14.98	14.79	14.7
Year24	16.45	16.09	10.4	18.39	17.75	17.62
Year25	17.53	15.06	11.71	16.83	15.13	13.73
Year26	17.6	16.85	12.9	16.44	16.17	15.6
Year27	18.38	13.49	8.05	17.19	17.06	16.24
Year28	18.97	18.92	15.46	14.41	12.73	11.4
Year29	16.03	15.31	8.62	15.27	15.1	12.68
Year30	16.03	15.52	15.24	17.12	16.96	15.76
Year31	20.11	19.84	13.82	11.86	10.12	8.42
Year32	17.71	16.89	14.34	15.09	14.7	14
Year33	18.39	16.82	14.14	18.14	17.77	16.35
Year34	15.93	14.01	12.91	11.5	10.63	10.59
Year35	19.03	18.88	15.23	17.74	17.65	17.01
Year36	18.28	18.16	11.85	16.56	16.56	16.29
Year37	14.9	11.69	7.77	15.4	15.33	14.89
Year38	18.97	18.84	14.77	13.5	12.21	10.95
Year39	17.71	11.76	8.73	16.25	16.05	15.42
Year40	19.12	17.29	12.15	16.82	16.74	16.45
Year41	18.49	17.03	15.48	16.43	16.07	15.86
Year42	19.64	19.25	15.23	16.46	16.42	15.97
Year43	20.45	16.4	9.8	17.48	17.32	14.77
Year44	18.88	16.96	14.34	17.06	17.05	16.23
Year45	15.58	13.03	7.58	16.17	15.99	15.81
Year46	17.4	14.6	13.01	17.71	15.78	15.3
Year47	21.07	16.62	13.9	15.91	14.47	13.36
Year48	17.09	16.98	12.32	14.35	14.09	13.86
Year49	17.37	15.33	9.98	16.76	16.73	16.03
Year50	12.7	10.84	9.07	14.05	13.89	13.75

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	NOBL.CLS1	NOBL.CLS2	NOBL.CLS3	OKFU.CLS1	OKFU.CLS2	OKFU.CLS3

Year1	16.92	16.23	10.65	20.3	19.12	19.12
Year2	15.88	13.77	12.55	19.18	16.51	16.51
Year3	15.61	13.73	12.25	20.19	20.01	20.01
Year4	14.39	12.13	9.54	22	16.42	16.42
Year5	14.09	13.15	10.5	21.83	17.36	17.36
Year6	16.55	15.52	14.17	21.95	19.49	19.49
Year7	14.42	13.14	12.32	19.1	18.85	18.85
Year8	18.8	18.8	16.56	20.56	16.48	16.48
Year9	13.18	11.17	8.05	18.41	18.38	18.38
Year10	16.86	15.83	13.08	20.6	20.55	20.55
Year11	14.55	13.04	9.54	19.41	16.47	16.14
Year12	17.31	17.22	12.2	18.14	16.84	16.84
Year13	16.83	16.61	14.94	20.07	20.01	20.01
Year14	15.98	14.09	13.47	17.81	16.75	16.75
Year15	16.39	10.26	9.41	21.03	14.91	14.91
Year16	15.68	15.08	11.56	18.96	18.57	18.57
Year17	12.85	10.74	8.65	15.6	13.28	13.28
Year18	16.32	14.06	11.09	20.74	19.88	19.88
Year19	14.93	14	10.23	14.64	11.9	11.9
Year20	15.7	13.57	12.71	19.22	18.27	18.27
Year21	14.5	12.67	8.33	19.83	18.4	18.4
Year22	15.99	13.58	8.37	15.35	14.85	13.79
Year23	15.44	10.41	5.15	17.75	16.49	16.49
Year24	16.43	15.74	11.97	16.69	14.73	14.73
Year25	17.99	15.97	13.54	19.81	15.23	15.23
Year26	13.88	12.69	8.45	19.46	18.42	18.42
Year27	15.81	11.59	7.35	16.68	16.58	16.58
Year28	15.4	15.37	14.95	18.19	17.21	17.21
Year29	15.17	13.21	8.39	15.14	14.47	14.47
Year30	14.31	10.96	10.67	17.46	17.23	17.23
Year31	18.83	18.64	15.35	12.82	11.04	11.04
Year32	15.67	14.82	11.86	14.52	12.39	12.39
Year33	16.69	16.34	10.6	15.41	13.83	12.96
Year34	14.88	12.81	12.04	10.99	10.12	10.12
Year35	16.87	14.24	13.75	17.08	16.95	16.95
Year36	18.34	16.58	12.92	18.4	17.56	17.56
Year37	11.89	10.15	6.63	13.85	12.31	12.31
Year38	14.92	13.6	13.53	14.65	13.34	13.34
Year39	13.77	13.22	9.68	15.85	15.49	15.49
Year40	15.16	13.69	10.58	19.29	17.72	17.72
Year41	17.48	16.9	15.16	16.63	15.86	15.86
Year42	18.1	15.66	12.93	18.77	18.68	18.68
Year43	19.34	16.11	9.84	17.83	15.77	15.77
Year44	16.73	15.33	12.61	18.47	18	16.96
Year45	15.05	12.87	7.98	17.36	15.22	15.22
Year46	15.08	13.54	12.75	17.81	15.41	15.41
Year47	17.56	14.94	13.02	15.83	12.51	12.51
Year48	16.25	13.67	11.13	14.02	11.67	11.67
Year49	18.11	15.45	11.36	16.62	14.1	14.1
Year50	9.13	5.89	5.6	13.93	10.23	10.23

