A PILOT STUDY FOR ESTIMATING LAND USE CHANGE

by

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ABSTRACT

A two stage area-point sampling design was tested to estimate land use change in a fast growth county. Random square miles were selected, then subsampled at a density of 20 points per square mile. Twelve land use categories were derived from an aggregation of the USGS Land Use/ Land Cover system. High altitude color infrared aerial photography was interpreted for two dates nine years apart. The sample design was tested empirically against digitized values obtained from a land use inventory at one date. Paired sample differences, of land use proportions within the sample squares, were used to derive land use change statistics. Sample points were paired between dates to identify changes between land use categories through the construction of transition matrices.

Paired sample differences are recommended to specifically address land use change. An initial 5% sample of paired differences is advised to base the sample size upon land use change at the reporting level of interest. Recommendations are suggested for stratification to reduce the sample variances, thereby increasing the precision.

Introduction

The Economic Research Service, United States Department of Agriculture (USDA), entered into a cooperative agreement with the Department of Geography at Oregon State University to design a land use change sampling methodology which could be used on fast growth counties. A pilot study was proposed in a portion of Washington County, Oregon, one of 139 designated fast growth counties, to test the methodology. This report presents the results of the pilot study.

Literature Survey

There exists a small but growing body of literature on the estimation of land use change using sampling methods. Sampling methodology strives to provide accurate estimates of a population within a set margin of error and described by a certain level of confidence. Successful sampling will provide such estimates at costs less than surveying an entire population.

A series of national land use studies began in 1958, when the Soil Conservation Service, USDA, undertook the Conservation Needs Inventory (CNI). This inventory utilized a two-stage sampling methodology on all rural land, exclusive of federal land and certain other lands. Sample areas were randomly selected for the first stage, then field examination was undertaken for three randomly allocated points within each sample area (USDA 1962).

In 1962, Berry analyzed the relative efficiencies of various sampling methods as they applied to area sampling, finally recommending a stratified systematic unaligned sampling methodology. Much of the study was based upon the statistical theory presented earlier by Quenouille (1949). Even though this method appears to hold a preferred standing in much subsequent literature, some authors have questioned the conclusiveness of his empirical results (Frazier and Shovic 1980; Bryant and Russwurm 1983). Using this method, sample error calculations would need to be experimentally determined as "no trustworthy method for estimating [the variance] from the sample data is known" for systematic sampling (Cochran 1977). However, in his study areas, Berry experimentally obtained variance estimates for the stratified systematic unaligned method showing an increased sampling efficiency of one to three times that of a simple random method.

Sloggett and Cook (1967) undertook a study utilizing a stratified systematic unaligned sample of points to estimate the major economic effects of flood prevention on small watersheds. The sampling rate was derived by assuming a random sample and was considered equal to or larger than that actually needed because of Berry's calculation of the higher efficiency for the systematic sampling scheme.

Holmes, in 1967, made an attempt to clarify the differences in area vs. locational sampling. Regarding random vs. systematic sampling methodology he states that truly random sampling is "statistically impeccable" and that the high variances which usually result can be reduced through stratification. Systematic sampling, he felt, could be adequately randomized within a grid framework by non-alignment or random selection of the starting point. However, he indicates a weakness exists in that the probability of the classification of any particular point is in direct proportion to the size or distribution of the dominant characteristics of the population. This suggestion is supported through analysis by Fitzpatrick-Lins (1981), who demonstrated that a stratified systematic unaligned sampling design is area-weighted. That is, the majority of sample units are selected from categories which cover the most area. Categories of interest which covered small areas were not well-represented. Smarrt and Grainger (1974) similarly demonstrated that small scattered areas of interest tend to be less well represented by systematic sampling, although they found a better representation with a stratified systematic unaligned design than with other systematic procedures.

A 1968 study by Stobbs designed to map land use and measure land use change in underdeveloped countries utilized a random point sample to insure a valid estimate of the sampling error. Sampling density in Stobb's study was preset in accordance with the desired precision at the national level; therefore, local precision varied depending on the patterns of land use.

A study by Dill and Otte (1971) of urbanization in 96 counties in the northeastern states utilized the randomly allocated sample points from the 1958 Conservation Needs Inventory (CNI). They stratified each county into equal-size areas and randomly sampled the CNI sample points which were identified on aerial photography. Sample errors and confidence limits were included with the study and rural land conversion was estimated.

