PREDICTING CHANGES IN LAND USE PATTERNS RESULTING FROM WATER RESOURCE INVESTMENT USING A NON-STATIONARY MARKOV PROCESS

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By

H. Evan Drummond
Department of Agricultural Economics
Oklahoma State University

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PREFACE

This report summarizes the findings of a substantive research project performed under the sponsorship of the Office of Water Resources and Technology through matching grant B-030-OKLA, and the Oklahoma Agricultural Experiment Station. The research focused on the feasibility of using Markov processes to estimate changes in land use patterns associated with the construction of water resource development projects.

All objectives of the original project have been successfully completed as documented in this report. Additional research exploring the local fiscal impacts caused by land use changes was facilitated by a two month extension of the original contract period. The results of this additional research are reported in Appendix III and have been accepted for publication in a professional journal.

The data collection phases of the research project were performed jointly with Drs. Hecock and Rooney, principle investigators of B-030-OKLA. The assistance of the Tulsa Corps of Engineers in providing aerial photographs is acknowledged.

The assistance of Mr. Lonnie R. Vandeveer in the preparation and evaluation of the data for Keystone Reservoir is greatly appreciated. The data for the Pine Creek area were partially collected by Miss Gwen Gales. Much of the descriptive work for Pine Creek was completed by Miss Gales. The data collected for this project and the methodological technique being evaluated provided the basis for the M.S. thesis research of both these students.

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CHAPTER I

INTRODUCTION

The impact of large scale water resource development projects (WRDPs) on land use patterns in the immediate vicinity of the project is an important dimension of the overall economic impact of WRDPs. Knowledge of the land use impact of a WRDP can be useful in a variety of manners. Ex ante estimates may be incorporated into the computation of expected benefits and costs of the project; and, they may be used by land use planners to anticipate the demand for additional public services in the vicinity of the WRDP. Ex post estimates of the land use change caused by the project are useful in the measurement of net economic benefits associated with the project; and, they may be indicative of benefits that would accrue to proposed WRDPs.

In this study, the ex post land use change caused by Corps of Engineers water resource development projects at two sites is estimated using a unique methodological approach. The ex post analyses provide useful insight into the land use change process following the completion of WRDPs, and they provide the basis for evaluating the ex ante potential of the methodology.

Objectives

The original specific objectives of the project were to:

1. Identify and analyze historical patterns of land use in two study areas where large public water resource investments have been made.

2. Develop a dynamic model of land use capable of predicting the land use patterns in each study area that would have existed in the absence of the water resource investment.

3. Modify the dynamic land use model to account for the differential impact of water resource investments on land use patterns.

4. Evaluate the efficacy of the dynamic land use model as a predictor of the differential impact of water resource investment on patterns of land use.

As the research progressed and the full analytical capabilities of the methodology were recognized, it became apparent that additional empirical work beyond the original objectives was justified. The general dimensions of this additional work are discussed later in this chapter.

Procedures -- An Overview

The basic methodological tool chosen to estimate land use change in this study is the Markov process. Basically, this is a mathematical tool that permits the researcher to extrapolate previous patterns of land use change into future time periods. The Markovian procedure is particularly well adapted for the present study because it permits the simultaneous estimation of any number of land use categories with the restriction that the total acreage of all use categories must remain constant. The technical aspects of the procedure are more fully discussed in Chapter II.

The viability of the Markov process for predicting land use patterns will be tested for two study areas: Keystone and Pine Creek reservoirs.

These two study areas in Oklahoma were chosen on the basis of data availability and because they are dissimilar. The Keystone project in east central Oklahoma is a large project located near a major metropolitan area. Its location is shown in Figure 1-1. By contrast, the Pine Creek project in extreme southeastern Oklahoma is a relatively small project in terms of the geographical coverage of the lake and is remote from any significant population centers. Moreover, there are several other lakes with recreational potential in the immediate vicinity of Pine Creek (Hugo and Broken Bow reservoirs, for example), while there were none near Tulsa at the time Keystone was completed.

Aerial photos were used to measure historical land use by category in each study area. Estimates of land use <u>change</u> were based on the data collected which showed the land use pattern prevailing in each study area before and after the projects were completed. These estimated patterns of land use change were input to the Markov model to project land use patterns in time periods beyond the period for which the specific land use data were collected. These estimates of changing land use patterns formed the basis for the remainder of this study. Detail concerning the empirical base for this study is provided in Chapter III.

The differential land use impact of a water resource development project is the difference between land use patterns after the completion of the project and the estimated land use pattern that would have prevailed if the project had not been constructed. That is, the <u>net</u> impact of the WRDP is equal to the difference between estimated land use patterns based on pre-WRDP growth patterns, and land use patterns based on post-WRDP growth patterns. If the growth patterns before and after the project are virtually

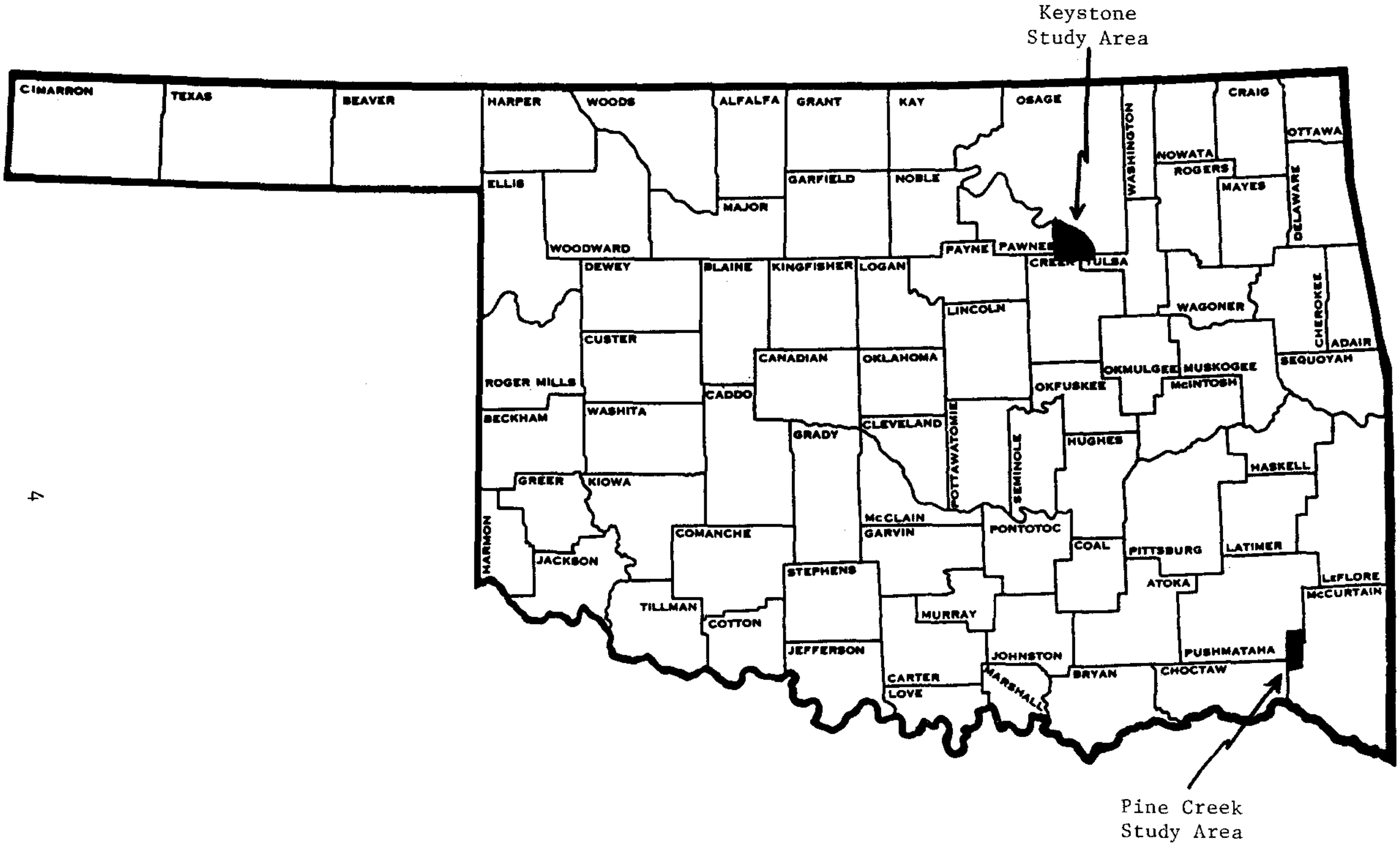


Figure 1-1. Location of Keystone and Pine Creek Study Areas: Oklahoma

the same, then the net impact will be constant over time. However, if the WRDP causes any shifts in the land use transition pattern, then the net impact of the WRDP on land uses will constantly change over time. The land use implications of this dynamic adjustment process in the two study areas are discussed in Chapters IV and V.

Estimates of net land use change based on transition probabilities matricies in which each element of the matrix is taken to be a function of time are also presented in Chapters IV and V. Land use estimates based on transition probabilities computed in this manner are commonly called "dynamic" Markov estimates. While such transition matricies are conceptually attractive, the data requirements are somewhat awesome and the implicit assumption that there is some relationship between each element of the transition probabilities matrix and time is often questionable. The specific procedures used to compute dynamic transition probabilities for this study are discussed in Appendix 2.

The results of the study are summarized in the final chapter. The ex post estimates of differential land use change estimated with the static Markov models are consistent with apriori expectations. The estimates generated by the dynamic transition probabilities demonstrated some characteristics which are inconsistent with apriori expectations. The feasibility of using Markov estimates of net land use change associated with WRDPs for ex ante prediction purposes is also discussed in the final chapter.

Impact Analysis for Keystone

The initial research on the Keystone study area provided a means for determining the net impact of the Keystone project on the land market in the study area. The shifting land use pattern results in a redistribution of property wealth from agricultural uses to residential and other uses. The redistribution impact of these changes was estimated as shown in Appendix 3. Then, the gains in the local tax base associated with movement of land into higher valued uses was compared with the loss in the tax base caused by the inundation of nearly 20% of the study area. Estimates were also made of the additional demands on public services that are associated with the changing land use patterns. Finally, the estimated additional demand for public services was compared with the ability of the modified tax base to support it assuming that all else remains constant.

CHAPTER II

METHODOLOGY

The purpose of this chapter is to discuss the theoretical concepts underlying the procedures used to project land use patterns and estimate land use change in this study. The procedures used to project future land uses are stationary and dynamic Markov chain processes. Land use protections obtained from the Markov model are subsequently used to estimate land use change associated with reservoir construction.

Review of Literature

Economists are frequently interested in measuring the change in economic variables through time and in estimating what paths these variables may take in future periods of time. The Markov process is a statistical procedure which may be used to generate such information. Although the basic concepts of Markov chains were introduced in 1907, their use by economists is a relatively recent phenomenon.

The Markov process has been used by several authors to project farm numbers [11, 15,16]. Of those studies, Krenz in 1964 used the process to project farm numbers in North Dakota for the years 1975 and 2000. He made use of several different base periods for each projection and concluded that Markov chains have important advantages over traditional procedures when used to project farm numbers: (1.) projections can be made more conveniently for each size category of farms; and, (2) the method provides additional information which is not readily obtainable with traditional techniques.

Hallberg employed the technique to analyze the size distribution of plants manufacturing frozen milk products in Pennsylvania during the period 1944-1963. He suggested a method based on multiple regression techniques of replacing the constant transition probabilities with probabilities which are a function of various factors including structural characteristics in the industry. [4]

More recently, Burnham, has used the Markovian framework to project future land use patterns in the Southern Mississippi Alluvial Valley. He concludes that the process can be adapted to project the future implications of past land use trends provided appropriately specified data are available. In addition, the model provides a framework for analyzing alternative institutional policies designed to attain specific land use futures. [2]

Theoretical Concepts of the Finite Markov Chain Process

A stochastic process may be described as a sequence of experiments in which the outcome of each individual experiment in the sequence depends on some probability, P. A finite stochastic process exists when the range of possible outcomes is finite. If the probability, P, does not depend on the history of the systems prior to the previous time period, a special type of stochastic process called a Markov process exists. According to Kemmeny [8]

> A markov chain process is determined by specifying the following information: There is given a set of states (S_1, $S_2 \ldots, S_r$). The process can be in one and only one of these states at a given time and it moves successively from one state to another. Each move is called a step. The probability that the process moves from S_i to S_j depends only on the state S_i that it occupied before the step. The transition probability P_{ij}, which gives the probability that the process will

> move from S_i to S_j is given for every ordered pair of states. Also an initial starting state is specified at which the process is assumed to begin (p. 148).

Assume the variable of interest is land use. The finite Markov chain process requires that r different land use categories be defined and that movements between these land use categories over time be summarized in a land use flow matrix. Land use transitions must be regarded as a stochastic process. Once the land use flow matrix is estimated, the probability (P_{ij}) of moving from one land use category (S_i) to another land use category (S_j) is computed as:

$$P_{ij} = \frac{S_{ij}}{\sum_i S_{ij}} \tag{1}$$

Each P_{ij} represents the fraction of land that started in land use category S_i in period t and moved to land use category S_j in the following period. Therefore, P_{11} represents the proportion of land that started in S_1 in time t and continued in S_1 in time t + 1. Similarly, P_{12} is the proportion of land that was in S_1 in time t and S_2 in time t + 1. These transition probabilities may be expressed in the form of a matrix such as:

$$P = \begin{array}{c} \\ S_1 \\ S_2 \\ \cdot \\ S_r \end{array} \!\!\begin{array}{c} \begin{array}{cccc} \underline{S_1} & \underline{S_2} & \cdots & \underline{S_r} \end{array} \\ \left(\begin{array}{cccc} P_{11} & P_{12} & \cdots & P_{1r} \\ P_{21} & P_{22} & \cdots & P_{2r} \\ \cdot & \cdot & \cdots & \cdot \\ P_{r1} & P_{r2} & \cdots & P_{rr} \end{array} \right) \end{array} \tag{2}$$

where P is a transition probability matrix.

An important kind of Markov process and the one of concern in this study is the regular Markov chain process. A Markov chain process is regular if the p_{ij} elements of each row sum to unity and are non-negative. These two assumptions are appropriate for projecting land uses since they imply land is neither created nor destroyed during the land use transition process.

A Markov chain process may be either stationary or dynamic. Stationarity in a Markov chain process means that the transition probabilities in P do not change over time. In a land use analysis, this means that factors influencing land use change over the time period in which the transition matrix is constructed remain the same throughout future time periods. A dynamic Markov process is one in which the transition probabilities are assumed to change with time in some sort of regularly described pattern. Both stationary and dynamic probability estimates are considered in this study.

Static Land Use Change Model

The transition matrix given in (2) and an initial vector of land uses completely defines the Markov chain process. Given this information it is possible to project land uses in the n^{th} time period or step. If Q_o represents the initial land use vector, then the following procedure may be used to project land use patterns in each future time period.

$$\begin{aligned} Q_oP &= Q_1 \\ Q_1P &= Q_2 \\ \cdot \quad & \quad \cdot \\ \cdot \quad & \quad \cdot \\ \cdot \quad & \quad \cdot \\ Q_{n-1}\ P &= Q_n \end{aligned}$$

or Q_n may be written as:

$$Q_n = Q_o[P]^n$$

The static Markov chain process may also be used to project equilibrium land use distributions. If a Markov chain process is regular, then as the transition matrix is raised to successively higher powers, all rows converge to a unique row vector termed the equilibrium vector. The equilibrium vector represents the unique organization of land uses in which net movements from one land use category to another is zero, i.e., land use movements out of each state are exactly equal to movements into that state. More specifically, if P is a regular transition matrix, there exists a matrix T, consisting of identical rows, to which P^n will converge as n approaches infinity. Each row of T is the same vector t, and all elements of t are non-negative.

One method for calculating the equilibrium vector is to multiply the P matrix times itself a large number of times until some power of P reaches the equilibrium configuration; however, this would be a tedious process. Alternatively Judge and Swanson [7] propose another method for calculating the equilibrium vector. They note that in equilibrium the distribution vector must be invariant, i.e.,

$$tP = t$$

$$\text{therefore } t(P-I) = 0 \tag{3}$$

where I is an identity matrix. (3) forms a system of n-1 linearly independent equations and n unknowns. They further note that since t is a probability vector,

$$\sum_j t_j = 1 \tag{4}$$

These two equations (equations (3) and (4)) form a system of n linearly independent equations and n unknowns from which it is possible to solve for the unique values of t.