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	OKLA.CLS1	OKLA.CLS2	OKLA.CLS3	OKMU.CLS1	OKMU.CLS2	OKMU.CLS3
Year1	18.57	18.13	17.88	17.49	17.06	17.04
Year2	18.01	17.88	12.24	16.43	16.14	11.24
Year3	17.87	17.74	15.72	16.99	16.39	10.77
Year4	15.84	15.61	13.61	18.53	18.46	15.54
Year5	18.26	17.83	17.19	14.83	13.39	10.29
Year6	16.43	16.28	14.42	18.53	18.49	14.26
Year7	18.45	18.22	17.03	18.18	17.22	15.33
Year8	19.33	19.21	18.45	19.17	19.1	11.62
Year9	16.88	16.33	14.16	15.1	15.03	13.22
Year10	17.8	16.63	15.41	17.75	17.61	16.62
Year11	14.16	13.59	12.52	16.67	16.54	9.58
Year12	17.06	16.14	15.78	12.65	10.45	10.32
Year13	19.16	18.48	17.12	16.95	16.79	15.65
Year14	16.45	14.61	12.78	17.97	17.61	16.87
Year15	16.99	16.8	9.47	17.25	17.25	11.91
Year16	17.5	16.97	15.13	16.51	16.22	12.86
Year17	16.61	16.05	14.21	16.84	14.39	11.56
Year18	18.76	18.74	17.14	18.86	18.83	15.11
Year19	14.86	14.62	11.88	14.77	14.76	11.55

Year20	18.17	17.27	15.14	17.76	17.69	16.13
Year21	19.41	19.01	17.72	16.77	15.44	12.23
Year22	18.15	18.05	14.31	14.67	13.14	10.67
Year23	18.22	18.09	11.81	17.97	17.96	11.55
Year24	18.08	17.61	14.61	17.22	15.43	11.06
Year25	16.51	15.67	13.7	13.58	11.8	10.08
Year26	17.96	17.38	17.07	17.3	17.16	15.09
Year27	18.86	18.63	12.99	18.41	18.31	12.69
Year28	20.78	20.09	19.09	20.24	17.83	15.3
Year29	16.49	15.23	14.63	16.33	14.73	12.14
Year30	17.94	17.76	16.91	17.5	17.24	15.32
Year31	19.51	17.99	16.18	19.25	17.61	15.37
Year32	16.14	15.05	13.6	16.41	14.67	12.85
Year33	18.7	18.46	13.68	16.91	16.71	15.42
Year34	14.37	13.4	10.22	10.92	10.34	10.32
Year35	18.09	17.22	14.22	16.15	15.9	15.71
Year36	18.61	18.53	15.16	13.92	13.74	12.56
Year37	15.32	15.15	9.62	14.9	14.61	10.34
Year38	17.64	17.59	17.35	10.85	9.98	9.48
Year39	18.09	17.93	13.25	13.05	13	11.84
Year40	19.83	19.64	18.08	16.02	14.72	14.14
Year41	19.63	18.25	17.22	14.97	13.88	13.55
Year42	19.43	19.31	15.66	15.93	15.63	15.2
Year43	17.15	16.62	14.64	15.41	15.21	11.14
Year44	19.54	19.03	15.9	17.68	17.59	17.01
Year45	15.89	15.87	13.3	15.63	15.57	10.62
Year46	18.38	17.15	15.68	17.11	15.5	12.06
Year47	17.68	17.32	16.35	11.53	10.14	9.72
Year48	17.78	17.47	17.2	15.03	14.52	14.37
Year49	17.14	16.55	15.9	17.84	17.4	16.03
Year50	15.15	15.14	11.78	13.45	13.36	9.75