Land use change statistics were derived from a 24 million acre study area in the southern Mississippi River valley by Frey and Dill in 1971 using small scale (1:125,000) aerial photography and USDA photo indexes. Sample points were selected using an aligned systematic procedure resulting in 38,000 points distributed with a density of approximately one point per square mile over the entire study area. Sample error was expected to be small even for land uses comprising only 1 or 2 percent of the study area because of the large number of sample points.

Two-stage sampling was adapted by Zeimetz (1976) to a study of land use change in fast growth counties. Large scale (1:20,000) USDA aerial photography was available in 53 of 129 counties for two dates which approximated the 10 year interval from 1960-1970. Photo frames were chosen systematically from flight lines and a random point subsample, with a density of 20 points/square mile, was taken of each selected frame. The sample error was calculated for one date of the two stage sample by assuming random selection at both stages. Points were paired to enable the construction of land use transition matrices identifying changes between land use categories. Simple comparison of land use inventories at the two dates provided the estimates of change.

In 1980 Frazier and Shovic published a study which evaluated land use sampling designs for detecting change in rural areas. Designs were evaluated using a method similar to that of Zeimetz, where samples were distributed using a two stage area-point methodology. Greatest precision in estimating land use proportions was obtained from a stratified random paired point methodology, although a simple random method showed no significant difference in precision in their study area. Their work agrees in substance with Van Genderen (1978) who states that "stratified random sampling techniques have been readily accepted as the most appropriate method of sampling in resource studies using remote sensor imagery, so that smaller areas can be satisfactorily represented." Systematic selection of samples in a N-S direction when compared to samples selected in an E-W direction resulted in inconsistent sample errors, whereas the standard errors of stratified random and simple random were consistent. This was an important point because it modeled the selection of aerial photos from flight lines. The authors stressed the advantages of paired random sample differences in order to increase the efficiency of land use change studies and to allow a statement about the precision of the results, rather than the alternative method of comparing sample means from two different dates.

Rosenfield (1982) advocated the use of unaligned systematic point samples and the multinomial probability distribution in the estimation of land use change when more than two categories of land use are involved. The preliminary experiment presented does not provide adequate empirical data for comparison with other studies.

In 1983, Bryant and Russwurm published a report on area sampling methodology. They did not undertake a land use study, but rather reviewed the methodologies of several countries with active national sampling programs. Recommendations for a Canadian rural land use monitoring program were presented.

Sampling Method

In the light of previous land use change studies, a two-stage random sampling methodology utilizing paired area-point sample differences between dates was chosen for this pilot study. Random techniques were employed to allow the calculation of the sample error and the construction of confidence intervals in order to appraise the significance of the results.

Since the focus of the study was to identify land use change and not to determine the distribution of land uses at two different times, sample statistics were determined from paired sample differences. Using paired sample differences, the efficiency of land use change statistics can be increased since individual sample units may show consistency over time but may also exhibit wide variation when compared to sample units located elsewhere. Confidence levels based upon the spatial variations at different dates will usually be lower than those describing the temporal variation using paired sample units (Bryant and Russwurm 1983). Land use proportions determined for each date will therefore have lower precision than the land use change estimates.

Stratified sampling was not used because objective and practical criteria for stratification were elusive. Appropriate criteria would enable boundaries to be constructed so that homogeneity is maximized within strata and differences between strata are also maximized. Samples taken from each strata would then have a lower variance and fewer samples would be required for a stated level of precision. For land use change detection, strata criteria would need to define strata whose homogeneity is based on the potential for change. However, very little research has been done on the causal variables related to land use change (Bryant and Russwurm 1983). Additionally, criteria would need to be equally applicable to all of the 139 fast-growth counties identified for a proposed national study. Possible approaches to stratification are discussed in the Recommendations section of this study.

The first stage of the sample was an area sample of random square miles. A random, twenty point subsample of each square mile sample was taken as the second stage. Variance was addressed only in relation to the selection of the first-stage sample square miles because it is primarily dependent on the spatial distribution of first stage samples; the area of each sample square is a very small percentage of the total sample area (Frazier and Shovic 1984). Each sample square had a different set of random points which were identically paired at the two time periods. The selection of sample squares with a point density of 20 dots as a sample design is based upon the work of Zeimetz (1976) and Frazier and Shovic (1980). The latter tested a number of different designs of sample area and dot densities, concluding that 20 dots/square mile was an efficient combination with an acceptable error factor.