Estimating Actual Differential Land Use Change

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. The initial state is designated as vector Q_a of length r, and the land use pattern at the end of the time period (i.e., the period over which the r by r transition probability matrix ${}_{ab}P$ is computed) is Q_b. Then it follows that:[1]

$$Q_b = Q_a \cdot {}_{ab}P \tag{5}$$

Assuming that land use transition is a stochastic process in which any future movement is independent of past movements and that ${}_{ab}P$ is both regular and stationary, then (5) can be generalized to predict land use patterns in n, where $n \geq b$ ($n = 0$ in a).

$${}_{ab}Q_n = Q_a \cdot {}_{ab}P^n \tag{6}$$

${}_{ab}Q_n$ denotes an estimated land use vector in time period n based on a transition probability matrix constructed over the time period a,b. The land use prediction model in (6) is valid only if the stability of P is assumed between b and n. With this requirement, it is assumed that the rate of change of economic and other factors influencing land use change patterns remains constant over the projection period. This assumption is maintained throughout the remainder of this study, unless explicitly stated otherwise.

Suppose that a large scale public investment such as the construction of a reservoir occurred in the study area in time period m_1 to m_2 where $b \geq m_1$ $m_2 > n$. Then the land use pattern predicted by (6) for time period n (${}_{ab}Q_n$) may deviate from the actual land use pattern observed in n (Q_n). The difference between 1) the predicted land use pattern that would have existed in n in the absence of the reservoir construction during m_1 to m_2, and 2) the actual observed land use pattern in n is the differential land use change caused by development of the lake. Thus the differential land use impact (D_n) of the reservoir in time period n is:

---

[1] In the notational conventions used in this study, all subscripts refer to either points in time or time periods. A left subscript is the time period (base period) over which the variable is estimated or measured, while the right subscript is the time at which the variable is estimated or measured. Land use vectors (Q) for which there is no left subscript are observed. Those with a left subscript are estimated by the Markov model. A superscript is the power to which the variable is to be raised.

$$D_n = Q_n - {}_{ab}Q_n = Q_n - Q_a\,[{}_{ab}P]^n \tag{7}$$

Vector D_n in (7) provides a more accurate estimate of the differential land use impact of reservoir construction than "with and without" 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 projected to time n, thereby accounting for land use changes that would have occurred, ceteris paribus, if the reservoir had never been constructed.

The technique given in (7) may be represented graphically. Actual differential land use change (D_n) for a single land use category i is illustrated in Figure 2-1. The actual quantity of land use i follows the solid line over time while the projected land use i had the reservoir not been constructed follows the broken line. Actual differential land use change associated with reservoir construction at any time from m_1 to n is the vertical distance between these two lines. Figure 2-1 is a two dimensional representation of differential land use change for a single land use while estimates generated by a Markov model are r + 1 dimensional. In the model, net land use change is estimated for each land use category simultaneously with the restriction that the sum of all changes must be equal to zero.

Projecting Future Differential Land Use Change

The above model may be extended to project the future impacts of land use change associated with reservoir construction. Projected differential land use change impacts of reservoir construction are differential land use changes resulting from reservoir construction at some future time period where it is not possible to measure actual observed land use patterns. In this case actual ob-

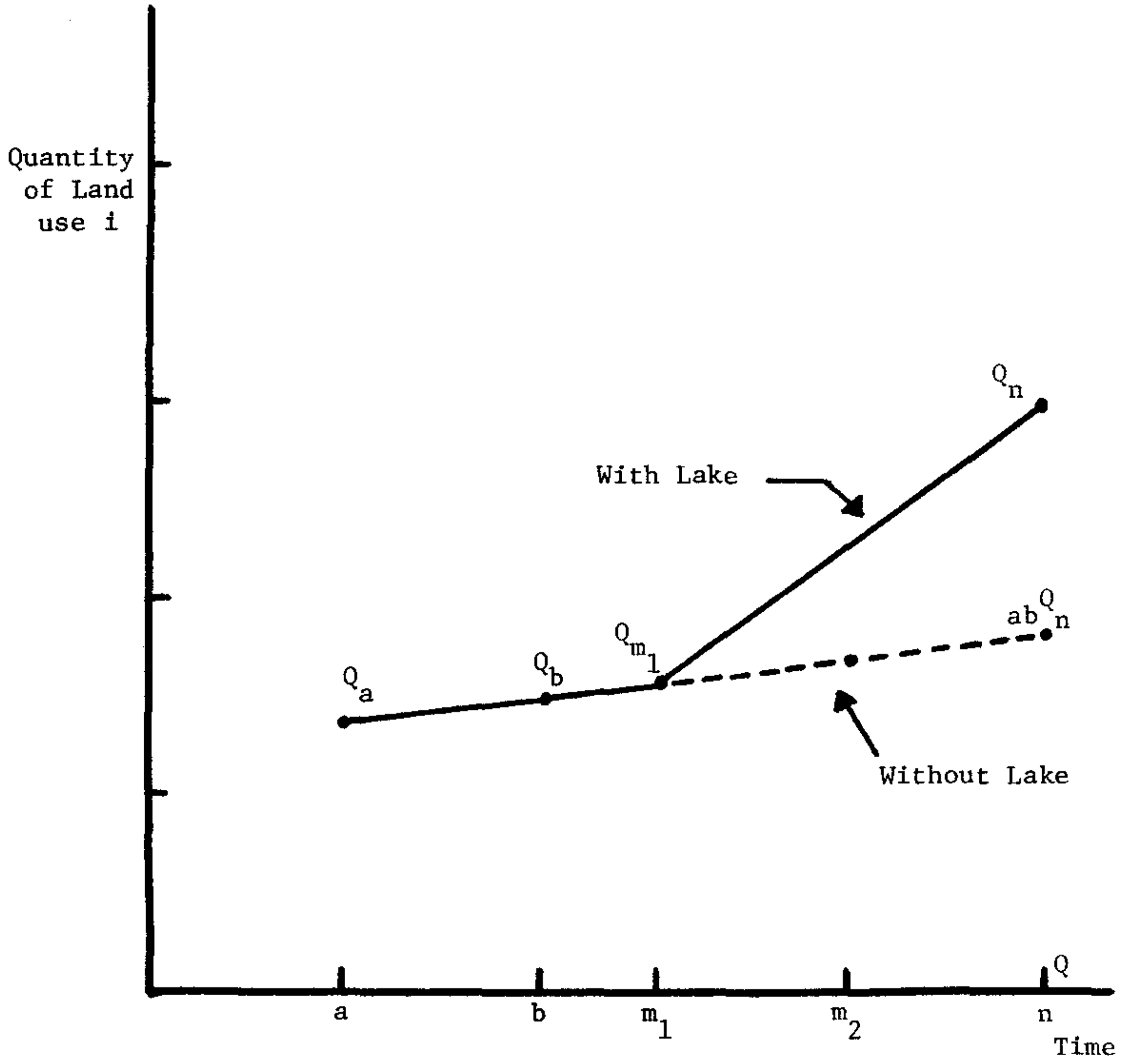


Figure 2-1. Illustration of Actual Differential Change in Use i Associated with Reservoir Construction

servations of Q_n in (7) are replaced by Markovian estimates of future land use patterns based on a post-investment (a time period following reservoir construction) matrix of transition probabilities. The difference between estimates of land use patterns at time n based on pre-investment and post-investment transition probabilities is a measure of the projected differential impact of the investment at time n.

More specifically, let ${}_{ab}P$ (where $a < b \leq m_1$) be the transition matrix reflecting the land use transition patterns before the lake was initiated and ${}_{cd}P$ (where $m_2 \leq c < d$) be the transition probabilities derived over a time period following completion of the lake. If the presence of the lake affects the land use transition process, then ${}_{ab}P \neq {}_{cd}P$.

The estimated land use pattern in n (where $n \geq d$) that would have occurred if the investment had not been made is estimated using pre-investment transition probabilities.

$$ {}_{ab}Q_n = Q_a \; [{}_{ab}P]^n \tag{8} $$

The land use pattern that is projected to exist in n as a consequence of reservoir development is estimated using post-investment transition probabilities and a post-investment original state (Q_c):

$$ {}_{cd}Q_n = Q_c \; [{}_{cd}P]^{n-c} \tag{9} $$

The difference between the estimates in (9) and (8) is the projected differential land use impact ($\hat{D}_n$) of the investment at time (n).

$$ \hat{D}_n = {}_{cd}Q_n - {}_{ab}Q_n = Q_c \; [{}_{cd}P]^{n-c} - Q_a \; [{}_{ab}P]^n \tag{10} $$

The procedure used to determine projected differential land use change for one land use is illustrated in Figure 2-2. The actual quantity of land in use i

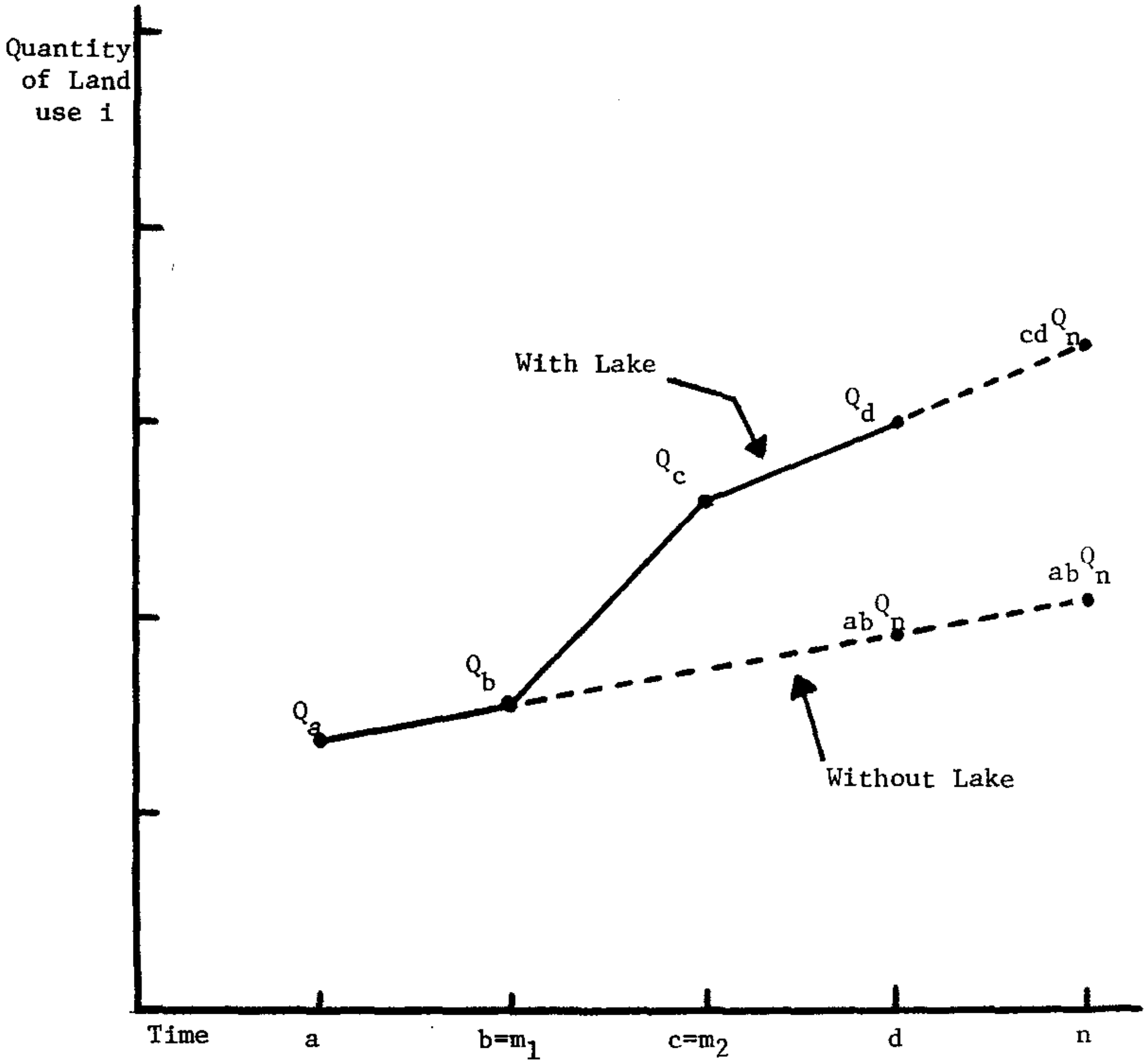


Figure 2-2. Illustration of Projected Differential Change in Land Use i Associated with Reservoir Construction

is shown by the solid line while the projected land use i had the reservoir not been constructed in the area follows the broken line. Projected differential land use change for land use i resulting from reservoir construction at time n is the vertical distance between ${}_{cd}Q_n$ and ${}_{ab}Q_n$.

Since ${}_{cd}P$ and ${}_{ab}P$ are regular transition matrices, (10) may be estimated for any $n \geq d$ including n at infinity. As n approaches infinity, ${}_{ab}P$ and ${}_{cd}P$ approach equilibrium states in which net land use transitions in each will be zero. Projected differential land use change at $n = \infty$ provides an estimate of the eventual, total land use impact of the reservoir development in which all land use adjustments attributable to the lake are considered. These estimates should be of special interest in analyzing and evaluating the long-term impacts of reservoir construction and are comparable to estimates of lifetime benefits usually computed in benefit-cost analyses.

Dynamic Land Use Change Model

In the previous section a differential land use change model was developed in which land use change is taken as the difference between two estimates of land use, each estimate being derived by a static Markov model. As mentioned previously, a static Markov change model is one in which all of the transition probabilities are assumed to be constant. In a dynamic Markov model the transition probabilities are assumed to change over time. The advantage of a dynamic Markov change process with probabilities as a function of time is that the land use changes caused by the construction of a water resource development project may initially be quite great, but that the impact of these changes over time will diminish and eventually fade away. It may well be that land use changes after the water resource development project impacts have all been felt will be no different than those which occurred before.

The essential difference between a static transition probability matrix such as (2), and a dynamic transition probability matrix is that in a dynamic matrix each element p_{ij} is a function of time. Each of the elements in a dynamic transition probability matrix must satisfy the basic conditions for a Markovian transition probability matrix: that each p_{ij} be greater than or equal to 0; and that the sum of the p_{ij} in each row be exactly equal to 1. Within a dynamic framework the second assumption becomes very crucial since each p_{ij} is a functional relationship with time. This particular assumption requires that the sum of several independent functional relationships must be equal to 1 in each time period. With a static model this assumption is not critical because the values of the p_{ij} do not change. However, within the dynamic framework the sum of the elements of each row must be equal to one <u>in each time period</u>.

Previous studies utilizing dynamic Markov change probabilities have followed either one of two techniques for generating dynamic transition probabilities. The first technique was first employed by Halberg in 1969 [4]. This technique calls for a linear extrapolation of each element in each row with the rate of linear change being the same throughout the row. For each matrix thus estimated adjustments are made in the elements such that the sum of the elements is equal to 1. The disadvantages of this procedure are twofold. In the first place it must be assumed that the rate of change of the transition probabilities is constant over time. Thus, even though estimates are dynamic, they are inflexible. The second difficulty is that quite often the sum of the elements within each row are not equal to 1. This particular problem has been resolved by Halberg with the use of a constrained least squares procedure in which all elements of a single row are estimated simultaneously. Through this procedure it is possible to force the sum of all elements to be equal to 1. However, this procedure does not prevent the possibility of an element falling below zero. In such cases it is necessary to adjust the estimates made by arbitrarily setting any non-positive elements equal to zero and increasing all positive elements such that their sum be equal to 1. The second approach to estimating non-linear transition probabilities is a geometric adjustment model developed by Salkin, Just, and Cleveland [14]. In this approach it is assumed that each element of the transition matrix adjusts to the previous year's change in a fixed amount as shown in equation (11).

$$p_{ij,\, t+1} = p_{ij,\, t} + \theta_i \,(p_{ij,\, t} - p_{ij,\, t-1}) \tag{11}$$

Each p_{ij} in each time period t + 1 is equal to the previous year's transition matrix element $(p_{ij,t})$ plus a certain proportion of the difference between the previous year's and the next previous year's transition matrix elements. The proportion of adjustment in (11) is θ_j. This θ_j is the proportion of the previous years adjustment which occurs in the current year. For instance, if θ_j is equal to 50%, then in each year 50% of the previous year's adjustment occurs. This geometric adjustment procedure causes the transition probabilities to adjust rapidly in the first years following the initial change and then to taper off as time increases. The dynamic adjustment model in (11) may be solved by converting (11) into a structural equation as shown in (12).

let $a_{ij} = p_{ij,\, -1}$ (12)

and $B_{ij} = p_{ij,o} - p_{ij,\, -1}$

then $p_{ij,o} = a_{ij} + B_{ij}$

$$p_{ij,1} = p_{ij,o} + \theta_1 B_{ij} = a_{ij} + B_{ij} + \theta_i B_{ij}$$

$$p_{ij,2} = p_{ij,1} + \theta_i^2 B_{ij} = a_{ij} + B_{ij} + \theta_i B_{ij} + \theta_i^2 B_{ij}$$

$$\vdots$$

$$p_{ij,t} = a_{ij} + B_{ij}\; B_{ij} \sum_{n=o}^{t} \theta_i^n$$

The general structural equation may be expressed as

$$p_{ij,t} = a_{ij} + B_{ij}\left(\frac{1-\theta_i^t}{1-\theta_i}\right) \tag{13}$$

in which the value of p_{ij} in any time period is a function of a_{ij}, B_{ij}, θ_i and time. Since a_{ij}, B_{ij}, and θ_i do not vary with time, there is a non-linear relationship between the value of $p_{ij,t}$, and t which is determined by the value of these three parameters. By means of a maximum likelihood estimation procedure it is possible to estimate the values of the parameters, a_{ij}, B_{ij}, and θ_i based on observed values of the transition probabilities and time. The estimated values of the parameters may then be used to generate a system of dynamic transition probability matrices for each future time period. Since θ_j in (11) is assumed constant for each row of the transition probability matrix, it is possible to estimate the p_{ij} such that the sum of all of the estimates is always equal to 1 using the constrained least squares technique mentioned above. As before there is a problem that sometimes the estimated p_{ij} values will fall below zero. In these cases it is necessary to adjust all other values upwards, such that the total of the non-zero elements be equal to 1.