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	OSAG.CLS1	OSAG.CLS2	OSAG.CLS3	PAWN.CLS1	PAWN.CLS2	PAWN.CLS3
Year1	18.42	18.38	12.82	18.67	18.66	13.7
Year2	18.42	12.36	9.05	16.57	10.46	9.7
Year3	16.46	15.15	13.93	14.75	13.2	12.73
Year4	20.32	17.94	15.39	17.32	16.05	14.05
Year5	16.09	13.13	12.86	13.24	12.25	10.58
Year6	17	16.96	15.8	19.06	18.43	15.8
Year7	16.07	15.13	13.95	17.61	15.36	12.59
Year8	20.15	18.7	14.07	19.64	18.14	15.58
Year9	17.43	15.45	12.26	14.46	11.93	9.39
Year10	17.05	16.19	12.24	17.15	16.85	15.36
Year11	19.31	18.61	13.82	16.43	14.45	12.29
Year12	17.98	17.86	12.09	17.35	17.03	12.82
Year13	19.38	19	15	19.68	18.01	14.65
Year14	14.53	13.3	11.74	16.31	16.25	13.08
Year15	17.99	14.79	12.24	17.19	12.13	10.31
Year16	17.88	16.69	12.67	16.32	14.98	11.98
Year17	18.46	14.53	10.92	15.71	14.3	12.08
Year18	17.73	17.4	14.61	15.28	12.85	10.5
Year19	15.93	13.22	9.55	15.84	13.85	9.61
Year20	16.12	13.97	12.5	14.26	12.53	11.01
Year21	18.67	15.81	9.22	17.93	15.73	12.18
Year22	15.99	15.64	10.4	15.83	15.78	10.79
Year23	17.25	14.4	9.85	16.45	13.58	8.95
Year24	18.08	16.24	10.75	18.44	18.06	13.72
Year25	19.46	18.62	12.85	18.78	16.79	13.72
Year26	17.49	16.46	14.88	16.9	15.32	11.96
Year27	15.21	13.87	7.93	17.53	14.04	7.95
Year28	11.61	10.71	10.42	17.33	15.17	12
Year29	13.74	12.52	11.54	19.99	16.22	11.05
Year30	17.02	15.79	13.53	16.42	12.82	11.25
Year31	15.05	13.48	12.57	18.74	18.69	15.22
Year32	12.13	11.83	10.13	16	15.25	13.89
Year33	16.46	15.21	14.11	18.4	17.76	13.1
Year34	16.84	15.93	10.83	17.93	17.22	14.36
Year35	19.67	15.15	12.45	18.06	15.19	12.56
Year36	13.89	12.76	11.84	14.47	13.93	12.46
Year37	14.6	13.3	11.06	15.5	13.05	7.06
Year38	14.38	13.72	12.38	14.74	13.96	13.37

Year39	11.31	10.07	7.99	16.58	15	10.41
Year40	19.85	16.1	11.89	17.93	14.98	11.25
Year41	16.91	16.01	15.19	18.26	16.84	16.62
Year42	15.98	14.98	12.34	16.85	16.37	13.29
Year43	14.75	12.66	10.02	15.91	13.76	11.99
Year44	17.86	17.17	12.68	17.62	17.14	15.29
Year45	17.18	15.21	9.2	17.31	16.63	11.63
Year46	16.33	15.5	11.35	14.85	12.6	10.18
Year47	16.19	15.14	13.03	13.11	12.17	11.68
Year48	15.42	15.18	12.15	16.06	15.79	11.06
Year49	20	18.88	14.16	19.56	18.4	15.25
Year50	13.69	8.9	8.35	13.74	9.45	7.05

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	PYNE.CLS1	PYNE.CLS2	PYNE.CLS3	PITS.CLS1	PITS.CLS2	PITS.CLS3
Year1	17.51	17.51	12.13	18.66	18.44	14.31
Year2	16.77	16.77	12.63	17.56	17.55	9.26
Year3	15.68	15.68	11.58	16.25	16.2	12.01
Year4	15	15	12.29	18.61	18.6	14.59
Year5	16.94	16.94	12.55	20.04	18.9	11.25
Year6	18.06	18.06	15.74	17.94	17.8	14.77
Year7	14.61	14.61	10.9	16.92	15	14.72
Year8	17.75	17.75	13.21	19.07	17.74	10.84
Year9	12.59	12.59	8.97	16.9	15.93	12.56
Year10	15.49	15.49	12.42	15.86	13.34	10.18
Year11	13.83	13.83	10.03	19.36	19.19	11.48
Year12	13.33	13.33	12.52	16.96	14.3	12.18
Year13	16.85	16.85	15.59	15.12	13.8	11.95
Year14	13.2	13.2	12.01	17.71	16.16	14.1
Year15	16.72	16.72	8.67	17.83	16.17	14.52
Year16	17.03	17.03	14.33	17.23	16.23	10.75
Year17	12.78	12.78	10.6	17.34	16.64	9.4
Year18	16.99	16.99	11.77	17.35	16.63	13.24
Year19	16.14	16.14	9.19	14.8	14.01	9.18
Year20	18.4	18.4	13.54	18.67	18.63	13.97
Year21	16.39	16.39	10.94	15.58	13.98	12.21
Year22	15.98	15.98	8.8	16.34	15.93	9.13
Year23	16.52	16.52	8.98	17.71	17.54	10.14
Year24	16.49	16.49	12.83	17.89	17.48	13.75
Year25	16.24	16.24	11.6	16.91	15.33	13.91
Year26	16.6	16.6	11.87	17.55	16.51	15.46
Year27	17.13	17.13	7.8	18.14	17.47	6.95
Year28	17.04	17.04	15.46	17.07	16.21	15.88
Year29	15.01	15.01	10.22	14.65	11.11	10.51
Year30	17.54	17.54	12.95	18.95	18.23	13.56
Year31	16.02	16.02	14.08	15.18	13.31	11.83
Year32	14.37	14.37	10.1	16.22	15.57	11.84
Year33	18.76	18.76	12.85	20.12	18.09	14.83
Year34	12.13	12.13	10.06	15.73	15.11	12.5
Year35	18.44	18.44	13.04	17.77	17.26	12.14
Year36	17.46	17.46	11.99	19.2	18.31	12.54
Year37	14.21	14.21	5.97	15.3	14.28	7.79
Year38	16.19	16.19	12.47	16.97	16.31	13.62
Year39	15.11	15.11	9.97	17.88	17.85	11.03
Year40	17.68	17.68	12.23	18.74	17.36	14.28
Year41	17.84	17.84	14.55	18.75	16.83	8.64
Year42	16.29	16.29	12.17	20.55	20.01	13.44
Year43	17.11	17.11	10.2	18.26	17.47	11.77
Year44	17.52	17.52	14.47	19.46	17.83	9.99
Year45	13.38	13.38	7.14	15.11	14.62	8.36
Year46	13.25	13.25	12.73	17.4	16.94	16.08
Year47	16.31	16.31	10.3	20.6	19.29	11.4
Year48	16.7	16.7	12.72	16.5	14.86	14.76
Year49	14.93	14.93	13.18	17.27	16.38	12.61
Year50	11.07	11.07	7.68	14.43	14.33	10.47