The appropriate sample size to give the required maximum allowable error at a given confidence level was estimated from a 5% pilot sample of paired random sample differences in the study area. Land use was interpreted at each of the 20 random points within the 8 sample square miles. Proportions of each category of land use within a sample square were recorded. Comparison between the same sample squares at different dates indicated whether or not there was a change in the proportion of each land use class.

These paired sample differences were recorded as proportions for each matched sample area maintaining the sign convention to record the direction of change. This constituted a population of differences from which sample means $(\overline{D})$, standard deviations (S_D), and standard errors of difference $(S_{\overline{D}} = S_D/\sqrt{n})$ were calculated in percent for each land use (Snedecor and Cochran 1980:83).

The variance (S^2_D) of the 5% pilot sample was used to estimate the required paired sample size (n) once the desired half-width (d), as a percent of the total study area, of the confidence interval was selected. Student's t distribution for a two-tailed test with the appropriate confidence coefficents and degrees of freedom (n-1) was used because population parameters were unknown. The appropriate calculation follows (Frazier and Shovic 1980):

$$n = \frac{t^2 \ S^2_D}{d^2}$$

The required sample size was calculated for each land use, using a constant half-width. The largest sample size was chosen for a conservative estimate. If the resulting sample size was greater than 10% of the population (N) then it was revised by the finite population fraction to arrive at n', where (Snedecor and Cochran 1980:442):

$$n' = \frac{n}{1 + \frac{n}{N}}$$

Once the revised sample size was determined, based upon the requirements of the study, paired sample differences were obtained from a random selection of sample squares.

Confidence intervals for the estimated population mean (μ_D) of each land use change were constructed as follows (Snedecor and Cochran 1980:86):

$$\overline{D} \pm t(1-\alpha\ ;\ n-1)S_{\overline{D}}$$

The confidence interval enclosing the estimated proportional change of each land use indicated whether the sample results would have significance at the desired confidence level. If the confidence interval includes zero then random variation could account for the difference between the two dates with regard to a particular land use.

Land Use Classification and Aerial Photography

Land use was classified into 12 categories which were adopted with some modification from the classification system proposed by Anderson (1976) and utilized by the United States Geological Survey (USGS) (see Table 1). Many earlier land use studies had developed new classifications or redefined those existing. The USGS System attempts to address the needs of a number of potential users by providing a hierarchy of classes capable of aggregation at different levels. Explicit and extensive definitions have also been provided to assure standard usage (Anderson 1976; Loelkes 1982; 1983).

Color infrared (CIR) photography was chosen for interpretation because of the greater contrast provided between objects and their surroundings. It is sensitive to both the visible and reflected infrared portions of the electromagnetic spectrum and has been found to have excellent haze penetration capability, making it especially useful for high altitude interpretation of land/water interfaces, vegetation cover types, and for delineation of urban land use (Lillesand and Kiefer 1979).

The aerial photography available for a national study for the more recent date, 1980-1984, was determined to be National High Altitude Program (NHAP) photography with a nominal scale of 1:58,000. The photography for the earlier date, 1970-1974, is available for nearly all of the potential study counties as small scale (1:120,000) CIR photography.

In addition to calculating statistical sampling error, the sampling methodology designed for this study was tested empirically against a land use map produced from the 1982 NHAP photography. The general approach to mapping land use followed that of the USGS Land Use/Land Cover program. USGS map delineations utilize different minimum polygon widths and sizes for urban versus rural land use types. This convention was followed, although minimum polygons were selected appropriate for the 1:58,000 scale from a table provided by Loelkes (1983). This table indicated the selection of a 2.5 acre or a 125 foot minimum width polygon for the classes defining Urban or Built-up land, Other Agricultural Land, Confined Feeding, and Water. A 10 acre minimum polygon or a 660 foot width was the minimum designation for all other classes. From tests on the small scale 1:120,000 photography it was determined that these minimum polygon sizes and widths could be identified accurately for sample point classification, although construction of a land use map at that scale using those standards would have been difficult. The minimum polygons used in this study are smaller than those used in the USGS mapping program, which are 10 acres and 40 acres; however, the smaller polygons are more appropriate to detect land use change occurring incrementally on small rural lots. Small farms would be less likely to be included with urban designations if a minimum rural polygon size of 10 acres were used. A density criterion of four dwellings per 10 acres was applied to distinguish rural residential areas of sufficient development to be classed as urban or built-up.

Detailed procedures for drawing the sample, adjusting photo scales, coding land use change, and the conversion of sample points into acreage figures are contained in the project report, listed under references (See: Behm and Pease 1985). The reader is referred to this document for a full description and analysis of the project.

