ESTIMATING THE DIFFERENTIAL CHANGE IN LAND USE ASSOCIATED WITH RESERVOIR CONSTRUCTION

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Much attention has been focused recently on the need for land use planning in this country. With federal land use legislation pending, it seems imperative that resource economists develop quantitative methods for evaluating and predicting land use change [4]. The need to develop appropriate estimation techniques is most apparent for land use change in areas which have received substantial investment in a relatively short period of time. Construction of multi-purpose reservoirs is the most important type of public investment that has impacted land use patterns in Oklahoma since the "dust bowl" days [8].

In previous research, impact of reservoir construction on property values, land use, housing and business activities; and spatial patterns of land use change surrounding a reservoir area were estimated [6, 9, 5, 7]. For the most part, previous studies have used the traditional "before and after," or control area approaches, coupled with regression analysis to estimate changes associated with reservoir construction. However, there are no known studies that attempt to directly quantify and project the differential impact of land use change resulting from reservoir construction. The "before and after" approach is inappropriate because it fails to distinguish the portion of land use change associated with reservoir construction from that associated with changing economic conditions. The control area approach does estimate differential land use change, but it suffers from the difficulty of finding a comparison area similar in all respects to the study area but without the presence of a reservoir. Moreover, the control area approach assumes the difference in land use changes between the two areas is solely due to reservoir construction. This paper presents the results of a research project in which a differential land use model was developed to estimate the differential impact of reservoir construction on land use change within the immediate area.[1]

The differential land use model builds upon research reported by Burnham [2], demonstrating the efficacy of a finite Markov-chain process as a land use simulation model. He concludes that the Markovian process can be adopted to project future implications of past land use trends; moreover, the process provides a framework for analyzing alternative institutional policies designed to influence future land use patterns.

The research reported herein takes the Markovian framework one step further, in that it is used to develop a differential land use model (hereafter referred to as the DLUM) of land use change. The DLUM quantifies and projects land use trends with the aid of a Markov model. Trends in land use patterns before reservoir construction are compared to actual and projected land uses, following the construction of the reservoir, to estimate differential land use change.

The following discussion will develop the DLUM, which may be used for estimating land use change associated with reservoir construction. In subsequent

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[1] The term "differential" is used here to signify the difference between land use patterns that actually exists after the construction of the reservoir and the land use pattern that would have existed in the same time period if the reservoir had never been constructed. Consequently, the differential land use impact of a reservoir is the net impact or net change generated by the original investment.

sections, the differential land use change resulting from the construction of the Keystone Reservoir in central Oklahoma will be estimated and discussed.

THE MODEL

A stationary, finite Markov chain model consists of two major components: a flow matrix and a transition probability matrix. A flow matrix summarizes the quantity of land moving from each land use into all others during a definite time period. The transition or flow from one category to another is regarded as a stochastic process with a known probability of occurrence. The matrix of these probabilities is the transition probability matrix [1].

Each ${}_{ab}P_{ij}$ element of the transition probability matrix ${}_{ab}P$ shows the probability of land in use i shifting into use j during the time period a to b. For the special case of the stationary Markov process, ${}_{ab}P$ is assumed to remain constant during the period of analysis, each ${}_{ab}P_{ij}$ element is nonnegative, and $\Sigma_{i=1}^{k} P_{ij}=1$. The requirement that the summation of the transition probability elements for each land use group assures that land may not be created or destroyed during the land use transition process.

Estimates of future land use patterns are determined by the transition probability matrix and the original state, or original distribution of the land among use categories. We shall designate the initial state as a vector Q_a of length k, and Q_b as land use at the end of the time period (i.e., the period over which the transition probability matrix ${}_{ab}P$ was computed). Then it follows that:

$$Q_b=Q_a \cdot {}_{ab}P \qquad (1)$$

Assume that land use transition is a stochastic process in which any future movement is independent of past movements, then (1) can be generalized to predict land use patterns in n, where $n \geq b$ and n=0 in a.

$${}_{ab}Q_n=Q_a[{}_{ab}P]^n \qquad (2)$$

${}_{ab}Q_n$ denotes an estimated land use vector in time period n based on a transition probability matrix constructed over the time period a,b.

Suppose a large scale public investment, such as the construction of a reservoir, occurred in the study area in time period m where $b<m<n$. Then the land use pattern predicted by (2) for time period n would deviate from the actual land use pattern observed in n. The difference between the estimated land use pattern that would have existed in n (in the absence of the reservoir construction in m), and the actual observed land use pattern in n, is the estimated differential land use impact of the reservoir construction.