+

	PONT.CL	PONT.CLS2	PONT.CLS3	POTT.CLS1	POTT.CLS2	POTT.CLS3
Year1	15.75	15.61	11.11	17.94	15.85	11.18
Year2	15.81	13.98	9.44	17.79	12.63	10.35
Year3	15.29	12.36	11.29	18.59	18.22	14.84
Year4	16.91	14.19	10.68	20.34	17.87	13.01
Year5	17.82	15.61	13.01	20.73	17.71	13.97

Year6	15.34	14.06	12.28	19.06	16.21	12.88
Year7	18.17	18.15	15.55	19.57	18.76	14.17
Year8	21.4	19.66	13.42	19.53	15.83	10.33
Year9	16.67	15.62	10.34	16.77	13.86	11.29
Year10	17.93	16.37	14.82	19.98	17.87	13.02
Year11	18.12	14.01	10.52	17.79	13.01	9.84
Year12	13.64	12.93	10.11	18.74	17.57	16.32
Year13	17.59	15.41	13.94	19.25	18.26	13.23
Year14	17.81	14.19	13.49	15.85	14.4	13.79
Year15	18.7	12.78	10.6	20.55	16.18	12.98
Year16	17.39	16.64	14.35	17.84	15.21	12.52
Year17	16.75	13.95	10.43	18.87	15.72	12.15
Year18	20.03	17.48	14.23	18.59	18.55	13.31
Year19	11.27	10.76	9.98	20.03	19.11	12.6
Year20	17.96	16.87	15.95	16.92	16.04	13.51
Year21	13.32	11.16	10.75	13.82	11.29	10.7
Year22	17.69	16.07	11.2	16.98	16.8	11.14
Year23	17.66	12.59	7.56	18.65	17.3	11.9
Year24	16.29	16.18	11.63	20.13	17.76	14.07
Year25	16.8	15.13	11.1	15.18	14.12	13.67
Year26	18.2	17.13	10.93	18.93	16.14	15.14
Year27	16.24	10.29	4.72	16.83	14.58	7.46
Year28	18.01	17.15	15.68	18.19	15.16	13.88
Year29	15.26	14.49	6.9	13.06	12.69	8.97
Year30	18.6	18.58	15.99	17.33	15.07	14.3
Year31	14.04	13.88	11.64	19.39	17.35	15.74
Year32	16.64	15.9	12.09	16.47	15.64	14.93
Year33	17.82	15.58	14.82	17.89	16.96	12.41
Year34	14.35	12.8	10.19	16.28	14.46	12.11
Year35	15.73	15.46	13.18	19.46	17.75	15.8
Year36	17.96	16.48	12.09	16.22	15.35	14.02
Year37	15.17	12.93	7.64	14.71	11.72	6.08
Year38	18.81	18.72	15.2	18.41	18.22	13.12
Year39	15.32	11.64	8.28	16.28	13.14	10.65
Year40	17.05	14.24	9.17	18.66	17.79	12.98
Year41	17.74	15.57	13.97	18.02	15.49	10.94
Year42	18.04	14.94	11.4	18.29	17.16	14.33
Year43	19.02	16.68	11.31	19.4	19.04	14.76
Year44	17.3	16.37	12.12	19.39	19.32	12.92
Year45	12.38	10.65	7.75	16.24	14.03	9.39
Year46	15.83	13.04	12.16	17.35	16.8	12.92
Year47	16.99	15.8	13.57	20.57	18.93	14.59
Year48	14.01	13.79	12.55	17.86	13.71	12.46
Year49	16.47	15.89	12.57	17.83	17.46	13.3
Year50	11.94	10.02	8.7	13.43	8.07	7.14