Results

This study utilized a two-stage paired random sample difference methodology in conjunction with aerial photography to estimate land use change. The estimated change for each land use from 1973 to 1982 is listed in Table 2 within ±5% of the total area with 90% confidence. Whether or not the change is statistically significant is also indicated. Table 3 is a land use transition matrix giving the estimated acreage of land use change between specific classes. Acres in these classes are converted to percentages of the total study area in Table 4. As suggested earlier, the paired sample difference methodology provides lower levels of precision to the actual land use distributions than to estimates of change. As indicated in Table 6, 33 paired random square mile samples in both 1973 and 1982 will estimate the land use distribution at each date within ±10% of the total area with 95% confidence.

An evaluation of the land use change estimates could be achieved by constructing two land use inventory maps at the same scale, overlaying them and measuring the polygons indicating land use change, but this could not be accomodated under budget constraints. However, an evaluation was undertaken to test the sampling method on the existing land use distribution at one date. An inventory of land use was mapped onto a clear acetate overlay of each 1982 NHAP frame using the procedure of USGS Land Use/Land Cover maps (Loelkes 1982; 1984). In this case the land use polygons were delineated according to the minimum mapping width and area as revised for our study. Each polygon was digitized and proportions of land use in the study area determined.

As already mentioned, the 5% pilot sample predicted that 33 random samples would estimate land use proportions within ±10% of the total area of the actual digitized totals with 95% confidence. The results in Table 7 show that all of the land uses which cover more than 1.0% of the study area were within the resulting confidence intervals. Bryant and Russwurm (1983) suggest that land uses accounting for less than 3.0% of the land cover might be considered below a threshold level of importance. Comparison of the digitized area proportions and the sample proportions for each land use reveals that the sample results are much closer than indicated by the confidence interval. This suggests the conservatism of the sampling methodology and the potential for initially using a smaller half-width to determine the sample size.

Ground truthing the interpreted land use classes at the 1982 date was performed via an actual visit to a sample of the mapped sites. Four points from the 20 sample points in each square mile were randomly selected for field verification. A total of 132 points, or 20%, were available. Access to some of the sites was limited and actual verification was accomplished for 113 sample points (see Table 8). Even though no attempt was made to equally or proportionally represent the land use classes of the points groundtruthed, the proportions generally represented the actual distributions of the major land uses. Misinterpreted points were 5% of the total number of points groundtruthed.

The increase in efficiency offered by paired sample differences for estimating change is indicated by the number of samples required to achieve a specified level of confidence (see Table 6). The 5% pilot sample of 1973 photography indicated that to estimate cropland and pasture within ±10% of the total area with 95% confidence a sample size, n', of 22 was required. The same confidence level with the same 5% sample in 1982 would require 27 samples. As Frazier and Shovic (1980) indicated, a minimum sample size determined for one date may not accurately represent land use at another date with the same precision. Anyone undertaking a study using paired random samples at the two dates would therefore use at least 27 samples. However, if paired random sample differences of the same 5% sample were used, a minimum sample size of only 16 is required to estimate change within ±10% of the total area at the 95% confidence level.

A paired random sample at 27 was selected from the 1973 and 1982 photography and paired random sample differences were obtained for 16 samples for comparison (see Table 9).

From the 27 samples, the mean proportions of cropland and pasture for 1973 and 1982 were 59.44% and 51.11% respectively. However, one cannot say absolutely that the change in land use is the difference between the means, (-8.33%). Construction of confidence intervals would indicate that the means may vary by ±11.21% in 1973 and ±13.30% in 1982.

Using 16 paired sample differences, which is all that is required for the same precision, the estimate of the change in cropland and pasture from 1973-1982 was -8.75%. This shows little actual difference from the percent change arrived at earlier by subtraction (-8.33%). However, the confidence interval constructed for the mean sample difference includes zero, indicating that random variation could account for the observed difference between the two dates. This was not apparent from substracting the sample means from two dates. Table 9 gives the means for the 27 paired samples for 1973 and 1982, and their differences by subtraction. It also gives the mean change derived from paired sample differences and indicates for which land use categories the observed change is significant.

In terms of aerial photography acquisition, a potential disadvantage of the methodology is that it requires coverage of the entire study area. In the Zeimetz (1976) study and the methodology used in France's land use monitoring program, a two-stage sample based upon large scale photo frames allowed a first stage selection of only certain frames (Bryant and Russwurn 1983). A comparison with the methodology of this pilot study can be made for both the number of airphoto frames required for a national study and the distribution of sample areas.