Let ${}_*Q_n$ be the observed land use in n and ${}_{ab}Q_n$ be the estimated land use predicted by (2), using a transition probabilities matrix based on land use flows during the pre-investment time period. Then the differential land use impact D_n of the reservoir in time period n is:

$$D_n = {}_*Q_n - {}_{ab}Q_n = {}_*Q_n - Q_a[{}_{ab}P]^n \qquad (3)$$

Vector D_n in (3) provides a more accurate estimate of the differential land use impact of reservoir construction than "before and after" techniques frequently used in project analysis. This is because the pattern of land use change in the pre-investment time period a to b is continued to time n, thereby accounting for land use changes that would have occurred in the absence of reservoir construction, *ceteris paribus.*

What are the over-all, long-term impacts of land use change associated with reservoir construction? For information of this nature, the DLUM may be expanded to estimate projected differential land use impacts of reservoir construction. The difference between estimates of land use patterns in n, based on pre-investment and post-investment transition probabilities, is a measure of the projected differential impact of the investment. In this case, actual observations of ${}_*Q_n$ in (3) are replaced by Markovian estimates of future land use patterns based on a post-investment matrix of transition probabilities.

More specifically, let ${}_{ab}P$ (where $a<b<m$) be the transition probabilities matrix reflecting land use flow patterns before the investment and ${}_{cd}P$ (where $m<c<d$) be the transition probabilities derived between (c) and (d), both of which occur after the investment. If the reservoir construction affected the land use flow process, then ${}_{ab}P \neq {}_{cd}P$. The estimated land use pattern in (n) (where $n>d$), that would have occurred if the investment had not been made, is estimated by (2), using pre-investment transition probabilities. The land use pattern assuming construction of the projected reservoir is estimated using post-investment transition probabilities and a post-investment original state (Q_c):

$${}_{cd}Q_n = Q_c[{}_{cd}P]^{n-c} \qquad (4)$$

The difference between the estimates in (2) and (4) is the projected differential land use impact ($\hat{D}_n$) of the investment at time n.

$$\hat{D}_n = {}_{cd}Q_n - {}_{ab}Q_n = Q_c[{}_{cd}P]^{n-c} - Q_a[{}_{ab}P]^n \quad (5)$$

If ${}_{cd}P$ and ${}_{ab}P$ are regular transition matrices, then (5) may be estimated for any $n>d$ including $n=\infty$. As $n \to \infty$ ${}_{ab}P$ and ${}_{cd}P$ approach equilibrium steady states in which net land use transitions in each will be zero. Estimates of (5) for $n=\infty$ provide an estimate of eventual, total land use impact of the reservoir development in which all land use adjustments attributable to the investment are considered. These estimates should be of special interest in analyzing and evaluating the long term impacts of reservoir construction.

EMPIRICAL RESULTS

The DLUM was used to estimate and project differential land use change in the area of the Keystone Lake. Keystone is a large multiple-purpose reservoir project located approximately 20 miles west of Tulsa, Oklahoma. Construction of the reservoir began in 1957 and was completed for flood control operation in 1965. The study area includes all land within approximately four miles of the lakeshore.

The selected period of study is 1948 to 1970, with two subperiods: 1948-58 and 1964-70. The two subperiods represent, respectively, pre-investment and post-investment time periods.[2] Land uses were defined and grouped into categories corresponding to the land uses shown in Table 1. Land uses at each of approximately 3,000 sample points, covering more than 91,000 acres, were quantified at the beginning and end of each subperiod using aerial photographs obtained from the Army Corps of Engineers. Land use flows were derived from these data [10].

Estimated land use flow matrices are summarized in Tables 1 and 2. Nondiagonal elements of the transition matrices represent flows of land from one use to another, while diagonal elements represent land uses remaining in the same land use category throughout the period. For instance, in Table 1 the element at the intersection of row (H) and column (A) indicates that 2.7 acres of cropland shifted to commercial uses, while the element at the intersection of row (H) and column (H) indicates that 2,391.6 acres of land remained in cultivated land throughout the time period. The original state vectors Q_a (for 1948) and Q_c (for 1964) are obtained by summing the row elements of each transition matrix.