+

	LATI.CLS1	LATI.CLS2	LATI.CLS3	SEMI.CLS1	SEMI.CLS2	SEMI.CLS3
Year1	0	17.1	12.82	18.85	18.85	14.01
Year2	0	13.37	8.35	19.81	19.81	12.56
Year3	0	15.72	11.01	17.98	17.98	12.18
Year4	0	18.8	13.19	18.14	18.14	12.32
Year5	0	19.32	9.24	20.5	20.5	13.96
Year6	0	18.67	14.36	21.29	21.29	14.6
Year7	0	18.34	14	18.55	18.55	14.25
Year8	0	19.27	13.64	20.51	20.51	13.08
Year9	0	18.68	13.16	18.12	18.12	13.77
Year10	0	18.8	13.89	19.09	19.09	16.17
Year11	0	15.85	8.93	18.86	18.86	10.57
Year12	0	17.97	16.84	18.38	18.38	14.44
Year13	0	19.42	17.44	18.94	18.94	13.75
Year14	0	19.02	13.53	16.6	16.6	14.21
Year15	0	17.66	14.49	19.78	19.78	11.86
Year16	0	18.04	14.23	15.91	15.91	11.64
Year17	0	17	13.62	13.79	13.79	9.6
Year18	0	17.74	13.21	19.16	19.16	14.8
Year19	0	15.89	12.49	13.71	13.71	10.67
Year20	0	16.01	14.09	18.06	18.06	14.82
Year21	0	16.5	12.24	14.8	14.8	10.96
Year22	0	12.45	9.12	16.4	16.4	8.79
Year23	0	9.03	8.84	16.58	16.58	8.78
Year24	0	19.87	14.22	14.6	14.6	10.72

Year25	0	18.87	13.48	14.01	14.01	11.84
Year26	0	9.14	8.05	16.58	16.58	10.34
Year27	0	10.15	9.87	15.35	15.35	4.5
Year28	0	12.19	9.17	18.82	18.82	15.97
Year29	0	17.7	11.63	12.56	12.56	9.23
Year30	0	17.94	12.96	17.27	17.27	13.47
Year31	0	17.49	15.24	16.28	16.28	16.01
Year32	0	17.68	13.61	16.15	16.15	10.68
Year33	0	15.87	10.58	18.74	18.74	11.67
Year34	0	16.91	13.24	13.75	13.75	12.91
Year35	0	18.86	15.33	18.37	18.37	14.18
Year36	0	17.18	14	18.2	18.2	13.57
Year37	0	13.06	9.05	15.68	15.68	7.26
Year38	0	16.07	11.6	17.93	17.93	12.86
Year39	0	13.62	11.05	17.92	17.92	10.9
Year40	0	18.33	13.97	18.89	18.89	13.41
Year41	0	17.21	10.02	17.6	17.6	13.29
Year42	0	18.44	15.69	18.76	18.76	15.92
Year43	0	18.51	13.64	18.65	18.65	11.16
Year44	0	14.3	8.87	17.83	17.83	11.88
Year45	0	15.69	10	16.29	16.29	7.58
Year46	0	18.08	14.39	16.57	16.57	12.66
Year47	0	20.23	16.22	18.96	18.96	12.73
Year48	0	17.31	14.52	16.04	16.04	12.63
Year49	0	14.2	10.6	14.9	14.9	12.12
Year50	0	12.74	9.94	13.48	13.48	9.41

+

	TULS.CLS1	TULS.CLS2	TULS.CLS3	WAGN.CLS1	WAGN.CLS2	WAGN.CLS3
Year1	18.26	18.26	16.96	18.01	17.63	17.56
Year2	14.45	14.45	14.37	17.49	17.49	17.48
Year3	15.37	15.37	14.6	17.74	17.62	17.54
Year4	17.16	17.16	14.3	18.84	18.77	18.67
Year5	18.6	18.6	14.24	21.43	21.14	20.85
Year6	18.02	18.02	15.26	22.5	22.5	22.5
Year7	17.39	17.4	13	19.46	18.71	17.69
Year8	18.45	18.46	14.33	20.58	20.53	20.51
Year9	14.77	14.74	12.63	18.82	18.17	18.09
Year10	14.57	14.58	13.98	19.76	19.74	19.45
Year11	16.13	16.13	14.54	18.44	18.07	18.02
Year12	18.27	18.27	17.13	20.07	19.81	18.78
Year13	19.71	19.71	15.96	19.44	19.11	18.93
Year14	15.53	15.54	14.97	17.47	17	16.45
Year15	16.21	16.21	15.85	19.39	19.02	18.74
Year16	15.5	15.5	13.98	17.44	17.38	17.09
Year17	13.55	13.54	11.76	15.46	14.97	14.74
Year18	16.69	16.7	16.52	19.21	19.02	17.97
Year19	12.05	12.05	11.99	17.41	17.21	16.92
Year20	17.34	17.34	15.55	19.52	19.51	19.23
Year21	13.52	13.53	12.16	17.48	17.13	16.54
Year22	13.28	13.28	11.32	17.68	17.17	15.86
Year23	15.43	15.43	14.22	18.47	18.37	18.21
Year24	18	18	15.56	20.38	16.95	15.8
Year25	15.26	15.26	14.49	16.45	15.96	15.41
Year26	18.93	18.93	14.61	18.7	18.61	18.15
Year27	17.23	17.23	12.74	18.14	18.04	16.02
Year28	17.26	17.26	17.22	19.52	18.46	17.21
Year29	13.34	13.4	9.88	18.96	15.86	12.29
Year30	12.39	12.42	11.24	19.27	19.08	19.05
Year31	18.08	18.17	17.99	18.22	16.21	14.04
Year32	14.39	14.38	11.15	16.03	15.85	15.61
Year33	17.24	17.24	11.23	19.88	19.08	17.42
Year34	17.29	17.29	15.74	15.67	13.97	12.23
Year35	17.89	17.91	11.56	19.29	19.19	19.05
Year36	16.06	16.06	10.35	16.16	16.09	15.8
Year37	14.01	14.01	7.56	16.91	16.79	15.65
Year38	14.47	14.46	12.64	15.27	14.73	14.68
Year39	13.68	13.68	9.24	12.79	12.66	12.23
Year40	15.35	15.35	8.59	20.34	19.96	19.69
Year41	16.89	16.89	9.23	19.19	19.09	17.54
Year42	16.49	16.49	9.07	18.49	18.32	16.79
Year43	16.83	16.83	8.32	17.92	17.01	15.53