The use of dynamic transition probabilities for estimating land use parallels that described previously for static transition probability matrices. The principle difference is that with dynamic transition probability matrices there will be a unique transition probability matrix for each and every year.

$$p_t = \begin{bmatrix} p_{11,t} & \cdots & p_{ir,t} \\ p_{ri,t} & \cdots & p_{rr,t} \end{bmatrix} \tag{14}$$

Matrix (14) may be compared to (2) in which all of the transition probabilities were assumed static. For each year land use may be computed using the dynamic transition probability matrix p_n:

$$\hat{D}_n = {}_dQ_n = Q_o[p_n] \tag{15}$$

where ${}_dQ_n$ is used to identify the vector of estimated land uses in n generated by dynamic transition matrices. Equation (15) should be compared with (6) in which a static transition probability matrix was used to estimate land use change. In the static case the transition probability matrix p is raised to the n^{th} power and then multiplied times the original land use vector in order to obtain a land use projection for time period n. In the dynamic case each element of p_n is directly estimated for the n^{th} time period by (13).

The differential land use change in any time period n may be estimated with the dynamic transition probability matrix as the difference between the dynamic estimates for time period n, and the static estimate based upon the initial time period ab as shown in (16).

$${}_d\hat{D}_n = {}_dQ_n - {}_{ab}Q_n = Q_o p_n - Q_o\ {}_{ab}p^n \tag{16}$$

Differential land use change estimated by the dynamic transition probability matrix is nothing more than the difference between the two matrices, the dynamic and the initial static matrix. Equation (16) should be compared to (10). In (10) both the pre-lake and the post-lake land use vectors are estimated with static transition probability matrices while in (16) the post-lake transition probability matrix is dynamic and the without lake land use estimates are based on a pre-lake static transition probability matrix.

A similar procedure may also be used to estimate actual land use changes associated with the construction of a water resource development project. To do this one simply needs to replace the second term of (16) with observed land use change is time period n. When dynamic transition probability matrices are used it is not possible to estimate an equilibrium land use vector. Thus all dynamic results presented in this paper will use only those estimates made for specific future time periods.

In the chapters that follow both static and dynamic estimates of differential land use change will be presented for Keystone Reservoir and Pine Creek Reservoir. These estimates will be compared and contrasted to test the universality of the estimation procedures discussed in this chapter and to ascertain the sensitivity of the estimates to the particular estimating technique used. The next chapter will discuss the data handling techniques employed to develop the necessary land use information and the estimation of the transition matrices. The two chapters after that will present the estimation results for Keystone and Pine Creek.

CHAPTER III

DATA COLLECTION AND PREPARATION

The heart of a Markovian land use model is the transition matrix. The transition matrix is derived from observed land use flows in the study areas. For this study two water resource development projects were analyzed: Keystone Reservoir near Tulsa, Oklahoma and Pine Creek Reservoir in the extreme southeastern corner of Oklahoma. For each study area data were collected for a number of time periods showing land use at each time period. These data were coded and then stored in computer data banks such that it was possible to measure all changes in land use at each specific point in the study areas. These measures of land use change were than combined to produce a matrix of transition probabilities which in turn was used to estimate future land use patterns.

In this chapter the specific procedures used to collect these data in each of the study areas will be described. A more thorough discussion of the exact procedures for Keystone can be found in Vandeveer [19] and for Pine Creek in Gales [3]. This chapter will describe in general terms the procedures that were used in deriving transition probability matrices.

Collecting Land Use Data

Keystone

Land use data for the Keystone study area were collected for approximately 3,000 observation points, each of which was a square area 500 meters on a side. The data were collected from aerial photographs provided by the U. S. Army Corps of Engineers in Tulsa. For each observation point land use data were coded on a code sheet shown as Figure 1. Data were collected for 1948, 1958, 1964, and 1970. In each of the four years data were collected for each of the 3,000 observation points. Thus a total of approximately 12,000 data sheets were completed. For each data sheet a computer card was prepared and the data stored on the computer.

A coding procedure was to delineate each half-kilometer square sample area by a series of east-west and north-south coordinates on a topographic map. By this procedure it was possible to assign each sample area a unique pair of coordinates by which it could be identified. Once the coordinate grid had been transferred to the aerial photographs, an examination was made of the land use within each sample area. For most land uses the coding procedure used was simply to determine whether or not that particular land use occurred within that sample observation. If the land use was present then the appropriate line on the land use coding sheet was given a value of 1 indicating that particular land use was present.

The coding for agricultural land (which comprises the vast majority of total land use within the study land area) was a little more exact. For each sample area the coder was asked to estimate the

Figure 3-1. Land Use Coding Sheet: Keystone

(1-3)	____________	X coordinates (East-West)	of SW corner
(4-7)	____________	Y coordinates (North-South)	
(8)	____________	Residential (1 if present)	
(9)	____________	Commercial (1 if present)	
(10)	____________	Manufacturing (1 if present)	
(11)	____________	Extractive (1 if present)	
(12)	____________	Highway Transportation or Parking (1 if present)	
(13)	____________	Railroads or Other Utilities (1 if present)	
(14)	____________	Institutional (1 if present)	
(15)	____________	Cultivated Land, Orchards, Horticulture, Feedlots	0 = 0 - 10% 1 = 11 - 50% 2 = 50 - 100%
(16)	____________	Pasture, Rangeland, Grassland	
(17)	____________	Woodland	
(18)	____________	Lake Water 0 = None 1 = Conservation 2 = Flood (854') 3 = Both	
(19)	____________	Other Impoundments, Ponds (1 if present)	
(20-1)	____________	Count of Structures present. All man-made structures.	
(22)	____________	Study Region 1 = Keystone 2 = Pine Creek	
(23-4)	____________	Year (last two digits)	
(25-6)	____________	Coder Initials	

approximate proportion of the total sample area that was used for cultivated, pasture and woodland. As shown in Figure 3-1 a value 0, 1, or 2 was entered for each of these three land use categories depending upon the proportion of the total land use that was estimated to be accounted for by that particular agricultural land use.

The portion of the study area which was inundated by the lake was also coded in a slightly different manner. That portion of the lake which was in the conservation pool was coded with a 1, and that portion which was in the flood pool was coded with a 2. By this procedure it was possible to distinguish between that area which was normally inundated and that which usually would be available for recreational uses.

The data entered on each land use coding sheet were then converted to acreage distributions within each sample cell. Each of the one-half kilometer square sample cells contains approximately 62 acres. A computerized algorithm which is more fully described in Vandeveer [19] was developed to convert the "present or not present" type of information contained on the land use coding sheets to acreage data. This procedure was greatly facilitated by the coding procedure used for agricultural land since each of these uses was given a relative weight. The algorithm converted the "present or not present" data to acreage data using a number of parameters developed by Vandeveer based on a more thorough sampling procedure in which a dot grid was used to estimate the average number of acres occupied by the particular land use when that land use was present. For instance, Vandeveer found that when highway transportation was coded as being present in a sample observation it occupied an average of 2.2 acres of land. This estimated average value of 2.2 was then used for each instance in which a transportation land use was coded as being present.

For residential land uses a slightly more complex procedure was used based upon the count of structures present. Using a sampling procedure based on a dot grid, Vandeveer found that the average rural residential lot occupied 1.17 acres. This value was then multiplied times the number of structures present to estimate the total amount of residential land use within the study area.

Once the land use data for each sample cell in the Keystone study area were converted to acreage values, they were aggregated to estimate transition matrices reflecting land use change between the sample years. For example, the procedure described above was used to determine the land use pattern in 1948 and 1958 in the Keystone study area. These data were then used to infer the land use transitions that occurred over this time period. The procedure used to derive the land use transition matrices will be described later in this chapter.

Pine Creek

The procedure used to code land use information in the Pine Creek area was quite different from that used for the Keystone area. It was felt that the procedures used in Keystone had seriously limited the capacity to identify significant land use change. Consequently, a revised procedure was developed for Pine Creek. The data for Pine Creek were coded from aerial photographs obtained from the U. S. Corps of Engineers in Tulsa, and from the U. S. Dept. of Agriculture, Agricultural Stabilization and Conservation Service. The photographs were obtained for years 1955, 1960, 1961, 1963, 1965, 1970, and 1974.

The principle differences in procedure used for Pine Creek are three. In the first place the sample area size was reduced from approximately 62 acres to 20 acres. The objective was to reduce the amount of sampling error that might occur within a given sample area. Obviously the smaller the sampling area the greater the amount of detail possible. The second and most important change from the procedure used for Keystone was that the number of acres of each land use were directly measured on the aerial photographs. This direct measurement of the acreage within each land use was accomplished with a dot grid. A dot grid is simply a transparent plastic sheet with a large number of regularly spaced dots. The grid used for sampling the Pine Creek had approximately 16 dots for the 20 acre cell. The dot grid was randomly placed on the aerial photograph and the number of dots falling upon each land use were recorded on the land use coding sheet shown as Figure 3-2. In this manner land use acreages were directly estimated. The third major procedural change for the Pine Creek area was to verify the sampling error of the dot grid by taking a second count. This was accomplished by lifting the dot grid from the aerial photo after the dots had been counted and randomly replacing it on the same sample cell in a different position. The number of dots for each land use was then counted a second time. After the coding had progressed through approximately one-fourth of the total requirements, statistical analyses were performed to determine whether there was a significant difference between the results of the first and second count. These tests demonstrated there was no statistically significant difference between the two counts. Hence, it was decided to make only one count for the remaining observations.

Figure 3-2. Land Use Coding Sheet: Pine Creek

Coordinates of southernmost point

southwest to northeast diagonal ________ (1-3)

southeast to northwest diagonal ________(4-6)

Land Use Code	Dot Count	1st Count	2nd Count
1.	Cultivated Land, feedlots, etc.	______(7-8)	______(9-10)
2.	Pastureland, rangeland	______(11-12)	______(13-14)
3.	Forested, woodland	______(15-16)	______(17-18)
4.	Residential and farmsteads	______(19-20)	______(21-22)
5.	Roads, highways, parking lots	______(23-24)	______(25-26)
6.	Railroads, electric transmission or other utilities	______(27-28)	______(29-30)
7.	All others; commercial, institutional, etc.	______(31-32)	______(33-34)
8.	Impoundments	______(35-36)	______(37-38)
9.	Lake or stream water	______(39-40)	______(41-42)

Land Use Codes at northernmost point ______(43)

Year of photo ______(44-45)

Size of observation (1 if not full size) ______(46)

Estimating Land Use Flows

Estimated land use at each time period within each of the two study areas was measured using the procedures described above. The next step in estimating transition probabilities for use in a Markov chain model is to estimate land use flow between time periods. The land use flow for each sample cell was estimated using a procedure described below and then aggregated for each of the two study areas.

Unfortunately the sampling procedure described above did not measure actual land use changes. Instead land uses patterns before and after a time period during which land use flows occurred were measured. Thus it was necessary to make some basic assumptions with regards to the relationship between changes in land use patterns between points in time and land use flows during the time period. These assumptions were incorporated into a computerized algorithm for deriving land use flow matrices from the coded land use data. This algorithm is more fully described in Vandeveer and Appendix 1.

For each sample cell the land use in time period 1 and 2 were compared. Some land uses increased over the time period and others decreased. It was assumed that land which was found to be in any given use in both time periods had continued in that use during the time period. That is, if in 1948 five acres of residential land were observed in a particular sample cell and in 1958 seven acres of residential land were found to exist in this sample area, then it was assumed that the second observation represented exactly the same five acres of land as had been observed in the first plus two additional new acres of residential land. It is conceptually possible that the first five acres had been converted into some other land use and that by the second time period a new seven acres of residential land had been developed. While this is a conceptual possibility it was assumed that in those cases where land uses were observed in both time periods, no change had occurred. Because of this assumption the total amount of change occurring is probably slightly underestimated by the algorithm.

For those land uses that either increased or decreased the algorithm makes some basic assumptions with regards to the distribution of increasing uses from decreasing uses. Since most of the decrease occurred in the agricultural area the main burden of the algorithm is to distribute new nonagricultural land uses among those agricultural uses shown to be declining.

Land use flows for each sample area in each study area were computed using this algorithm. While it is certain that there were some basic errors of measurement involved in using the algorithm, the large number of sample areas will tend to even out the errors associated with individual cells.

An example of a land use flow table is shown in Table 3-1. This particular table shows land use flows in the Pine Creek area between 1955 and 1963, a period prior to the construction of Pine Creek Reservoir. The rows of this table show 1955 land uses, the columns represent 1963 land uses. Thus by reading across a row the flow or change of land uses from 1955 to 1963 can be observed. For instance, the residential row shows that of the total 176 acres of residential land observed in 1955, 86 acres of it was converted to agricultural use, 59 acres of it remained in residential use, and 32 acres were

Table 3-1

Land Use Flows: Pine Creek 1955-63

1955 Use	1963 Use			
	Agricultural	Residential	All Others	Total
Agricultural	29,548	33	342	29,923
Residential	86	59	32	176
All Others	285	11	379	675
Total	29,920	103	752	30,775

note: errors may be present due to rounding.

converted into other uses such as for highways, commercial establishments, etc. Perhaps the most surprising element in this land use flow table is the conversion of residential into agricultural land uses. This probably reflects the depopulation of the area as old farmsteads were torn down prior to construction of the Pine Creek Reservoir.

By reading across the row, total land use in 1955 can be observed. For instance in 1955 total residential land use was 176 acres. The column total is the total land use in 1963 which was 103 acres of residential land use. The row totals and column totals represent the sum of the data that are input to the land use flow algorithm in order to determine the interior elements of the flow matrix.

Estimating Transition Probability Matrices

Land use flow data such as that shown in Table 3-1 are used to derive land use transition probability matrices which are subsequently used in the estimation of future land use patterns by the Markov chain process. The transition probability matrix shows the probability of each land use in the initial time period being converted into every other land use by the end of the time period. The transition probability matrix which was derived from the land use flows in Table 3-1 is shown in Table 3-2. Each element of the Table 3-2 is derived as follows:

$$P_{ij} = F_{ij} / \sum_{j=1}^{n} F_{ij} \qquad (1)$$

where F_{ij} is the land use flow from use i to use j; and, P_{ij} is the probability of this transition. For example in the residential row in Table 3-1 86 acres of the 176 total will be converted to agricultural

Table 3-2

Land Use Transition Probabilities: Pine Creek, 1955-63

1955 Use	1963 Use			
	Agricultural	Residential	All Others	Total
Agricultural	.9875	.0011	.0114	1.0000
Residential	.4866	.3345	.1789	1.0000
All Other	.4228	.0160	.5613	1.0000

uses. Thus the transition probability shown in Table 3-2 for residential into agricultural is 0.4866 (86/176). Each other element of the transition probability matrix is computed in the same manner. Notice that the row totals of the transition probability matrix are always equal to 1. This indicates that all land in the initial time period is converted into some other use--that land is neither created nor destroyed between the two time periods, but instead merely converted into other uses.