The objective of the Zeimetz study was to sample 10% of the study area; however a 15% sample resulted. If a 15% sampling fraction were used for comparison, the methodology of our pilot study should estimate the mean land use change within ±5% of the total area with 80% confidence. The national sample area, 25,842 square miles, would require 3231 B&W photo frames at a scale of 1:20,000 which each cover approximately 8 square miles. The second date would be the same scale, but obviously the frames would not be perfectly paired to the first date. If frames were closely paired then about the same amount would be involved for the second date or a total of 6462 frames. However, if frames of the second date were not closely paired with those of the first, up to 4 times as many frames would be required to pair points. Small scale total coverage using 1:120,000 and 1:58,000 photo scales for the respective dates would require 3207 frames, but large scale partial coverage may require purchasing and handling from 6462 to 16,155 frames. In a study area the size of this pilot study, 163 square miles, a sampling fraction of 15% would amount to about 24 square miles. Using large scale photos (1:20,000), the sample would require only 3 airphoto frames.

The comparison value of the land use classes used in our pilot study with those of other studies may present some inconsistency. The USGS classification combines cropland and pasture uses together at Level II. Loelkes (1983) states that, even at Level III, cropland is difficult to separate from pasture and usually requires site validation. This presents some difficulty for comparing agricultural data derived from aerial photography with data from field surveys such as the National Resource Inventory, or the Census of Agriculture. These data sources use classification systems which categorize cropland separately, but combine pastureland with rangeland.

Summary

This study has been directed to the estimation of land use change through the use of sampling methodology and aerial photography. A two-stage paired random sample of differences was utilized to detect change.

The use of a two-stage technique allowed for intensive coverage of the selected areas to identify changes encompassing small acreages. The interpretation effort is also concentrated on a compact area. Paired points allowed for the construction of a land use transition matrix identifying "from-to" changes in land use by category. Random methodology was used in order to appraise the statistical significance of the estimated land use changes.

An alternative sampling design, recommended by several researchers, to that tested in this study is the stratified, systematic, unaligned design (Berry, 1962; Cochran, 1977; Berry and Baker, 1968; Taylor, 1977; Fitzpatrick-Lins, 1981; Dickinson and Shaw, 1977). Although not strictly amenable to statistical tests of error, because of its non-random design, several empirical studies have shown results to be as precise or more precise than random designs. Had the budget permitted, it would have been desirable in this study to test this design against our inventory proportions and evaluate precisions and costs relative to the two stage random sampling design.

For a given sample size, either methodology would benefit from the reduced variance attainable using paired sample differences to estimate land use change. To determine sample size, an initial 5% pilot sample ensures that the sample size is based on the existing distribution of land use change within the study area. In a multi-county study, this would ensure that statistics from each county were reported with the same level of precision.

Recommendations

The study provides a suitable methodology for the detection of land use change. A review of the results and procedures has identified areas of concern where recommendations are appropriate.

The first is the use of small-scale aerial photography. Although it is available for most of the study counties, it does present a potential source of inaccuracy. Sample points must be accurately placed or pairing will not be achieved. Inaccurate pairing could result in an erroneous indication of change from one land use category to another.

If larger scale photography could be obtained, or enlargements made of the available small-scale photography, paired points would be more easily obtained. This was not a major problem in our study, although if several air photo interpreters were employed for a national study, the matter should be addressed.

Other concerns are the allowable error selected for the study and the high variance (S^2_D) which resulted. The confidence intervals were calculated from a preselected half-width of either ±5% or ±10% of the total study area. Sample sizes based upon these half-widths were calculated and used in the estimation of change. The estimated urban (classes 11-17) change was an increase by 9.85% of the total study area, but the resulting magnitudes of change for all land use classes varied from -0.30% to 6.82% of the study area. The half-widths of the resulting 90% confidence intervals varied from 52% to 71% of the estimated mean land use change (see Table 2). The study could be improved by reducing the width of the confidence interval. This would increase the sample size and reduce the variance among the samples.

Two suggestions could be made for establishing the half-width. It could be arbitrarily set at a smaller percentage of the study area, for example ±2%, which would more accurately reflect the magnitude of the change expected when there are numerous land use classes. It could otherwise be set as a percent, perhaps 20% or 30%, of the mean of each land use identified at the earlier data. This could be done at the 5% pilot sample stage. The resulting area percentages would be divided by two and used as confidence interval half-widths for sample size estimation.