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Year44        15.87        15.87        13.8         18.93        18.87        18.27
Year45        16.09        16.09        16.22        18.47        18.17        17.58
Year46        15.61        15.61         9.46        18.22        18.08        18.08
Year47        13.97        13.96         8.2         17.56        15.33        12.93
Year48        13.08        13.08         6.82        15.79        13.79        12.48
Year49        16.75        16.82         7.15        19.08        18.99        18.5
Year50        14.02        14.02         6.77        15.69        14.39        14.14
;
Scalar AvgTgT Average annual required target in Mg/700000/;
Scalar YrTgt Yearly Target in Mg/700000/;
Scalar Penalty cost of not processing one Mg /187.5/;

*/375 liters per Megagram of switchgrass feedstock
*/ wholesale ethanol price @ $2.14 per Gallon
*/http://www.ams.usda.gov/mnreports/lswethanol.pdf) around $0.5 /lites
*/ Penalty costs:$ .57*375 = $214/Mg

Variables
OBJ                         Objective Function
X(C,L)                      Hectares of land by county and land class
RAKING(T,C,L)               Hectares of land Raked
BALING(T,C,L)               Megagram Bailed
TRANSPORT(T,C,L)            Megagram Transportated
Short(T)
Exces(T)
Positive Variables
X(C,L),RAKING(T,C,L),BALING(T,C,L),TRANSPORT(T,C,L),Short(T), Exces(T);
Equations
COST                         Production costs
LAND(C,L)                    Resource Constraints
AvgTARGET(T)                 Average Target Constraints
RAKACTIVITY1(C,L)            Raking Constraints Year 1
RAKACTIVITY2(C,L)            Raking Constraints Year 2
RAKACTIVITY3(C,L)            Raking Constraints Year 3
RAKACTIVITY4(C,L)            Raking Constraints Year 4
RAKACTIVITY5(C,L)            Raking Constraints Year 5
RAKACTIVITY6(C,L)            Raking Constraints Year 6
RAKACTIVITY7(C,L)            Raking Constraints Year 7
RAKACTIVITY8(C,L)            Raking Constraints Year 8
RAKACTIVITY9(C,L)            Raking Constraints Year 9
RAKACTIVITY10(C,L)           Raking Constraints Year 10
RAKACTIVITY11(C,L)           Raking Constraints Year 11
RAKACTIVITY12(C,L)           Raking Constraints Year 12
RAKACTIVITY13(C,L)           Raking Constraints Year 13
RAKACTIVITY14(C,L)           Raking Constraints Year 14
RAKACTIVITY15(C,L)           Raking Constraints Year 15
RAKACTIVITY16(C,L)           Raking Constraints Year 16
RAKACTIVITY17(C,L)           Raking Constraints Year 17
RAKACTIVITY18(C,L)           Raking Constraints Year 18
RAKACTIVITY19(C,L)           Raking Constraints Year 19
RAKACTIVITY20(C,L)           Raking Constraints Year 20
RAKACTIVITY21(C,L)           Raking Constraints Year 21
RAKACTIVITY22(C,L)           Raking Constraints Year 22
RAKACTIVITY23(C,L)           Raking Constraints Year 23
RAKACTIVITY24(C,L)           Raking Constraints Year 24
RAKACTIVITY25(C,L)           Raking Constraints Year 25
RAKACTIVITY26(C,L)           Raking Constraints Year 26
RAKACTIVITY27(C,L)           Raking Constraints Year 27
RAKACTIVITY28(C,L)           Raking Constraints Year 28
RAKACTIVITY29(C,L)           Raking Constraints Year 29
RAKACTIVITY30(C,L)           Raking Constraints Year 30
RAKACTIVITY31(C,L)           Raking Constraints Year 31
RAKACTIVITY32(C,L)           Raking Constraints Year 32
RAKACTIVITY33(C,L)           Raking Constraints Year 33
RAKACTIVITY34(C,L)           Raking Constraints Year 34
RAKACTIVITY35(C,L)           Raking Constraints Year 35
RAKACTIVITY36(C,L)           Raking Constraints Year 36
RAKACTIVITY37(C,L)           Raking Constraints Year 37
RAKACTIVITY38(C,L)           Raking Constraints Year 38
RAKACTIVITY39(C,L)           Raking Constraints Year 39
RAKACTIVITY40(C,L)           Raking Constraints Year 40
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RAKACTIVITY41(C,L)          Raking Constraints Year 41
RAKACTIVITY42(C,L)          Raking Constraints Year 42
RAKACTIVITY43(C,L)          Raking Constraints Year 43
RAKACTIVITY44(C,L)          Raking Constraints Year 44
RAKACTIVITY45(C,L)          Raking Constraints Year 45
RAKACTIVITY46(C,L)          Raking Constraints Year 46
RAKACTIVITY47(C,L)          Raking Constraints Year 47
RAKACTIVITY48(C,L)          Raking Constraints Year 48
RAKACTIVITY49(C,L)          Raking Constraints Year 49
RAKACTIVITY50(C,L)          Raking Constraints Year 50
BALACTIVITY(T,C,L)          Baling Constraints
TRANSPORTACTIVITY(T,C,L)    Transportation Constraints
QtShort(T)                  Used to determine level of shortage for each state of nature
MaxDev
;
* The Opt*Sum(T,Short(T))/100000 is added to the objective function to illustrate how
* a penalty for shortages may be imposed for each Mg based on the conversion rate.
* The Sum of the total shortage over the 50 states of nature is(50*2,000 tons/day)
provides an estimate of the upper bound
* average number of shut days per year is 16 days obtained from model 1 (solved for avg.
yield).
* Total allowable shortage for 50 years 50*2000*14.2 =1420000.