Transition probability matrices for each of the transition periods in each of the study areas were derived in this manner. Transition probability matrices were computed for variety of different sample sizes, subsamples, and levels of use category disaggregation. A full set of tables for Keystone can be found in Vandeveer [19] and for Pine Creek in Gales [3]. Transition probability matrices for the three highly aggregated use categories presented in this report are shown in Appendix 1.

CHAPTER IV

EMPIRICAL RESULTS: KEYSTONE STUDY AREA

The primary objective of the research reported in this study is to evaluate the feasibility of using Markov transition probabilities to estimate land use change associated with the construction of a Water Resource Development Project (WRDP). As described in the previous chapters land use data were collected and land use transition probability use matrices developed. Given these data it is a relatively simple task to estimate future land use patterns. Such estimates may be made using either static transition probabilities, or a dynamic system of transition probabilities. In this chapter the land use observed in each of the time periods in the Keystone study area is reported and the results obtained from static and dynamic Markov estimates of future land use patterns are discussed.

Description of the Study Area

Keystone Lake is part of a large multiple purpose water resource development project located approximately 20 miles west of Tulsa, Oklahoma. The Flood Control Act of 1950 authorized the Keystone Lake project for construction by the Corps of Engineers. Construction of Keystone Dam began in 1957 and was completed for flood control operation in 1965. The primary objectives of the project were flood control and storage to assure sufficient flow on the Mc-

Clelland-Kerr Arkansas River navigation system. Other benefits include hydroelectric power, recreation, wildlife and retention of upstream sediment. As shown in Figure 4-1 the lake is located in Pawnee, Creek, Osage and Tulsa counties, and during floods in Payne county. The dam is located several miles up the Arkansas River from Sand Springs, Oklahoma. A four lane highway runs parallel to the river and crosses the lake just upstream from the dam. This four lane highway provides immediate access for Tulsa area residents to the lake.

There are several urban areas in the study area. the most important being Cleveland in the northwestern corner of the study area. Mannford and Prue were originally located in the inundated area and were relocated as part of the project. Since completion of the project there has been substantial residential development near the shores of the lake. Many of these are permanent residents who work in the greater Tulsa area and commute to the lake [1].

The study area includes all areas within the boundary shown on Figure 4-1 and outside of the conservation pool of the lake. Additionally, to be included in the study area it was necessary that aerial photographs in each of the four years sampled be available. Hence, of the total area shown as being the study area actual land use data reported in this study represents only that portion which is not inundated and for which complete data were available.

Observed Land Use

The total area sampled in the study area is 91,670 acres. As expected the composition of the land use over time has changed from

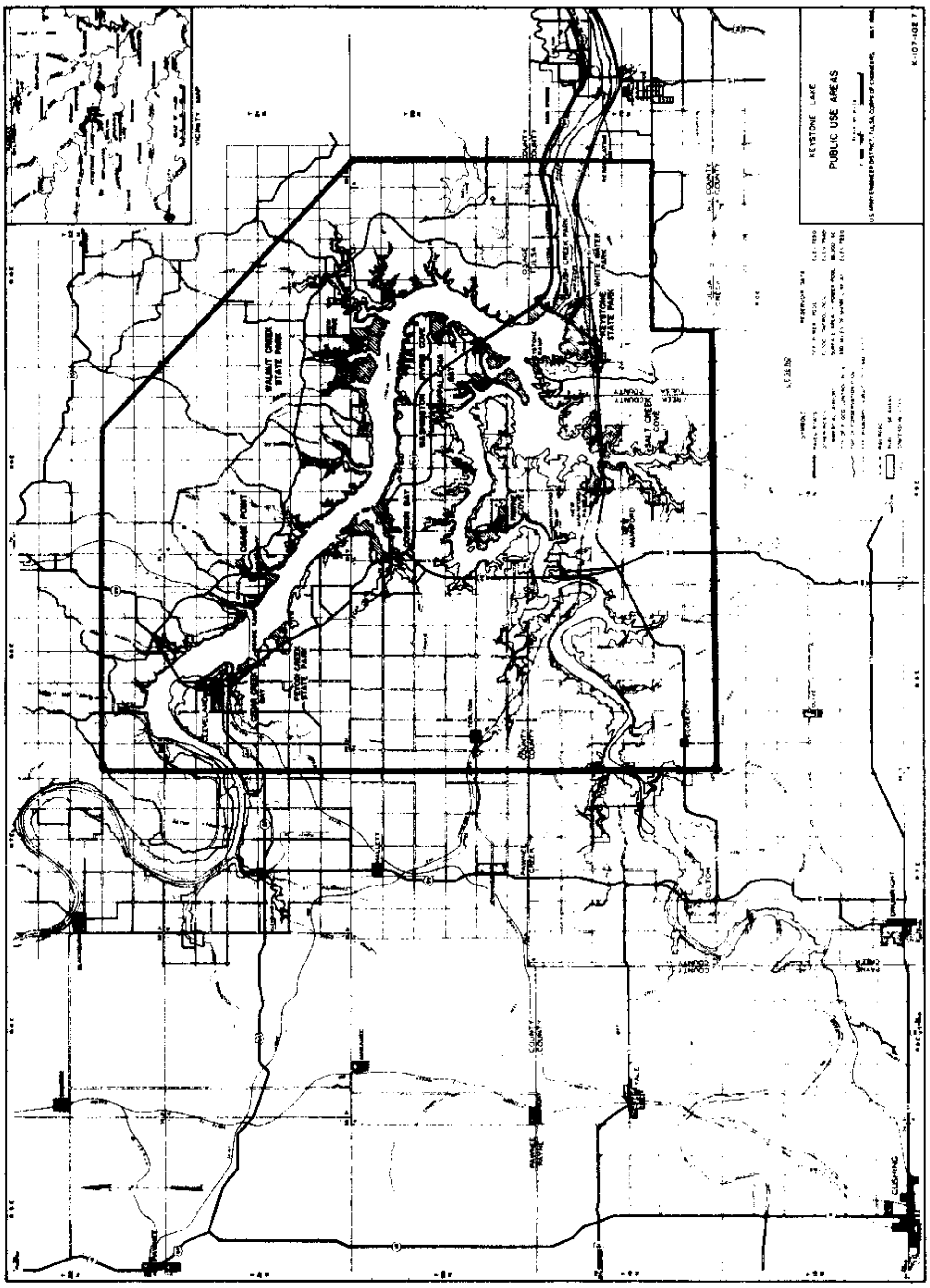


Figure 4-1

Keystone Study Area

agricultural to nonagricultural uses as shown in Table 4-1. Over the 22 year period in which land uses were identified, approximately 1500 acres of agricultural land were converted into nonagricultural uses. As a consequence agricultural uses dropped from 97% of the total study area in 1948 to slightly more than 95% in 1970. The decline in agriclutural uses was due to an increase of approximately 75% in residential use between 1948 and 1970, and a lesser increase in all other uses. In the "all other" category the greatest increases occurred in the commercial land use category.

Within the agricultural land uses the most significant change was the rather abrupt decline in cropland between 1958 and 1964. This decrease in cropland may reflect the preference of urban developers for using this kind of land for new construction rather than land with a harsher topography such as that usually used for pasture and woodland. Some of the decline in cropland may have occurred within the flood pool area which came under the jurisdiction of the Corps of Engineers.

Although nonagricultural land uses constitute less than 5% of the total study area, it is the change in these uses that constitutes the focus of this study. The impact of the Keystone project on these nonagricultural uses is shown in Figure 4-2. Note that between 1948 and 58 there was a small increase in total nonagricultural land uses. About the same magnitude of change occurred between 1964 and 70. But, between 1958 and 1964 (the period during which the project was constructed) there was an abrupt change in nonagricultural land use. Apparently, a rather normal rate of land use change into nonagricultural uses was experienced both prior to and following the construction of the

Table 4-1

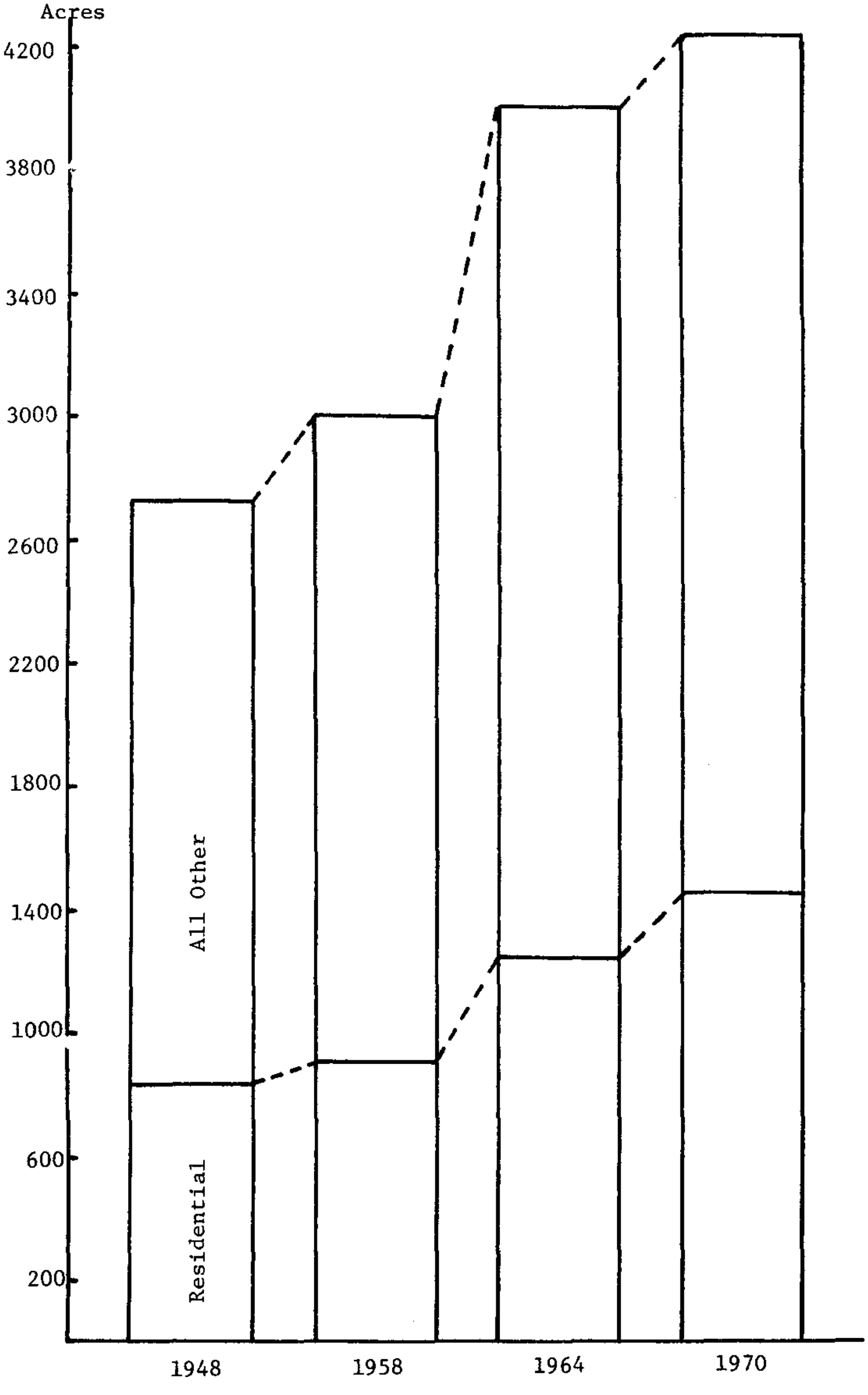
Observed Land Use: Keystone Study Area

Use	1948	1958	1964	1970
	acres			
Cropland	6,108	6,485	3,492	2,883
Pasture	29,983	34,404	33,154	32,847
Woodland	52,610	47,389	50,577	51,282
Impoundments	237	318	441	422
Agriculture Sub-Total	88,938	88,596	87,664	87,434
Residential	828	899	1,240	1,454
Commercial	48	76	197	189
Extractive	78	280	313	347
Transportation	1,232	1,277	1,475	1,491
Utilities	507	495	714	689
Institutional	40	48	66	66
All Other Sub-Total	1,905	2,175	2,766	2,781
Total	91,670	91,670	91,670	91,670

Note: Some rounding errors may be present.

Figure 4-2

Residential and All Other Land Uses: Keystone



project, but there was a substantial one-shot impact of nonagricultural uses during construction of the project. Between 1958 and 1964 residential land uses increased by nearly 38% and all other land uses increased by approximately 27%. This unusually rapid rate of change probably can be attributed to the construction of the Keystone project and the relocation of Prue to New Prue and Mannford to New Mannford (Figure 4-2).

Static Projections Of Land Use

As described in the prevoius chapter, land use flows between time periods were estimated using the observed land use patterns before and after the time period. From these matrices, transition probability matrices are derived which are then used within the Markovian framework to estimate future land use patterns. The estimates discussed in this section are based on static transition probability matrices derived for the period 1948-58, 1958-64, 1964-70. The earliest time period is characteristic of the pattern of land use change prior to the construction of the Keystone project. The latest time period (1964-70) is taken to be characteristic of land use change patterns following completion of the project. Although results for all three transition matrices will be presented it is the pre-WRDP and post-WRDP estimates that are of greatest interest since these will be used to estimate differential land use change associated with construction of the project.

The land use patterns estimated by the static transition probability matrices (Appendix 1) are shown in Tables 4-3, 4-4 and 4-5.

Table 4-2

Percentage Composition of Land Use:
Keystone Study Area

Use Category	1948	1958	1964	1970
	percent			
Agricultural	97.02	96.65	95.63	95.38
Residential	0.90	0.98	1.35	1.59
All Other	2.08	2.37	3.02	3.03

Table 4-3

Estimated Land Use: Keystone
(Based on Static 1948-58 Transition Matrix)

Year	Agricultural	Residential	All Other
Observed Land Use	---acres---	---acres---	---acres---
1948	88,938	828	1,905
1958	88,596	899	2,175
Estimated Land Use			
1964	88,446	930	2,291
1970	88,310	959	2,400
1980	88,138	996	2,535
2000	87,921	1,044	2,705
Equilibrium	87,674	1,102	2,894

Table 4-4

Estimated Land Use: Keystone
(Based on Static 1958-64 Transition Matrix)

Year	Agricultural	Residential	All Other
Observed Land Use	---acres---	---acres---	---acres---
1958	88,596	899	2,175
1964	87,664	1,240	2,766
Estimated Land Use			
1970	86,972	1,499	3,198
1980	86,203	1,794	3,669
2000	85,422	2,112	4,136
Equilibrium	84,957	2,318	4,394

Table 4-5

Estimated Land Use: Keystone
(Based on 1964-70 Static Transition Matrix)

Year	Agricultural	Residential	All Other
Observed Land Use	---acres---	---acres---	---acres---
1964	87,664	1,240	2,766
1970	87,434	1,454	2,781
Estimated Land Use			
1980	87,112	1,748	2,809
2000	86,635	2,175	2,859
Equilibrium	85,787	2,898	2,985

In each case the observed land use patterns in the two years delineating the period for which land use flows were estimated are shown as well as estimates for future time periods based on the static transition probabilities. By comparing the change in observed land use patterns with those which are estimated, it is obvious that the Markovian process is little more than a procedure for extrapolating past land use changes into future time periods. Markovian extrapolations are unique in that all land use categories are extrapolated simultaniously with the restriction that the sum of all use categories must be constant.

In Table 4-3 the time period over which the transition matrix is estimated is 1948-58, a 10 year period. Since the transition matrix covers a 10 year period the estimates which are obtained from the transition matrix in the second time period are estimates for 1968, and in the third time period for 1978, etc. The values shown for 1964, 1970 and other years all have been derived by exponential extrapolation of estimated values. At the bottom of each table is shown the land use data at a time period identified as equilibrium. These data are long-run land use estimates which are obtained from the equilibrium vector of the Markov process. They show the land use pattern that will exist when a final equilibrium is reached and all land leaving a particular use is just exactly equal to the amount of land entering into that use such that no net land use change will be noted. For the most part the equilibrium values are not significantly different from those in the year 2000 indicating that a large proportion of the total estimated land use change will occur by 2000. The magnitude of the difference between the 2000 and equilibrium estimates for any given land use can be taken as an indicator of the rate of land use adjustment. If there is a large difference between the two, then the adjustment process is relatively slow.