The actual sample size would be selected from among those calculated. A trade-off between precision and costs would have to be made when selecting the appropriate number of samples for the study. Land uses with small rates of prevalence would require large sample sizes, but those land uses may not be of key importance to the study. A smaller number of land use classes may also be appropriate.

Variances of the study could be further reduced by stratification of the study area. As previously discussed, very little research has been conducted on the variables which may predict land use change. However, as a practical approach, stratification could be undertaken to reduce the variance at each time period. This would most likely reduce the overall variances of the change statistics.

Three different methods of stratification can be suggested. The first would be the use of Landsat imagery to delineate boundaries of generalized land use classes such as urban versus resource lands. Another method would be the use of USGS land use/land cover maps to obtain the boundaries of the Level I classes, which could then be aggregated into several homogeneous strata. Both of these methods would rely on previous classifications of land use which may bias subsequent results.

The third method would use Urbanized Area boundaries which are delineated by the Bureau of the Census. Urbanized Areas are defined primarily on a population density of 1000 people/square mile, rather than on a land use classification. They are mapped as three contiguous components: Incorporated place, Census designated place, and Other area (U.S. Bureau of the Census 1981). These component areas and the remaining land in each county may serve to define either two or three strata from which one could sample. Homogeneous strata based on population density would suggest a justifiable link with land use change.

The preceding recommendations should be considered before application of the proposed sampling methodology. The precision and efficiency of the sampling design will be improved by these modifications.

Table 1

Pilot Study Land Use Classification
(numbers refer to USGS Levels)

1. Urban or Built-up Land

11	Residential
12,13,15,16	Commercial and Services, Industrial, Industrial Complexes, Mixed Urban
14	Transportation, Communications, and Utilities
17	Other Built-up Land

2. Agricultural Land

21	Cropland and Pasture
22	Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural areas
23,24	Other Agriculture Land and Confined Feeding Operations

3. Rangeland

4. Forest Land

5. Water

6. Wetland

7. Barrenland

Table 2

1973-1982 Land Use Change
33 Paired Random Sample Differences
(in percent)

Land Use	$\bar{D}$ (Mean)	S_D (Standard Deviation)	$S_{\bar{D}}$ (Standard Error)	90% Confidence Interval	Half-width as a percent of the mean	Significance
11 Residential	6.82	13.51	2.35	6.82 ± 3.99	59	Yes
12 Commercial & Industrial	2.58	4.53	0.79	2.58 ± 1.34	52	Yes
14 Transportation	0	-	-	-	-	-
17 Other Built-up	0.45	2.61	0.45	0.45 ± 0.76	-	No
21 Cropland & Pasture	-6.06	14.51	2.53	-6.06 ± 4.29	71	Yes
22 Ornamental Horticulture	0.76	5.47	0.95	-0.76 ± 1.61	-	No
23 Other Agriculture	0.15	1.97	0.34	0.15 ± 0.58	-	No
3 Range	0	-	-	-	-	-
4 Forest	-2.73	5.01	0.87	-2.73 ± 1.48	54	Yes
5 Water	0	-	-	-	-	-
6 Wetlands	-0.30	1.74	0.36	-0.30 ± 0.51	-	No
7 Barren	0	-	-	-	-	

Table 3

Land Use Transition Matrix in Acres

1981-82 Land Use

1973 Land Use	11	12	14	17	21	22	23	3	4	5	6	7	1973 Total
11 Residential	15015.7	474.18	-	-	158.06	-	-	-	-	-			15647.94
12 Commercial & Industrial	-	3003.14	-	-	-	-	-	-	-	-			3003.14
14 Transportation			316.12	-	-	-	-	-	-	-	-	-	316.12
17 Other Built-up	158.06	316.12	-	1264.48	-	-	-	-	-	-	-	-	1738.66
21 Cropland & Pasture	5690.16	1738.66	-	474.18	53582.34	1106.42	316.12	-	-	-	-	-	62907.88
22 Ornamental Horticulture	-	-	-	-	1738.66	-	-	-	-	-	-	-	5532.1
23 Other Agriculture	158.06	-	-	158.06	-	-	-	-	-	-	-	-	316.12
3 Range	-	-	-	-	-	-	-	-	-	-	-	-	0
4 Forest	1422.54	158.06	-	316.12	948.36	-	-	-	11538.38	-	-	-	14383.46
5 Water	-	-	-	-	-	-	-	-	-	158.06	-	-	158.06
6 Wetlands	316.12	-	-	-	-	-	-	-	-	-	-	-	316.12
7 Barren	-	-	-	-	-	-	-	-	-	-	-	-	0
1981-82 Total	22760.64	5690.16	316.12	2212.84	56427.42	4899.86	316.12	0	11538.38	158.06	0	0	104319.6