Land use projections from the Markov process based on data in Table 1 are used in (3) to compute

TABLE 1. LAND USE TRANSITIONS IN THE VICINITY OF KEYSTONE RESERVOIR, OKLAHOMA, 1948 TO 1958

Land Use in 1948	Land Use in 1958										
	A	B	C	D	E	F	G	H	I	J	Total
	acres										
A. Commercial	24.1	0.1	0.0	0.5	0.0	0.0	3.7	0.3	15.5	3.8	48.1
B. Extractive	0.0	41.7	3.5	1.1	0.0	0.1	*	3.5	13.3	14.6	78.0
C. Transportation	0.3	3.1	966.4	3.0	3.9	3.1	3.7	42.2	112.2	94.2	1,232.1
D. Utilities	0.7	3.7	12.2	308.7	0.4	2.2	1.8	11.8	89.1	75.9	506.6
E. Institutional	3.2	0.2	0.0	0.2	18.6	0.0	5.3	1.7	7.4	3.3	39.8
F. Impoundments	1.0	3.2	6.3	2.2	0.0	127.4	1.3	12.1	43.7	40.0	237.1
G. Residential	1.6	6.5	3.4	2.3	0.0	3.0	601.6	24.2	120.4	64.5	827.5
H. Cultivated Land	2.7	19.4	38.9	8.9	2.8	17.8	50.0	2,391.6	2,380.9	1,194.5	6,107.7
I. Pastureland	12.0	67.0	74.7	44.6	8.5	66.9	165.5	2,347.3	22,997.6	4,199.0	29,983.0
J. Woodland	30.7	135.1	171.1	123.4	13.6	97.6	65.8	1,650.1	8.624.1	41,698.7	52,610.2
TOTAL	76.2	280.0	1,276.7	494.7	47.8	318.2	898.8	6,484.7	34,404.3	47,388.7	91,670.0

NOTE: Totals may not be equal to row or column sums because of rounding error.
***Less than 0.05.**

[2]The pre-investment and post-investment transition probabilities matrices are based on land use flows measured over different time spans. It is assumed that the rate of change of land use was uniform during each observation period, there should be no bias introduced into the results by this procedure.

TABLE 2. LAND USE TRANSITIONS IN THE VICINITY OF KEYSTONE RESERVOIR, OKLAHOMA, 1964 TO 1970

Land Use in 1964	Land Use in 1970										
	A	B	C	D	E	F	G	H	I	J	Total
	acres										
A. Commercial	60.2	6.7	4.1	0.4	0.3	2.3	9.0	20.9	43.3	49.3	196.6
B. Extractive	1.8	207.5	7.1	2.6	0.1	1.4	2.2	4.4	34.7	51.2	312.9
C. Transportation	1.1	2.7	1,287.8	2.5	0.0	1.6	2.9	8.9	71.7	95.9	1,475.4
D. Utilities	4.9	4.5	4.0	577.8	0.0	3.7	4.3	3.3	49.1	62.7	714.3
E. Institutional	0.0	0.2	0.0	0.0	47.8	0.7	4.9	0.1	8.4	4.2	66.4
F. Impoundments	0.3	4.9	2.1	2.1	0.0	333.8	2.1	6.6	37.2	52.2	441.4
G. Residential	17.2	5.5	5.6	0.2	0.0	0.1	1,083.4	11.4	53.9	62.1	1,239.6
H. Cultivated Land	21.1	14.2	8.2	4.9	3.6	6.1	23.3	1,391.5	1,483.4	536.2	3,492.5
I. Pastureland	57.9	47.8	79.3	36.6	11.8	31.6	189.1	999.3	26,803.9	4,896.4	33,153.8
J. Woodland	24.0	52.7	92.7	61.4	2.8	40.9	133.0	436.3	4,261.3	45,472.0	50,577.2
TOTAL	188.6	347.0	1,491.0	688.6	66.4	422.1	1,454.2	2,882.7	32,847.2	51,282.4	91,670.0

NOTE: Totals may not be equal to row or column sums because of rounding error.

the actual differential land use change that had occurred at Keystone reservoir by 1970 [3]. As shown in the fifth column of Table 3, the construction of Keystone Lake generated a differential increase in all nonagricultural land uses (with exception of extractive uses such as oil drilling).[3] Increases in transportation and utilities reflect the necessary rerouting of roads, highways, power lines and railroads within the reservoir area. Residential uses accounted for more than one-half of the increase in nonagricultural uses. As might be expected, commercial and institutional land uses increased in the area as the result of increased recreational and residential activities.

Actual DLUM estimates for 1970 indicate that total agricultural uses of land decreased by 891 acres. The differential impact caused a decrease in cultivated and pasture lands, while woodland acreage increased. This phenomenon suggests that, following reservoir construction, more emphasis was placed on esthetic attributes of the area as a complement to newly created recreational and leisure opportunities.