The rapid change in nonagricultural land uses during the construction phase that was noted earlier is evident in Table 4-4. The rapid rate of increase in residential and all other land uses over the 1958-64 time period is extrapolated in the estimates based on this transition matrix. As a consequence, the all other land use category is estimated to be well over 4000 acres in equilibrium compared to estimates of under 3000 acres for both the 1948-58, and 1964-70 transition probability matrices. The reason for this is demonstrated graphically in Figure 4-2. The dotted line connecting the bars for each year can be thought of as a rate of land use change of nonagricultural land uses. Note that the rate of change in the 58-64 period was much more rapid than that found to have occurred in the 48-58 and 64-70 time period.

Static Differential Land Use Change

Static differential land use change refers to the change in land uses estimated by static transition probability matrices. The term differential is used to emphasize that estimated change is based on the difference between two land use estimates, each of which is derived by a static Markovian process. Differential land use change estimates are of two varieties. Actual land use change is estimated by Equation 7 in Chapter 2. Actual land use change is the difference between land use estimated by a pre-WRDP transition matrix, and observed land use after the completion of the WRDP. Projected differential land use change is estimated by Equation 10 in Chapter 2. For these estimates the difference is taken between two land use estimates based on a pre-

WRDP and a post-WRDP transition probabilities matrix.

Actual Differential Land Use Change Estimates

Actual differential land use change is the difference between the 1970 land use pattern which is estimated based on the pre-WRDP transition matrix, and the 1970 observed land use pattern. As shown in Table 4-6, 1970 estimates from the 1948-58 static transition probabilities matrix are compared to 1970 observed land uses. For each land use category, the difference between the pre-WRDP estimates and the observed acreages is the differential land use change. As expected, agricultural use declined from that which it would have been had the Keystone project not been constructed. Residential and all other uses in 1970 were greater than what they would have been in 1970 if 1948-58 growth and development patterns had continued.

The figures in Table 4-6 must be carefully interpreted. For example, residential land use in 1970 is estimated to have been 959 acres if the Keystone project had not been constructed. In fact, after the Keystone project was completed the total amount of residential acreage was 1454. Thus, a comparison of estimated residential uses based on a pre-Keystone growth rate and actual post-Keystone land use, shows an increase of 495 acres in residential land use. This differential land use change may be taken as a 1970 estimate of the net impact of Keystone Lake. Since the 1970 estimate of 959 acres already has accounted for expected growth in residential land use, the only difference between the data in the first and second columns is the construction of Keystone Reservoir. Consequently, the 495 acres of differential land

Table 4-6

Actual Differential Land Use Change:
Keystone, 1970

Land Use	1970 Acreage Estimated by 1948-58 Static Transition Matrix	1970 Acreage Observed	1970 Differential Land Use Change
Agricultural	88,310	87,434	- 876
Residential	959	1,454	+ 495
All Other	2,400	2,781	+ 381

use change may be attributed to the change in development patterns that were associated with the Keystone project.[1]

The relative impact of the Keystone project on residential land use is far greater than that on all other land uses. Residential land uses are estimated to be approximately 52% greater in 1970 than that which was expected based on previous growth patterns. All other land uses for 1970 are estimated to be approximately 16% greater than the level expected. Consequently, the most significant impact of the Keystone project on land use in 1970 is in the residential category.

Projected Differential Land Use Change

Projected differential land use change refers to the difference between estimated land uses in future time periods derived from pre-WRDP and post-WRDP transition probabilities matrices. Projected differential land use change in the Keystone study area for the year 2000 and in equilibrium are shown in Tables 4-7, and 4-8 respectively.

A comparison of Table 4-6 with Tables 4-7 and 4-8 provides some interesting insights into the projected growth pattern in the Keystone area following completion of the water resource development project. Agricultural land use in 1970 was observed to have declined by 876 acres. By the year 2000 this decline will have increased to 1286 acres and in equilibrium 1887 acres. Decreases in agricultural land use correspond to increases in residential and all other land uses.

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[1] Development patterns in the study area may have been impacted by a variety of external factors in addition to the Keystone project. To the extent other factors are important, the land use change attributed to the Keystone WRDP is overestimated.

Table 4-7

Projected Differential Land Use Change:
Keystone, 2000

Land Use	2000 Acreage Estimated by Pre-WRDP Static Transition Matrix	2000 Acreage Estimated by Post-WRDP Static Transition Matrix	2000 Differential Land Use Change
Agricultural	87,921	86,635	- 1,286
Residential	1,044	2,175	+ 1,131
All Other	2,705	2,859	+ 154

Table 4-8

Projected Differential Land Use Change:
Keystone, Equilibrium

Land Use	Equilibrium Acreage Estimated by Pre-WRDP Static Transition Matrix	Equilibrium Acreage Estimated by Post-WRDP Static Transition Matrix	Equilibrium Differential Land Use Change
Agricultural	87,674	85,787	- 1,887
Residential	1,102	2,898	+ 1,796
All Other	2,894	2,985	+ 91

The 495 acre land use change for residential observed in 1970 increases to 1131 acres in 2000 and nearly 1800 acres in equilibrium. In other words the impact of the Keystone project on residential land use increases over time. In comparison, the all other land use category (primarily infrastructural land uses) is at its height in 1970 with 381 acres of differential change. By 2000 the differential change in all other land uses has fallen to 154 acres and in equilibrium to 91 acres. These results suggest that with completion of the Keystone project substantial infrastructural investments were made, such as the rerouting of road networks and development of new commercial centers. However, over time the amount of infrastructural land use that would have been required had Keystone not been constructed catches up with that which is estimated to have occurred following construction of Keystone. In other words, the impact of the Keystone project on all other land uses is primarily a one-shot impact with little additional differential change following 1970.

Dynamic Projections Of Land Use

Land use pattern in the Keystone study area may also be projected using a system of dynamic transition probabilities as described in Chapter 2. Future land use patterns for the Keystone study area estimated by a system of dynamic transition probabilities are shown in Table 4-9. These data were obtained by Equation 15 in Chapter 2 where the transition probabilities are estimated by Equation 13. The estimation procedure used is more fully described in Appendix 2.

As with static estimates of land use patterns, the dynamic esti-

Table 4-9

Estimated Land Use: Keystone
(Based on dynamic transition matrix)

Year	Agricultural	Residential	All Other
Observed Land Use			
1948	88,938	828	1,905
Estimated Land Use			
1958	88,210	1,135	2,324
1964	88,101	1,186	2,382
1970	88,003	1,232	2,435
1980	87,895	1,263	2,511
2000	87,776	1,263	2,630

mates indicate that agricultural uses will decline while residential and all other uses increase. With dynamic transition probabilities it is impossible to derive an equilibrium vector, therefore, these data are not shown in Table 4-9. Note however that by 2000 residential land use has already achieved a steady state, there being no change between 1980 and 2000. Estimates for further time periods not shown here indicate that the pattern estimated for 2000 is near an eventual equilibrium.

Dynamic Differential Land Use Change

Actual 1970 and projected differential land use changes estimated by dynamic transition probabilities are shown in Table 4-10. The actual differential land use change is simply the difference between the 1970 land use pattern estimated by the dynamic transition matrix and the land use pattern observed in 1970. The actual change in 1970 estimated by dynamic transition matrices is less than the static differential land use change.

Projected differential land use change is the difference between estimated land use based on dynamic transition probabilities shown in Table 4-9 and land use patterns shown in Table 4-3 which were estimated by the pre-WRDP static transition probabilities. The differential land use change estimated in this manner is shown for 1980 and 2000 in Table 4-10. These results should be compared to those in Tables 4-7 and 4-8. Several differences are signigicant.

Perhaps the most interesting characteristic of the dynamic land use change estimates is that the amount of estimated change is much less

Table 4-10

Dynamic Differential Land Use Change: Keystone

Year	Agricultural	Residential	All Other
<u>Actual Change</u>			
1970	-569	+222	+346
<u>Projected Change</u>			
1980	-243	+267	-24
2000	-145	+219	-75

than that estimated by the static transition probability matrices. This is probably a consequence of the geometric adjustment which is used in estimating the dynamic transition probabilities. As a consequence of this adjustment mechanism the transition probabilities in the dynamic model tend towards an equilibrium transition probabilities matrix not unlike that of the pre-WRDP time period. As a consequence, most of the land use change estimated to occur within the dynamic model occurs soon after the completion of the project. By contrast, in the static estimates the same rate of change is assumed to occur during all future time periods.

Another interesting finding in Table 4-10 is that the all other land use category is estimated to have a negative differential land use change in 1980 and 2000. This means that as a consequence of the construction of the Keystone project the amount of land used in the study area in the all other category is less than what would have been expected had the project not been built. This finding is contrary to apriori expectations and is difficult to sustain based on observed patterns of land use change near Keystone and other water resource development projects. Although the direction of change estimated for all other land use is negative the magnitude of the change is quite small.

Finally the results for residential land use in the dynamic model suggest that the initial impact of the Keystone project on residential land use declines over time. The estimated increase in residential land use in 1970 is 273 acres but by 2000 it has declined to 219 acres. In other words, the rate of increase of residential land use estimated by the dynamic model in future time periods is less rapid than that estimated by the 1948-58 static transition probabilities. Consequently, the magnitude of the differential increase in residential land use tends to decline over time.

CHAPTER V

EMPIRICAL RESULTS: PINE CREEK

The empirical procedures used to estimate land use change near Keystone were repeated for Pine Creek Reservoir to provide generality to the initial results. With a few exceptions which were detailed in Chapter III, the data collection procedures for the Pine Creek study area were identical with those used for Keystone. In this chapter the results obtained from Markovian projections of the land use patterns in the Pine Creek area will be presented.

Description of the Area

Pine Creek Reservoir is located in the extreme southeastern corner of Oklahoma primarily in McCurtin county with a small portion of the study area in Pushmataha and Choctaw counties. Pine Creek Reservoir was approved for construction in the 1958 Flood Control Act. Construction of the dam was begun by the Tulsa Corps of Engineers in 1963. Impoundment behind the dam began in 1969 and the conservation pool was filled in that year.

The Pine Creek Reservoir, unlike Keystone, is not located near any major metropolitan areas. The closest urban area of any consequence is Wright City which is the location of some forestry operations by private companies. The nearest city is Broken Bow, Oklahoma which has a population of 2000 and is located approximately 22 miles east of Pine

Creek Reservoir. The area surrounding Pine Creek Reservoir is primarily wooded on the eastern side with some mixed farming on the western side.

Pine Creek is part of a seven reservoir system designed to control the Little River and to reduce floods on the Red River into which Little River flows. The dam controls a drainage area of approximately 635 square miles. The conservation pool at normal lake levels covers 3800 acres and is sufficient for storage of nearly 5400 acre feet of water. The flood control pool covers 17,200 acres which means that the flood control pool covers an area approximately 4 1/2 times the size of the conservation pool. This is quite important for reasons that will be discussed later. The relationship between the size of the conservation pool and the flood pool can be seen in Figure 5-1. The shaded area surrounding the lake is the flood pool area, while the lake is the white area. That area which is dotted is part of the flood pool which is reserved as an Oklahoma State Game Management Area. The study area for Pine Creek is bounded by the heavy black line on Figure 5-1.

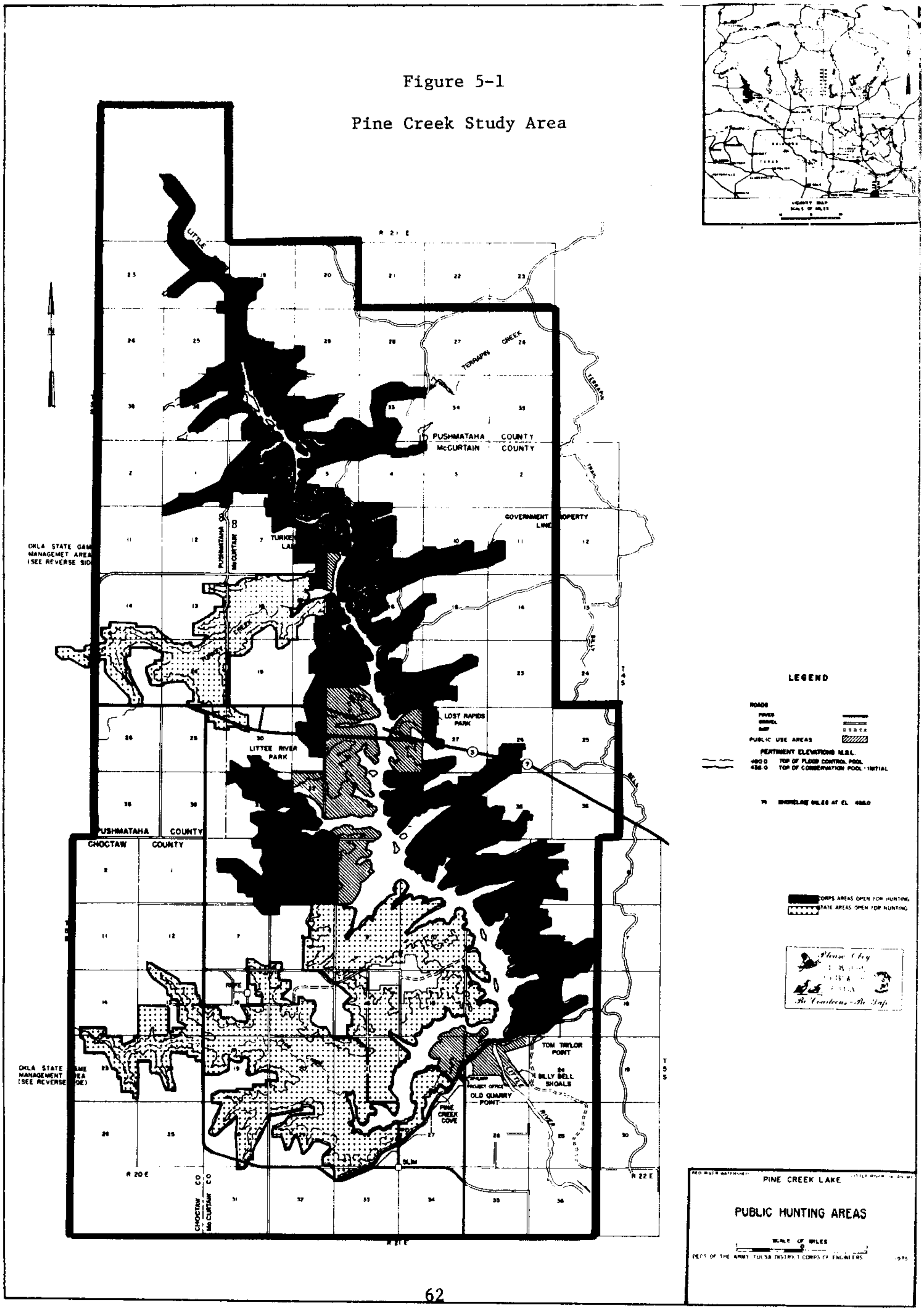
Access to Pine Creek is provided by state highway 3 (and 7) which crosses the lake approximately 5 miles north of the dam. This highway is a major thoroughfare in southeastern Oklahoma linking Atoka and Antlers to the Broken Bow, Idabel area. A paved road from the dam to Wright City was built following completion of the project.

Observed Land Use

As indicated in Chapter III, land use data for the Pine Creek study area were collected for a total of 7 different years: 1955, 1960, 1961, 1963, 1965, 1970 and 1974. For each of these years with the exception

Figure 5-1

Pine Creek Study Area



of 1960 and 61, aerial photographs were available for the entire study area. Unfortunatley, the 1960 and 1961 aerial photographs were limited to the immediate region of the dam. Consequently, they are excluded from consideration in this report. Summary data for these years may be found in Gales [3].

The land use patterns observed in the sample years are shown in Table 5-1. Perhaps the most significant change which occurred over the 19 year study period was the shift of what previously was woodland into pastureland. Undoubtedly, a major portion of this shift which occurred between 1965 and 1970 was in the flood plain area surrounding the lake. Due to the sampling procedure the flood pool area is included in the study area, but the conservation pool area is not. Consequently, land use changes outside of and within the flood pool area are reflected in the data shown in Table 5-1.

When the data in Table 5-1 are aggregated to three principle land use categories and expressed on a percentage basis as in Table 5-2 it can be observed that little change in the land use pattern occurred between 1955 and 1974. Residential land uses occupied approximately one-half of one percent of the total land area in 1955 and in 1974 with an interesting peak observed in 1965 during the construction phase. This may reflect some residential build up in the area during the construction period.