Table 4

Land Use Transition Matrix
% of Total Area

1973 Land Use	1981-82 Land Use 11	12	14	17	21	22	23	3	4	5	6	7	1973 Total
11 Residential	14.39	.45	-	-	.15	-	-	-	-	-	-	-	15.00
12 Commercial & Industrial	-	2.88	-	-	-	-	-	-	-	-	-	-	2.88
14 Transportation	-	-	.30	-	-	-	-	-	-	-	-	-	.30
17 Other Built-up	.15	.30	-	1.21	-	-	-	-	-	-	-	-	1.67
21 Cropland & Pasture	5.45	1.67	-	.45	51.36	1.06	.30	-	-	-	-	-	60.30
22 Ornamental Horticultural	-	-	-	-	1.67	3.63	-	-	-	-	-	-	5.30
23 Other Agriculture	.15	-	-	.15	-	-	-	-	-	-	-	-	.30
3 Range	-	-	-	-	-	-	-	-	-	-	-	-	0
4 Forest	1.36	.15	-	.30	.91	-	-	-	11.06	-	-	-	13.79
5 Water	-	-	-	-	-	-	-	-	-	.15	-	-	.15
6 Wetlands	.30	-	-	-	-	-	-	-	-	-	-	-	.30
7 Barren	-	-	-	-	-	-	-	-	-	-	-	-	0
1981-82 Total	21.82	5.45	.30	2.13	54.09	4.70	.30	0	11.06	.15	-	-	100

Table 5

5% Pilot Sample Results

Land Use Classification	Paired Random Samples 1973% $\overline{X}$	1973% S	1982% $\overline{Y}$	1982% S	Paired Random Sample Difference 1973-82% $\overline{D}$	1973-82% S_D
11 Residential	10.63	14.00	17.50	22.83	6.88	11.00
12 Commercial	-	-	3.75	5.82	3.75	5.82
14 Transportation, Utilities & Communications	-	-	-	-	-	-
17 Other Built-up	-	-	0.63	1.77	0.63	1.77
21 Cropland & Pasture	70.63	21.12	63.75	24.31	-6.88	17.10
22 Horticulture	10.00	13.63	6.25	10.26	-1.88	3.72
23 Other Agriculture	0.63	1.77	-	-	-0.63	1.77
3 Range	-	-	-	-	-	-
4 Forest	15.63	20.78	8.13	13.87	-1.88	3.72
5 Water	-	-	-	-	-	-
6 Wetland	-	-	-	-	-	-
7 Barren	-	-	-	-	-	-

Table 6

Sample Size (n') for Cropland and Pasture
From the 5% Pilot Sample

Confidence Level		Paired Random Sample 1973	Paired Random Sample 1982	Paired Random Sample Differences 1973-82
95%	±5%	62	73	46
	±10%	22	27	16
90%	±5%	46	56	33
	±10%	16	19	11
80%	±5%	29	36	20
	±10%	9	11	6

Table 7

1981-82 Land Use Distribution

Land Use	Digitized Area: Acres	Digitized Area: Percent	33 Random Samples: $\overline{Y}$	33 Random Samples: S	$S\overline{y}$	95% Confidence Interval; t(.05,32)	Is Digitized Area Within the Interval?	$\frac{\text{Digitized-Sample}}{\text{Digitized}}$ %
11 Residential	18,528	16.8	21.82	26.27	4.57	21.82 ± 9.33	Yes	30
12 Commercial	5,963	5.4	5.45	9.30	1.62	5.45 ± 3.31	Yes	1
14 Transportation, Utilities & Communication	1,066	1.0	0.30	1.21	0.21	0.30 ± 0.43	No	70
17 Other Built-Up	2,207	2.0	2.12	4.51	0.79	2.12 ± 1.61	Yes	6
21 Cropland & Pasture	66,104	60.0	54.24	32.19	5.60	54.24 ± 11.44	Yes	10
22 Horticulture	3,638	3.3	4.55	7.64	1.33	4.55 ± 2.72	Yes	38
23 Other Agriculture	357	0.3	0.30	1.74	0.30	0.30 ± 0.61	Yes	0
3 Range	0	0	0	-	-	-	-	-
4 Forest	11,793	10.7	11.06	15.45	2.69	15.45 ± 5.49	Yes	3
5 Water	66	0.1	0.15	0.87	0.15	0.15 ± 0.31	Yes	50
6 Wetland	210	0.2	0	-	-	-	-	100
7 Barren	373	0.3	0	-	-	-	-	100
Total	110,233	100%	100%					