COST..OBJ =E=
(SUM((C,L),LNDCST(C,L)*X(C,L))+RAK*SUM((T,C,L),RAKING(T,C,L)/50)+BAL*SUM((T,C,L),BALING(T
,C,L)/50)+
SUM((T,C,L),TRNSCST(T,C,L)*TRANSPORT(T,C,L)/50)+sum(t,short(t)/50)*(Penalty));
LAND(C,L)..X(C,L)=L=TOTLAND(C,L);
AvgTARGET(T)..SUM((C,L),TRANSPORT(T,C,L))=G=700000-short(t);
MaxDev..sum(t,short(t))=L=00000;
QtShort(T)..  700000 - SUM((C,L),AnYld(T,C,L)*Raking(t,C,L)) - short(T)+ Exces(T) =e= 0;
RAKACTIVITY1(C,L)..RAKING('Year1',C,L) - X(C,L) =L= 0;
RAKACTIVITY2(C,L)..RAKING('Year2',C,L) - X(C,L) =L= 0;
RAKACTIVITY3(C,L)..RAKING('Year3',C,L) - X(C,L) =L= 0;
RAKACTIVITY4(C,L)..RAKING('Year4',C,L) - X(C,L) =L= 0;
RAKACTIVITY5(C,L)..RAKING('Year5',C,L) - X(C,L) =L= 0;
RAKACTIVITY6(C,L)..RAKING('Year6',C,L) - X(C,L) =L= 0;
RAKACTIVITY7(C,L)..RAKING('Year7',C,L) - X(C,L) =L= 0;
RAKACTIVITY8(C,L)..RAKING('Year8',C,L) - X(C,L) =L= 0;
RAKACTIVITY9(C,L)..RAKING('Year9',C,L) - X(C,L) =L= 0;
RAKACTIVITY10(C,L)..RAKING('Year10',C,L) - X(C,L) =L= 0;
RAKACTIVITY11(C,L)..RAKING('Year11',C,L) - X(C,L) =L= 0;
RAKACTIVITY12(C,L)..RAKING('Year12',C,L) - X(C,L) =L= 0;
RAKACTIVITY13(C,L)..RAKING('Year13',C,L) - X(C,L) =L= 0;
RAKACTIVITY14(C,L)..RAKING('Year14',C,L) - X(C,L) =L= 0;
RAKACTIVITY15(C,L)..RAKING('Year15',C,L) - X(C,L) =L= 0;
RAKACTIVITY16(C,L)..RAKING('Year16',C,L) - X(C,L) =L= 0;
RAKACTIVITY17(C,L)..RAKING('Year17',C,L) - X(C,L) =L= 0;
RAKACTIVITY18(C,L)..RAKING('Year18',C,L) - X(C,L) =L= 0;
RAKACTIVITY19(C,L)..RAKING('Year19',C,L) - X(C,L) =L= 0;
RAKACTIVITY20(C,L)..RAKING('Year20',C,L) - X(C,L) =L= 0;
RAKACTIVITY21(C,L)..RAKING('Year21',C,L) - X(C,L) =L= 0;
RAKACTIVITY22(C,L)..RAKING('Year22',C,L) - X(C,L) =L= 0;
RAKACTIVITY23(C,L)..RAKING('Year23',C,L) - X(C,L) =L= 0;
RAKACTIVITY24(C,L)..RAKING('Year24',C,L) - X(C,L) =L= 0;
RAKACTIVITY25(C,L)..RAKING('Year25',C,L) - X(C,L) =L= 0;
RAKACTIVITY26(C,L)..RAKING('Year26',C,L) - X(C,L) =L= 0;
RAKACTIVITY27(C,L)..RAKING('Year27',C,L) - X(C,L) =L= 0;
RAKACTIVITY28(C,L)..RAKING('Year28',C,L) - X(C,L) =L= 0;
RAKACTIVITY29(C,L)..RAKING('Year29',C,L) - X(C,L) =L= 0;
RAKACTIVITY30(C,L)..RAKING('Year30',C,L) - X(C,L) =L= 0;
RAKACTIVITY31(C,L)..RAKING('Year31',C,L) - X(C,L) =L= 0;
RAKACTIVITY32(C,L)..RAKING('Year32',C,L) - X(C,L) =L= 0;
RAKACTIVITY33(C,L)..RAKING('Year33',C,L) - X(C,L) =L= 0;
RAKACTIVITY34(C,L)..RAKING('Year34',C,L) - X(C,L) =L= 0;
RAKACTIVITY35(C,L)..RAKING('Year35',C,L) - X(C,L) =L= 0;
RAKACTIVITY36(C,L)..RAKING('Year36',C,L) - X(C,L) =L= 0;
RAKACTIVITY37(C,L)..RAKING('Year37',C,L) - X(C,L) =L= 0;
RAKACTIVITY38(C,L)..RAKING('Year38',C,L) - X(C,L) =L= 0;
RAKACTIVITY39(C,L)..RAKING('Year39',C,L) - X(C,L) =L= 0;
RAKACTIVITY40(C,L)..RAKING('Year40',C,L) - X(C,L) =L= 0;
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RAKACTIVITY41(C,L)..RAKING('Year41',C,L) - X(C,L) =L= 0;
RAKACTIVITY42(C,L)..RAKING('Year42',C,L) - X(C,L) =L= 0;
RAKACTIVITY43(C,L)..RAKING('Year43',C,L) - X(C,L) =L= 0;
RAKACTIVITY44(C,L)..RAKING('Year44',C,L) - X(C,L) =L= 0;
RAKACTIVITY45(C,L)..RAKING('Year45',C,L) - X(C,L) =L= 0;
RAKACTIVITY46(C,L)..RAKING('Year46',C,L) - X(C,L) =L= 0;
RAKACTIVITY47(C,L)..RAKING('Year47',C,L) - X(C,L) =L= 0;
RAKACTIVITY48(C,L)..RAKING('Year48',C,L) - X(C,L) =L= 0;
RAKACTIVITY49(C,L)..RAKING('Year49',C,L) - X(C,L) =L= 0;
RAKACTIVITY50(C,L)..RAKING('Year50',C,L) - X(C,L) =L= 0;
BALACTIVITY(T,C,L)..BALING(T,C,L)-(AnYld(T,C,L)*RAKING(T,C,L))=L=0;
TRANSPORTACTIVITY(T,C,L)..TRANSPORT(T,C,L)-BALING(T,C,L)=L=0;
*AvgYield.. Sum((C,L),AvgYld(C,L)*X(C,L)) =G= 0;