The all other land use category increased steadily over the study period. Two important trends in nonagricultural land uses are shown graphically in Figure 5-2. The first is the rapid increase in these uses that occurred between 1963 and 1965 when initial construction began. The second is the decrease in nonagricultural land uses between 1965 and 1970 which is probably due to two factors: 1) the egress of construction workers following completion of the dam in 1969; 2) the

Table 5-1

Observed Land Use: Pine Creek Study Area

	1955	1963	1965	1970	1974
Land Use	acres				
Cropland	1,255	725	420	1,075	863
Pastureland	6,473	5,707	6,498	22,315	18,890
Woodland	22,120	23,411	22,596	6,277	9,822
Impoundments	76	78	143	115	139
Agricultural Sub-Total	29,923	29,920	29,658	29,781	29,713
Residential	176	103	240	100	146
Transportation	669	747	844	888	901
Utilities	0	0	19	0	0
Others	6	5	13	4	13
All Others Sub-Total	675	752	876	892	914
Total	30,775	30,775	30,775	30,775	30,775

Note: Some rounding errors may be present.

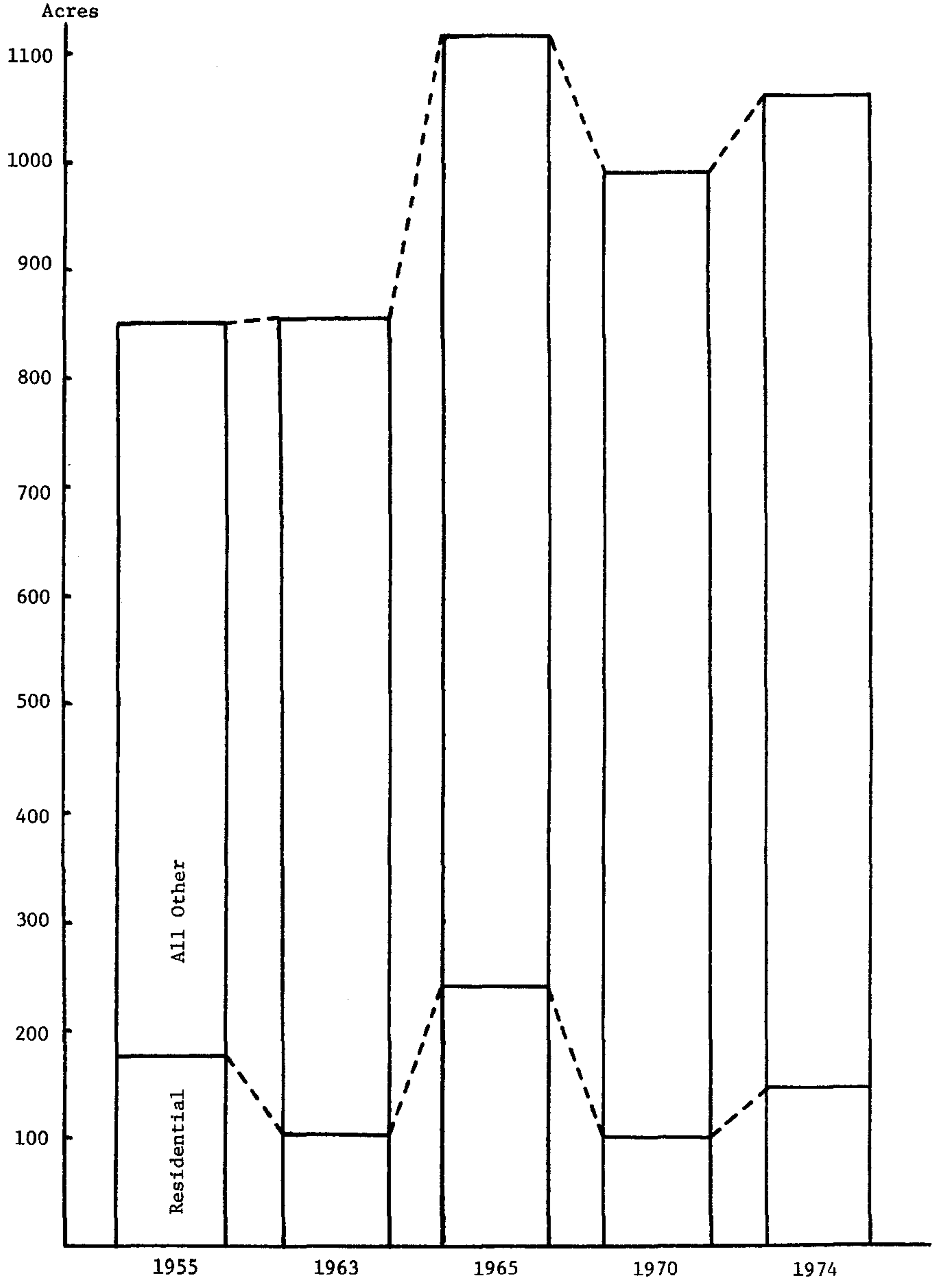
Table 5-2

Percentage Composition of Land Use:
Pine Creek Study Area

Land Use	1955	1963	1965	1970	1974
	percent				
Agricultural	97.23	97.22	96.37	96.77	96.55
Residential	0.57	0.33	0.78	0.32	0.47
All Other	2.19	2.44	2.85	2.90	2.97

Figure 5-2

Residential and All Other Land Uses: Pine Creek



relocation of residential and commercial enterprises located within the flood plain area. The growth in residential land use and all other land uses between 1970 and 1974 reflects a return to normal or pre-WRDP growth patterns.

Static Projections of Land Use Patterns

Future land use patterns based on observed transition probabilities were estimated using the Markov change procedure discussed above. The results are presented in Tables 5-3 through 5-6. The data in each of these tables are derived from the static transition probability matrices in Appendix 1.

Since there are five years of observations for the Pine Creek area it was possible to obtain four unique transition matrices for Pine Creek. The results from these four matrices are presented in Tables 5-3 through 5-6. As expected the estimated land uses based upon each transition matrix reflect the rate of change on land use over the observed time period. A comparison of the estimates in Tables 5-3 through 5-6 and Figure 5-2 is interesting. For instance, in Figure 5-2 notice the decline in residential land use and an increase in all other land uses while total nonagricultural land uses remain more or less constant. This pattern of change is reflected in Table 5-3 where total agricultural land use remains approximately the same throughout the estimated period which residential declines from 176 acres to 69 acres and all other land uses increase from 675 to 807 acres. Between 1963 and 1965 both residential and all other land uses increased. These increases are reflected in Table 5-4 where residential increases from 103 to 624 acres in equilibrium time period. The decline in residential acreage observed between 1965 and 1970 is reflected in Table 5-5 and the increase from 1970 to 1974 is shown in Table 5-6. The rather uneven pattern of ob-

Table 5-3

Estimated Land Use: Pine Creek
(Based on Static 1955-63 Transition Matrix)

Year	Agricultural	Residential	All Other
	acres		
Observed Land Use			
1955	29,923	176	675
1963	29,920	103	752
Estimated Land Use			
1970	29,914	82	779
1974	29,910	77	787
2000	29,901	69	804
Equilibrium	29,899	69	807

Table 5-4

Estimated Land Use: Pine Creek
(Based on Static 1963-65 Transition Matrix)

Year	Agricultural	Residential	All Other
	acres		
Observed Land Use			
1963	29,920	103	752
1965	29,658	240	876
Estimated Land Use			
1970	29,307	445	1,023
1974	29,177	529	1,069
1980	29,091	587	1,096
2000	29,042	623	1,110
Equilibrium	29,040	624	1,111

Table 5-5

Estimated Land Use: Pine Creek
(Based on Static 1965-70 Transition Matrix)

Year	Agricultural	Residential	All Other
	----------------acres----------------		
Observed Land Use			
1965	29,658	240	876
1970	29,781	100	892
Estimated Land Use			
1974	29,820	71	882
1980	29,851	56	868
2000	29,871	53	851
Equilibrium	29,873	53	849

Table 5-6

Estimated Land Use: Pine Creek
(Based on Static 1970-74 Transition Matrix)

Year	Agricultural	Residential	All Other
	- - - - - - - acres	- - - - - - - - - - - -	- - - - - - - - - - - -
Observed land use			
1970	29,781	100	892
1974	29,713	146	914
Estimated land use			
1980	29,658	177	938
2000	29,610	200	963
Equilibrium	29,607	201	965

served land use change in the Pine Creek area makes the use of extrapolated data very tenuous.

To compensate for the fluctuations in the observed data between 1955 and 1965 these three years of observed land use data were combined to derive an average transition probability matrix for the ten year time period. Estimated land use patterns derived from this transition matrix are shown in Table 5-7. Since the 1955-65 time period most nearly corresponds to the time period prior to the construction of the lake and the 70-74 period corresponds to the post-lake time period, the data in Tables 5-6 and 5-7 will be used in computing differential land use change.

Static Differential Land Use Change Estimates

Differential land use change in the Pine Creek study area may be estimated either as the difference between observed and estimated land use patterns or as the difference between two estimated land use patterns. The former estimates are called actual differential land use change patterns.

Actual Differential Land Use Change

The actual differential land use change in the Pine Creek study area for 1974 is the difference between observed land use patterns in 1974 and the 1974 land use patterns estimated by the 1955-65 combined transition matrix. The relevant data are shown in Table 5-8. The results are quite unexpected and in each case contrary to the direction of change expected. Agricultural land uses in the study area had increased from what would have been expected based on the 1955-65 pattern of land use change had the reservoir not been constructed,

Table 5-7

Estimated Land Use: Pine Creek
(Based on Static 1955-65 Combined Transition Matrices)

Year	Agricultural	Residential	All Other
	---acres---		
Observed Land Use			
1955	29,923	176	675
1965	29,658	240	876
Estimated Land Use			
1970	29,664	199	912
1980	29,621	208	946
2000	29,601	211	963
Equilibrium	29,598	212	965

Table 5-8

Actual Differential Land Use Change:
Pine Creek, 1974

Land Use	1974 Estimates based on 1955-65 transition matrix	1974 Observed Land Use	1974 Differential Land Use Change
	- - - - - - - - - - - - acres	- - - - - - - - - - - -	- - - - - - - - - - - -
Agricultural	29,643	29,713	+70
Residential	203	146	-57
All Other	929	914	-15

while residential and all other land uses decreased from expected values. The greatest relative change occurred in the residential category where the observed land use pattern is approximately 28% below that which was predicted for 1974 based on 1955-65 rates of growth.

The principle cause of the somewhat unexpected results in Table 5-8 is probably the relocation of nonagricultural land uses from the flood pool area to areas outside the flood pool. Since the flood pool area is part of the study area, changes within this area are reflected in the data. Current Corps of Engineers regulations prohibit private residential or commercial use of land in the flood pool. Hence by 1969 all such land uses were eliminated within the flood plain. An examination of detailed data (not presented herein) show a relatively rapid increase in residential and all other land uses outside the flood area in 1970-74 time period, but this increase was not sufficient to compensate for the rather substantial loss of residential and all other land uses within the flood plain. A cursory examination of Figure 5-2 will make this point rather clear. The actual differential land use change shown in Table 5-8 reflects the pattern of change shown in Figure 5-2.

Projected Differential Land Use Change

The expected future differential impact of the Pine Creek project may be estimated by comparing land use patterns predicted by transition matrices developed prior to the water resource development project with land use patterns predicted by post-WRDP transition matrices. The results obtained from such estimates are shown in Tables 5-9 for the year 2000 and 5-10 for the estimated equilibrium vectors. The results are interesting in several respects. In the first place it can be observed that almost all land use change estimated to occur will have occurred by the year 2000. A second

Table 5-9

Projected Differential Land Use Change:
Pine Creek, 2000

Land Use	2000 Acreage Estimated by Pre-WRDP Static Transition Matrix	2000 Acreage Estimated by Post-WRDP Static Transition Matrix	2000 Differential Land Use Change
Agricultural	29,601	29,610	+9
Residential	211	200	-11
All Other	963	963	0

Table 5-10

Projected Differential Land Use Change: Pine Creek, Equilibrium

Land Use	Equilibrium Acreage Estimated by Pre-WRDP Static Transition Matrix	Equilibrium Acreage Estimated by Post-WRDP Static Transition Matrix	Equilibrium Differential Land Use Change
Agricultural	29,598	29,607	+9
Residential	212	201	-11
All Other	965	965	0

and more interesting finding is that the estimated projected differential land use change is insignificant for each land use category and in fact is equal to zero for all other land uses. So in the long-run, there is no perceivable pattern of land use change due to the construction of the Pine Creek project.

These results may be combined with those shown previously in Table 5-8 to demonstrate that the primary impact of the Pine Creek project was to cause immediate dislocation of some residential and other non-agricultural land uses out of the flood pool area, but that by the year 2000 the one-shot impact of this dislocation will have been eliminated. This result is not unexpected since Pine Creek is too far away from any major urban centers to attract permanent residential developments.

Dynamic Projections of Land Use

The land use patterns in the Pine Creek area projected by the dynamic transition probabilities matrix is shown in Table 5-11. A decline in agricultural land use is estimated to occur between 1955 and 1974, followed by a reversal of this tendency through the year 2000. All other land use shows an opposite pattern: an increase between 1955 and 1974 and a decrease thereafter. Residential land use is estimated to increase throughout the period.

Dynamic Differential Land Use Change

Actual differential land use change is the difference between observed land use patterns and those which are estimated to occur. In this case the estimates are based on the dynamic transition probability matrices. As shown in Table 5-12 the actual land use in 1974 for agricultural and residential uses is less than that which is predicted

Table 5-11

Estimated Land Use: Pine Creek (Based on Dynamic Transition Matrix)

	Agricultural	Residential	All Other
Year	acres		
Observed Land Use			
1955	29,923	176	675
Estimated Land Use			
1974	29,801	185	785
1980	29,812	187	772
2000	29,841	193	737

Table 5-12

Dynamic Differential Land Use Change: Pine Creek

Year	Agricultural	Residential	All Other
	-----------------	acres	-----------------
Actual Change			
1974	-88	-39	+129
Projected Change			
1980	+191	-21	-174
2000	+240	-18	-226

to have occurred by the dynamic land use model. For instance, in Table 5-11 the predicted level of agricultural land use is 29,801 while the actual level of agricultural land use in 1974 was 29,713. Thus the actual level of agricultural land use in 1974 is 88 acres less than that which was expected given the dynamic rate of land use change.

The projected differential land use change based on dynamic transition probabilities is shown in the lower half of Table 5-12. These estimates are obtained by taking the difference between dynamic estimates in Table 5-11 and the static estimates based on a time period prior to completion of the water resource development project shown in Table 5-7. For both 1980 and the year 2000 the quantity of land used for agricultural purposes is predicted by the dynamic model to be greater than that which would have been expected given the pattern of land use change prior to construction of Pine Creek project. Both residential and all other land uses are below pre-WRDP expectations. Taken literally these results suggest that nonagricultural land uses in the Pine Creek area will decline as a consequence of the completion of the Pine Creek project relative to what they would have been otherwise. In both cases total land use in residential and all other land uses will be greater than it was in 1955, but in neither of these categories will it be greater than what it would have been had the WRDP not been initiated.

One possible explanation for the phenonmena demonstrated in Table 5-12 is the inclusion of the flood pool area in the study area. Prior to completion of the WRDP this land area was open to residential and all other forms of land development, but following completion of the Pine Creek project this land fell under the administration of the Corps of Engineers and the Oklahoma State Department of Wildlife Conservation. Further private development within the shaded portion of the study area in Figure 5-1 was subsequently restricted.

Thus to some extent the results in Table 5-12 may reflect the nature of the data base which encompassed both flood pool and privately owned land outside of the control of the Corps of Engineers. Future research should endeavor to segregate the study area into that portion which is controlled by the Corps of Engineers and that which is privately managed. This problem was not present in the Keystone area for two reasons: 1) unlike Pine Creek where the flood pool is 4 1/2 times as large as the conservation pool, the flood pool area in Keystone is relatively small compared to the conservation pool; 2) the study area in Keystone encompassed a broad band of land beyond flood pool area such that any flood pool included in the study area was relatively minor. For Pine Creek nearly half of the entire study area is in the flood pool.

capable of predicting land use patterns in each study area that would have existed in the absence of the water resource development project, 3) use these predictions to estimate the differential impact of the water resource development projects on land use patterns, and 4) evaluate the efficacy of a dynamic land use model as a predictor of the differential impact of water resource development projects on patterns of land use.

These four specific objectives were completed. The detailed results were presented in the previous chapters. In the remainder of this chapter these results will be summarized and a few concluding comments made with regards to the utility of the methodology employed.