Table 8

Error Matrix of Groundtruth Results

Photointerpreted Land Use	Observed Land Use												Interpreted Total
	11	12	14	17	21	22	23	3	4	5	6	7	
11 Residential	30	1	-	-	-	-	-	-	-	-	-	-	31
12 Commerical	-	4	-	-	-	-	-	-	-	-	-	-	4
14 Transportation, Utilities & Communications	-	-	0	-	-	-	-	-	-	-	-	-	0
17 Other Built-up	-	-	-	-	-	-	-	-	1	1	-	-	2
21 Cropland & Pasture	-	-	-	-	58	3	-	-	-	-	-	-	61
22 Horticulture	-	-	-	-	-	5	-	-	-	-	-	-	5
23 Other Agriculture	-	-	-	-	-	-	0	-	-	-	-	-	0
3 Range	-	-	-	-	-	-	-	0	-	-	-	-	0
4 Forest	-	-	-	-	-	-	-	-	10	-	-	-	10
5 Water	-	-	-	-	-	-	-	-	-	0	-	-	0
6 Wetland	-	-	-	-	-	-	-	-	-	-	0	-	0
7 Barren	-	-	-	-	-	-	-	-	-	-	-	0	0
Observed Total	30	5	0	0	58	8	0	0	10	0	0	0	113

Table 9

Comparison of Paired Samples and Paired Sample Differences

Land Use Classification	1973 in Percent				1981-82 in Percent					16 Paired Random Sample Differences 1973-82 In Percent				
	$\bar{X}$	S	$S_{\bar{X}}$	95% Confidence interval, t(.05,26)	$\bar{Y}$	S	$S_{\bar{y}}$	95% Confidence interval, t(.05,26)	$\bar{Y}-\bar{X}$	$\bar{D}$	S_D	$S_{\bar{D}}$	95% Confidence interval, t(.05,15)	Significance
11 Residential	18.33	19.61	3.77	18.33 ± 7.75	26.30	27.05	5.21	26.30 ± 10.71	7.97	9.69	7.17	4.29	9.69 ± 9.14	Yes
12 Commercial	3.52	6.62	1.27	3.52 ± 2.61	6.67	9.90	1.91	6.67 ± 3.93	3.15	3.44	4.73	1.18	3.44 ± 2.52	Yes
14 Transportation, Utilties & Communications	0.37	1.33	0.26	0.37 ± 0.53	0.37	1.33	0.26	0.37 ± 0.53	0	0	-	-	-	-
17 Other Built-up	1.85	4.42	0.85	1.85 ± 1.75	2.41	4.88	0.94	2.41 ± 1.93	0.56	0.63	2.50	0.63	0.63 ± 1.34	No
21 Cropland & Pasture	59.44	28.33	1.58	59.44 ± 11.21	51.11	33.64	6.47	51.11 ± 13.30	-8.33	-8.75	16.98	4.25	-8.75 ± 9.06	No
22 Horticulture	2.96	8.23	1.58	2.96 ± 3.25	3.33	7.21	1.39	3.33 + 2.86	0.37	-.63	4.03	1.01	-0.63 ± 2.15	No
23 Other Agriculture	0.37	1.33	0.26	0.37 ± 0.53	0	-	-	-	-.37	0.31	2.87	0.72	0.31 ± 1.53	No
3 Range	0	-	-	-	0	-	-	-	0	0	-	-	-	-
4 Forest	12.59	16.95	3.26	12.59 ± 6.70	9.63	14.34	2.76	9.63 ± 5.67	-2.96	-4.38	6.29	1.57	-4.38 ± 3.35	Yes
5 Water	0.19	0.96	0.18	0.19 ± 0.56	0.19	0.96	0.18	0.19 ± 0.37	0	0	-	-	-	-
6 Wetland	0.37	1.92	-	0.37 ± 1.13	0	-	-	-	-.37	-	-	-	-	-
7 Barren	0	-	-	-	0	-	-	-	0	0	-	-	-	-

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