*The 700,000 is the quantity needed for each state of nature if the facility runs
*350 days per year and requires 2,000 tons per day.
*This equation is used to compute Short(T).  In states of nature with Excess production
*Exces(T) will be greater than zero.  No penalty need be applied for excess production.
*In the objective function, the Short(T) values may be summed across all states of nature
*and divided by 50 states of nature and 2000 tons per day to obtain an estimate of the
*average number of days per year that the plant will be idle if the solved plan is
*implemented.

MODEL RETURNS/ALL/;
SOLVE RETURNS USING LP MINIMIZING OBJ;
Display X.L;
Display Raking.L;
Display Transport.L;
Display Baling.L;
Display Obj.L;
parameter Landleased Total hectares of land leased ;
Landleased=SUM((C,L),X.L(C,L)) ;
display Landleased;
parameter Raked Average hectares of land raked ;
Raked=SUM((T,C,L),Raking.L(T,C,L))/50 ;
display Raked;
parameter Totbaled Average Mg of switchgrass baled per year ;
Totbaled=SUM((T,C,L),Baling.L(T,C,L))/50 ;
display Totbaled;
parameter Transported total Mg of switchgrass transported ;
Transported=SUM((T,C,L),Transport.L(T,C,L))/50 ;
display Transported;
Display Short.L ;
display exces.l;
*Years and quantity with quantity short of 700000
Parameter IdleAvg;
IdleAvg = Sum(T,short.L(T))/100000 ;
*total feedstock demand  for 50 states of nature 50*2000 = 100000
Display IdleAvg;
Parameter CostPerYr;
CostPerYr  =   (Obj.L)/700000;
*CostPerYr  =   (Obj.L)/(700000*50);
Display CostPerYr;
Parameter ShtAvg;
ShtAvg = Sum(T,short.L(T))/50 ;
Display ShtAvg;
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VITA

Deepayan Debnath

Candidate for the Degree of

Doctor of Philosophy

Thesis: THREE ESSAYS: RESERVOIR MANAGEMENT; SWITCHGRASS LAND LEASING; AND ITS ENVIRONMENTAL IMPACT

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Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in December, 2012.

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