Methodology

The general objective of the research reported herein is methodological. Most previous studies of land use change caused by WRDPs have compared "before" and "after" land use patterns, implicitly assuming that the differences between the two were caused by the project. By comparison the methodology employed in this project used a "what would have been" and "after" approach for estimating land use change. That is, estimated land use change is taken as the difference between land use patterns observed after completion of the project and estimates of what that land use pattern would have been if the project had not been completed.

The methodology employed in this study to estimate or project land use patterns is a Markov chain process. The Markov process is a mathematical technique that allows the simultaneous extrapolation of any number of land use categories with the restriction that the total amount

CHAPTER VI

SUMMARY AND CONCLUSIONS

Water resource development projects affect the impacted area in a variety of manners. Frequently an attempt is made to quantify these impacts to evaluate the feasibility of a proposed project. Recently increased attention has been directed to ex post analyses of the impact of water resource development projects. Numerous studies have attempted to evaluate the impact of major large scale water resource development projects on the economic base of the impacted area. The research reported in this study focused on one aspect of these changes.

A large scale water resource development project (WRDP) affects land use in the project area in two significant manners. First, a portion of the impacted area is inundated and further use of the land is precluded. A second impact of a WRDP is the change in land use patterns caused by the change in the area's economic base. It is this latter change that is the focus of the research project summarized in this report.

Objectives

The general objective of the research reported in this study is to develop a land use model capable of predicting differential land use change caused by water resource development projects. The specific objectives of the project were to; 1) identify and analyze historical patterns of land use in two study areas, 2) develop a dynamic model land must always remain constant. The basic data requirements of a Markov process are an original land use pattern and a matrix of land use transition probabilities. This matrix shows the probability of land in any given use at the beginning of a time period being transferred into every possible use by the end of the time period. The transition probability matrix shows land use transitions among all use categories for a specific time period which may be any number of months or years long. The vector of original land uses pre-multiplied by the transition probabilities matrix equals the land use pattern at the end of the time period. Assuming that the transition probabilities are constant with respect to time, the land use pattern at the end of the first time period may be multiplied by the same matrix of transition probabilities to obtain land uses in time period two; multiplied again by the transition matrix to estimate the land use pattern in time period 3, etc. In this manner it is possible to estimate land uses in any future time period given nothing more than an original land use pattern and a transition probabilities matrix.

For this study, transition probability matrices were estimated based on patterns of land use change prior to and following the construction of a water resource development project. The pre-WRDP transition probabilities reflect the dynamic pattern of land use change which existed in the impacted area prior to construction of the WRDP. Projections into future time periods based on pre-WRDP transition probabilities are valid estimates of what the land use pattern would have been in the impacted area if the WRDP had not been constructed. The difference between these estimates and observed post-WRDP land use patterns provides an estimate of the differential land use impact of the WRDP.

Estimates of future land use impacts are derived by projecting post-WRDP land use change patterns and comparing them to projected land use patterns based on pre-WRDP transition probabilities. The difference is equal to the projected differential impact of the WRDP on land uses.

This methodology can be further refined by estimating transition probabilities which change over time and are themselves affected by the WRDP. Dynamic transition probabilities may be estimated using a geometric adjustment method such that the probabilities tend towards an eventual equilibrium.

Empirical Findings

The above methodology was tested using data collected from two study areas. The first is the Keystone Reservoir project located near Tulsa, Oklahoma. The second is Pine Creek reservoir located in the extreme southeastern corner of Oklahoma. These two study areas were chosen because of data availability and because of their dissimilarities. The results from each area are discussed below followed by a brief summary of some additional work that was undertaken as a consequence of the original Keystone work.

Keystone

Keystone Reservoir is a large multi-purpose water resource development project located approximately 20 miles west of Tulsa, Oklahoma. The total study area encompassed approximately 181,000 acres of which approximately 32,000 acres were inundated by Keystone Lake. The construction of the lake necessitated the relocation of two small communities and encouraged the rapid development of residential and recreational development near the shores of the lake. Access to the lake is provided by a four-lane highway from Tulsa.

Land uses were observed from aerial photographs of the study area for 1948, 1958, 1964 and 1970. The Keystone project was completed in 1963, such that the change in land use is observed between 1964 and 1970 can be taken as indicative of land use changes following the project and land use changes observed between 1948 and 1958 are representative of changes is land use patterns prior to the initiation of the Keystone project.

Due to its proximity to a metropolitan area the immediate impact of the Keystone project was a relatively large increase in residential and other nonagricultural land uses. Agricultural use fell immediately following construction of the reservoir while nonagricultural uses increased. By 1970 nonagricultural uses increased by an estimated 900 acres (26%) over the estimated acreage which would have been present had the project not been completed.

The projected differential land use change shows an interesting pattern for Keystone. Residential land uses are estimated to continue to increase well past the year 2000. That is, the difference between the estimated residential acreage based on post-WRDP and pre-WRDP transition matrices continues to increase over time. By contrast, the differential impact estimated for all other nonagricultural, nonresidential land uses tends to decline over time. Since most of these uses are of a infrastructural nature this result is not at all unexpected. The interpretation which may be given to this result is that infrastructural land use changes required by the change in the economic base of the area were all made immediately following the construction of the reservoir, such that no additional land use shifts into these uses will be required for an extended period thereafter.

In summary the observed pattern of differential land use change at Keystone and the differential land use change which is projected for future time periods are consistent with apriori expectations and economic theory. Estimated differential land use change estimated by the dynamic transition probabilities was usually consistent with apriori expectations, but the quantity of change was less than that predicted by the static model and the adjustment period was more rapid.

Pine Creek

Pine Creek reservoir is located in southeastern Oklahoma in an area of rolling, heavily wooded hills. The Pine Creek project is primarily a flood control project with a total conservation pool area of 3,800 acres. The study area included a total of approximately 31,000 acres around, but not including , the conservation pool. The nearest population center is Broken Bow, which is located approximately 25 miles east of Pine Creek. The reservoir is accessible by a two-lane highway which crosses the lake about 4 miles north of the dam.

Land use data were collected for the Pine Creek area from aerial photographs taken in 1955, 1963, 1965, 1970 and 1974. Since the dam was completed in 1969 the 1955, 1963 and 1965 data are taken as pre-WRDP observations and the 1970-74 data are assumed indicative of changes in the land use pattern following completion of the project.

The growth pattern observed in the Pine Creek study area is heavily influenced by the scope of the Pine Creek project. Although, the surface area of the conservation pool is only 3,800 acres the surface area of the flood control pool (which is 42 feet above the conservation pool elevation) is 17,200 acres. Consequently, of the total study area, approximately 13,400 acres or 44% of the total is in the flood control pool and managed by the Corps of Engineers.

The pattern of land use change observed for the Pine Creek area is quite interesting. Both residential and all other nonagricultural land uses in 1974 were less than the levels that were estimated based on the pre-WRDP land use estimates. This is probably due to a decline in these land uses in the flood control portion of the study area with possible relocation beyond the study area. Residential land uses in 1974 are approximately 28% less then they would have been had the project not been completed. A detailed examination of the data support the contention that most of this was caused by relocation of residential uses within the Corps of Engineers management area.

Estimates of the projected differential land use change in the Pine Creek area suggest that the initial impact of the project will be eliminated by 2000. In fact, by that time there are only minuscule differences between estimated land use patterns based on the pre-WRDP and post-WRDP development patterns. In other words, after the initial impact of the project land uses are projected to return to approximately the same pattern that would have existed if the project had not been initiated. In summary, the Pine Creek results suggest that the immediate impact of the project necessitated some relocation of land uses, but that the long run impact of the project on land use patterns will be negligible. Since Pine Creek is somewhat remote this is not an unexpected finding. Projected land uses based on a system of dynamic transition probabilities produced results that were somewhat confusing and inconsistent with apriori expectations.

Fiscal Impact of Land Use Change

The estimates of differential land use change in the Keystone area created many additional research opportunities. One such avenue of additional research was pursued under sponsorship of the research project reported in this study. Details concerning the research procedure and results of this additional research effort are presented in Appendix III and summarized below.

As land use patterns change, the aggregate amount of wealth in the form of property in the area will also change. Property wealth will be affected by a WRDP in three manners: 1) by increasing per unit property values, 2) by changing land use patterns, and 3) by inundating a portion of the study area. The net impact on the total amount of property wealth in the study area caused by items 2 and 3 was estimated. Although nearly 18% of the Keystone study area was inundated and the property lost altogether, the total value of property in the study area increased by more than five million dollars due to increased residential and commercial uses of the non-inundated land base. As a consequence the net assessed value of property for purposes of ad valorem taxation increased by an estimated $1.1 million within the study area.

In Oklahoma ad valorem taxes provide partial support for common schools and general county government. The 39 mills which may be levied for current expenditures by schools would produce an additional $42,000 of revenue as a consequence of the increase in property value in the study area. The estimated revenue increase for general county government is nearly $11,000; but, as shown in Appendix III expected expenditures for common schools and general county government are also affected by WRDP. For instance, additional residential land uses implies an increase in the area population which implies additional school children. Rough estimates of the increase in common school expenditures suggest that the additional revenues will be adequate to pay for only 46% of additional common school expenditures and 14% of additional general county government expenditures. These estimates are subject to a variety of errors, but nonetheless are indicative of the magnitude of the fiscal impacts associated with land use changes.

Evaluation of the Methodology

The methodology used in this project and the results reported in this document are primarily of an ex post nature. In both study areas the estimated changes in land use patterns based on pre-WRDP transition matrices are deemed to be consistent with apriori expectations. Since these estimates and projections are not subject to validation, it's impossible to test the accuracy of the estimates or the methodology. Nonetheless, the nature of the results obtained in the two study areas suggests that the methodology is sensitive to the particular characteristics of each study area.

The potential for using the methodology in an ex ante manner is considered quite limited. If apriori expectations of future land use changes associated with any contemplated project are obvious, then the methodology may be feasible if not somewhat trite. However, the difficulty of quantifying ex ante transition probability matrices would probably nullify any beneficial attributes the methodology may possess.

Attempts to use dynamic transition probabilities matrices to estimate or project land use patterns were generally unsuccessful. The problems associated with this methodology are many. In the first place the data requirements are much greater than for the estimation of a static transition probabilities matrix. In the second place the geometric adjustment model used in this study requires the estimation of an equation with non-linear parameters. The techniques available to perform such estimates are somewhat limited and appear to give results that are very sensitive to changes in the data. Finally, the dynamic transition probabilities estimation procedure averages changes over a number of time periods such that the estimated pattern of change is not characteristic of any time period but instead is characteristic of an average of all time periods. As is always the case, an average often tends to obscure more than it reveals.

Ex post estimates of land use change using static transition probabilities have been shown to be useful tools in evaluating the impact of WRDPs. Most previous studies have attempted to estimate changes in economic patterns in the impacted area. The results of this study suggest that most previous analyses have failed to identify and evaluate the permanent changes in land uses which have occurred. The efficacy of the methodology used in this study as a tool in impact analyses was demonstrated by evaluating the impact of the Keystone project on the property tax base and the demand for public services within the study area. A variety of other uses of the ex post estimates of land use change may be envisioned.

Additional research using this methodology is suggested in an effort to further generalize the results reported herein. Such research should emphasize patterns of land use change associated with exogenous impacts other than water resource development projects.

In addition the methodology would appear to be appropriate for analysis of urban growth and land use change near other large scale investments such as interstate highways, energy facilities, etc. Additional research is also suggested to evaluate the impact of water resource development projects on the property market in the immediate vicinity of the project. This study is focused only on land use and not on land value. An expansion of this work in which land values are also considered would provide useful insight into the net impact of major projects on the private land market.

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APPENDIX 1

ESTIMATION OF TRANSITION PROBABILITIES MATRICES

As explained in Chapter III, the data collected for this study were adequate to measure the amount of land in each use category at particular points in time. The flow of land uses among categories over time was indirectly estimated using a computerized algorithm. The output of this algorithm is a land use flow matrix for each sample observation. These data are then aggregated for each study area and converted to transition probabilities matrices.

The Algorithm[1]

Land use categories were divided into three groups, each of which is treated differently in the algorithm. These groups are:

Group	Land Use Categories Included in Each Group
1.	Commercial, Extractive, Institutional
2.	Transportation
3.	Utilities, Impoundments, Residential, Cultivated Land, Pastureland, Woodland

Each city in the study area is identified by a set of coordinate boundaries. Sample observations within these coordinate boundaries are identified as city sample observations. All sample observations

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[1] This section is taken from Vandeveer [19], Appendix C.

not identified as city are rural sample observations. Slightly different sets of assumptions regarding land use flows were developed for rural and city sample observations.

Algorithm for Rural Sample Observations

The principal diagonal of a land use flow matrix represents land use acreages that remain in their respective land use categories throughout the time period in which the matrix is estimated. In describing the procedure for estimating the principal diagonal of the sample observation land use flow matrix, some mathematical notation is necessary. Assume that the beginning land use vector is B_i where $i = 1, ...r$, and the ending land use vector for the time period is E_i where $i = 1, ...r$. Then each F_{ii} = minimum (B_i, E_i) where F_{ii} are the diagonal elements of the land use flow matrix.

The off-diagonal elements of the land use flow matrix represent land use flows between alternative land uses over time. These elements are computed using appropriate assumptions regarding land use flows between alternative land uses.

In estimating the off-diagonal elements of the land use flow matrix, it is assumed that increasing land uses come from decreasing land uses in the sample observation in the time period. More specifically, it is assumed that if the acreage of a land use variable in group one or three increases over the time period, then this increase in acreage comes proportionately from decreasing agricultural land use.[2] However, if there is no decrease in agricultural land use acreages or

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[2] Agricultural land uses included in this analysis are cultivated land, pastureland and woodland.

if the decrease in agricultural land use acreages is not as large as the increase in group one or three acreage, then the remaining acreage increase is assumed to come proportionately from all other land use categories with acreage decreases. Transportation (group 2) acreage increases are assumed to come proportionately from all land use categories with acreage decreases in the sample observation.

Algorithm for City Sample Observation

A procedure similar to the one discussed in the previous section is used to estimate a land use flow matrix for each sample observation that is located in a city. The main diagonal of the land use matrix is developed in the same way; however, the assumptions used to compute the off-diagonal elements (land use flows over the time period) of the matrix are modified.

In estimating the off-diagonal elements of the land use flow matrix, it is assumed that if the acreage of a land use category in group one increases, then this increase comes proportionately from agricultural categories with acreage decreases. If there is no decrease in agricultural land use acreages or if the decrease in agricultural land use acreages is not as large as the increase in acreage of the group one category, then the increase in acreage of the group one land use category is assumed to come from any decrease in residential acreage. If the acreage decrease in agricultural and residential land use is not large enough to accomodate acreage increases in the group one land use variable, then the remaining increase is assumed to come proportionately from all other land uses with acreage decreases. Assumptions regarding land use flow for land use categories in groups two and three are the same as those for a sample observation which is located in a rural area.

Transition Probabilities Matrices

The above algorithm was used to compute the land use flow between each pair of dates for each sample observation. The estimates were then aggregated by study area. Transition probabilities matrices are computed directly from the land use flow matrices. Each element of the transition probabilities matrix shows the probability of land moving from one class to another. The sum of the elements in each row is 1.0 since all land in the initial time period must move into another use (off-diagonal elements) or remain in the same use (diagonal elements).

The static transition probabilities matrices for each study area and for each time period considered are shown in Tables A1-1 through A1-7. The only data reported in this study are for the aggregated use categories of agricultural, residential, and all other. Greater detail can be found in Vandeveer [19] and Gales [3]. Gales also reports findings for the limited sample taken in 1961 and 1963 of the immediate vicinity of Pine Creek dam.