Projected differential land use impact in infinity estimated by (5) reveal a most interesting pattern of long-run differential change. In the agricultural uses, the pattern observed for 1970 generally continues, but in the nonagricultural uses the previous pattern of change does not continue. In fact, all significant nonagricultural change occurs in the residential category. Most of the facilitative or nonresidential uses actually show a slight decline in differential impact between 1970 and infinity. This result is particularly apparent in Table 4, which shows the percentage distribution of the total nonagricultural differential land use impact in selected years.

Results in Table 4 indicate that the early differential impact on nonagricultural, nonresidential land uses is initially quite substantial, but over time the projected differential incidence of these land use categories steadily declines. What this suggests is that reservoir construction immediately stimulates infrastructure or facilitative investments associated with land uses such as transportation and utilities. These land uses immediately increase at a rate far exceeding the pre-reservoir rate, thereby causing a relatively large, relatively early differential impact. However, after an initial flurry of activity, there is little land use conversion to these uses. In later time periods, the land use pattern that would have existed had the reservoir not been constructed gradually catches up with the post-investment land use pattern. This catch-up process reduces the differential impact for nonagricultural uses except for residential land use which steadily increases. This secular increase in

[3] This result probably reflects the impact of increased easement costs for drilling rights associated with the shift to nonagricultural uses in the area.

TABLE 3. ACTUAL AND PROJECTED LAND USE AND DIFFERENTIAL LAND USE CHANGE, KEYSTONE RESERVOIR, OKLAHOMA

Land Use	Actual Land Use	Projected Land Use: Based on Pre-investment Transition Probabilities		Projected Land Use: Based on Post-Investment Transition Probabilities	Differential Land Use Change	
	1970	1970	Infinity	Infinity	1970[a]	Infinity[b]
Non-Agricultural Uses			Acres			
Commercial	189	92	104	201	97	97
Extractive	347	399	513	412	-52	-101
Transportation	1,491	1,327	1,516	1,624	164	108
Utilities	689	485	465	575	204	110
Institutional	66	52	57	60	14	3
Residential	1,454	990	1,337	2,804	464	1,467
Sub-Total	4,236	3,345	3,992	5,676	891	1,684
Agricultural Uses						
Impoundments	422	369	427	351	53	-76
Cultivated	2,883	6,883	7,586	2,401	-4,000	-5,185
Pasture	32,847	37,507	41,927	30,462	-4,660	-11,465
Woodland	51,282	43,566	37,737	52,779	7,716	15,042
Sub-Total	87,434	88,325	86,677	85,993	- 891	-1,684
Total	91,670	91,670	91,670	91,670		

NOTE: Column totals may not equal column sums because of rounding error.

[a]First column of data minus the second.

[b]Fourth column of data minus the third.

residential incidence over time suggests that the construction of a reservoir significantly influences the esthetic qualities of the area, thereby increasing the desirability of the area for suburban and/or second homesite construction.

LIMITATIONS

Additional research estimating differential land use changes associated with reservoir construction might include several modifications. In this study, the size of sample observations within the study area was arbitrarily selected. Further research could develop a system of sample observations which conforms more nearly to the contour of the reservoir. This would produce more accurate estimates of differential land use change associated with reservoir construction. This method would also permit measurement of the change in land use intensities by proximity to the reservoir.

The differential land use model used in this study assumes that transition probabilities remain constant through time. This means that existing trends in land use change in each of the subperiods are assumed to continue into the future. Further research should include an investigation of how transition probabilities change over time to allow for development of a system of nonstationary transition probabilities which would compensate for changing economic conditions.

The differential land use change estimated in this study is solely attributed to the construction of Keystone Lake. Other exogenous factors influencing

TABLE 4. INCIDENCE OF ACTUAL AND PROJECTED NONAGRICULTURAL DIFFERENTIAL LAND USE, KEYSTONE RESERVOIR, OKLAHOMA

Land Use	Percent of Total Land Use Differential Within Selected Land Uses: Percent of Actual Differential Land Use		Percent of Projected Differential Land Use	
	1964	1970	2000	∞
Commercial	14.21	10.89	6.90	5.76
Extractive	-4.06	-5.84	-7.62	-6.00
Transportation	21.95	18.41	10.26	6.41
Utilities	28.43	22.90	11.55	6.53
Institutional	2.03	1.57	.48	.18
Residential	37.44	52.08	78.43	87.11
Total	100.00	100.00	100.00	100.00

NOTE: Each entry shows the proportion of the estimated total differential increase in nonagricultural land use resulting from the construction of the reservoir for each land use category.

land use change are assumed to remain constant or to be nonexistent. The study does not specifically consider unique land use changes associated with necessary relocation of the minor urban centers. Also, the study does not attempt to explicitly account for land use change associated with the opening of a major expressway or establishment of rural water districts in the study area.

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