Table A1-1

Transition Probabilities Matrix

Keystone, 1948 - 58

1948 Use	1958 Use		
	agricultural	residential	all other
Agricultural	.9882	.0032	.0086
Residential	.2563	.7270	.0167
All Other	.2596	.0077	.7328

Table A1-2

Transition Probabilities Matrix

Keystone, 1958 - 64

1958 Use	1964 Use		
	agricultural	residential	all other
Agricultural	.9811	.0060	.0128
Residential	.2091	.7603	.0306
All Other	.2549	.0097	.7354

Table A1-3

Transition Probabilities Matrix

Keystone, 1964 - 70

1964 Use	1970 Use		
	agricultural	residential	all other
Agricultural	.9900	.0040	.0060
Residential	.1029	.8740	.0231
All Other	.1872	.0084	.8043

Table A1-4

Transition Probabilities Matrix

Pine Creek, 1955 - 63

1955 Use	1963 Use		
	agricultural	residential	all other
Agricultural	.9875	.0011	.0114
Residential	.4866	.3345	.1789
All Other	.4228	.0160	.5613

Table Al-5

Transition Probabilities Matrix

Pine Creek, 1963 - 65

1963 Use	1965 Use		
	agricultural	residential	all other
Agricultural	.9812	.0047	.0142
Residential	.2139	.7195	.0665
All Other	.3722	.0356	.5921

Table A1-6

Transition Probabilities Matrix

Pine Creek, 1965 - 70

1965 Use	1970 Use		
	agricultural	residential	all other
Agricultural	.9866	.0010	.0123
Residential	.5841	.2524	.1636
All Other	.4339	.0106	.5555

Table A1-7

Transition Probabilities Matrix

Pine Creek, 1970 - 74

1970 Use	1974 Use		
	agricultural	residential	all other
Agricultural	.9827	.0022	.0151
Residential	.2965	.5304	.1731
All Other	.4704	.0290	.5006

APPENDIX 2

ESTIMATING DYNAMIC MARKOV TRANSITION PROBABILITY MATRICES

As briefly described in Chapter II, the dynamic transition probabilities used in this study were derived using a geometric adjustment model [14] where

$$P_{ij,t+1} = P_{ij,t} + \Theta_i(P_{ij,t} - P_{ij,t-1}) \qquad \text{(A2-1)}$$

If Θ_i is assumed constant for each row i, then (A2-1) can be solved as

$$P_{ij,t} = A_{ij} + \beta_{ij}\left(\frac{1-\Theta_i^t}{1-\Theta_i}\right) \qquad \text{(A2-2)}$$

where $A_{ij} = P_{ij,-1}$ and $\beta_{ij} = P_{ij,0} - P_{ij,-1}$. Equation (A2-2) may be estimated by a linear regression model of the form:

$$P_{ij,t} = b_0 + \sum_{j=1}^{n} b_j A_{ij} + \sum_{j=1}^{n} c_j \left(\frac{1-\Theta_j^t}{1-\Theta_1}\right) \qquad \text{(A2-3)}$$

where b_0 is forced to be equal to zero, n is the order of the transition matrix and A_{ij} are dummy variables equal to 1 when the dependent variable is from the j^{th} column and equal to zero otherwise. (A2-3) is estimated for each i.

(A2-3) is not linear with respect to the coefficient of Θ_i and consequently cannot be estimated by ordinary least squares. Instead a maximum likelihood procedure was used [6]. This routine estimates the parameters of (A2-3) for a variety of values of Θ_i, choosing that

Θ_i which gives the best statistical fit as measured by R^2. In other words, the values of b_n and c_n (n=1,.,3) and Θ_i are estimated simultaneously, with the total value of $\sum_{j=1}^{n} P_{ij} = 1$ for each i.

For each row, the input data are the transition matrix elements from each of the static transition probability matrices, the time period from which that matrix is drawn, and the column dummy. The estimated coefficients of A2-3 for the dynamic transition matrices are shown in Tables A2-1 and A2-2. These estimates were then used to calculate the individual elements in the dynamic transition probabilities matrix for each time period t. A special computerized algorithm was developed to perform the geometric adjustments. If any estimated elements fell below zero, they were assumed equal to zero and all other elements in that row were increased accordingly such that the row totals were always exactly equal to 1.0.

TABLE A2-1

ESTIMATED PARAMETERS OF THE DYNAMIC TRANSITION PROBABILITIES MATRIX: KEYSTONE

Land Use and Parameter	Agricultural	Residential	All Other
Agricultural			
b_j	1.011839	-0.007278	0.005789
c_j	-0.176078	0.119600	0.053156
Θ_j	0.115385	0.115385	0.115385
Residential			
b_j	0.280505	0.700437	0.019058
c_j	-0.013049	0.012417	0.000632
Θ_j	0.984615	0.984615	0.984615
All Other			
b_j	0.276003	0.008111	0.716059
c_j	-0.006030	0.000073	0.005940
Θ_j	0.984615	0.984615	0.984615

TABLE A2-2

ESTIMATED PARAMETERS OF THE DYNAMIC TRANSITION PROBABILITIES MATRIX: PINE CREEK

Land Use and Parameter	Agricultural	Residential	All Other
Agricultural			
b_j	1.070167	-0.030589	-0.039578
c_j	-1.791111	0.686593	1.104519
Θ_j	0.046154	0.046154	0.046154
Residential			
b_j	3.003111	-3.101678	1.098567
c_j	-54.524410	75.450520	-19.926110
Θ_j	0.046154	0.046154	0.046154
All Other			
b_j	0.395906	0.916993	0.587190
c_j	0.003742	0.000752	-0.004503
Θ_j	0.984615	0.984615	0.984615

APPENDIX 3

IMPACT OF LAND USE CHANGE ON PRIVATE PROPERTY WEALTH, TAX BASE, AND PUBLIC SERVICE DEMANDS

The purpose of this appendix is to estimate the change in property wealth in the study area associated with land use changes resulting from the construction of Keystone Lake and relate these changes to the supply of and demand for public services. In Chapters IV and V actual differential land use changes associated with the project were estimated. The results indicate that agricultural uses decreased while nonagricultural land uses increased. With these land use changes an increase in property wealth may result because of a) increases in land and improvements prices due to the proximity of the reservoir, and b) land use pattern adjustments in the reservoir area. In this Appendix, only changes caused by the latter are considered. Property values are assumed to remain constant within each use category. Thus, all charges in property value reported herein are caused by adjustments in the use pattern only.

Actual Differential Property Wealth Change

Current property wealth may be estimated using the actual land use pattern (Q_n) and per unit market values of land and improvements.

$$W_n = Q_n V'_n + Q_n I'_n \qquad \text{(A3-1)}$$

where Q_n is a vector of r land use quantities existing in the reservoir area at time n. V'_n and I'_n are transposed vectors (of length r) of per unit values of land and improvements respectively at time n. It is assumed that V_n and I_n do not vary with n.

Projected land uses $({}_{ab}Q_n)$ in the study area had the project not been constructed are estimated by equation (8) in Chapter II. Using these estimates, the property wealth had the project not been constructed $({}_{ab}W_n)$ is:

$$ {}_{ab}W_n = {}_{ab}Q_n V'_n + {}_{ab}Q_n I'_n \qquad \text{(A3-2)} $$

Actual differential change in property wealth is estimated by the difference between actual property wealth estimated by (A3-1) and property wealth had the project not been constructed estimated by (A3-2).

$$ P_n = W_n - {}_{ab}W_n \qquad \text{(A3-3)} $$

P_n is the estimated actual differential change in property wealth at time n resulting from the changes in land use patterns caused by the construction of Keystone Lake.

Impact of Land Use Change on the Tax Base: Keystone[1]

The estimated differential change in land use resulting from construction of Keystone Lake is shown in Table A3-1. Note that these data are different from those presented in Chapter IV due to the inclusion of the inundated portion of the study area. Column 1 shows the actual number of acres in each land use category in 1970. Column 2 shows the projected acreage in each land use category had the lake not been built. Column 3 (col. 1 minus col. 2) shows the estimated

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[1] This section is taken from Knight and Drummond [9].

TABLE A3-1

Differential Land Use Change Resulting From Construction of Keystone Reservoir

Land Use	Observed Land Use in 1970 With Keystone	Estimated 1970 Land Use Without Keystone	Differential
	acres		
Non-Agricultural Uses			
Residential	2,481.60	1,960.14	+521.46
Commercial	376.66	181.50	+195.16
Extractive	606.07	789.50	-183.43
Transportation	2,558.20	2,628.04	- 69.84
Utilities	1,111.48	960.11	+151.37
Institutional	124.61	103.45	+ 21.16
Sub-total	7,258.62	6,622.74	635.88
Agricultural Uses			
Impoundments	649.92	731.42	- 81.50
Cultivated	4,979.93	13,626.61	-8,646.68
Woodland	78,406.71	86,255.30	-7,848.59
Pastureland	57,395.66	74,258.51	-16,862.85
Sub-total	141,432.22	174,871.84	-33,439.62
Lake	32,803.74	0	+32,803.74
Total	181,494.58	181,494.58	0

differential land use change resulting from the lake. The data indicate that construction of Keystone resulted in a decrease in all agricultural uses accompanied by an increase in most nonagricultural uses. Most of the loss in agricultural land was caused by inundation with the remainder resulting from a shift of non-inundated agricultural land to nonagricultural uses.

The data in Table A3-1 may be used to estimate the change in the property tax base associated with the construction of Keystone. A new lake will affect the tax base in two manners: First, land use patterns will change with some net additions to the high valued uses such as residential and commercial. As shown in Table 1, there was a net gain of 635 acres of these high values uses which is offset by the loss of 33,440 acres of relatively low value agricultural land. A second factor which may cause a change in the size of the tax base is a change in the value per acre of property in each land use. Presumably, residential property values per acre will increase as a consequence of the lake being nearby. In order to isolate only one of these two changes associated with the construction of Keystone, it is assumed that per acre property values before and after the construction of the lake are the same. In doing so, estimates of change in the tax base will certainly be underestimated to the extent of relative price changes.

The estimated change in the property tax base associated with the differential change in land use patterns is shown in Table A3-2. Change in the tax base is equal to change in each land use category times the per acre value of land in that use.[2] The per acre values for residential

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[2] These values were obtained from responses to a questionnaire by members of the Oklahoma Society of Farm Managers and Rural Appraisers. The average responses were deflated to 1970 dollars. For further information see Vandeveer [19].

Table A3-2

1970 Impact of Keystone Lake on the Property Tax Base

Land Use 1/	Acreage Differential	Land and Improvement Value per Acre	Net Change in Property Value ($1,000)	Average Assessment Rate 2/ (percent)	Change in Gross Assessed Value ($1,000)	Change in Homestead Exemptions ($1,000)	Change in Net Assessed Value
Residential	+ 521	$ 14,400	+ 7,509	18	+ 1,328	- 502	+ 826
Commercial	+ 195	$ 15,860	+ 3,095	16	+ 497	0	+ 497
Extractive	- 183	119	- 22	16	- 4	0	- 4
Impoundments	- 82	119	- 10	5	- 1	0	- 1
Cultivated	- 8,647	214	- 1,853	5	- 94	0	- 94
Woodland	- 7,850	102	- 801	5	- 40	0	- 40
Pastureland	- 16,863	134	- 2,262	5	- 114	0	- 114
TOTAL	- 32,909		+ 5,655		+ 1,572	0	+ 1,070

note: data are rounded to nearest integer values

1/ Only private, taxable land uses are included

2/ Weighted average of Creek, Pawnee, Osage and Tulsa counties and commercial land uses (column two) are relatively high because of the importance of buildings and improvements in the total property value. As shown in the third data column, increases in these values offset losses due to inundation at a rate of approximately two to one. The $5.7 million increase in total property value raised gross assessed value by $1.6 million and net assessed value by $1.1 million.

By Oklahoma law, counties are limited to 39 and 10 mills respectively for common school current expenditures and general county government. Therefore, with a net change in the tax base of $1,070 thousand the revenues available for current expenditures at common schools will increase by $41,736. General county government revenues which are earmarked for support of the county sheriff, administrative offices and most functions other than schools and roads will increase by $10,702.

Impact of Land Use Change on Local Government Expenditures: Keystone[3]

The increased cost to county governments of providing public services associated with construction of Keystone Reservoir result from additional population in the area and from additional traffic generated by the recreational potential of the lake. In this section changes in two specific local government expenditures--common schools and general county government--will be estimated. Earmarked property tax levies support each. The net impact of the Keystone project on each of these county expenditures will be estimated separately and and then compared with the previously estimated changes in revenues to determine the structural impact of a WRDP on the fiscal environment of

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[3] This section is from Knight and Drummond [10].

local governments.

Common Schools

Common school expenditures of county governments are determined by the number of students in the district and expenditures per student. Assuming constant levels of expenditure per student it is only necessary to estimate the change in number of students in order to derive an estimate of total change in school costs.

Knight and Drummond [10] estimated that the 1970 differential population change in the study area is 3,272. In the four county area common school enrollment is 23.56% of the population [18] and the average operating expenditures per student are \$275.55 [13]. Thus, the net change in 1970 common school costs caused by Keystone may be estimated as follows:

$$\begin{array}{c}\text{Change in}\\ \text{School Costs}\end{array} = \left(\begin{array}{c}\text{Change In}\\ \text{Population}\end{array}\right) \left(\frac{\text{School enrollment}}{\text{population}}\right) \left(\frac{\begin{array}{c}\text{Operating}\\ \text{expenditures}\end{array}}{\text{Students}}\right) \quad \text{(A3-4)}$$

$$= (3{,}272) \quad (0.2356) \quad (275.55) = \$212{,}417$$

Thus, the estimated increase in cost of public schools resulting from construction of the reservoir is \$212,417.

General County

The relationship between county characteristics and the cost of general county government was estimated by a regression model in which each county of Oklahoma was taken as an observation. In the simplest model which gave a good fit the explanatory variables were population and area, and the dependent variable was level of county expenditures other than common school and highway expenditures [12]. The resulting predictive equation was as follows:

$$\begin{array}{c}\text{General}\\ \text{County}\\ \text{Expenditures}\end{array} = -147{,}563.35 + 27.30\ (\text{Population}) + 96.10\ (\text{Area}) \qquad (\text{A3-5})$$

Since the total area of the impacted counties was not changed by the construction of the lake, the change in general county expenditures is simply a function of the population change:

$$\begin{array}{c}\text{Change in}\\ \text{General County}\\ \text{Expenditures}\end{array} = 27.30 \left(\begin{array}{c}\text{Change in}\\ \text{Population}\end{array}\right) \qquad (\text{A3-6})$$

$$= 27.30 \ (3{,}272) = \$89{,}326$$

Thus, a $89,326 increase in general country expenditures has resulted from construction of Keystone Lake which must be financed by the 10 mill property tax levy.

Net Fiscal Impact of Keystone

In the previous sections, estimates were made of the impact of Keystone Lake on the earmarked revenue for and expenditures on common schools and general county government. These results are summarized in the first two rows of Table A3-3. In each case, increased expenditure demands are at least five times greater than the earmarked revenue that is estimated to result from the net change in the economic base associated with the construction of Keystone Lake. The obvious implication of these results is that a system of rigid earmarking of revenues may not provide local governments adequate revenue generating capacity in areas impacted by major exogenous investments. Alternatively, exogenous investments may cause public service reductions in the impacted area because demands at present service levels increase more rapidly than the earmarked revenues available to finance them.

Table A3-3

Estimated Fiscal Impact of Keystone Reservoir

	Common Schools	General County Government
Estimated Change in Earmarked Revenue	$ 41,736	$10,702
Estimated Change in Expenditures	$212,417	$89,326
Earmarked Revenues as a Percent of Total	42.46%	85.03%
Earmarked Expenditures	$ 90,192	$75,954
Earmarked Revenues as a Percent of Earmarked Expenditures	46.27%	14.09%

For both common schools and general government expenditures, earmarked revenue is not the only financing that is provided. In the case of common schools, earmarked county funds provide slightly more than two-fifths of total operating expenditures, with the rest being provided by state matching funds and federal assistance programs. Since the level of funding from both of these sources is closely tied to school attendance, revenues from these sources should increase in response to the net population increase caused by Keystone. The data labeled "earmarked expenditures" in Table A3-3 correct for non-earmarked funding by reducing expenditure estimates in proportion of the level of non-earmarked revenues. Even after making this correction, only one-half of the increases earmarked expenditures would be covered by earmarked revenues, indicating that a reduction in spending per student would necessarily occur. Since spending per student has to be a valid indicator of the quality of education [5], the conclusion may be drawn that the development of Keystone Lake (within an environment of earmarking) could cause a decline in educational quality in the four county area if county assessors do not increase assessed values following completion of the project.

A similar adjustment in general county government expenditures was made to account for that portion of general county funds that is derived from fees and charges [17]. Even after this correction, the increase in earmarked revenues is adequate to finance only 15% of the increased earmarked expenditures that would be required to maintain prior levels of service for the increased population.

The estimates presented in the Appendix are certainly gross and subject to a variety of errors, but the general magnitudes of the earmarked revenue shortfalls are substantial. Errors are known to exist in the estimates due to the assumption that property values did not increase due to the project. Nonetheless, if the revenue estimates were doubled and the expenditure estimates halved, there would still be a shortfall on general county government of more than one-fourth of earmarked expenditures.